AP 3373

(2nd Edition)

STANDARD TECHNICAL TRAINING NOTES

ELECTRICAL AND ELECTRONIC TRADES

TRADE PRACTICES

AND

SERVICING PROCEDURES

By Command of the Defence Council

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MINISTRY OF DEFENCE

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CONTENTS

Note: A detailed contents list is given at the beginning of each section and chapter.

FOREWORD

1. These notes are issued to assist airmen and apprentices under training in the electrical and electronic trades. They are not intended to form a complete text-book but are to be used in conjunction with lessons and demonstrations given at schools of technical training. They may also be used to assist airmen on continuation training at other RAF stations.

2. These notes deal with trade practices and servicing procedures in a general way. They do not cover specific details of servicing instructions in use in the RAF. Such details are contained in the official Air Publication for an equipment or an aircraft and this should always be consulted during any servicing operation.

3. No alteration to these notes may be made without the authority of official Amendment Lists.

4. Readers of this publication are asked to report any unsatisfactory features which they may notice. Such features may be factual errors in words or illustrations; ambiguous, obscure, or conflicting information; or omissions. All such unsatisfactory features should be reported to Headquarters Technical Training Command (Trg 4c) on RAF form 6734.

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SECTION 1

TOOLS AND WORKSHOP PRACTICES

CHAPTER 1

MATERIALS

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Introduction

1. Most materials used in electrical and electronic equipment are chosen for their ability to control the flow of current in a circuit. Thus we have *conductors* (mainly metals) which provide an easy path for current flow; and *insulators* (very often synthetic materials) which prevent the current leaving a chosen path. *Mechanical properties* of these materials are also important because the conductor or insulator may have to act as part of the equipment structure.

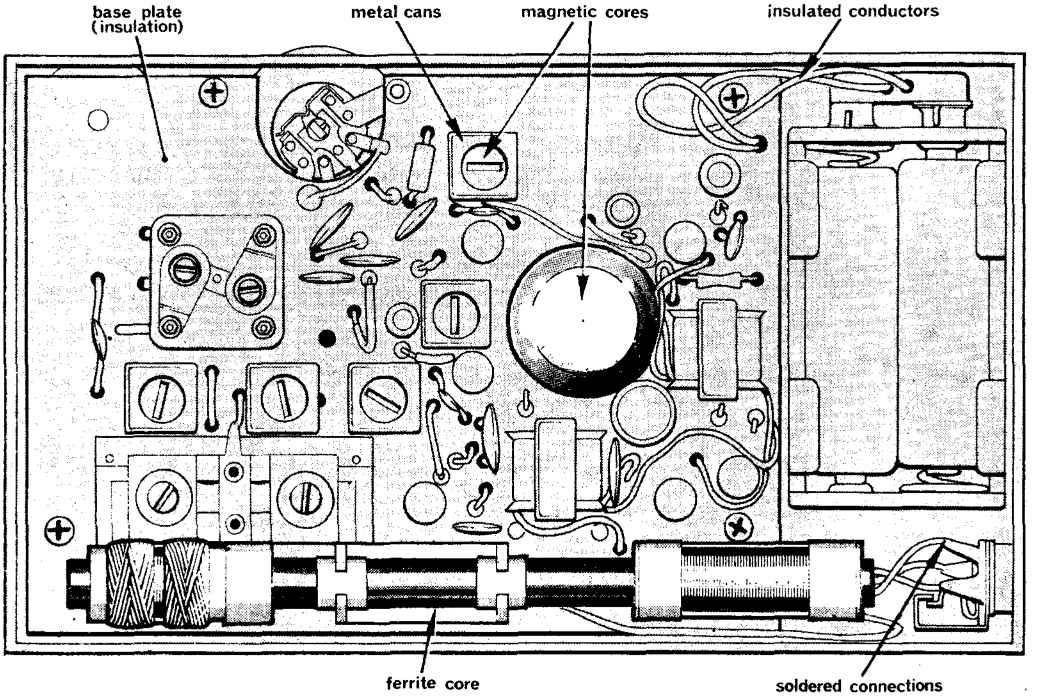

Fig. 1 Materials used in a transistorized radio

2. Fig. 1 shows the inside of a portable transistor radio. From this drawing we can see that this single piece of equipment uses many different types of material. We shall consider such materials in this chapter, starting with conductors and insulators, and then going on to summarize the properties of some of the more common magnetic and structural materials.

Conductors

3. These are materials chosen for their ability to transfer electricity from one point to another with the minimum possible loss. Some of the more common conductors and examples of their uses are discussed in the following paragraphs.

4. **Silver.** Silver is the best conductor of electricity but costs too much for general wiring use. At very high radio frequencies, currents travel along the surface of a conductor and silver plating is used to reduce surface resistance, e.g. the inside of a waveguide or resonant cavity.

5. **Copper.** Copper conducts electricity almost as well as silver and as it is much cheaper it is used for all normal wiring. It is easily joined by soldering, easily worked, and resistant to many forms of corrosion. For surface to surface connections, e.g. in plugs and sockets, gold plating is often used to increase resistance to atmospheric corrosion.

6. **Aluminium.** Aluminium has a conductivity about two-thirds that of copper and is only one-third as heavy. It is used for overhead conductors, such as those used in the national grid, and may have a thin steel core for extra strength. With small amounts of copper and magnesium added, a large range of alloys are produced which have good conducting abilities and mechanical strength. These alloys are used to make the chassis and panel parts of most electrical and radio equipments.

7. **Solder.** Soft solder is an alloy of 60% tin and 40% lead which has a low melting point and is used to form joints between conductors.

8. **Brass.** Many types of brass are made containing different amounts of copper and zinc. They are resistant to corrosion, easily worked, and stronger than pure copper. They are used for the manufacture of waveguides, bearings and general parts, e.g. non-magnetic nuts and bolts.

9. **Phosphor-bronze.** This is an alloy of copper and tin (6%) with a small amount of phosphorus. It is used for the brushes of electric motors, as a bearing surface in instruments, and for springs which have to conduct electricity.

10. **Platinum and molybdenum.** These two metals melt at very high temperatures and are extremely resistant to oxidation. They are used as contact points for relays and circuit breakers.

11. **Wire-glass seals.** An alloy of copper with 46% nickel expands at the same rate as glass when it is heated; it is used for connections into valves and other glass capsules.

12. **Mercury.** At normal temperatures mercury is the only metal which is a liquid and it is used as the contactor in switches which operate by inertia or by 'tilt angle'.

13. **Resistance wires.** In the construction of accurate or high-current resistors, wires are used as the resistance element. The two most common are 'Eureka' (60% copper with 40% nickel) and a selected alloy of 80% nickel with 20% chromium.

14. **Carbon.** Although not a metal, carbon is a moderate conductor of electricity and is used for brushes in light machines and data transmission devices. Carbon composition elements are normally used for fixed and variable resistors.

Insulators

15. These materials are used to stop the flow of current from one part of a circuit to another, from one wire to another in the same loom, and as bases on which to mount components without connecting them electrically.

16. **Rubber.** A form of vulcanised rubber was until recently the most common insulating cover for wiring. It is tough, flexible, and waterproof but is damaged by petroleum products and heat. To minimize this damage some rubber covered cables have an outer sheath of braided cotton or metal. Synthetic rubbers, such as 'Neoprene', are widely used for the moulded inserts of plugs and sockets.

17. **PVC.** PolyVinyl Chloride has superseded rubber for general use at low frequencies. It is a soft plastic with a high resistance and is not affected by petroleum; but it cannot be used at high temperatures.

18. **PTFE.** PolyTetraFluoroEthylene is a harder plastic than PVC and can be used at all temperatures likely to occur in electronic equipment. It is resistant to acids, alkalis, petroleum products and most solvents. It has a much lower power loss than PVC at high frequencies and can be used in coaxial plugs as well as for general wiring insulation. Because of its greater rigidity, sheets of PTFE can be used as tag boards for mounting components and as separators between subassemblies.

19. **Porcelain and ceramics.** These materials are made by firing clays in a pottery oven and have an extremely high resistance. They are used as insulators for very high voltages, such as those of the national grid, and will withstand extremes of weather. Beads made of ceramic are often used as the insulating cover on wires used at high temperatures. Modern high-voltage capacitors use ceramics as the dielectric material.

20. **Polythene.** Sometimes called polyethylene, this is a flexible soft plastic which melts easily. It has a low power loss at radio frequencies and is used as the dielectric in coaxial cables. It can be moulded easily and is used for sealing plugs and sockets.

21. **Nylon.** Nylon is another plastic which can be easily moulded. It is used for bushes and in plugs and sockets.

22. **Bakelite.** This is a hard material made from wood-flour and slate dust, bonded with a synthetic resin. It is moulded to form terminal blocks, fuse boxes, switch housings and general insulated casings. Laminated bakelite is also used for printed circuit boards.

23. **Epoxy resin laminates.** Laminates of paper, linen or fibre glass, bonded with special resins known as epoxy resins, are normally used as printed circuit boards. They are corrosion proof, non-inflammable, have low losses and are resistant to tracking. After manufacture or repair, printed circuits are coated with a protective insulating varnish to enable them to be used in tropical conditions.

Magnetic Materials

24. Ferromagnetic materials are used to couple together two or more circuits without direct electrical connection, e.g. as cores of transformers. There are also devices which depend on a magnetic field for their operation, e.g. motors, relays, and magnetrons. (For information on magnetism see AP3302 Part 1A, Section 2).

25. **Iron and steel.** Soft iron and steels are readily magnetised but are rarely used because of the superior properties of specialised alloys. Iron containing about 5% silicon is used for the cores of power transformers and in the construction of electric motors and generators.

26. **Cobalt.** Cobalt is not used as a pure metal but an alloy of iron containing 35% cobalt will retain magnetism for very long periods and is used for making permanent magnets.

27. **Nickel.** An alloy of 75-80% nickel with iron, called 'Permalloy', is used for magnetic screening of instruments and cathode ray tubes. In the form of laminated thin strips it is used for the cores of wide-band transformers. Because of its low saturation level it is not used when d.c. fields are present or for large signal applications. For audio frequency power transformers, inductors, and relays, an alloy of iron containing 40-50% nickel is used. 'Alnico' is used for permanent magnets and is an alloy of aluminium, nickel and cobalt.

28. **Ferrites.** Ferrites are non-metallic compounds of iron, oxygen and a divalent metal such as manganese, zinc, nickel or magnesium. They are very poor conductors of electricity and have a high initial permeability. As they are poor conductors eddy current losses are negligible, and they are replacing iron dust and laminations as the core material of inductors and transformers. Hysteresis losses are also small and ferrites can be used at high frequencies as cores for transformers and aerial coils. In waveguide assemblies ferrites are used as switches and isolators which have no moving parts. Rings made from ferrites are used as memory storage devices in digital computers. Ceramic/ferrite assemblies are made by firing suitably shaped mixes in a pottery oven.

Metals

29. Some metals are used in electrical and electronic assemblies because of their mechanical properties. They can be divided into two classes: ferrous, in which the metal is basically iron; and non-ferrous, in which the metal contains no iron. The main non-ferrous metals used are the light alloys of aluminium and magnesium.

30. **Iron.** Pure iron is a weak metal and is seldom used alone, but the addition of small amounts of carbon (up to 1.5%) greatly strengthens the metal and it is then called steel. Cast iron contains many impurities including about 5% carbon. It is brittle but wears to a good surface and is used for the manufacture of machine frames and for surface tables. Wrought iron contains fewer impurities and about 0.2% carbon. It is easily worked by all methods except casting and is used for the cores of generators and for making chains.

31. **Steel.** Mild steel contains up to 0.2% carbon and very few impurities, making it stronger and more uniform than wrought iron. It is easily forged, machined, or stamped to shape and is used for casings, plates, tubes and all parts where strength is required. High carbon steel contains about 1% carbon and can be made very hard by suitable heat treatment. It is used for the manufacture of cutting tools.

32. **Alloy steels.** These are combinations of low carbon steel with some other metal, usually in fairly small quantities. The addition of these metals improves a particular property of the steel, making it suitable for special applications. Steel containing 3% nickel is used for gearwheels and shafts; with a small amount of chromium as well as nickel it is used for ball and roller bearings. Another mixed nickel/chromium steel (usually called stainless steel) is used for generator and motor shafts, gears and crankshafts.

33. **Invar.** This is an alloy of steel and 36% nickel which has an extremely low coefficient of expansion and is widely used for instrument parts.

34. **High-speed steels.** The addition of tungsten or molybdenum to steel enables it to remain hard even at fairly high temperatures. This alloy is used for high-speed drills, taps, dies and other cutting tools for machine use.

35. **Aluminium alloys.** Pure aluminium is a light metal, very soft and weak; but it is sometimes used for the manufacture of waveguides when light weight is important. Alloys containing small amounts of copper, magnesium and silicon are comparable in strength to mild steel and are very easily worked. They are extensively used in aircraft for panels, chassis and scanner dishes and are good conductors. To increase resistance to corrosion they may be 'anodised' by forming a stable oxide film on the surface.

36. **Magnesium alloys.** Magnesium alloys are about two-thirds the weight of the aluminium alloys. They can be cast and are used for aircraft parts, e.g. the frames of scanner assemblies.

CHAPTER 2

HAND TOOLS

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Introduction

1. In this chapter we shall consider the common hand tools used by electrical and electronic tradesmen. Some of the special tools used only for wiring will be found in Chapter 4. Modern practice is to have a 'shadow board' on which the tools normally used are mounted (Fig. 1). A shadow board is a black wooden board on which the outlines of tools are painted in white. Retaining clips secure the tools against their appropriate shadows on the board. By checking the shadow board the NCO responsible can see, quickly and easily, which tools are 'out' and thus reduce the possibility of an accident being caused by loose tools in an aircraft.

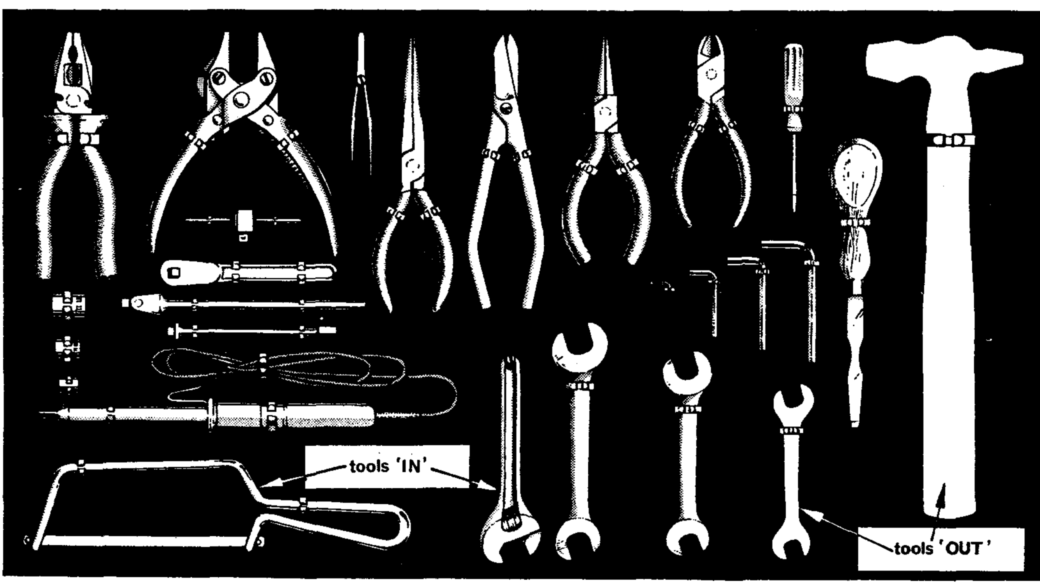


Fig. 1 Shadow board and tools

Screwdrivers

2. A screwdriver consists of a hardened steel blade fitted with a suitable handle, usually made from an insulating material. Screwdrivers are classified by the length of the blade, e.g. screwdriver common 6 ins. Some screwdrivers have a ratchet mechanism in the handle to permit speedy operation (Fig. 2). Ratchet and 'pump type' ratchet screwdrivers should not be used on an aircraft.

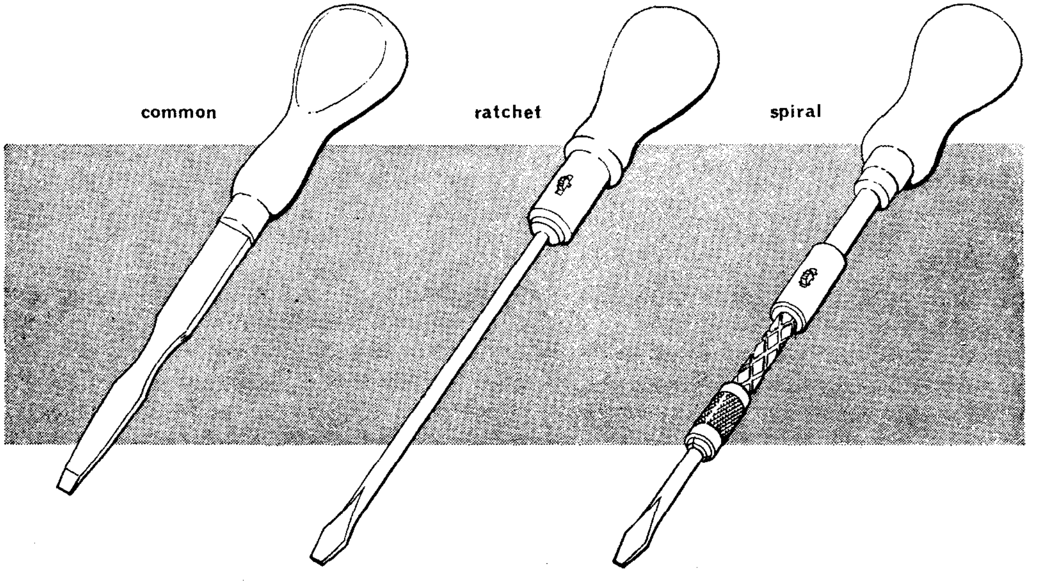


Fig. 2 Screwdrivers

3. The size of screwdriver used should be carefully chosen to suit the job. The working end of the blade should be ground flat to prevent slipping and should be a good fit in the screw slot (Fig. 3). To adjust preset potentiometers a good tradesman will select an insulated screwdriver which fits exactly and will not use it for any other work, thus minimizing wear on the equipment resulting from routine alignment.

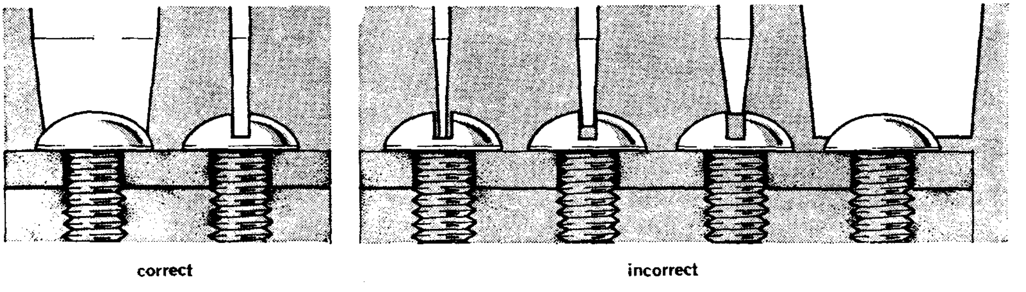


Fig. 3 Choice of screwdriver

4. **Phillips screwdrivers.** Phillips screws have a cross-shaped recess in the screw head and require a specially shaped screwdriver (Fig. 4). There is less tendency for a Phillips screwdriver to slip from the screw head and it can be used with power driven tools when fitted with a suitable torque clutch.

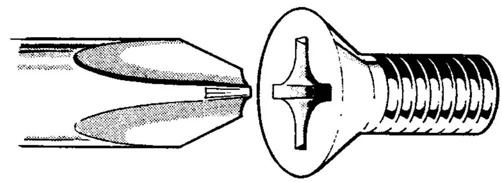


Fig. 4 Phillips screw system

5. **Allen keys.** Some set bolts have circular heads with a hexagonal recess, and are tightened or slackened with an Allen key (Fig. 5). These keys are made of hardened steel and are classified by the distance across the flats of the hexagon.

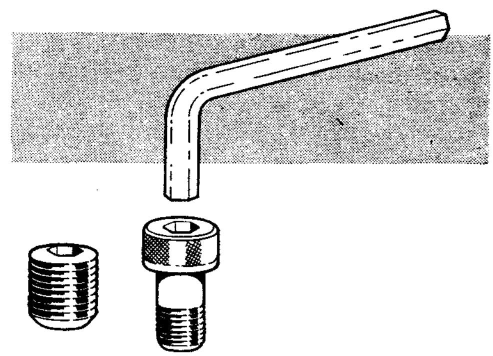


Fig. 5 Allen key and set bolts

Spanners

6. Spanners are used to tighten or loosen nuts on screw threads. When tightening a nut a steady force is all that is needed. The use of a hammer or a spanner-lengthening device will always damage the threads. A torque wrench enables a measured amount of force to be applied.

7. Spanner sizes are marked on the jaw face (or shank) with the distance across flats of the nuts that they fit. Spanners made for use with unified threads are marked with this distance correct to two decimal places and the decimal point is omitted. Thus a spanner marked 44 and 50 will fit nuts $\frac{7}{16}$ in. and $\frac{1}{2}$ in. across flats.

8. **Open-jaw or set spanners.** These are usually double ended with a different size at each end. The jaws are set at 30° to the shank to make it easier to adjust awkwardly placed nuts (Fig. 6).

Fig. 6 Open-jaw spanner

9. **Ring spanners.** Ring spanners apply the load equally on all faces of the nut and are preferable to open-jaw spanners. The ends are usually made with twelve points (bi-hexagonal) to make it easier to operate when spanner movement is restricted (Fig. 7).

Fig. 7 Ring spanner

10. **Box spanners.** These also give total enclosure of the nut and are used when the only access is from directly above the nut. The double sided handle reduces side thrust when turning (Fig. 8).

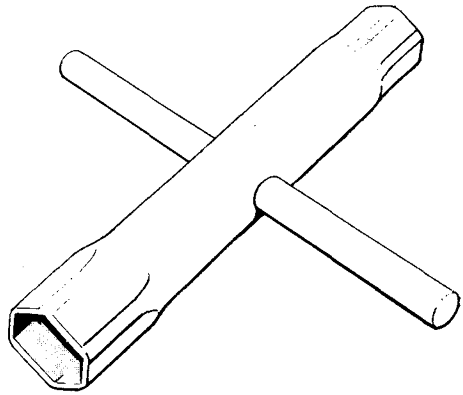


Fig. 8 Box spanner

11. **Socket spanners.** These spanners combine the advantages of both ring and box spanners. They are usually supplied in sets with ratchet handles and extension pieces to enable them to be used in almost any position (Fig. 9). They can be driven by power tools fitted with a suitable torque clutch. A hand operated torque wrench is shown in Fig. 9.

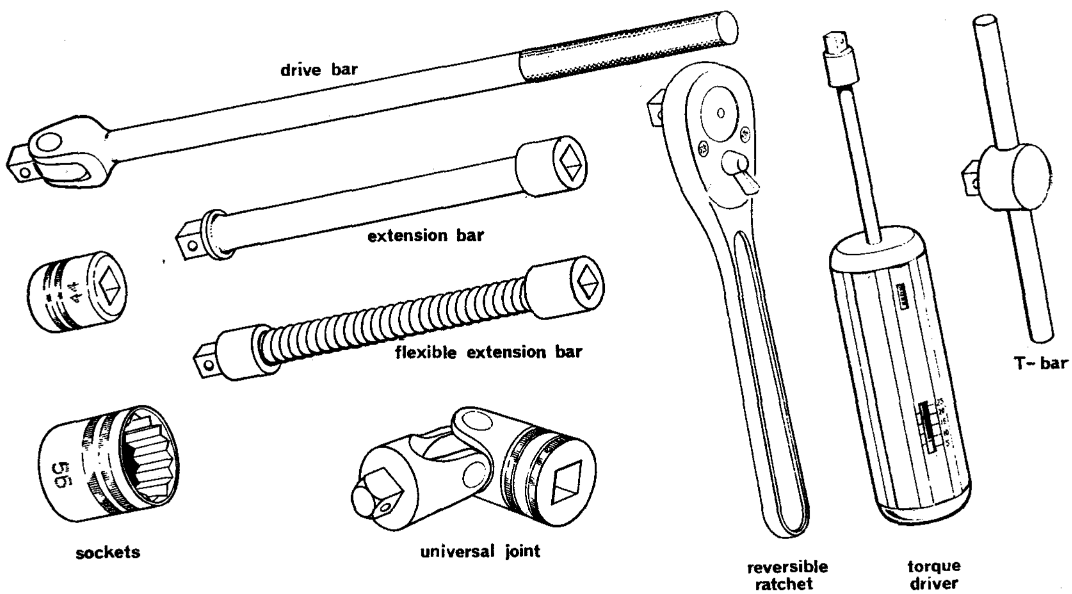


Fig. 9 Socket spanner set

12. **Adjustable spanners.** These should only be used when a fixed spanner of the correct size is not available. They are classified by overall length (Fig. 10).

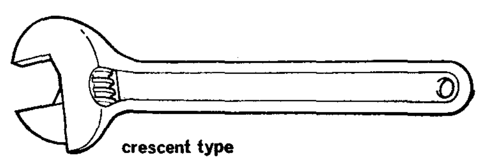


Fig. 10 Adjustable spanner

13. **Special spanners.** Special types of spanner are made to suit splined nuts and special screw fittings such as are used on waveguide couplings.

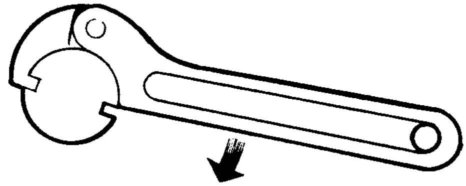


Fig. 11 'C' spanner

a. 'C' spanners. Made to fit externally-splined ring nuts (Fig. 11). Adjustable types are also available.

b. Peg spanners. This spanner has two (or more) pins which fit into holes in the screw fitting (Fig. 12). The type shown is used for adjusting synchros.

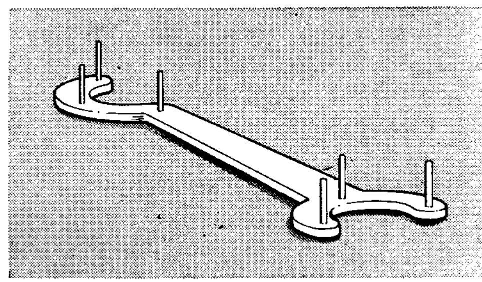


Fig. 12 Peg spanner

c. Splined tube spanners. These are a form of box spanner for use on threaded ring nuts. They are made to fit external, internal or castellated splines. The types illustrated are for use on Plessey plugs and sockets.

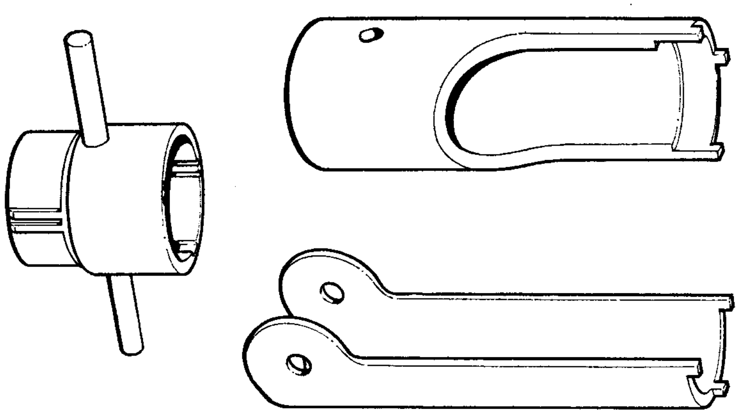


Fig. 13 Splined tube spanners (Plessey)

d. Strap spanners. The strap spanner is to be used *only for slackening* knurled nuts on plugs and sockets. When the strap length is correctly adjusted any increase of load on the handle tightens the grip of the strap on the nut.

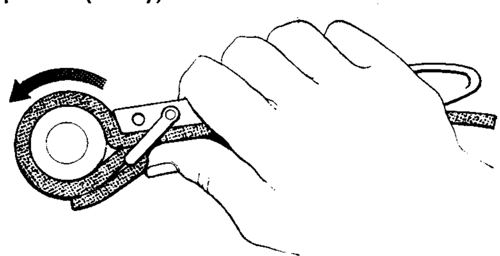


Fig. 14 Strap spanner

14. **Tuning tools.** A wide variety of special tuning tools is available. Each is designed for alignment of a particular radio set. They are basically a combination of a screwdriver and a box spanner (Fig. 15).

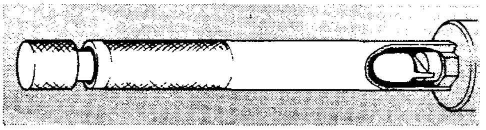
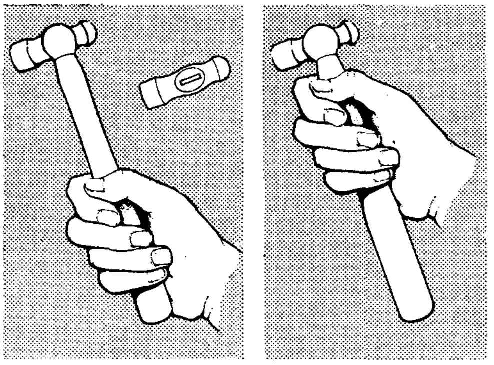


Fig. 15 Tuning tool

Hammers

15. A hammer consists of a high carbon steel head, hardened on the working faces and attached to a wooden shaft. The head must be wedged securely to the shaft with the wedge lying parallel to the axis of the head. A hammer should be held close to the end of the shaft to obtain maximum control of a blow (Fig. 16).



correct incorrect

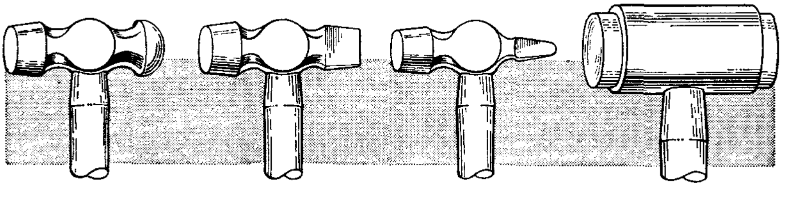
Fig. 16 Use of the hammer

16. Hammers are classified by the type and weight of the head (Fig. 17).

a. Ball pein. This hammer is used for all normal engineering work; the ball enables a blow to be delivered to a very small working area.

b. Cross pein and straight pein. These hammers are also in general use, the narrow pein being convenient for working in a narrow space.

c. Nylon faced. Used when damage to the surface of a soft material must be avoided.



ball pein straight pein cross pein nylon faced

Fig. 17 Types of hammer

Punches and Drifts

17. Punches are used to localise the blow of a hammer and to prevent damage to the area surrounding the working point. Various types are available, some of which are shown in Fig. 18.

a. Centre Punches. Centre punches are used to make small indentations or 'pops' to locate the point of a drill or to act as a pivot for dividers. They are made of hardened steel ground to a point at an angle of 60° for general work. For drill location an angle of 90° is more suitable.

b. Pin punches. These are used to knock out tight bolts, rivets or tapered pins and are classified by the diameter of the working end. They are made of hardened steel and may be either tapered or parallel.

c. Hollow punches. These are used for punching holes in soft sheet materials. The work to be punched should be supported on a wooden block to prevent damage to the cutting edge of the punch.

18. Drifts are bars or tubes of steel, brass or aluminium which are specially shaped to drive out bearings or shafts.

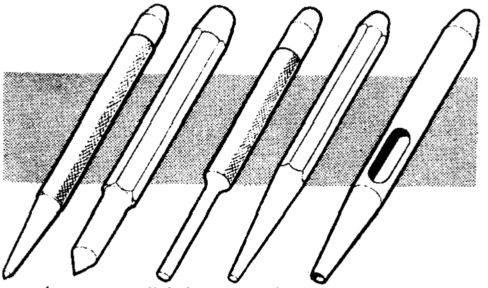


Fig. 18 Punches

Pliers and Nippers

19. **Pliers.** Pliers are used for gripping small objects which cannot easily be handled with the fingers. They can be used in places where the fingers will not go and for holding objects which are too hot to touch. Typical uses are holding components during soldering, removing split pins from locknuts and pulling wires through small holes. The jaws of different types of pliers are shaped to suit their normal applications. Classification is by type of jaw and overall length (Fig. 19).

20. **Nippers.** Nippers are used for cutting wires or small bolts and are very often incorporated as part of a pair of pliers. Some special types of nippers and pliers used for wiring work are discussed in Chapter 4; the more general types are illustrated in Fig. 19.

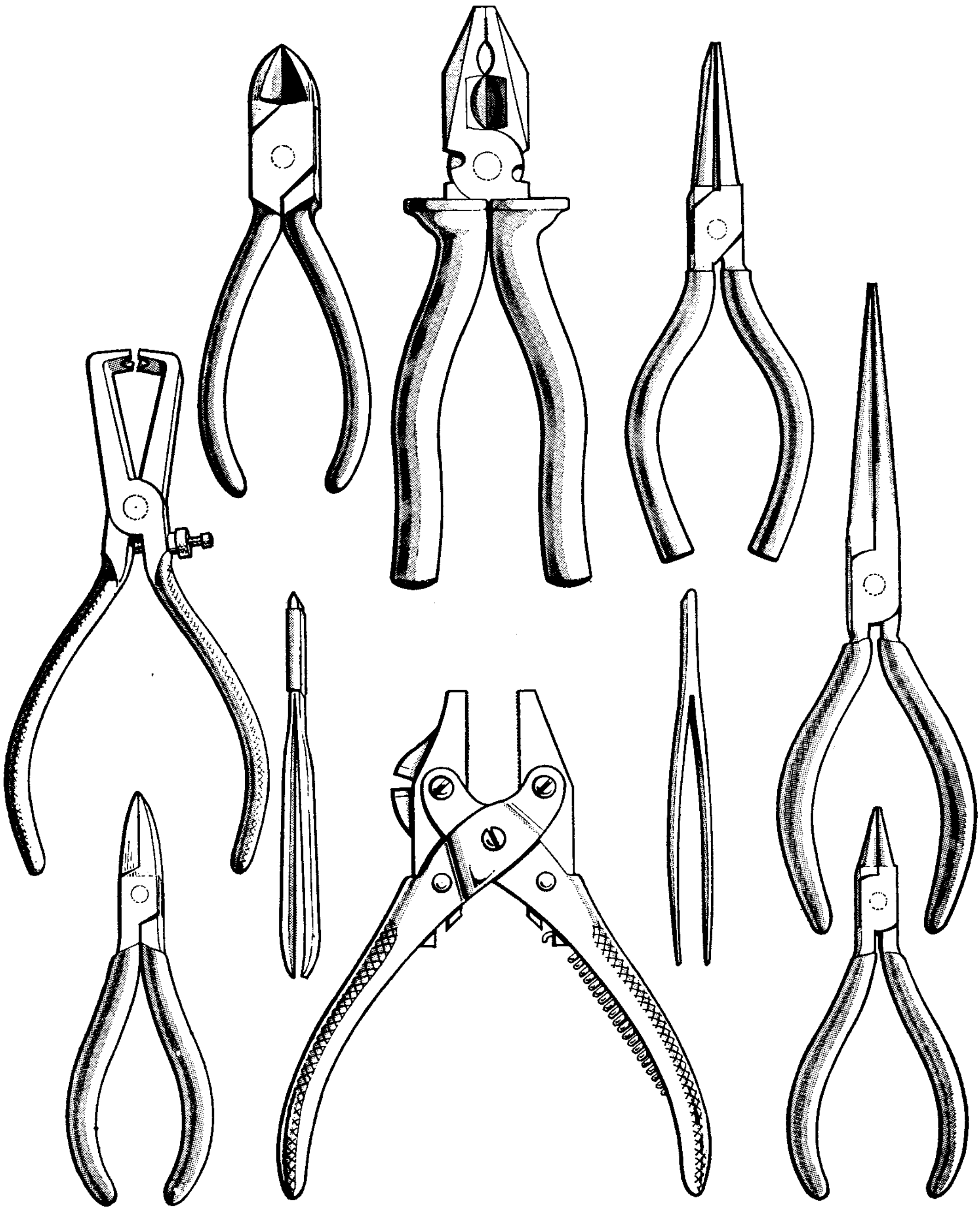


Fig. 19 Pliers and Nippers

Cutting Tools

21. **Hacksaws.** A hacksaw is used for cutting material to approximate size. It consists of a frame, classified by length, to which the saw blade is fitted with the teeth pointing away from the handle (Fig. 20). The blade can be turned at right angles to the frame to enable long narrow strips to be cut from a sheet of material. The blade should be tensioned so that it gives a slight ring when flicked with the thumb.

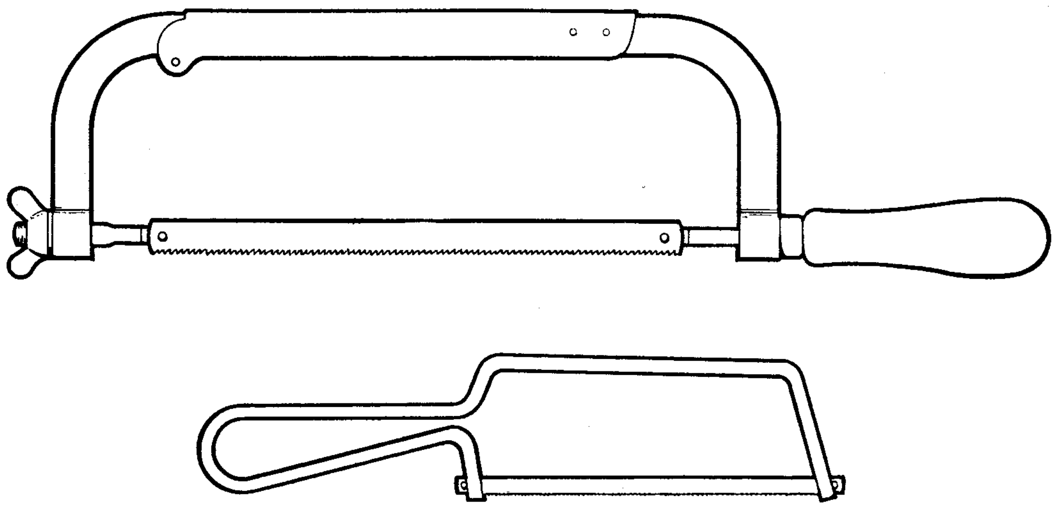


Fig. 20 Hacksaws

22. For cutting thin or hard materials a fine-toothed blade should be used (24-32 teeth per inch). Hand pressure is applied on the forward stroke only, and best results are obtained by cutting with the full length of the blade. For thick or soft materials a coarse blade is used (18 teeth per inch). A progressive pitch blade is available on which the teeth are finely spaced at the front end and become gradually coarser towards the rear.

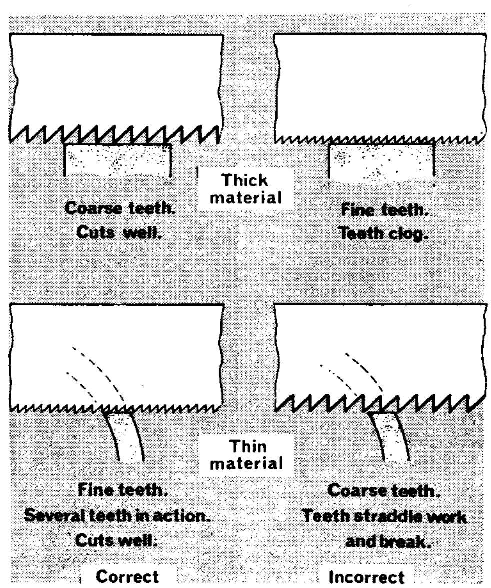


Fig. 21 Choice of hacksaw blade

23. **Shears.** Shears are made from high carbon steel with hardened blades, and are used for cutting sheet materials quickly. For heavy work various types of tinman's shears are available with straight or curved blades. For most electrical work watchmaker's shears with blades 1½ in. long are used (Fig. 22). For heavy work involving long straight edges the job is best done in the workshop using a guillotine.

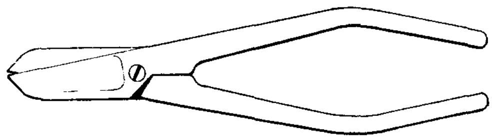


Fig. 22 Shears (watchmaker)

Vices

24. **Bench vices.** A vice is used to hold material firmly in a required position while work is being done. The jaws have serrated faces to give an increased grip but can be fitted with soft metal 'clams' to protect a finished surface (Fig. 23). Most vices have a quick release mechanism to enable the jaw spacing to be changed easily. Bench vices are classified by weight and length of jaw.

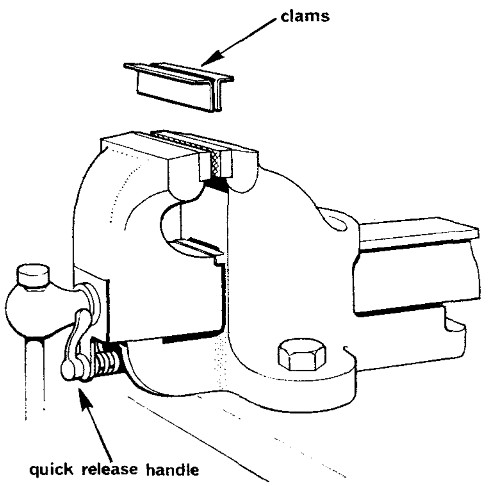


Fig. 23 Bench vice

25. **Hand vices.** Various forms of hand vices and 'G-clamps' are made. They can be used for holding small jobs firmly in the hand or for clamping parts together while an adhesive sets hard.

Files

26. Files are used to remove material from a surface. The blade, in which teeth are cut, is made of hardened steel while the tang is left soft. Classification is by length, section, cut and grade. Length is measured from the shoulder to the tip of the blade.

27. **Section.** Standard cross-sections are shown in Fig. 24.

a. Hand. This flat file is for general use. One edge may have no teeth (the 'safe' edge) to enable work to be done close to a finished surface.

b. Half round. Used for filing irregularly shaped work and the insides of large holes.

c. Round. Sometimes called a 'rat-tail', the round file is used for filing out small circular holes.

d. Three square. Used for filing small corners.

e. Square. Used for filing small flat surfaces where a hand file is not convenient.

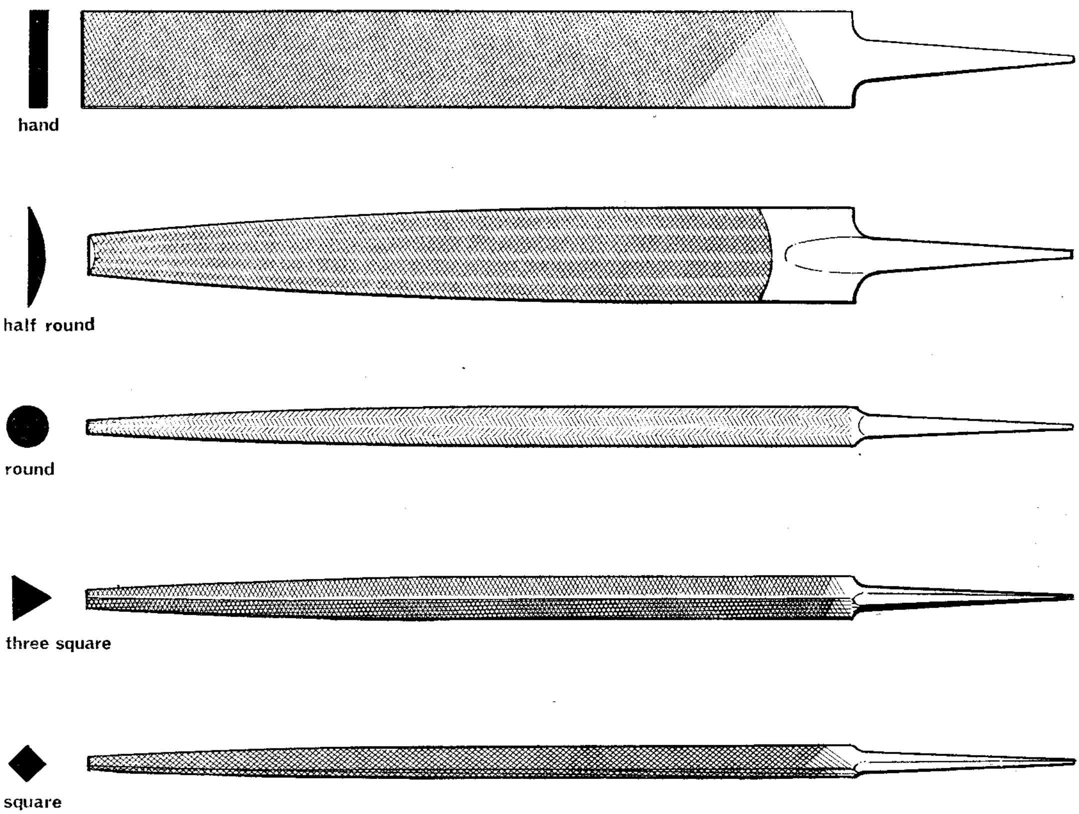


Fig. 24 Types of file

28. **Cut.** The common cuts are shown in Fig. 25.

a. Single cut. The teeth of this cut are less likely to clog than other types so these files are used for work on soft materials. Round files and the curved face of half round files are normally single cut.

b. Double cut. Used for general filing. Most hand files are double cut.

c. Dreadnought. The curved teeth enable this file to be used for quick filing on soft metal surfaces.

d. Rasp. Used on very soft materials such as wood or plastic.

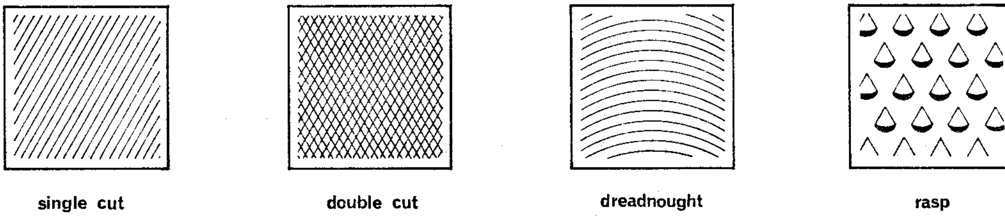


Fig. 25 File cuts

29. **Grade.** The grade of a file is the pitch of the cutting teeth and governs the rate of cutting and the quality of the finished surface. Three common grades are issued:

a. Bastard. This is the coarse grade and is used for rough work because of its high cutting speed.

b. Second cut. Cuts slower than a bastard file but gives a better finish. Used for general work.

c. Smooth. Produces a good finish but as its rate of cutting is very slow it is advisable to use it only for finishing.

Measuring Devices

30. **Rules.** Rules are used for measuring length; they are made of steel and are usually graduated in both English and metric systems. They are precision devices and should be treated with care, particularly the end which forms the zero datum of the measuring scale.

31. **Calipers.** Calipers are used with a rule for measuring distances between surfaces or for comparing the sizes of several objects. The different types of common calipers and their uses are shown in Fig. 26.

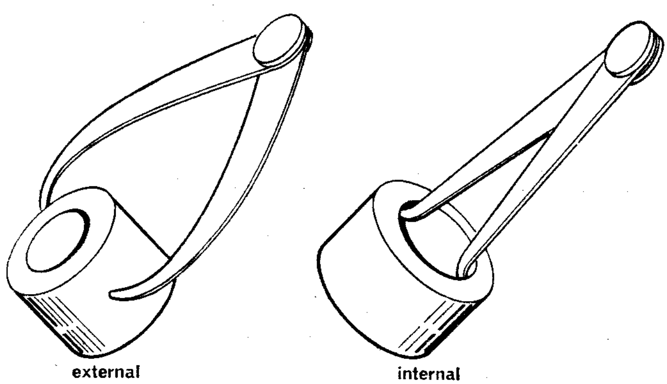
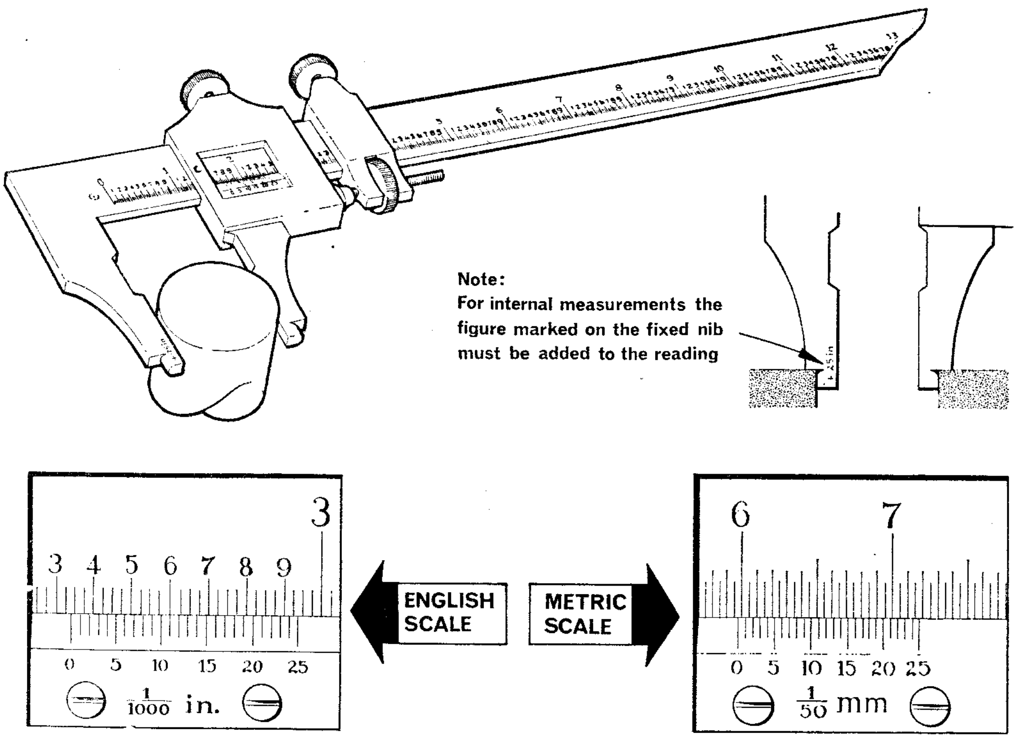


Fig. 26 Calipers

32. **Vernier calipers.** This type of caliper is used for accurate measurements and has a built-in rule. Fig. 27 shows measurement of the outside diameter of a cylinder, with inset views showing how the English and metric scales (on opposite sides of the caliper) are read. Calipers are precision instruments and must be kept in their cases when they are not in use.

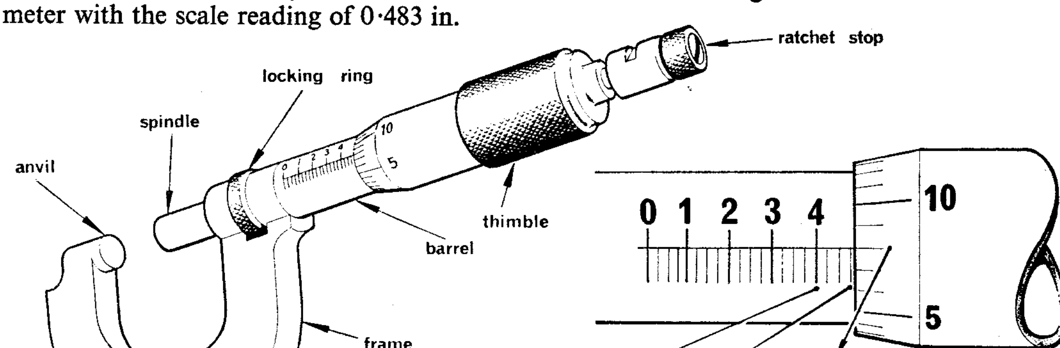


main scale divisions recorded by vernier zero = 2·325
coinciding vernier division 11 (x·001) = ·011
MEASURE (inches) = 2·336

main scale divisions recorded by vernier zero = 59·50
coinciding vernier division 18 (x·02 mm) = 0·36
MEASURE (millimetres) = 59·86

Fig. 27 Vernier caliper and scales

33. **Micrometer.** This is another precision instrument used for the accurate measurement of external diameters; usually of small wires in the electrical trades. Fig. 28 shows an external micrometer with the scale reading of 0·483 in.



0·400 in. + (3 × 0·025 in.) + 0·008 in.
= 0·400 in. + 0·075 in. + 0·008 in.
= 0·483 in. on a 0 to 1 in. Micrometer
or 1·483 in. on a 1 in. to 2 in. Micrometer and so on

Fig. 28 Micrometer and scale

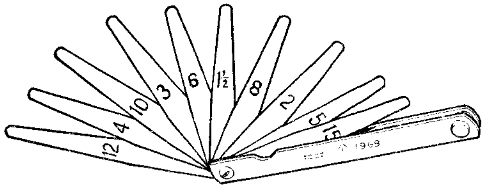


Fig. 29 Feeler gauges

34. **Feeler gauges.** Feelers are used to measure small clearances or gaps, e.g. between electrical contact points. A set consists of a number of thin flexible steel blades of various sizes (usually 1½ to 15 thousandths of an inch).

Marking-out Tools

35. **Scribers.** Scribers are used to mark cutting lines on metal surfaces (Fig. 30). They are made of steel with a sharp hardened point. Scribers must not be used to mark out lines on any aircraft alloys (other than cutting lines) as the scratch could easily turn into a fatigue crack. A graphite pencil should be used for marking out, but *all* traces of pencil line must be removed when the work is completed. A grease pencil (of any colour but black which could contain graphite) should be used to delineate a defect, such as a crack, where the marking has to remain for more than a few hours.

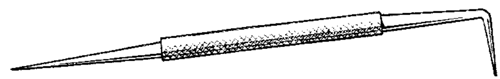


Fig. 30 Scriber

36. **Dividers.** Dividers are used to set out distances and to scribe arcs and circles (Fig. 31). They are classified by the length of the legs which are made of hardened steel and should be kept equal in length. When dividers are not in use the points should be protected by sticking them into a cork.

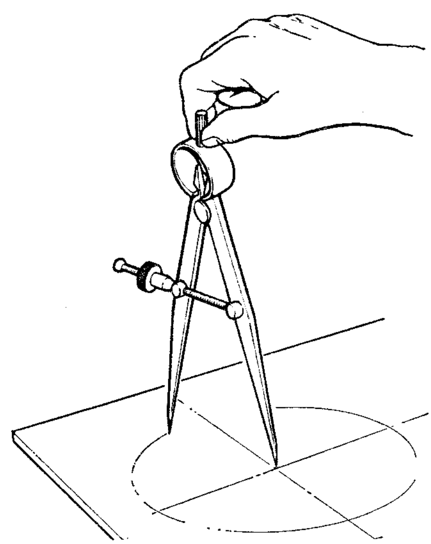


Fig. 31 Dividers

37. **Fitter's square.** A square is used when scribing lines at right angles to a surface or edge, and for checking the truth of a right angled piece of work. It is made of steel and consists of a stock fitted with a blade set at exactly 90°. Periodically it should be tested as shown in Fig. 32 using the true edge of a flat surface.

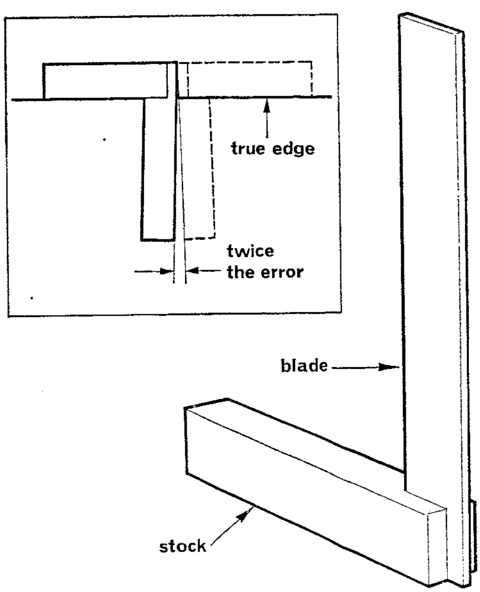


Fig. 32 Fitter's square

38. **Surface plate.** A surface plate is used for testing flat surfaces or to form a flat base from which marking-out measurements may be taken. It is made of close-grained cast iron and is ribbed on the underside to increase rigidity and prevent warping. Care must be taken to protect the surface. It should be kept clean, and when not in use should be lightly oiled and protected with a wooden cover.

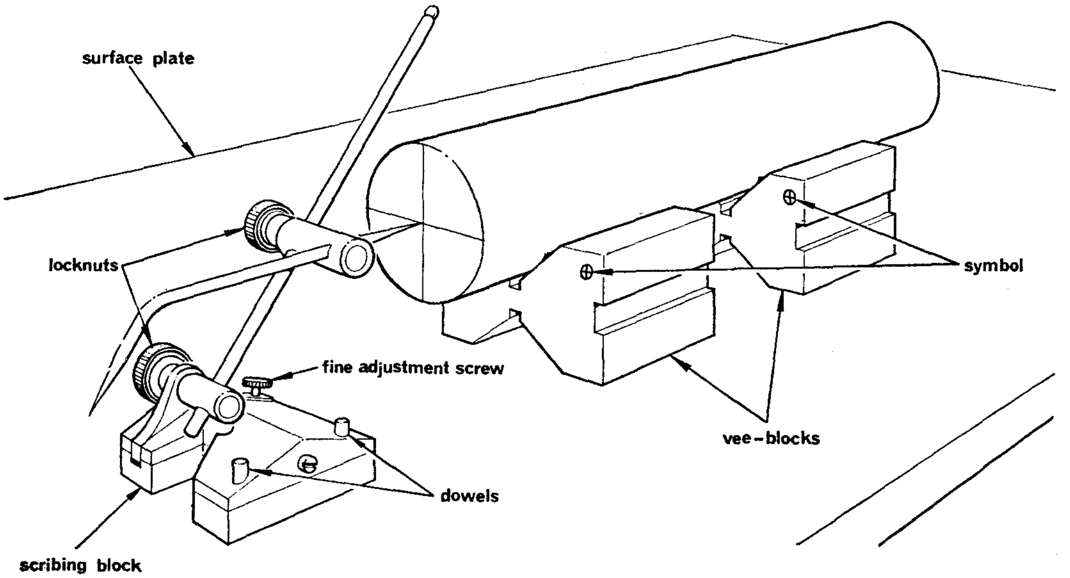


Fig. 33 Use of marking-out tools

39. **Vee blocks.** These are supplied as a pair and are used to support cylindrical work for marking-out on a surface plate (Fig. 33). All faces of vee blocks are machined as a pair and given an identification number. For correct positioning of the job the blocks used should have the same number at the same side of the work.

40. **Scribing block.** This is used when scribing lines parallel to a true surface and is normally used on a surface plate or a special marking-off table. The height of the scriber can be adjusted and locked in position; fine adjustment is then provided by a screw on the base. Dowels in the base can be used to allow the block to slide along a machined edge. Fig. 33 shows a block being used for marking-out on a cylinder.

Lubricating Devices

41. A large number of different greases and oils are in use in the electrical and electronic trades. All lubricants should be kept clean and covered to keep out dust and grit. Oil or grease must *never* be used near oxygen because of the risk of explosion. Always use the right quantity of the correct lubricant as over-lubrication may cause flash-over in electrical equipment.

42. **Grease guns.** These are provided to force grease under pressure into the bearings of machines. The universal model is supplied with four nozzles for use with different nipples (Fig.34). After changing a nozzle it is advisable to prime the new one before fitting it to a nipple.

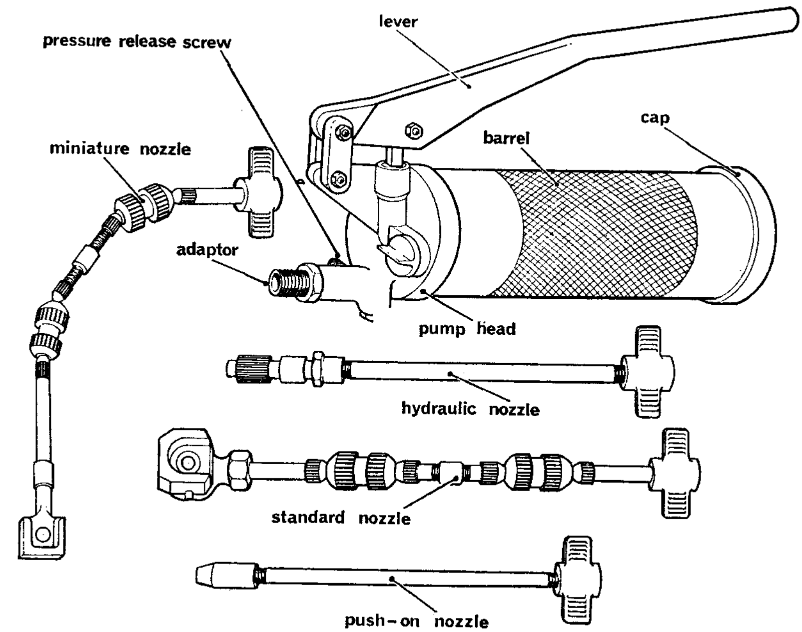


Fig. 34 The universal grease gun

43. **Oil cans.** Oil cans (Fig. 35) are a convenient method of applying oil to the point required without spillage. They should be clearly labelled to show the type of oil they contain.

44. **Hypodermic syringes.** These are used to apply measured quantities of oil to confined spaces. The needle used is normally ground flat to minimize the risk of personal injury (Fig. 36). A syringe should be used with care to prevent breaking the needle, and it should be fitted with a protective cap when not in use. An inspection mirror is often used when the point of application is not easily visible.

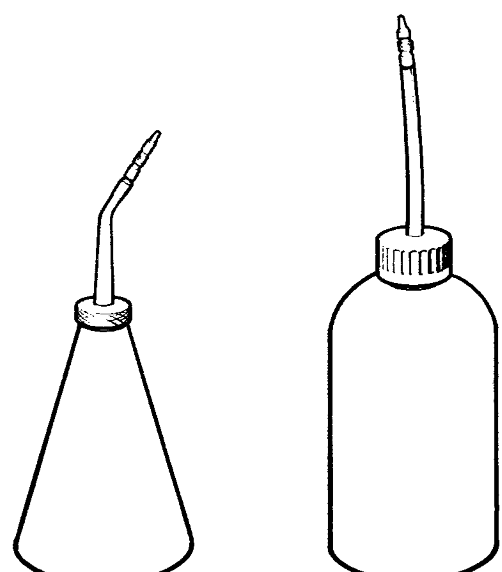


Fig. 35 Oil cans

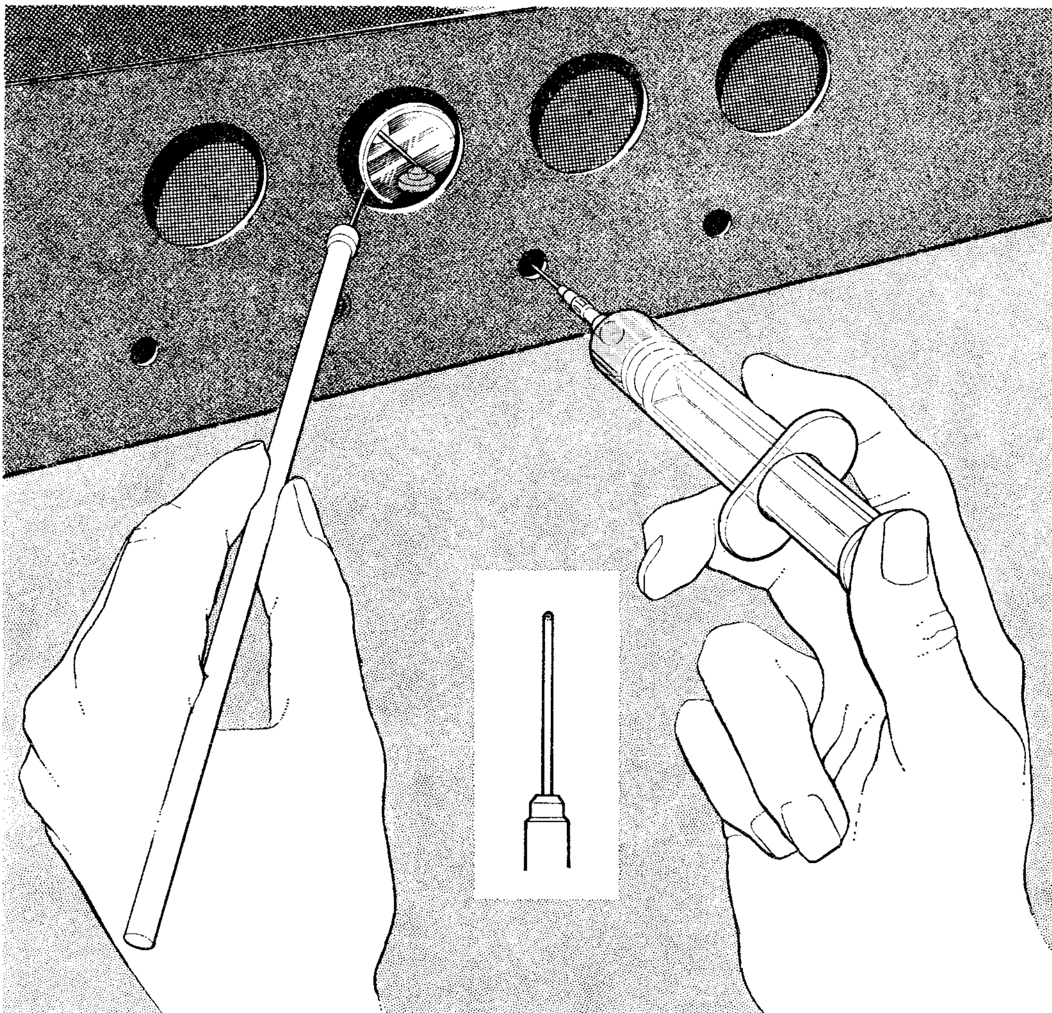


Fig. 36 Using a hypodermic syringe for lubricants

CHAPTER 3

WORKSHOP PRACTICES

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Introduction

1. Modifications to equipment very often involve the use of simple workshop processes and are embodied by an electrical or electronic tradesman. The manufacture of simple testing or servicing aids can also involve the use of these practices. If the tools required are not available, the work is carried out by a general engineering tradesman at station workshops.

Drilling

2. Drills are used for cutting circular holes in materials. When drilling a large hole, or where accuracy is essential, a fixed powered drilling machine is used. For general work using small drills a hand drill or a portable electric drill is normally used.

3. **Twist drills.** These are the most efficient drills for general metal work (Fig1). They are made of high carbon steel or of alloy steel. Alloy steel drills are commonly called 'high-speed drills' because they can be run at high speeds and temperatures without losing their hardness. The spiral fluting presents the cutting edge to the material at the correct angle and clears the swarf formed during the cutting.

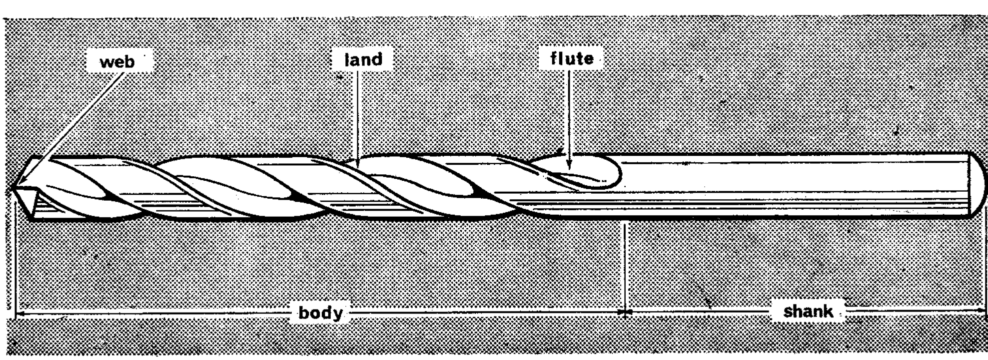

Fig. 1 Twist drill

4. **Drill sizes.** The size of a particular drill is marked on the shank; but with small sizes this is impractical and a drill gauge must be used. Twist drills for service use are supplied in the following sizes:

a. Metric. The minimum drill size is 0·35mm diameter, but the range for general use runs from 1·00mm upwards in steps of 0·05mm. Metric drills have superseded the numbered and fractional ranges; there is a metric size which will replace each drill in the obsolete ranges.

b. Fractional (inch) sizes. The minimum drill size is $\frac{1}{64}$ in. diameter; sizes increase in steps of $\frac{1}{64}$ in.

5. **Drill angles.** To cut properly, a drill must have the correct cutting and clearance angles. The angles most suitable are shown in Fig 2. It can be seen that the drill does not come to a fine point; because of this a centre punch is used as a marker to prevent the drill wandering. When drilling a large hole a much more accurate result can be obtained by using a pilot drill (slightly larger than the pointed end of the main drill) to produce a guiding hole.

6. **Drilling procedure.** The following rules apply whether drilling is done by hand or by using a power driven machine:

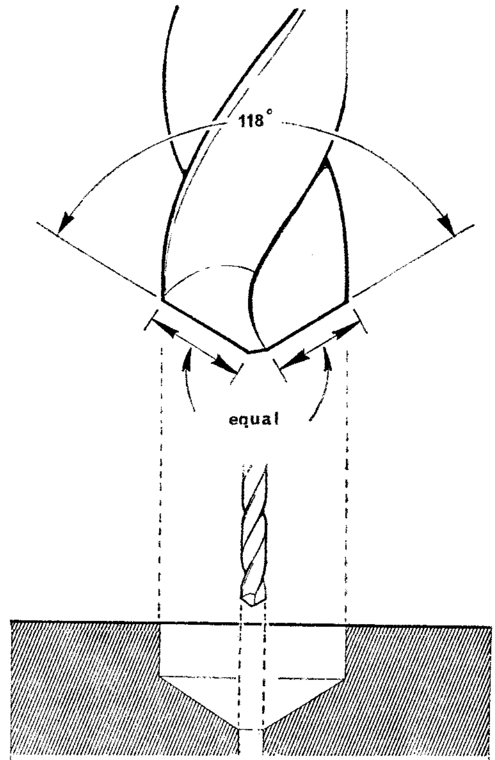

Fig. 2 Drill angles

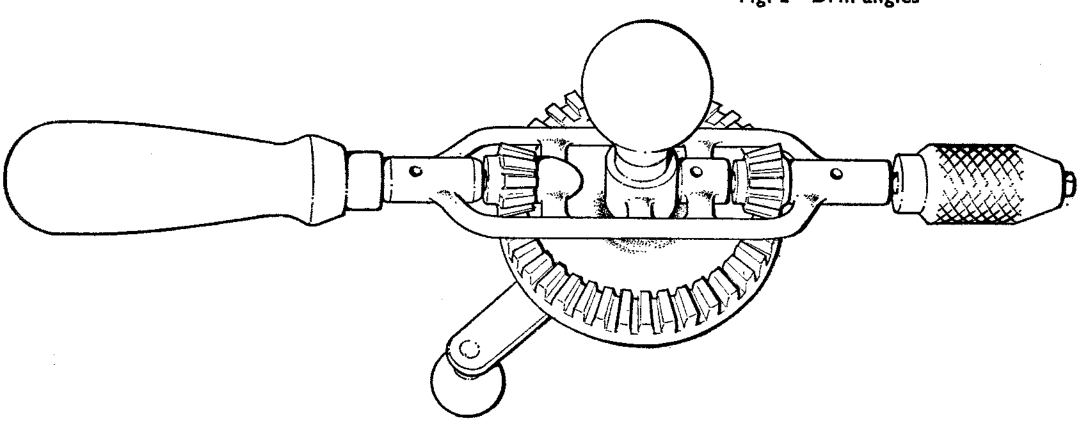

Fig. 3 Hand drill

a. Mark the centre position of the hole to be drilled by using a centre punch (90° end) to make a 'pop' mark.

b. Fit the correct size of drill into the chuck and rotate the drive to check that the drill is correctly centred.

c. Secure the work in a vice, using a wooden block to support thin sheet materials if required.

d. Place the tip of the drill in the centre pop. Keep the drill perpendicular to the work surface and rotate the drive clockwise slowly until the drill bites into the surface.

e. Increase the speed of the hand drive and apply more pressure on the rear handle of the drill until the correct speed and feed is obtained. Apply lubricant if necessary to keep the drill cool.

f. If a hole of limited depth is required make a pencil or chalk mark on the body of the drill at the required distance from the point. Pause several times during drilling, stop the drill, and clear any swarf from the hole.

g. When drilling right through a material the pressure should be reduced towards the end of the job to prevent breaking of the surface as the drill emerges.

h. Continue rotating the drill clockwise whilst withdrawing it from the job.

7. **Countersinking.** To remove burrs from the edge of a hole, or to countersink a hole for a screw head or rivet, a rose bit is used (Fig 4). For steel, or other hard metals, a rose bit is not suitable and a large size twist drill must be used.

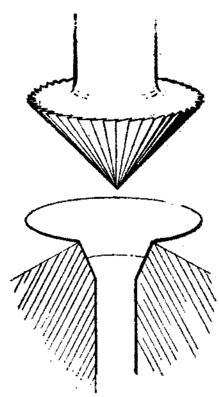

Fig. 4 Countersinking

8. **Power-driven drills.** Electric hand drills are a very useful timesaver, but can be dangerous unless they are kept in good condition and are handled carefully. Fixed power-operated drilling machines are normally used only by authorized tradesmen (Fig 5).

a. Always check the condition of the electric lead and plug. If there is any damage do not use the drill until it has been serviced.

b. Make sure that the job is firmly secured in a vice or on a drill platform.

c. Use a lubricant to keep the point of the drill cool; kerosine is suitable for most metals.

d. Do not force the feed or the drill may break.

e. If swarf builds up at the drill point stop the machine before attempting to clear it away.

f. Wear goggles to protect your eyes.

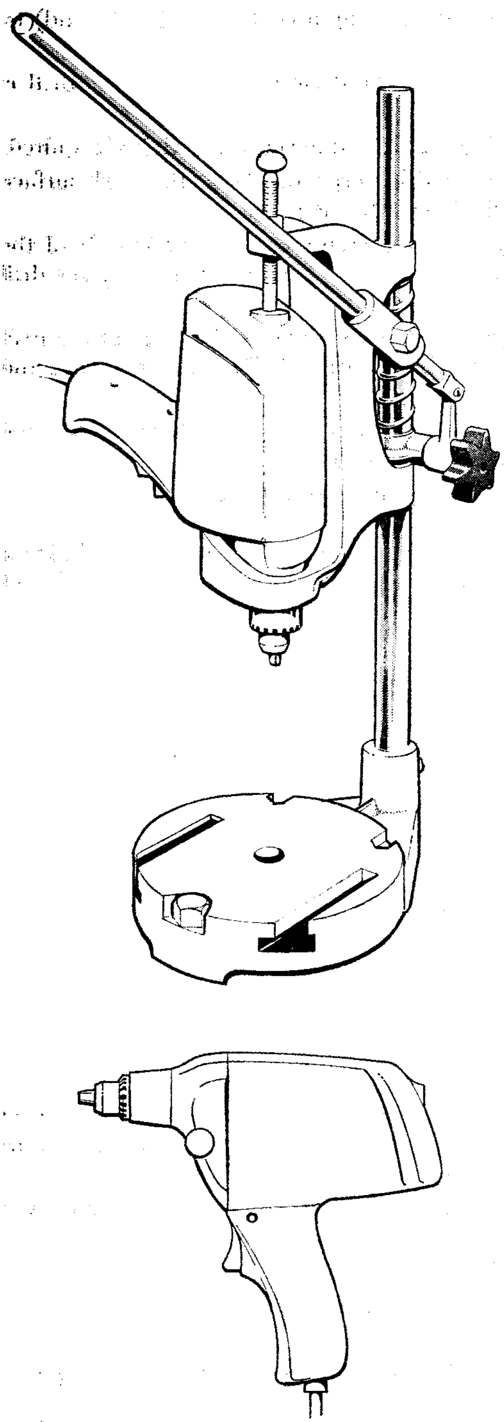

Fig. 5 Power drills

9. **Accuracy.** Accurate drilling is very important when an expensive equipment is being modified. For best results a drill must run at the correct speed and feed for the material being cut. The speed of power machines is usually adjustable and large size drills should be run at low speeds. The correct rate of feed can be determined only by experience; when an accurate result is wanted it is advisable to practice on a spare piece of metal before starting the actual job.

Grinding

10. Emery or carborundum wheels are used for removing hard metals, such as the alloy steels, and for shaping and sharpening tools. Coarse and fine wheels are supplied, the degree of fineness being determined by the grain size of the hard abrasive powder which forms the wheel. Grinding wheels are very brittle and are easily broken.

11. Proper use of a power-driven grinding wheel will produce a smooth level surface (Fig 6).

a. Put on safety goggles to protect the eyes.

b. Adjust the job rest in front of the wheel so that it lies close to the wheel, preventing the job jamming between the rest and the wheel.

c. Use the face of the wheel only, and move the job from side to side to keep wear on the wheel even. Do not exert heavy pressure on the wheel as this will ridge the working face.

d. To retain the hardness of steel during grinding its temperature must be kept down by frequent quenching in cold water.

e. Do not attempt to grind a soft metal such as brass or aluminium because the particles will clog the wheel.

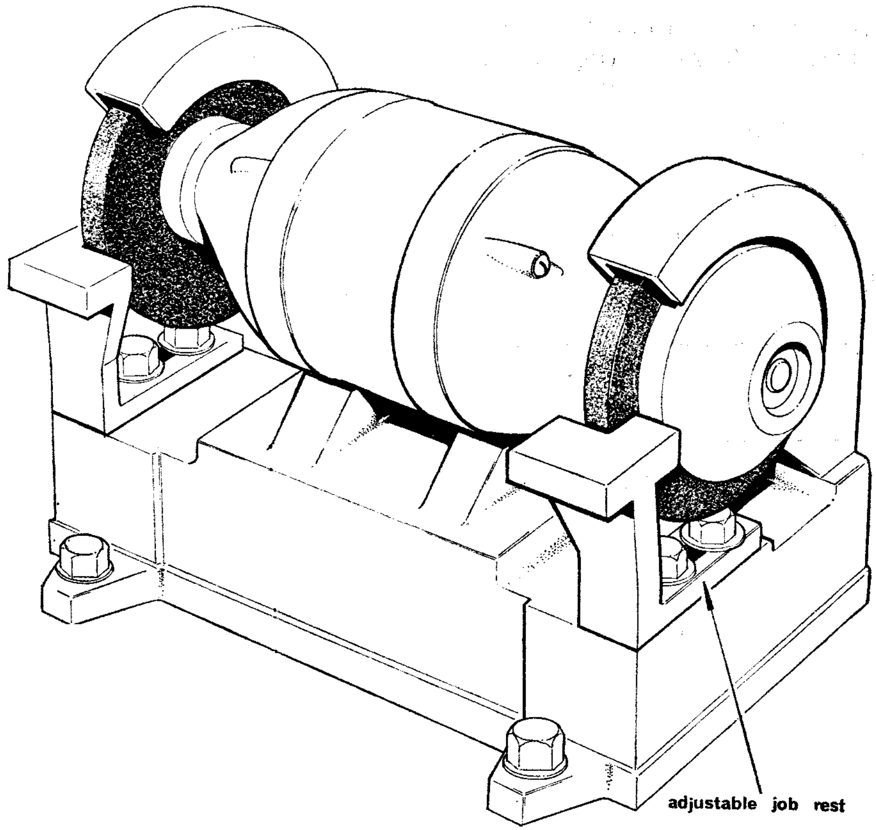

Fig. 6 Grinding machine

Screwcutting

12. Screw threads are helical grooves cut either on the external surface of a cylinder or on the internal wall of a cylindrical hole. The thread is 'right hand' when clockwise rotation causes it to engage.

13. **Thread systems.** There are a number of different sizes and types of thread in common use in the service, but they can be divided into two basic groups:

a. Fine threads. The closely spaced threads allow accurate tightening torque to be used and provide the high resistance to vibration necessary for some applications. The BSF (British Standard Fine), ANF (American National Fine) and the UNF (Unified Fine) are in common use in aircraft and in good quality general engineering. The BA (British Association) is another fine thread mainly used in electrical and radio equipments.

b. Coarse threads. Coarse threads are used in general engineering where they are useful for the rapid assembly and dismantling of parts. They are not used on aircraft as they are affected by vibration. Common types are BSW (British Standard Whitworth), ANC (American National Coarse) and UNC (Unified).

A metric version of the unified thread is being developed by the ISO (International Organization for Standardization) which will eventually replace all other thread systems.

14. **Taps.** Taps are used to cut *internal* screw threads. They are short screws of hardened steel fluted to form cutting edges (Fig. 7). The top of a tap is made square to fit into a tap wrench. Taps are supplied in sets of three:

a. Taper tap. This is the first tap used when cutting a thread. It is tapered over its length, except for the last six threads, so that it can be entered freely into a hole drilled to the root diameter of the thread.

b. Second tap. This is used after the taper tap to deepen the threads, where it has not been possible to cut full threads with the taper, *eg* in a blind hole. It is tapered for the first six threads only (Fig. 7). In some sets, such as BA sizes, a second tap is not supplied.

c. Plug tap. This tap has no taper and is used to cut a full thread to the bottom of a blind hole.

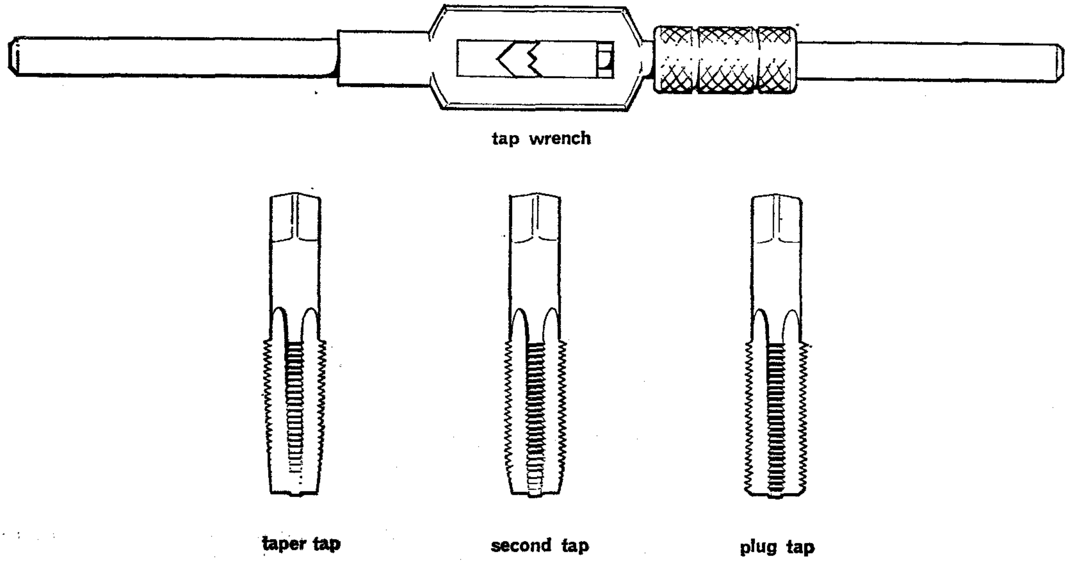

Fig. 7 Taps and tap wrench

15. **Internal screwcutting.** Before a tap can be used a hole must be drilled to the thread root diameter. The correct drill size for a particular thread may be found from a table of tapping sizes.

a. Clamp the work firmly in a vice.

b. Enter the taper tap vertically into the hole and test with a fitter's square.

c. Fit a tap wrench and turn the tap clockwise in a series of short arcs, applying an equal downward force with each hand.

d. Turn the tap back frequently to break the cuttings into small chips. If the hole is blind, remove the tap and clear the cuttings from the hole.

e. Lubricate the tap when necessary with either cutting oil or kerosine.

f. When the taper tap reaches the end of its travel use the second tap, and when necessary the plug tap, until a full thread has been cut.

16. **Dies.** Dies are used for cutting *external* threads and consist of an internal hardened steel thread, fluted to form a cutting edge. The circular die has a standard outside diameter so that all sizes fit into a standard stock to form a complete tool (Fig. 8). The die is held in the stock by a knurled screw that beds into a split in the die. This split allows a slight adjustment of size to be made by two further screws on the stock. The threads at one end of the die are tapered for easier starting, and this end should be furthest away from the stock shoulder (Fig. 8).

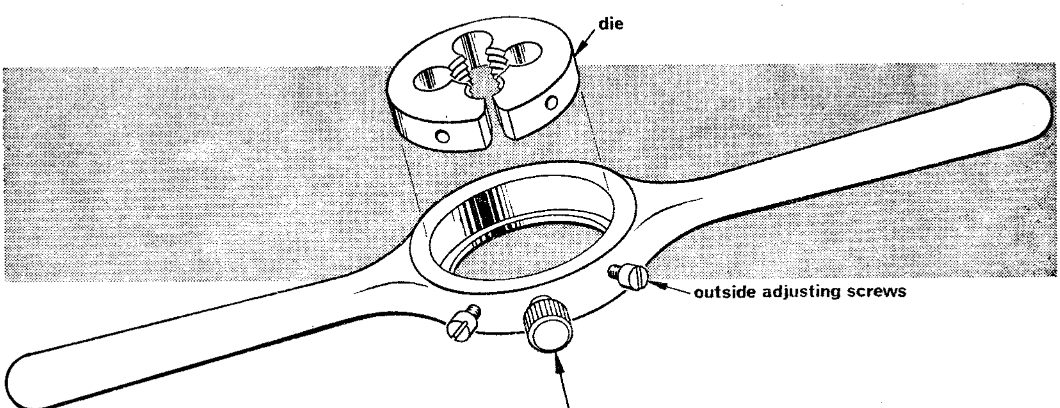

Fig. 8 Die and die stock

17. **External screwcutting.** The diameter of thread cut with a tap cannot be altered; that cut with a die can be altered slightly with the stock adjusting screws. Thus, if two mating threads are required, the internal thread is cut first and the external thread can then be cut to mate with the required degree of tightness. Before a thread can be cut, a rod is required having an outside diameter the same as the nominal diameter of the thread.

a. Taper the first $\frac{1}{8}$ in. of the rod with a file to give an easy start to the die.

b. Slacken the outer screws on the stock and tighten the centre screw. This sets the die to cut the maximum diameter thread.

c. Clamp the rod vertically in a vice with the tapered end uppermost, and apply the tapered end of the die to the taper on the rod. Ensure that the stock is square to the rod and turn it clockwise to start the thread.

d. Cut in a series of half turns, reversing each time to break up the cuttings. Lubricate if necessary with cutting oil or kerosine.

e. When a sufficient length of thread has been cut remove the die and test the thread for fit in its mating thread. If it is too tight increase the cut of the die by tightening the stock adjustment screws (outer) and recut the thread until the desired fit is obtained.

f. Using a file, carefully remove the taper from the end of the threaded rod.

Riveting

18. Rivets are a form of permanent fastening used with sheet metal construction. Solid rivets are supplied with one head already formed. A variety of head shapes, diameters, lengths and metals are available. It is important that the rivet used should be of the same metal as the work to be riveted in order to prevent corrosion. Tubular rivets are used when joining thin metal sheets or when there is a gap between the parts to be joined.

19. Holes for rivets must be drilled larger than the rivet to allow for spread. The correct size can be found from tables. The length of rivet used must equal the combined thickness of the plates to be joined plus an allowance necessary to form the second head.

20. **Snaphead riveting.** The three tools needed for snaphead riveting are a 'dolly' to support the preformed head, a 'set-up' to close the plates and a 'snap' which shapes the second head (Fig. 9).

a. Mark out the position of the rivet; centre pop and drill a hole of the correct clearance size.

b. Carefully remove all burrs from the hole.

c. Insert a rivet of the correct length. To prevent movement of the plates during riveting they should be clamped or bolted together.

d. Support the preformed head in the dolly, place the set-up over the rivet shank and strike the set-up lightly. This brings the plates close together and the preformed head hard against the plates (1).

e. Remove the set-up and strike the rivet shank several times to spread the rivet in the hole (2).

f. Place the snap over the end of the rivet, hold it square to the plates and form the second head by striking the snap with a hammer (3).

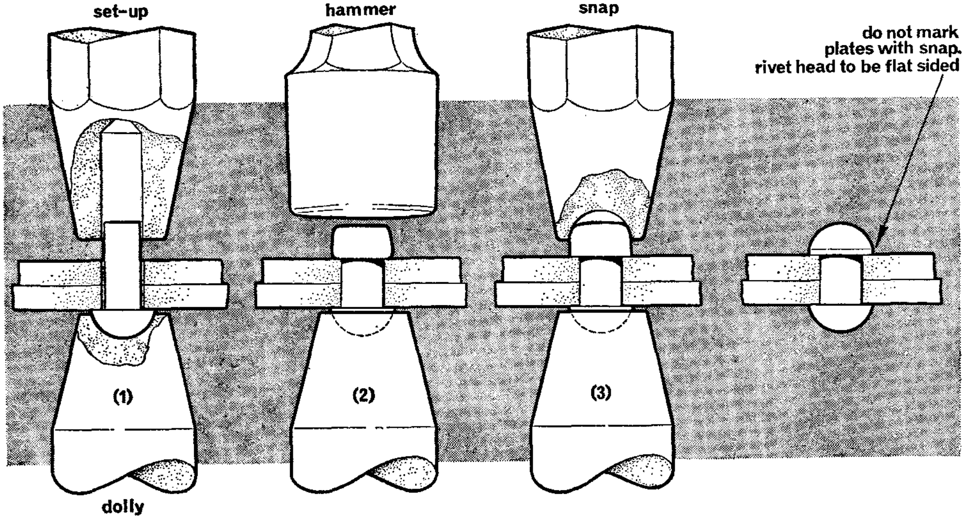

Fig. 9 Snaphead riveting

21. **Riveting faults.** Some of the more common faults and their causes are shown in Fig. 10. If a rivet has to be removed, file a flat on the pre-formed head, centre pop and drill almost through the head using a drill of the same diameter as the rivet shank. Chip off the drilled head using a sharp chisel and drive out the rivet with a parallel pin punch.

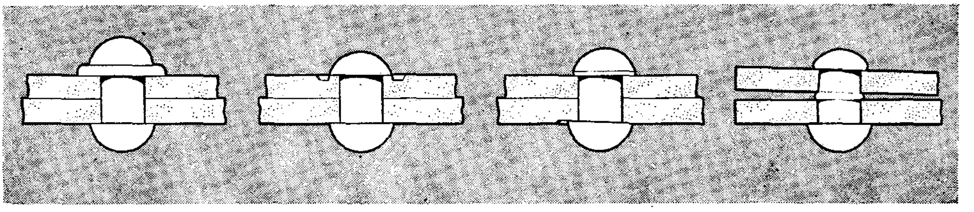

Fig. 10 Common riveting faults

22. **Tucker pop riveting.** These rivets are hollow and are supplied mounted on a mandrel (Fig. 11). A riveting tool of the 'lazy-tongs' type is provided for closing the rivet. They can be used in positions where only one end of the rivet is accessible.

a. Mark out the position of the rivet; centre pop and drill a hole of the correct size. Ensure all burrs are removed.

b. Fully extend the lazy-tongs and insert the shank of the mandrel into the jaws of the chuck. Slightly compress the tongs to grip the mandrel and insert the rivet into the hole.

c. Hold the chuck firmly against, and square to, the surface being riveted and compress the tongs. This action causes the head of the mandrel to close the rivet and then break off (Fig. 12).

d. Remove the broken pieces of the mandrel and dispose of them in a safe place.

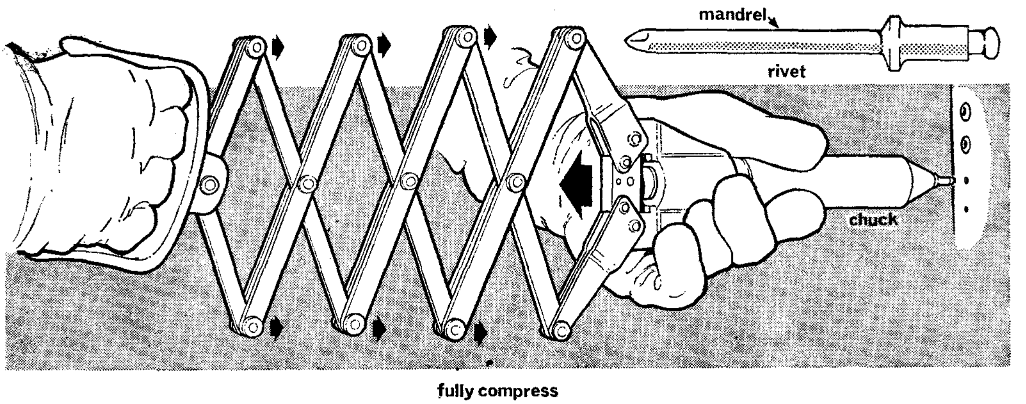

Fig. 11 Tucker pop riveting tool

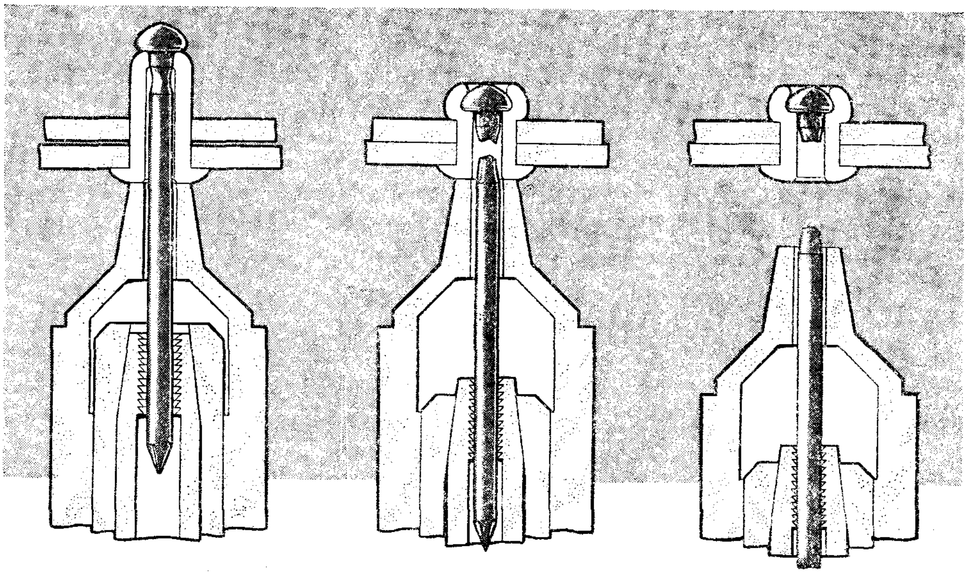

Fig. 12 Formation of a pop rivet

Sheet Metal Punches

23. Sheet metal punches are used to make clean holes in sheet metal in one quick and simple operation. Round, square or rectangular holes can be made for fitting valve bases, relays or transformers to the equipment chassis. Punches are mainly used at third line or in workshops where modifications are carried out. A hole is first drilled through the chassis, this enables the two halves of the punch to be bolted together one either side of the chassis. The two halves are then tightened using an allen key and will punch a burr-free hole.

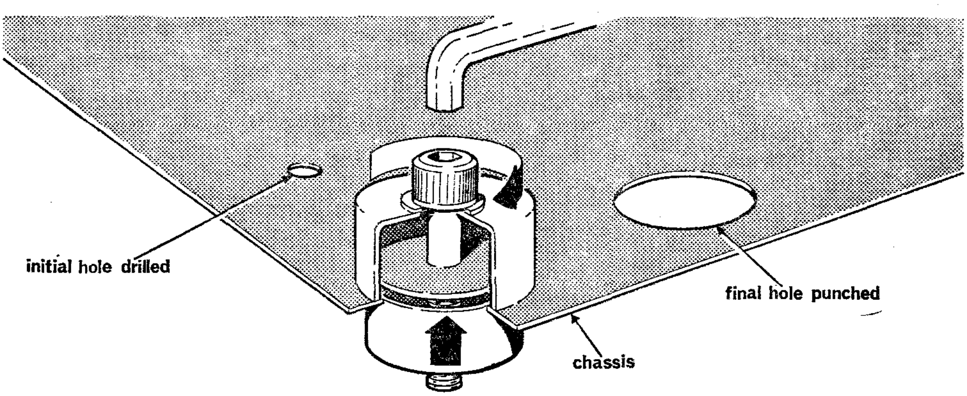

Fig. 13 Sheet metal punching

CHAPTER 4

ELECTRICAL CONNECTIONS

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Introduction

1. The type of wire used to make an electrical connection depends on the operating conditions and environment of the equipment to be connected. A high current connection requires a conductor of large cross-sectional area to keep the voltage dropped by the cable to a minimum, and to prevent over-heating. If high voltages are present the insulation round the conductor must be sufficient to prevent breakdown and current leakage. Cables carrying high frequency alternating currents must have a metal screen to prevent interference being caused by stray fields. When oils or petrol may be present the type of insulation used must be able to withstand their effects without breaking down. These and other conditions are met by a large range of wires and cables; the common types are described in this chapter.

2. Wires must be connected to each other, or to terminals, without introducing excessive losses. Joints should have as small a resistance as possible and must also be mechanically sound within the limits of their operating conditions. There are three main classes of connection:

a. Permanent. Crimped joints of various types are the recommended method of making permanent joints in wiring systems. Some small joints, usually inside a miniaturized equipment, have been *welded* by the manufacturer.

b. Repairable. The main type of joint used inside equipments is the *soldered* connection. Some modern equipments use the solderless *wrapped wire* joint as the normal connecting method.

c. Removable. Removable connections are made by *plugs and sockets* of various types or by *taper pins.* When both ends of a cable are terminated by a plug or socket it is called a *connector.* Methods of making removable connections are considered in chapter 5.

3. This chapter deals with cables and the methods used in wiring up equipments and aircraft. As component parts become more reliable, wiring failures are causing an increasing percentage of equipment breakdowns. New and more reliable connecting methods are being developed but a major improvement in reliability can be achieved by careful, accurate work by electrical and electronic tradesmen.

Cables

4. The conducting material normally used in cables is copper, but for some aircraft applications aluminium is preferred because of its lighter weight. These aluminium cables are mainly of high current capacity and have the letters AL at the end of their names. Care should be taken not to fit copper terminations to an aluminium cable (and *vice versa*) as corrosive action will quickly destroy the effectiveness of the joint.

5. **Aircraft cables.** A large number of aircraft at present in service are fitted with PREN cables

which are obsolescent, and are being replaced for general use by the NYVIN range. The pren range of cables have a number which indicates the current rating of the core in d.c. amps, e.g. Pren 4 (4 amps), Prenal 100 (100 amps, aluminium cored). Modern types of cable are numbered by the American method which is based on the size of the core and the American wire gauge (AWG). Smaller cables have higher numbers, e.g. Nyvin 22 (4 amps), Nyvinal 2 (100 amps).

a. Pren cables. The conductor is covered with a sheath of glass braid and an outside sheath of polychloroprene. Nypren cables have an additional outer cover of nylon to protect them against chafing and the active synthetic oils used on aircraft.

b. Nyvin. Two grades of nyvin cables are in general use in the service. Type A will withstand temperatures up to 105°C and has the name printed in red. Type B will operate up to 90°C and has the name printed in black. All aluminium cored cables in service use are type B. The number printed on the nylon braided sheath gives the conductor size (AWG). They are flame resistant and are not affected by petrol, oils or hydraulic fluids. The maximum working voltage is 600 volts r.m.s. at 1600 Hz. Construction details of various cables in the range are shown in Fig. 1.

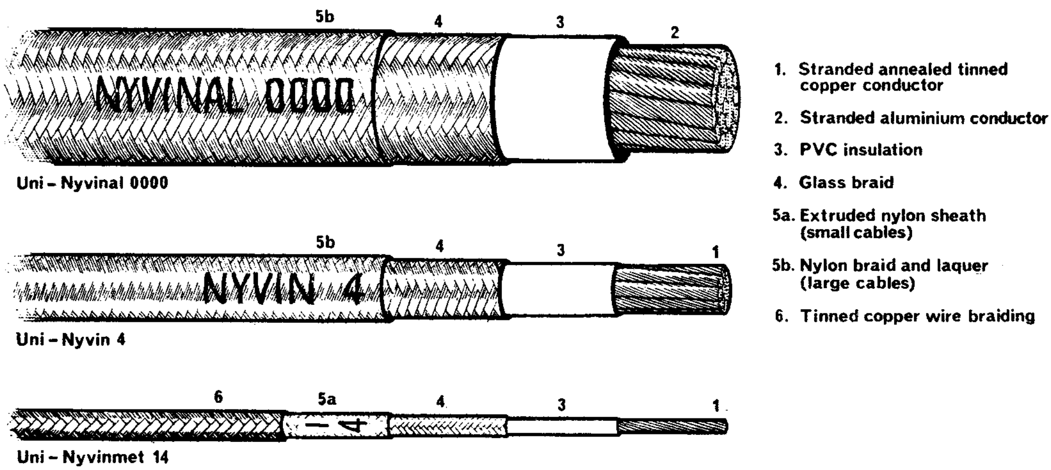


Fig. 1. Nyvin cables

c. Tersil. The Tersil range of cables are designed for use at temperatures up to 190°C, and are resistant to oils and hydraulic fluids. During a fire the burnt silicone rubber insulation

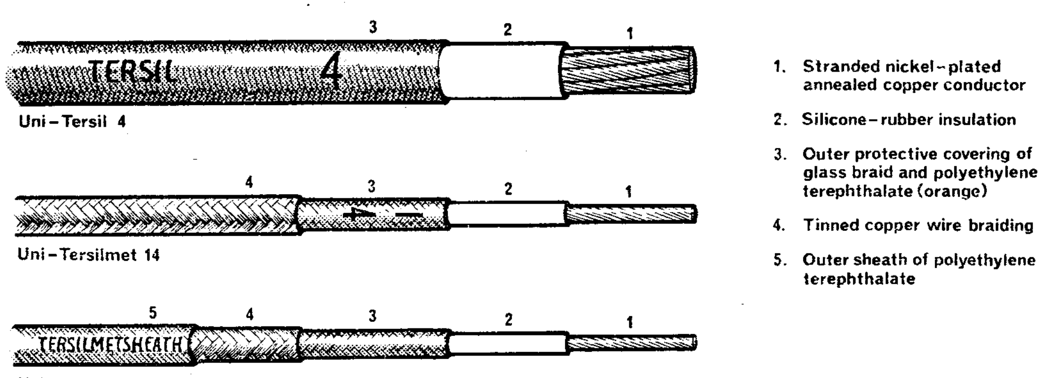
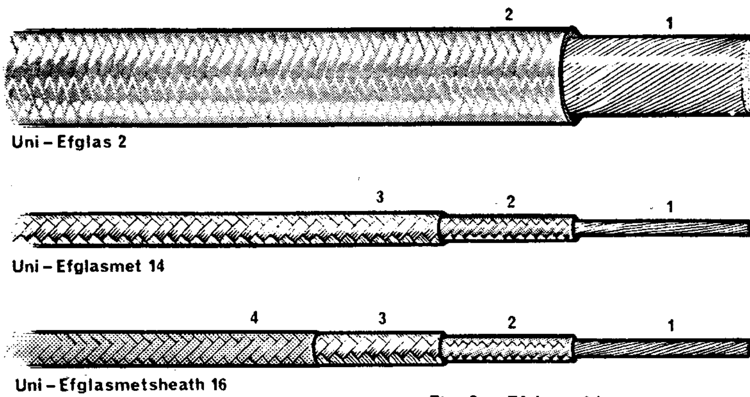


Fig. 2. Tersil cables

retains sufficient insulating properties to enable the circuits to function for not less than 5 mins, as it is retained in position by the glass braided cover.

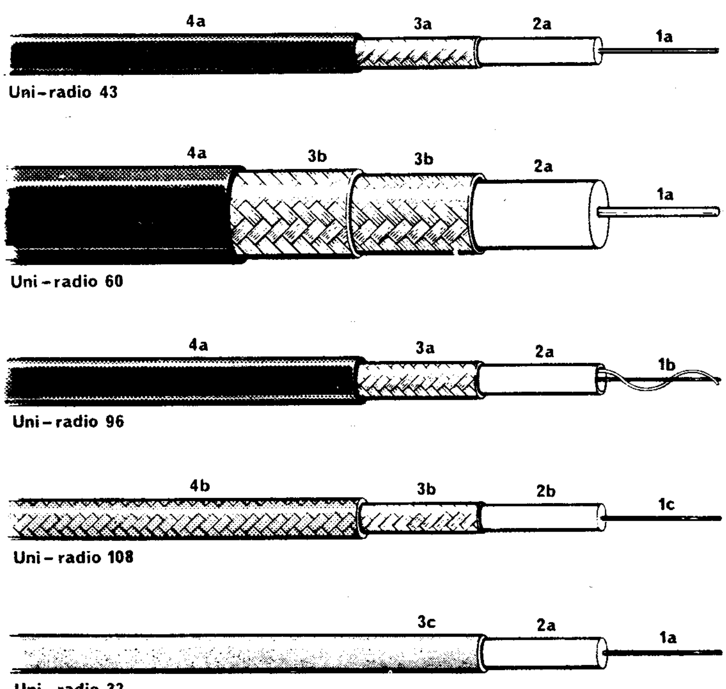
d. Efglas. Efglas cables are designed for use at high temperatures, up to 240°C, and have nickel-plated copper conductors to prevent oxidation. They are resistant to all aircraft fluids including 'ester-based' oils. Efglas is non-inflammable and will withstand severe overloads in an emergency.



1. Stranded nickel-plated annealed copper conductor
2. Insulating cover of glass braid and PTFE
3. Nickel-plated copper wire braiding
4. Outer sheath of PTFE and glass braid

Fig. 3. Efglas cables

6. **Radio frequency cables.** These cables are of coaxial form and are designed to carry RF energy at frequencies up to 3000 MHz. They are given the name of *uni-radio*, followed by a number.



1. Inner conductor of:
   a. annealed copper
   b. copper covered steel
   c. silver plated copper
2. Dielectric insulation of:
   a. polythene
   b. PTFE
3. Outer conductor of:
   a. annealed copper braiding
   b. silver-plated copper braiding
   c. lead alloy sheath
4. Protective sheath of:
   a. PVC
   b. PTFE

Fig. 4. Uni-radio cables

These cables have a characteristic impedance determined by their physical size; mainly 50Ω, 75Ω or 100Ω. Lead alloy outer sheaths are used when the cable requires maximum screening or has to be buried underground.

7. **General and equipment wiring.** General wiring is classified by the number of strands and strand diameter of the conducting core e.g. 19/·006 which will carry about 4 amps. The type and thickness of the insulation used depends on temperature and voltage requirements. Most modern wires are either PVC or PTFE insulated. Some internal equipment wiring is not insulated and uses a single strand of tinned copper wire. This wire is classified by diameter on the standard wire gauge e.g. 24 SWG.

8. **Printed circuits.** Printed circuits are used instead of wiring for most internal applications in radio, computers and missiles. They reduce the clutter of wiring, save space and assembly time and have greater reliability. They consist of a thin layer of copper, bonded to a laminated insulating sheet. An electrical circuit drawing is transferred to the copper by a photographic process, and excess copper etched away in an acid bath. The remaining copper forms the electrical conductors of the required circuit. The printed circuit can be drilled or punched to enable components to be soldered directly to the copper conductors.

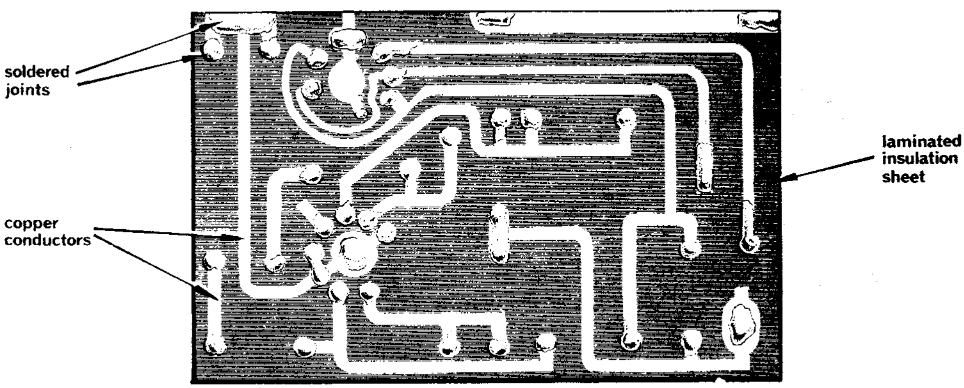


Fig. 5. Printed circuitry

Cable Preparation

9. **Stripping.** Removal of the insulation from a conductor is a very important part of electrical work. Two basic methods are possible; mechanical, i.e. by using a knife edge, and thermal, i.e. melting the insulation. During mechanical stripping great care must be taken to avoid removing wire strands from the conductor core. The insulation must be completely removed or a poor electrical joint will result. Thermal stripping avoids the danger of cutting the strands but may cause corrosion of the conductor by decomposition products formed when the insulator is melted. Too little heat may cause a thin film of insulator to be left on the conductor resulting in a poor electrical joint. A satisfactory thermal stripper for service use has not yet been developed and stripping is done mechanically using special pliers.

10. **Stripping pliers.** The adjustable stripping plier shown in Fig. 6 is for general stripping of wires up to $\frac{5}{32}$ inch outside diameter of conductor. The adjustment screw is set so that the jaws will not close to a smaller size than the conductor and is then locked in position by the knurled locking nut. The pliers have a self-opening spring action and insulated handles. It is advisable to test the adjustment by stripping a spare piece of wire and checking that no damage is caused to the conductor.

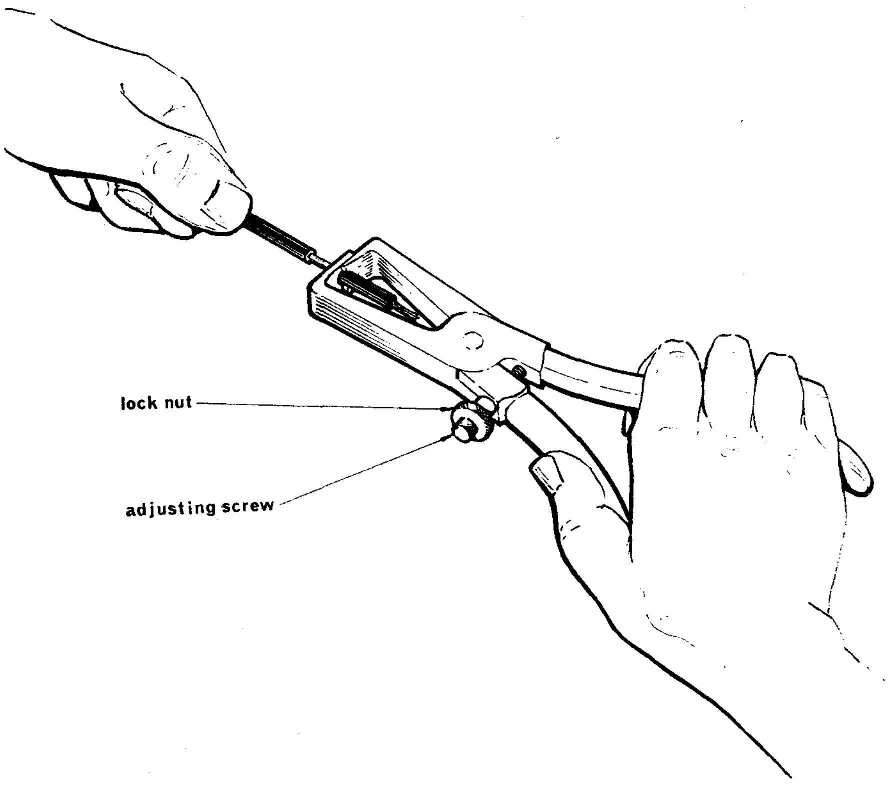


Fig. 6. Stripping pliers

11. **Stripping tool.** The Hellerman semi-automatic stripping tool is designed to make a clean strip up to $\frac{7}{8}$ inch long without nicking the conductor. The wire is placed between the clamping jaws with the end to be stripped protruding through the appropriate hole (marked with AWG number) for the stripping distance required. First pressure on the handles closes the clamping jaws and grips the wire firmly in the required position. The cutting blades close to the diameter of the conductor and cut through the insulation. On applying more pressure to the handles the upper sections move apart pulling the insulation away from the conductor. The standard tool has three holes for sizes 8/10/12 AWG. The blades are easily changed for a set with six holes from 16–26 AWG. A similar type of stripping tool made by Plansel has four sets of interchangeable blades.

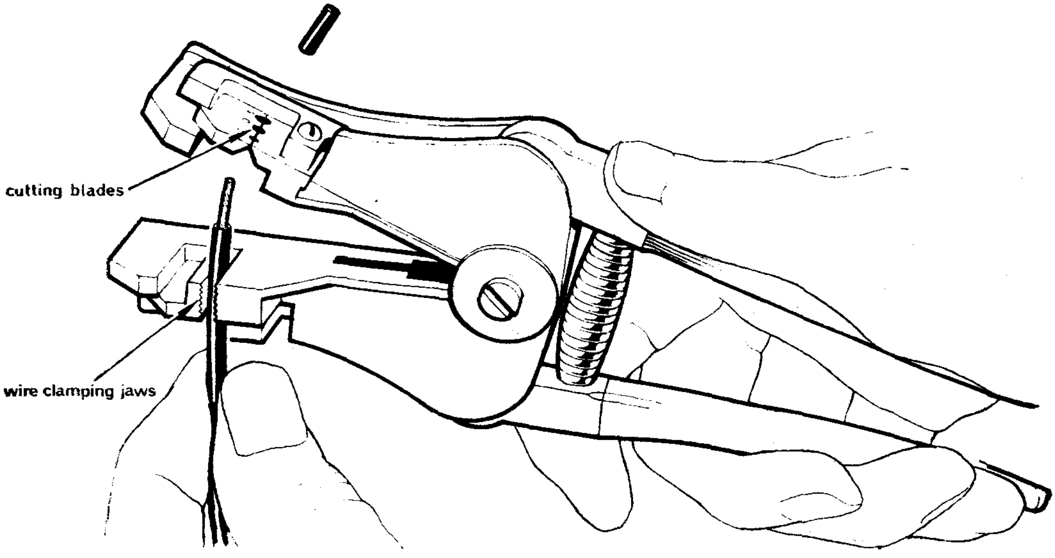


Fig. 7. Semi-automatic stripping tool

12. **Preparation of metal-sheathed cables.** The braiding is removed by a cable stripping hook and trimmed to the required length using watchmaker's shears. To prevent the ends from fraying and to obtain electrical continuity, metal ferrules are fitted using the pliers shown in Fig. 8. The outer ferrule is slid over the metal braiding. The inner ferrule is slid along the insulation to fit under the braiding. The ferrules are then clenched together with the pliers and any excess braiding is trimmed off.

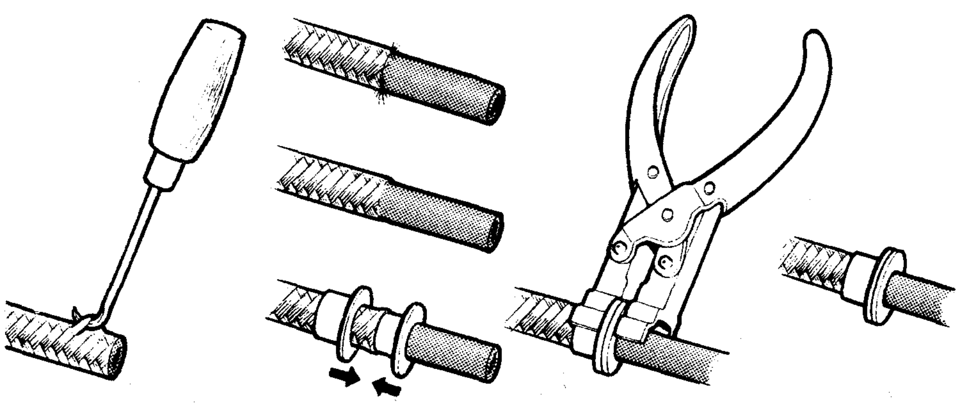


Fig. 8. Preparing a metal-sheathed cable

13. **Insulating sleeves.** A wide range of synthetic rubber insulating sleeves is available. They are used as cable markers and to support and insulate a cable at its point of entry to a plug or termination. They are fitted using special three-pronged pliers, usually called 'Hellerman pliers'. Three sizes of pliers are available to cover the whole range of sleeves.

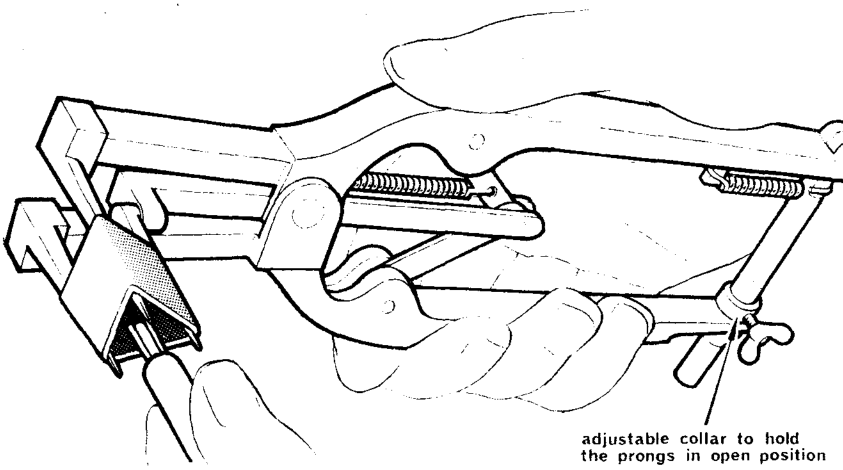


Fig. 9. Fitting an insulating sleeve

a. Lubricate the prongs with a *small* quantity of Hellerene oil.
b. Slip the sleeve over the prongs of the pliers.
c. Compress the handles of the pliers to expand the sleeve.
d. Place the expanded sleeve in position over the cable.
e. Release the handles and withdraw the pliers, leaving the sleeve in the required position.

Heat Shrinkage Sleeving (Thermofit)

14. **Thermofit.** Thermofit tubing is made from an extruded insulating material which has been subjected to nuclear radiation during manufacture. The application of hot air causes the tube to shrink to a predetermined diameter without any appreciable loss of length. In the expanded form (i.e. as supplied) these tubes can be easily slipped over terminals, cables or irregularly

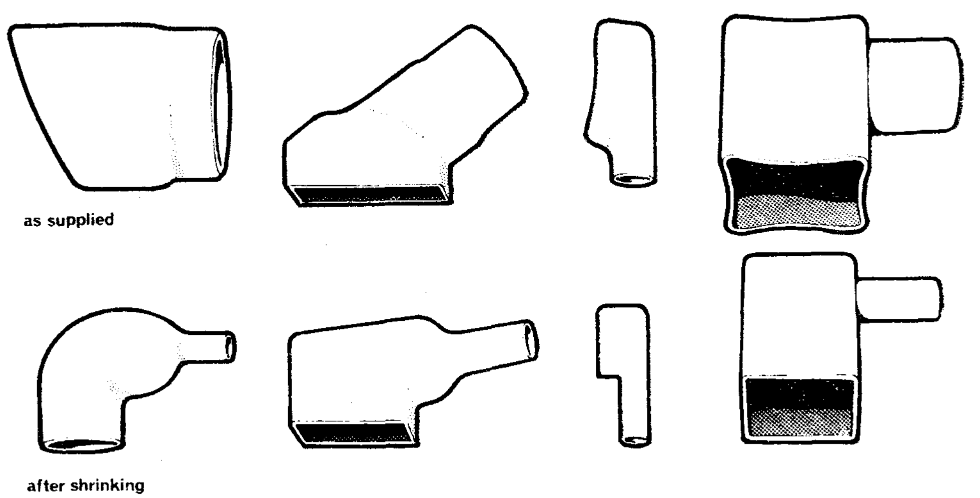


Fig. 10. Heat shrinkage products

shaped objects. On shrinking, the material forms a tight mechanical bond with the item over which it was placed. To obtain the correct fit the material selected should have a recovered size (i.e. shrunk) slightly less than the smallest item to be insulated. A range of moulded parts such as 'Y' and 'T' junctions and 'boots' for connectors is also available (see Fig. 10).

a. Ensure that the component over which thermofit is to be shrunk will withstand the temperatures involved in shrinking the type of sleeve selected.

b. Protect items in the vicinity of the work by using a suitable heat shield.

c. To prevent splitting, the diameter of the component should not be greater than 1·4 times that of the recovered tubing.

d. Apply heat, starting at the centre of the tubing and working towards the ends to allow air or moisture to escape.

15. **Thermo gun (type M150).** The thermo gun is a mains operated device for producing hot air which is specially designed for the shrinkage of Thermofit products. A range of heat deflector shields is provided, (see Fig. 11). Due to the exposed heating elements and motor the thermo gun is not suitable for use on aircraft because of the fire risk. For aircraft applications Thermofit products should be shrunk using the thermo pistol.

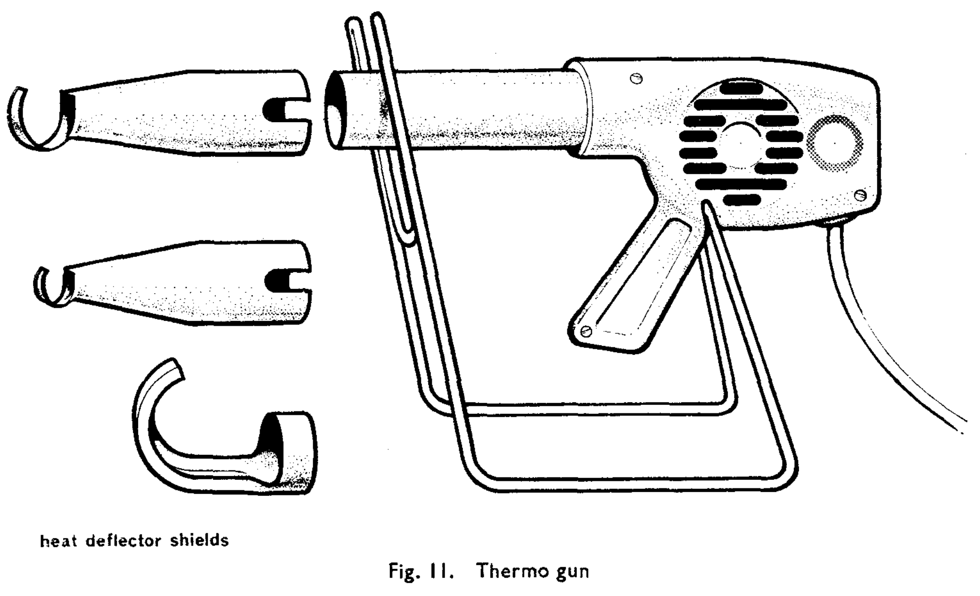


Fig. 11. Thermo gun

16. **Thermo pistol.** This device operates from an air supply obtainable from a special air regulator control box. A pressure switch in this regulator cuts out the heater element if air pressure falls. The heating element is of the totally enclosed type and is mains operated. A range of heat deflector shields is provided (Fig. 12).

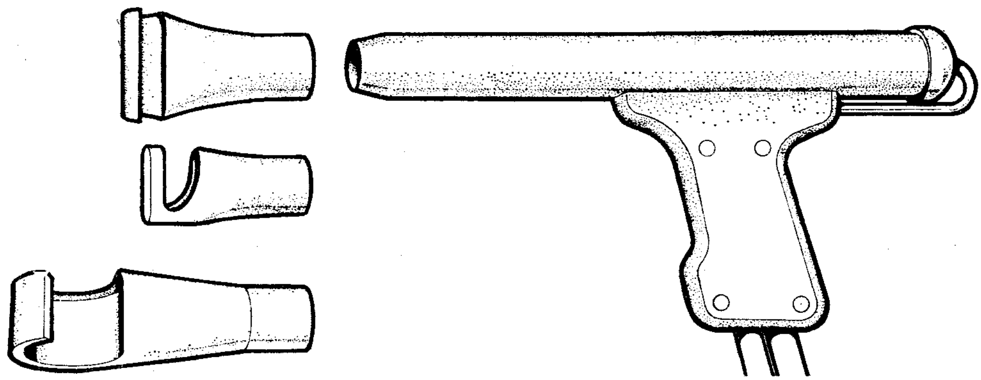


Fig. 12 Thermo pistol

Crimping

17. Aircraft interconnections use solderless lugs mechanically crimped to the cable by special tools. These joints require less operator skill than soldering and have a lower failure rate. An efficient crimp produces a continuous mass of metal from the lug and conductor (Fig. 13).

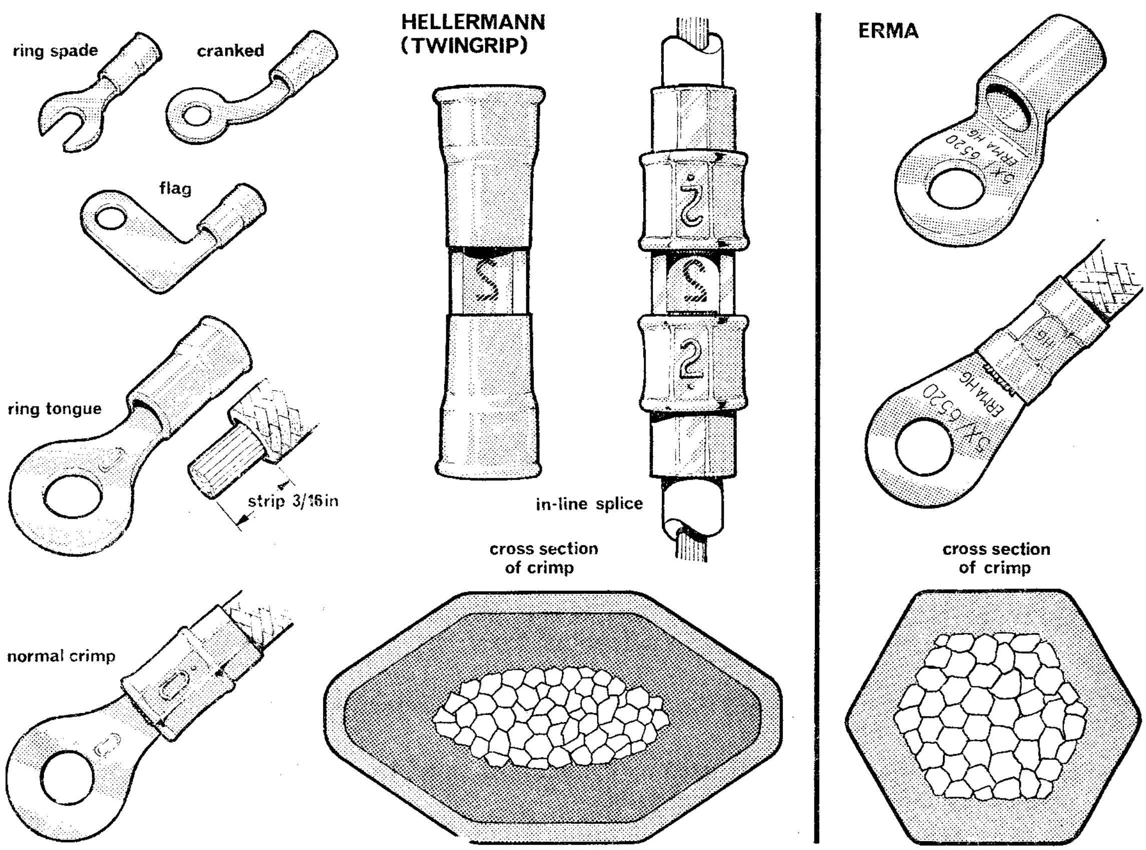


Fig. 13 Crimped terminations

18. **Hellermann kit.** The kit supplied contains three hand crimping tools (Fig. 14) with colour coded handles for cables from 22/20 AWG (size No 0 colour green), 18/16 AWG (size No 1 colour red), and 14/12 AWG (size No 2 colour blue). Three gauges are also supplied to carry out periodical checks on the tools. The Hellermann compression terminals for use with these tools are of the 'twingrip' type which grip both the conductor and the insulation to form a joint of high mechanical strength. The crimp formed is of an irregular octagon shape and may be either normal or transverse.

a. Normal. The maximum after-crimp dimension is in the same plane as the palm of the terminal. This method is illustrated in figure 15 and is the most often used.

b. Transverse. The maximum after-crimp dimension is formed at right angles to the palm of the terminal. This method is occasionally used to enable the completed terminal to be fitted into a narrow space such as a moulded channel in a fuse box or block.

In order to obtain the correct pressure to produce a good electrical joint the tools are fitted with a ratchet mechanism which prevents the jaws from opening before the joint is fully formed. An automatic checking system is also fitted which impresses the tool size number on the terminal barrel during crimping. This number *must* match the size reference engraved on the terminal palm by the manufacturer. A check must be carried out to ensure that the number is correct and that it is the right way up (*see* Fig. 15) before a completed termination is accepted as serviceable.

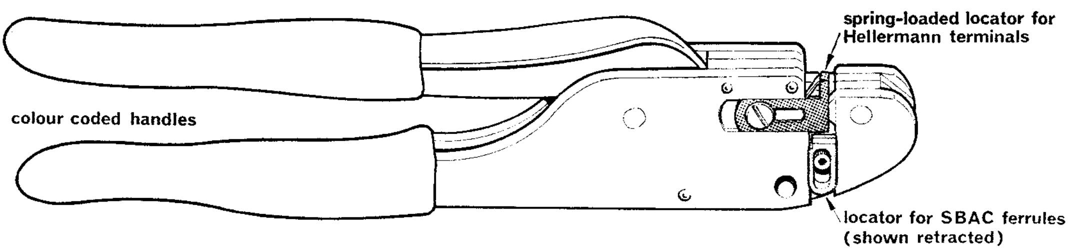


Fig. 14 Hellermann crimping pliers

19. **Use of Hellermann crimping tools.**

a. Select a suitable terminal for the cable in use (number on terminal palm).

b. Select the correct tool for this terminal (colour coded handles).

c. Strip the cable insulation about 3/16 inch (slightly less for size 0).

d. Push the cable end into the terminal barrel until the insulation fits against the shoulder inside the barrel and check that the end of the conductor *just* protrudes from the palm end of the terminal barrel.

e. Ensure that the SBAC locator on the tool is retracted. Insert the terminal and cable into the tool jaws and push the end of the terminal barrel up against the spring-loaded locator (*see* Fig. 15).

f. Close the tool handles until the ratchet mechanism operates and releases the completed termination.

g. Check that the number impressed on the terminal barrel is correctly orientated and is the same as the number on the terminal palm.

h. Fit an insulating sleeve if required.

Note: In-line connectors are held by the free barrel and inserted in the tool in the same manner, with the slot underneath engaging on the spring loaded locator to ensure that the crimping barrel is held centrally between the tool dies. After crimping the numbers impressed on the connector *must be checked* for correct orientation as shown in figure 15.

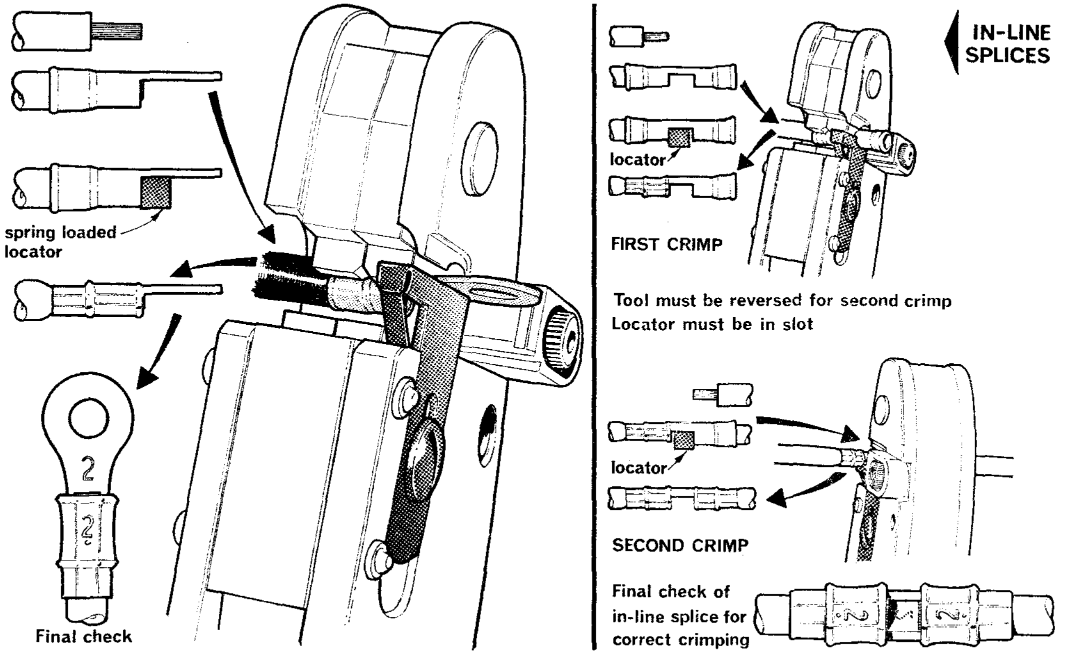


Fig. 15 Use of Hellermann crimping tool

20. **Erma hand-crimping pliers.** The kit supplied for service use contains two hand-crimping tools and a set of interchangeable dies (Fig. 16). The minor tool has a fixed head with three

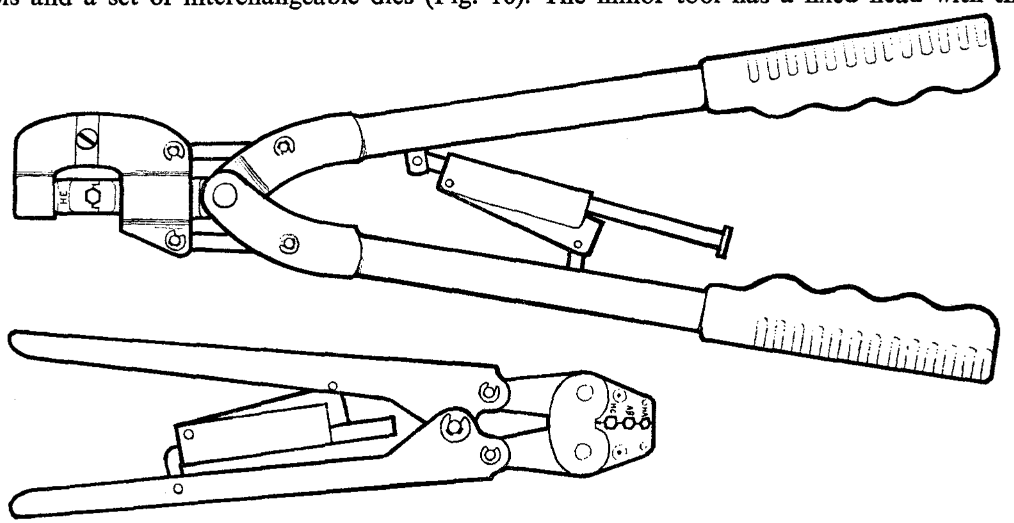


Fig. 16 Erma hand crimping pliers

crimping positions for cable sizes AWG 18/16/14 marked HA/HB/HC. The standard tool is fitted with a set of dies marked with a code size, e.g. HF for size AWG 8. Both tools produce a crimp of regular hexagon shape and have a full closure mechanism which prevents the terminal being removed before crimping is complete. The kit is obsolescent but is still in use for cable size AWG 10 and 8.

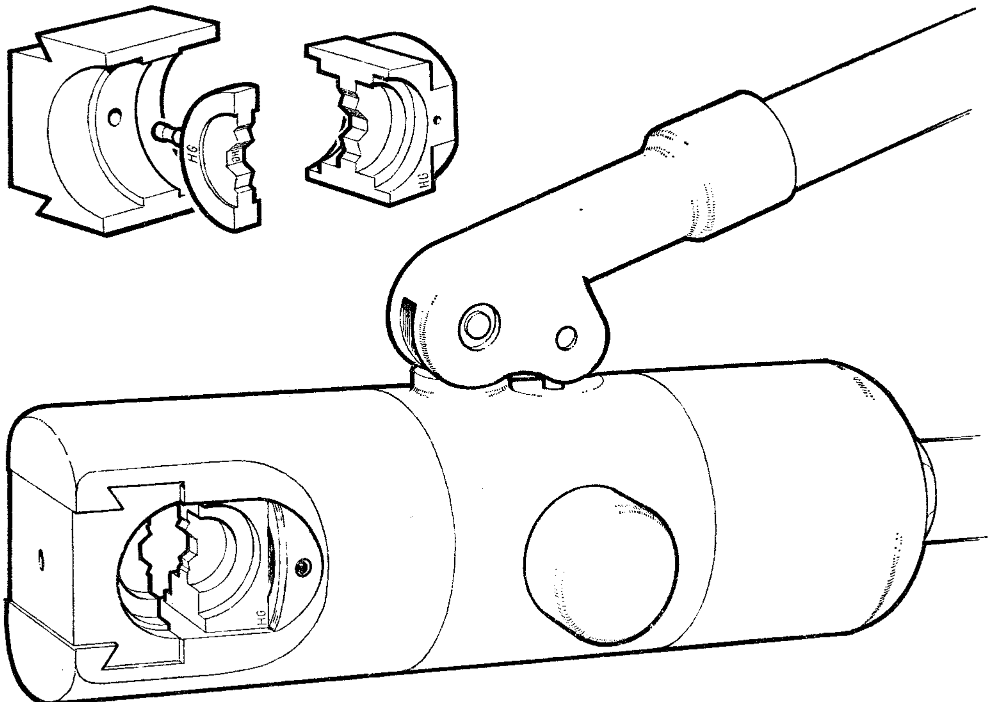


Fig. 17 Erma crimping machine (assembly)

21. **Erma hand-operated hydraulic crimping machine.** This machine is supplied as a kit containing eight sets of dies for cable sizes from AWG 6 to AWG 0000, and an allen key used for fitting the dies to the machine. The crimp formed is a regular hexagon shape and has two code letters impressed on it by the dies during crimping. These code letters are HG, HH—HN (for cable sizes AWG 6, 4—0000) and are the same as those marked on the cable lugs by the manufacturer.

22. **Preparation of machine.** The machine operating handles should be screwed into position and the code letters stamped on the dies checked for size. If the dies are to be changed carry out the following procedure.

a. Select the two matched dies bearing the correct code letters for the size of cable in use. Check that the lugs to be used have the same code letters marked on the terminal palm.

b. Remove the upper die adaptor by sliding it from the dovetailed head of the tool. This leaves the slotted head of the tool open to allow the lower die to be fitted to the ram. Insert the spigot on the upper die into the hole in the die adaptor until it is held in position by a spring-loaded steel ball.

c. Close the hydraulic valve by turning the knob clockwise. Pump the handles a few times to move the ram upwards and disclose the hexagon socket screws which hold the lower die.

Slacken these screws using the allen key provided with the kit. Fit the lower die into the ram so that the screws fit into the recesses on either side of the die. Tighten the screws to hold the die, ensuring that they are below the surface of the ram body. Open the hydraulic valve to retract the ram.

d. Slide the upper die adaptor, complete with die, into the dovetailed grooves until it is located centrally by a spring-loaded steel ball.

23. **Operation of Erma machine.** Check that the two-letter code on the cable lugs and on both dies is correct for the size of cable to be terminated.

a. Close the hydraulic valve. Place the lug centrally between the dies and pump the handles until the lug is lightly gripped.

b. Strip the cable insulation so that when it is inserted in the lug the insulation lies flush against the end of the barrel and the conductor projects slightly from the other end.

c. Insert the conductor into the barrel of the lug and pump the machine until the dies are fully closed. A safety valve will operate with an audible click and pressure on the pump handles is greatly reduced.

d. Open the hydraulic valve to allow the ram to retract. The crimped termination can then be removed from the machine.

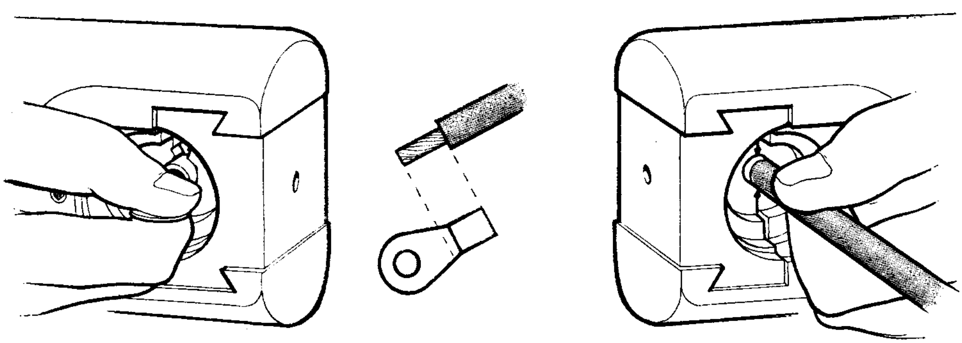


Fig. 18. Erma machine in use

Soldering

24. Connections inside electronic equipments are normally made by soldered joints. Due to the increasing reliability of modern components, failure of soldered connections is causing an increasing proportion of the total equipment failures. A recent reliability study found that faulty joints caused one-sixth of the total failures of an airborne equipment. The reliability of a soldered joint depends on the condition of the materials to be joined and on the care and skill of the operator making the joint. Poor joints caused by surface oxidation can be virtually eliminated by sealed storage methods and by *careful preparation of the materials immediately prior to soldering*. A high level of operator skill can be attained by *regular repetitive practice* and by meticulous attention to detail when making a joint.

25. **Solder.** Soft solder is an alloy of tin and lead which is melted and allowed to flow between the surfaces to be joined. A fused joint is formed by an alloying action between the solder and the metal surfaces. The joint produced is not very strong mechanically but is a good conductor of electricity. Soldered joints can only be used at temperatures below 150°C. The most suitable

solder for electrical work contains 60% tin and 40% lead, melting at 190°C. Some solders contain small amounts of antimony or copper and melt between 190°C and 240°C. The soft solder normally used for electrical work is supplied as 22 SWG. flux-cored wire.

26. **Flux.** Soft solder cannot alloy with a metal if there is any barrier such as oil, grease or oxide present at the joint surfaces. These surfaces must be thoroughly cleaned and a flux must be used to prevent oxide formation when making the joint. The flux used for electronic work is a high-grade chemically developed resin. The residue is non-corrosive, moisture-proof, and hard, to avoid pick-up of dust. Residue should always be removed from joints used at high frequencies to prevent its dielectric properties from affecting the circuit.

27. **Heat sinks.** Some components (e.g. transistors) are easily damaged by heat and must be protected during the soldering operation. A thermal shunt (Fig. 19) can be made by sweating copper bars into the jaws of a crocodile clip. When in use the shunt is clipped to the wire between the component and the joint (as near the joint as possible) so that heat is absorbed by the copper bars and does not reach the component. When soldering leads to miniature connectors, the connector should be mated and heat applied for the shortest possible time. The mated connector will act as a heat sink for the one being soldered and help to prevent damage to the insulation.

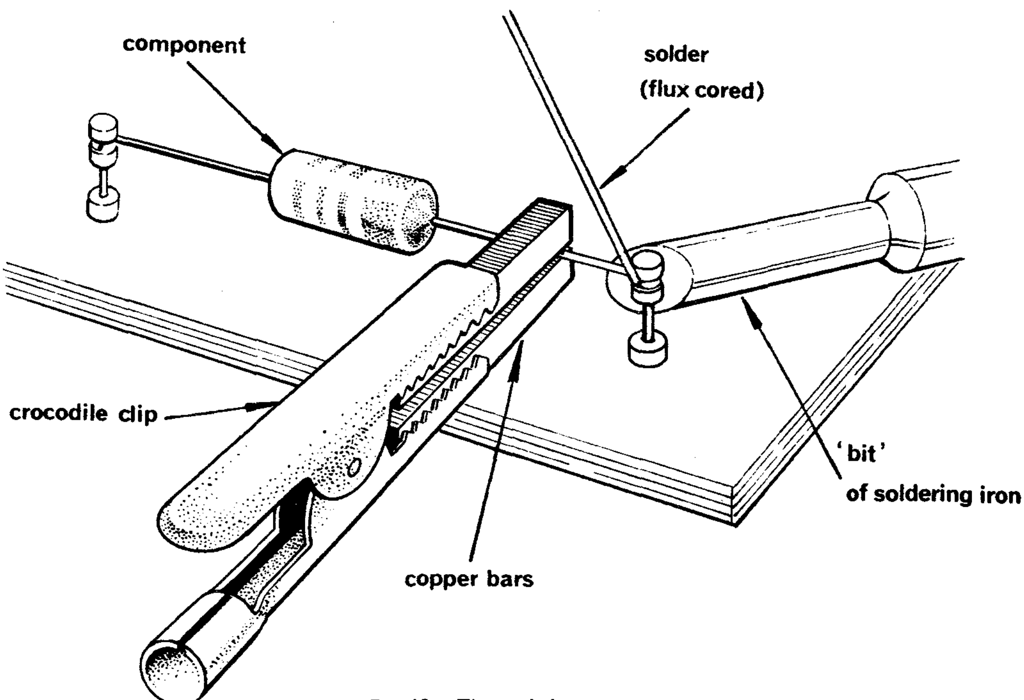


Fig. 19. Thermal shunt in use

28. **Soldering irons.** To enable the solder to run freely and to combine with the surfaces to be joined the solder *and* the surfaces must be at the correct temperature. The normal method of applying heat is with an electrically-heated soldering iron. The working end, or 'bit', is made from copper because it is a good conductor of heat and it alloys with solder to give a 'tinned' working face. A large number of different irons are in service use, mainly for specialised tasks, but most general work can be done using one of the types described below (see Fig. 20).

a. Solon type 983 (1B/4229). This is a mains-operated iron with a 240-watt element and a fixed oval shaped bit. It is used for heavy-duty soldering tasks mainly done by station workshops.

b. Solon type 964 (1B/4234). This is a lighter version of the above iron with a 65-watt element. It is used for light and medium tasks by station workshops and electrical workshops.

c. Antex type G240 (1B/1300172). The Antex miniature iron has a mains-operated 18-watt heating element which reaches working temperature in about 90 secs. The bit is detachable and four sizes are supplied: $\frac{3}{32}$ inch, $\frac{1}{8}$ inch, $\frac{3}{16}$ inch and $\frac{1}{4}$ inch. These bits are designed for long life and are of a special iron-coated type known as 'Ferraclad'. The iron is used for all general purpose work in electronic centres and on aircraft, and replaces several existing types of iron.

d. Low voltage irons. Several types of low voltage irons are in service use for working on printed circuit boards or on transistorized equipments. They are mains-operated through electrostatically-screened isolating transformers.

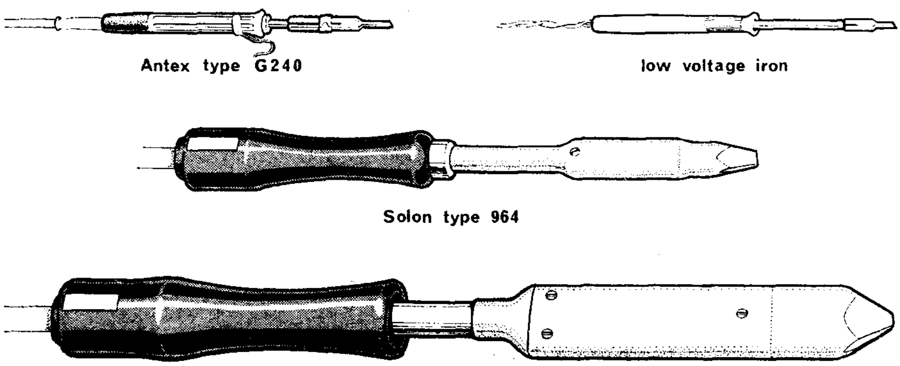


Fig. 20. Soldering irons

29. **Care and maintenance of irons.** When properly used a soldering iron has a very long life. The bit should be kept clean and tinned at all times; any oxides which form on the bit should be removed using a wire brush and the bit should be retinned immediately. Overheating will cause the bit to become pitted and oxidised; to prevent this the iron should be switched off when not required and placed on a heat sink during shorter intervals between jobs. As with all electrically operated tools, frayed or damaged leads are dangerous. A special point to watch is that the hot bit does not come into contact with the mains lead, as melted insulation may allow a short circuit to occur and start a fire.

30. **Desoldering tools.** These devices allow the rapid removal of solder from tags or printed circuit board component mounting points. This greatly simplifies the servicing task and reduces the possibility of damage being caused by the application of excessive heat during component replacement.

31. **The Soldapullt desoldering tool.** This is a spring-loaded vacuum operated device which is used in conjunction with a normal soldering iron. To avoid heat damage to printed circuit boards a miniature iron should be used at its full working temperature.

a. Operation

(1) Press the black knob against a firm surface to engage the release latch.

(2) Apply heat to the joint. Hold the tip of the tool against the joint at a 45° angle. *Do not press into the joint as this may damage the tip.*

(3) As soon as the solder is fully molten press the release latch button. Remove the soldering iron *as soon as* the vacuum stroke is completed.

(4) If necessary the vacuum stroke may be slowed down by restricting the air exhaust ventilators with the fingers; however a fast vacuum action is usually more efficient than a slow one.

(5) Reset the tool immediately to eject solder from the tip.

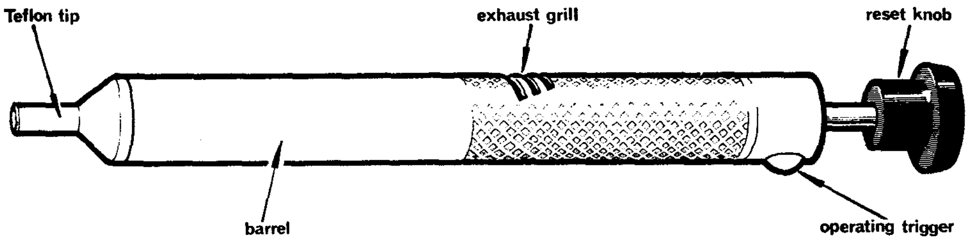


Fig. 21. The 'Soldapullt' tool

b. Cleaning. After several cycles of operation the tool should be cleaned out.

(1) Press the black knob firmly against a surface until the teflon tip is ejected from the tool.

(2) Pull the tip completely off with the fingers.

(3) Brush out any solder from the tool barrel.

(4) Replace the tip and push it firmly home.

(5) Occasionally lubricate the plunger mechanism with a small amount of silicone grease, applied through the exhaust holes.

32. **The Phillips aspirated iron.** This desoldering tool has a 45-watt heating element and is mains-operated. The vacuum is obtained from a foot pump, connected to the tool by a plastic suction tube. A special stand is provided which can also be used as a clamp/swivel for bench mounting the tool (see Fig. 22). **The tool must not be used upside down.**

a. Operation. Attach the plastic tube to the tool and position the pump on the floor in a position where it can be operated without discomfort. Allow the iron to reach its full working temperature.

(1) Apply the tip of the tool to the point to be desoldered, keeping the bit as near vertical to the panel as possible.

(2) Allow the solder to melt; depress the pedal of the pump and remove the iron. *Do not leave* the iron in contact with a printed circuit board for longer than necessary as excess heat will cause damage.

(3) Replace the tool on the special stand provided. *The iron must not be laid on its side* as this could allow molten solder from the reservoir to block the vacuum line or filter.

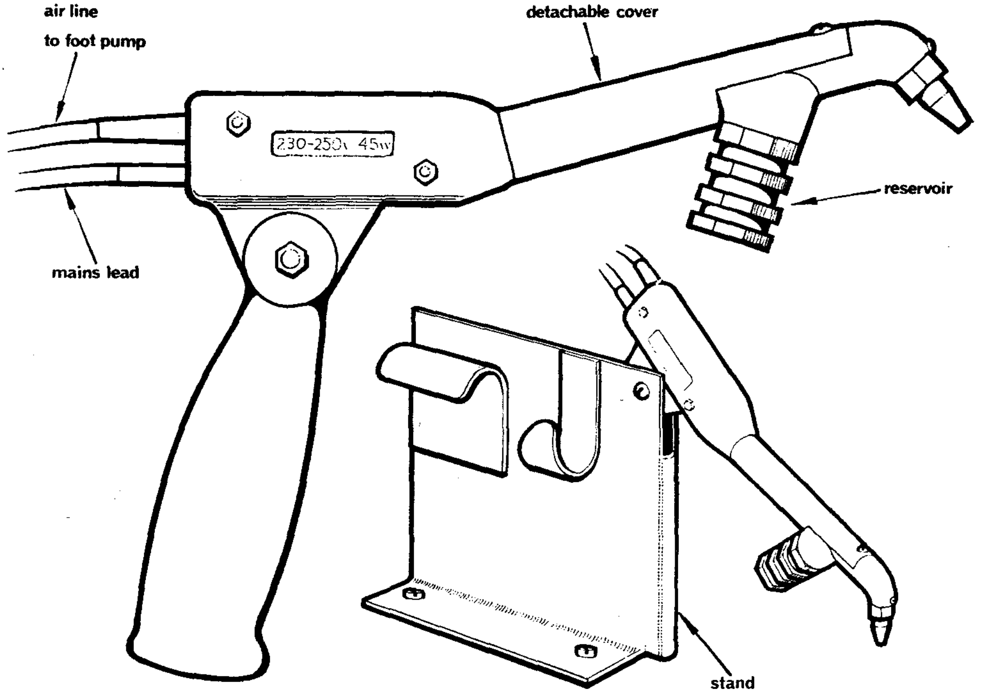


Fig. 22. Phillips aspirated desoldering iron

b. Cleaning. After about 50 operations the reservoir must be unscrewed and emptied. This should be done with the iron at working temperature using the box spanner provided. The moving parts of the pump should be lightly oiled to ensure maximum efficiency.

33. **Soldering procedure.** Good soldering is a skill which can be developed only by repetitive practice. The basic method is as follows.

a. Clean and tin the working face of the soldering iron bit. Allow the iron time to reach the correct working temperature. A low voltage iron should be used for transistorized circuits.

b. The surfaces to be soldered must be clean, bright and free from oxides. Some cables have a wax protective coating which must be removed with a suitable solvent.

c. Make a firm mechanical connection and apply heat sinks to protect sensitive components.

d. Apply the tinned iron *to the surfaces to be joined.* Apply the flux-cored solder to the work, not to the iron. If the work is sufficiently hot the solder will readily melt and run into the joint.

e. When enough solder has been applied the iron should be removed and the joint allowed to cool naturally. It is important that the solder solidifies before the surfaces are allowed to move. A properly soldered joint should have a bright smooth surface.

f. Remove any surplus flux from the joint and remove the heat sinks.

34. **Common soldering faults.** All the faults described below are the result of careless working methods or lack of skill.

a. Dry joints. This is the name given to a joint when the solder fails to alloy with the work surfaces. A dry joint usually has a dull rough surface and can be easily broken by slight pressure with the blade of a screwdriver. It will cause a high resistance connection, possibly intermittent, which may be very difficult to trace after the equipment has been returned to service. The most common causes of dry joints are grease, dirt and moving the joint before the solder has solidified.

b. Insulation damage. The insulation on a wire or component can be damaged by the application of heat for too long a period. A short circuit can then be caused by vibration or movement of the exposed conductor and could result in an equipment fire. The damaged insulation must be replaced or a suitable insulating sleeve fitted.

c. Excessive solder. The flexibility of a stranded cable can be destroyed by allowing excess solder to run along the strands from a joint. The rigid end could fracture under vibration conditions causing an open circuit and total loss of the circuit function. Excessive solder on the buckets of miniature connectors or the conducting strips of a printed circuit board will reduce the spacing between adjacent connections and may allow arcing to occur at high altitudes.

d. Spikes. A spike or tail of solder projecting from a joint can be caused by using an iron which is not at its full working temperature or which has a dirty bit. These spikes may cause corona discharge to take place at high voltages and affect the operation of the circuit. In extreme cases the tail may touch an adjacent connection under vibration conditions and cause a short circuit.

e. Excess flux. Flux residue left on or near a joint will act as a dielectric at high frequencies and may affect the circuit. It can be removed by gentle pressure with a screwdriver blade.

35. **Modern soldering developments.** The growing use of miniaturization and integrated circuits has produced some new soldering techniques, aimed at improving the reliability of the connections formed.

a. Preforms. Solder can be obtained in the size and shape most suitable for a particular application. These shapes are called preforms and one is used for each joint. The most common forms are balls, rings and pellets. They are usually melted electrically by passing a high current through the assembled joint from a suitable machine. Accurate control of the current and of its path through the joint are essential and this is mainly a manufacturing technique at present.

b. Solder shrink sleeves. These consist of a sleeve of the thermofit type containing a small ring of preformed solder. The joint is assembled and heated using a hot air supply. The sleeve shrinks permanently and the solder melts to form an insulated joint in one operation. A typical solder used is a tin/lead/silver alloy for joining silver plated wires with PTFE insulation. This method is particularly suitable for the assembly of subminiature connectors.

Wrapped Joints

36. The solderless wrapped joint has been introduced to improve the reliability of connections inside an equipment. A tinned copper wire is secured round a rectangular terminal post by a number of close fitting turns, normally not less than six. The action of wrapping the wire causes the sharp corners of the terminal post to bite into the wire, producing 24 gastight mechanical joints. Stranded wires cannot be used for wrapped joints. The standard size terminal post is a rectangle 0·036 inch by 0·048 inch made of monel metal, and tinned copper wires from SWG 20 to 26 may be used. (24 SWG is used for leads). A smaller size, 0·015 inch × 0·030 inch, using 30 SWG wires has been developed but is not yet in service use. The joints can be visually checked to ensure that the turns are correctly wound and are sufficient in number.

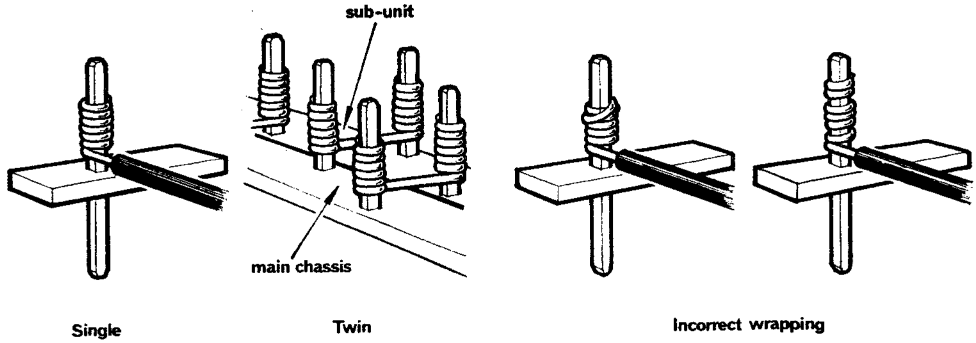


Fig. 23. Wrapped joints

37. **Advantages of wrapping**

a. Reliability. A twin wrapped joint used to replace plugs and sockets for the interconnections between sub-units reduces the equipment failure rate. The single wrapped joint used for connecting components is more reliable than the soldered joint; particularly when made by relatively unskilled personnel.

b. Heat. As no heat is used in the process damage cannot be caused to transistors or miniature components. The insulation on wire leads cannot be melted.

c. Foreign objects. There is no possibility of foreign objects such as drops of solder or flux remaining in the equipment.

d. Operator skill. The joint can be easily made and inspected, allowing some routine servicing tasks to be carried out reliably by semi-skilled tradesmen.

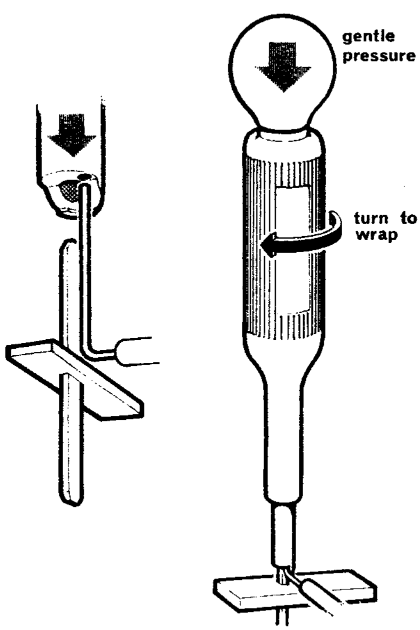


Fig. 24. Single wrap

38. **Wrapping tools.** Hand and electrically operated tools are available for making wrapped joints. They are precision tools, and should be treated with care and stored in a suitable box when not in use.

a. Single wrap joints. These are used for connecting components or leads to a terminal post.

(1) Strip the lead insulation (if any) for about one inch.

(2) Lie the lead alongside the terminal post as shown in Fig. 24. A component lead should be bent to allow the component to lie flat against the base board.

(3) Fit the tool over the terminal post and the lead.

(4) Apply gentle pressure and turn the tool clockwise until all the lead is wound round the post.

(5) Check that there are at least six properly wound turns forming a satisfactory joint.

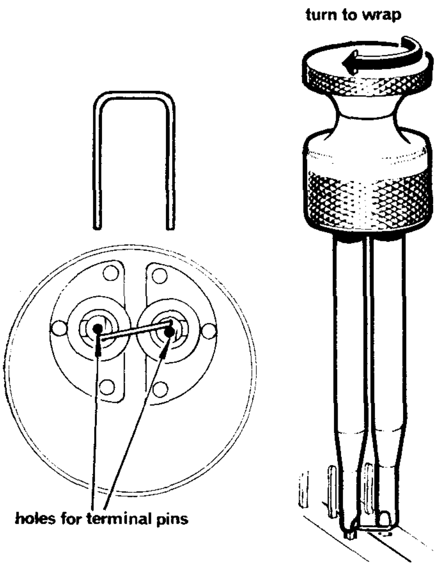


Fig. 25. Twin wrap

b. Twin wrap joints. These are used to connect sub-units to the main chassis or to each other. A power-driven winding tool is available to enable a large number of joints to be made without operator fatigue.

(1) A U-shaped link of 24 SWG tinned copper wire is used (see Fig. 25).

(2) Fit the link into the working heads of the double wrapping tool as shown in Fig. 25 and place the tool heads over the two terminal posts to be joined.

(3) Apply gentle pressure and turn the end of the tool clockwise until the joint is complete.

(4) Check each joint for the correct number of properly wound turns.

(5) Check that the wire linking the posts is straight. Note that if the wire is not fitted to the tool exactly as shown in Fig. 25 slack may result which could cause a short circuit.

c. Unwrapping. Joints must be unwrapped to change components or sub-assemblies and a special tool is provided to unwrap the joint without damaging the terminal post. A considerable number of rewraps may be made on a terminal pin, but *the unwrapped lead or component cannot be re-used.*

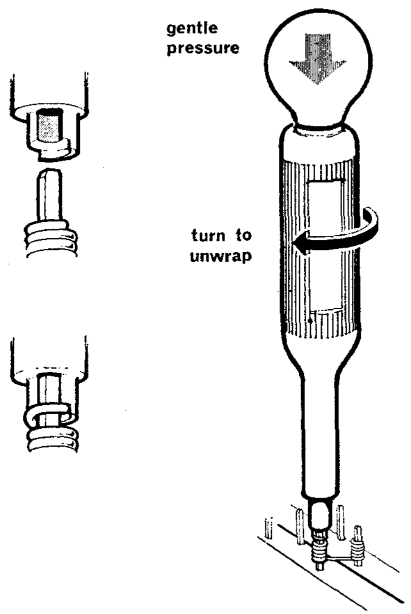


Fig. 26. Unwrapping

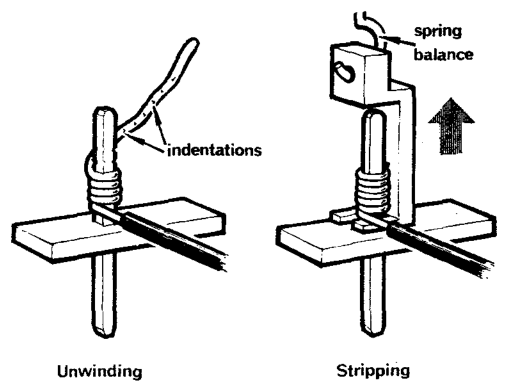


Fig. 27. Testing a wrapped joint

39. **Periodic checks.** To check that the wrapping tool is operating correctly periodic tests should be made on the joints formed. A correctly made joint of 24 SWG wire on a standard terminal pin should require a pull-off force of not less than 7 lb. (see Fig. 27). A second test for wire tension is made by carefully unwrapping a joint. Indentations should be seen where the wire was wrapped round the terminal post corners (Fig. 27). These indentations should not be so deep as to appreciably weaken the wire.

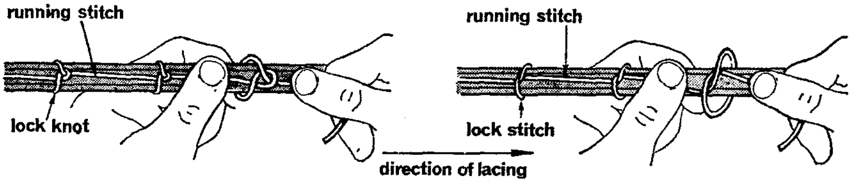
Looming and Lacing

40. Several wires which run close together along parallel paths can be laced into a compact group to form a cable loom. The lacing helps to support the wires and keeps them in position away from any possible source of damage.

a. Lacing. A running stitch is pressed tightly against the cable loom by means of locking knots or locking stitches formed at regular intervals along the loom. The running stitches should be kept in line, and parallel to the wires of the cable loom (see Fig. 28).

(1) *General wiring.* The lacing cord used for most aircraft looms is one millimetre diameter p.v.c. covered nylon cord, coloured black. Looms are bound by continuous lacing and are tied with locking knots spaced as far apart as adequate support will allow. In some cases a rot-proofed braided flax cord is used, normally sea-green or brown.

(2) *Equipment wiring.* In miniaturized radio equipments the lacing is often done using a thin waxed linen or flax tape. As this tape is less prone to slip than the nylon cord, the lacing is often tied with locking stitches spaced evenly at one inch or half inch intervals along the loom.



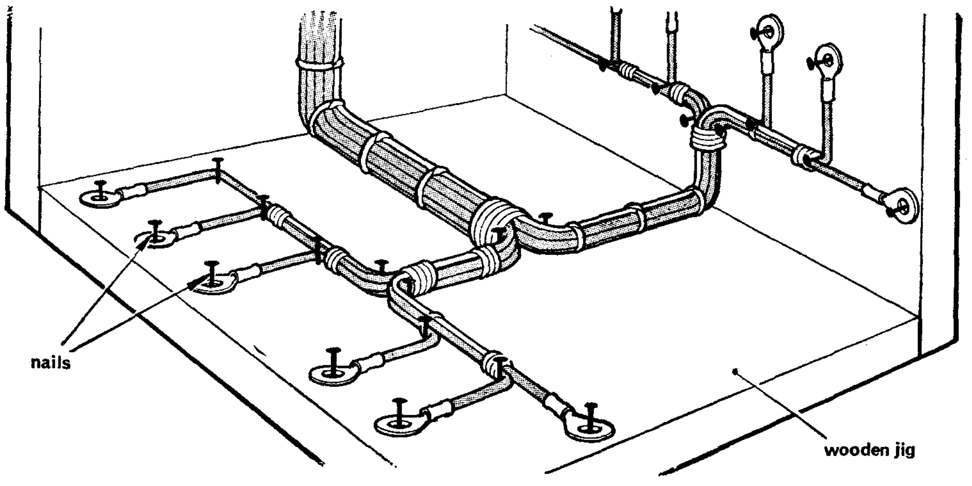


Fig. 28. Making a cable loom

b. Start. Two methods of starting lacing are in common use.

(1) *Whipped start.* Hold one end of the cord on the cable and wrap about four turns tightly around the cable and over the cord (Fig. 29). When the end is well secured whip a further eight turns and make a lock stitch (the whipping can be continued for any distance required as a protection against chafing).

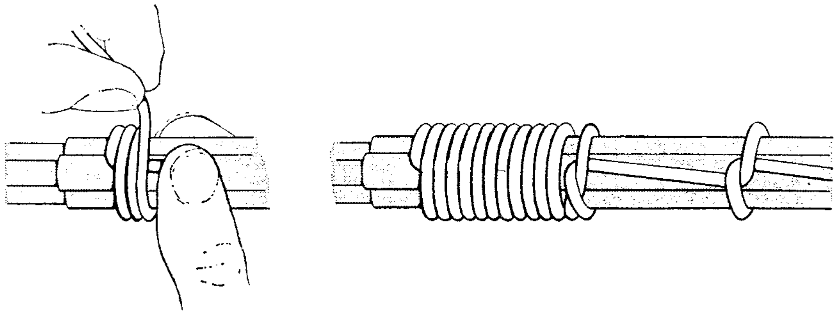


Fig. 29. Whipped start

(2) *Knotted start.* Make a clove hitch around the cable and secure the ends with a reef knot (Fig. 30). Make a lock stitch and then lace normally.

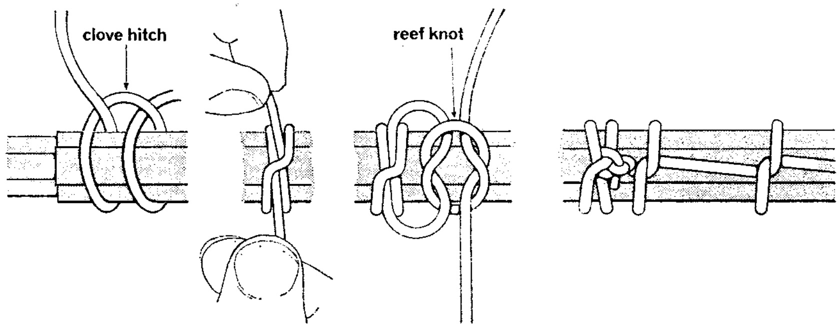


Fig. 30. Knotted start

c. Finish. To terminate the cable lacing wrap the cord four times round the loom, tight against the last lock stitch. Using a separate piece of cord, form a loop and lay it along the loom (Fig. 31). Wrap eight turns over the loop and pass the end of the running cord through the loop. Pull the loop out by its free ends, thus locking the cord under the last eight turns. Cut off any excess cord.

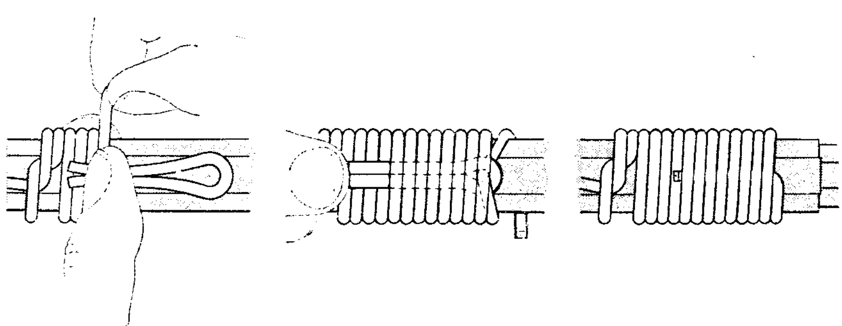


Fig. 31. Terminating lacing

d. Branching. If only one wire is branched out from the main cable loom it should be branched out at a lock stitch without any variation in lacing. If a group of wires leaves the loom at the same point they should be laced together. At the required branching point make a lock stitch, wrap six turns closely together and make another lock stitch. This whipping takes any sideways forces due to the junction without straining the main lacing or separating the wires of the loom. Form the wires into the required branch loom, using a knotted start where it leaves the main cable.

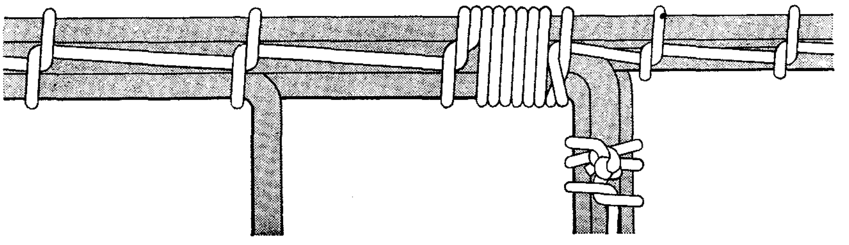


Fig 32 Branching a cable loom

Cable Binding

41. A group of wires can also be formed into a cable loom by binding them together at suitable intervals. The binding method uses a pre-tensioned nylon strapping and preformed nylon closures. These closures are fastened using a special binding tool (Hellerman Tyton Mk 4 Fig 33). The strapping is supplied in 24 foot reels which enables looms of almost any size to be handled. Two types of closure are available (*see* Fig. 34), one of which has a single hole fixing lug to enable the loom to be fastened to a panel or chassis if required. Where the loom may have to be removed occasionally for servicing or repair operations it can be fitted to the airframe using the special nylon cradle shown in Fig 34.

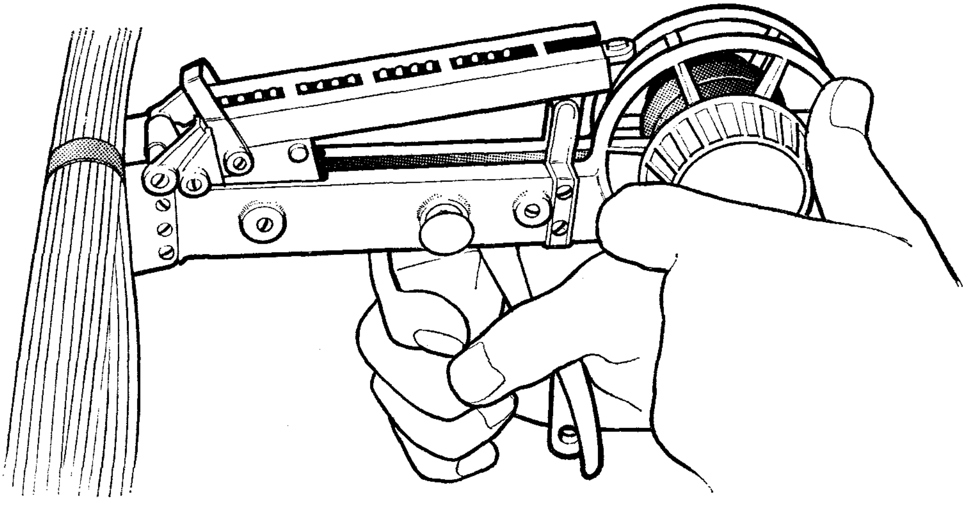


Fig 33 Cable binding tool

42. Strapping from the tool is passed round the group of wires and back through the nylon closure in the head of the binding tool. To fasten the loop the binding is tightened and the nylon retaining rivet of the closure is driven home by the tool. This forces both thicknesses of the

strapping into a closely mated hole (Fig 34). The nylon rivet expands slightly when forced into position, and will remain in position even under vibration conditions. As the strapping is not pierced during the fastening process it retains its full strength and will not tear out of the closure.

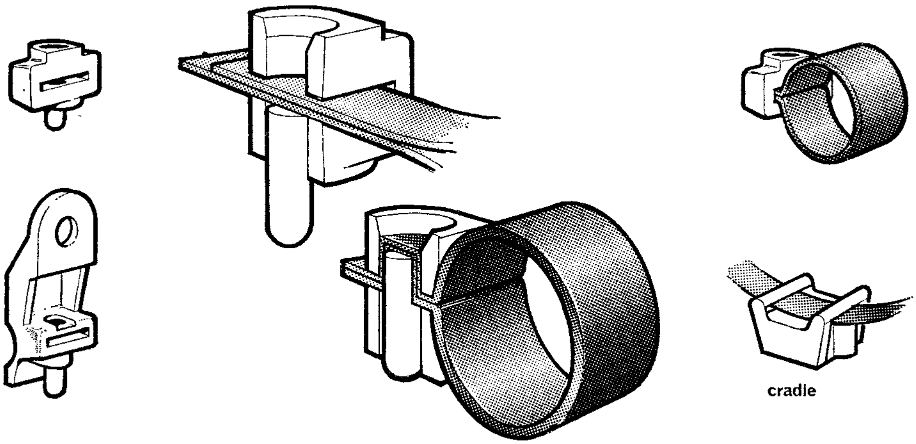


Fig 34 Cable binding method

43. **Loading the Tool.**

a. Strapping. Hold the large knob on the reel holder and unscrew the small locking knob on the right side of the tool. Pull out the large knob with its square spindle. Place a 24 foot reel of strapping into the holder so that the strap feeds forward from the bottom of the reel. Push the spindle through the reel, and tighten the locking knob. Swing the magazine out of the way and feed the end of the strapping under the back plate and along the shallow channel on top of the tool. Do not push the strapping through the head of the tool unless there is a closure in position in the head (*see* para 44b).

b. Closures. Release a row of 20 closures from the frame supplied, using the magazine loading tool (Fig 35). Slightly raise the rear end of the magazine, and hold back the small lever on the front of the magazine with the thumb. Slide the loading tool with closures into the magazine and release the small lever. Withdraw the loading tool, leaving the closures held in the magazine.

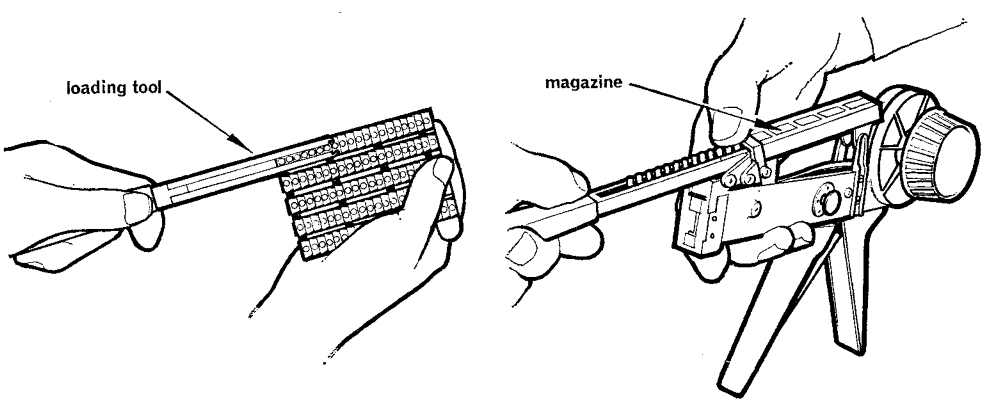


Fig 35 Loading the magazine

44. Operation

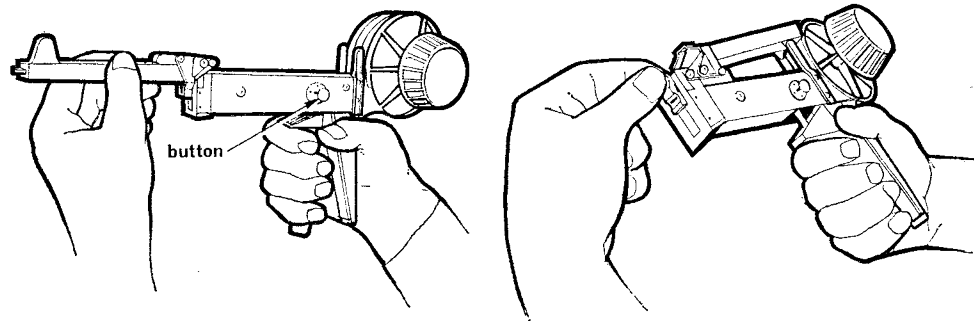


Fig 36

a. A normal closure is loaded into the head of the binding tool as shown in figure 36. Hold in the button, hold in the trigger and release the button. Swing over the magazine, release the trigger and swing back the magazine. If a single lug closure is to be used, it should be pressed into the head of the tool whilst the trigger is squeezed.

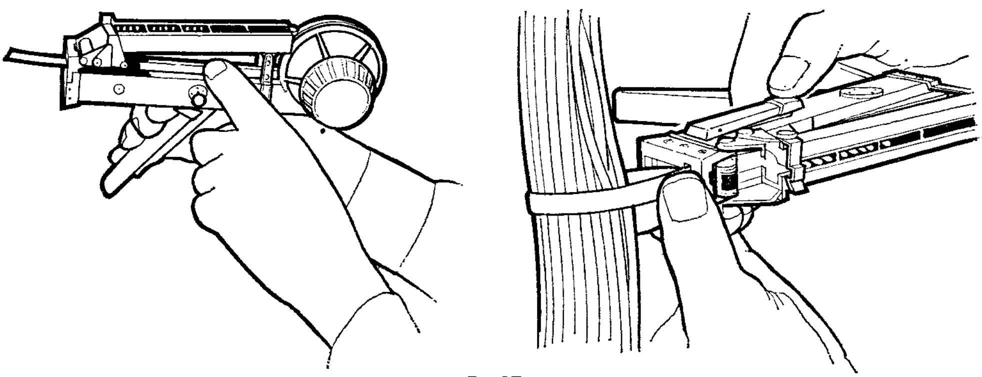


Fig 37

b. Push out a length of strapping through the closure in the tool head (Fig 37). Pass the strapping round the wires and feed about 1 inch back through the closure in the tool head. Press the lever on the right-hand side of the tool to grip the free end of the strap in position.

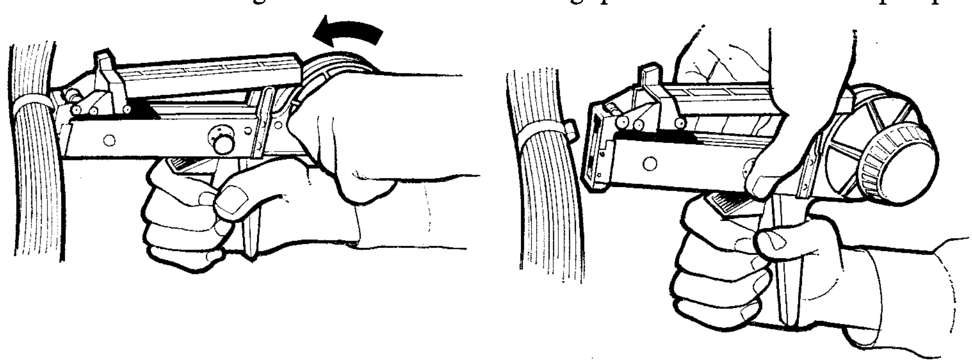


Fig 38

c. Tighten the loop by turning the reel anticlockwise and fasten the closure by squeezing the trigger (keeping the strap under tension). Release the trigger, and cut off excess strapping by pressing the button on the left-hand side of the tool and re-squeezing the trigger.

CHAPTER 5

CONNECTORS

List of Contents

Introduction

1. Because of the large number of interconnecting leads between units of an electrical or radio installation, multiple core cables with associated plugs and sockets are used. For ease of servicing, plugs and sockets must have positive location and be capable of quick removal. When mating a plug and socket, care should be taken to ensure that the pins of the plug are fully engaged in the socket. The coupling ring should be lightly greased with low temperature grease and tightened by hand. If it is difficult to *disconnect* a plug a strap spanner may be used.

2. When a plug or socket is temporarily disconnected a protective cap must be fitted. This prevents dirt or oil entering the housing and protects the screw threads from damage.

3. Some modern types of plug and socket have removable contact inserts. These are a precision fit into the insulated moulding and must be fitted by using the correct type of tool as specified by the manufacturer.

Mains Connectors

4. Three cored cables are used for mains connectors. They have colour coded leads for ease of identification (see figure 1). This standard colour code is now coming into international use. The conductors are stranded for flexibility and their size is usually specified by the number of strands and their diameter; e.g. 23/·0076 means that each lead consists of twenty three strands, each of which is ·0076 inches in diameter. For service purposes, this size is rated at 4 amps (see AP1086) and it is the cable size used for general purposes *eg* test equipment leads. Other sizes are available at higher current ratings.

There are two types of insulation in common use. Trisheathground cable has a tough natural rubber sheath and is used where flexibility is very important *eg* on 'mobile' test equipment and on power tools. Other 'non-mobile' items are generally connected with PVC sheathed three cored cable. Modern plugs are of the thirteen amp flat-pin type shown in figure 1, but there are still a lot of the older round-pin five and fifteen amp plugs in use. The lead positions are the same in all cases.

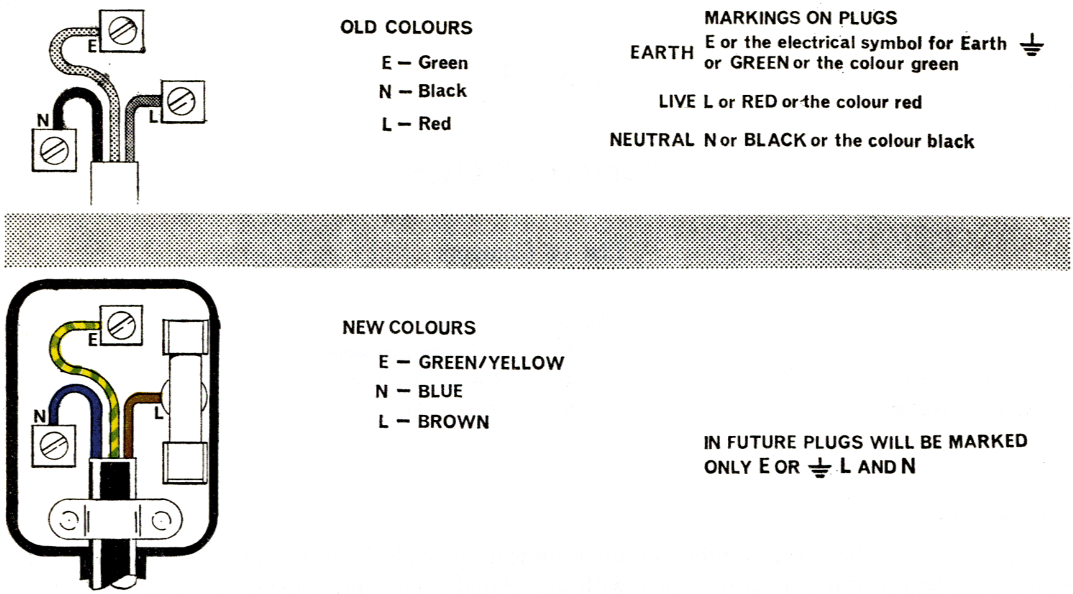


Fig. 1 How to fit a flex to a plug

Notes:

1. The fuse fitted to these plugs should be of a suitable rating to *protect* the equipment being supplied.

2. The screws holding the cable clamp should be tightened to obtain a good grip on the flex and thus prevent it from being pulled out of the plug by mishandling.

3. *Personal safety*. Before using mains-operated portable equipment or power tools, the cable must always be examined to make sure that the insulation is not damaged. If the plug is cracked, chipped, or has a broken top, it must be replaced before the equipment may be used.

Soldered Connectors

5. Several types of plug and socket in general use are attached to the cable by soldered joints. For assembly instructions of a particular type either the manufacturers leaflet or AP 4343 should be consulted. The most common type is the Plessey Mk. 4.

6. The Plessey Mk. 4 range consists of nine basic plugs or sockets accommodated in three basic shell sizes. They are normally supplied as fixed plugs (for mounting on equipment panels) and free sockets (for terminating cables). A range of straight and right angled outlets is provided to enable the connector to be fitted in almost any position. The orientation of the plug or socket in its shell can be altered using a special tool kit supplied (see Chap 2, Fig 13). By using different orientations for adjacent plugs the chances of mis-connection are minimised.

7. **Assembly.** Figure 2 shows an exploded view of a Plessey Mk. 4 socket and names the various parts. The procedure for connecting cables to this type of socket is described below:

a. Dismantle the socket into the component parts shown in Figure 2. Correct the orientation of the socket body in the shell if necessary. Obtain the type of outlet required for the finished connector.

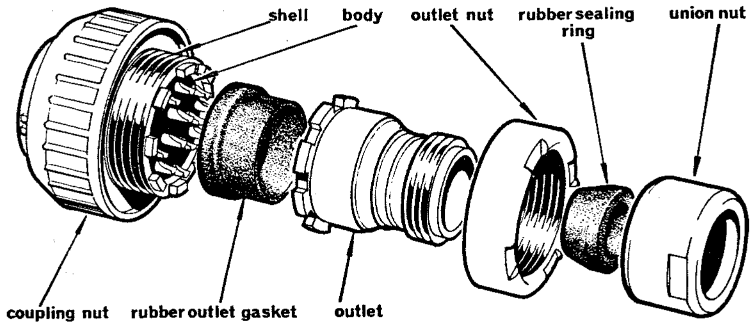
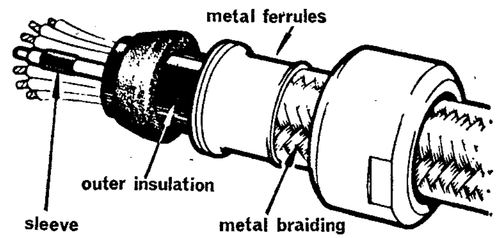
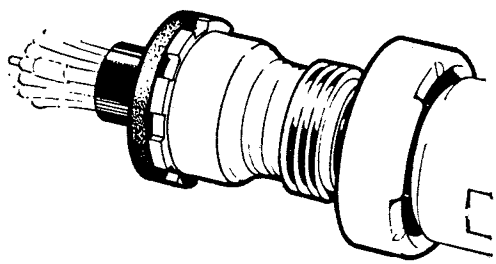


Fig 2 Exploded view of Plessey Mk 4 socket

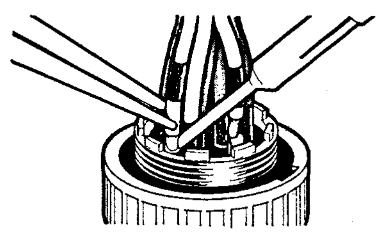
b. (1) Slip the union nut over the cable end.
(2) Strip the cable braiding (approx 1 inch).
(3) Clamp the metal braiding between metal ferrules. (Chap 4, para 12).
(4) Strip outer insulation (approx $\frac{1}{2}$ inch).
(5) Fit the rubber sealing ring over cable.
(6) Strip each wire for one-eighth inch.
(7) Tin each wire, using 22 SWG resin cored solder and a miniature iron.
(8) Fit a half inch insulating sleeve over each lead, using Hellerman pliers.



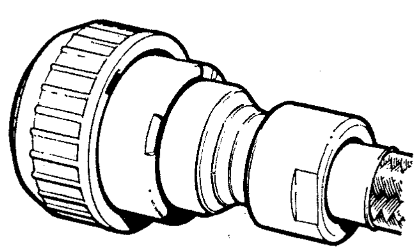
c. (1) Slip the outlet nut, the outlet, and the rubber outlet gasket over the end of the cable.
(2) Ease back the metal braiding and the component parts of the housing to obtain working room for the soldering iron to be used in comfort.



d. (1) Fill the buckets with solder, using a miniature iron at its full working temperature.
(2) Solder the leads into the correct places.
(3) Test each joint with a light pull.
(4) Clean off any surplus flux, using a stiff brush and solvent.
(5) Position the sleeves flush against the main body moulding.



e. (1) Insert the rubber outlet gasket into the main body.
(2) Fit the outlet into the castellations of the main body.
(3) Tighten the outlet nut.
(4) Slide forward the metal braiding and its retaining ferrules.
(5) Tighten the union nut.



f. After assembly, all connectors should be checked electrically to ensure that:

(1) All leads are connected to the correct positions.

(2) All joints have a low resistance.

(3) All leads are insulated from each other and from the shell of the connector.

Crimped Connectors

8. Modern connectors (plugs and sockets) have removable contact inserts made to American Wire Gauge specifications. These inserts are crimped to the leads using the Erma-Buchanan crimping tool. This tool is issued as a kit (1H/418) which consists of a box, the tool, three locators, and two gauges. Additional locators are scaled against specified types of plug, and provision is made in the box for storing up to twenty types. The crimp formed by the tool is of the four indent type (*see* inset in figure 3).

9. **Locators.** These are sometimes called positioners, and automatically adjust the tool to:

a. Position the insert so that its crimping area is in the indent area of the tool.

b. Set the depth of crimp to that required by the insert.

c. Set the point at which the automatic ratchet in the tool releases.

Because of these functions it is essential that the correct type of locator is used for the insert to be crimped. To ensure this, the type of connector and the contact part number must be known, and reference made to the electrical manual or the tables provided by the tool manufacturer. The three locators provided with the tool kit are for use with insert sizes 20/16/12 AWG made to specification MIL 3190.

Note that it is necessary to use two locators for the Plessey UK-AN series, 1H/407 for pins and 1H/408 for sockets. It is possible to crimp the pin insert in the socket locator but the crimp produced is *not* acceptable.

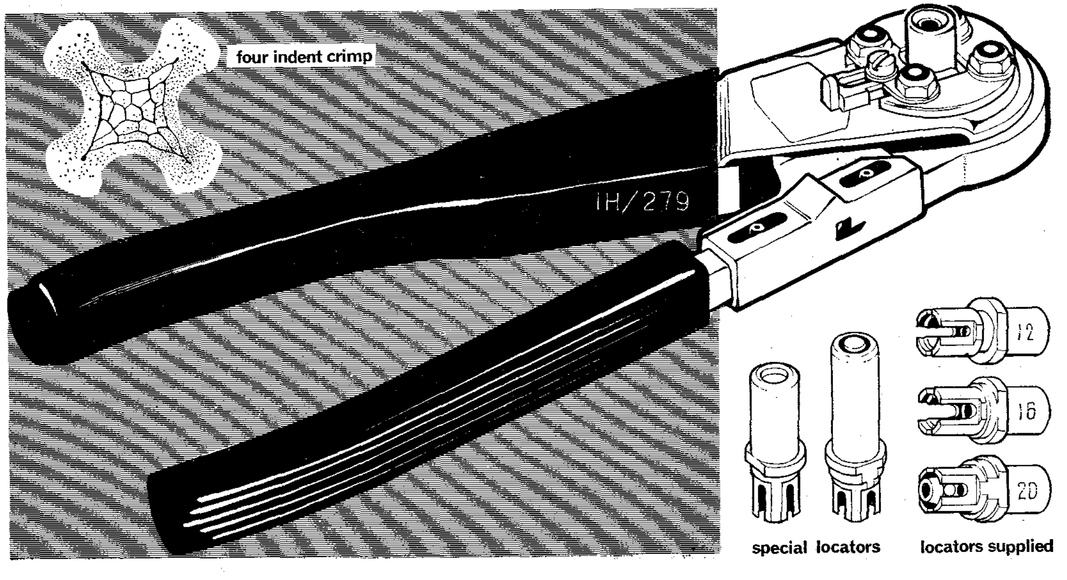
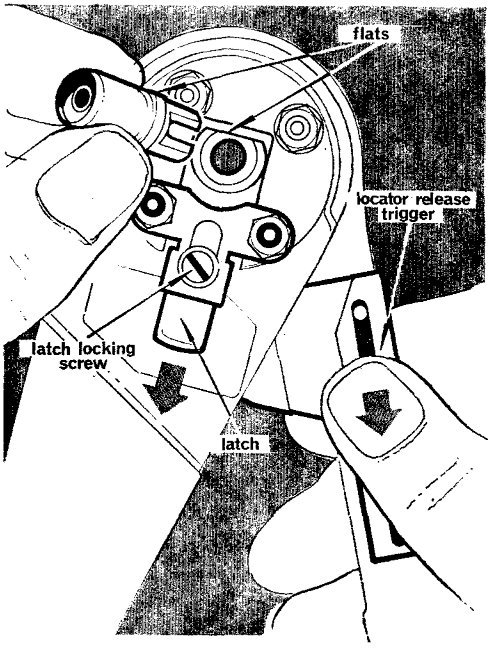


Fig 3 Erma-Buchanan crimping tool

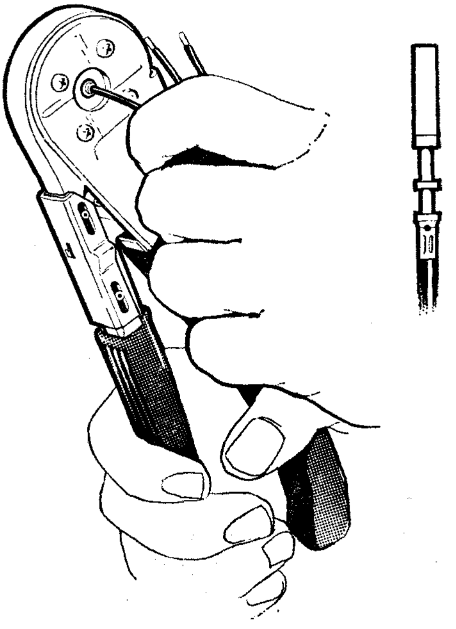
10. **Operation.** Select the correct locator for the type of insert to be crimped. Prepare the cable by stripping to the length required by the contact insert *eg* three-sixteenths of an inch for Plessey UK-AN series with size 16 inserts.

a. (1) Open the tool by applying pressure to the handles until the ratchet releases.
(2) Loosen the latch locking screw.
(3) Pull the latch to the fully open position.
(4) Place the tool handles against a firm surface, and pull the locator release trigger fully down against the spring.
(5) Insert the locator so that the flat on the locator mates with that on the tool head.
(6) Release the locator trigger.
(7) Close the latch and lock it in position with the latch locking screw. The latch will not close properly unless the locator has been fitted in the correct position.



Gauge Checking. The crimping tool is a precision instrument and must be checked at monthly intervals using the gauges provided. Instructions for the use of these gauges are given in the electrical manual and the Erma-Buchanan handbook. The inspection and test is recorded on RAF Form 2976.

b. (1) Place the prepared cable into the crimp pot of the insert.
(2) Check that the conductor is visible in the hole and that the end of the cable insulation is flush with the end of the pot.
(3) Push the assembled insert and cable into indenter opening of the locator, from the side opposite to the latch and release mechanism. Ensure that the insert is fully seated in the locator.
(4) Squeeze the tool handles together until the automatic release ratchet operates. The handles can then be released and the tool will open to allow the crimped insert to be removed.



Sleeving. As the cable insulation fits into the moulded body of the plug or socket the leads do not require sleeving. If a smaller wire than normal is used, a sleeve may be needed to seal the cable entry. It should be fitted prior to inserting the insert in the plug or socket body.

11. **Contact inserts.** These inserts are fitted and removed using special tools developed by the manufacturer. To prevent damage to the insulated moulding of the plug or socket it is *essential* that the correct tool is used. These tools may be lubricated with a small amount of silicone fluid (MS 2704) and should be used with extreme care. To prevent distortion of the insulator all

positions must be filled. If a position is not required either a blank insert or a special 'filler' insert should be fitted. Large contacts should be inserted first, and the others inserted working outwards from the centre of the moulding.

12. **Assembly of Plessey UK-AN series plugs.** Slide the rear cover components of the plug assembly on to the crimped connector and inserts. Select the correct insertion tool (colour coded handles) by reference to the table supplied by the manufacturer.

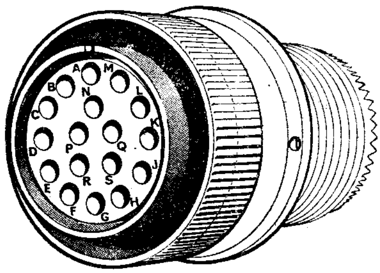


Fig. 4 Plessey UK-AN connector

(1) Fit the leader to the nose of the insertion tool and lubricate the tip with a small amount of silicone fluid.
(2) Place the leader in the correct hole from the front of the body moulding.
(3) Keep the tool in line with the hole and press home until the collar on the tool is against the moulding.
(4) Remove the leader and insert the wired contact fully into the nose of the tool.
(5) Grip the socket body and the wire to keep them in line and withdraw the insertion tool.
(6) A gentle pull on the wire will then ensure correct positioning of the insert.

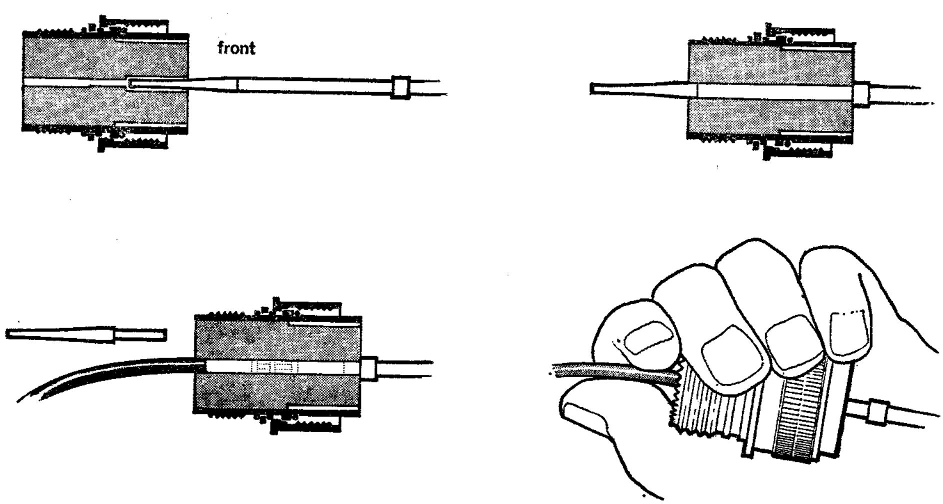


Fig. 5 Insertion of contact inserts

13. **Contact removal (Plessey UK-AN).** Ejection tools are also colour coded and it is *essential* to use the correct tool to prevent damage to the insulated moulding. The tools are inserted from the front and placed over the plug contact (or into the socket contact). They should be pushed through with a steady pressure until the contact is ejected. Care must be taken to keep the tool in line with the hole.

Hellermann Deutsch Connectors

14. The Hellermann Deutsch range of connectors have been adopted as preferred items for use on new equipments coming into the service. As they will also intermate with several other types, they can be used as standard replacements for defective connectors when listed as authorized spares in the appropriate Air Publication.

Warning. It is possible to mate a free plug (with pin contacts) and a fixed receptacle which may also have pin contacts. This gives a pin to pin connection and always results in severe damage to both connectors. When refitting equipments etc, great care must therefore be taken to positively identify *all* connectors before any attempt is made to mate *any* of these together.

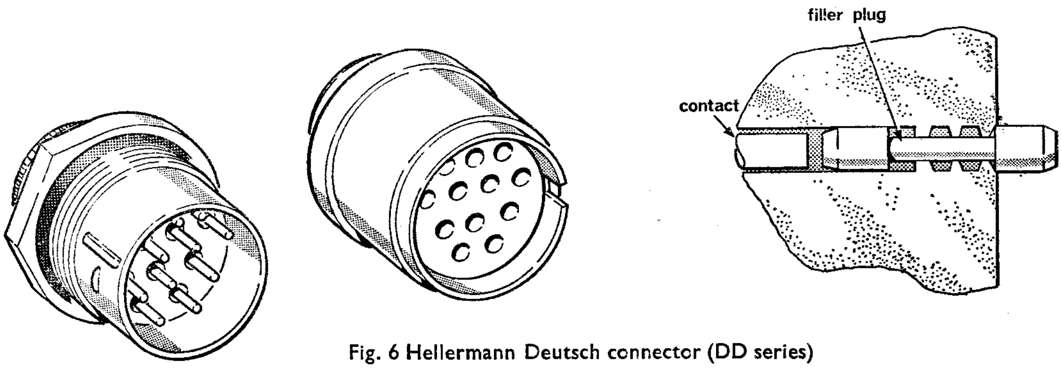


Fig. 6 Hellermann Deutsch connector (DD series)

15. **Filler plugs.** It is necessary to assemble all contacts even though they may not be connected to conductors. For the unconnected contacts, filler plugs of the appropriate size are pressed into the insulator by hand pressure (behind the contact, see figure 6). These plugs maintain the pressure sealing qualities of the connector. They can be removed when required by using the normal contact ejection tool.

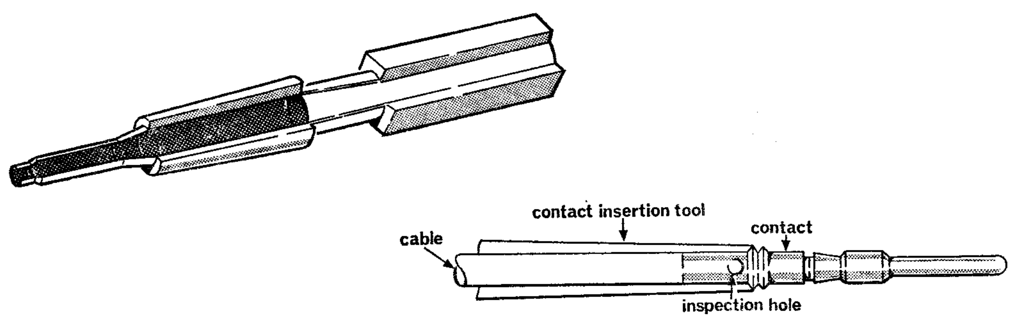


Fig. 7 Contact insertion (Hellermann Deutsch)

16. **Contact insertion (Hellermann Deutsch).** The following assembly procedure applies to both male contacts (pins) and to female contacts (sockets).

a. Check that the insertion tool is the correct one for the connector type to be assembled and that it is the correct size for the contacts being inserted.

b. Apply the insertion tool to the crimped contact and cable, ensuring that the end of the insertion tool is butted against the shoulder of the contact (see figure 7).

c. Push the insertion tool, contact and cable straight into the rear face of the connector insert cavity until the contact snaps into its retained position.

d. Pull insertion tool straight back out of the connector.

e. A light pull on the cable will verify that the contact is in its retained position. If the contact is not retained it must be *completely removed* from the connector insert before re-application of the insertion tool. Under no circumstances must an insertion tool be applied to a partially inserted contact.

17. **Contact removal (Hellermann Deutsch).** The following method applies to both pin and socket contacts.

a. Check that the removal tool is the correct size for the contact to be removed.

b. Slide the removal tool tube towards the tool handle (see figure 8).

c. Centre the removal tool probe on the selected contact but do not apply any pressure on the probe.

d. Slide the removal tool tube into the mating face of the connector insert using only moderate finger pressure.

e. Maintain finger pressure on the removal tool tube and steadily apply pressure by the palm of the hand to the removal tool probe until the contact unseats from its retaining spring clip. If the contact fails to release, pull the removal tube free, rotate the tool and repeat the procedure.

f. Pull the contact free of rear insert cavity and then remove the tool from the mating face cavity of the connector.

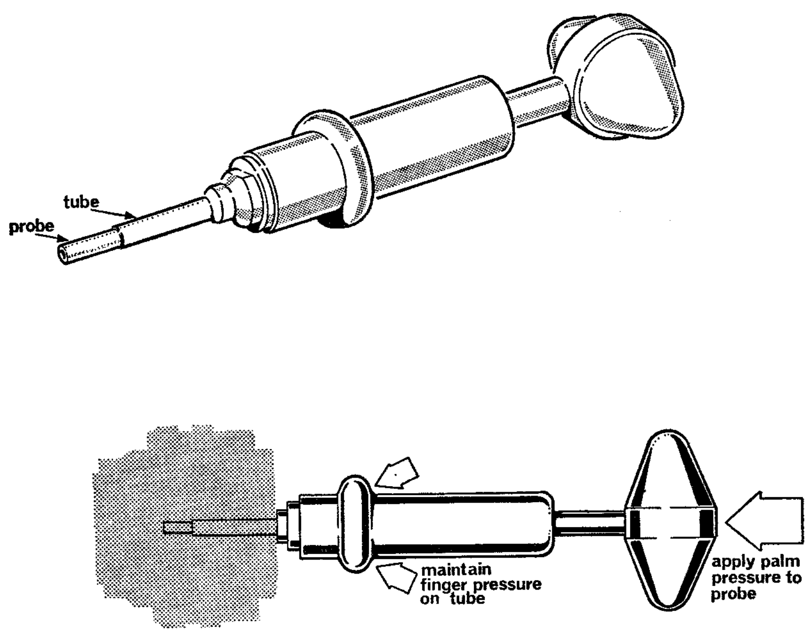


Fig. 8 Contact removal (Hellermann Deutsch)

Coaxial R.F. Connectors

18. Coaxial cables are used at radio frequencies. The copper braiding, normally earthed, serves both as a screen and as the second conductor. It is important to ensure a good connection between the braiding and the plug or jack body, particularly if the braiding is not earthed. An exploded view of a BNC type connector is shown in Figure 9.

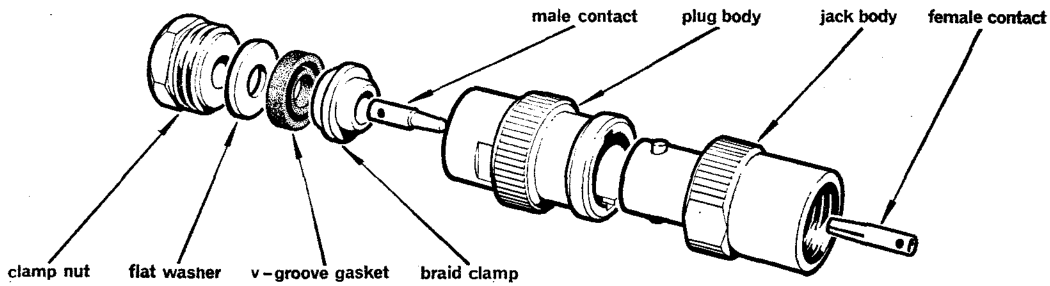
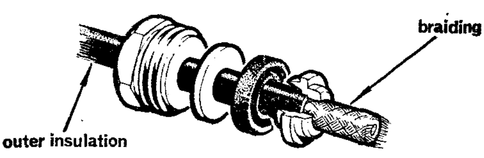


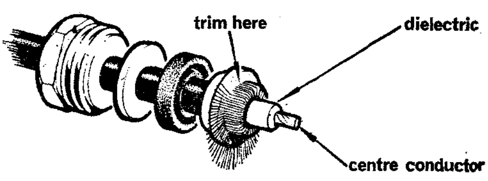
Fig. 9 Exploded view of BNC connector

19. **Assembly.** Remove all the component parts shown in Fig. 9.

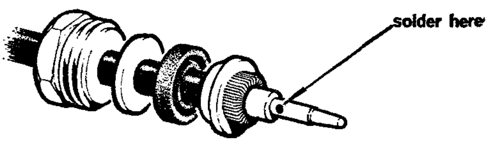
a. (1) Strip off the outer insulation sheath for three eighths of an inch.
(2) Comb out the braiding and form a taper.
(3) Slide the clamp nut and flat washer over the outer sheath.
(4) Fit the V-grooved gasket with the groove towards the cable end.
(5) Fit the braid clamp with the internal shoulder against the outer sheath.



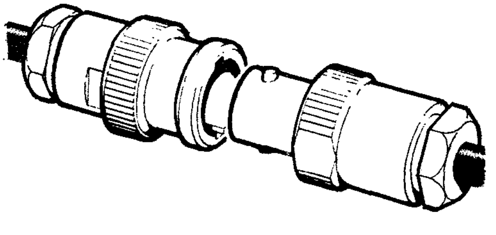
b. (1) Fold the braiding over the braid clamp and trim off the excess using watchmakers shears.
(2) Strip the dielectric 7/64 inch from the braid clamp.
(3) Cut off the centre conductor to 7/64 inch from the end of the dielectric.
(4) Tin the centre conductor, using 22 SWG flux-cored solder and applying heat for as short a time as possible.



c. (1) Fit the contact over the centre conductor to lie flush against the end of the dielectric.
(2) Hold the cable and the contact together and solder. Apply the iron for as short a time as possible.
(3) Clean any excess solder or flux from the outside of the contact.



d. (1) Slide the grooved gasket, washer and lock nut up to the braid clamp.
(2) Push the plug body firmly over the cable assembly.
(3) Engage the clamp nut with the body of the plug and tighten it, keeping the plug and cable in position.



Taper Pins

20. Taper pins are a method of making a quickly removable semi-permanent electrical connection. A tapered pin is crimped to the wire and then forced into an accurately machined mating socket. Due to the extremely high contact pressure the surfaces are self cleaning and a low noise, low resistance joint is formed. The pin is retained in the socket by the self-locking wedge action of the taper. Special tools are needed for both insertion and removal. The pin may be removed and replaced several times without injuring the quality of the connection. The type of pin used by the service is the '53' series pre-insulated diamond grip (PIDG) solid pin, made by Aircraft-Marine Products (AMP).

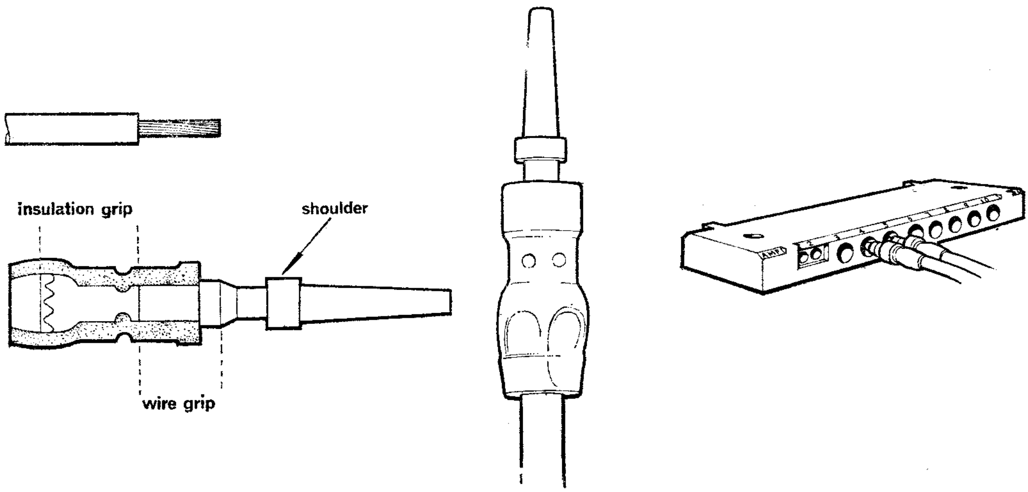


Fig. 10 Taper pins (PIDG type)

21. **PIDG pins.** These are $3\frac{1}{2}°$ tapered solid pins with a small end diameter of ·053 inch. They are made of brass and are supplied either gold or silver plated. They have a closed barrel wire entry, fitted with a bonded vinyl or nylon insulating sleeve (Fig. 10). The sleeve is colour coded; yellow for sizes 24-22 AWG, white for 20-18 AWG, and black for size 16 AWG. The mating receptacles are made from beryllium copper and are either gold or silver plated. They are supplied in a variety of moulded nylon and polythene blocks which have good dielectric properties and are designed to prevent moisture entrapment.

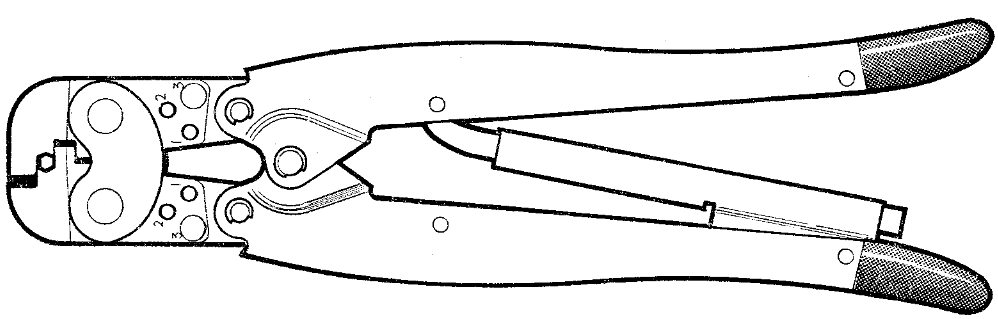


Fig. 11 The 'certi-crimp' tool

22. **The 'certi-crimp' tool.** Taper pins are crimped to the wires using the certi-crimp hand tool (Fig. 11), which has a ratchet mechanism to ensure correct crimp depth. Wires should be stripped 3/16 inch before crimping into the barrel which is about ⅜ inch long and grips both the conductor and the insulation. The tool used for AWG 24-22 pins (yellow) has both handles colour coded yellow. The tool for AWG 20-18 (white) pins and AWG 16 (black) pins has one white and one black handle. As a cross check to ensure that the correct tool has been used the crimping tool leaves either one (yellow) or two (black or white) dots on the crimping barrel of the crimped terminal.

23. **Insertion.** Care must be taken not to twist or tilt taper pins during insertion. The insertion tool used is the type L captive tool which holds the pin until a pull test is applied by the operator and thus ensures that a secure connection is made every time.

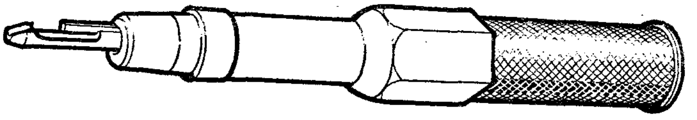


Fig. 12 Insertion tool (type L)

a. The receptacle must be held firmly against a solid surface e.g. a bench top, with the pin entry holes uppermost.
b. Put the pin into the tool by pressing the conductor crimp section into the tool slot from the side.
c. Place the pin into its entry in the block and push down on the end of the tool until it trips. This spring loaded tripping action ensures that pins are inserted with the correct amount of force.
d. Slowly pull the outer sleeve of the tool until it just moves to test the retention of the pin in the block and disengage the tool.

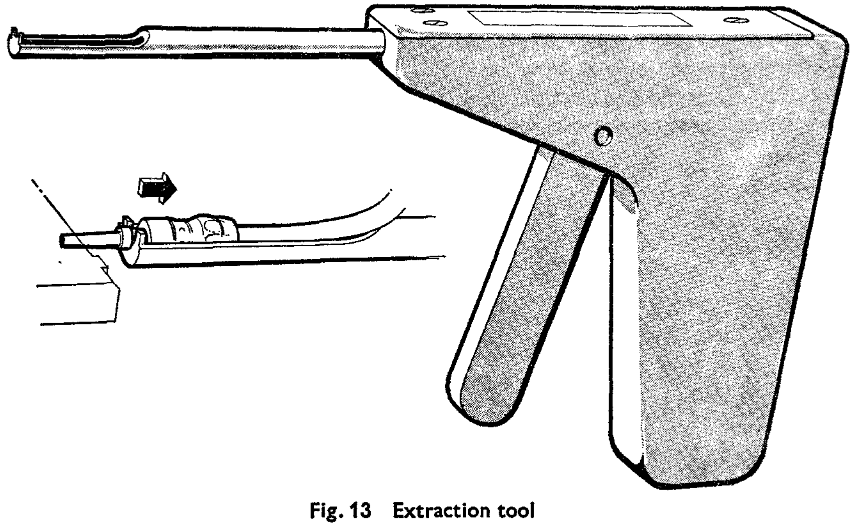


Fig. 13 Extraction tool

24. **Extraction.** Place the tip of the extraction tool between the two shoulders on the taper pin and pull the trigger to remove the pin from the block.

CHAPTER 6

FASTENING METHODS

List of Contents

Introduction

1. Various fastening methods are in use in the electrical and electronic trades. Equipments of modular construction are assembled before installation and are fitted with a suitable dust cover. Panels may have to be removed from an aircraft or cabinet, to gain access to electronic equipment for servicing purposes. An aircraft installation must be secured to the airframe and protected from vibration by special mountings. Identity and modification labels are fastened to most equipments. One common fastening method already considered is riveting (see Chap 3); other methods are described in this chapter.

Nuts and Bolts

2. A bolt is a specially shaped metal rod with an external (male) screw thread (Fig. 1) and is designed to mate with a nut which has an internal (female) thread of the same type. Several different thread systems are in use and a nut of one system cannot be fitted to a bolt of another system. The parts to be joined have a hole of the correct diameter (found from thread clearance tables) drilled through them. The bolt is pushed through this hole and the parts are tightened together by fitting the nut.

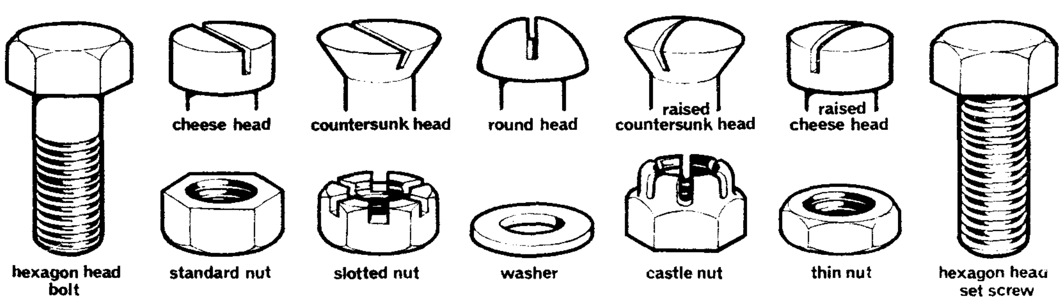


Fig. 1. Nuts and bolts

3. **Washers.** A washer is normally placed under the nut to prevent surface damage being caused as the final tightening torque is applied. During dismantling each nut and washer should be replaced on the original bolt immediately after removal. This reduces the possibility of mislaying the nut or washer which could become a flight safety hazard.

4. **Studs.** A stud is a metal rod with a male thread at each end (Fig. 2). One end of the stud is screwed into a threaded hole in one of the parts to be joined. The other part is fitted over the stud and tightened in position by fitting a washer and nut to the end of the stud.

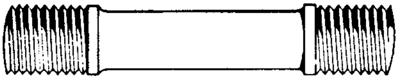


Fig. 2. Stud

Locking Devices

5. Vibration can cause a nut to slacken off or to separate from its bolt. In an aircraft any loose object is a flight safety hazard; on the ground component part separation may cause equipment failure. Various methods of locking a nut in position have been devised and are in common use on electronic equipments.

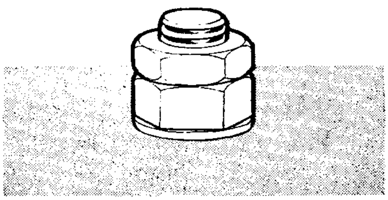


Fig. 3. Locknut

a. Lock nut. A lock nut is slightly thinner than an ordinary nut and is tightened down firmly on top of the main nut. This wedges the threads and prevents the main nut from slackening (Fig. 3).

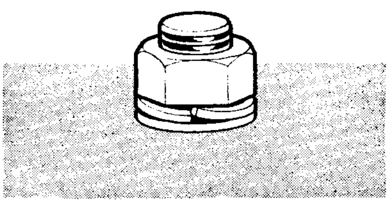


Fig. 4. Spring washer

b. Spring washer. This is a single coil of square section spring with sharp ends and is fitted as shown in Fig. 4. When the nut is tightened the sharp ends of the spring dig into the nut and the surface and hold the nut in position. Provided the spring washer retains its springing action it may be re-used. To prevent damage to the face of a component a plain washer may be fitted below the spring washer.

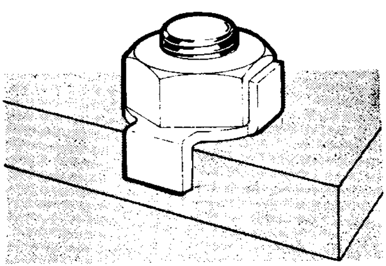


Fig. 5. Tab washer

c. Tab washer. This is a metal washer with two or more tabs and is suitable for use with standard nuts (Fig. 5). One tab is bent against the face of the nut and the other over a suitable edge of the component. Tab washers must be used *once* only. Some tab washers are designed with a tab which fits into a slot or hole in the component; and others which fit against a flat or groove of a special bolt.

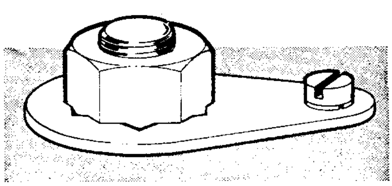


Fig. 6. Locking plate

d. Locking plate. This is a thin metal plate fitted over the nut after tightening. The plate is then screwed to the component surface (Fig. 6). As a locking plate may be re-used repeatedly it is a very common system when servicing procedures require frequent removal of a nut.

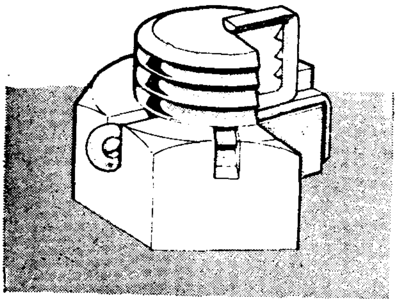


Fig. 7. Split pin

e. Split pin. A split pin is used with a slotted or castellated nut. The steel pin lies in a slot in the nut and passes through a hole in the bolt. The pin must be secured in position by bending the legs as shown in Fig. 7. A split pin must be used *once* only.

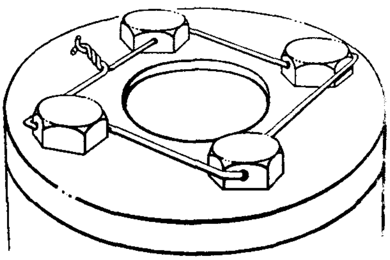


Fig. 8. Locking wire

f. Locking wire. The nut or bolt to be secured is supplied already drilled. After tightening the thread, a steel wire is passed through the hole and secured to companion bolts or to the component (Fig. 8). The lay of the wire must be such that it comes under tension as the bolts tend to slacken. To be effective the wire must be tight and it can be used *once* only.

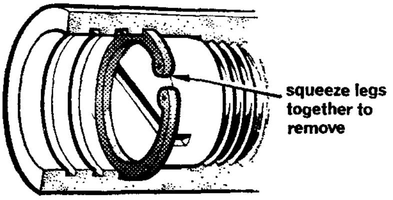


Fig. 9. Circlip

g. Circlips. Circlips are made of spring steel and are used to lock ringnuts and similar devices. The circular part of the clip fits into a groove and the short bent end fits into holes drilled in the items to be locked together. Circlips are made for both internal and external fitting. The common steel wire type may be used *once* only.

6. **Stiffnuts.** These nuts are designed so that the friction between the threads of the nut and bolt is so great that the nut is self locking. When assembled the end of the bolt must protrude from the end of the nut by at least one complete thread. Stiffnuts can be re-used but are not suitable for use at high temperatures.

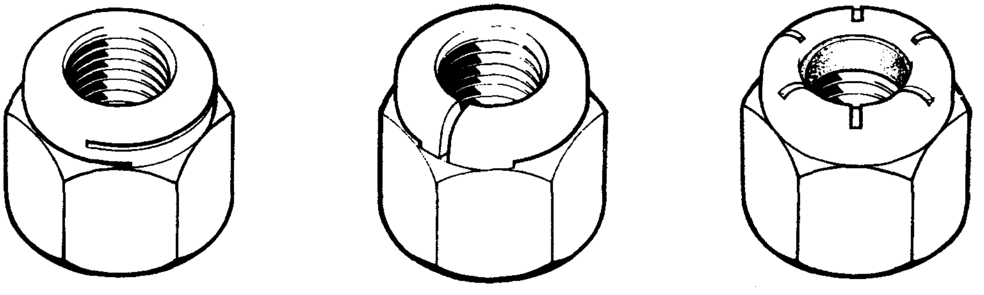


Fig. 10. Types of stiffnut

Self-tapping Screws

7. Self-tapping screws are used to secure thin gauge sheet metal where nuts and bolts or rivets are impractical. They are screwed into a hole of the correct diameter and form their own thread. The screw head may be slotted or cruciform; four types in common use are shown in Fig. 11.

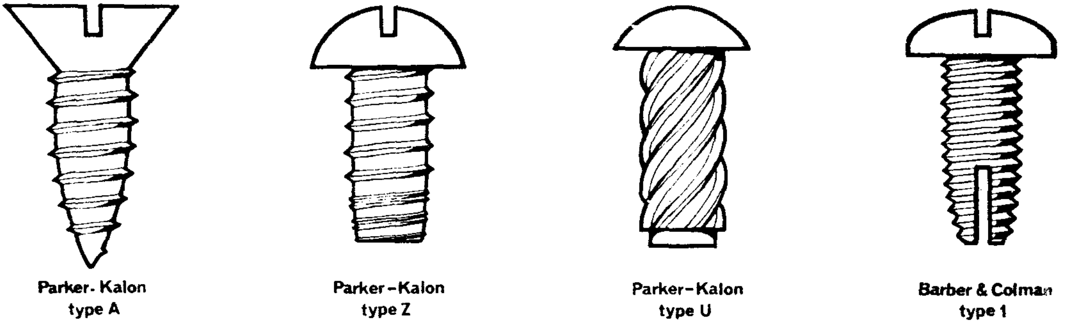


Fig. 11. Self-tapping screws

Quick Release Fasteners

8. Special fasteners have been designed to hold sheet metal panels in position and to allow for their rapid removal and replacement during servicing. They are often used to secure metal dust covers to electronic equipments. The two standard types in common use are the 'Dzus' and 'Oddie' fasteners.

9. **Dzus fastener.** The Dzus fastener (Fig. 12) consists of a catch and a spring. The catch is held in position on the detachable panel by a rubber grommet or a circlip. The spring is attached to the under side of the fixed component, usually by rivets. A helical slot in the body of the catch engages with the spring, drawing it up when the catch is given a quarter of a turn in a clockwise direction. The fastener is unlocked by a quarter of a turn anti-clockwise. A special Dzus key is used to operate the fastener.

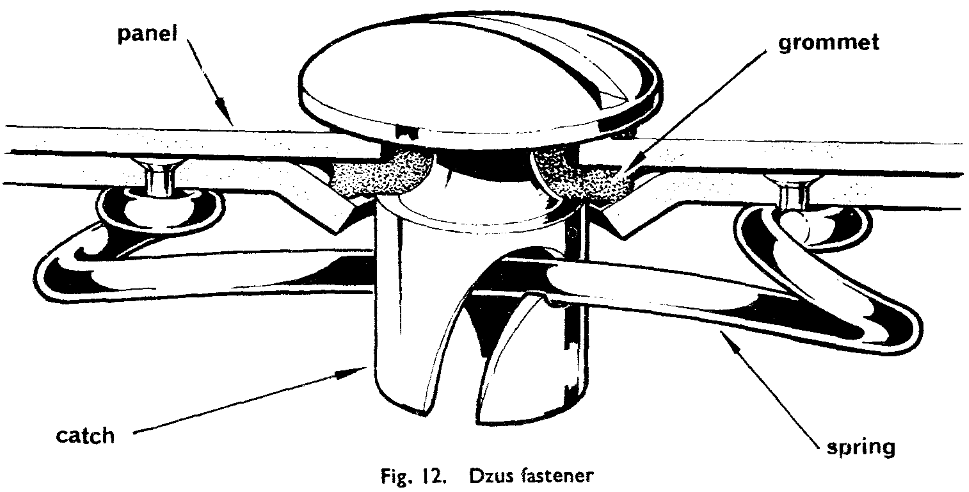
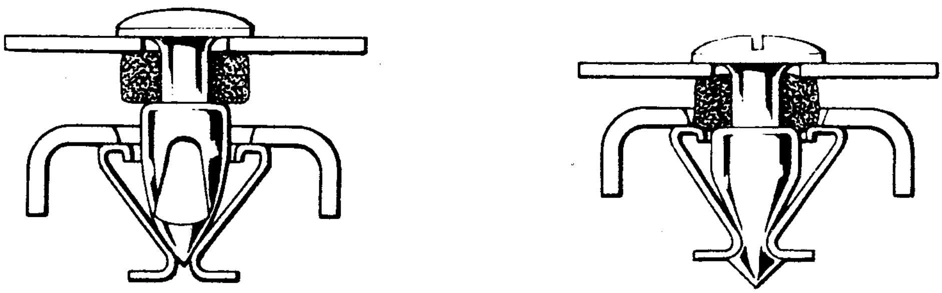


Fig. 12. Dzus fastener

10. **Oddie fastener.** The Oddie fastener is often used to secure sheet metal inspection panels to radio equipment. As shown in Fig. 13, a central stud is held in position in the panel by a rubber washer or a coiled spring. A two legged spring clip is fastened to the fixed component, usually by rivets. The stud is bullet shaped and has two diametrically opposite recesses at the jointed end. The fastener is locked by positioning the recesses in line with the legs of the spring and pressing the stud home. There should be a definite click as the fastener engages. The fastener is unlocked by giving the stud a quarter of a turn in either direction, thus turning the recesses out of engagement with the spring legs.



Opened **Locked**

Fig. 13. Oddie fastener

Antivibration Mountings

11. The majority of electronic and instrument equipment is secured to the airframe by antivibration mountings to minimise the effects of engine vibration or impact on the components within the equipment. Various types of mountings are in use and are rated by the weight of equipment which they will support properly. A flexible rubber gasket is used to absorb vibration and separates the frame fastened to the equipment from that fastened to the aircraft. Four or more mountings are used to support each equipment. Because of the insulating effect of the rubber gasket, flexible bonding strips must be used if an efficient electrical connection between the equipment and the airframe is required.

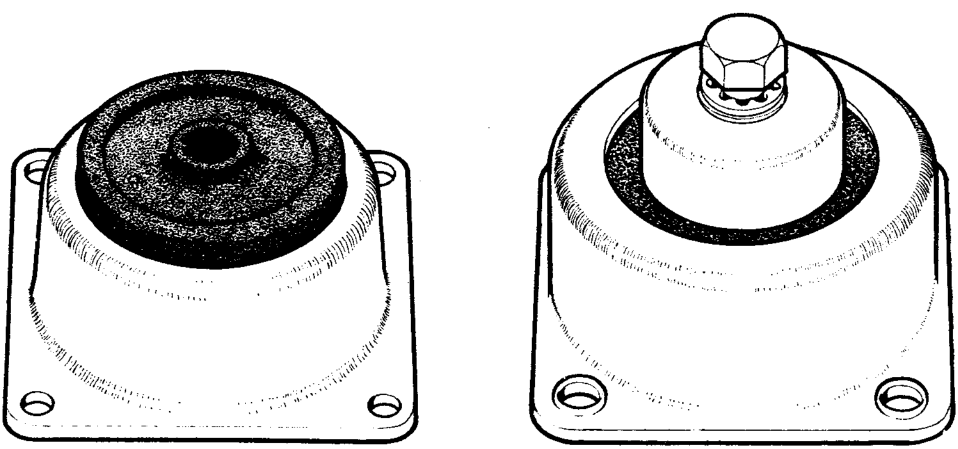


Fig. 14. Antivibration mountings

Adhesives

12. The great advantage of using an adhesive as a fastening method is the ability of adhesive to fill the joint area completely and thus prevent the ingress of air or water. A very large number of different adhesives and bonding compounds are in service use for a wide range of applications such as locking preset potentiometers, sealing pressurized cabins, and sticking composition flooring to a metal aircraft. It is essential to use a compound which will perform efficiently the function required; reference should always be made to the appropriate aircraft or equipment AP. Only those adhesives which are in common use in the electrical and electronic trades are considered in this chapter.

13. **Cleanliness.** The vital importance of absolute cleanliness cannot be over-emphasized. An adhesive bond is no stronger than the surfaces to which the adhesive is applied; thus if the adhesive is applied on a film of dirt or grease the strength of the resulting bond is only that holding the grease to the material surface. Whenever possible the surfaces should be degreased, using as a cleaning fluid the solvent on which the adhesive is based. If no solvent is specified either trichlorethylene or an equal mixture of white spirit with naptha coal tar solvent may be used.

14. **General working practices.** The application of adhesives or cleaning solvents should be carried out in a well lit ventilated working area at a temperature of not less than 18°C (65°F). Almost all of these compounds are highly inflammable and their use near a naked flame is extremely dangerous and must be avoided. The manufacturer's instructions should be followed and any adhesive which has exceeded its shelf life should not be used.

a. Carefully remove *all* traces of dirt, oil, grease, paint, french chalk or old adhesive compound from the surfaces to be joined.

b. If a cleaning or degreasing solvent has been used, allow the surfaces to dry and wipe them with a clean soft cloth.

c. *Do not touch* or handle a cleaned surface. Even the slight trace of grease which is left by the finger tips may be sufficient to spoil the joint.

d. If a brush or spatula is to be used it must be thoroughly *cleaned and dried* before use to prevent contamination of the joint by dirt or other types of adhesive compounds.

e. A joint must not be moved or subjected to any strain until the adhesive used has *fully cured.* During this setting period fumes are released as the solvent evaporates and may cause corrosion if the work is not adequately ventilated.

15. **Varnish, oil** (8010–99–947–7826). This is a locking varnish used to hold preset capacitors, inductors or resistors in position after alignment. It is a dark red compound which does not fully harden with age. To use, dip the end of a screwdriver in the varnish and apply a small quantity to the junction of the parts to be joined. Allow 2–4 hours for the solvent to evaporate and the varnish to set before replacing the equipment covers. To re-adjust a preset control which has been locked, the varnish must first be softened using remover, paint (8010–99–947–7825). Apply a few drops from a pencil shaped brush and allow 2–3 minutes for the varnish to soften before attempting adjustment. The solvent will evaporate in about 2 hours and the original varnish will relock the component. If necessary a *small* amount of extra varnish may be used.

16. **Bostik adhesive No 1261** (33H/9430380). Bostik No 1261 is used for securing and sealing instrument glasses to prevent the ingress of moisture into aircraft electrical indicators, temperature gauges etc. It is a dark brown to black rubber based resin and is effective at temperatures up to 100°C. When supplied it contains a petroleum solvent, which is volatile and highly inflamm-

able so the lid of the ½ pt. container must be replaced firmly immediately after use. The surface to be joined should be cleaned and an even film of adhesive applied to both surfaces using a stiff brush. Allow the adhesive to dry for 10–20 minutes then press the surfaces firmly together, taking care not to trap any air in the joint. Bostik 1261 can also be used for joining rubber components to rubber, wood or metal surfaces.

17. **Loctite.** Loctite is a penetrating liquid polymer, soluble in trichlorethylene, which remains fluid when exposed to air. It hardens into a tough plastic when excluded from air in contact with metal surfaces. Cured loctite is virtually insoluble and the bond can be broken only by applying force. It is used for locking screw threads e.g. the nuts and bolts holding component parts to equipment sub-units. Five grades, of different shear strengths, are available and are colour coded for easy identification. Reference should be made to the appropriate AP to determine which grade to use, as the use of too strong a grade may cause the bolt to shear when dismantling. Cadmium plated, anodised or non-metallic parts must be dipped in loquick activator to enable a suitable bond to form. Direct application of loctite from the container to the thread is possible as loctite will penetrate by capillary action. Care must be taken to ensure that loctite does not come into contact with any moving parts. Hardening is complete in 24 hours, but may be accelerated by pre-treatment with loquick or by allowing the bond to stand 30 minutes at room temperature followed by 10 minutes at 100°C. Loctite has a shelf life of 12 months provided no metal particles get into the bottle and there is no contamination by loquick activator.

18. **Titebond No 22** (33H/9995814). Titebond No 22 is a general use adhesive, often used for sticking identity or modification labels to radio equipments. It should not be used on cellulose surfaces. It is highly inflammable giving off a heavy vapour and should not be used near a naked flame. Thoroughly clean and degrease the surfaces to be joined. Stir the adhesive and apply a thin even coating to both surfaces using a clean brush. Allow the coated surfaces to stand until they are almost dry (about 5 minutes), then press them together, taking care to exclude all air bubbles. An alternative method is to allow the coated surfaces to dry completely. They may be stored until needed and must then be moistened with acetone and pressed firmly together. Titebond is supplied in ½ pt. tins which should be firmly closed after use and stored in a cool place.

19. **Araldite**—2 tube pack (33H/9437791). Araldite is an epoxy resin adhesive supplied in two separate tubes. The blue tube contains the resin base and the black tube a special hardener. Chemical action takes place when these two materials are mixed and results in a resin bond of very high strength which is heatproof and waterproof. Araldite can be used for joining most materials in common use, but is not recommended for use with thermoplastics such as polythene. To prepare for use mix equal amounts of resin base and hardener by stirring thoroughly together, (using a piece of wood or scrap material as a stirrer). This mixture will remain usable for 3 or 4 hours at normal room temperatures so only sufficient should be mixed for the job in hand. The surfaces to be joined must be cleaned and degreased, then coated with an even film of the adhesive mixture. Bring both surfaces firmly together and clamp them in position until the resin is fully set. At normal room temperature Araldite sets hard in about 12 hours but the joint does not attain maximum strength for 3 days. Setting is much more rapid if moderate heat is used:

a. about 24 hours to full strength if placed on a radiator.

b. 30 minutes to full strength in an oven at 149°C (300°F).

c. 3 hours at a temperature of 79°C (175°F).

Care should be taken to ensure that the items being joined will not be damaged by the temperatures used to cure the adhesive.

CHAPTER 7

WORKSHOP DRAWING

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Introduction

1. The object of a workshop drawing is to pass ideas and instructions to the tradesman in such a way that the work can be completed quickly and accurately. To make a drawing easy to read it should show all necessary information without repetition. Standard drawing methods must be used to prevent ambiguity and to enable any tradesman to work directly from the drawing.

Scale

2. It is not always possible to make a drawing the same size as the object it represents. The ratio of the drawn size to the actual size is called the scale and must be stated clearly at the foot of the drawing. If 1 inch on the drawing represent 4 feet the scale will be 1 : 48 and *all parts* of the drawing are shown $\frac{1}{48}$th of their actual size.

3. **Drawing size.** The scale to be used for a particular drawing is chosen so that it can be drawn on a standard size of drawing sheet without losing its clarity. Some of the BSI recommended sizes are:

40 in × 27 in. 30 in × 20 in. 20 in × 15 in. 15 in × 10 in. 10 in × 8 in.

These are the overall sizes of the drawing sheets so the actual drawing frame will be slightly smaller.

Pictorial View

4. Fig. 1 shows an easily understood method of drawing an object. This form of drawing is used for supplementary sketches to clarify the standard method of drawing which is called orthographic projection (Para 6).

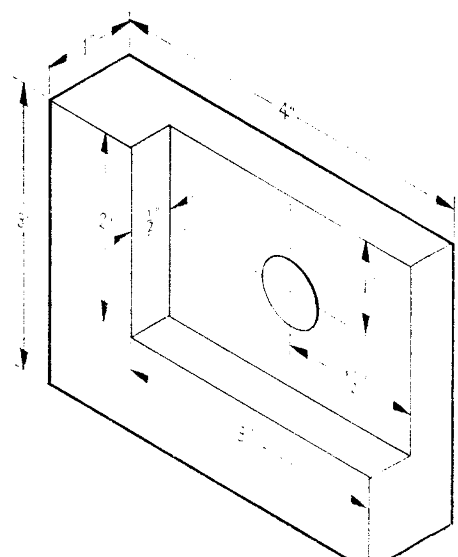


Fig. 1. Pictorial view

5. **Isometric projection.** This is a form of pictorial view used when an object is basically rectangular in shape. More complex shapes are difficult to draw and are liable to appear distorted. Fig. 2 shows a rectangular block drawn isometrically showing that all isometric lines are at 30° or 90° to the horizontal.

A *true* isometric projection has all lines drawn approx 82% of their true length. This makes the drawing look the same size as the actual object viewed in perspective. A full size drawing using actual lengths presents the same pictorial shape and is more often used as it is easier to draw. Fig. 1 is also drawn isometrically.

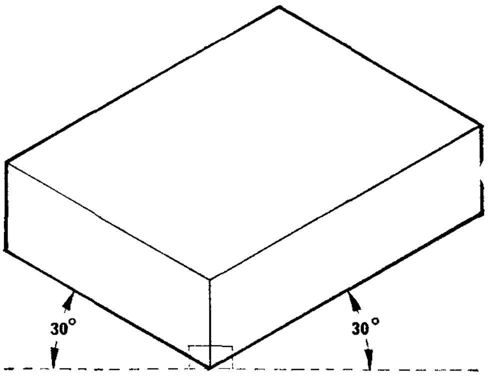


Fig. 2. Isometric lines

Orthographic Projection

6. Orthographic projections show an object as it actually is when viewed from any of its sides. Six views are possible but three are normally sufficient to give all the information required. Two standard methods are used: first angle projection and third angle projection. British drawings are traditionally first angle and American drawings third angle but third angle drawings are coming to be generally accepted as they are more natural.

The method used should be clearly stated on the drawing.

7. **First angle projection.** Imagine the object of Fig. 1 suspended in a box from which the top, front and right hand sides have been removed (Fig. 3).

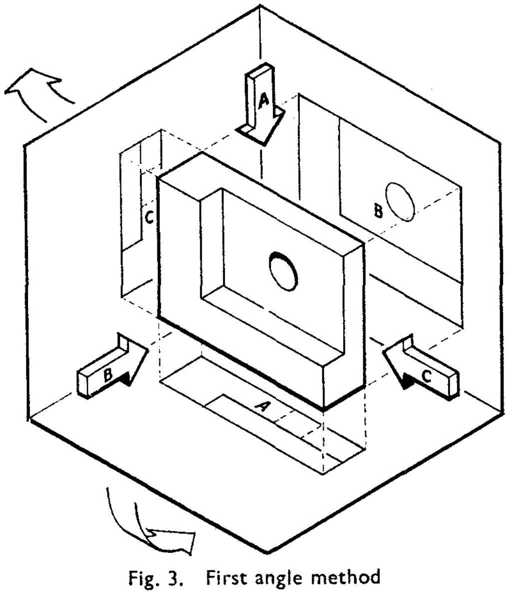


Fig. 3. First angle method

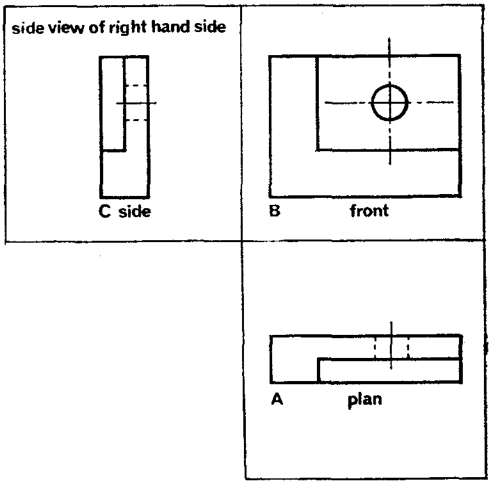


Fig. 4. First angle projection

Now project the views of the object as seen when looking square at each face on to the *inside* faces of the remaining walls and base of the box. By hinging back two walls of the box until they are in the same plane as the rear, three views are obtained as shown in Fig. 4.

Note that each view displayed is *remote* from the side it portrays.

8. **Third angle projection.** Imagine the object suspended in a transparent box so that it can be viewed through the sides and lid (Fig. 5). The views projected on the lid and right hand-side can be hinged to the plane of the front to give the three views shown. Notice that each view is adjacent to the face which it portrays.

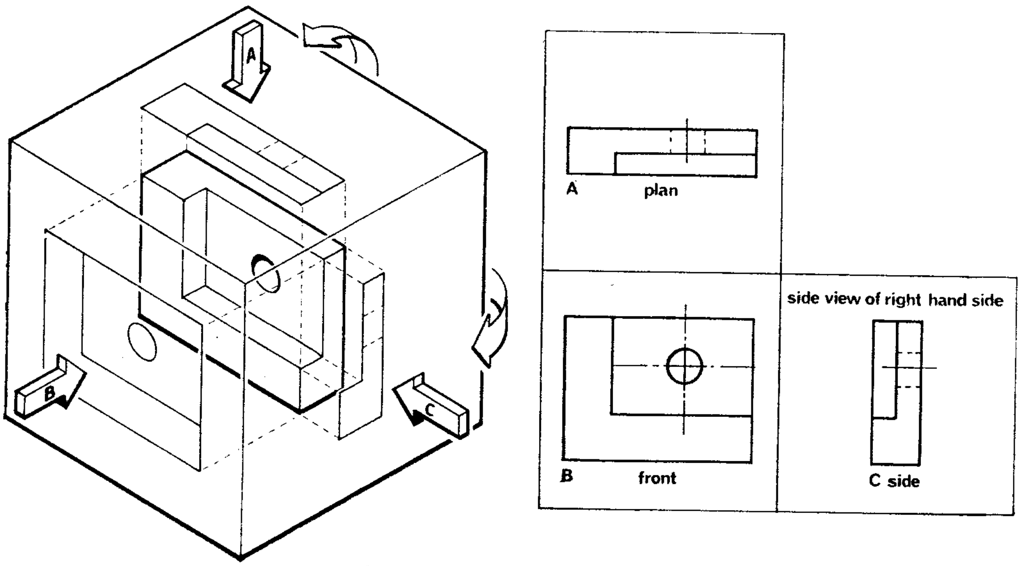


Fig. 5., Third angle projection

	Type of line	Example	Application
a	Continuous thick		Visible outlines
b	Continuous thin		Dimension lines Hatching of sections Projection or extension lines
c	Short dashes (thin)		Hidden details
d	Long chain (thin)		Centre lines Path lines of movement
e	Short chain (thin)		Development of false views To show adjacent parts Alternative position of a moving part
f	Continuous wavy (thick)		Irregular boundary lines Short break lines
g	Ruled with zig-zags		Long break lines
h	Thick chain		Viewing planes Cutting planes

Fig. 6. Types of lines

Types of Lines

9. Fig. 6 shows the types of lines that should be used on drawings, those given as thick being about three times the width of the thin lines.

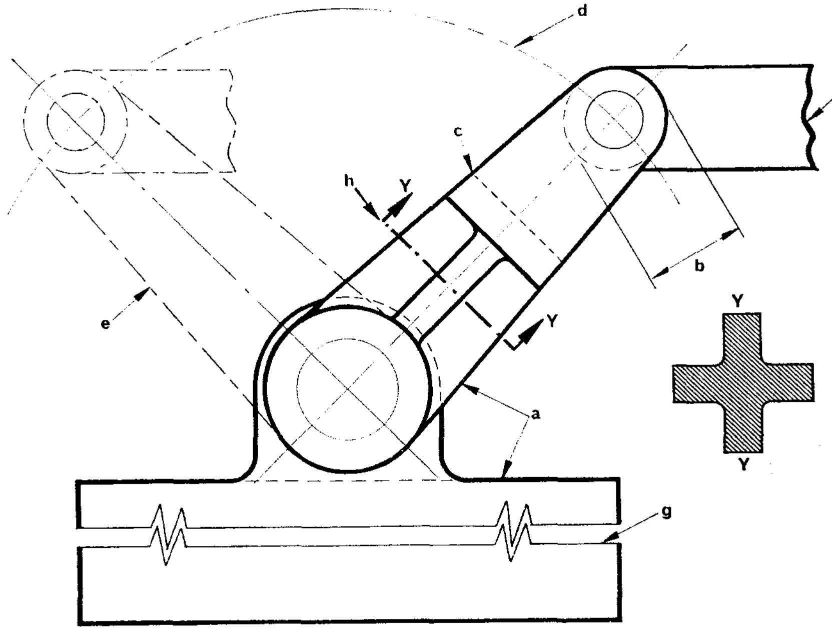


Fig. 7. Typical drawing showing use of lines

Fig. 7 shows the use of these lines, the letters and annotations corresponding to those given in Fig. 6.

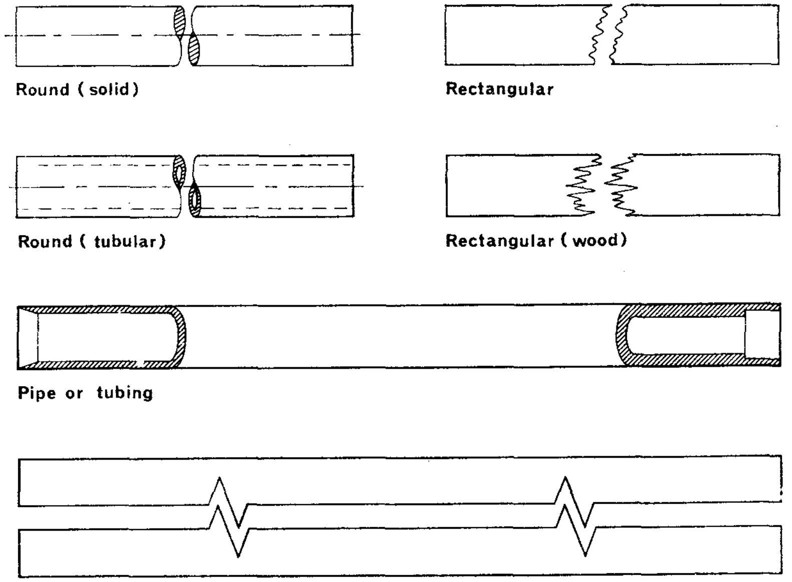


Fig. 8. Conventional breaks

Breaks

10. When a component is symmetrical about an axis or is of extreme length, a part or broken view may be used (Fig. 8).

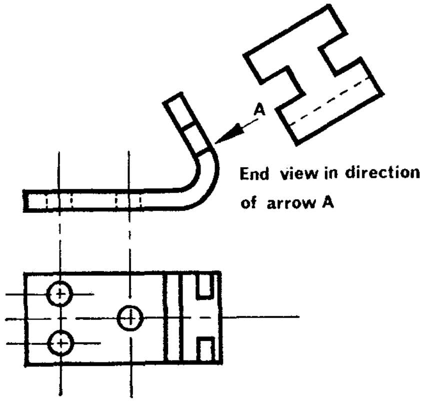


Fig. 9. Auxiliary view

Auxiliary Views

11. If a part is complicated an auxiliary view may be given (Fig. 9). This type of view is mainly used to show projected views of inclined faces. It is drawn directly in line with an arrow which represents the direction in which the object is viewed.

Sections

12. Section views show the object as it would appear if it had been cut through with a hacksaw. The plane of sectioning is usually taken along one of the main centre lines. Sectioned parts are marked by hatching using continuous thin lines at 45° to the horizontal (Fig. 10). The section hatching of adjacent parts should be in different directions (or to a different pitch if three or more parts are involved). In all views showing sections of the same part the section hatching should be the same in direction and spacing.

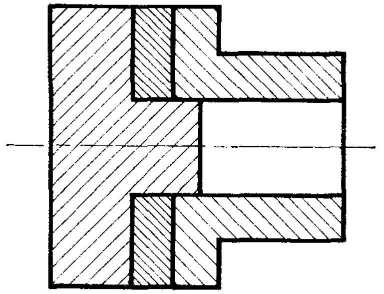


Fig. 10. Use of section hatching on three parts

13. If an object is symmetrical it is common practice to draw a half section view. This shows half the object in section with the other half in plan or elevation. Part section views may be used when it is desired to show part of the object with greater clarity. The subject may also be viewed on two or more planes to provide extra information without additional drawings. This type of view is called staggered section. (Fig. 11).

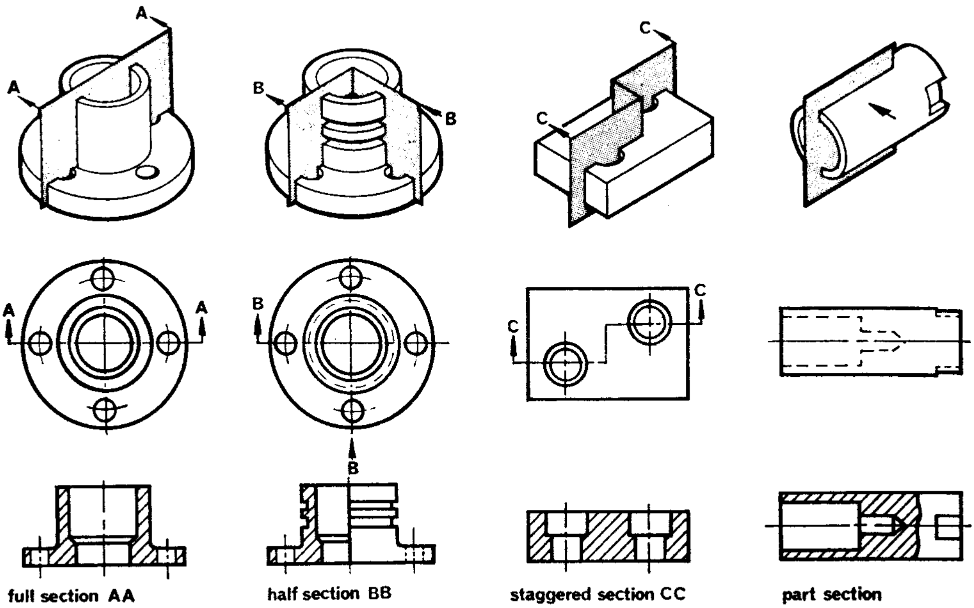


Fig. 11. Sectioned views

14. **Parts normally not sectioned.** If the cutting plane of a section drawing passes through simple parts whose shape is well known, these parts are shown in outline only. Examples are bolts, nuts, rivets, rods, keys, pins, shafts and other similar simple parts (Fig. 12).

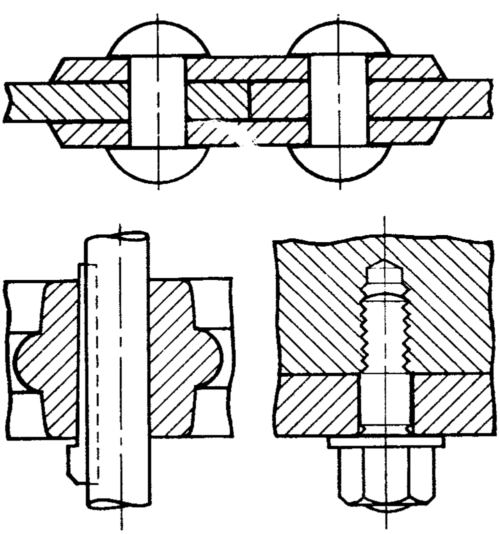


Fig. 12. Parts normally not sectioned

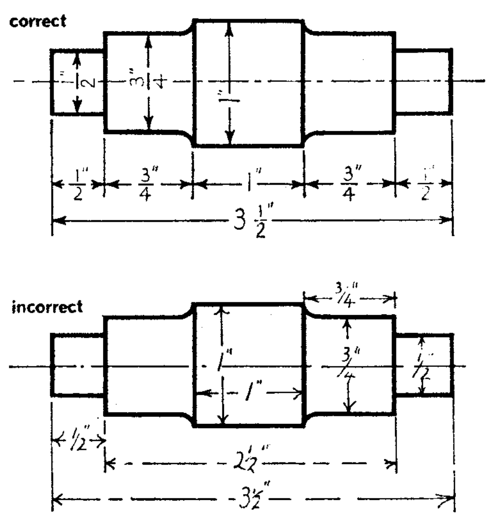


Fig. 13. Dimensioning

Dimensions

15. Dimensions are for the use of the tradesman and should be given in a clear manner without unnecessary repetition. Measurements should never be made from a drawing or print as it is possible for shrinkage to have occurred

during processing. Dimensions which affect the function of the object are normally given a tolerance. All dimensions figures are to be placed so that they can be read from the bottom or right hand side of the drawing. Vulgar fractions should be drawn larger than whole numbers and the dividing line must be parallel to the dimension line.

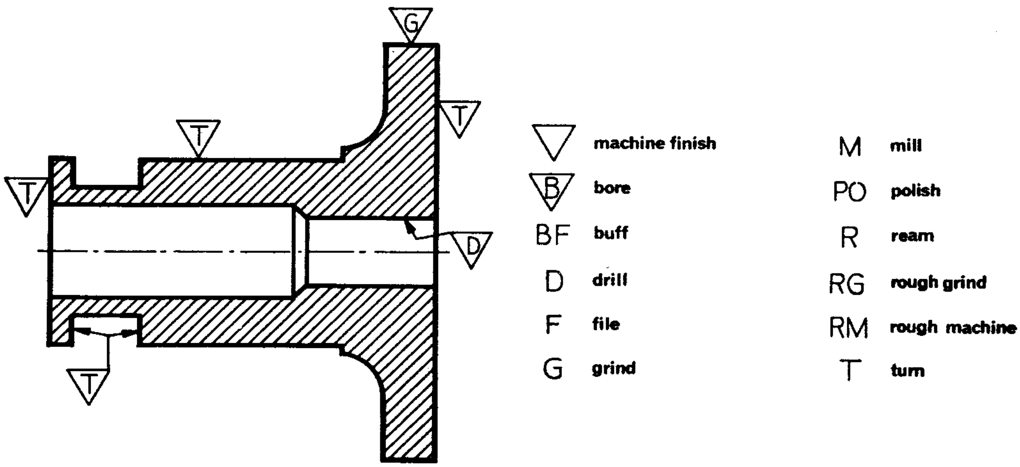


Fig. 14. Machining symbols

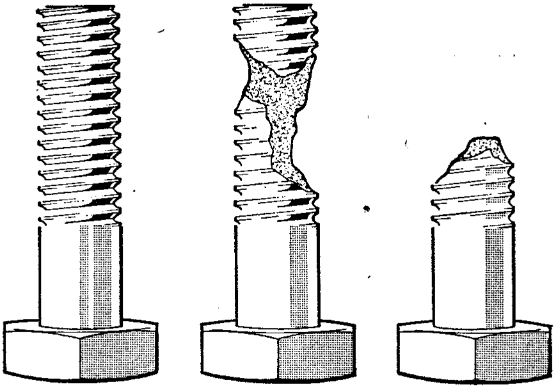
Machining Symbols

16. On production drawings surfaces which are to be machine finished are marked with a triangle, one point of which touches the surface concerned or is attached to a leader line. Letter symbols are used to specify the machining process used (Fig. 14).

Title Block

17. The title block is usually placed at the bottom right hand corner of the sheet. It provides the reference for all symbols used on the drawing and also shows:

a. Drawing or part number.
b. Description of drawing.
c. Scale.
d. Material used.
e. Number of articles required.
f. Draughtsman's signature.



CHAPTER 8
CORROSION

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Introduction

1. Corrosion is the destructive conversion of metals to metallic oxides or salts which do not possess the physical or electrical properties of the original metal. As most of these oxides and salts are poor conductors of electricity the efficiency of electrical and electronic equipments will be very seriously affected by even small amounts of corrosion. Terminals, junction boxes, plugs and sockets, and earthing or bonding points are the major sources of trouble. The mechanical properties of a metal assembly are also affected as corrosion eats away some of the metal over a period of time and thus causes weak points which could lead to structural failure. Tradesmen must be constantly aware of the damage caused by corrosion and of the treatments necessary to combat its spread.

Galvanic Action

2. The major cause of corrosion is primarily an electro-chemical action similar to that which takes place in the simple electric cell. The metal with the most positive electrochemical potential gives up molecules, via the electrolyte, to the other metals nearby and corrosion sets in. The electrolyte in the case of corrosion is the atmosphere, which always contains water vapour and small amounts of dissolved chemicals, mainly acids. For this reason the rate of corrosion will increase in conditions of high humidity such as at sea, and also in industrial areas where the chemical content of the atmosphere is high. Like all chemical actions, corrosion takes place quicker at high temperatures, and special measures are taken to protect equipment which is to be used in tropical zones. When electrical currents are passed across the junction of two different metals in the presence of moist air the corrosion rate becomes extremely high as a process similar to electroplating is then taking place.

3. **The electrochemical series.** All metals are said to be electropositive because of their ability to form positive ions when taken into solution under suitable conditions. The common metals used in the electrical trades are listed below in order of their electrochemical potentials. Hydrogen has been included in the list as it forms the most common positive ion of all, being present in water and almost all acids. The hydrogen ion is the 'gremlin' responsible for almost all corrosion.

Most positive	1 Magnesium	6 Nickel	11 Mercury
	2 Aluminium	7 Tin	12 Silver
	3 Zinc	8 Lead	13 Gold
	4 Cadmium	9 *Hydrogen*	14 Platinum
	5 Iron	10 Copper	

TABLE 1. The electrochemical series

The position of various alloys in the table depends on their composition, but a general idea can be obtained if the major constituent of the alloy is known. The metals with the least positive potentials (silver etc) are often called the 'noble metals' because of their resistance to attack by acids or corrosion.

4. If two different metals are in contact with one another in a moist atmosphere galvanic action will take place. In general the rate at which this action takes place depends on the *difference* in the electrochemical potentials of the two metals. Thus the further apart in the above table the metals are, the greater will be the rate of corrosion. The metal which is *the more electropositive will be eaten away* over a period of time unless precautions are taken to prevent or greatly reduce the rate of the galvanic action. Those metals further up the table than hydrogen will all oxidise in the presence of moist air. Some of these oxides are useful; others are a menace.

Oxides

5. **Stable oxidation.** The corrosion of zinc and aluminium in normal air causes the formation of an insoluble oxide which forms a close-fitting skin on the surface of the metals. This skin prevents further contact between the electrolyte (moist air) and the metal surface and halts the corrosion process. The naturally formed oxide skin on aluminium is often not sufficient protection so an artificial oxide coating is formed and the metal is then said to have been 'anodised'. This oxide coating will not conduct electricity and so *must* be removed before making electrical connections. Steel water tanks and containers are often plated with zinc to prevent rust formation, and are then said to be 'galvanised'.

6. **Rust.** Oxide formation on iron and steels is commonly known as rust and is easily identifiable by its reddish-brown colour. Although it is largely insoluble in water rust does not form a protective coating over the metal surface. In fact almost the reverse occurs; the rust coating is uneven, flaky and acts as a moisture trap. This means that the rate of corrosion will greatly increase when rust is present. The metal surface will become pitted due to the uneven corrosion and this acts as a further moisture trap. Plainly rust is a menace and must be dealt with immediately it is found or the metal will become so corroded that the part will have to be replaced.

Materials which provoke Serious Corrosion

7. **Battery electrolytes.** Lead-acid batteries use strong sulphuric acid as the electrolyte. Alkaline and nickel-iron batteries use potassium hydroxide solution. Both electrolytes attack metals leaving them weakened and liable to atmospheric corrosion. Care should be taken to

avoid spillage from batteries and a suitable neutralizing agent should be readily available in case of accidents. Spilt sulphuric acid is neutralized with a 20% (by weight) solution of sodium bicarbonate. Spilt potassium hydroxide (other than in aircraft) is neutralized with a saturated solution of boric acid.

8. **Electrolyte spilt in aircraft.** The procedure given in AP 119A–0200–1C must be used when electrolyte is spilt in an aircraft. Basically this procedure is: wash—neutralize—wash—check for neutral with BDH universal indicating paper. On aircraft the neutralizing agent for potassium hydroxide is 5% chromic acid solution.

9. **Mercury.** Mercury is an extremely active source of corrosion and is also extremely poisonous. When handling instruments containing mercury great care must be taken to avoid spillage. The safety precautions laid down in AP3158 Vol 2 must be strictly observed. If mercury is spilt in an aircraft the procedure in AP119A–0200–1C is to be applied.

10. **Organic chemicals.** Many organic chemicals, including hydraulic oil, will dissolve synthetic paints and cellulose finishes. This leaves the metal surface unprotected and enables corrosion to start. If any of these chemicals are spilled the trade NCO must be informed so that the correct procedures for making good the protective finish can be applied without delay.

Common Protective Coatings

11. **Noble metals.** Electro-plating of parts with the noble metals is quite common in electrical equipments. If a good surface to surface contact is required between two metal components of small surface area it is essential that the surfaces remain clean. Any corrosion could impair the electrical connection to such an extent as to render the circuit unserviceable. This is particularly important in miniature plugs and sockets, relays and switches and their contact surfaces are quite often gold plated. Another important use is at microwave frequencies where currents travel along the surface of a conductor (skin effect). Many waveguide components are made from aluminium alloys to conserve weight. As aluminium oxide coatings will not conduct they must not be allowed to form and the conducting surfaces are usually silver plated.

12. **Other metal plating.** It is quite common for components to be plated with a more electro-positive metal. When corrosion occurs the plating is attacked in preference to the component; this can be detected and the component changed before failure occurs. If two metals well separated in the electrochemical table must be in contact the least positive metal is often plated with a third metal from an intermediate position to reduce the rate of galvanic action. An example is where aluminium cables must be fitted to copper or brass terminals. Special copper lugs are used, plated with either tin or nickel and then with cadmium so that the final junction is between cadmium and aluminium. This junction is nowhere near as active as copper/aluminium and corrosion of the aluminium is almost entirely eliminated. Steel bolts for use with aluminium alloy components are normally cadmium plated for the same reason.

13. **Chemical treatment.** Aluminium alloys and magnesium alloys which are likely to be exposed to humid conditions are often *chromated.* This treatment involves boiling the parts in a chromic acid solution so that a close-fitting protective skin of chromate salt is formed on the metal surface. Ferrous metals can be treated in a bath of acid phosphate solution to form a similar skin of metallic phosphate. These treatments alone are not sufficient protection and the treated parts are normally sealed and protected by painting.

14. **Paints.** The purpose of paints is to prevent the access of water to the metal surface. Cellulose finish, enamels and plastic coatings all serve the same purpose and a wide variety of special finishes are in service use. An example is the plastic coating applied to printed circuit boards to protect the very thin copper conducting strips. After any repairs to a circuit this coating must always be made good. Care must be taken to avoid damage to any finished surface, and any damage found should be reported to the trade NCO so that the correct remedial action can be taken.

15. **Lubricants.** When parts of metal assemblies are required to rotate or where ease of movement between two parts is essential the coatings mentioned above cannot be used. To reduce friction the metal parts are left clean and may be polished. To protect these surfaces from corrosion, moist air and water are excluded by a film of lubricant such as oil or silicone grease. The only precaution needed with this kind of protection is to ensure that an adequate supply of fresh lubricant is *always* present at the surfaces.

16. **Desiccants.** In many totally enclosed assemblies, such as electronic equipments, metal parts must be clean for reasons of conductivity. To protect them from corrosion, desiccators containing silica gel are used. These desiccators attract the available water vapour and keep the air inside the equipment dry. Desiccators must be checked regularly to ensure that they are serviceable and should be reactivated in cases of doubt. Equipment which is packed for storage or transit is normally packaged with several bags of silica gel desiccant.

Care of Protective Coatings

17. A protective coating—whether it is an electroplating, an oxide film, or merely a coat of paint—will, as long as it remains intact, adequately protect a metal against surface corrosion. Unfortunately, applying a protective coating is one thing; trying to maintain it in all sorts of working conditions is like trying to go through life without falling down and grazing a knee. Nevertheless, every possible precaution must be taken to preserve this protective barrier (Fig. 1).

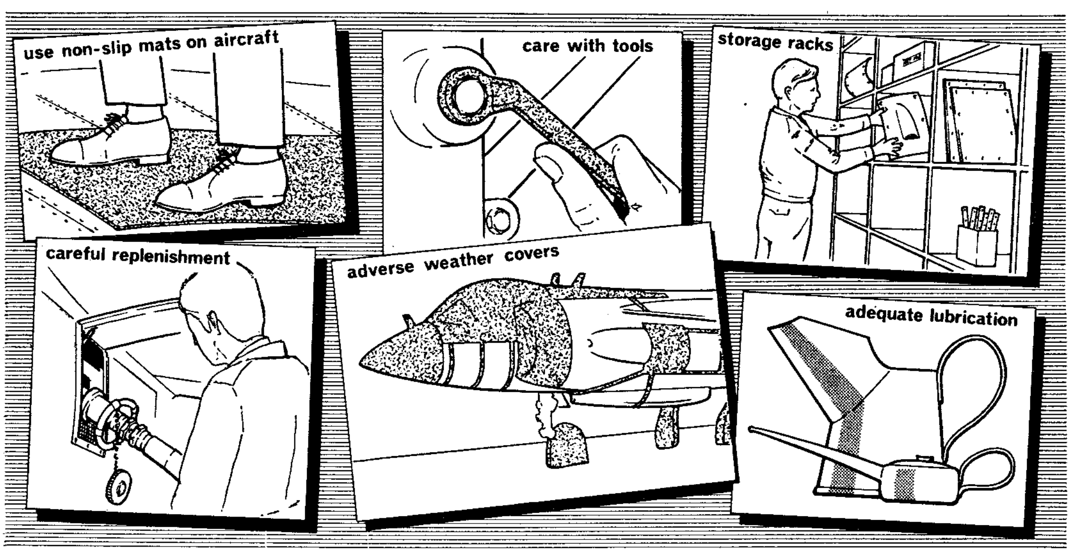

Fig. 1 Care of protective coatings

In practical terms this means:

- wearing the correct footwear if you have to move about on painted surfaces, and using special non-slip rubber mats where necessary.
- being less hasty when dismantling and assembling equipment to avoid damage to the metal surface when using spanners, screwdrivers and similar hardened tools.
- placing removed access panels and cowlings in their proper stowage racks where they cannot be kicked, trodden upon, driven over, or otherwise damaged.
- exercising care when making replenishment connections between aircraft and support equipment.
- the use of protective covers, guards, and bungs in adverse weather conditions.
- the careful lubrication of moving parts.

18. A range of mineral oils, greases, and temporary protectives are supplied to give first aid to any protective coating which may deteriorate or become damaged. They are also used to give additional protection to painted surfaces, to give temporary protection to mechanical moving parts and certain unpainted items, and for the preservation of equipment in storage. These protectives are applied to surfaces which have been cleaned and thoroughly dried and are applied with a brush, by a spray, or by dipping. Some of the temporary protectives frequently used in the RAF are:

- **Protective PX-1.** This is a lanolin and white spirit mixture used for the short-term preservation of mechanical parts. It is a greenish-black liquid which can be put on with a brush, a spray, or by dipping the article in the liquid. When the white spirit in the mixture evaporates it leaves a thin, soft protective cover over the part.
- **Protective PX-3.** This is a lanolin-resin solution pigmented with zinc chromate. Two coats of PX-3 will give good protection to metals that are otherwise unprotected or only lightly protected. It is applied with a brush or a spray; when applied as a spray the operator *must wear a face mask* to avoid inhaling the poisonous zinc chromate content.
- **Protective PX-7.** PX-7 is a soft petroleum jelly similar to vaseline. It is used for protecting battery terminals and certain torpedo mechanisms.
- **Protective PX-9.** This is a lanolin-resin solution containing a red dye. It is used for the preservation in store of engine parts, weapon parts, and a wide range of tools.
- **Protective PX-10 & PX-24.** These are water-displacing fluids which are commonly used for wiping down aircraft metal surfaces after cleaning. The oily fluid has an extremely low surface tension and high capillary action and is able to drive itself under any water droplets and physically lift them like a wedge. This protective has an effective life of about four weeks.

Detection of Corrosion

19. Corrosion is an insidious enemy that never gives up. Despite the preventive measures taken to contain it, it still succeeds in producing many unwelcome surprises. Although corrosion cannot be eliminated, the key to living with it is early detection and swift rectification. If you notice a damp spot, a discoloured area, blistered or cracked paint, loose rivets, or a powdery deposit—report it immediately. ALL CORROSION IS POTENTIALLY DANGEROUS AND MUST BE EXAMINED BY A TRADE NCO. ONLY HE CAN DECIDE WHETHER OR NOT THE CORROSION CAN BE RECTIFIED AND, IF SO, WHAT METHOD IS TO BE USED.

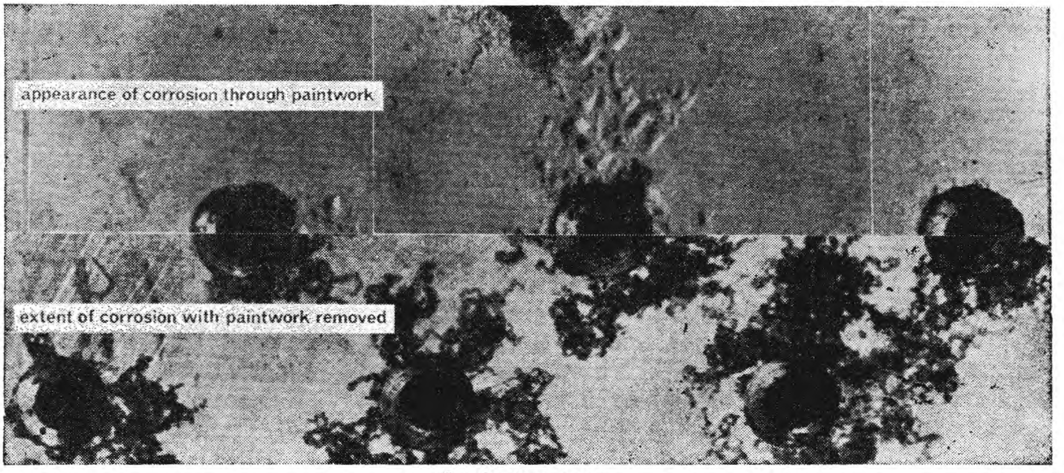

Fig. 2 Corrosion

Treatment of Light Corrosion

20. The treatment of corrosion is dealt with in AP119A–0200–1 which also gives details of the various chemicals and finishes required. In general a complete treatment requires the following stages:

a. Cleaning the affected area, often by use of a degreasing solution.

b. Stripping the paint or other protective finish from the area and its immediate surrounds.

c. Removal of all traces of the corrosion products.

d. Neutralising of all remains and any cleaning solution left in pits or crevices.

e. Restoration of any surface protective film if this is possible.

f. The replacement of the paint or other protective finish with the least possible delay.

21. **Copper alloys.** Copper based alloys have a relatively high resistance to corrosion under normal conditions. Any verdigris which does form can be easily removed with mild abrasive cleaning carried out with a rag and suitable metal polish.

22. **Ferrous metals.** Rust is best removed by mechanical abrasion. Emery cloth, wire brushes, steel wool and small power buffers are all acceptable except on highly stressed parts. When the parts are clean and dry the specified protective finish should be applied without delay.

23. **Light alloys.** Abrasives and steel wool *must not be used* on the light alloys as they damage the basic protective film on the metal surface. For details of the chemical treatments required see AP119A–0200–1.

SECTION 2

SAFETY PRECAUTIONS AND AIRFIELD PRACTICES

CHAPTER 1

FIRE AND FIRE EXTINGUISHERS

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Introduction

1. Combustion takes place when a fuel combines chemically with oxygen causing a rapid rise in temperature. In order that the fuel can combine readily with oxygen it must be either in a gaseous state or be converted into gas by the application of heat. The amount of heat required varies according to the type of fuel involved, as does the amount of heat produced during combustion. Among the materials that produce considerable heat when burned, and which require little heat to become gases, are explosives; so rapid is their combustion it is almost impossible to control.

Fire Prevention

2. Fire prevention is everybody's business and all persons concerned in handling and servicing aircraft should be constantly aware of their responsibilities in this respect. The hazard of fire in aircraft can only be reduced by efficient servicing methods and observance of the fire regulations which are displayed in all RAF workshops and servicing bays. All precautions must be backed by the ability to minimize the effects of a fire by prompt and effective use of first aid fire-fighting appliances. A detailed account of fire regulations is outside the scope of these notes, but the following points have a general application:

a. **Flammable liquids.** Aircraft fuel and lubricants, hydraulic oils, de-icing fluid, and kerosene are common fluids which are easily ignited. Any spillage or leakage of fuel must be investigated and cleaned up immediately. The risk of fire is particularly high during refuelling or defuelling aircraft, when there is a danger of the flammable fuel vapour being ignited by a spark caused by static electricity discharging to earth.

b. **Engines.** Electrical servicing trolleys, air compressors, and other engine-driven equipment should not be operated very near to aircraft. The engines of such equipment must be stopped before work begins on the fuel system of an adjacent aircraft. They must not be restarted until fuelling is completed and the hoses disconnected.

c. **Oxygen systems.** Oxygen is normally stored in aircraft in high pressure cylinders. Any leakage from these cylinders, or any part of an oxygen system, will add to the ferocity of a fire. Oil and grease must not be used on oxygen equipment because of the risk of explosion. The regulations regarding the storage, installation and servicing of oxygen cylinders must be strictly observed.

d. **Explosives.** Buildings containing explosives have a specific fire class symbol prominently displayed on or near the building. Each symbol consists of a black geometrical shape on a yellow square. In the centre of the symbol is the fire class number. Details of these symbols, and their meanings are illustrated in Poster No. 76 (Markings on Buildings containing Explosives). They must be fully understood by all persons who work in, or near, explosives areas.

e. **Cleaning materials.** Waste petroleum, oils, and lubricants from drip trays and degreasing tanks must not be allowed to accumulate in hangars or workshops. They should be removed at the end of each day's work and destroyed in an authorized disposal pit or an incinerator. Any rags impregnated with these fluids, paint, or wax, must be kept in a metal container fitted with a lid when not actually in use and destroyed in the same manner.

f. **Naked lights.** Smoking is not permitted in the vicinity of aircraft, hangars, fuel installations, or explosive areas. Matches and cigarette lighters must not be carried when working on aircraft or explosives.

g. **Electrical equipment.** All portable electric tools must be properly earthed. Flexible cables should be inspected frequently to ensure that the insulation is undamaged. Portable electric lighting equipment must be of the safety type with wire cages fitted over the bulbs to prevent accidental breakage.

Fire Extinguishing Agents

3. As fires are caused by chemical combination of fuel and oxygen from the atmosphere it naturally follows that a fire can be extinguished by separating the fuel and oxygen. A fire can also be extinguished if the temperature of the burning mass can be lowered sufficiently to prevent gases being released from the fuel. For electrical fires it is of vital importance that a non-conducting extinguishing agent is used.

4. **Water.** Water is an efficient extinguishing agent provided it can be applied in sufficient quantity to greatly reduce the temperature of the fire. It is dangerous to use water against fires involving electricity or flammable liquids. The density of water is greater than that of most flammable liquids, including aircraft fuels and lubricants, and the burning mass would float on the water and extend the area of the fire.

5. **Foam.** Water can be made to float upon the surface of fuels and oil by reducing its density to below that of the burning liquid. A suitable foaming agent is added to the water which is then aerated, that is, charged with air or gas. Two types of foam are in general use for fire-fighting.

a. **Chemical foam.** Aeration of the water occurs as the result of a chemical reaction when acid is allowed to mix with a solution of a suitable alkali; each bubble of foam is filled with carbon dioxide gas (CO_2). This gas will not support combustion and is heavier than air and as a result the close-textured blanket of gas-filled bubbles displaces the oxygen in the fire zone and smothers the fire.

b. **Mechanical foam.** Water containing a foaming agent can also be converted to foam by mechanical agitation, but in this case, the bubbles are filled with air. The blanketing effect of mechanical foam is less than that of a chemical foam because of the presence of air in the bubbles, and a much greater mass of foam is required to achieve comparable results.

6. **Dry Powder.** The powder, usually potassium sulphate, is expelled from a container under gas pressure. The discharge forms a dense cloud of powder which occupies the space immediately above the surface of the fire, replacing the oxygen available for combustion. In addition, the powder particles themselves rapidly absorb heat and reduce the temperature in the fire zone. Dry powder is primarily intended for use against liquid fuel fires.

7. **Inert gases.** Mention has already been made of the blanketing effects of carbon dioxide gas in chemical foam. Any inert gas, provided it is heavier than air, will produce similar results when applied to the seat of a fire. Inert gas is particularly useful for electrical fires and fires in aircraft. Some extinguishers are supplied in container form with the gas under pressure; others use vaporizing liquids which are transformed into inert gases when sprayed into the fire zone.

First Aid Fire-fighting Appliances

8. A considerable number of the fires which occur are discovered early enough to be promptly put out by the use of first aid fire-fighting appliances. These are extinguishers which are provided in buildings, and servicing areas, for instant use by persons in the vicinity of an outbreak of fire. Although they vary in size and content, all the appliances are portable and simple to operate. The cylinders of these fire extinguishers are painted in accordance with a national colour code which is used to identify their contents.

9. **Soda acid.** This extinguisher is a handy method of storing water for immediate use under pressure (Fig 1). It is used to cool a burning mass to a point below its ignition temperature. It must not be used on liquid fires or those involving electricity. Its use is confined to solid material fires such as wood, paper, or clothing. The extinguisher consists of a steel cylinder, painted red, and fitted with a brass head cap which holds the operating plunger. Underneath the cap is a cage containing a sealed glass bottle of sulphuric acid, mounted immediately below the operating plunger. The cylinder contains an alkaline charge of bicarbonate of soda dissolved in water.

Operation. Remove the safety clip and strike the plunger a hard blow. This breaks the glass bottle and allows the acid to mix with the alkali solution. A chemical action produces CO_2 gas in sufficient quantity to raise the pressure in the cylinder and force the liquid out. The jet of water is directed to the seat of the fire from as short a distance as possible.

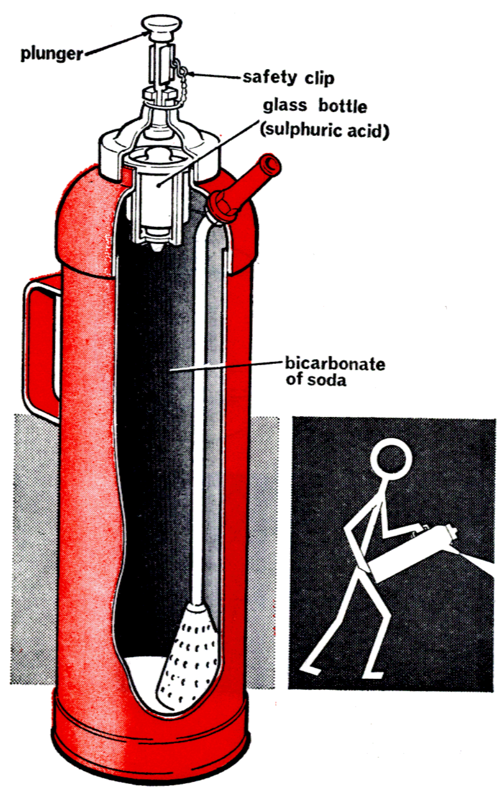

Fig. 1. Soda acid extinguisher

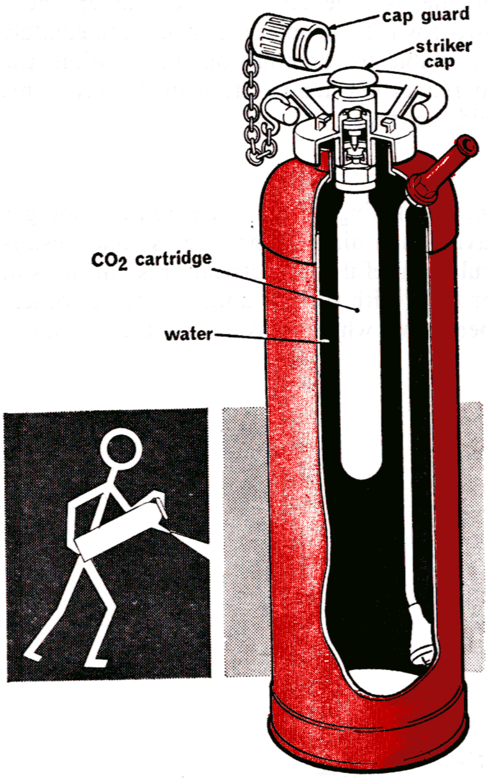

Fig. 2. Water/gas extinguisher

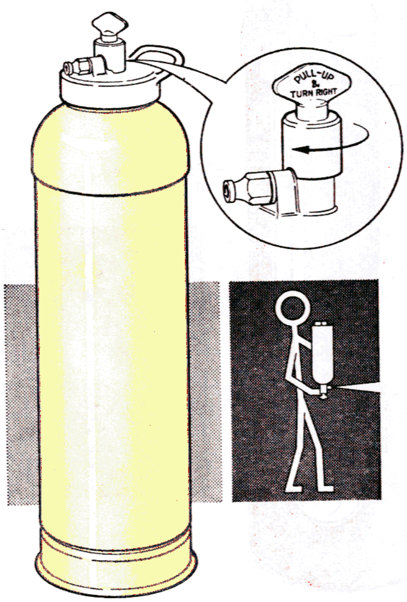

Fig 3. 2 gallon foam extinguisher

10. **Water/gas.** Soda acid extinguishers are now obsolescent and are being replaced as they become unserviceable by Water/gas extinguishers (Fig 2). The water in this improved type of extinguisher is forced out by the operation of a CO_2 cartridge fitted inside the cylinder. Gas is released from the cartridge when the striker cap in the headpiece is given a sharp blow. A guard is fitted to prevent accidental discharge.

11. **Chemical foam.** The 2 gallon foam extinguisher is primarily intended for use on burning liquids but may be effectively used against solid material fires. The cylindrical body of the extinguisher contains an alkaline charge of bicarbonate of soda and a foaming compound (Fig 3). Inside the cylinder an inner container holds an acid charge of aluminium sulphate and water. A sealing mechanism in the headpiece of the extinguisher prevents the two solutions mixing when the cylinder is upright.

Operation. Pull up the key handle and turn it clockwise. Place a finger over the outlet nozzle, invert the extinguisher using the handgrip across the base, and shake vigorously before releasing the jet. The two solutions mix, and foam containing CO_2 gas, spurts from the nozzle. The volume of foam produced is enough to cover 10 square feet when applied evenly over the fire. This is the only type of extinguisher which is operated by turning upside down.

12. **CO_2 trolley.** This mobile appliance is provided primarily for the protection of parked aircraft and is specially designed for dealing with outbreaks of fire during engine-starting. It must always be available when engines are being started or run-up on the ground. Fig 4 shows the trolley which carries two cylinders each containing 10 lb of liquified CO_2. Each cylinder is fitted with a disc-closure valve coupled through a manifold to a length of high pressure hose and a telescopic applicator with an insulated handle. To prevent 'cold burns' the applicator must be held by the insulated handle.

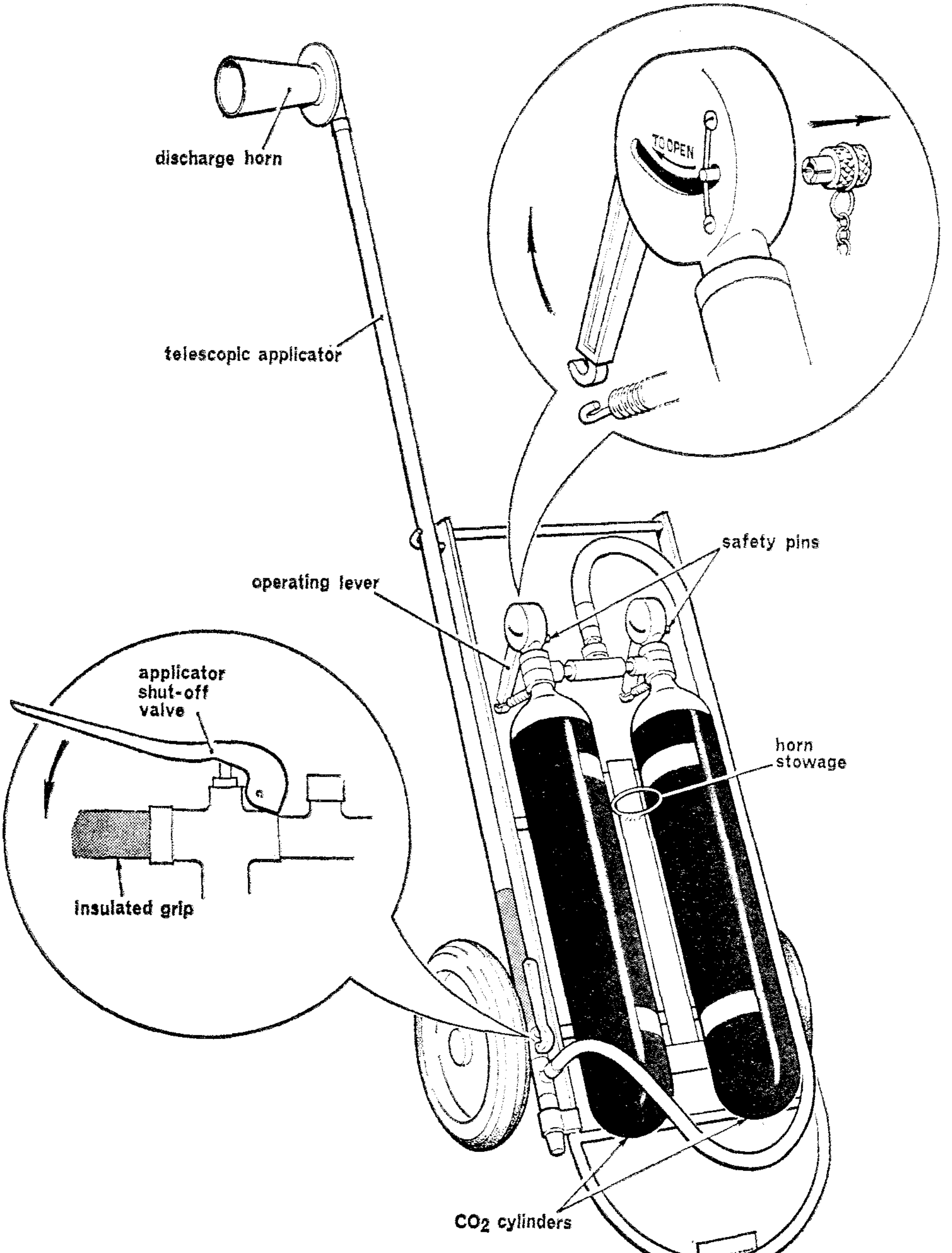

Fig 4. CO_2 trolley (Flight Line type)

Operation. Carbon dioxide is released from each cylinder by removing the safety pin from the operating head and pulling up the operating lever. The telescopic applicator extends automatically as soon as the shut-off valve on the applicator is squeezed. The discharge of CO_2 is then controlled by operating the shut-off valve as required. Should the fire be extinguished before a cylinder is empty the remaining contents must be discharged and a fully-charged replacement cylinder fitted.

of V/STOL aircraft at forward airstrips where it is necessary to provide equipment which can be delivered easily by helicopters or light vehicles. The extinguisher consists of a cylinder containing about one gallon of BCF under pressure. The head of the cylinder has two handles: the lower handle is for carrying the extinguisher whilst the upper handle is used to control the discharge of the cylinder's contents. A safety pin is normally inserted in the control handle so that the extinguisher cannot be discharged accidentally. When the extinguisher is operated the BCF is conveyed from the cylinder through a short flexible tube to a telescopic applicator.

Operation. Remove the safety pin and squeeze both the carrying and control handles together. If required, the handles can be kept together by using the 'D' ring fitted to the carrying handle. Direct the nozzle of the applicator into the affected engine compartment.

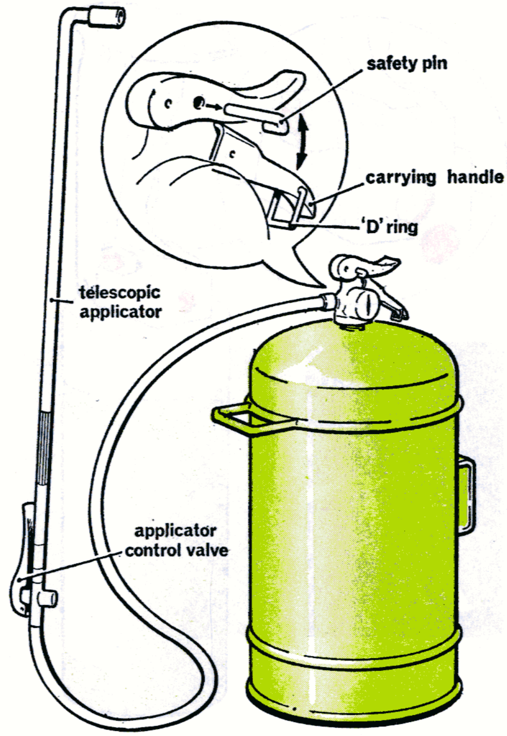

Fig 7. 16 lb BCF extinguisher

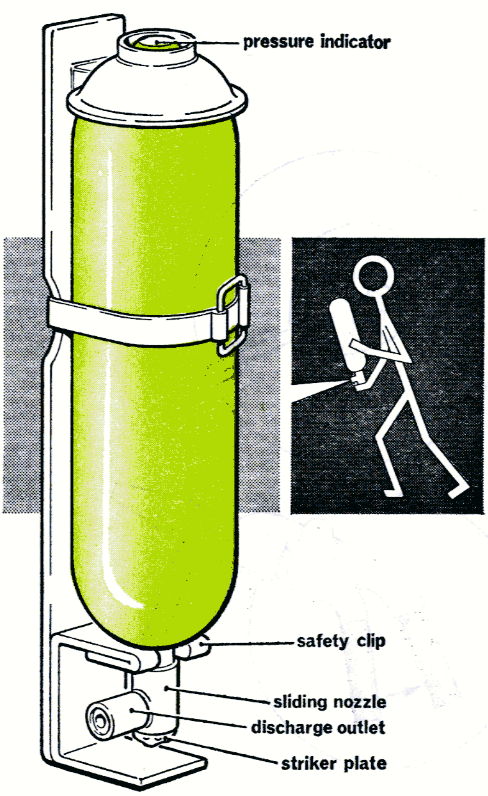

Fig 8. 3 lb BCF extinguisher

16. **3 lb BCF.** This extinguisher is provided for the suppression of fire in delicate electric or electronic apparatus. It consists of a lightweight cylinder containing BCF which is an extinguishing agent that does not conduct electricity or leave behind a harmful residue. BCF is also effective against small oil and liquid fires and is provided as an accessory for vehicles and engine-powered ground equipment trolleys. The fumes from BCF are much less toxic than those given off by other vaporizing liquids. A white disc at the top of the cylinder is a pressure indicator; it should be almost impossible to depress it when the extinguisher is fully charged. The discharge outlet at the bottom of the cylinder is sealed by a fragile disc which is broken when the sliding nozzle assembly is given a sharp blow. A safety clip fitted above the nozzle prevents accidental discharge during transit. This clip is removed before the extinguisher is mounted in its bracket.

Operation. Remove the extinguisher from its

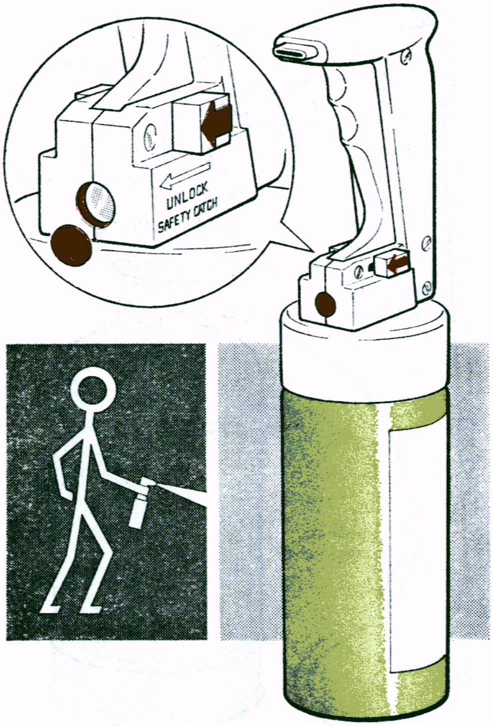

Fig 9. 1·5 kg BCF extinguisher

mounting bracket and give the striker plate a sharp blow. Since the discharge of BCF is immediate, the user must be in position to attack the fire as soon as the striker plate is struck.

17. **1·5, 2·5, and 3·5kg BCF.** This improved type of BCF extinguisher consists of a plastic operating handle and a detachable container which can be of 1·5, 2·5, or 3·5kg capacity.

Operation. Unlock the safety catch by pushing it forward as directed by the red arrow. Holding the extinguisher upright, aim at the base of the fire and squeeze the operating lever. The action of squeezing the lever will cause the vaporizing liquid to spurt from the nozzle built into the handle; the same action breaks a red plastic disc at the base of the handle thus indicating that the extinguisher has been used.

To recharge after use, squeeze the operating lever and, when the container is completely ex-

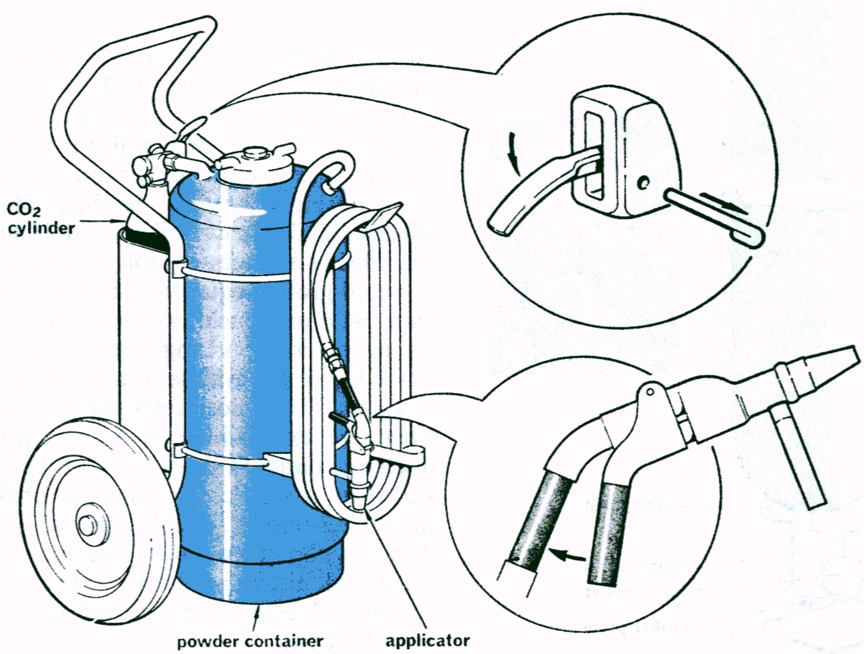

Fig 10. Dry powder trolley

hausted, unscrew it from the handle. Reset the safety catch and replace the broken indicator disc with a new disc. Screw on a new BCF container.

18. **Dry powder trolley.** The 150 lb dry powder trolley is provided to supplement the foam extinguishers at POL compounds and fuel installations. The trolley consists of a cylindrical powder container coupled to a small CO_2 gas cylinder. A discharge tube from the powder container is connected to a length of high pressure hose with an applicator at the delivery end. The applicator has a trigger-operated valve which, when open, projects the gas/powder mixture in the form of a forceful 'jet' which then expands into a dense cloud of fine powder particles.

Operation. Remove the safety pin from the CO_2 cylinder head and push down the lever. This pressurizes the powder container and drives the powder as far as the valve in the applicator. Remove the applicator from its socket and uncoil the hose from the trolley. The discharge of the gas/powder mixture is then controlled by the applicator valve.

Fire Protection in Aircraft

19. The majority of fires which occur in aircraft on the ground are associated in some way with the aircraft engines and its fuel system. It follows, therefore, that the fire protective measures in aircraft are mainly concerned with these major danger zones. The engine bays are usually divided into compartments by vertical bulkheads made of titanium or stainless steel. These act as fire walls and help to resist the spread of fire. Each of these fire zones has its own access panel through which an extinguisher can be effectively discharged; these panels are prominently marked either by being painted wholly red or in red outline with 'Fire Access' stencilled on them or nearby. In the event of a fire enveloping the whole engine every advantage would be taken of other access points such as air intakes, exhaust outlets, and servicing panels.

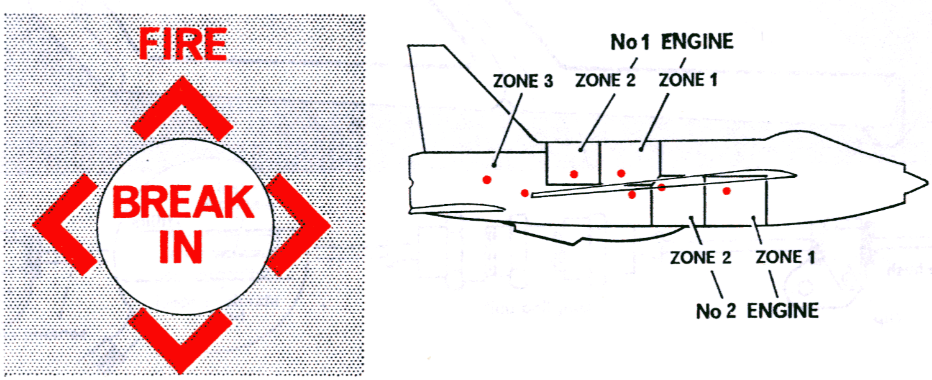

Fig 11. Fire zones and access panels

20. A fire warning system is installed in most modern aircraft and is normally coupled with an automatic method of extinguishing fires that occur in danger zones such as engine bays, fuel tank compartments, and bomb bays. Warning of fire is given by a set of indicator lamps in the aircraft cockpit. Each lamp is electrically connected to a network of detectors situated in the likely fire zones. Each detector is a heat- or flame-sensitive element which ensures that when the ambient temperature reaches a point consistent with an outbreak of fire, an electric circuit is completed to the appropriate fire warning lamp.

21. The warning systems installed in RAF aircraft are mainly Firewire detectors. This system consists of sensing elements, secured by special clips and fittings, which are routed through the potential fire zones. The sensing element is a stainless steel capillary tube containing a central wire electrode which is separated from the wall of the tube by a special filling material. The electrical resistance of the filling material decreases with increase in temperature and rises as the temperature falls. When the temperature of the element reaches a critical value the current flow in the circuit becomes sufficient to operate an electric switch causing the warning lamp to light up. As the temperature falls in the fire zone, the switch is reset and the lamp goes out.

22. **Care of Firewire.** Firewire elements are extremely sensitive to mishandling. All persons working on aircraft should know where these elements are and how to treat them. Any kinking, flattening, or acute bending of the tube can lead to a false warning of fire and result in the pilot abandoning the aircraft unnecessarily. No attempt is to be made to reshape a distorted element. Moisture too, is an enemy of detector systems. New lengths of Firewire are provided with end sealing caps which must remain in place until immediately before installation.

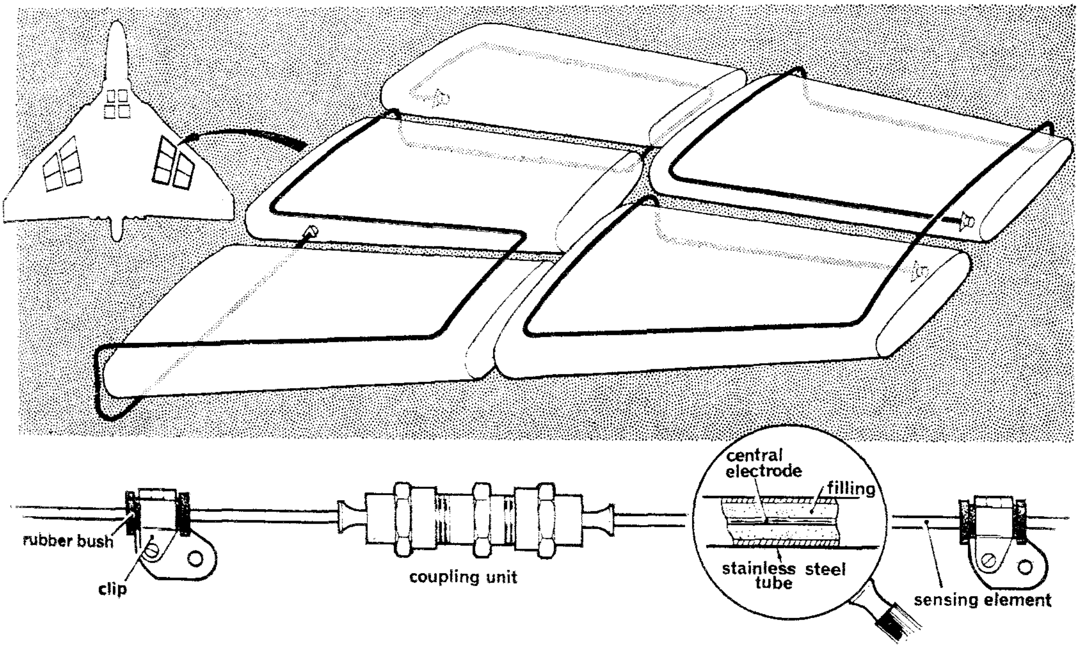

Fig. 12 Firewire detector system (fuel tanks)

23. **Automatic fire extinguishers.** The fire extinguishing system consists of a number of automatic fire extinguishers which, when operated, supply an extinguishing agent under pressure through a system of pipes to the danger zones. In response to a fire warning the pilot, or co-pilot, can press the appropriate push-button in the cockpit which will operate the automatic fire extinguisher and spray the affected compartment. When the fire is under control and the temperature in the fire zone has fallen to normal, the warning is automatically cancelled. In the event

of a crash-landing the extinguishers are operated by inertia switches. Each extinguisher contains methyl bromide in liquid form, kept under pressure by nitrogen gas. The extinguishers are coloured peacock blue and pertinent details are marked in yellow on the cylinder. When discharged from the cylinder the jet of methyl bromide quickly vaporizes forming a blanket of inert gas which displaces the atmospheric oxygen and smothers the fire.

Operation. The methyl bromide is released from the cylinder by the removal of a plug by an electrically-fired cartridge unit. The force of the explosion also causes a metal indicator to protrude from the headpiece of the extinguisher to show that it has been operated. The liquid methyl bromide then flows from the outlet through the pipe-line system to the spray nozzles. A more rapid discharge is obtained from dual-head extinguishers having two outlets and two cartridge units which are normally fired simultaneously.

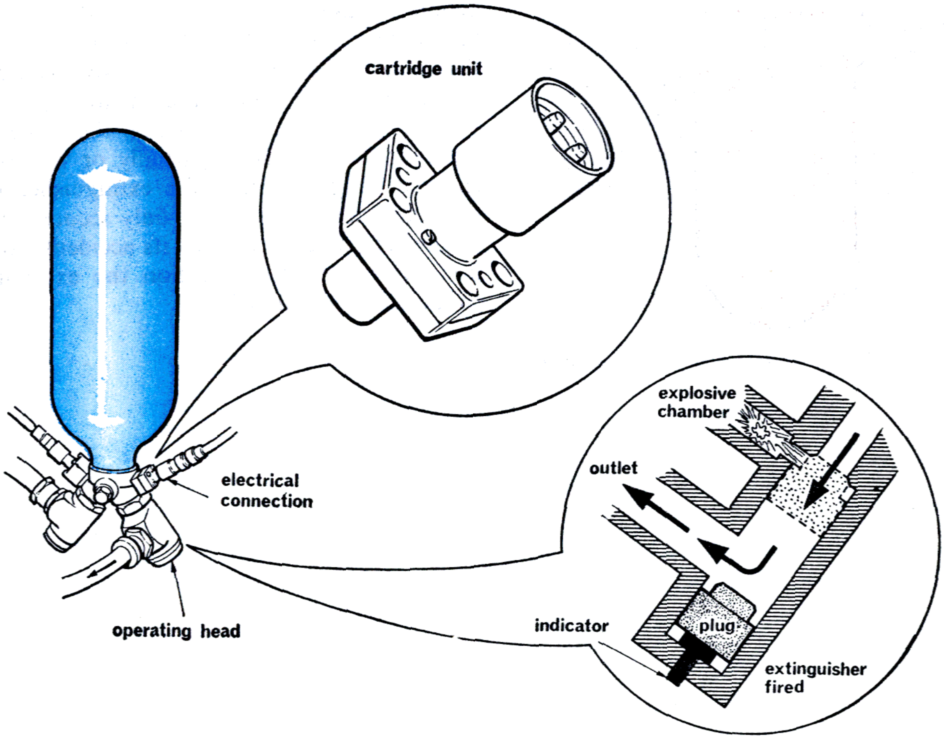

Fig 13. Aircraft automatic extinguisher

24. **Cartridge units.** The removable cartridge unit is a combined electric plug and explosive charge that is bolted to the headpiece of the extinguisher. Completion of the electric circuit to the plug assembly heats an internal fuse which ignites the explosive charge and fires the cartridge. Because it is an explosive device and susceptible to deterioration, the cartridge unit is given a definite 'life'. Stored in its polythene bag its life span is seven years: installed in an aircraft this is shortened to two years or a specified number of flying hours. Records of the 'lives' of cartridges are kept by the Unit Weapons Officer. The removal, replacement, and servicing of cartridges is the responsibility of the Weapons tradesman.

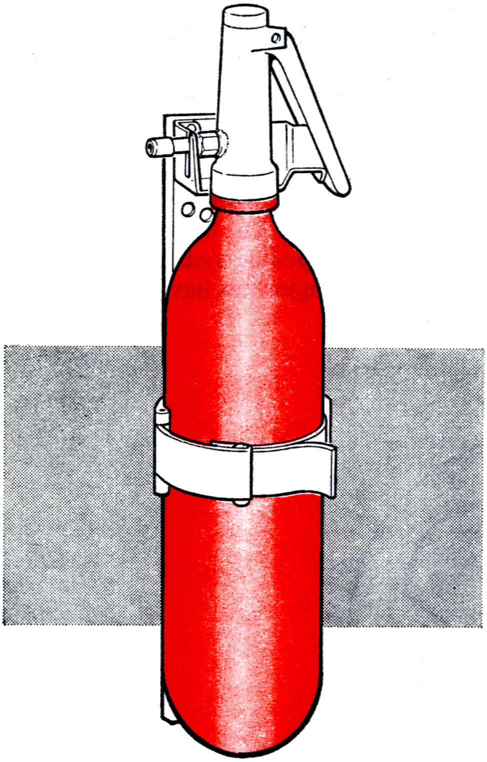

Fig 14. Aircraft extinguisher hand operated (BCF)

25. **Hand-operated extinguishers.** These extinguishers are used for combating fires in fuselage compartments and are conveniently stowed at each appropriate crew station. Similar extinguishers are included in the emergency equipment accessible from the outside of the fuselage: these are for rescue purposes, the stowage position being clearly indicated by the red fire extinguisher symbol.

26. The type of extinguisher currently installed in aircraft contains BCF. This extinguisher is operated with one hand simply by gripping the headpiece and squeezing the trigger lever. This action releases a powerful jet of vaporizing liquid that can be stopped at will by releasing the lever. This trigger action also causes an indicator pin to pierce the metal cap on the cylinder headpiece to show that the contents of the cylinder have been partially or wholly discharged. Fig 14 shows the extinguisher in its stowage bracket which not only secures the extinguisher but also prevents its accidental operation. For speedy recognition the extinguisher container is coloured RED.

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CHAPTER 2

ACCIDENT PREVENTION AND FIRST AID

List of Contents

Introduction

1. Safety regulations in force in the RAF are designed to prevent accidents and should be strictly obeyed, but an accident can still happen any time, anywhere. A minor accident can be worsened by the lack of attention shown to the casualty or by the misplaced efforts of an over-enthusiastic helper. Some knowledge of first aid is always an asset; the ability to perform artificial respiration is essential to ALL whose work involves the use of electricity. Remember the two "golden rules" of first aid:

a. Perform immediately only those actions necessary to save life or to prevent the emergency from worsening.

b. Send for medical aid as soon as possible.

2. **General rules of first aid.** If you are present at an accident:

a. Do not panic—act quietly yet quickly. Try to reassure the casualty—speak gently. Physical contact often helps—hold his hand.

b. Do not move an injured person—unless it is necessary to get him away from a source of danger such as fire, electricity or a structure liable to collapse and cause further injuries.

c. Stop any bleeding and treat for shock. Keep the patient warm, remove clothing only when necessary for the patient's comfort or to prevent bleeding.

d. Watch the patient all the time. Be ready to start artificial respiration immediately if breathing stops.

e. Keep spectators away and give the patient fresh air if possible.

Electric Shock

3. **Precautions.** Electricity strikes without warning; the only safeguards against it are to observe all safety regulations and to ensure that you and *all* your colleagues can perform artificial respiration. Safety regulations are published in AP 3158 Vol 2 but the following points should be borne in mind:

a. Safety interlocks on equipment should not be over-ridden unless it is necessary for servicing or adjustment purposes.

b. Two or more persons must be present at all times when work is being carried out on "live" equipment.

c. The person doing the work must stand on a rubber insulating mat and should work "one-handed" if at all possible.

4. **Treatment**

a. Switch off the current at once. If this is not possible the victim should be removed from contact by using any available insulator such as a broom. Be careful to avoid contact with live conductors, or the patient, with bare hands. Stand on a rubber mat while moving the patient from contact if this is possible.

b. START ARTIFICIAL RESPIRATION IMMEDIATELY. Speed is vital; any known method of respiration is better than a delay.

c. Loosen the patient's collar and any tight clothing *without interrupting the artificial respiration.*

d. If as a result of electric shock the patient is suffering from burns they should be covered with a sterile dressing if this can be done *without hindrance to the artificial respiration.*

e. Send for medical aid. Even after apparent recovery the victim should be seen by the medical officer as victims of electric shock sometimes suffer a relapse.

Artificial Respiration

5. If the brain is deprived of oxygen for four minutes irreversible changes take place in it; the aim of artificial respiration is to forestall these changes by the immediate oxygenation of the blood. Therefore, the importance of beginning artificial respiration AT ONCE and continuing it without interruption cannot be over-emphasized. All other treatments or considerations must be implemented only if they in no way interfere with the immediate, efficient and unremitting application of artificial respiration.

6. **Method.** The mouth to mouth method of artificial respiration, commonly called the "kiss of life", is the recommended method because of its ease of application and because the operator can tell when air has been forced into the victim's lungs. If the patient has jaw injuries, or no teeth, the mouth to nose method should be used. In both methods the victim should be laid on his back. (See Fig. 1).

Shock

7. This condition often results from accidents and is due to loss of blood, or blood plasma, which may be internal and therefore difficult to detect visually. It is a serious condition and is often characterised by:

a. faintness or giddiness.

b. pallor.

c. cold, clammy skin.

d. feeling of sickness, or vomiting.

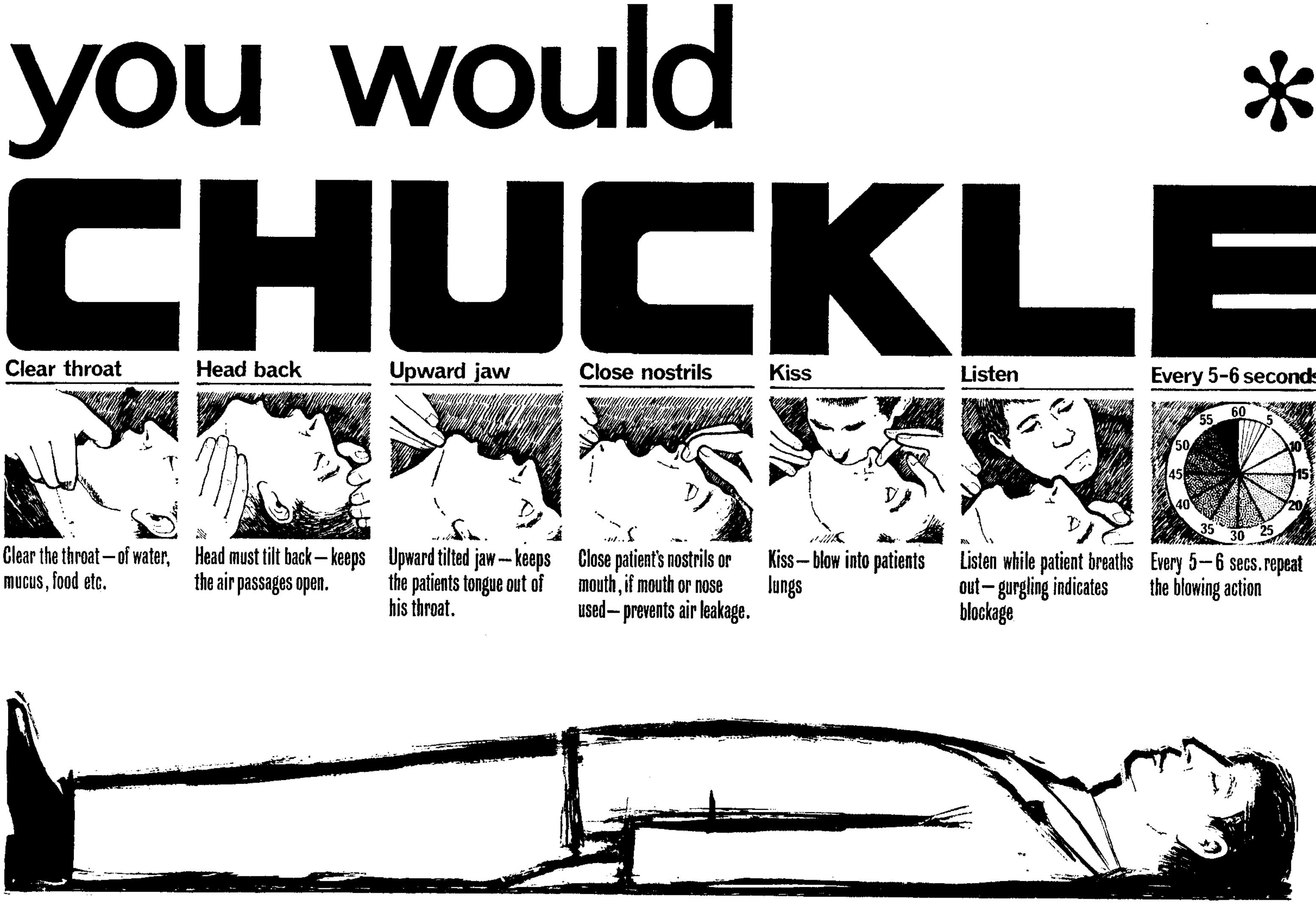
In some cases the patient may lose consciousness. Shock is always aggravated by pain and is a common cause of death following severe injuries or extensive burns.

8. **Treatment.** Severe cases require hospitalisation and the medical officer (MO) should always be called as soon as possible:

a. Reassure the casualty.

b. Lay the casualty on his back with the head low and turned to one side. If there is interference with breathing or the patient has vomited lay him in the three-quarters prone position (see Fig. 2).

c. Loosen clothing at the neck, chest and waist.



AL1, Feb, 1967

Fig. 1. Artificial respiration

d. Wrap him in a blanket, rug or greatcoat.

e. If he complains of thirst sips of warm sweet tea may be given unless the patient's injuries are such that an anaesthetic may be required. Do not give the patient any alcohol.

f. Do not apply heat or friction to the limbs; hot water bottles should not be used.

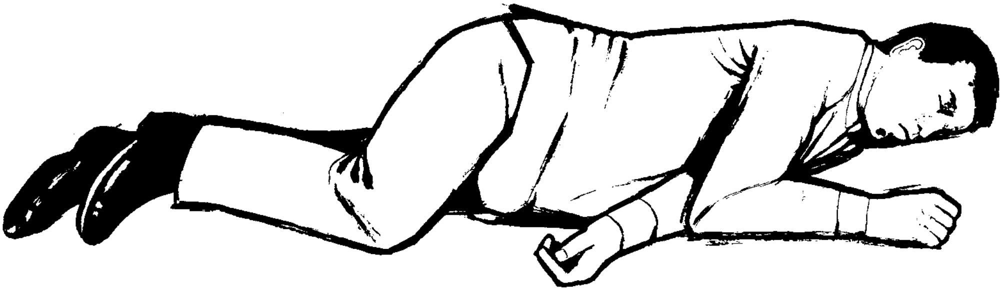


Fig. 2. The three quarters prone position

Burns

9. A burn is an injury caused by dry heat or chemicals as a result of which the skin goes red and blisters may form. In severe cases the skin may be destroyed and the tissues underneath damaged. Burns are always extremely painful and are usually accompanied by shock due to loss of plasma into the tissues. They are commonly caused by:

a. Dry heat, such as fire or contact with hot metals.

b. Friction, such as contact with a moving wheel or rope.

c. High tension electricity, lightning strikes, or high power r.f. fields.

d. Severe cold e.g. contact with liquid oxygen, dry ice etc.

e. Corrosive chemicals such as the acid or alkaline electrolyte from storage batteries.

The danger from a burn increases with its surface area and medical aid should be obtained without delay in all cases.

10. **Treatment for chemical burns.** Always take reasonable precautions against burning by contact with contaminated clothing, particularly if strong sulphuric acid (used in most batteries) is involved.

a. Flush the burn thoroughly AT ONCE using plenty of water—warm if possible.

b. Eyes should be held open and flushed for at least 15 minutes. The MO should be called to all eye injuries.

c. Contaminated clothes should be removed while flushing burns.

d. If the burn is serious flushing should be continued until the MO arrives.

11. **Treatment for general burns**

a. Avoid handling the affected area any more than is necessary, as it will be sterilised by the heat.

b. Do not apply lotions of any kind.

c. Do not break blisters or remove burned clothing.

d. Cover the area (including burned clothing) with a dry sterile dressing if possible. If a sterile dressing is not available clean lint or freshly laundered linen may be used.

e. Bandage firmly unless blisters are present, in which case the dressing should be held in place or fastened with a *lightly* tied bandage.

f. In a minor case give large quantities of fluid, preferably warm, weak, sweet tea. In serious cases when an anaesthetic may be required fluids should not be given.

g. Treat for shock if necessary.

Bleeding

12. Severe loss of blood will cause the patient to go into a shocked condition, therefore bleeding should be stopped as soon as possible.

a. If glass or a weapon is deeply embedded in the wound it should *not* be removed. A pad should be applied to both sides of the wound.

b. In other instances, apply a clean dressing or pad to the wound and press it there.

c. If bleeding is from a limb, raise the limb while maintaining pressure on the dressing.

d. If blood is vomited or if the injury is to the abdomen do not give fluids to the patient.

e. Treat for shock if necessary.

Radioactivity

13. Some of the valves used in modern equipments contain radioactive materials and dangerous radiations are given off by some modern inspection techniques which use X-rays. Serious injury to health can be caused by:

a. Contamination of wounds by fragments of broken radioactive valves.

b. Effects of the vapour released from broken valves either by inhaling fumes or eating food contaminated by this vapour or dust from the immediate area.

c. Exposure to radiation due to incorrect use of X-ray equipment.

All safety regulations (AP 3158 Vol 2) must be obeyed, and all radioactive items handled with extreme care.

14. **Treatment**

a. Cuts or abrasions *must* be reported to the MO who must be told that the injury was sustained while in contact with radioactive material.

b. If the MO is not available:

(1) Wash the wound with soap and large quantities of clean water.

(2) Stimulate mild bleeding by applying manual pressure around the wound.

Loss of Consciousness

15. The most common cause of loss of consciousness, when injuries are not involved, is by exposure to fumes from anaesthetic liquids. A large number of the chemicals used for degreasing or fire fighting have serious toxic effects when inhaled, such as CTC and methyl bromide. Always work with chemicals in a well ventilated place. Do not smoke, eat or drink in any area where chemicals are used.

16. **Treatment**

a. Ensure an adequate supply of fresh air.

b. Lay the patient down with his head low—no pillows.

c. Remove false teeth and ensure the patient's air passages stay open. Be ready to give artificial respiration if breathing stops.

d. Loosen tight clothing at the neck, chest and waist.

e. Bathe the patient's face with cool water. Do not attempt to give fluids to an unconscious or semiconscious patient—they may choke.

f. If a heart attack is suspected or the cause of unconsciousness is not apparent the MO should be called as soon as possible.

Broken Bones

17. Accidents resulting in broken bones are commonly caused by slipping on an oil or grease patch on a workshop or hangar floor. The floor should be kept clean at all times and should not be used as a storage place for objects which could cause someone to trip and fall. If heavy objects, such as generators, are being handled the proper lifting tackle must be used. Do not walk under suspended loads or place your limbs in a position where a slipped load could cause an injury.

18. The treatment of broken bones should always be carried out by medical personnel, as an injury may be aggravated by well meaning but misplaced attention. The following rules apply:

a. Do not attempt to straighten the injured part.

b. If the patient *must* be moved for his own safety, the injured part should be supported.

c. Reassure the patient.

d. Do not give the patient fluids as an anaesthetic will almost certainly be required.

CHAPTER 3

SAFETY AND RESCUE

List of Contents

Flight Safety

1. The purpose of flight safety is to contribute to the Royal Air Force task by reducing to a minimum human and material losses due to aircraft accidents.

2. **Effects of accidents.** Modernization of the RAF has greatly increased the effect of an accident on operational efficiency. A nuclear weapon, carried by one aircraft, has more effect than the thousand-bomber raids of the last war. The aircraft required for the modern task are highly complex specialised machines and are extremely expensive, but the numbers needed are comparatively small. Because of the smaller number of aircraft in operational use accidental losses affect the ability of the RAF to fulfil its task efficiently. The main effects of accidents are:

a. Loss of life. Loss of human life cannot be calculated in terms of money. For a transport aircraft carrying a large number of passengers absolute safety standards are vital.

b. Loss of materials. The high cost of modern aircraft means that the repair of even minor damage has become very expensive. To this cost we must add those of the manpower and materials used for crash recovery and the cost of making good any property or lands damaged during the crash or the recovery.

c. Flying and servicing efficiency. The loss of an aircraft or aircrew means that a squadron flies at a reduced operational strength. Training a replacement aircrew to operational standards takes time and costs are high. If an aircraft needs repairs, skilled tradesmen have to be diverted from the servicing task for a considerable period of time. This could lower the normal standard of servicing efficiency.

d. Morale. In extreme cases accidents may result in a loss of confidence between the air and ground crews or between the aircrew and their aircraft. This loss of morale could cause careless flying or slipshod work and result in a further increase of accidents.

3. **Causes of accidents.** The main causes of aircraft accidents can be summarised under four main groups, *all* of which could be reduced by greater care on the part of the personnel concerned.

a. Pilot/aircrew error. About 35% of major accidents are caused by pilot error, a large proportion of these being due to disregard of regulations. As the speed and size of aircraft increases the possible margin of error is greatly reduced and the chances of an accident due to mishandling increase.

b. Natural, operational and medical (NOM) hazards. About 20% of accidents are caused by NOM hazards, the greatest single cause being jet engine failure after striking birds. Operational requirements may cause flying to take place in poor weather conditions or at low altitudes and may result in an accident. Accidents can be caused by pilots who fly with a cold or after dental treatment.

c. Technical defects. Failure of the aircraft structure or component parts during flight causes about 35% of the total accidents. These failures are usually due to design or manufacturing faults.

d. Servicing errors. About 10% of the total accidents are caused by errors on the part of the groundcrew. These errors are usually due to carelessness, lack of supervision or inaccurate technical recording.

4. **Prevention of accidents.** The 50% accidents caused by servicing errors or technical defects could be greatly reduced by a safety-conscious ground staff. Servicing errors can be almost entirely eliminated, and many technical defects can be found *before they reach a critical stage*. Good servicing has three vital ingredients:

a. Careful work. Concentrate on the job and make sure that all connectors, panels and equipments are properly secured. Always work from the AP or servicing schedule to ensure that no part of the operation is omitted. If there is any doubt at all about how a job should be done consult the appropriate trade NCO. All work should be carefully checked by an NCO before it is certified as completed satisfactorily.

b. Accurate documentation. All work must be accurately recorded and signed for as it is done. This ensures that any unfinished work can be safely completed by another tradesman. The phrase 'ground tested—found serviceable' should only be used after the most thorough checks have failed to reproduce the fault symptoms, and the system has been carefully examined for corrosion and security.

c. Observation. Anything which does not look, sound or smell normal should be reported to the NCO of the relevant trade. If the aircraft is already moving an emergency 'flash' call can be made to the controller to prevent take off. The things to look for during servicing include the following:

(1) Foreign objects—loose tools, swarf, rivets or mandrels, dirt.
(2) Damaged cables—chafed or frayed wiring or insulation damage caused by fluids.
(3) Faulty earthing—oxidation, corrosion or broken bonding leads.
(4) Water or other fluids—faulty or damaged seals and broken pipelines.
(5) Discoloration caused by overheating or by fluid leaks.
(6) Corrosion or contamination by mercury or acid.
(7) Insecurity of attachment—especially plugs, panels and electrical interconnections.
(8) Faulty or broken locking devices.
(9) Loose or missing rivets.
(10) Cracks, fractures or distortion.
(11) Loose clips or cable supports.
(12) Damaged or collapsed springs—especially on anti-vibration mountings.
(13) External damage due to bird strikes, particularly around jet engine air intakes.

Personal Safety

5. **Assisted escape systems.** The bulky clothing and equipment worn by aircrew for high speed, high altitude flight makes rapid escape from an aircraft impossible without mechanical assistance. Explosive devices are used to jettison the canopy or escape hatch. The crew member, complete with special aircraft seat and parachutes, is then ejected at a speed and direction which

will enable him to safely clear the aircraft tail unit. In most systems the complete ejection and descent is controlled automatically once the sequence is initiated. All aircraft fitted with assisted escape systems are marked with a *red danger warning triangle* in an easily visible position (see Fig. 5).

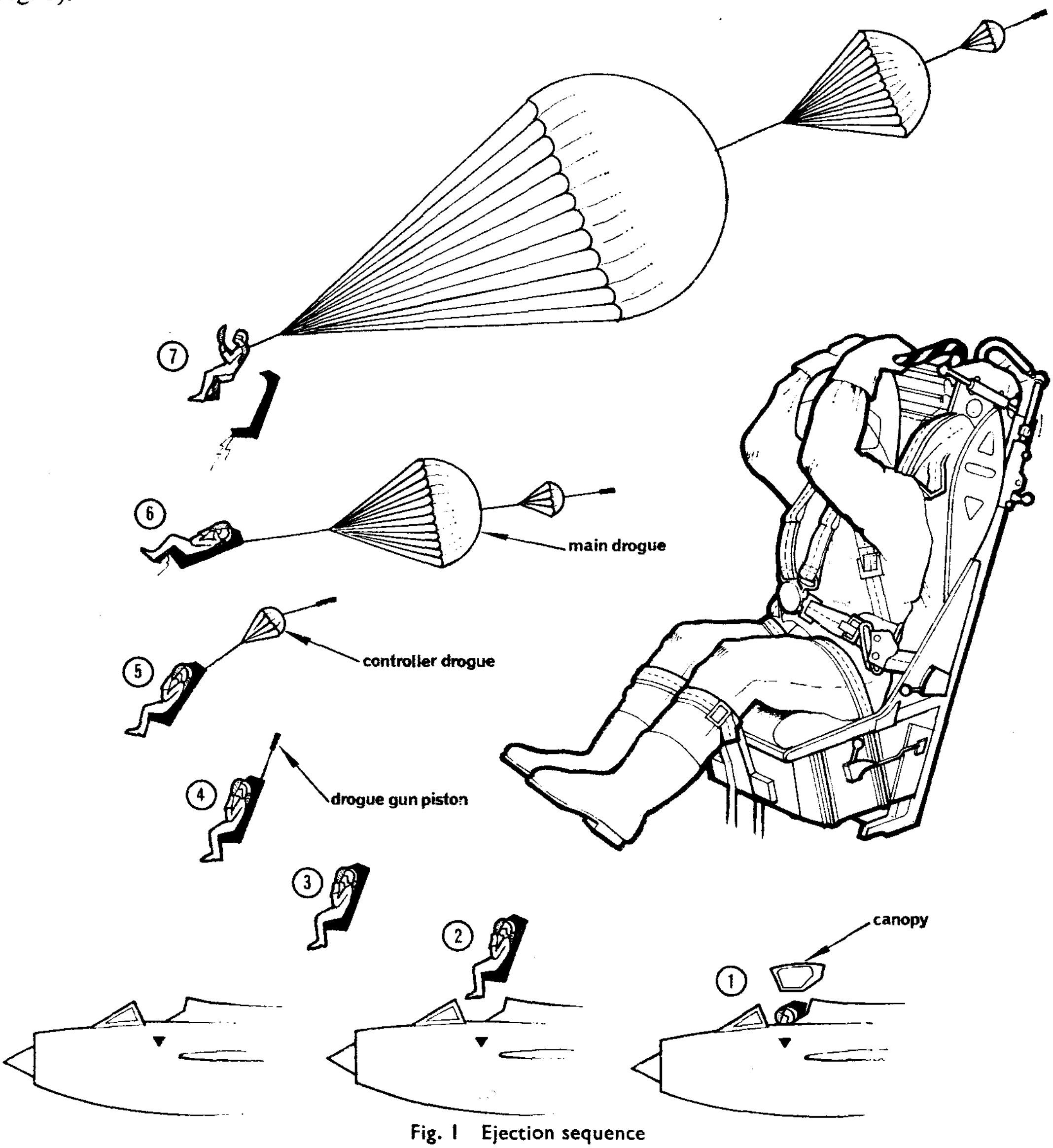


Fig. 1 Ejection sequence

6. **Ejection seats.** These seats are designed to save life and are only dangerous if the *essential safety precautions* are ignored. A typical seat consists of the following items:

a. A special seat structure and pan fitted with leg restraining cords and a safety harness. The pilot's parachute and survival equipment are packed in the seat structure and are attached to the harness.

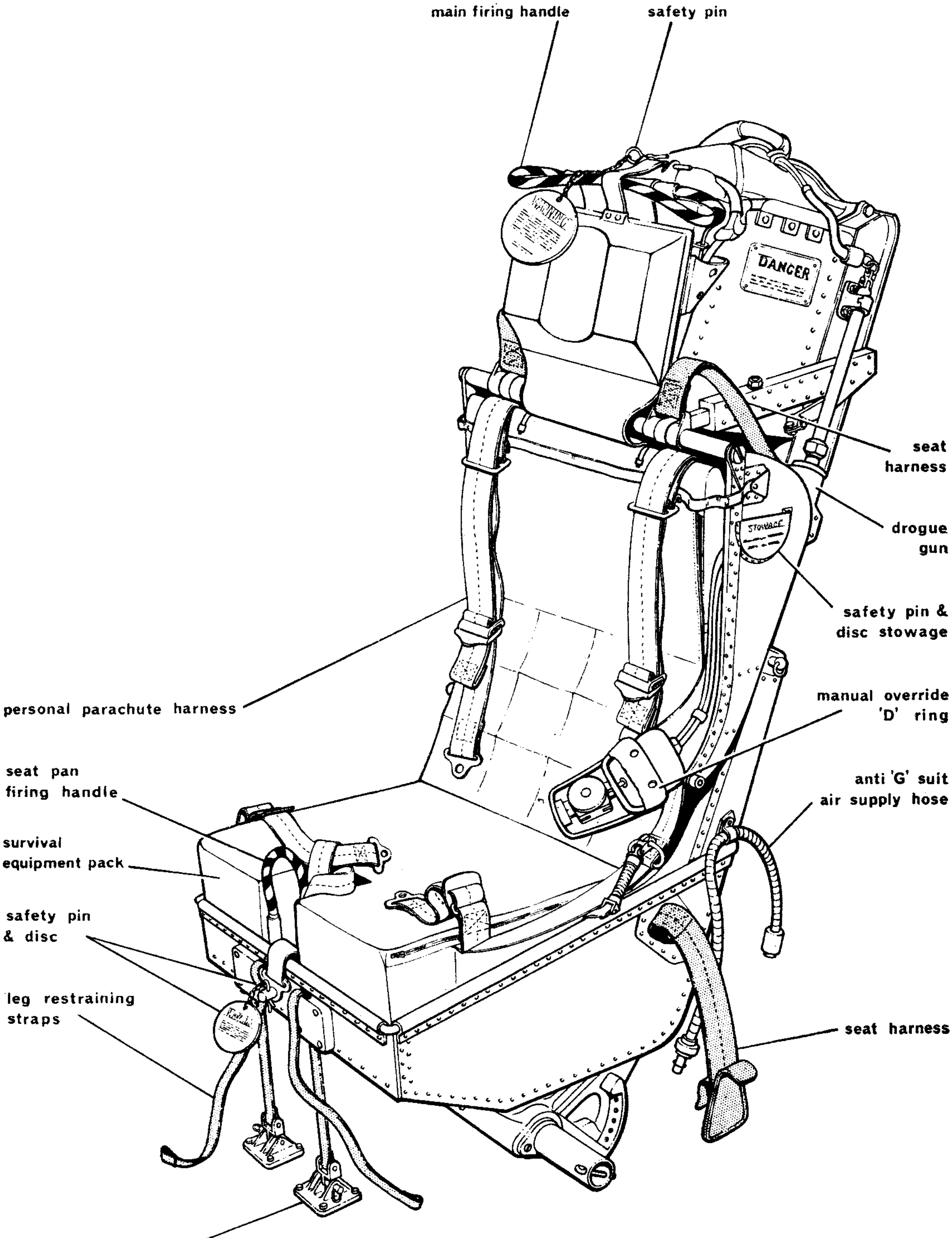


Fig. 2 Typical ejection seat

b. Guide rails along which the seat structure will slide on its way out of the aircraft. The cartridge operated main ejection gun is usually an integral part of the guide rail structure.

c. A cartridge operated jettison system to dispose of the canopy or hatch before ejection of the seat. A built-in time delay mechanism gives a one second delay between canopy jettison and firing of the main ejection gun.

d. The main firing handle to initiate the ejection sequence. This handle has a face screen attached which protects the pilot from the effects of the slipstream.

e. An alternative firing handle, on the seat pan, is connected to the main firing handle by a Bowden cable. This handle is for use only when it is impossible to operate the main handle *eg* in conditions of high "g".

f. A drogue gun (cartridge-operated) which fires a metal bolt, connected to a small drogue (controller) and a main drogue, about half a second after ejection. These drogues stabilise the seat and slow it down from the aircraft speed before the main parachute is deployed.

g. A time release unit (3 secs) with barostatic override delays deployment of the main parachute until the drogues have had time to stabilise the seat. The barostatic device prevents operation above 10,000 ft and so reduces the time taken to descend from high altitudes.

h. Some seats are designed for use at low level and low speeds. These have a $1\frac{1}{4}$ second time delay unit and a 'G' controller. The 'G' controller prevents operation while the seat is decelerating so that the parachute does not get torn at high ejection speeds.

j. An emergency oxygen supply for breathing should an ejection be made at high altitude.

7. **Ground safety devices.** When the aircraft is on the ground the ejection mechanisms *must* be prevented from operation to protect the ground crew from injury. These safety devices take the shape of safety pins that pass through the 'sears' of the firing mechanism. There are up to four of these pins: one each for the canopy jettison, the time delay trip lever, the main ejection gun and the drogue gun. The correct position of these pins varies with the operational state of the aircraft.

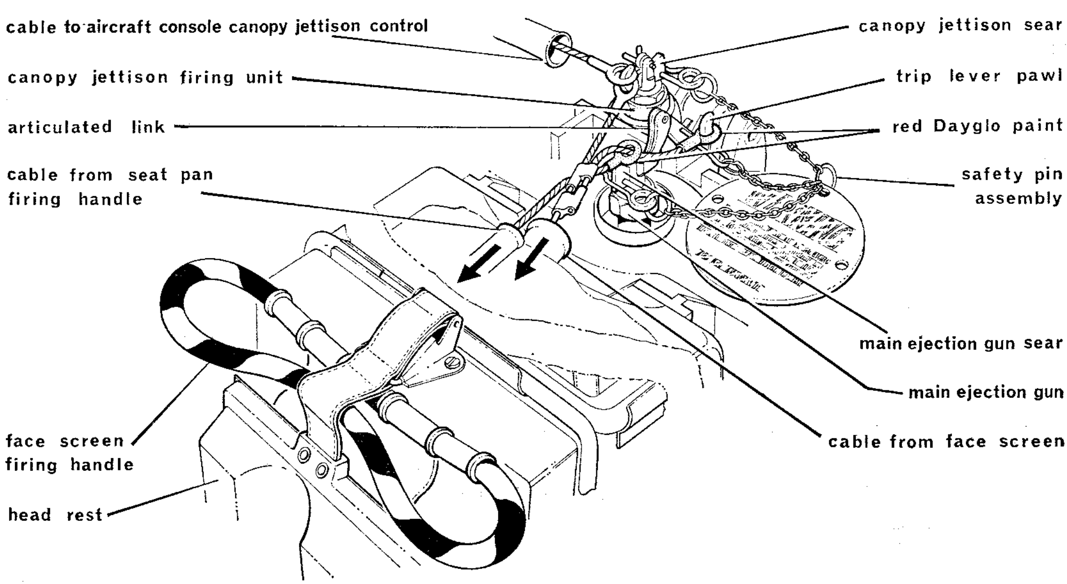


Fig 3 Safe for servicing

a. Ready to fly. Before flight it is the *pilot's* responsibility to ensure that all safety pins are removed and stowed in the pocket provided. Similarly at the end of the flight it is the *pilot's* responsibility to make the seat 'safe for parking'.

b. Safe for parking. The pins are placed in position to prevent operation of either the main or alternative firing handles (Fig 2). Under no circumstances should any person lean over the cockpit of an aircraft unless these handles are locked. It is the responsibility of a *named armament tradesman* to make the seat 'safe for servicing' before any person is allowed in the cockpit.

c. Safe for servicing. In this condition all firing pin sears are locked with safety pins (*see* Fig 3). It must be emphasised that *only named armament tradesmen* are allowed to change the condition of the seat to or from 'safe for servicing'.

WARNING. Always check that the pins are in the 'safe for servicing' position before entering the cockpit. If in doubt, or if the pins need repositioning, the individual must report to the NCO i/c Aircraft Servicing who will detail the qualified armament tradesman to reposition the pins.

8. **Aircraft danger zones.** Tradesmen who work on or near aircraft must be fully aware of the dangers due to propeller blades and jet engine exhausts. When an aircraft engine is running, and during engine starting, always keep well clear of the aircraft. Special care must be taken with turbo-prop aircraft where although the engine may not be running the wind may cause the propeller to rotate. With jet engines the danger zones extend to the front and rear of the engines (*see* Fig 4). Extreme caution is needed when approaching a helicopter with its engines running or about to start. The rotor blades may drop suddenly or the fuselage may swing taking the tail rotor round in an arc.

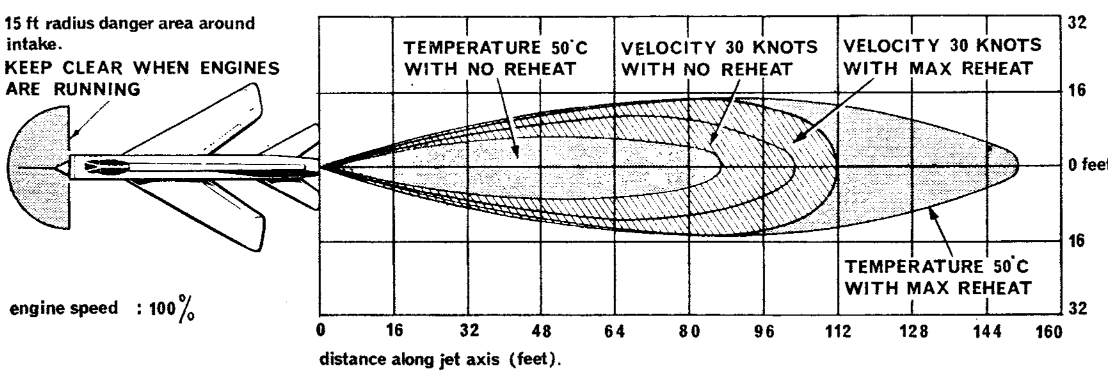


Fig 4 Jet engine danger zones

a. Arming. During arming of an aircraft tradesmen must keep clear of the front of the aircraft. It is usual to make a 50 yard radius around the aircraft a prohibited zone for everyone other than the armament crew. Warning notices will be displayed in a prominent position during arming and disarming.

b. Noise. The noise produced by jet or gas turbine engines is sufficient to cause injury to servicing personnel unless adequate precautions are taken. Ear defenders are available and must be worn by all personnel exposed so noise which:

(1) causes pain.

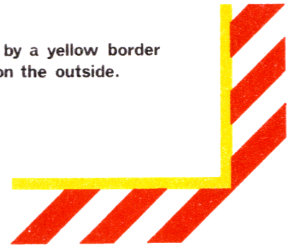
(2) makes shouted conversation necessary at distances of 3 ft or less.

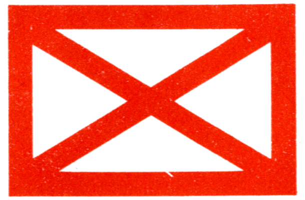
(3) is likely to persist for one hour or more when work has to be done within 100 ft of the source.

GENERAL

Walkways.

These are defined by a yellow border with a red fringe on the outside.

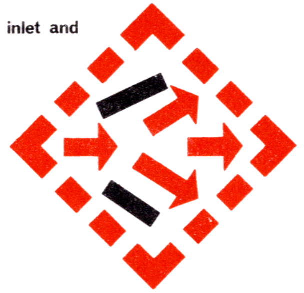




Prohibition of access.

Weak points on an aircraft fuselage may be marked.

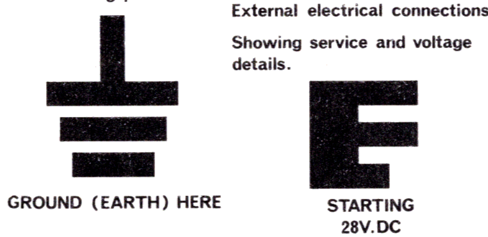
Airborne power plant inlet and exhaust marks.



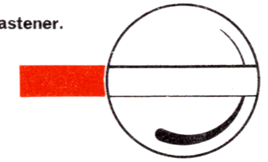
Earthing points.

External electrical connections.

Showing service and voltage details.



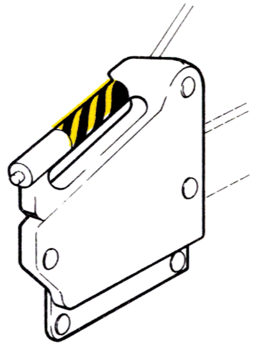
Cowling fastener.



INTERNAL MARKINGS

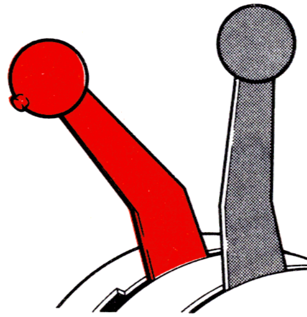
Ejection seat firing handle.

The centre portion of the ejection seat firing handle is striped matt black and yellow and the sides are painted red. The words "DO NOT PULL HANDLE" are painted in red on the head rest.



Emergency controls.

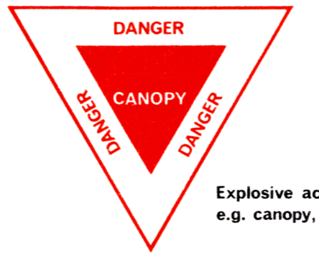
All emergency controls are painted matt black and have at least two diagonal yellow stripes.



Normal controls.

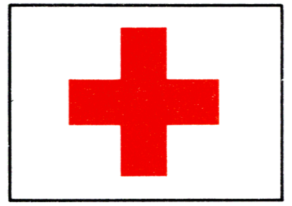
Normal controls are painted light grey and control locking levers are painted red.

EMERGENCY MARKINGS



Explosive actuated devices e.g. canopy, ejection seats or hatch.

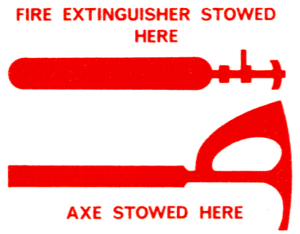
Location of first aid kit access panel.



FIRE PANEL

Fire access panels fitted to engine cowling

Position marks for emergency equipment which is accessible from outside the aircraft. The silhouette is marked at the exact position of the item shown.



The emergency canopy or hatch release control and operating instructions.

Break-in points on selected areas of the fuselage where entry can be gained with the minimum of obstruction.

CUT HERE FOR EMERGENCY RESCUE

REPLENISHMENT SYMBOLS

Fuel.

A four pointed star with the NATO code number for the type of fuel.

F – 40

H – 515

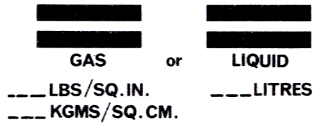
Hydraulic fluid.

A circle with the type of fluid indicated by the NATO code number.

De-icing fluid.

The grade of fluid is shown by the NATO code number.

S – 738

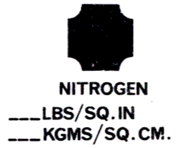


Oxygen.

For breathing. The filling pressure is marked.

Nitrogen.

A square with the corners removed. The filling pressure is given in both English and metric units.



Fire systems.

A diamond with the name of the extinguishant.

Pneumatic systems.

A large X with the maximum permissible charging pressure.

0 – 149

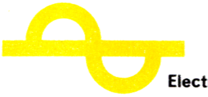
Engine lubricating oil.

A square with the NATO code number for the type of lubricant.

INSPECTION SYMBOLS

Batteries.

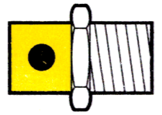
Access panel for inspection of aircraft batteries.



Electronic equipment access panels.

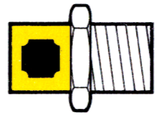
A sine wave about a horizontal bar.

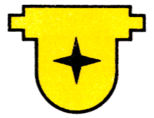
De-icing circuit inspection points.



Hydraulic system test points.

Nitrogen tank test points.



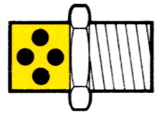


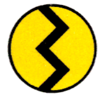
Filter inspection point.

Contains the four point star for fuel.

Cabin pressure test point.

Contains the four dot symbol for air.





Static connection inspection points.

GROUND HANDLING MARKINGS

Jacking point.

A square with two slanting legs.

Slinging or hoisting points.

A hook on a horizontal bar.

Picketing point.

Towing point.

A circle enclosing a white disc.

Tail support point.

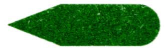
A yellow disc drawn around the support point.

Normal entrance.

The operating instructions are printed in the immediate vicinity.

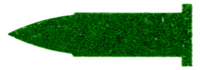
NORMAL HATCH TO OPEN PUSH & TURN

ARMAMENT MARKINGS

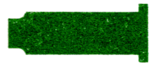


Gun.

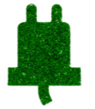
Firing control.



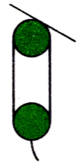
Cartridge container.



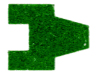
Gun feeding.



Rocket control.



Bomb hoist.



Link container.

INSPECTION SYMBOLS

Batteries.

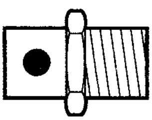
Access panel for inspection of aircraft batteries.

Electronic equipment access p

A sine wave about a horizont

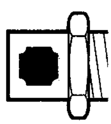
De-icing circuit inspection points.

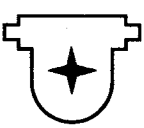
Fig. 5 Servicing and safety symbols



Hydraulic system test p

Nitrogen tank test points.



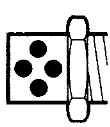


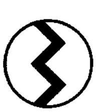
Filter inspection point.

Contains the four point star for

Cabin pressure test point.

Contains the four dot symbol for air.





Static connection inspection p

c. Fuelling. When aircraft fuel is to be transferred to or from an aircraft all personnel not directly involved in the transfer should keep well clear. Smoking, naked lights and engine driven ground equipment must be kept at least 50 feet away from the aircraft. No work may be carried out on any radio or electrical equipment during fuelling because of the fire risk. The aircraft and fuel tanker must be adequately earthed and the fuel nozzle bonded to the aircraft *before* fuel transfer commences. Protective clothing must be worn by the refuelling crew who are also responsible for the display of warning notices.

d. Liquid oxygen (LOX). Liquid oxygen is only to be handled by qualified personnel who must wear the approved type of protective clothing, goggles and gloves. As any contact with liquid oxygen will cause severe freezing and 'cold burns' it must be handled with extreme care. All personnel must keep clear of the overboard spillage drains in case of accidental overfilling or spillage. Normal fire precautions must be observed as for fuelling. LOX must be kept well away from grease, oils or fuels because of the explosion hazard.

9. **Servicing and safety symbols.** Symbols and markings are used to facilitate servicing and to give warnings, the neglect of which could cause injury to personnel or damage to equipment. They are marked on the airframe, or the outside of doors and access panels as a guide to the servicing point covered by the panel. Units of pressure are specified in both metric and English systems i.e. kgms/sq. cm. and lb/sq. in. The NATO code number of the material used is also indicated where appropriate. The most important symbols are shown in Fig. 5 together with the colour coding system used for easy identification. This colouring may be varied slightly to suit operational requirements or to make the symbol more prominent against a coloured background.

Electrical Safety

10. **Portable equipment.** Portable electrical equipment for aircraft use operates from a 28 volt d.c. supply, obtained from a servicing trolley. Other types of portable equipment operate from the normal mains supply of 230–250 volts a.c. It is essential to check the supply voltage before using any portable equipment as a misconnection may be dangerous and will certainly damage the equipment.

a. Before use. Inspect the equipment for obvious signs of unserviceability such as:

(1) A frayed or cracked lead.

(2) A loose, cracked or incomplete plug.

(3) A loose or broken on/off switch.

(4) Exposed conductors, particularly at cable entry points.

(5) Poor or broken earthing connections—a three pin plug should always be used unless the equipment is 'double-insulated'.

b. In use. Observe all fire precautions and:

(1) Make sure there is no strain on the electric lead.

(2) Keep the lead clear of oil patches.

(3) Ensure that the lead is not run over by trolleys or vehicles.

(4) If the equipment is to be left unattended it should first be disconnected.

11. **Armament circuits.** Most of the operating mechanisms for guns, rockets and bombs are now electrical. This makes any electrical servicing of an aircraft which is armed extremely dangerous. The armament trade is responsible for disconnecting guns and rockets at their supply sockets before servicing starts. Authority to reconnect these circuits can only be given by the NCO i/c armament trade. Some secret equipments are fitted with explosive destruction devices which are the responsibility of the armament trade. These devices should be removed before the equipment is taken to a servicing bay.

12. **Aircraft aerials.** When functional testing of an aircraft transmitter is to be carried out, the radio tradesman must warn all other members of the servicing team. Energy from the aerial can cause a spark capable of igniting any nearby inflammable vapour. The radiation from the aerials of most primary radar equipments, which operate in the microwave radiation band, contains sufficient energy to be a hazard to the health of nearby personnel. Safe working distances are given in the servicing schedules and all personnel should be warned not to loiter in the vicinity of these aerials. When an aircraft transmitter aerial is radiating the following work is not permitted:

a. Carrying out refuelling of the aircraft or of any other aircraft within a radius of 50 ft.

b. Doping or painting the aircraft surface within 6 ft of the aerial.

c. Any work on the exterior of the aircraft within 6 ft of the aerial.

13. **Insulation testing.** Due to the increased use of transistors and other components which will not withstand high test voltages; insulation testing of an installation is not permitted unless it is specifically called for in the servicing schedules or authorized by a specialist officer. When testing is permitted, care should be taken to ensure that the type of tester used does not generate voltages capable of damaging the installation.

14. **Firewire systems.** The 'firewire' automatic fire detection system depends for its operation on the decrease in resistance of a special sensing element when it is heated. This element consists of a semi-flexible stainless steel tube with a coaxial central conductor wire, separated from the tube walls by a filling material with an inverse temperature/resistance characteristic. Physical damage or the entry of water into the element will cause a loss of resistance and may result in a spurious fire warning. The danger of these 'false-alarms' cannot be over-emphasised as they can result in aircrew ejection followed by the total loss of a valuable aircraft. During fitting or servicing of firewire elements the following precautions must be observed:

a. No grease or oil is to be used on the end connections.

b. New copper 'S' washers must be used when any connection is fitted or refitted.

c. All connections must be wire locked.

d. The sealing caps fitted to the ends of the element must be removed immediately prior to connection.

e. The wire must be properly supported by special clips at least $\frac{1}{4}$ inch from the aircraft frame.

f. The minimum bend radius is one inch and no bends must be made within $\frac{1}{2}$ inch of a supporting clip.

g. The route laid down in the relevant aircraft fire installation drawings must be followed exactly.

Aircraft Protection

15. **Safety locks.** Ground locks are fitted to the undercarriage systems of most aircraft to prevent accidental retraction on the ground. Some control surfaces such as ailerons are also locked in the central position to prevent damage. The locking devices fitted are painted red to make them easily visible and have a warning pennant attached. Whenever locks are fitted or removed an entry must be made in the aircraft log book (F700).

16. **Covers.** To prevent the entry of moisture, dust or grit some parts of the aircraft are fitted with protective covers. Examples are the pitot head, camera guns and jet engine air intakes. These covers are painted red for easy visibility and must always be removed before flight.

17. **Aircraft finish.** For high speed flight the drag imposed by the aircraft surface must be kept to an absolute minimum therefore the finish must be protected during servicing. Always use special aircraft mats when walking on the surface and ensure that these mats do not pick up grit from the hangar floor. Rubber soled shoes should be worn by all servicing personnel for aircraft work. When using tools these should not be laid on the aircraft surface; a piece of soft cloth should be used as protection. Scratches on the canopy will affect the pilot's view so special polishes and cloths are provided for cleaning. The canopy must never be cleaned with any other material.

Rescue

18. The procedure for rescue of personnel from a crashed aircraft is given in a Ministry of Defence pamphlet (PAM(AIR)333). In addition to the ejection seat and warning symbols given in this chapter all personnel should be aware of the method of approach to a crashed aircraft and the fire hazards involved.

19. **Approach.** Always approach the crash from an uphill—upwind direction to avoid the hazards of free fuel and vapours. Never park a vehicle in front of a military aircraft which may be armed. Park the vehicle uphill—upwind if possible and keep well clear of the aircraft to allow fire and crash vehicles room to manoeuvre. Leave the vehicle in a position such that it can be driven away quickly in an emergency without reversing or passing closer to the wreckage. As the average fire vehicle needs about 10 ft clearance when travelling at a reasonable speed, ensure that all vehicles are parked well clear of any road or path to the accident.

20. **Policing duties.** The following general policing duties will greatly assist the crash recovery services:

a. Onlookers. Onlookers should be kept as far back as possible in an uphill—upwind direction to minimise the risk of explosion.

b. Smoking. A no smoking rule must be rigidly enforced. Neither survivors, onlookers nor rescuers must be allowed to smoke in the vicinity of the crash.

c. Souvenirs. Under no circumstances may any parts be removed from the scene of an accident. The part taken may be the one needed by the accident board to determine why the aircraft crashed.

d. Local inhabitants. If the aircraft has crashed near buildings, their occupants should be advised to leave and remain in a safe area until further notice. All doors and windows facing the crash should be closed, gas or electricity turned off and all naked lights or domestic fires extinguished.

CHAPTER 4

AUXILIARY POWER SUPPLIES FOR AIRCRAFT

List of Contents

Introduction

1. To enable servicing or functional testing of electrical and radio installations to be carried out on an aircraft without running the aero-engines, an external supply of electrical power must be made available. A variety of mobile trolleys are available for this purpose, some of which can also be used for starting the engines of those aircraft not fitted with a self-start capability. Full information on electrical servicing and starting trolleys can be obtained from AP4343S, Vol. 1, Book 4.

2. Servicing trolleys can be considered as three functional groups:

a. Transformer/rectifier units (TRU) or electric motor driven generators for use in aircraft hangars or on bases where a three phase mains electricity supply is readily available.

b. Petrol or diesel engine driven generators for use on airfield dispersal sites where no suitable mains supply is available.

c. Lightweight (approx. 300 lbs) gas turbine driven generators for use in forward areas or where rapid deployment is required e.g. by helicopter. The use of a gas turbine also enables the trolley to be operated on a wide variety of fuels.

Electrically driven trolleys are quieter and more economical to run than the engine driven versions and have a better record of serviceability. The gas turbine units are extremely noisy, but this is acceptable when justified by the need for operational mobility.

3. **Safety.** The application of electrical power to an aircraft during servicing could cause serious injury or death to other tradesmen working on the aircraft. Permission to apply power *must always* be obtained from the NCO in charge of aircraft servicing (see unit servicing orders). Batteries are fitted in an aircraft to smooth the aircraft generator supply and for emergency use. These batteries have a small capacity and must *never* be used as the power source for functional tests or servicing.

NATO Connectors

4. The output cables from all modern ground supply trolleys are fitted with standard NATO rubber-moulded free sockets which mate with a fixed plug on the aircraft. To compensate for the voltage drop along the output cables the voltage at these sockets is fed back along 'sensing cores' to the automatic voltage regulation equipment on the generator. This arrangement enables the voltage supplied to the aircraft to be maintained constant under varying load conditions.

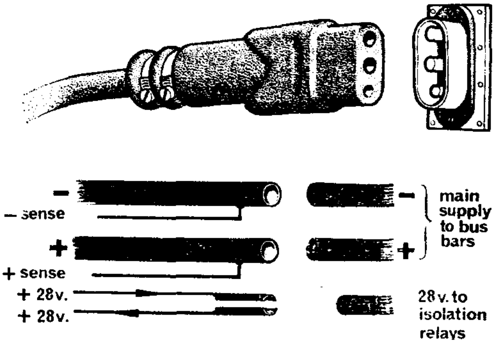


Fig. 1 NATO socket (28V d.c.)

5. **NATO socket (28V d.c.).** A three-pole in line arrangement is used for 28V d.c., the two supply poles on the aircraft plug are longer than the third or 'interlock' pole. The third pole of the socket is split in two, each half being connected to the trolley control panel by pilot cables which form a 'hold-on' circuit for the main d.c. supply contactor. If the socket is accidentally withdrawn while power is being delivered the third pole will break circuit first, releasing the main contactor which switches off the supply and prevents arcing at the aircraft plug. Circuits in the aircraft are also operated by the 28V from the interlock pole and automatically isolate the aircraft generators from the bus bars when power is being supplied from the ground.

6. **NATO socket (112V d.c.).** The Mk 1 V–bombers required a supply of 112V d.c. and a similar three pole socket was used. The interlock pole is offset to prevent accidental misconnections between the 28V and 112V d.c. systems.

7. **NATO socket (200V a.c. 3∅).** A six pole arrangement is used which includes two separate interlock poles. The four supply poles provide the three phases and a neutral which is normally tied to d.c. negative at the generator. The interlock poles of the aircraft plug are shorter than the supply poles to ensure that the a.c. contactor trips if the socket is accidentally removed to prevent arcing at the aircraft plug. Some aircraft circuits are arranged so that the a.c. interlock system will not operate unless 28V d.c. is connected to the aircraft and is switched on.

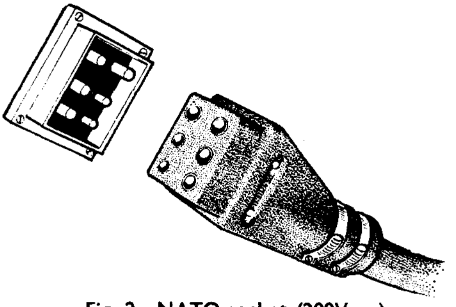


Fig. 2 NATO socket (200Va.c.)

Rectifier Type 37

8. **Introduction.** The rectifier type 37 is a transformer/rectifier unit which converts the 415V 50Hz. three phase mains supply to 28V d.c. with a continuous output rating of 6kW. (i.e. 200 Amps.). It has an intermittent overload rating of 16kW. and can therefore be used for starting the engines of most light aircraft. The type 37A, with a different transformer, was introduced to replace the type 37 at wastage rates and has a higher intermittent overload rating (32kW.). A general view of the unit is shown in figure 3; the input and output leads have been omitted for clarity.

9. **Operation.** The unit contains a three phase transformer and a bank of full-wave metal rectifiers. The on/off control is a rotary switch mounted on the control panel and is wired to each of the three input phases (see Fig. 4). Each phase is separately fused by a cartridge fuse rated at 15 amps. and these fuses are mounted inside the case behind an access panel. The output voltage control is a rotary four position switch, mounted on the control panel, wired to select tappings on the transformer primary windings. A voltmeter calibrated 0–40V. indicates the output voltage from the rectifiers.

10. The TRU 37 is used for all aircraft and static servicing bay 28V. d.c. supplies when less than 6kW is required. At high current loads there is a considerable voltage drop across the rectifiers and the output has a high ripple content. A locally manufactured smoothing unit for use with these rectifiers is shown in AP4343G, Vol. 1, Sect. 8.

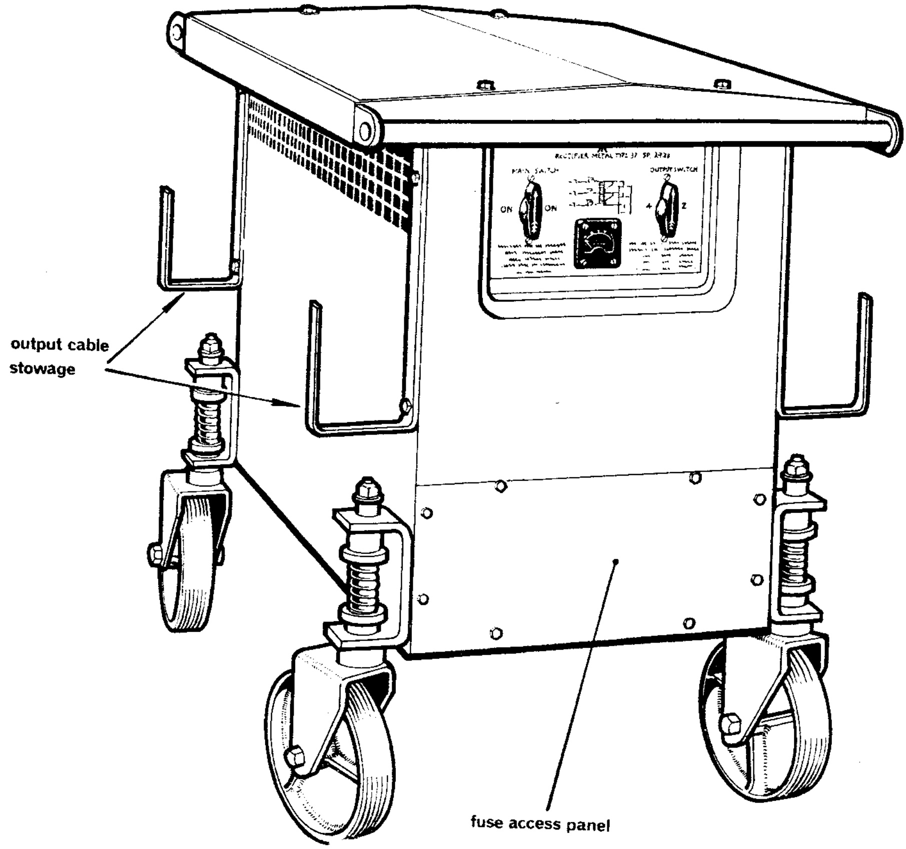


Fig. 3 Rectifier type 37

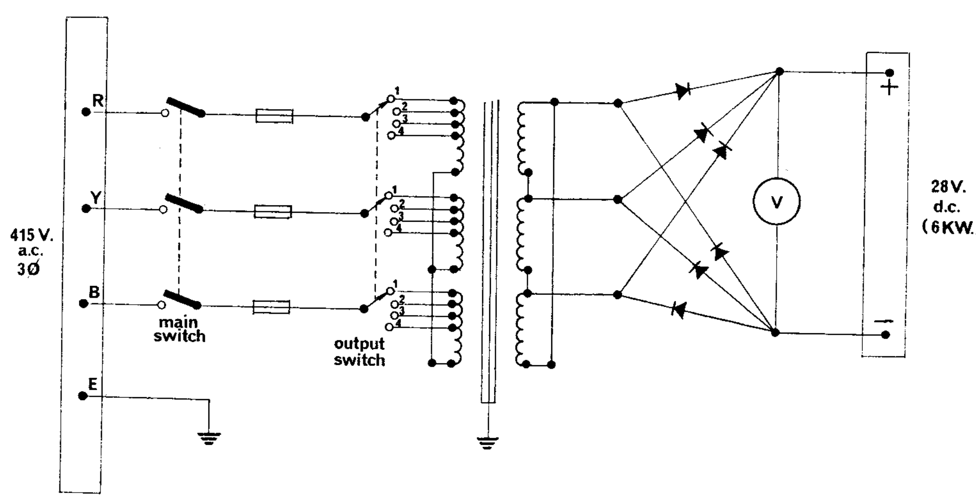


Fig. 4 Circuit of rectifier type 37

Electrical Servicing Trolley (4FE3786)

11. **Introduction.** This trolley is designed to provide electric power for servicing aircraft with a.c./d.c. systems. The output at 28V d.c. is rated at 6kW. continuous with a peak rating of 10kW. The three phase 200V a.c. 400Hz output is rated at 15kVA. continuous and will supply 22·5kVA for one minute. The generators are driven by a 32 h.p. squirrel cage induction motor operating from the 415V. 3-phase mains supply. Petrol engined versions of this trolley are also available driven by the Ford Zephyr range of engines. Those trolleys driven by the Mk. 3 Zephyr engine (4FE5615) have a 25kVA. continuous a.c. output rating.

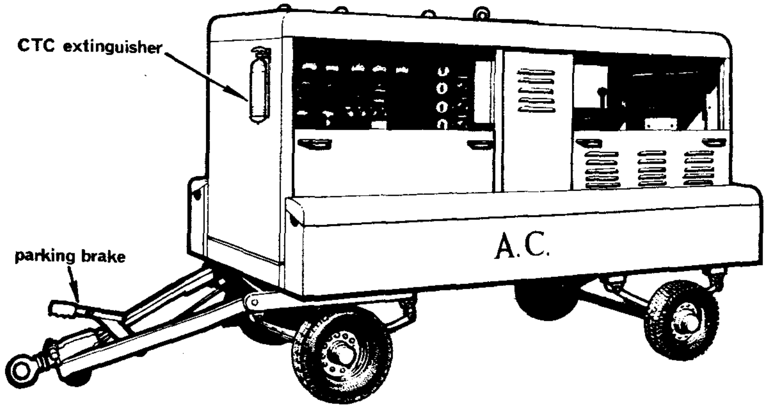


Fig. 5 Servicing trolley (4FE-3786)

12. **Auxiliary supply sockets.** Four auxiliary supply sockets are mounted on the control panel and may be used to operate test equipment or soldering irons during servicing. These sockets are independently switched and fused.

a. A four-pole socket, fed from the alternator output through a transformer, supplies 3-phase 400Hz a.c. at 115V. Each phase is fused at 5 amps.

b. A three-pole 5 amp. socket fed from one alternator output phase to supply single phase 400Hz a.c. at 115V.

c. Two three-pole sockets each of which is fed from the generator output through a switch and 15 amp. fuse to supply 28V d.c.

13. **Main cables.** Two 50 foot output cables are provided. The a.c. cable is a 9 core cable terminated by a 6 pole NATO socket. The d.c. cable is a 6 core cable terminated by a 3 pole NATO socket. The mains input cable of the electric motor driven trolley is also 50 feet long and is stowed in the locker on the side of the trolley.

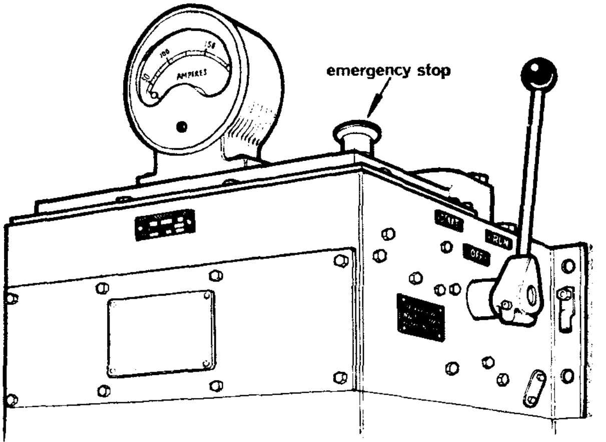


Fig. 6 Starter

14. **Starter.** At the rear of the trolley is an oil immersed, hand operated star-delta starter. Putting the handle in the 'start' position connects the motor stator windings as a star network and allows

the motor to accelerate. After the motor has reached operating speed the handle may be moved to the 'run' position; the stator windings are then delta connected. An interlock mechanism prevents the handle from being moved to the 'run' position without going through the 'start' position. An 'emergency stop' button is fitted to the top cover of the starter box.

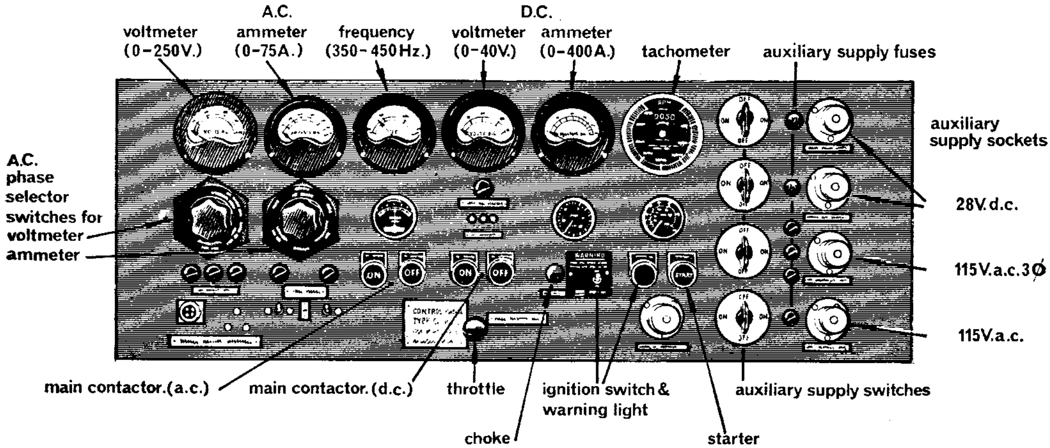


Fig. 7 Control panel

15. **Control panel.** Figure 7 shows a general view of the control panel of the petrol engine driven trolley. The panel on the electric motor version is the same except that the engine instruments and controls are omitted. When the main contactors are closed and power is being supplied to the aircraft warning lights on the canopy of the trolley are illuminated. The white light indicates 'd.c. power on' and the green light 'a.c. power on'. There are also two red 'obstruction warning' lights on the canopy roof, operated by a switch on the control panel. These lights must always be switched on at night and at any other time if required by unit servicing orders.

16. **Aircraft.** The aircraft types for which this trolley is required include the Lightning, Britannia, Belvedere, Gnat, Belfast and Canberra T-17. As the 28V d.c. supply is capable of providing up to 10kW. for a short period of time the trolley may also be used to start the engines of most light aircraft.

Electrical Servicing and Starting Trolley Mk 5. (4FE5146)

17. **Introduction.** The Mk 5 trolley is designed to supply d.c. electrical power for the servicing of aircraft radio, radar and electrical equipment and for the electrical starting of aircraft engines. The output at 28V d.c. is rated at 20kW. (700 amps.) continuous with an intermittent overload rating of 40kW. The generator is driven by a Ford Zephyr petrol engine.

18. **Auxiliary power supply sockets.** Two sockets are mounted at the rear of the trolley and are protected by dust covers. They may be used to operate test equipment or soldering irons and will supply 5 amps. at 28V d.c. from the generator output through a common fuse.

19. **Main cable system.** The 30 foot cable assembly for connecting the trolley to the aircraft is terminated by a standard 3 pole NATO socket. When not in use the assembly is stowed in a compartment on the side of the trolley, one end of which is slotted to allow the cable to be

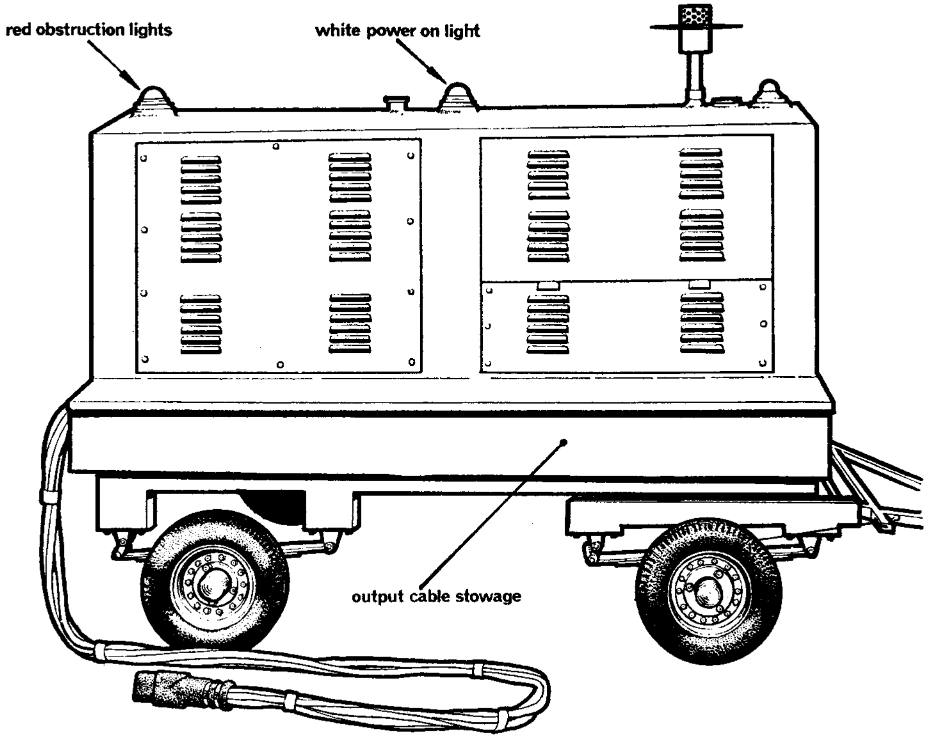


Fig. 8 Electrical servicing and starting trolley Mk 5

extracted easily. When large d.c. power levels are required for long periods of time a second cable assembly must be fitted in parallel to reduce the voltage drop.

20. **Starting.** Whenever the trolley is operated the radiator doors and the canopy panels either side of the engine compartment must be open to prevent overheating. The parking brake must be applied; and the obstruction lights switched on if required by airfield regulations. The starting procedure is as follows:

a. Pull out the choke control (only required when the engine is cold).

b. Pull out the hand throttle 'S' to the slow running position.

c. Switch the ignition on.

d. Firmly press the starter button.

e. Gradually push in the choke control as the engine warms up.

f. When the engine runs smoothly push in the hand throttle and allow the engine speed to be controlled by the governor.

g. Connect the output cable assembly to the aircraft.

h. Press the main contactor 'ON' button to obtain power.

21. **Control panel.** Figure 9 shows a general view of the control panel which has the engine instruments and controls on the right and the generator instruments on the left. The d.c. voltmeter is connected to the voltage sensing cables in the NATO socket and records the actual voltage being supplied at the aircraft plug.

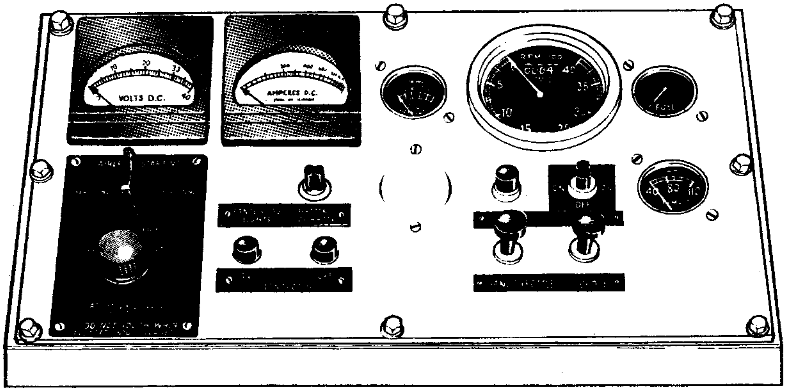
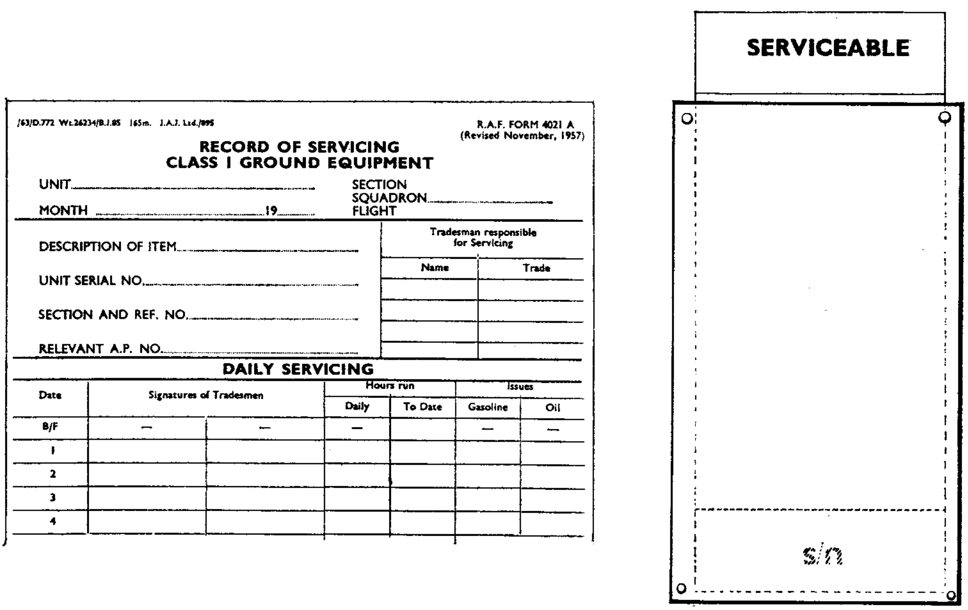


Fig. 9 Control panel

22. **Aircraft**. The types of aircraft for which this trolley is required include the Javelin, Canberra, Wessex, Jet Provost, Dominie and Shackleton.

F4021A

23. RAF form 4021A is the 'Record of Servicing Class 1 Ground Equipment' and is used for all electrical trolleys. A separate form is used for each item of equipment and is normally kept in a specially designed holder on the equipment. The form is folded and placed in the holder in such a way that either the word 'serviceable' or 'U/S' is visible at the top. Each form lasts for a period of one calendar month and the completed forms are kept for a further period of 6 months by the technical recording section.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R.A.F. FORM 4021 A
(Revised November, 1957)

RECORD OF SERVICING
CLASS I GROUND EQUIPMENT

UNIT.................... SECTION
SQUADRON....................
MONTH .... 19........ FLIGHT

DESCRIPTION OF ITEM....................
UNIT SERIAL NO....................
SECTION AND REF. NO....................
RELEVANT A.P. NO....................

Tradesman responsible for Servicing	
Name	Trade

DAILY SERVICING

Date	Signatures of Tradesmen		Hours run		Issues	
			Daily	To Date	Gasoline	Oil
B/F	—	—	—		—	—
1						
2						
3						
4						

Fig. 10 Form 4021A

24. The F4021A is signed daily by the tradesman using the equipment who certifies that he has carried out the daily checks as laid down in the equipment AP. and has found the item serviceable for use. After use the tradesman also enters the hours run and consumable stores issued (i.e. petrol and oil) on the front of the form. If any defect is found this is entered in the 'Change of Serviceability and Repair' log on the reverse of F4021A and the form is replaced in its holder to show 'U/S'. Repairs are normally carried out by the general engineering and ground electrical tradesmen who will enter details in the C of S and R log and return the equipment 'serviceable'. Periodic servicing details are also entered on the reverse of F4021A.

25. **Daily checks.** The daily servicing checks for each type of trolley are laid down in the appropriate AP. In general terms checks are made for security, water/coolant level, oil level, tyre pressures and hand-brake action.

Lightweight Generators

26. Turbine driven electrical servicing trolleys have been introduced to meet the need for lightweight support units easily air-transportable by helicopter. These trolleys use 9kW. brushless aircraft generators driven by high speed (40000 rev/min) gas turbines. The normal weight is between 300 and 400 pounds and the units measure 2 ft. square and about 4 ft. long. Like most gas turbines a wide variety of distillate fuels may be used such as petrol, diesel oil or kerosine. Because of the high running speed of the turbine the generators have a very high peak overload performance e.g. 650 Amps for 5 secs, and are capable of starting jet engines. Ear defenders should be worn by the operating personnel as protection against the high noise level of the turbine.

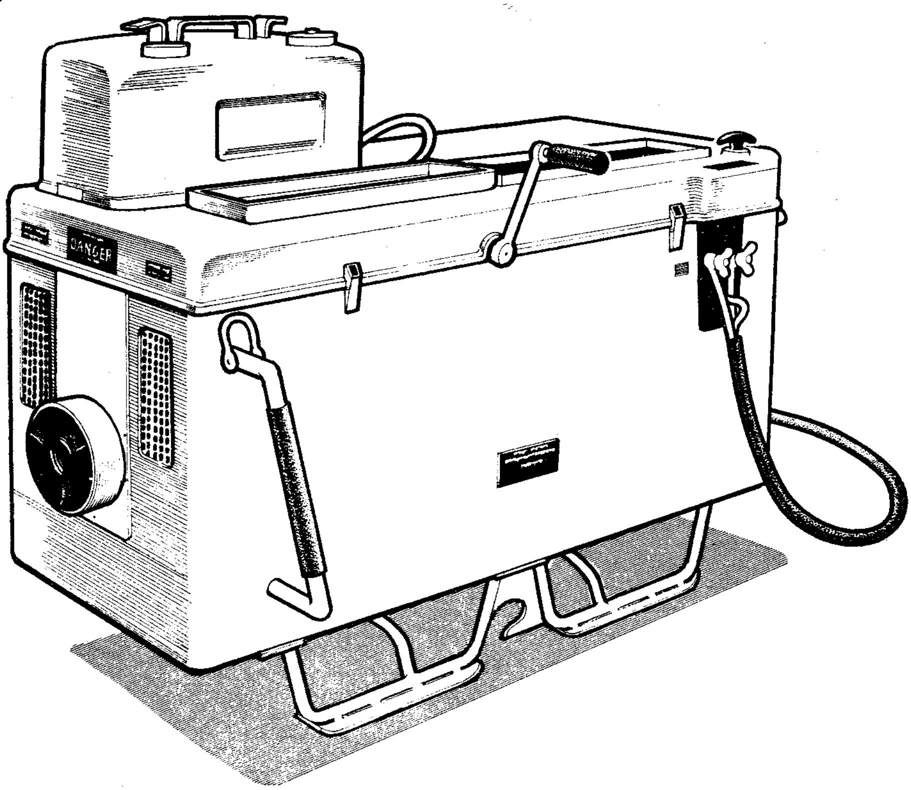


Fig. 11 Turbine trolley (Rotax) 28V d.c. 9kW

27. Operating principles

a. Start. Connect up a fuel supply and open the fuel cocks. Set the control lever to the start position and motor the turbine with the hand crank. After self-sustaining speed has been reached the turbine will accelerate automatically to about 20000 rev/min. (idling speed). Check the oil pressure and the jet pipe temperature (JPT).

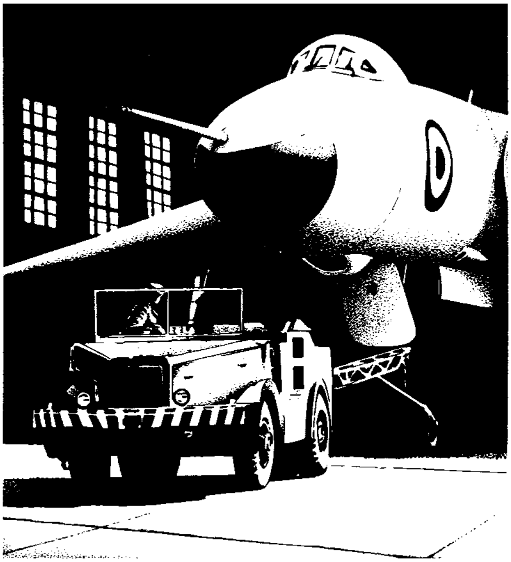
Warning. In the case of a false ('wet') start; the fuel cocks should be closed and a period of two or three minutes allowed for fuel drainage before a restart is attempted.

b. Operation. Move the control lever to the operate position and allow the turbine to accelerate to full running speed (40–45000 rev/min.) before applying a load.

Warning. Monitor oil pressure and JPT during operation.

c. Shut-down. Move the control lever to the start position. The engine is now over-running its fuel supply and drawing cool air through the turbine causing the JPT to fall from about 600°C to about 350°C before idling speed is reached. *As soon as* the temperature falls sufficiently, or idling speed is reached, set the control lever to 'stop' and allow the turbine to shut down. Close the fuel cocks.

Warning. At standstill of the turbine the control lever must be left in the 'stop' position.



CHAPTER 5

GROUND HANDLING OF AIRCRAFT

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Introduction

1. In its natural element, the sky, an aircraft enjoys almost complete freedom of movement. Provided that the pilot accepts and abides by the rules that are designed to control traffic in the air and to eliminate the dangers of collision, the likelihood of an aircraft sustaining any form of damage during flight – apart from enemy action and the unpredictable bird strike – is rare. On the ground and out of its natural environment the story is a very different one. In the relatively confined space of the normal airfield, surrounded by domestic buildings, hangars, other aircraft and their servicing support equipment, the risk of damage by collision is very real indeed.

2. When on the ground and moving under its own power the safety of the aircraft is firmly in the hands of the taxying pilot. He, in turn, relies upon a *marshalling team* for safe guidance to and from an allotted parking area. Once the aircraft is parked, the onus shifts from the pilot to the appointed ground crew who, by adopting the approved handling techniques, are tasked with making the aircraft safe to work upon and fully protected from the vagaries of the local weather. Should this mean that, subsequently, the aircraft has to be moved to a servicing hangar or similar shelter, a qualified handling team will ensure that the move takes place smoothly and with safety.

3. Perhaps the simplest way of dealing with the events which are likely to occur during an aircraft's spell on the ground, is to follow the progress of an aircraft from the moment of landing to eventual take-off, creating in the meantime situations which take in the various aspects of aircraft ground handling. To begin with, let it be assumed that the aircraft has completed its sortie, is clear of the runway, and is taxying towards the appointed parking area. This destination could be any one of a number of paved areas on the airfield that are specially designed for the accommodation and day-to-day servicing of aircraft. On the taxiway the aircraft is still under the direction of Air Traffic Control who not only tell the pilot where he is to go but also the precise route he is to take. As he proceeds, the pilot is guided by lines marked on the taxiway; the centre of the track is usually indicated by a broken yellow line whilst the edges of the taxiway, if not clearly defined, may be highlighted by continuous yellow lines (Fig. 1). At night the lines give way to coloured lights, green for the centre line, and blue or amber for the taxiway edges.

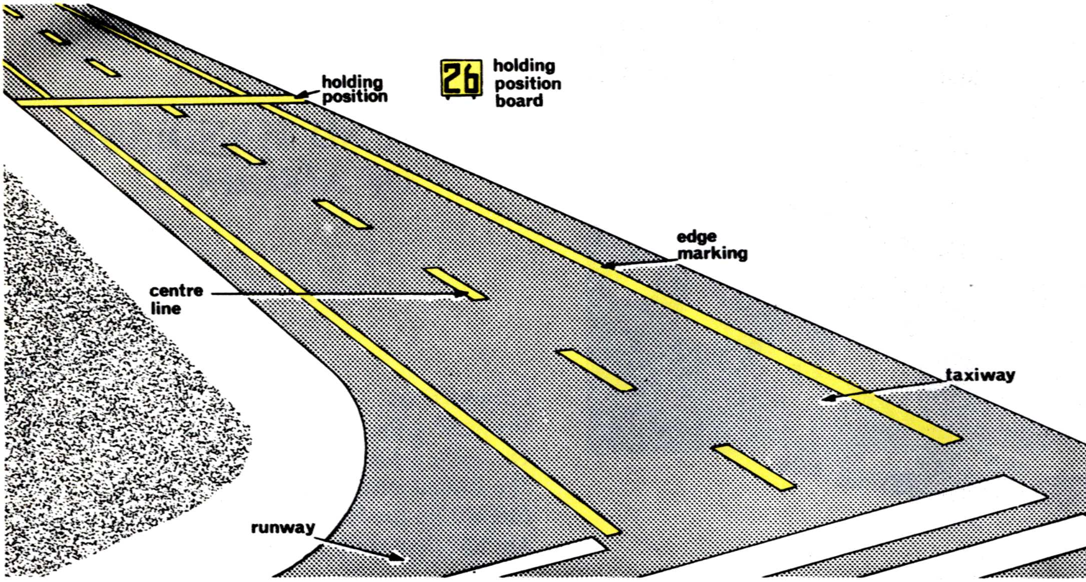


Fig. 1. Taxiway Markings

Marshalling the Aircraft

4. Even before the aircraft lands, preparations for its reception at the allotted parking area will be well in hand. A particular slot is allocated for the aircraft and the area cleared of any obstructions; the attendant safety and support equipment is moved to a safe, yet convenient distance. If the landing

Fig. 2. Parking Area Lights

takes place at night, all the necessary lighting in the reception area is switched on. This includes ground-level sodium lights, floodlights, and any coloured lights that may be installed to indicate the centre line and periphery of the parking area (Fig. 2).

5. A handling party, led by a senior NCO, is appointed to greet and marshal the aircraft to its parking position. Since the RAF has no specialist trade of 'aircraft marshaller', the handling party, often referred to as the 'duty crew', is made up of an adequate number of fully-trained aircraft tradesmen. In short, you and your colleagues. In anticipation of the aircraft's arrival, the SNCO briefs the marshallers on the route the aircraft is to take and directs them to their respective stations. Each marshaller is equipped with a yellow-orange waistcoat, which is intended to make him conspicuous, and when available two bats, similar to table-tennis bats, with which to make the appropriate signals to the aircraft pilot. At night the same signals are made using special illuminated wands (Fig. 3). When receiving aircraft fitted with gas turbine engines he will also, of course, be wearing ear defenders. As each marshaller reaches his particular station he will stand where he can be seen by the pilot when the aircraft reaches the area under his control. Since the pilots of large aircraft occupy the seat on the port side of the cabin, the safe standard marshalling position is one ahead of the aircraft and in line, approximately, with the port wing tip (Fig. 3). Whilst it may seem advantageous to stand directly ahead of the smaller, combat-type aircraft, where the pilot is able to look ahead as well as on either side, there is the hazard of the jet intake area to be considered. Any miscalculation of the extent of this danger area – particularly easy to do at night – could mean that there is indeed a marshaller 'dead' ahead.

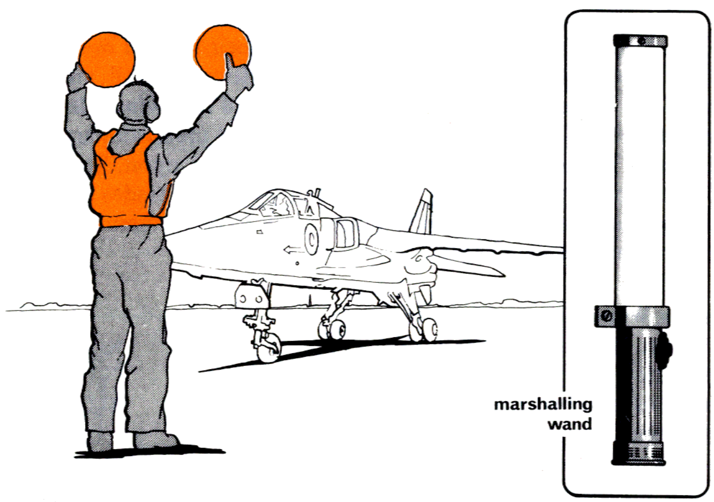


Fig. 3. The Marshaller

6. Once the aircraft leaves the taxiway it passes out of the hands of the Air Traffic Controller and, from this point on, its safe movement becomes a matter of teamwork between the taxying pilot and the marshallers. At the entrance to the parking area the aircraft is met by the first of the marshallers who attracts the attention of the pilot in the manner shown in Fig. 3. Having made contact with the pilot by what is virtually a 'this way please' signal, the marshaller proceeds to usher the aircraft forward whilst other members of the team take up positions at the wing tips of the aircraft. By using standard signals they will indicate clearance, or otherwise, to the pilot and the current marshaller. If the aircraft is required to taxy a considerable distance, marshallers will be spaced along the route and the aircraft passed from one marshaller to the next by the appropriate 'over to you' type of signal. In

this way the need for any one marshaller to walk backwards – a particularly dangerous practice in a busy parking area – is considerably reduced. From reception to final parking of the aircraft the marshaller is called upon to use a number of approved marshalling signals. The full range of signals, designed to cope with the marshalling needs of all types of RAF aircraft, is illustrated and described in the pull-out pages at the end of this chapter. The same relevant signals are also used when an aircraft is being towed or manhandled.

7. Once the aircraft is in position the pilot begins his shut-down procedure. This, for the groundcrew, marks the end of the marshalling duty and the beginning of the servicing task. However, before proceeding further it is, perhaps, appropriate at this point to emphasize just how important the marshalling duty is. Although it may not be, in the strict sense, a very technical job, it is nevertheless a very responsible part of your work on aircraft. To conduct a £1 million pounds aircraft through a crowded parking area without damage to itself or to its surrounds, is not a job to be tackled by the faint-hearted or under-trained. When called upon for marshalling duties make sure that you know the correct marshalling procedure and are fully conversant with the oncoming, or outgoing, aircraft – this means an appreciation of its size and peculiar features, knowing where its danger areas are, and its manoeuvring capabilities. Finally, and above all, take no risks.

The Parked Aircraft

8. When not required for flying, an aircraft is normally housed in a hangar. However, for short periods between flights, or longer periods when hangar space is not available, an aircraft may be parked in the open provided that it is both secure and weatherproof. Normally, the positioning of the aircraft for parking is determined by convenience and the ease of servicing. Of course there are exceptions – for instance, the larger transport type of aircraft with their tall and broad fin surfaces which are especially affected by strong, gusty winds. When these conditions prevail, and a choice of position is possible, such aircraft and others similarly affected, are headed into wind. Once the aircraft is in position, before any effective servicing can begin, several important precautionary steps need to be taken before the aircraft can be declared to be secure and safe to work upon. Strictly speaking, these are actions which are called for in the servicing schedules of particular trades but, in practice, it is often the responsibility of qualified members of the handling party to carry them out, checks being made by the specific tradesmen when servicing begins.

9. **Brakes and chocks.** When in position for parking, the movement of the aircraft is restricted by the application of the brakes and by placing chocks in front of, and behind, the main landing gear wheels. Once the chocks are in position the pilot may be signalled to release the parking brake to allow the wheel braking mechanisms, which are inevitably made hot during landing, to cool down. Care is needed when approaching wheels whose brakes have been applied excessively and are, therefore, dangerously over-heated. The danger of fire and, possibly, explosion exists even after the aircraft has stopped because of the time required for the wheel structure to cool. In these circumstances, or whenever overheated brakes are suspected, it is advisable when approaching aircraft wheels to proceed carefully from a fore-and-aft direction only (Fig. 4).

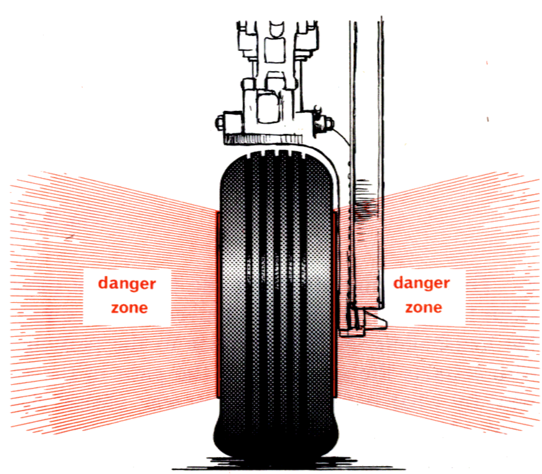
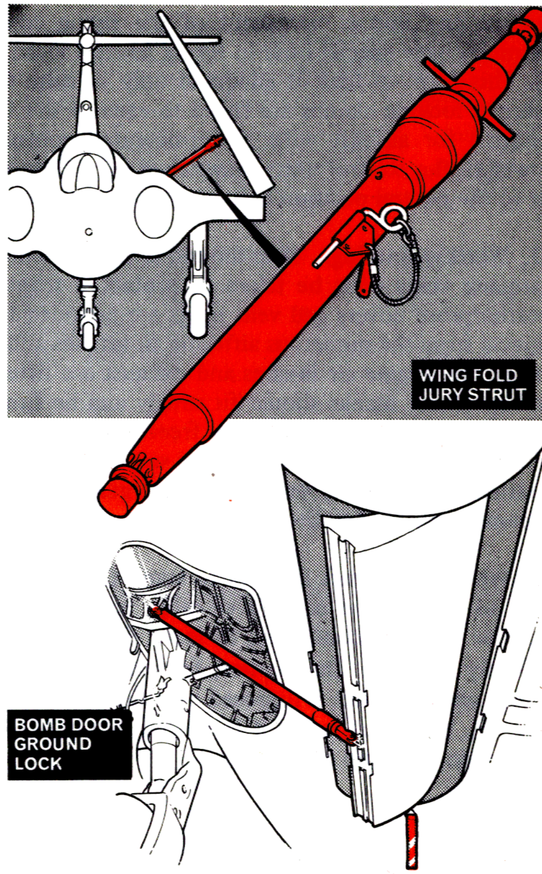


Fig. 4. Wheel Brake Hazard

10. **Ground locks and safety devices.** It is the pilot's responsibility before he leaves the aircraft cockpit to ensure that the explosively-operated ejection seat and canopy are made safe for parking. Clad in his bulky flying clothing he will experience some difficulty in doing this and will rely on the assistance of a qualified member of the handling party in transferring the safety pins from the stowage to their respective 'Safe for Parking' positions. The precise location of each position is set out in the aircraft's Safety and Servicing Notes. Ground safety locks in the shape of jury struts, sleeves, and bridge pieces, are used to make safe other potential danger spots. These items include the power-operated landing gear, air brakes, bomb doors, hinged cockpit hoods, and wing-folding mechanisms. The locks are fitted immediately after flight and, unless they are required to be removed for a particular servicing operation, remain in position until the aircraft is required for further flight. Each safety lock is painted red and has a distinctively-coloured warning pennant attached to it to attract attention during pre-flight checks (Fig. 5).

11. In the cockpit a special locking gear is used to secure the control column and rudder bar and so



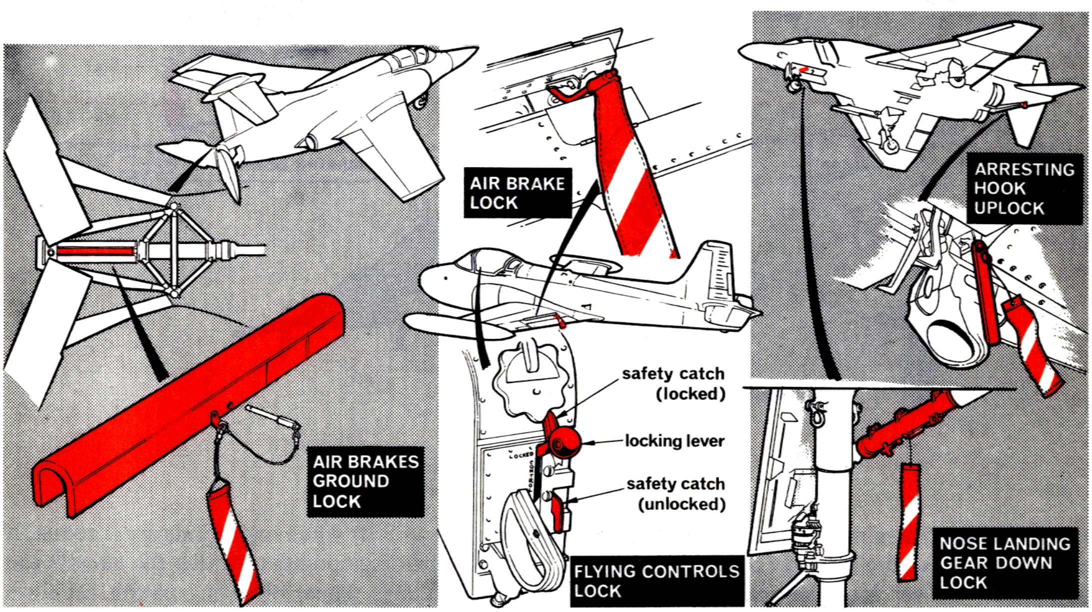


Fig. 5. Ground Safety Locks

prevent any undue movement of the flying control surfaces; some aircraft (the Jet Provost, for example) have special built-in flying control locks which are operated by a lever in the cockpit (Fig. 5). This form of lock is adequate only in calm weather conditions; in gusty conditions individual external locking clamps are fitted to each of the flying control surfaces. No flying control locks are required for aircraft with power-operated control surfaces. These are automatically locked when power to the control units is switched off. When parking such aircraft, the flying controls are to be set to the neutral position before switching off the control units.

12. **Weatherproofing.** If, at the end of the servicing tasks, the aircraft is to remain parked in the open, adequate steps must be taken to protect it from the harmful effects of the weather. A variety of weatherproof covers and vent plugs are provided to exclude moisture, dirt, stones, and other foreign objects from the numerous airframe air intakes and ducts. The rigid blanking boards specifically made to seal the engine air intakes and exhaust are fitted as soon as practicable after the aircraft has been parked. These blanks should fit snugly and be firmly secured. However, in wintry conditions, when there is a chance that they may freeze into position, a little of the appropriate de-icing fluid applied along the edges before being fitted will avoid having to subsequently use force to remove them. All weatherproof blanks, vent plugs, and guards are coloured bright red and some also have warning streamers attached to them.

13. Where an aircraft is likely to stand for a number of hours under strong sunlight, covers must be used to protect the cockpit or cabin transparencies. On the smaller, combat aircraft, it is common practice in these conditions to leave the cockpit hood open, provided that the cockpit itself is adequately shielded. The Harrier, for example, has its own sunshade. This is an umbrella-like cover which, when erected, is disposed over the top of the windscreen and under the front of the open hood (Fig. 6). When not in use it is stowed in a bag in the cockpit. Cockpit hoods are never left open in snow, rain, or damp conditions.

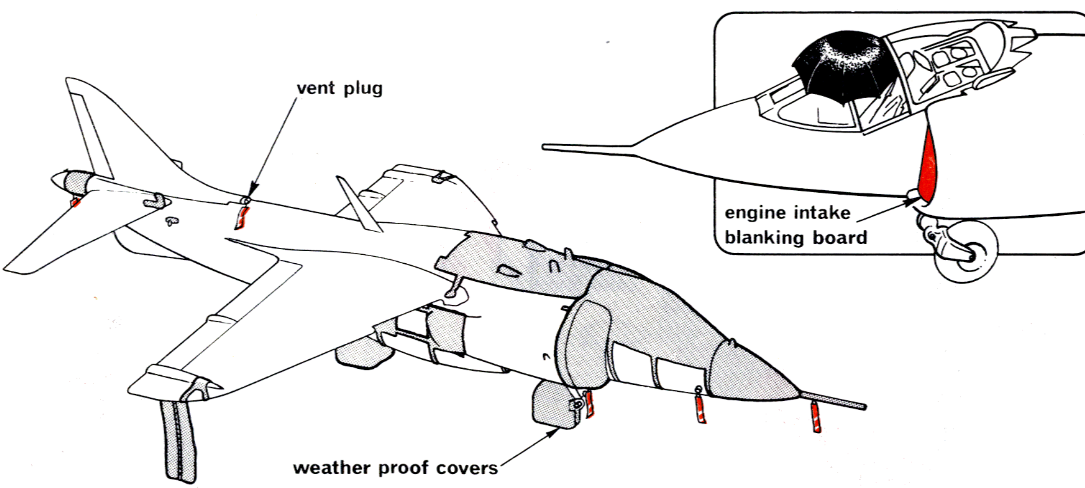


Fig. 6. Weatherproofing

14. **Picketing.** To minimize the risk of damage to the parked aircraft when high winds are forecast, it is necessary to secure it firmly to the ground by picketing. Anchorage points to which the aircraft can be secured are set into the concrete of the airfield hardstandings. These picketing points, set flush with the surface, are arranged in a symmetrical pattern which not only allows for the various types and size of aircraft, but also permits the aircraft to be headed, as near as possible, into the expected

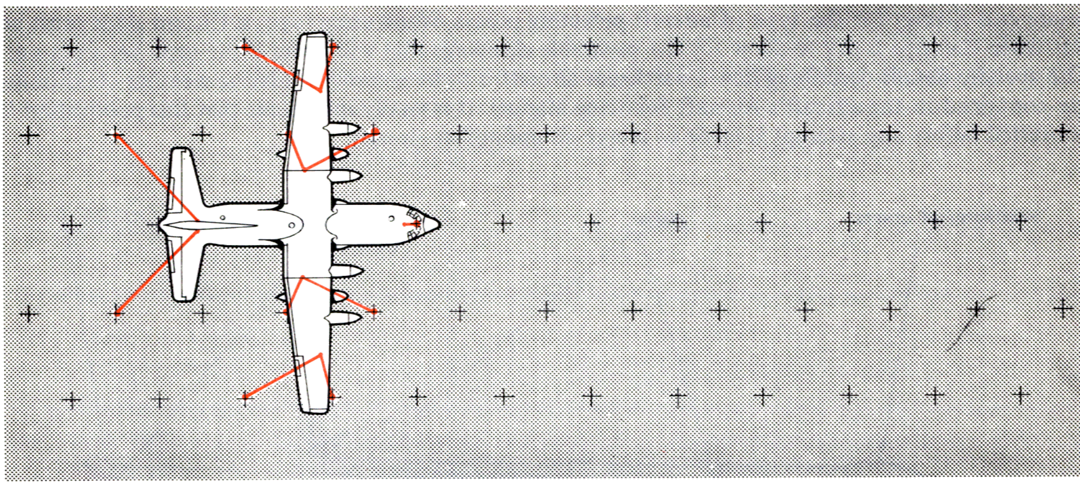


Fig. 7. Permanent Picketing Base

wind direction (Fig. 7). Further intermediate points of anchorage may be obtained by using picketing chains connected to adjacent picketing points. During hostilities, aircraft operating away from permanent picketing bases would either be flown out to suitable sites, or secured where they stand by spike or screw pickets driven into the ground.

15. The aircraft's picketing points are simply holes or attachment lugs provided in the stronger parts of the airframe to which shackles, ropes, or chains can be secured. The main anchorages which support the full aerodynamic load are usually situated on, or near to, the aircraft's landing gear. Other points, which are provided in the wings and fuselage, are designed to keep the aircraft in its correct position over the base anchorages and to resist the snatching and buffeting of the aircraft in gusty weather conditions. The location of each aircraft picketing point is indicated by the standard anchor symbol painted in a colour which contrasts with the aircraft's camouflage (Fig. 8).

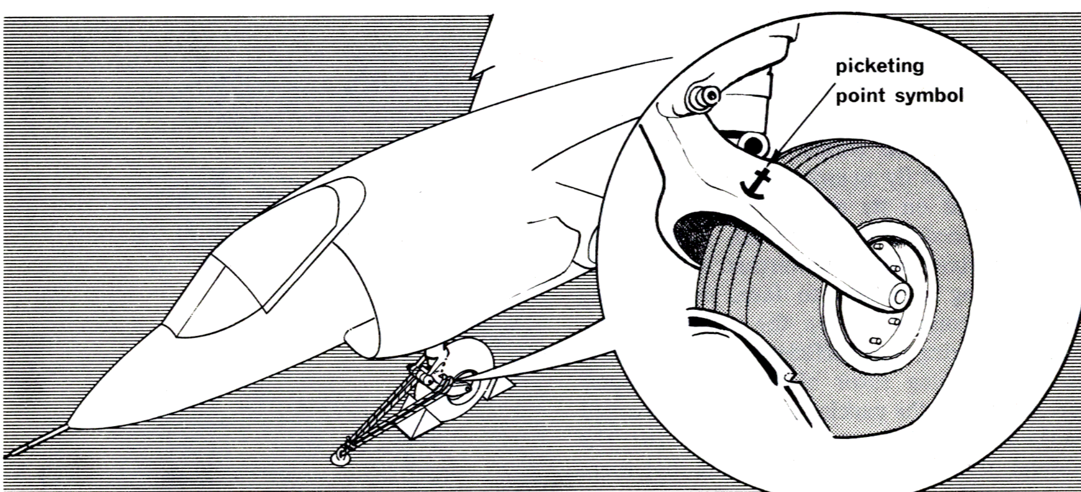


Fig. 8. Aircraft Picketing Point and Symbol

16. The aircraft is secured by lashings fastened to the base and aircraft picketing points (Fig 9). The lashings are of rope, steel cable, or chains, the cable and chains being made up in sets with the appro-

priate end fittings for the type of aircraft picketing points. When using rope, sufficient slack must be left when the rope is dry to allow for the inevitable shrinkage that will occur if the rope becomes wet. The specific details describing how a particular aircraft is to be secured in adverse weather conditions, are contained in the aircraft's Aircraft Servicing Manual. It is vitally important that this publication is consulted before any attempt is made to secure an unfamiliar aircraft.

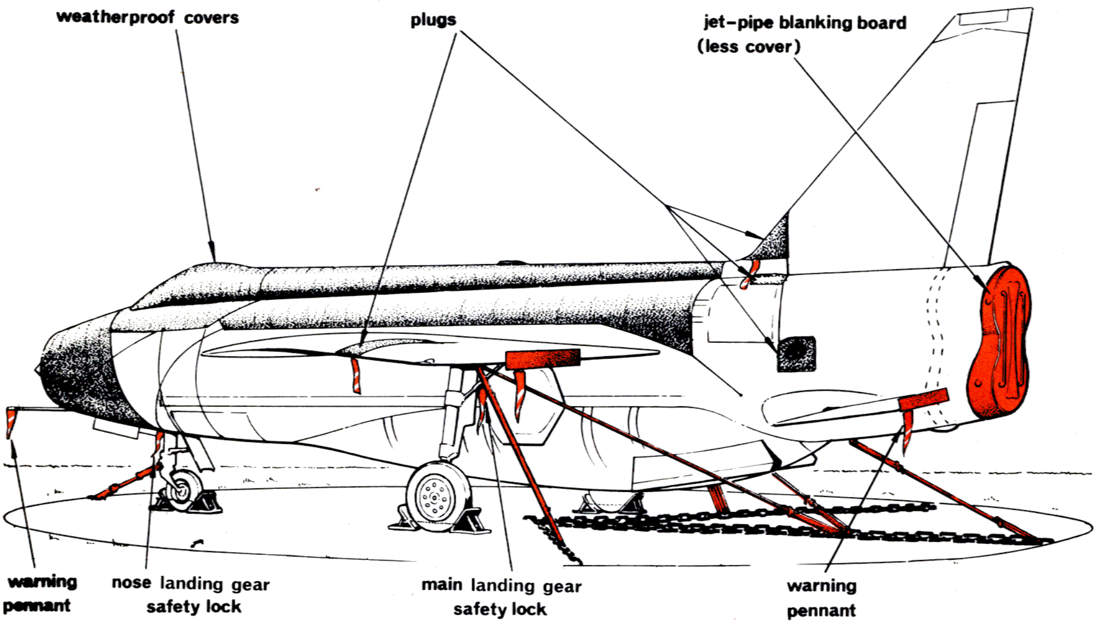


Fig. 9. Picketed Aircraft

The Parked Helicopter

17. The unique approach and manoeuvrability of the helicopter presents a different marshalling situation for which a separate set of signals is required. As one would expect with an aircraft which can fly in any direction, hover, and virtually land on its parking spot, the whole parking procedure is very much shorter than that of its fixed-wing counterpart. With few, if any, taxying problems to face, the handling party can concentrate on the major concern, that of ensuring that sufficient clearance exists for the whirling rotor blades. On helicopter parent stations the parking positions are marked on the surface of the parking area (Fig. 10). The interval between each mark ensures that there is ample clearance of the spread main rotor blades of each aircraft. When the aircraft is operating in forward areas, suitable landing sites allowing adequate clearance from obstructions would be cleared by the supporting groundcrew.

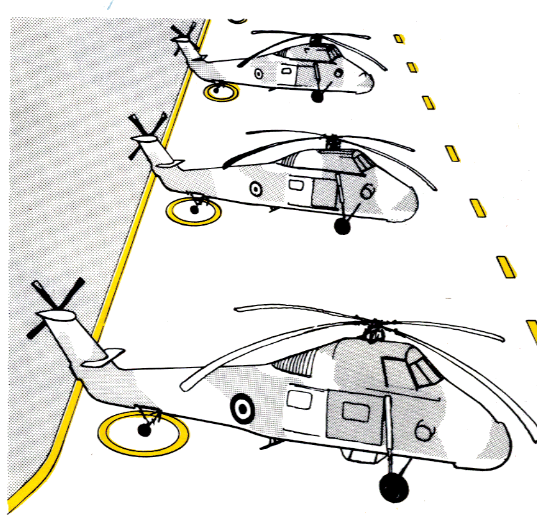


Fig. 10. Helicopter Parking Area

18. On touching down successfully, the pilot completes his shut-down procedure, which includes applying the parking brakes, shutting the engine down, and stopping the rotors by means of the rotor brake. He also locks a lever, called the 'collective pitch lever', which is used to control the individual movement or pitch of the main rotor blades. From here onwards the same principles of parking safety and security that are used in handling fixed-wing aircraft apply equally to the helicopter. The major difference, of course, is in the handling of the rotor blades. The main rotor blades, which on current helicopters reach up to 25 feet in length, droop considerably under their own weight when they eventually come to rest. Consequently, very great care is needed when handling to avoid adding to the strain which is already imposed on the main rotor mechanism. Whenever practicable, the rotor blades are moored by releasing the rotor brake and using the correct tools to move the blades and fit the blade tip covers (Fig. 11). In securing the ropes to the attachment brackets on the aircraft, every care is needed to ensure that the blade tip is not pulled down unduly. The tail rotor is immobilized by a special strap moored to a bracket on the side of the fuselage. Some helicopters, the Wessex for example have special gust locks which can be fitted to prevent the flapping of the tail rotor blades.

19. When a helicopter is to remain in the open with the blades spread for an extended period, it is made secure by picketing. This means that – in addition to applying the parking and rotor brakes, locking the tail wheel, positioning the chocks, and mooring the rotor blades – flying control locks have to be fitted in the cockpit, covers placed in position, and the aircraft tied down as shown in Fig. 11. You will note, in the illustration, it has been assumed that the aircraft is operating 'in the field', hence the use of screw-type pickets.

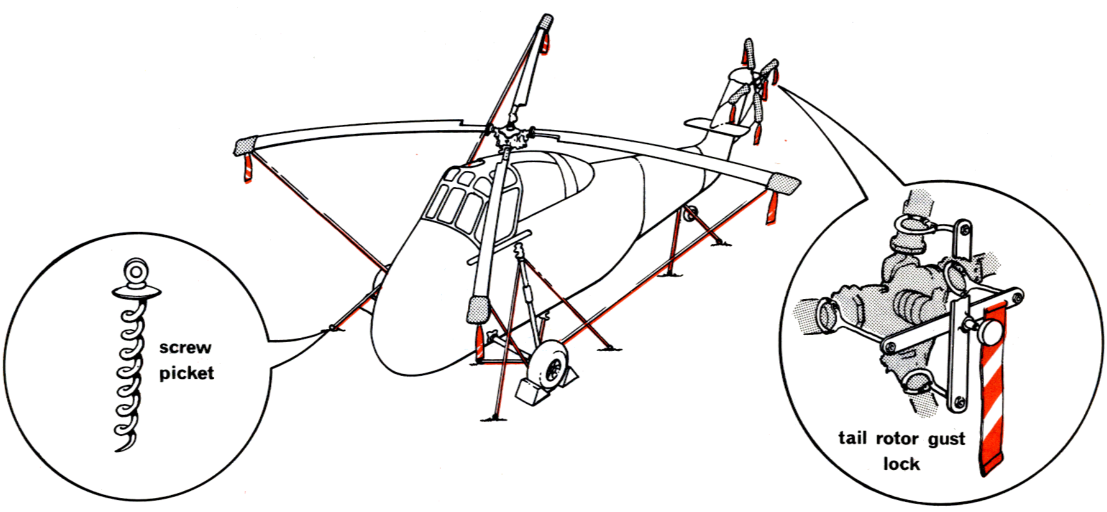
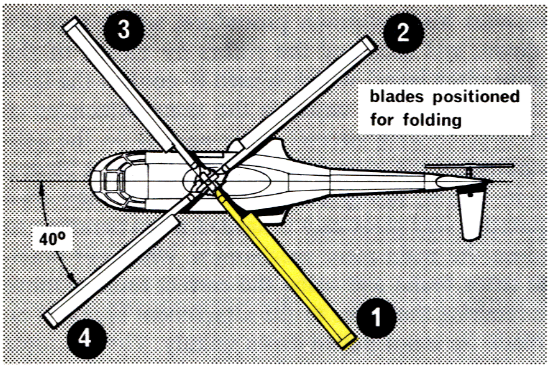
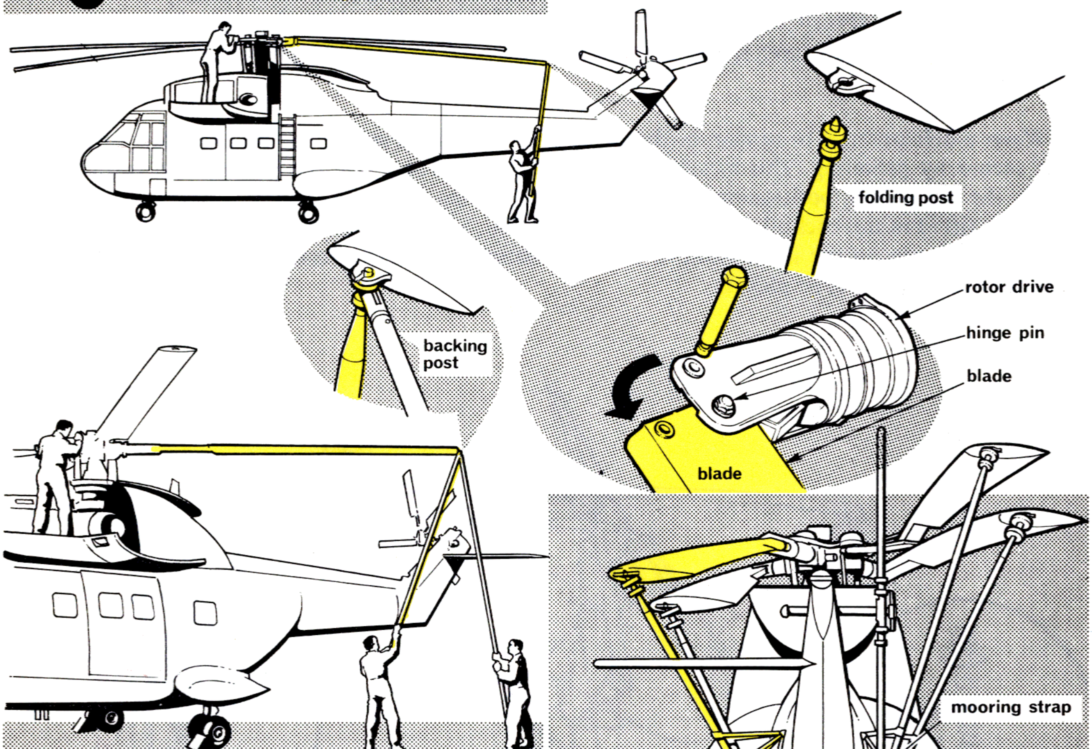


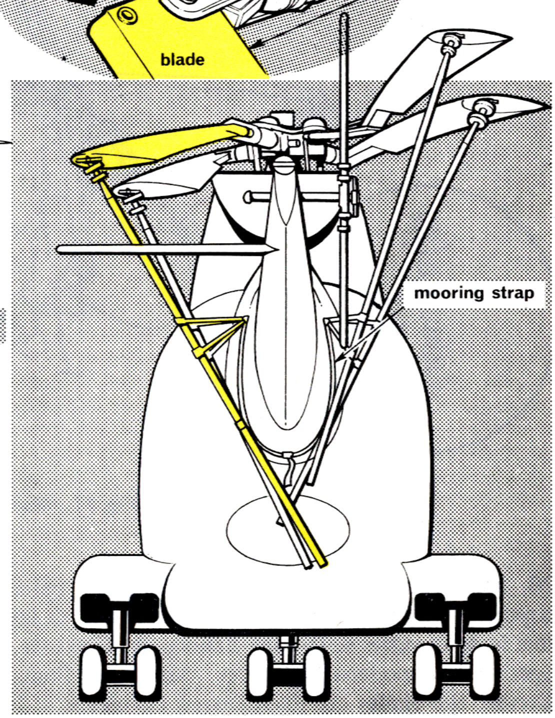
Fig. 11. Wessex Picketed

20. **Main rotor blade folding.** To reduce the space required for parking, servicing, or storing a helicopter, the main rotor blades can be folded to lay back along the side of the fuselage. Precisely how this is done varies with each helicopter. However, to illustrate the general principles involved in the operation, a modern helicopter, namely the Puma, is used as an example (Fig. 12). On this particular aircraft the blades are manoeuvred by means of long folding posts which, at the end of the folding process, are secured to the fuselage where they remain to support the weight of the folded blades. Assuming that the aircraft has been parked correctly, the stages in the blade folding procedure are:



- Release the rotor brake, rotate the blades to the correct position for folding and then reset and lock the rotor brake.
- Attach the appropriate locking tools, dampers, and stops to the main rotor mechanism.
- Supporting the weight of blade (1) using the folding post, remove the foremost of the two pins attaching the blade to the rotor drive. The pin remaining in place then becomes the folding hinge.





- Move blade (1) back and, at the end of the folding travel, hook the folding post on to the fuselage bracket. During this latter part of the operation, the weight of the blade is supported by an assistant using a backing post.
- Repeat the manoeuvre for blade (2) and, when the folding post is hooked in position, secure it to the other post in position with a mooring strap.
- Fold and secure blades (3) and (4) and posts in the same way.
- Finally, for safe custody, loosely insert in their respective sleeves, the four blade attachment pins that were removed.

Fig. 12. Helicopter Main Rotor Blade Folding

Aircraft on the Move

21. Eventually the aircraft will need to be moved from its parked position to the hangar, either to seek shelter or for servicing purposes. When this arises, the task will be undertaken by a handling party consisting of a supervising senior NCO and sufficient groundcrew to control and witness the safe movement of the aircraft. The size of the party is all-important, for whilst to employ an insufficient number is positively dangerous – indeed a move should never take place in such circumstances – too many can cause confusion and also result in chaos. The precise number of persons required to accomplish the move will depend upon the size and type of aircraft and how it is to be moved. Occasionally, when faced with de-bogging an unfortunate aircraft, an additional factor to be considered is the nature of the ground over which the aircraft has to travel. Consequently, the first task of a SNCO who is authorized to move an aircraft is to assemble a handling party that is adequate, both in number and ability, to cope with the task.

22. If the aircraft is to be *towed* his minimum personnel requirements will be:

- **a qualified driver** who is fully conversant with the towing equipment and competent to tow the aircraft to be moved. Like all other members of the handling party he is required to follow the instructions of the SNCO supervising the move.
- **a man in the cockpit** who is competent to operate and pressurize the aircraft brake system. Throughout the move he remains in visual and aural contact with the SNCO and operates the brakes, and any other cockpit controls and switches, as directed by the SNCO.
- **a man at each wing tip** who will maintain a careful watch for any obstruction in the aircraft's path and give a prompt and adequate warning of such a danger to the SNCO.
- **a man at the tail** who will ensure that there is always sufficient clearance between the tail unit and any overhead obstructions.

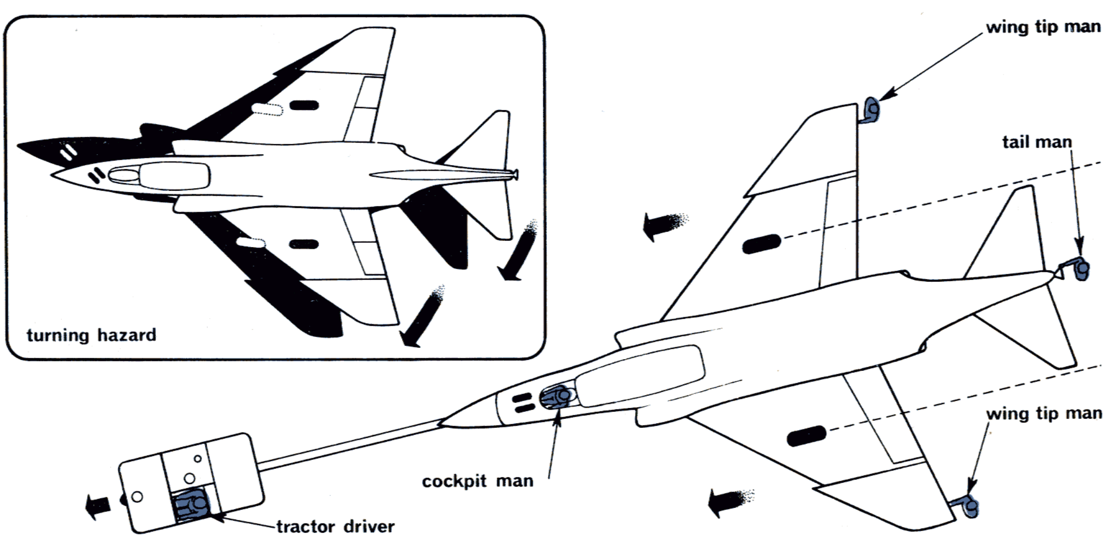


Fig. 13. Aircraft Towing

23. The illustration at Fig. 13 shows these key men in position for the forward towing of a Phantom aircraft. It also highlights the turning hazard associated with a swept wing aircraft. It can be seen that whilst the aircraft may clear obstructions when moving straight ahead or astern, an additional allow-

ance – sometimes referred to in Flight Safety literature as 'wing-tip growth' – is needed when the aircraft is turned. On being towed rearwards, a similar clearance may be required to allow for the 'swing-out' of the aircraft nose.

24. Although in every kind of aircraft movement the key positions indicated in Fig. 13 are relevant, the actual duties of the members of the handling party are governed by the type of aircraft and the circumstances of the move. For instance, if the same Phantom aircraft had to be manhandled instead of being towed, then the tractor driver's place would be taken by a member of the handling party with a steering arm, and the motive power supplied by as many as fifteen groundcrew pushing at selected 'push points'. As a further example, in Fig. 14 the movement of a Wessex helicopter illustrates how the towing forward or rearward of an aircraft can affect the actual work of the members of the handling party. The figure, which excludes the supervising SNCO who will be in a position where he can be seen by all members of the team, shows that whereas a minimum of five persons are required for towing the aircraft forward, only four are required to tow it in the opposite direction. In both cases the duties of the wing tip men are taken over by one man on the transmission servicing platform who is able – when the rotor brake is off – to turn the main rotor head to avoid any obstructions that are likely to foul the rotor blades. In towing the helicopter rearwards the steering arm and its operator give way to a towing arm and a tractor driver. In both examples these are the *minimum* requirements; extra handlers will be required as look-outs when the aircraft is manoeuvred through a crowded dispersal area, or a restricted opening, and to assist in pushing as required.

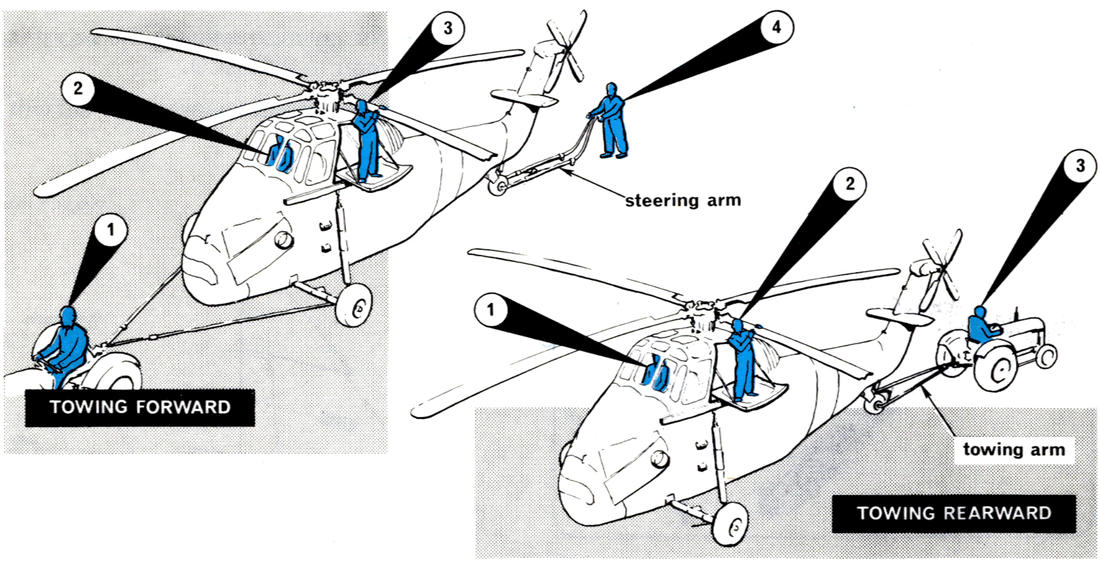


Fig. 14. Wessex Towing

25. **Towing equipment.** Having satisfied his personnel requirements, the attention of the SNCO now turns to the equipment needed. On the normal hardstandings of permanent airfields most RAF aircraft are towed forward by means of a rigid arm or bar attached to the nose wheel axle. With the aircraft's nose wheel steering mechanism disengaged, steering during the towing operation is automatic as the aircraft follows the track of the towing vehicle. Should any excessive resistance occur during towing, damage to the aircraft is prevented by a safety release mechanism which will automatically disengage the towing arm. When towing forward from the nose wheel is impracticable, the aircraft may be towed

rearwards by means of cables, or chains, attached to the main landing gear and using a steering arm at the nose wheel for manual steering. The towing of the Wessex helicopter (Fig. 14) illustrates the methods used to tow the few types of aircraft remaining in the RAF which have a tail wheel.

26. Towing arms or bars fall into two main categories: those that are adaptable for use on the number of aircraft of similar size, and those that are special-to-type and can only be used for one particular aircraft. The illustration at Fig. 15 shows an example of an adaptable type which is used for towing Harrier, Phantom, Buccaneer, and Lightning aircraft. The adjustable forked end of the tow bar is fitted with four-position turrets which can be rotated to fit the nose-wheel axles of the various aircraft. At the other end of the bar is the towing eye and the safety shear pin which is designed to fracture when an excessive load is applied to the aircraft nose wheel leg. Two shear pins are supplied for use with this tow bar and spares are carried in the stowage on the side of the bar. One pin is designed to fracture at 8500 pounds/force and coloured red; the other at 6800 pounds/force and is coloured blue. An informative tablet on the side of the tow bar indicates the particular shear pin to be used with each aircraft and the condition of the towing eye when a **shear pin failure** occurs.

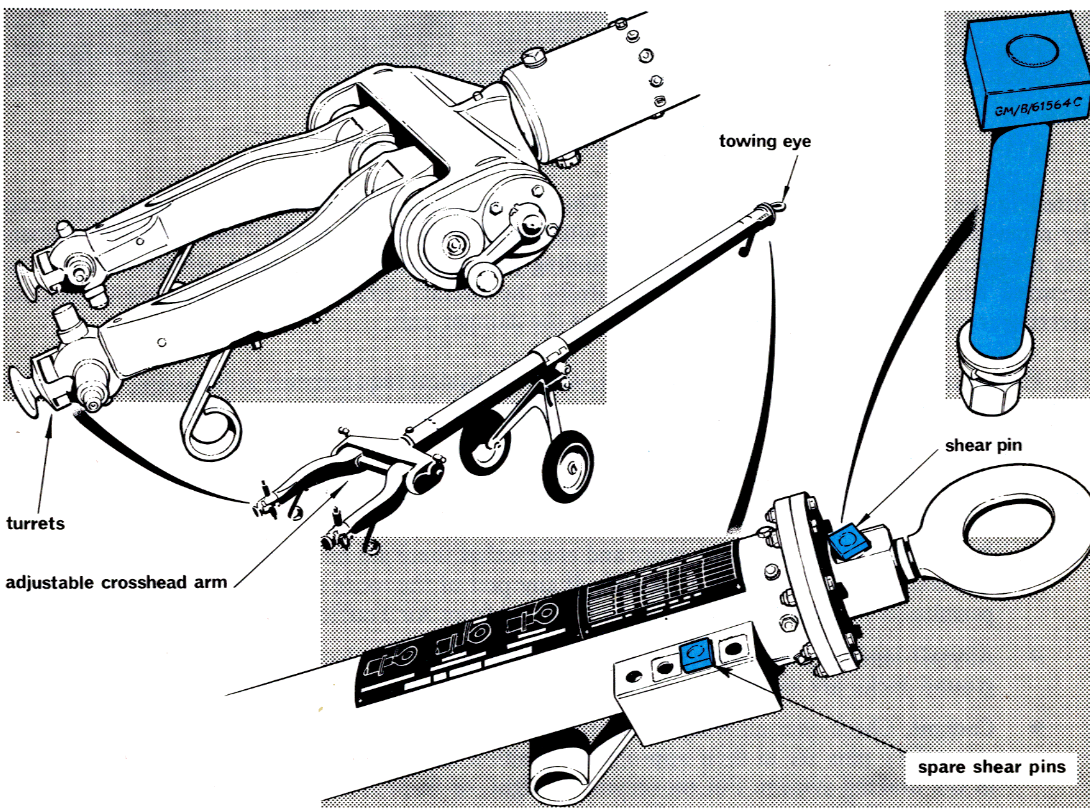


Fig. 15. Adaptable Tow Bar

27. As an example of the special-to-type towing arm, Fig. 16 illustrates the versatile equipment used to tow and steer the Puma helicopter. The complete towing arm assembly, consisting of a steering arm and a spring-loaded damper unit, is used for towing the helicopter on airfield hardstandings and ground over which it could normally taxi under its own power. Over softer ground the aircraft is towed rearwards using cables, arranged as bridles, attached to the main landing gear and with the steering arm

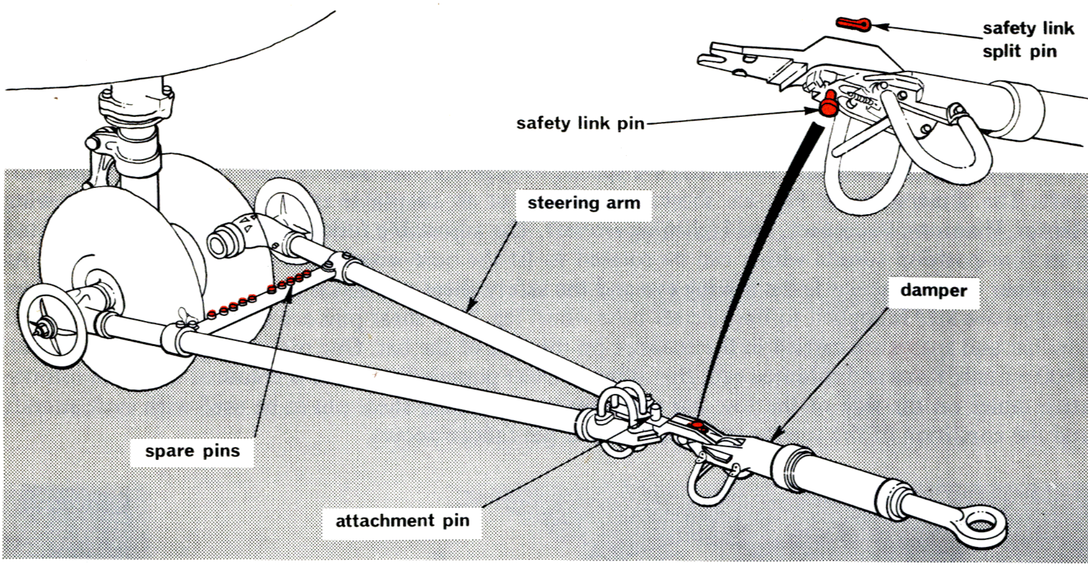


Fig. 16. Puma Tow Bar and Steering Arm

fitted to the nose wheel for manual steering. The steering arm can be separated from the damper unit by removing the connecting pin. In common with all other towing arms, the Puma towing equipment has a safety link shear pin to protect the landing gear against any abnormal stresses likely to be incurred when pulling, pushing, and even turning the aircraft. When the safety link pin breaks, the steering arm becomes completely detached from the damper unit.

28. **Preparation for the move.** At this point, with all physical requirements at hand and in a serviceable condition, consider now the precautionary checks the SNCO is bound to make before the move can actually begin.

- **MOD Form 700.** Consult the Aircraft Servicing Form (MOD F700) and ensure that the aircraft is in a safe condition to move.
- **Route.** Study the proposed route and ensure that there are no obstructions and that the surface is suitable for the type of aircraft. If any part of the route necessitates using the taxiway, permission to enter this area must be obtained from Air Traffic Control.
- **Aircraft landing gear.** Make sure that the landing gear is selected 'Down' and the necessary ground locks are in position. Check that the tyres are serviceable and correctly inflated.
- **Cockpit.** Check that all weapons switches are set to the 'safe' position and that the ejection seat safety pins are in their appropriate position. Ensure that sufficient pressure is available in the braking system. For movement at night, or in poor visibility, switch on the aircraft's navigation lights.
- **Airframe.** Check that all access panels, doors, and hatches are closed and that all external power is removed from the aircraft.

29. **Towing the aircraft.** With all preparations and safety checks completed to the satisfaction of the supervising SNCO, each member of the handling party takes up his appointed station and the aircraft is made ready to move. Assuming that the aircraft is to be towed forward in the normal way by means of the aircraft nose wheel, the first step is to disconnect the nose wheel steering mechanism and attach the towing arm, fitted with the appropriate safety shear pin, to the nose wheel axle (Fig. 17). (In the

case of an aircraft with a tail wheel, being towed rearwards, the tail wheel lock would be released before attaching the towing arm). When the other end of the towing arm has been connected to the towing vehicle, the retractable wheels of the arm can be raised until sufficient clearance for towing is obtained.

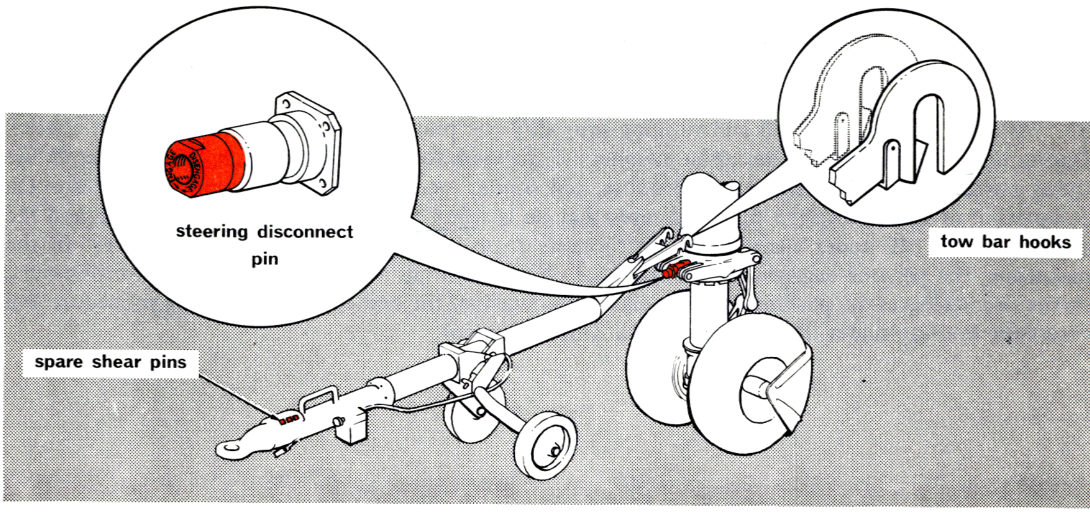


Fig. 17. Attachment of Tow Bar

30. Satisfied that the towing area is completely clear, the supervising SNCO will instruct the chocks to be removed from the wheels, the aircraft brakes to be released, and signal the driver of the towing vehicle to take up the load progressively and move off. Once under way, the towing speed over a hard level surface should be little more than a brisk walking pace, about 5 mph. When towing over softer ground, or on snow and ice which could seriously reduce the braking efficiency, even this slow speed should be reduced. Aircraft towing should be a smooth operation, avoiding any sudden acceleration, slowing down, or jerky movement since not all towing arms are fitted with damping devices to absorb the shocks involved. Any kind of turn will place an unusual load on the structure of the aircraft's landing gear. These dangerous loads increase very rapidly with the tightness of the turn, particularly in the tandem bogie landing gear of the type fitted to most large RAF aircraft. For this reason, it is essential that the number of turns of all kinds made during towing is kept to the very minimum, and those that have to be negotiated made as smooth as possible. Each aircraft has its own steering limits and minimum turning radii which are clearly set out in the particular Aircraft Servicing Manual.

31. Throughout the move the SNCO will be in a position to give instructions to the tractor driver and the man in the cockpit and to receive the appropriate signals from the wing-walkers and tail man. On arrival at the hangar, or the new parking position, the nose wheel is centralized before coming to rest, brakes are applied, and chocks placed in front of, and behind, the main landing gear wheels. The towing arm is then removed and the aircraft nose wheel steering mechanism (or tail wheel lock) reconnected.

Aircraft Departure

32. The first requirement of an aircraft that is authorized to fly is that it undergoes a Before Flight inspection. In this task each relevant member of the Flight Servicing team ensures that, from his indi-

vidual trade viewpoint, the aircraft is serviceable and fully prepared for the proposed sortie. When the inspection and all preparatory work has been completed, the MOD Form 700 is duly signed and the aircraft accepted for flight. Meanwhile the Flight Servicing team stand by to carry out the final handling procedures and to assist the aircrew, as required, in their pre-flight external and cockpit checks. Once the aircrew are aboard and any access ladders removed to a safe distance, the NCO, or senior member of the team, establishes communication with the pilot and awaits instruction from him, either by signal or intercom, that he is ready to start the engine(s). At this point and throughout the engine-starting process, a person manning the CO_2 fire extinguishing trolley must be stationed close by the engine(s) concerned, and the whole team alert for any signs of fire and fluid leaks.

33. With the engine(s) started and running smoothly the pilot continues with his pre-flight checks. During this vital period he relies upon members of the team for confirmation that, when selected, the flying controls, flaps, airbrakes, bomb doors, and similar mechanisms are functioning correctly. On completion of the checks the pilot indicates that he is ready to go, the chocks are removed, and the aircraft moves off under marshalling instructions from the leader of the handling party. In the meantime, the persons engaged in removing the chocks take up wing tip stations to act as look-outs. As the aircraft leaves the parking area the pilot acknowledges the end of the marshalling procedure and enters the taxiway under the direction of Air Traffic Control.

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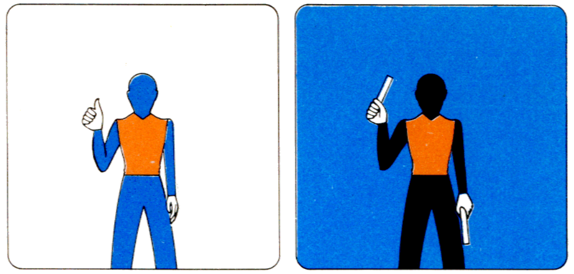
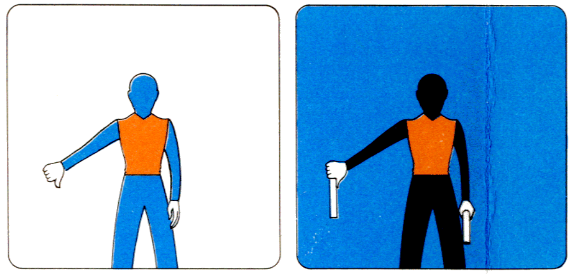
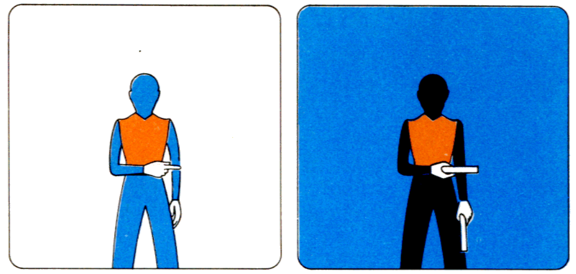
GENERAL MARSHALLING SIGNALS FOR ALL AIRCRAFT a.



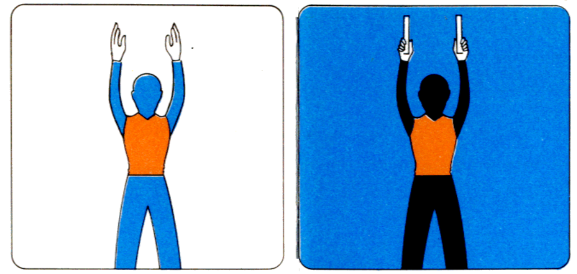
AFFIRMATIVE (ALL CLEAR)
HAND RAISED, THUMB UP.



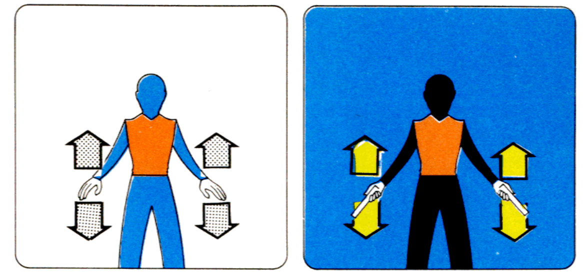
NEGATIVE (NOT CLEAR)
ARM HELD OUT HAND BELOW WAIST LEVEL, THUMB TURNED DOWNWARDS.



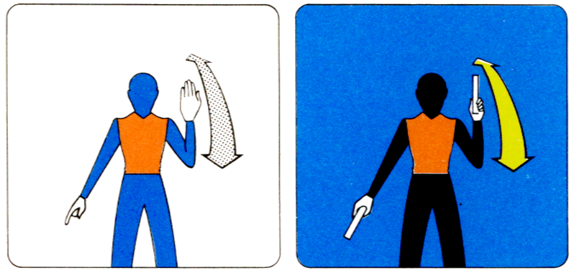
PROCEED TO NEXT MARSHALLER
RIGHT OR LEFT ARM DOWN, OTHER ARM MOVED ACROSS THE BODY AND EXTENDED TO INDICATE DIRECTION TO NEXT MARSHALLER.



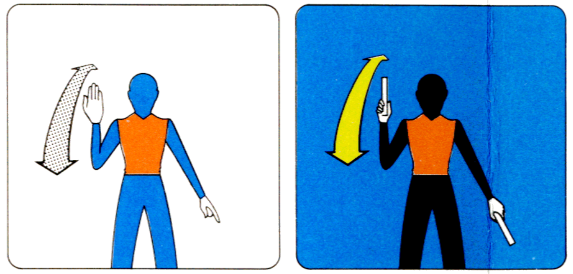
THIS WAY
ARMS ABOVE HEAD IN VERTICAL POSITION WITH PALMS FACING INWARD.



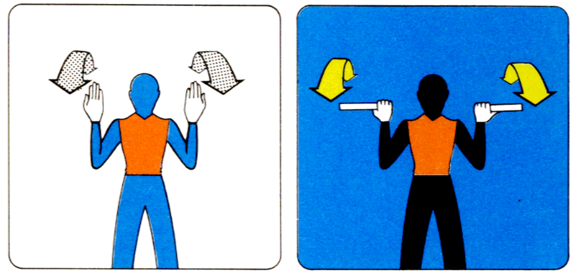
SLOW DOWN
ARM DOWN WITH PALMS TOWARDS GROUND, THEN MOVED UP AND DOWN SEVERAL TIMES.



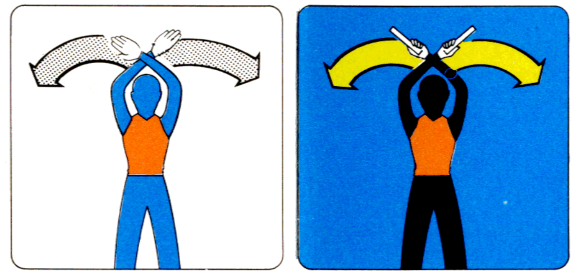
TURN TO LEFT
POINT RIGHT ARM DOWNWARD, LEFT ARM IS REPEATEDLY MOVED UPWARD-BACKWARD. SPEED OF ARM MOVEMENT INDICATING RATE OF TURN.



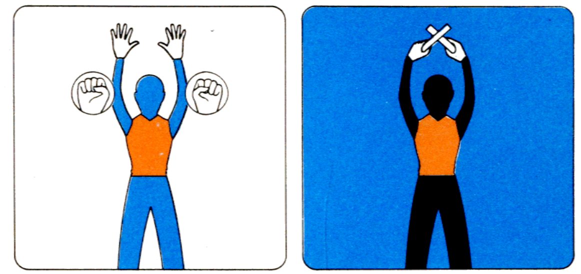
TURN TO RIGHT
POINT LEFT ARM DOWNWARD, RIGHT HAND REPEATEDLY MOVED UPWARD-BACKWARD. SPEED OF ARM MOVEMENT INDICATING RATE OF TURN.



MOVE AHEAD
ARMS A LITTLE APART, PALMS FACING BACKWARDS AND REPEATEDLY MOVED UPWARD-BACKWARD FROM SHOULDER HEIGHT.

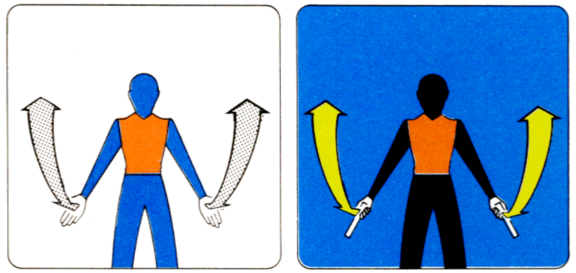


STOP
ARMS CROSSED ABOVE THE HEAD PALMS FACING FORWARD.

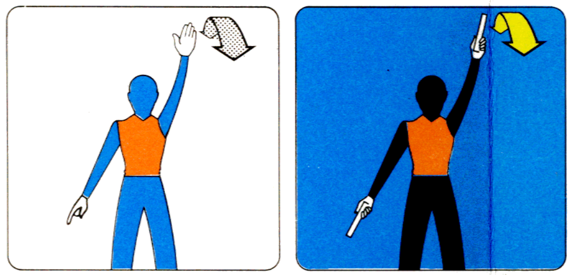


BRAKES – ON
DAY — ARMS ABOVE HEAD, OPEN PALMS AND FINGERS RAISED THEN FIST CLOSED WITH PALMS TOWARD AIRCRAFT
NIGHT— ARMS ABOVE HEAD, THEN WANDS CROSSED

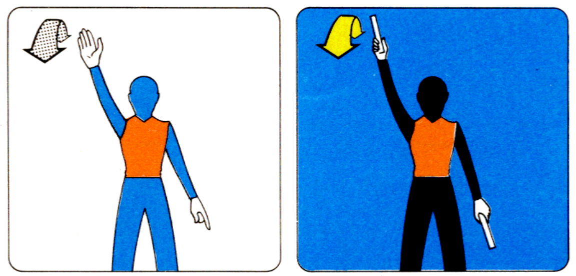
BRAKES – OFF
DAY — REVERSE OF ABOVE
NIGHT— CROSSED WANDS, THEN UNCROSSED



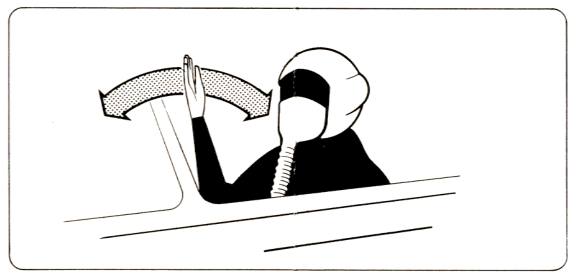
MOVE BACK
(ALSO USED TO PULL BACK AIRCRAFT UTILIZING ARRESTING WIRE)
ARMS BY SIDES PALMS FACING FORWARD SWEPT FORWARD AND UPWARD REPEATEDLY TO SHOULDER HEIGHT.



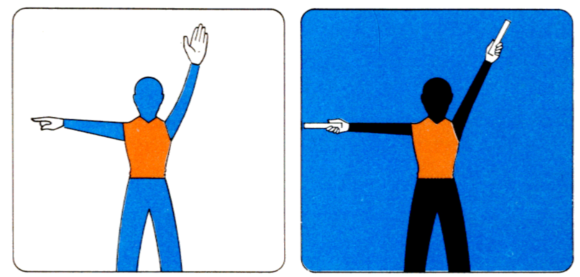
TURNS WHILE BACKING–TAIL TO LEFT
POINT RIGHT ARM DOWN AND LEFT ARM BROUGHT FROM OVERHEAD, VERTICAL POSITION TO HORIZONTAL POSITION, REPEATING LEFT ARM MOVEMENT



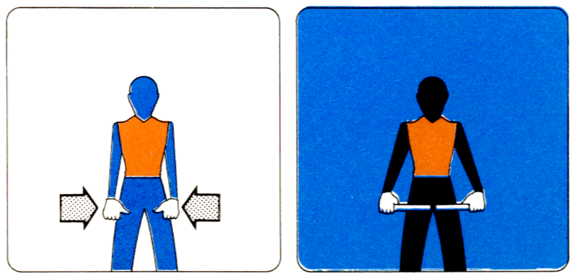
TURNS WHILE BACKING – TAIL TO RIGHT
POINT LEFT ARM DOWN AND RIGHT ARM BROUGHT FROM OVERHEAD, VERTICAL POSITION TO HORIZONTAL FORWARD POSITION, REPEATING RIGHT ARM MOVEMENT.



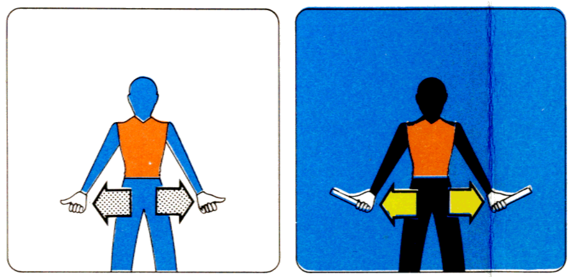
CLEARANCE FOR PERSONNEL TO APPROACH AIRCRAFT
A BECKONING MOTION WITH RIGHT HAND AT EYE LEVEL.



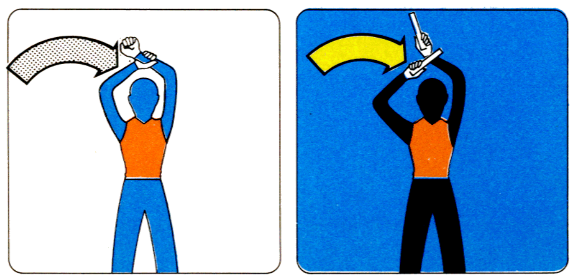
PERSONNEL – APPROACH THE AIRCRAFT
LEFT HAND RAISED VERTICALLY OVERHEAD, PALM TOWARDS AIRCRAFT. THE OTHER HAND INDICATES TO PERSONNEL CONCERNED AND GESTURES TOWARDS AIRCRAFT.



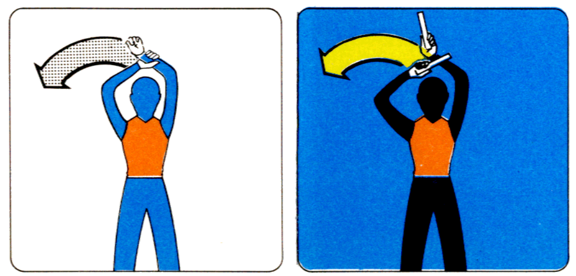
CHOCKS – INSERT
ARMS DOWN, FISTS CLOSED, THUMBS EXTENDED INWARDS SWING ARMS FROM EXTENDED POSITION INWARDS.



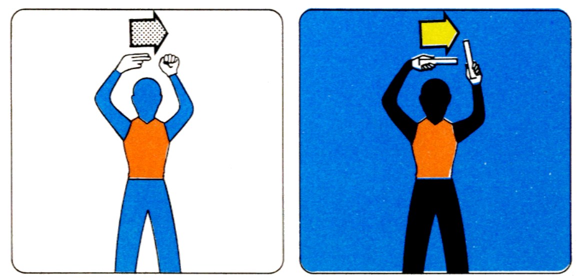
CHOCKS — REMOVE
ARMS DOWN, FISTS CLOSED, THUMBS EXTENDED OUTWARDS SWING ARMS OUTWARDS.



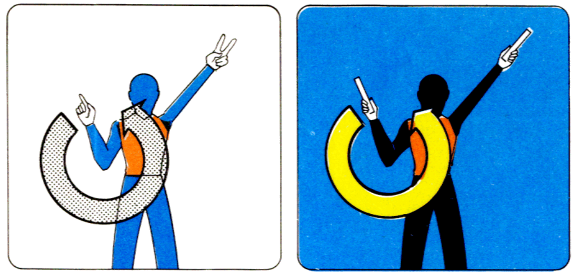
DOWN LOCKS/UNDERCARRIAGE PINS–INSTALL
WITH ARMS ABOVE HEAD. THE RIGHT HAND CLASPS LEFT FOREARM AND THE LEFT FIST IS CLOSED



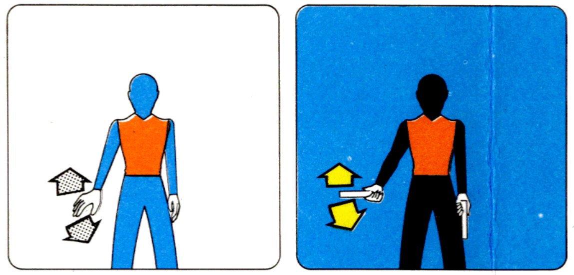
DOWN LOCKS/UNDERCARRIAGE PINS–REMOVE
WITH ARMS AND HANDS IN 'INSTALL-DOWNLOCKS' POSITION, THE RIGHT HAND UNCLASPS THE LEFT FOREARM.



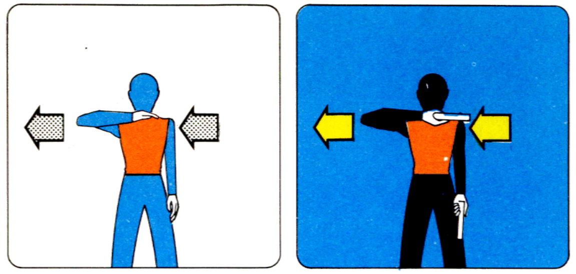
GROUND ELECTRICAL POWER SUPPLY–CONNECT
HANDS ABOVE HEAD, LEFT FIST PARTIALLY CLOSED, RIGHT HAND MOVED IN DIRECTION OF LEFT HAND WITH FIRST TWO FINGERS EXTENDED AND INSERTED INTO CIRCLE MADE BY FINGERS OF THE LEFT HAND.



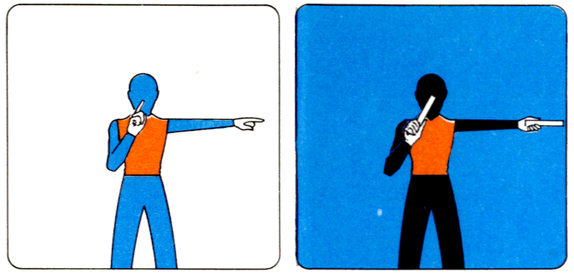
ENGINE(S) – START
LEFT HAND OVERHEAD WITH APPROPRIATE NUMBER OF FINGERS EXTENDED, TO INDICATE THE NUMBERS OF THE ENGINE TO BE STARTED, AND CIRCULAR MOTION OF RIGHT HAND AT HEAD LEVEL.



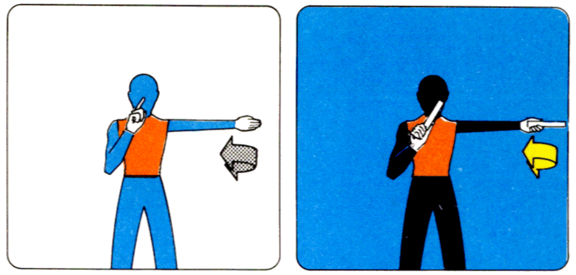
ENGINE(S) ON INDICATED SIDE – SLOW DOWN
ARMS DOWN WITH PALMS TOWARD GROUND, THEN EITHER RIGHT OR LEFT ARM WAVED UP AND DOWN INDICATING THAT LEFT OR RIGHT SIDE ENGINES RESPECTIVELY SHOULD BE SLOWED DOWN.



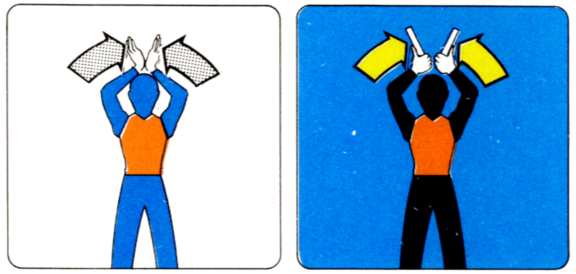
ENGINE(S) – CUT
EITHER ARM AND HAND LEVEL WITH SHOULDER, HAND MOVING ACROSS THROAT, PALM DOWNWARD. THE HAND IS MOVED SIDEWAYS WITH THE ARM REMAINING BENT.



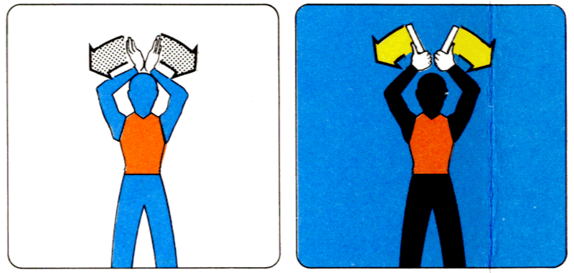
STEERING – ENGAGE NOSEGEAR
POINT TO NOSE WITH INDEX FINGER WHILE INDICATING DIRECTION OF TURN WITH OTHER INDEX FINGER.



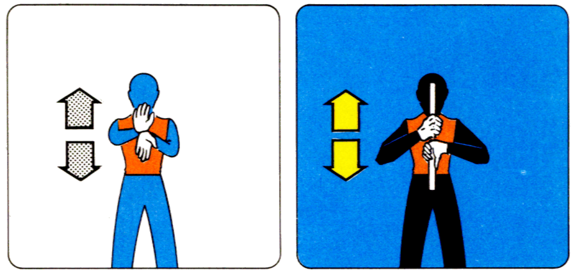
STEERING – DISENGAGE NOSEGEAR
POINT TO NOSE WITH INDEX FINGER, LATERAL WAVE WITH OPEN PALM OF OTHER HAND AT SHOULDER HEIGHT.



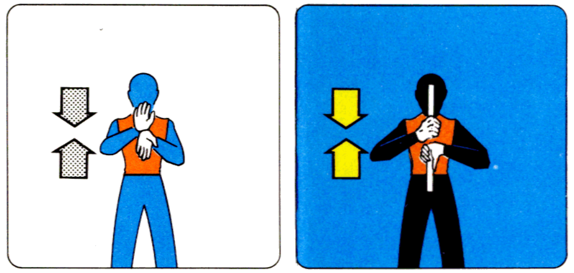
TAIL WHEEL – LOCK
HANDS TOGETHER OVERHEAD, OPENED FROM THE WRISTS IN A VEE THEN CLOSED SUDDENLY.



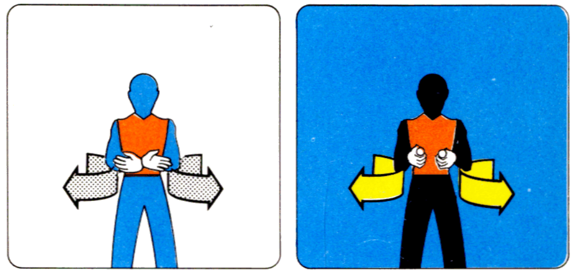
TAIL WHEEL – UNLOCK
HANDS OVERHEAD, PALMS TOGETHER THEN HANDS OPENED FROM THE WRISTS TO FORM A VEE WRISTS REMAINING TOGETHER.



WING FLAPS – LOWER
HANDS IN FRONT, PALMS TOGETHER HORIZONTALLY THEN OPENED FROM THE WRISTS CROCODILE-MOUTH FASHION.

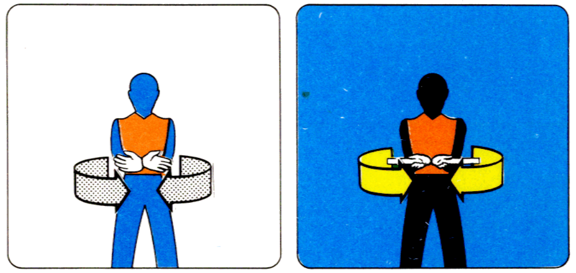


WING FLAPS – RAISE
HANDS IN FRONT, HORIZONTALLY. WITH PALMS OPEN FROM THE WRISTS, THEN SUDDENLY CLOSED.

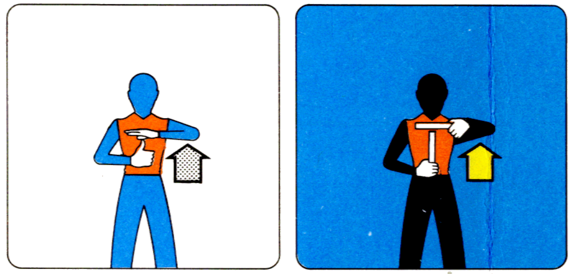


AIR BRAKES – OPEN
HANDS IN FRONT, PALMS TOGETHER VERTICALLY, THEN OPENED FROM THE WRISTS CROCODILE-MOUTH FASHION.

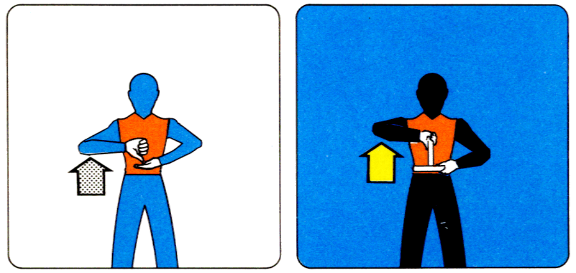
GENERAL MARSHALLING SIGNALS FOR ALL AIRCRAFT b.



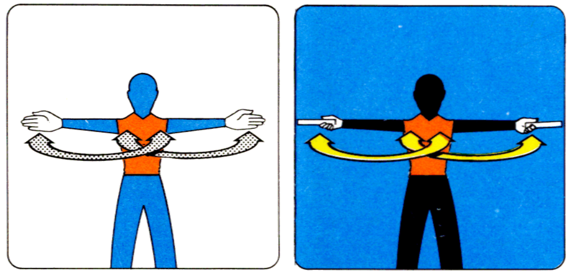
AIR BRAKES – CLOSE
HANDS IN FRONT, VERTICALLY WITH PALMS OPEN FROM THE WRISTS, THEN SUDDENLY CLOSED.



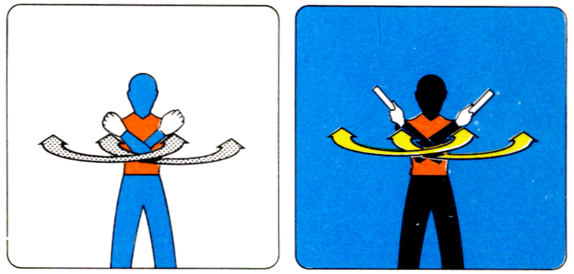
TAIL HOOK – UP
RIGHT FIST, THUMB EXTENDED UPWARD, RAISED SUDDENLY TO MEET HORIZONTAL PALM OF LEFT HAND.



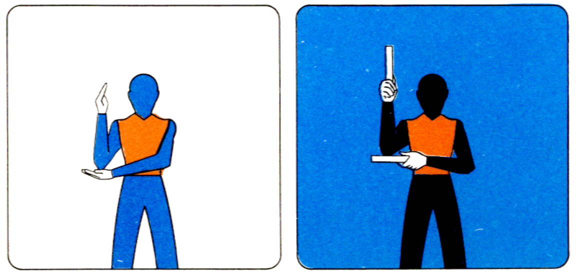
TAIL HOOK – DOWN
RIGHT FIST, THUMB EXTENDED DOWNWARD, LOWERED SUDDENLY TO MEET HORIZONTAL PALM OF LEFT HAND.



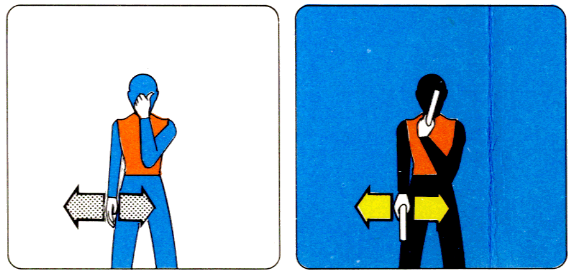
WINGS/HELICOPTER BLADES – FOLD
ARMS STRAIGHT OUT AT SIDES, THEN SWEPT FORWARD AND HUGGED AROUND SHOULDERS.



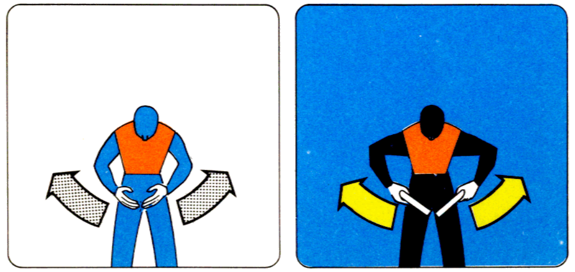
WINGS/HELICOPTER BLADES – SPREAD
ARMS HUGGED AROUND SHOULDERS, THEN SWEPT STRAIGHT OUT TO THE SIDES.



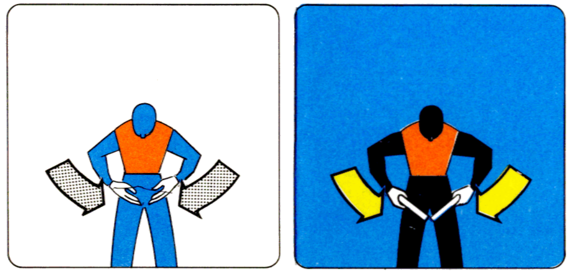
WINGS/HELICOPTER BLADES – LOCK
HIT RIGHT ELBOW WITH PALM OF LEFT HAND.



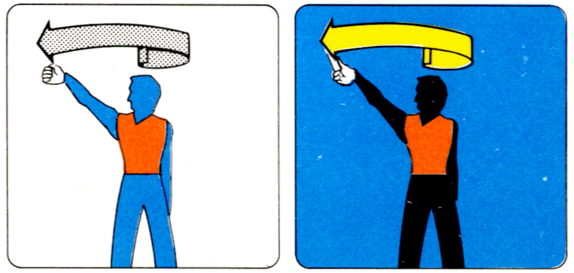
TILLER BAR/STEERING ARM IN PLACE
HOLD NOSE WITH LEFT HAND, RIGHT HAND MOVING HORIZONTALLY AT WAIST LEVEL.
a. THE AFFIRMATIVE SIGNAL IMMEDIATELY FOLLOWING SIGNALS MEANS: MAN IS TENDING BAR.
b. A NEGATIVE SIGNAL IMMEDIATELY FOLLOWING SIGNALS MEANS: NO ONE TENDING BAR.



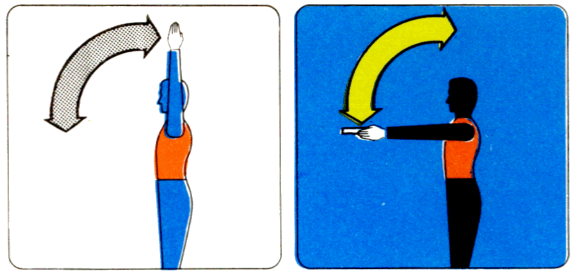
WEAPON BAY(S) DOOR(S) – OPEN
BODY BENT FORWARD AT THE WAIST, HANDS HELD WITH FINGERTIPS TOUCHING IN FRONT OF BODY WITH ELBOWS BENT AT APPROXIMATELY 45 DEGREES, THEN ARMS SWING DOWNWARDS AND OUTWARDS.



WEAPON BAY(S) DOOR(S) – CLOSE
BODY BENT FORWARD AT THE WAIST AND ARMS EXTENDED HORIZONTALLY, THEN ARMS SWING DOWNWARDS AND IN UNTIL FINGER TIPS TOUCH IN FRONT OF THE BODY WITH ELBOWS BENT AT APPROXIMATELY 45 DEGREES.

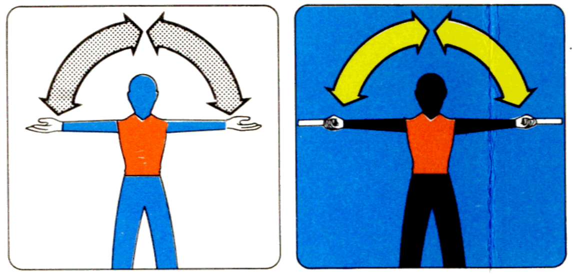


TAKE OFF
MARSHALLER CONCEALS LEFT HAND AND MAKES CIRCULAR MOTION OF RIGHT HAND OVER HEAD IN HORIZONTAL PLANE ENDING IN A THROWING MOTION OF ARM TOWARDS DIRECTION OF TAKE-OFF.



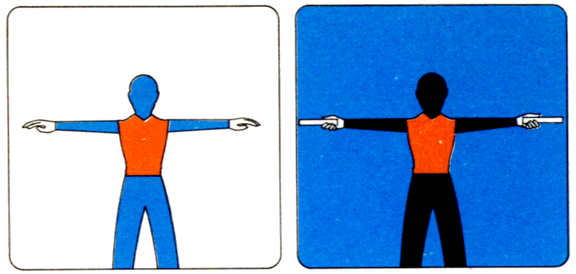
LANDING DIRECTION

MARSHALLER STANDS WITH ARMS RAISED VERTICALLY ABOVE HEAD AND FACING TOWARDS THE POINT WHERE THE AIRCRAFT IS TO LAND. THE ARMS ARE LOWERED REPEATEDLY FROM A VERTICAL TO A HORIZONTAL POSITION, STOPPING FINALLY IN THE HORIZONTAL POSITION.



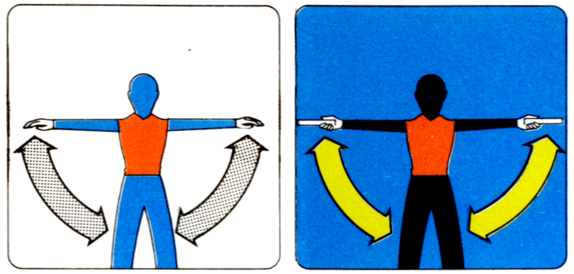
VERTICAL MOVEMENT–MOVE UPWARDS

ARMS EXTENDED HORIZONTALLY SIDEWAYS BECKONING UPWARDS, WITH PALMS TURNED UP. SPEED OF MOVEMENT INDICATES RATE OF ASCENT.



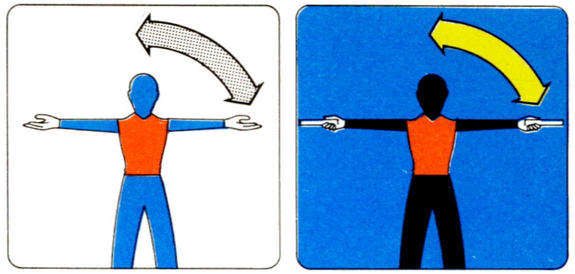
HOVER

ARMS EXTENDED HORIZONTALLY SIDEWAYS, PALMS DOWNWARD.



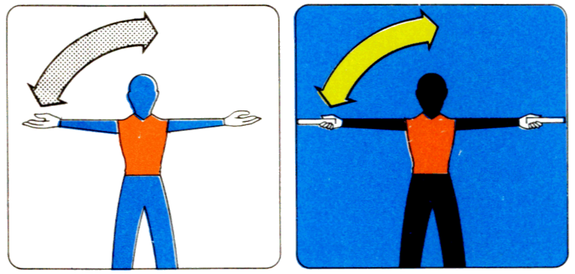
MOVE DOWNWARDS

ARMS EXTENDED HORIZONTALLY SIDEWAYS BECKONING DOWNWARDS, WITH PALMS TURNED DOWN. SPEED OF MOVEMENT INDICATES RATE OF DESCENT.



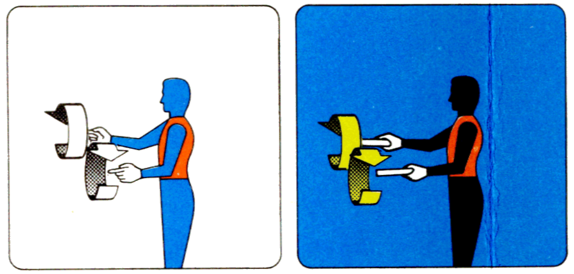
MOVE TO LEFT

RIGHT ARM EXTENDED HORIZONTALLY SIDEWAYS IN DIRECTION OF MOVEMENT AND OTHER ARM SWUNG OVER THE HEAD IN SAME DIRECTION, IN A REPEATING MOVEMENT.



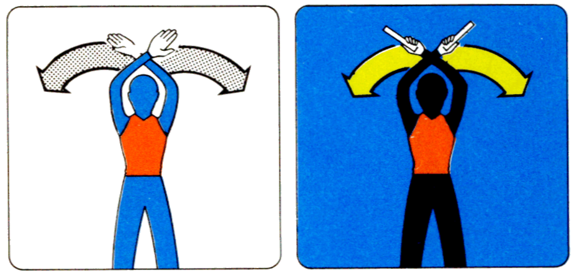
MOVE TO RIGHT

LEFT ARM EXTENDED HORIZONTALLY SIDEWAYS IN DIRECTION OF MOVEMENT AND OTHER ARM SWUNG OVER THE HEAD IN SAME DIRECTION, IN A REPEATING MOVEMENT.



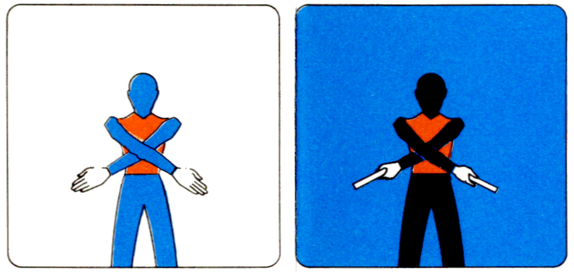
WHEELS – LOWER

WHEN AIRCRAFT APPROACHES MARSHALLER WITH LANDING GEAR RETRACTED, MARSHALLER GIVES SIGNAL BY SIDE VIEW OF A CRANKING CIRCULAR MOTION OF THE HANDS.



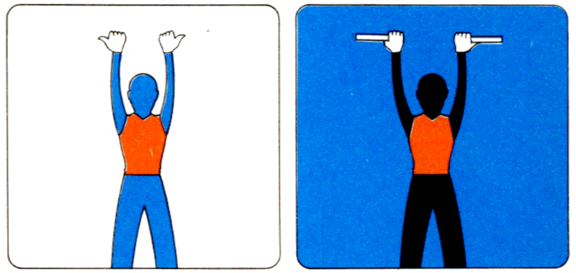
WAVE OFF

WAVING OF ARMS OVER THE HEAD



LAND

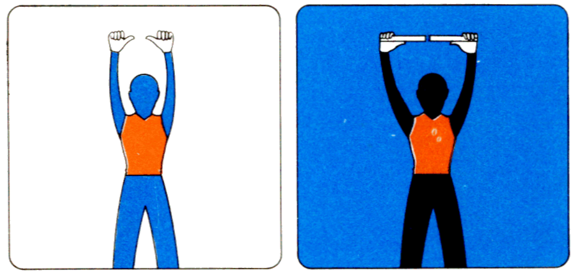
ARMS CROSSED AND EXTENDED DOWNWARDS IN FRONT OF THE BODY.



DROOP STOPS – OUT

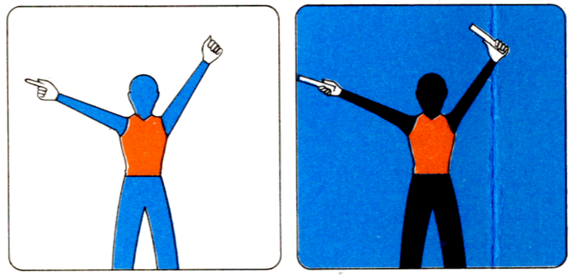
WHEN ROTOR STARTS TO 'RUN DOWN' MARSHALLER STANDS WITH BOTH HANDS RAISED ABOVE HEAD, FISTS CLOSED, THUMBS POINTING OUT.

MARSHALLING SIGNALS FOR SPECIAL AIRCRAFT



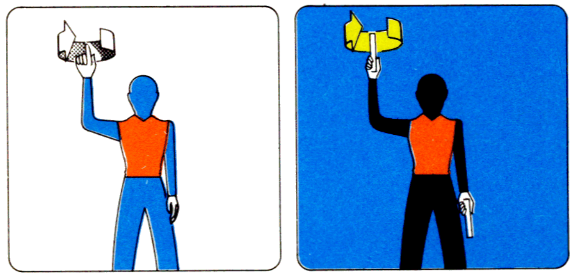
DROOP STOPS–IN

WHEN DROOP STOPS GO IN, MARSHALLER TURNS THUMBS INWARDS.



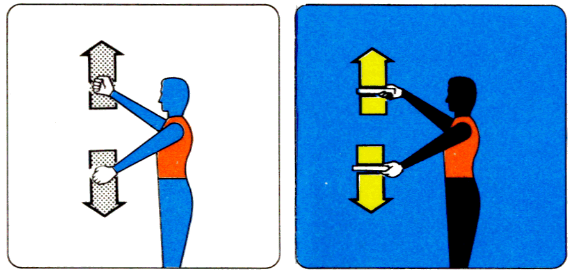
BLADE TIE-DOWNS – REMOVE

LEFT HAND ABOVE HEAD, RIGHT HAND POINTING TO INDIVIDUAL BOOTS FOR REMOVAL.



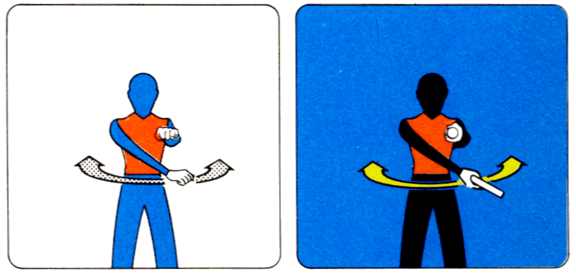
ROTOR(S) –ENGAGE

CIRCULAR MOTION IN HORIZONTAL PLANE WITH RIGHT HAND ABOVE HEAD



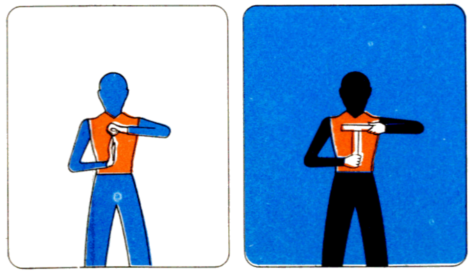
LOAD – HOOK UP

ROPE CLIMBING MOTION WITH HANDS



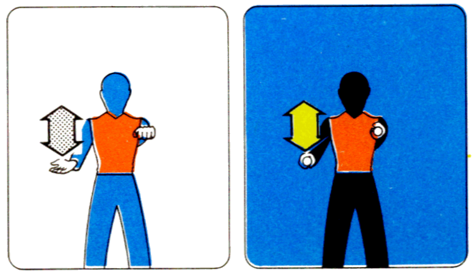
LOAD – RELEASE

LEFT ARM EXTENDED FORWARD HORIZONTALLY, FIST CLOSED , RIGHT HAND MAKING HORIZONTAL SLICING MOVEMENT BELOW THE LEFT FIST, PALM DOWNWARD.



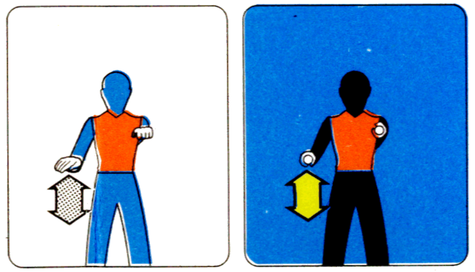
LOAD HAS NOT BEEN RELEASED

BEND LEFT ARM HORIZONTALLY ACROSS CHEST WITH FIST CLOSED PALM DOWNWARDS; OPEN RIGHT HAND POINTED UP VERTICALLY TO CENTRE OF LEFT FIST.



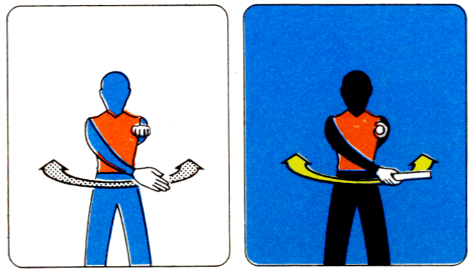
WINCH UP

LEFT ARM HORIZONTAL IN FRONT OF BODY, FIST CLOSED , RIGHT HAND WITH PALM TURNED UPWARDS MAKING UPWARD MOTION.



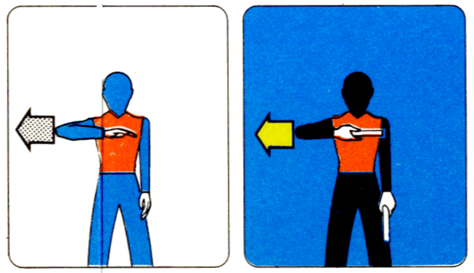
WINCH DOWN

LEFT ARM HORIZONTAL IN FRONT OF BODY, FIST CLOSED , PALM TURNED DOWNWARDS MAKING DOWNWARD MOTION. WITH RIGHT HAND



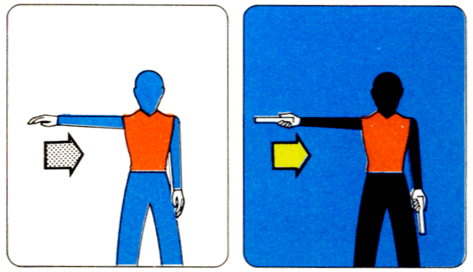
CABLE – CUT

A SIGNAL SIMILAR TO 'RELEASE LOAD' EXCEPT THAT THE RIGHT HAND HAS THE PALM DOWNWARDS AND NOT CLOSED . RAPID REPETITION OF RIGHT HAND MOVEMENT INDICATES URGENCY.



PYLON – SPREAD

BEND ELBOW ACROSS CHEST, PALM DOWNWARD. EXTEND ARM OUTWARD TO HORIZONTAL POSITION, KEEPING PALM OPEN AND FACING DOWN.



PYLON – FOLD

EXTEND RIGHT ARM HORIZONTALLY, PALM DOWNWARD. BEND ARM ACROSS CHEST, KEEPING PALM DOWN.

CHAPTER 6

MISCELLANEOUS GROUND SUPPORT EQUIPMENT (GSE)

List of Contents

Introduction

1. In the early days of the aeroplane, when it was small, low, and uncomplicated, it could be serviced from ground level with a few simple hand tools and elementary servicing equipment. Now that aircraft are larger and more complicated this is no longer true, and a vast array of equipment is needed even to gain access to the remote parts of the structure. As an example the 'Concorde', loaded and ready for flight, weighs 389 000 lb (176 450 kg), the top of the fuselage is over 22 ft (6.50m) from the ground and the highest point, the fin, is $37\frac{1}{2}$ ft (11·5m) high. Such modern aircraft require much specially-designed support equipment before servicing and repair work can be done efficiently and safely.

This chapter is intended to introduce the subject of 'Ground Support Equipment' and indicate what is necessary to back up a modern aircraft to keep it in fighting trim. You may wonder what this has got to do with you; however, let there be no doubt, it is only with the aid of the various ground support items that you can do your task at all. This makes you one of the main users of ground support equipment, and it becomes a part of your trade knowledge.

Ground Support Equipment

2. The term 'ground support equipment' (GSE) includes all items of non-airborne mechanical and electrical equipment that are used during servicing and repair of:

- Aircraft and aero-engines.
- Airborne weapons systems.
- Ground radio installations.
- Synthetic trainers.
- Mechanical transport.

This short list is intended as a guide only and is by no means a comprehensive list of machines and installations requiring specially-designed ground support equipment.

Recording and Servicing

3. Because of the complex and varied nature of the ground support equipment needed, each unit controls its use and repair by maintaining a register that lists the equipment, showing:

- Section and reference number, with a description of the item.
- Unit serial number for individual item identification.
- The quantity held on charge.
- The authorized scale.
- The flight or section using the equipment.
- The class of the equipment.
- Servicing due dates.

4. **Class grading.** To reduce the danger of personal injury caused by defective equipment, and to prevent over or under servicing of ground support equipment, experience has shown that the best overall results are obtained by grading or classifying ground support equipment. The classes found best suited to RAF requirements are:

- **Class 1.** This class covers all items that have a daily servicing certificate (RAF Form 4021A), items that need to be serviced before use and at daily and weekly intervals.
- **Class 2.** This class covers ground support equipment that receives scheduled servicing at monthly intervals.
- **Class 3.** Items of ground support equipment in this class receive workshop servicing at 3-monthly, or longer, intervals.

  To guide you towards understanding the type of ground support equipment that you may expect to find in each class, the following examples will be of value:

- **Class 1.** Much of this equipment is powered either electrically or by internal combustion engines and is of a complex nature, such as:
  - A trolley servicing and starting, electrical.
  - A trolley oil system flushing.
  - A trolley accumulator, electric starting for aero-engines.
- **Class 2.** This class of equipment includes static rigs sited in workshops, including:
  - Torque wrench setting rigs.
  - Grinders.
  - Muffle furnaces.
  - Valve spring testing machines.

  Also included are first-line items such as:
  - Tyre gauges.
  - Towing arms/bars.
  - Aircraft chocks.
  - A variety of replenishment trolleys.
- **Class 3.** This class consists mainly of items with few moving parts such as:
  - Tanks for component washing.
  - Demagnetisers.
  - Forges.
  - Ladders.
  - Inspection platforms.
  - Engine stands.

  Note: The class of any item of ground support equipment is liable to be changed in the light of experience, and this explanation of classes is only a guide to assist you with the correct handling and servicing of your GSE.

5. **Responsibility for servicing.** The overall responsibility for adequate servicing of ground support equipment is vested in OC Eng Wg, who normally sets up a ground support equipment section staffed by NCOs and airmen from the general engineering trade group. The SNCO in charge of this section is responsible for the register of ground support equipment and the records of servicing, repairs, STIs and location of all items. He allocates the unit serial numbers to the individual items and directs his tradesmen to paint, or otherwise fix, the numbers onto the items—whether the item remains in the GSE section or is on loan to a user elsewhere on the unit. The ground support equipment section may be incorporated into station workshops or, if the amount of equipment and staff warrant, it may be an independent section, responsible for all servicing other than first line.

6. **Servicing schedules.** Servicing schedules are provided so that items are methodically and periodically serviced to an acceptable level within the following scope:

- **Class 1.** An individual servicing schedule is produced for each type of class 1 ground support equipment.
- **Class 2.** A kind of omnibus schedule will cover servicing instructions suitable for groups of similar class 2 items.
- **Class 3.** There may be no schedules as such for class 3 items because they require limited servicing, lubrication, and anti-deterioration measures only.

Recording of Servicing

7. The user of class 1 ground support equipment is responsible for recording first line, before-use or daily servicing upon RAF Form 4021A. This document (Fig 1) provides spaces for recording the following information upon the front face of the form:

- Unit and flight or section.
- Description of items; section and reference numbers.
- Unit serial number.
- Hours run daily and grand total (this is important for overhaul purposes).
- Signature for daily servicing.
- Issues of gasoline and oil.

The reverse side of RAF Form 4021A records:

- Dates for weekly servicing.
- Dates for monthly servicing.
- Dates for quarterly servicing.
- Signature blocks for servicing tradesmen and supervisory NCO with date when the servicing was completed.

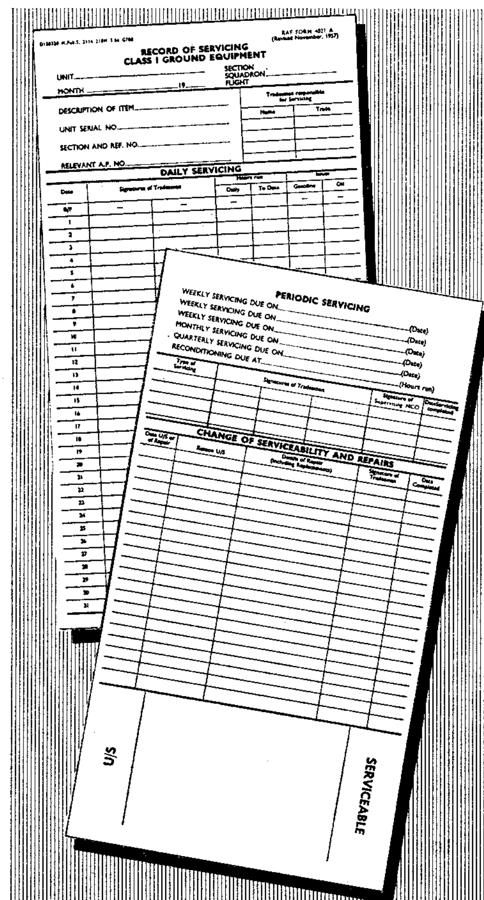


Fig 1 RAF Form 4021A

8. The lower part of the document provides a 'change of serviceability and repair log' that is completed by a tradesman who carries out rectification and repair work. When form 4021A is correctly folded and inserted into its holder, that is attached to the class 1 equipment, it indicates the item's condition, either serviceable or U/S (unserviceable) (Fig 2).

The more permanent records of servicing and other work done to ground support equipment are maintained by the NCO in charge of the GSE section who also holds the test certificates for slings and lifting tackle.

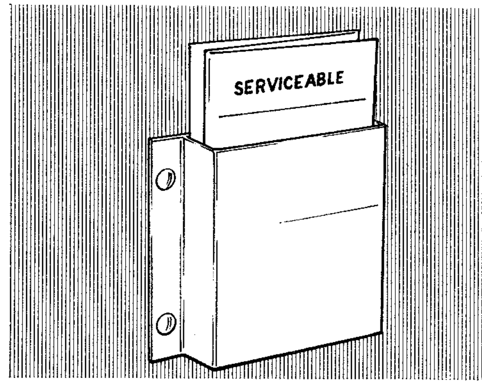


Fig 2 F4021A in holder

Ground Support Equipment

9. The amount and variety of ground support equipment is so extensive that any attempt at listing these items will serve no useful purpose; much of the modern equipment is designed for use with a particular aircraft type and is not of use to any other. It is necessary, however, for the user to adopt a sensible attitude towards his GSE realizing the important part that it plays in the operation of his aircraft. In fact, without adequate serviceable equipment it would not be possible to operate the aircraft at all. Taking into account the foregoing we will now deal in greater detail with but a few of the regular items of ground support equipment that you will handle, explaining both need and use.

LADDERS AND STEPS

Introduction

10. To gain working access to aircraft servicing points, special steps and ladders are often needed. These range from simple steps, like household steps, to large hydraulically-operated mobile aircraft entry steps. Ladders range from simple access ladders such as the 'Aircraft servicing ladder small' (Fig 3), to the complex arrangements of the 'Giraffe' series of aircraft servicing ladders (Fig 7) which, hydraulically-operated, give a working platform height over 35 ft (10·7m) and require the user to wear a safety harness that is to be firmly attached to a strong part of the structure. These items of ground support equipment listed in AP1086, AP4306A and described in AP1464G are, because of the possible risk of injury to personnel, class 2 items although some of the simpler ladders with no moving parts have been down-graded to class 3.

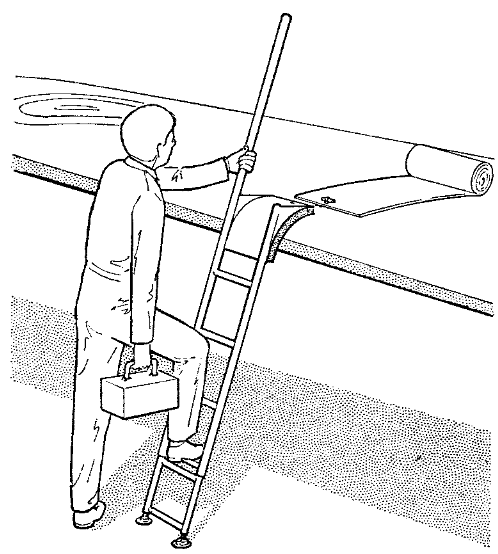


Fig 3 Aircraft servicing ladder small

Aircraft Servicing Ladders

11. There are several large ladders used during aircraft servicing with working platform heights up to 36 ft (11m). Included in this group are the mechanically-operated 'Ladders Elevating and Extending' Mk 2 and Mk 3, along with the Giraffe range of hydraulically-operated ladders.

Ladders Elevating and Extending (Fig 4)

12. The Mk 2 and Mk 3 ladders are of the same design and operation, with the smaller Mk 2 providing a working platform height of between 8 ft (2·4m) and 17ft (5·2m). The Mk 3 ladder is larger and provides a platform height from 17ft (5·2m) to 22ft (6·7m) and gives a minimum overhang of 9ft (2·8m). The maximum safe load for either platform is 400lb (180kg) provided that ballast is used to counter-balance the overhang.

13. **Description.** The base of the ladder is constructed from rigid tubular steel and mounted upon three wheels. The two front wheels are mounted on lockable castoring brackets, one at each corner of the front main tube structure; the third wheel is fitted centrally on the rear tube in a swivel mounting and is provided with a steering handle so that the ladder can be manoeuvred into position for aircraft servicing. A tow bar is fitted at the front so that the ladder can be towed by a suitable vehicle. The ladder and its bracing struts are mounted in pivots on the front base tube, and the ladder is also attached to a mechanism called 'the elevating gear'. Operation of the elevating gear handle will alter the angle of the ladder, raising or lowering the working platform. The ladder itself is built in sections which are arranged to slide on runners one upon another, to extend or shorten the useable length of the ladder. The ladder is extended by a hand-operated winch cable and is secured in the desired position by safety catches called 'ladder pawls'. When the ladder is in position, hand-operated screw jacks, one at each corner of the base, take the weight of the ladder to form a firm anchorage. Safety side rails afford security when climbing the ladder; the working platform is designed for one man only.

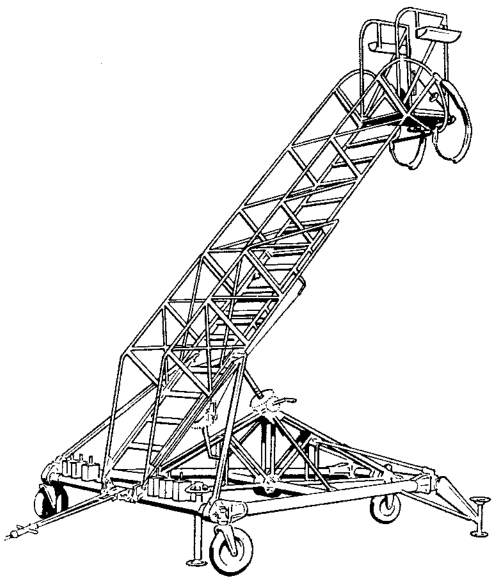


Fig 4 Ladder elevating and extending

14. **Ladder winch.** The ladder winch (Fig 5) is hand-operated and it is fixed to the under surface of the lower ladder section. A steel cable attached to the winch drum is arranged to pass over a pulley on the lower ladder and is then attached near the base of the sliding ladder section. Winding the cable onto the drum of the winch causes the moveable section of the ladder to slide over the fixed ladder, thus increasing the effective overall length. Two spring-loaded 'ladder pawls' attached to the fixed ladder section engage behind a rung of the sliding section to support the upper ladder, removing the load from the winch cable. A pawl control lever is used to retract the ladder pawls when the ladder is to be retracted. A ratchet mechanism prevents accidental unwinding of the winch drum, and mechanical stops prevent the ladder extending beyond safe limits.

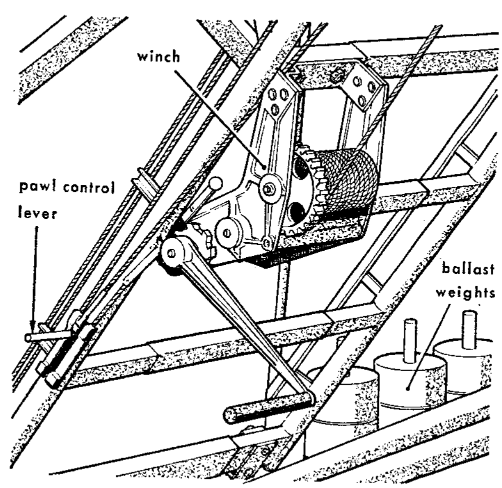


Fig 5 Ladder winch

15. **Ballast.** Before attempting to climb to the work platform make sure that the ballast weights are in position. These weights are mounted on the front main tube; twelve weights are needed for the shorter Mk 2 ladder assembly and eighteen for the longer Mk 3 ladder.

16. **Work platform.** A work platform that is large enough for one person is mounted at the top of the upper ladder section. It is provided with an adjustment to level the platform at different ladder angles. The platform level is adjusted by hand-wheels (Fig 6) that are coupled together to ensure equal movement of each side of the platform. Handrails and safety chains protect the user from falling.

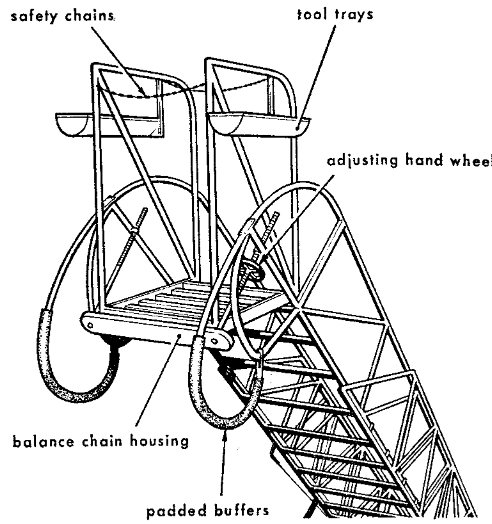


Fig 6 Working platform

Servicing

17. The ladder elevating and extending is a class 2 item, on which the user is responsible for first line servicing and before-use checks. The following actions will ensure that you obtain the best service from your ladder and that it is safe for you to use:

- Visually examine the base frame for defects.
- Make sure that the feet are secure and that the jacks operate freely.
- Lower the elevating gear; visually examine and lubricate as required.
- Visually examine the winch, drum, and cable.
- Operate the winch to prove the action of the ratchet and the ladder pawls.
- Visually examine the ladder rungs and the work platform.
- Check the padding on the buffers.
- Check the tyre inflation.
- Count the ballast weights—DO NOT USE THE LADDER UNLESS THE BALLAST IS COMPLETE.

The ladders are constructed so that they can be dismantled and packed into a small space for transportation purposes.

Giraffe Servicing Ladders

18. The 'Giraffe' range of aircraft servicing ladders (Fig 7) are hydraulically adjusted for height and overhang. The smaller unit has a single ladder with a work platform at the top. The ladder is pivoted at its base and supported under the work platform by the height-adjusting hydraulic ram.

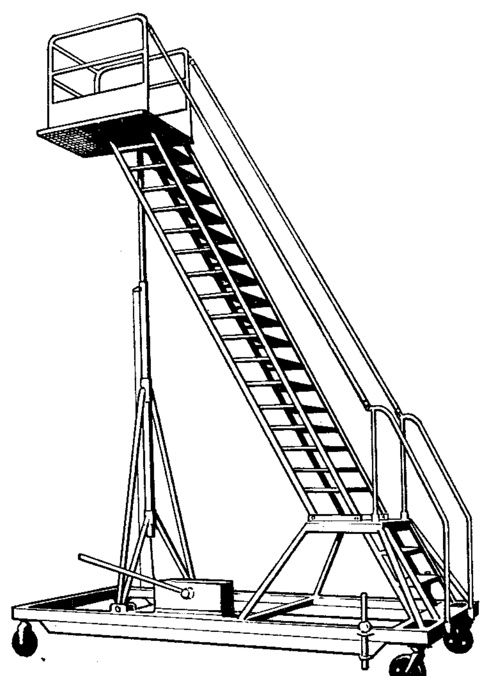


Fig 7 Giraffe ladder

The ladder is mounted upon a strong frame. Four small wheels, one at each corner, enable the ladder to be positioned accurately, and two hand-operated jacking feet, one at each side near the base of the ladder, steady the structure and prevent its movement when in use.

Special transportation wheels (Fig 8) are fitted when the ladder is towed or moved over rough ground.

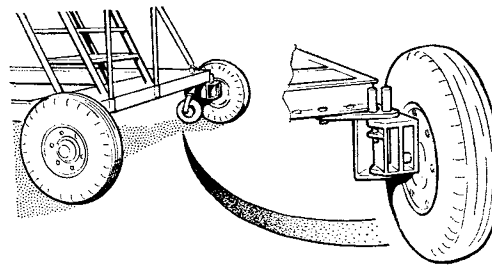


Fig 8 Transportation wheels

19. **Operation, general.** Near the base of the ram structure is a reservoir for the hydraulic oil, the ladder operating controls (Fig 9), and a pump. Operating the hydraulic pump will extend the ram and raise the platform to the desired working height. A locking mechanism locks the ram in position and removes the load from the hydraulic system when the steps are in use. The ram lock is released mechanically by a lever mounted beside the hydraulic reservoir. The platform cannot be lowered without mechanically withdrawing the ram lock and releasing the hydraulic pressure. When the ladder is in position it is steadied, before use, by lowering the two feet. The construction of this ladder is such that the steel non-slip steps are levelled automatically to suit the ladder elevation angles.

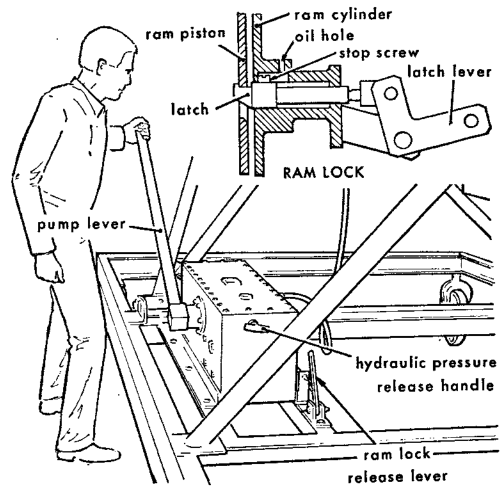


Fig 9 Ladder controls and ram lock

20. **Operating sequence.** A single operating sequence is effective for each type of ladder in the 'Giraffe' range. *To raise the platform*:

- Make sure that there is ample clearance.
- Operate the ram pump lever to raise the platform.
- Move the ladder base as required to gain the correct platform position.
- Check that the ram lock is properly engaged.
- Adjust the jacking feet until the ladder remains stable when personnel use the working platform.

CAUTION:

- The safe working load of the platform is 600 lb (270 kg).
- Personnel are to wear safety belts.

To lower the platform:

- Retract the jacking feet so that the ladder may be moved to prevent the lowering platform from striking the aircraft.
- Operate the ram pump to release the load from the ram lock.
- Hold or secure the ram lock release lever in the disengaged position.
- Open the hydraulic release valve.

CAUTION:

- The platform moves through an arc during lowering and must be prevented from striking the aircraft.

Servicing

21. First line servicing of these ladders is restricted to:

- Cleaning.
- Visual examination.
- Lubrication.

Before use you are to:

- Check the hyraulic fluid level.
- Clean ram and operating mechanisms.
- Visually examine for external oil leaks.
- Inspect all nuts and screws for security.
- Visually examine the structure for signs of defects.
- Check the operation of the ram lock and release mechanism.
- Check the operation of the hydraulic release valve.
- Lubricate and grease moving parts as required.

HIGH PRESSURE GAS CYLINDERS

22. Most modern aircraft have systems or components that need an initial charge of air, nitrogen or oxygen. These gases are handled in storage containers called 'gas cylinders'. The gas cylinders that you are most likely to handle may contain:

• Compressed air	(Aircraft systems).
• Compressed nitrogen	(Systems, tyres, undercarriages).
• Compressed oxygen	(Breathing for crews at altitude).
• Carbon dioxide	(Fire extinguishers).

The gas cylinders, at pressures ranging from 1800 psi (124 bars) to 6000 psi (414 bars) are often of similar size and shape, with the contents distinguished by the colour of the cylinder and the letters thereon. *Because of the possible disastrous results of charging a system or component with the wrong gas it is vital that you positively identify a gas from the cylinder colour and markings.* The cylinders are painted all over in one colour and the content name painted in large letters of a contrasting colour (Table 1).

Fig 10 shows the colour and markings for a compressed air cylinder and an oxygen cylinder.

When using gas cylinders to replenish aircraft systems and components you are to match the gas cylinder colour and markings with the system symbols (Chapter 3) and also the system requirements listed in MOD form 700. Because of their size and weight, gas cylinders are normally mounted on a four-wheeled trolley that is capable of carrying four cylinders connected by suitable high

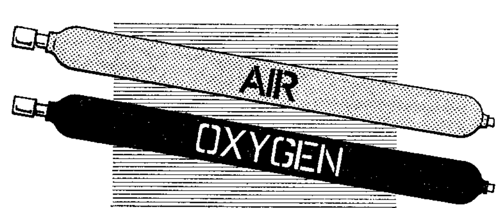


Fig 10 Gas cylinder markings

TABLE 1 Gas Cylinders

Gas Contained	Cylinder Colour	Lettering Colour	Max Pressure	Use
Air	Light Grey	AIR in Black	4000 psi (276 bars)	Charging aircraft systems, tyres, and accumulators.
Acetylene	Maroon	ACETY-LENE in White	225 psi (15·5 bars)	Welding.
Nitrogen	Light Grey, Black Neck Band	NITROGEN in Black	4000 psi (276 bars)	Fire proofing aircraft tanks, inflating tyres, under-carriage struts.
Oxygen	Black	OXYGEN in White	3600 psi (248 bars)	Aircrew breathing.
Carbon Dioxide	Black with White Neck band	White	1800 psi (124 bars)	Fire Fighting.

pressure pipes to a single outlet point. These trolleys (Fig 11) are heavy and require a tractor or several airmen to move them. For this reason, lighter two-wheeled trolleys are available to carry two cylinders or even a single cylinder. These lighter charging trolleys are more convenient for use by an unaided airman. Whatever the type of trolley, suitable valves are fitted to control the gas flow, with pressure gauges indicating both total and delivery pressures.

The outlet from each individual cylinder is connected to a rigid pipe forming part of a manifold leading to the charging regulator valve and is manually operated using a special key normally carried inside the regulator valve housing. It is good practice to retain one fully charged cylinder until others in the set are exhausted, using partially exhausted cylinders for initial charging of systems and those cylinders with higher pressures to complete the charging process. This is called the *cascade method* of charging a gas system.

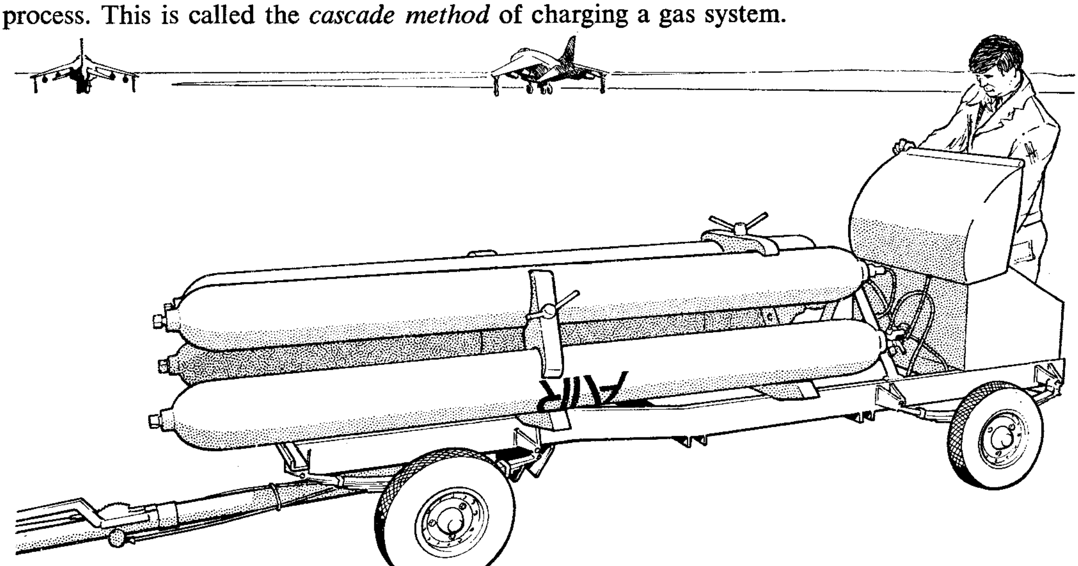


Fig 11 Gas cylinder trolley

23. **The charging regulator.** On no account attempt to use a high pressure gas trolley unless you understand how the charging regulator is used to control the outlet gas pressure. A simple example of a charging regulator is shown in Fig 12. By examining this drawing it can be seen that the pressure of the incoming gas (up to 6000 psi (414 bars)) is controlled by a valve and recorded on the 'high pressure gauge' and that the gas must pass through the reducing valve to reach the outlet side of the charging regulator. Turning the tee handle of the reducing valve anti-clockwise will reduce and eventually cut off the gas flow to the outlet altogether; turning the handle clockwise will increase the gas flow. Fitted between the reducing valve and the gas outlet is a low pressure gauge and a stop valve, in that order. The stop valve is used to shut off the gas outlet, and the low pressure gauge records the pressure fed to the aircraft system or component. The same type of charging regulator is used with oxygen, nitrogen and air charging trolleys. Before opening the outlet valve on the gas cylinder it is important to set the charging regulator controls:

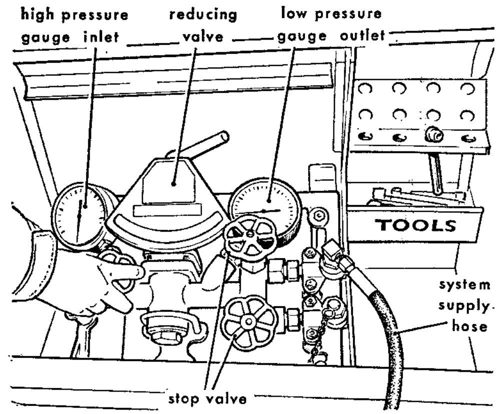


Fig 12 Charging regulator

- Reducing valve OFF (turned anti-clockwise).
- Stop valve OFF (turned clockwise).

The full pressure of the cylinder will then record on the high pressure gauge without the danger to personnel of a high pressure gas jet that could otherwise arise at the outlet side of the regulator. Before connecting the delivery line to the aircraft charging point, purge the line; the aircraft system pressure plus 10%, should then be set on the low pressure gauge by:

- Fitting a blanking cap to the delivery line outlet.
- Opening the stop valve.
- Slowly adjusting the reducing valve to obtain the correct reading.
- Lock reducing valve adjuster.

When the correct pressure reading is obtained on the low pressure gauge, close the stop valve and carefully release the pressure gas from the delivery line by slowly unscrewing the blank. Connect the delivery line to the aircraft charging point and, by opening the stop valve, commence charging the aircraft system.

DANGER:

- Gas compressed to high pressure can, when exhausting through a small outlet, produce a high velocity jet capable of producing blindness if directed into the eyes; it may even pierce the skin and cause serious injury.
- Great care is needed when handling high pressure gas delivery hoses to avoid pointing them towards other personnel or where they will cause dust or debris to blow about.

24. **Before-use servicing.** Before using a compressed gas trolley, carry out a 'before-use' inspection which must include the following visual checks:

- The gas cylinders are the correct colour and markings for the system to be charged.
- The cylinders are properly fitted and secured.
- The manifold pipes are properly fitted to the cylinders and inflation valves.
- The cylinders contain sufficient gas (high pressure gauge).
- The delivery hose is in good condition.
- If the gas is oxygen, the delivery hose and regulating valve mechanism are to remain *entirely free from oil and grease.*

TROLLEY, AIRCRAFT DEFROSTING PLANT

Introduction

25. Aircraft standing at readiness in inclement wintry weather may become covered by snow, hoar-frost and ice. It is most dangerous, if not impossible, for an aircraft to take off in this condition. It is, therefore, very important that all snow, frost and ice is removed, and prevented from re-forming before the aircraft attempts to take off. Various equipments are available for this purpose, some hand-operated and others engine-driven.

Equipment is needed for de-frosting all sizes of aircraft and access is required to the highest point. The engine-driven pump is capable of supplying about four gallons of de-icing fluid per minute at a working pressure of 300 psi (20 bars). The aircraft de-frosting plant is heavy and can be moved only by a tractor or other suitable towing vehicle.

26. **Filling the tank.** The de-frosting tank is filled from drums of fluid using the plant's own engine-driven pump. The operation is quite simple and the necessary equipment is always a standard part of the plant.

27. **Positioning the trolley.** The de-frosting plant trolley should be positioned upwind of the aircraft so that it gives access to spray the largest possible amount of aircraft skin surface area.

Servicing

28. This is a class 1 ground equipment item and requires a daily servicing before use. The servicing, hours run, and fuel and oil used are to be entered onto RAF Form 4021A. A schedule is available for details of the servicing required.

29. **General precautions.** To ensure safe and satisfactory operation of the aircraft de-frosting plant always carry out a proper visual examination before attempting to use the plant. A few minutes spent in checking the plant before use will pay handsome dividends.

The use of pre-heated fluid is the quickest way to remove ice, snow and frost from parked aircraft. However, hot de-icing fluid must not be sprayed onto windscreens and transparent panels because there is a danger of cracking them. The transparent panels must be treated independently.

AIR COOLING TROLLEYS

Introduction

30. It is now a well-established practice that we require and expect adequate heating systems for our houses, offices, cars and aeroplanes. Equally, in tropical climates, air-conditioning and cooling systems are very important. Aircraft have cooling systems that only operate when the engines are running. An aircraft with its engines stopped (in particular, if it is standing in the direct rays of hot sunshine) becomes like a furnace inside. This reduces the efficiency of servicing and aircrews; it is also distressing for passengers and may be detrimental to various aircraft equipment. To protect aircraft equipment, workers, and crew, the interior of the aircraft can be kept at an acceptable temperature by using a specially-constructed mobile refrigeration unit. The refrigeration units used to cool parked aircraft are called 'Trolleys Air Cooling'. These 'air cooling' units vary considerably in size and appearance and have a cooling capacity ranging from that equal to 20 000 BTU/hr and an air flow of 10lb per minute to a cooling capacity of 300 000 BTU/hr and an air flow of 100 lb per minute. Some of these trolleys can only be used for cooling aircraft and equipment, whereas others can also be used to cool the aircrew's ventilated suits after they board the aircraft. It is important that ground crew can recognize, position, and correctly use any of the 'trolleys air cooling' that are available. A typical 'air cooling' trolley is shown in Fig 13. This trolley is suitable for cooling the interior of large aircraft and equipment, but it does not have connections for ventilated suits. The refrigeration plant, cooling fans and the centrifugal cold air delivery fan are all driven by a single conventional 4-cylinder gasoline engine, like the engine of a car. The plant is automatic in operation and the cooling output depends upon the engine speed. The delivery temperature of the cold air will vary slightly depending upon the heat of the day, and a control valve prevents the delivery temperature from dropping below 0°C (32°F). Details of the supply points and the connections are found in the aircraft air publication along with cabin pre-conditioning procedures. Air cooling trolleys vary in shape, size, and type of engine, but they are all class 1 ground equipment and subject to daily scheduled servicing before use. Normal engine running safety precautions are to be observed, with the addition that the engine must not be run with the clutch disengaged for more than 2 minutes at any one time.

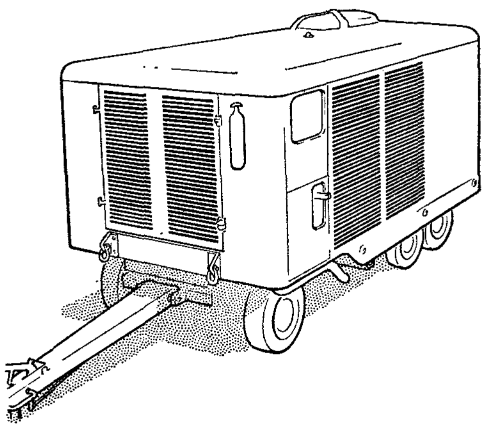


Fig 13 Air cooling trolley

VACUUM CLEANERS

Introduction

31. For removing dust and small foreign objects from difficult and not-easily accessible nooks and crannies of aircraft structures, vacuum cleaners are essential. These machines, with their tools and fittings, will collect dirt and small foreign objects from many places where it would otherwise not be possible to reach and clean. A variety of vacuum cleaners is available, from small hand-held cleaners, such as the dustette, to large wheeled equipment that needs a towing vehicle to move it around the servicing area. Most cleaners are electrically-driven and operate

from a mains supply, but some of the large heavy duty types use a gasoline engine (Fig 14) so that they can be used to clean the interior of aircraft standing on dispersals that have no mains electrical power supply.

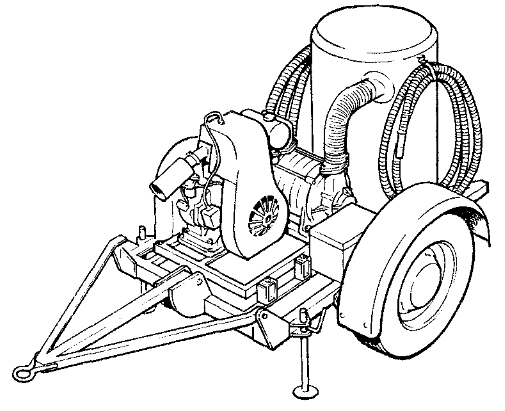


Fig 14 Vacuum cleaner

The cleaner illustrated is a heavy duty type driven by a gasoline engine and is subject to the normal rules and safety precautions that apply to running engines of class 1 ground equipment. The engine drives the turbo-exhauster vacuum pump by multi vee belts that are enclosed by a metal guard to protect the operator. The suction produced is such that the cleaner can operate through considerable lengths of hose and piping. It is designed to collect dust, litter and soft substances along with hard objects such as small stones, broken locking wire, pieces of metal, small nuts and screws without causing harm to the mechanism or filters. All debris that is drawn into the filter unit during a cleaning operation is deposited either in a dustbin at the bottom of the filter unit or in the filter bags above. A hand-operated shaker is provided so that debris in the filter bags may be shaken down into the dustbin without dismantling the unit. The dustbin is secured to the filter unit by a quick-release clamp (Fig 15) that permits quick and simple removal, for emptying, and refitting to the plant. When the release gear handle is lowered it locks the dustbin securely in position with an air-tight joint, and when it is raised and secured in a clip on the filter housing it permits removal of the dustbin, towards the rear, for emptying. To prevent accidental release of the dustbin during aircraft cleaning, the release handle is held in the locked position by a retaining arm or a small spring-loaded chain clipped to the base of the bin.

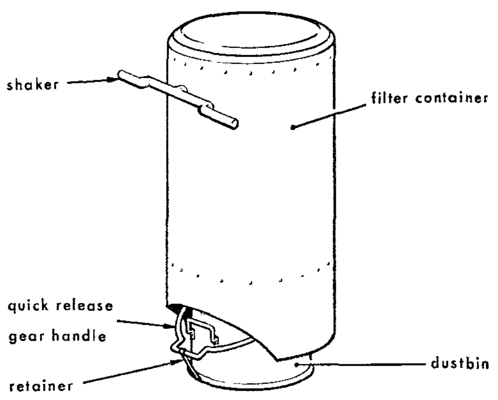


Fig 15 Dustbin release

32. **Preparing for use.** This particular heavy duty cleaner is driven by an air-cooled gasoline engine that must not be started or run unless the cooling cowl is fitted, in good condition and free from obstructions. Any attempt to run the engine without the cooling cowl will cause severe overheating. Likewise, the engine must not be run without the belt guard to protect you from injury caused by accidental contact with the moving belts. When the unit has been pre-use inspected and positioned ready for use, the engine starting routine is to:

- Turn on the fuel.
- Set the start and slow-running lever.
- For cold engines set the choke to the cold start position.
- Engage the starting handle and turn the engine to a position where pulling the handle upwards will turn the engine over compression.

- Pull the handle upwards with a quick movement; if the engine fails to start repeat this action. Do not attempt continual turning; the engine is fitted with an impulse starter and will start during an upward movement of the starting handle.

- As the engine warms up, set the choke to the normal running position.

- When the engine is running smoothly without choke, move the start and slow-running lever to free the throttle control, allowing the governor to take over; the engine speed will now increase to operating rpm.

33. **Using the cleaner.** The elbow, hoses, extension arms and tools may be plugged together to suit the cleaning requirements and may be changed one for another with the plant running. The end fittings should be used to their best advantage by using a fitting that is most suited to the area being cleaned. If, in some awkward situations, the cleaning tools will not do a satisfactory job, the debris may be dislodged by using the cleaner as a blower and then re-converting to vacuum to collect the dislodged debris.

34. **Using for blowing.** To use the equipment for blowing it is necessary to connect a hose onto the exhauster outlet elbow with the blowing bush, and either leave a hose in the filter inlet or secure the inlet flap in the open position. A special blowing nozzle (Fig 16) is provided in the tools.

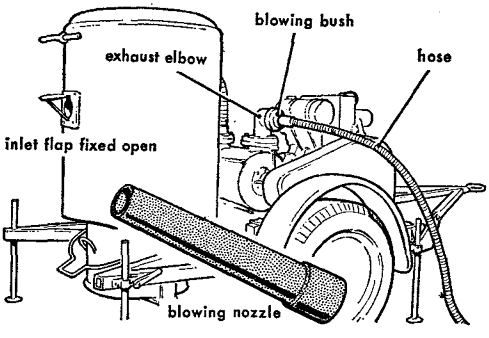


Fig 16 Connections for blowing

35. **Stopping the engine.** If the engine is to be stopped for only a brief period, use the cut-out button by pressing the button and holding it until the engine has stopped. If, however, the work is completed and there is no intention to start the engine again, it is to be stopped by turning off the petrol and allowing the carburettor to run dry. Vacuum cleaners, properly used, play an important part in flight safety—so after use attend to the equipment and:

- Stow the hoses neatly.

- Clean and pack the accessories so that they are not damaged when moving the plant.

- Carefully stow the extension arms and the starting handle.

THINK: If the equipment is complete, serviceable and properly packed it will all be ready to use next time.

Safety Precautions—Engine-driven Ground Support Equipment

36. All engine-driven ground support equipment falls into the class 1 category and must be serviced daily to an individual schedule, plus the following safety precautions when it is used:

- Position the equipment as far away from aircraft and flammable materials as is practical and down wind if possible.

- Do not refuel the equipment when the engine is running or within 100ft of aircraft.
- Suitable fire extinguishers are to be positioned before starting the engine.
- If used indoors, the equipment is to be positioned with the engine exhaust pointing away from personnel. A build-up of exhaust fumes is to be prevented—even if this means occasionally stopping the engine.

LAMPS AND FLOODLIGHTS

Introduction

37. A major problem in servicing aircraft is that of getting the right amount of light in the right place. It is easier and more accurate to work upon a part or component that is illuminated by a good light—preferably a clear white light that does not confuse colours. There are fortunately many aids to good lighting and it is important that you know how to use them to the best advantage. Most large lamps and floodlights require a mains power supply. However, there are exceptions that work quite well from batteries or low voltage auxiliary power sources. Whether the lamps are operated from a mains power supply or other sources they are grouped into one of two classes:

- Flameproof.
- Non-flameproof.

38. **Flameproof lamps.** A very important point is for you to recognize the difference between flameproof and non-flameproof lamps and understand the limitations of their use. Flameproof lamps are essential when lights are needed near fuel installations, when working on fuel systems, or in fact at anytime when flammable gases exist, may exist, or are suspected. Flameproof lamps are all sealed units and it is essential that all the seals and insulating compounds are maintained in good condition with any distorted or damaged parts replaced before use. Fig 17 shows the use of flameproof lighting equipment.

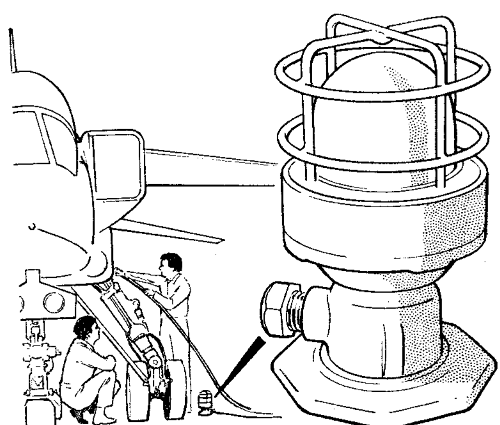


Fig 17 Using flameproof lamps

39. **Non-flameproof lamps.** This class includes hand inspection and pedestal lamps that are not sealed units. These lamps are quite safe for general use but are not safe to use in areas where dope or paint spraying is in progress or where other explosive gases abound. Under no circumstances are non-flameproof lamps to be used when refuelling or defuelling an aircraft.

40. **Pre-use checks.** Pre-use checks are simple and consist mainly of a visual examination to make sure that the lamp is complete and undamaged with a sound electrical cable that is free from knots and has an undamaged plug. The electrical serviceability of the unit is the responsibility of the electrical tradesman. Position the lamps where system fluids cannot leak or drain onto them and route the cables along a dry path where they will not be damaged by the wheels of ground equipment, tractors, or other MT vehicles and where they will not constitute a danger to other workers.

CRANES, HOISTS AND SLINGS

Introduction

41. Very many items of equipment, such as aero-engines, propellers, mainplanes, and other heavy crated spares that have to be lifted off transporters, or lifted into position for fitting, are far too heavy to be lifted manually. This situation calls for mechanical aids to lifting that are also capable of moving the load so that an item of equipment can be lifted from one place and lowered in another. This kind of lifting can be done by lifting equipment in these groups:

- Overhead rail with 'block and tackle'.
- Hand-operated cranes.
- Mechanically-operated cranes.
- Electrically-operated cranes.
- Gantries.
- Shearlegs and hoists.

Each of these groups has many items designed to lift differing weights to different heights and suitable for varying access situations. Because of the wide variety of equipment it is the intention to describe and explain only some items. However, before explaining the cranes themselves it is necessary to deal with the link between the lifter and the lifted—that is, the sling that makes a safe lift possible.

Lifting Slings

42. It was noted in the opening pages of this chapter that slings are treated in a special way that does not generally apply to other ground support equipment. Each sling has a test certificate (that could be equated to your birth certificate), which is originated when the sling is made and tested. It carries the same identifying numbers as the sling, along with other important information. No sling is to be used unless it has a valid test certificate that is held in the ground support equipment records section, along with a register of lifting tackle. Each sling is to carry a brass tag or tally which is to show indentification particulars and test information. A very important item of the test information is the 'safe working load' (SWL) because this gives the maximum weight of an object that can be lifted safely by that particular sling. Some slings are designed to lift a particular store such as an aero-engine, power plant, or an airframe part and these slings are not to be adapted or used for lifting anything else. Other slings of a more general nature may be used for lifting any stores within their safe working load. To enable the user to use the slings without continual reference to the test

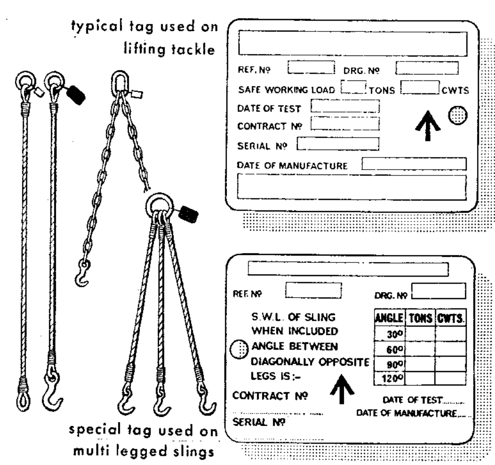


Fig 18 Sling identification tally

certificate the information on the brass tag must tally with that on the test certificate. The brass tag is to be fixed to the sling in such a way that it cannot be 'accidentally' removed. Any sling without such a tag must not be used; it is to be treated as unserviceable. Examples of the brass identification tags are shown in Fig 18.

When not in use, slings should be carefully stored to avoid kinking the cables. Rope, wire rope, and steel cable slings should be hung on pegs so that the legs hang freely. Identification markings should be painted onto the wall above each peg, inluding the SWL of the sling. For multi-legged slings the safe working load is required for varying angles that may be encountered during use. These angles are measured as an included angle between diagonally opposite legs, and SWL values are normally given for 30°, 60°, 90° and 120° (Fig 19).

REF NO	4L/2580
ANGLE	SWL cwt
30	58
60	52
90	42
120	30

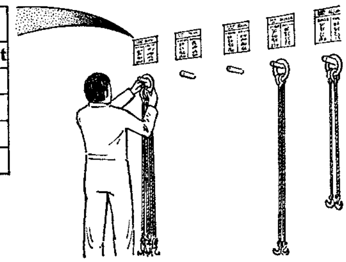


Fig 19 Sling stowage

Inspection and Servicing

43. The period and type of inspection required will vary with the material from which the sling is made but, in general, inspection and servicing is needed:

- Always before use.
- Monthly.
- Three-monthly.
- Six-monthly.
- Annually.

Although a selected SNCO will do the routine periodic servicing of the sling(s), all airmen should be capable of doing a safe 'before-use visual inspection'. In fact, it is vitally important that each person is competent to judge the condition of the sling(s) being used. This 'before-use' inspection is quite straightforward and starts by selecting the correct sling. If it is a special sling for an aero-engine or a mainplane, then it will be listed by section, reference number and title in the aircraft servicing manual. If, however, the lift requires a general purpose sling, then the right sling is the lightest one that has a safe working load greater than the weight to be lifted, with legs of a suitable length and number. Once the correct sling has been selected it is to be either placed on the hook of a crane or laid out for a pre-use inspection. This visual inspection is to include examining:

- The identification tag for dates and SWL.
- The lifting ring.
- The cable legs.
- The thimbles.
- The pick-up points—hooks or shackles.
- The seizings.

If the lifting ring and pick-up points show no signs of damage and the hooks or shackles are in good condition these parts can be accepted as fit to use. The cable legs require a closer look; here we must look for signs of kinks, knots, broken strands and corrosion. Do not use a sling if any leg shows signs of kinks or knots. Wear will show as brightness where the strands have rubbed together and, as wear reduces the strength of the sling, the diameter of each cable should be checked when wear is suspected. If broken strands or loose and damaged thimbles are found, the sling is not to be used unless certified serviceable by a competent SNCO. If no defects are found and all seizings are in good condition the sling may be considered fit to use. With the sling now ready for use it remains to correctly attach the sling to the jib of the crane and to the load ready for lifting.

Cranes and Hoists

44. If the crane is one supplied by the motor transport section it will have been inspected and, so far as you are concerned, is serviceable and safe to use. If, however, the crane is hand-operated and kept by the user in the hangar or workshop, then it requires a pre-use inspection before it can be considered safe to use. As an example of a crane that needs inspecting before use, we will take a portable engine hoist. This hoist has a maximum jib height of 15 ft and will safely lift any load up to 2 tons; it is hand-operated and requires a standard pre-use inspection. The hoist is mounted upon three rubber tyred wheels in the form of a triangle. The rear wheel, to which the steering and towing arm is attached, is permitted to castor for steering purposes. Steel plates are welded together into a base to which the main steel structure is bolted. The winch mounting is built up from more steel plates welded together and bolted onto the main structure (Fig 20). The hand-operated winch consists of a rope drum attached to a worm wheel driven by a worm that is turned by the winch handle. A flexible cable is attached to, and wound around, the rope drum so that turning the winch handle will either 'wind in' or 'pay out' the cable. The cable passes over two pulley wheels freely mounted on the main structure and around a third pulley that is part of the hook and pulley block; the cable end is firmly fixed to the main structure. Turning the winch handle to 'pay out' cable will lower the hook, and 'winding in' cable will raise the hook and any attached load. A pawl and ratchet arrangement acts as an automatic brake to hold the load in any position during lifting or lowering. Day-to-day servicing consists of visual inspection and minor lubrication such as:

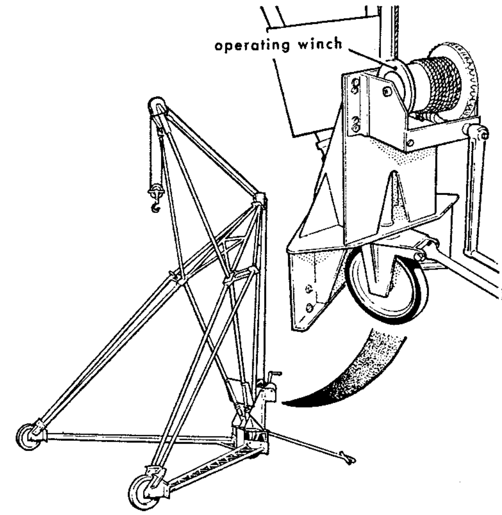


Fig 20 Hoist and winch

45. **Visual Inspection:**

- Nuts, bolts and welds.
- Lifting cable, hook and pulley block.
- Structure for signs of impact damage.
- Winch and mechanism.

46. **Lubrication:**

- Guide pulley spindles.
- The swivelling hook of the pulley block.
- The winch, worm, wormwheel and shaft bearings.
- The vertical shaft of the castoring wheel.
- The tow bar hinge.

47. **Precautions:**

These are simple and common sense; you are to:

- Make sure that the load is within the SWL of both crane and sling.
- Remain with a suspended load.
- Keep clear of a suspended load, using rope to steady high lifts.
- Prevent others from walking, or working, under a suspended load.

Safety

48. All lifting is to be supervised by a qualified SNCO who is aware of the regulations for using lifting tackle that are printed in AP 3158 Vol 2. The weight of crated loads is clearly painted on the outside of the crate and special items have their own slings. The SWL of a sling is marked on the identification tag, whilst cranes and hoists have their lifting capacity clearly marked on the structure.

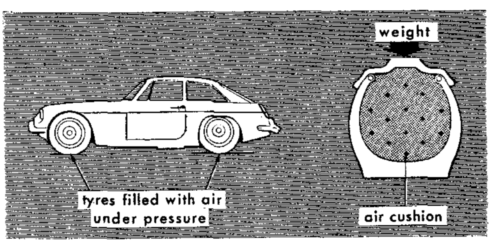
CHAPTER 7

PRINCIPLES OF FLIGHT

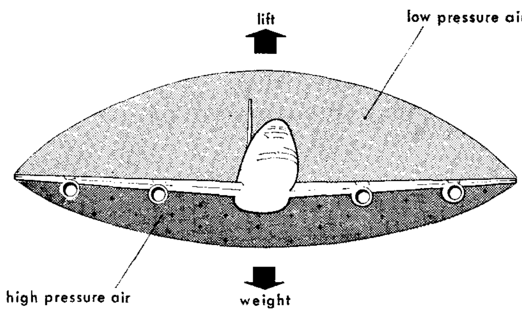
Introduction

1. Chapters 8 and 9 deal with fixed wing aircraft and helicopters. These subjects have much in common that can be dealt with under the heading "The Principles of Flight". These principles are used to explain, briefly, 'lift' and 'thrust', without which no aircraft can fly.

To grasp these principles we must first accept that air (the atmosphere), although it offers little resistance to movement, is capable of supporting very heavy weights. It is air, under pressure, that keeps the wheel of a loaded lorry or car away from the road surface; the tyre is only a container for the air (Fig 1a).



(a) air supporting car



(b) air supporting aircraft

Fig 1 Air as a support

2. It is not so easy to understand how 'free air' can support the greater weight of an aircraft. However, this it does whenever an aircraft flies (Fig 1b).

Aircraft that are heavier than air can only be supported in the air if they can produce a force that is, at least, equal to their weight. This force must be greater than the total weight to cause an aircraft to leave the ground and climb.

The force that causes the aircraft to leave the ground and fly is called 'lift' and the force that moves it forward (propulsive force) is called 'thrust'.

3. Both lift and thrust can be produced by the effect of air moving over a shape called an 'aerofoil' (Fig 2). To produce the 'lift' necessary for flight the large fixed wings of a conventional aircraft are, in section, of aerofoil shape. Propeller blades and the rotor blades of a helicopter are revolving aerofoils.

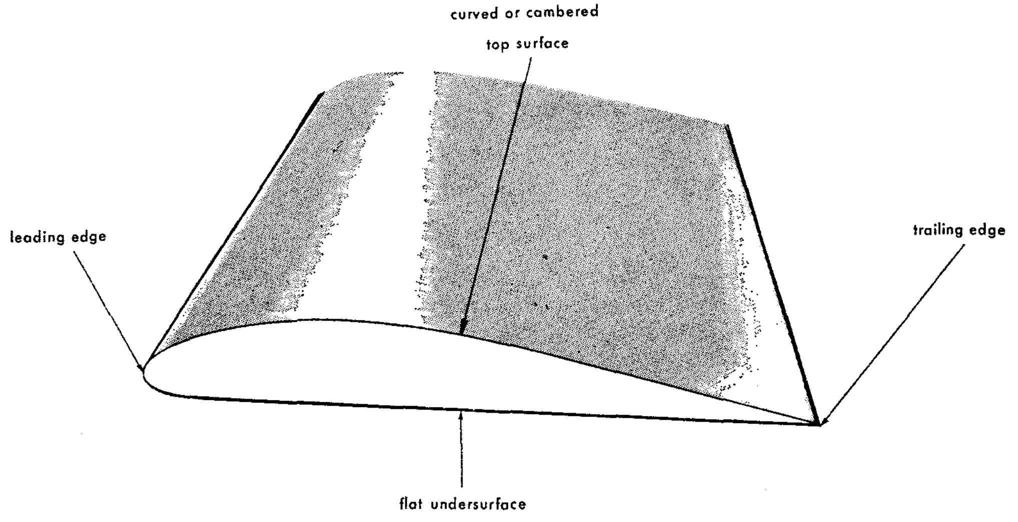


Fig 2 The aerofoil

Airflow and the Aerofoil

4. When an aerofoil shape moves through the air it disturbs the air which then flows over the aerofoil in a special way (Fig 3).

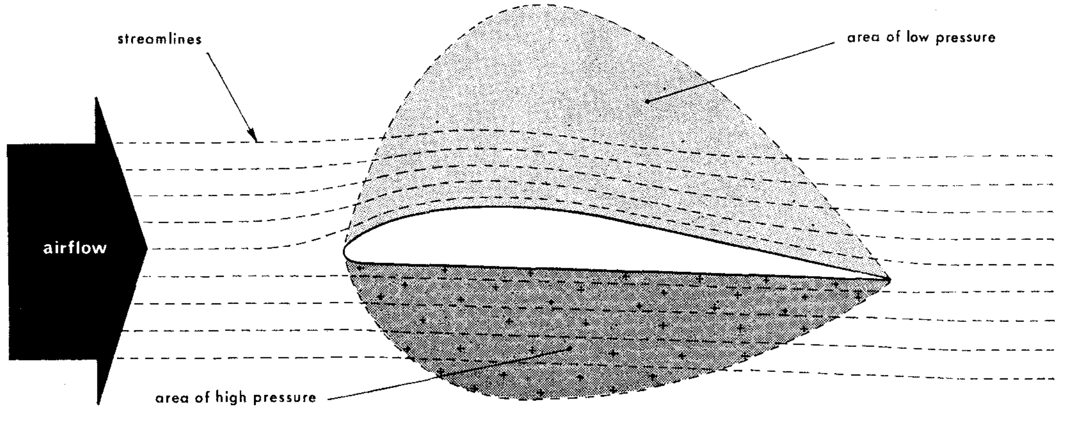


Fig 3 Streamlines around aerofoil

Experiments, using smoke in the airflow, have proved the behaviour of air flowing over various shapes, and it is now well known how air flows over an aerofoil shape. To show the airflow pattern dashed lines are used; these lines are named 'streamlines'.

Streamlines are used to show how lift is obtained from an aerofoil by indicating pressure and velocity changes in the airflow. When the streamlines are drawn near together they indicate high velocity, low pressure airflow; as the streamlines move further apart they indicate that the air velocity is reducing and the pressure is increasing.

The streamlines in Fig 3 show how the air flows around an aerofoil shape and how the pressure is lower on the curved surface and higher on the flat surface. The streamlines in front show the pattern of airflow before it is disturbed by the aerofoil. It is the *pressure difference* across the aerofoil that provides the useful force lift, produced by the wings of an aircraft. The propeller generates the same force, but because the propeller is mounted vertically the force acts forwards along the centre line of the aircraft and so is called 'thrust' (Fig 4).

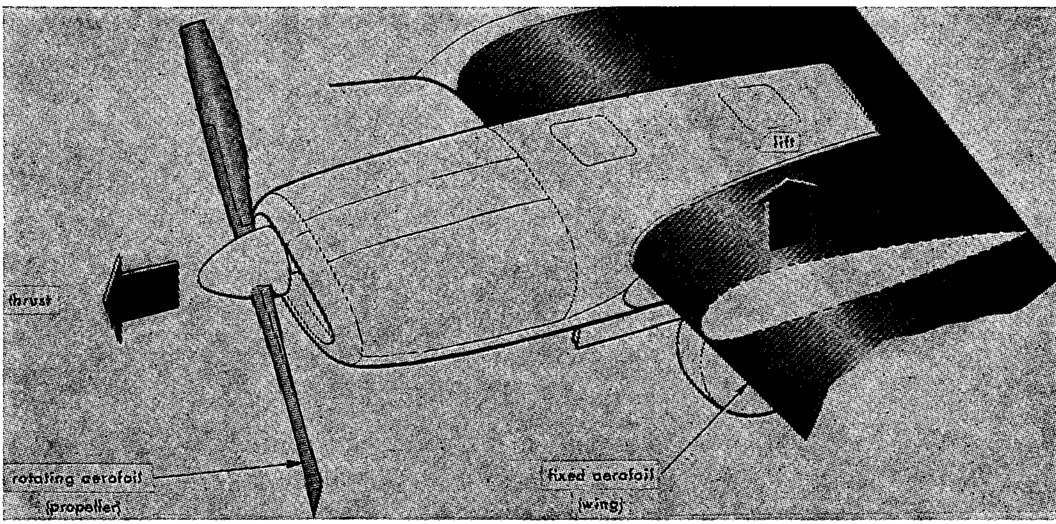


Fig 4 Lift and thrust

5. The aerofoil shape will not produce lift or thrust under all circumstances but it does encourage a smooth airflow and becomes effective as a lift or thrust producer when it is inclined at an angle to the airflow. This angle is called the 'angle of attack' and gives best results at about 4° (Fig 5).

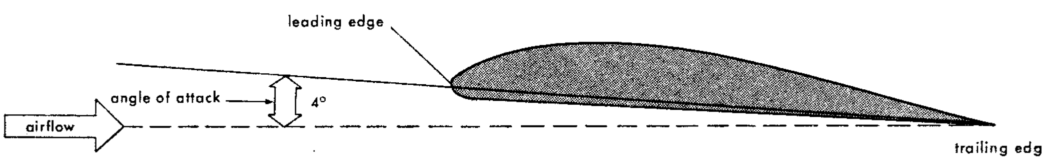


Fig 5 Angle of attack

6. The amount of lift or thrust produced by a wing, rotor or propeller blade depends upon many variants; the more important ones are:

- The shape of the aerofoil and the smoothness of its surface.
- The speed of the airflow over the aerofoil.
- The angle at which the aerofoil meets the air.
- The density of the air.

The total lift or thrust is obtained from the pressure difference acting across the aerofoil caused by the low pressure on the curved surface of the aerofoil and the high pressure on the flat surface. The greater part of the total lift or thrust is produced by the low pressure side of the aerofoil.

CHAPTER 8

ELEMENTARY AIRFRAMES

Introduction

1. The structure of an aircraft, with its engines or power plants removed, is known as an airframe. For ease of construction, assembly and dismantling, the airframe consists of a number of separate units or major components. An elementary knowledge of the names and functions of the major airframe components is, therefore, necessary. As a member of an aircraft servicing team this knowledge will help you to avoid causing damage, through ignorance, to the airframe structure.

Fuselage

2. The fuselage is the main body of the airframe to which, either directly or indirectly, all the remaining components are attached. A large aircraft fuselage is often built in three sections consisting of the nose, centre and rear fuselage (Fig 1a).

The fuselage contains the pilot's cockpit, known as the 'flight deck' on large aircraft; it may also contain fuel tanks, gun or rocket packs, and sometimes the propulsion units as in Fig 1b. It provides accommodation for the aircrew and may also have a bomb bay or space for passengers and freight.

When seated in the pilot's cockpit facing forward the left hand side of the aircraft is referred to as the port side and the right hand side as the starboard side.

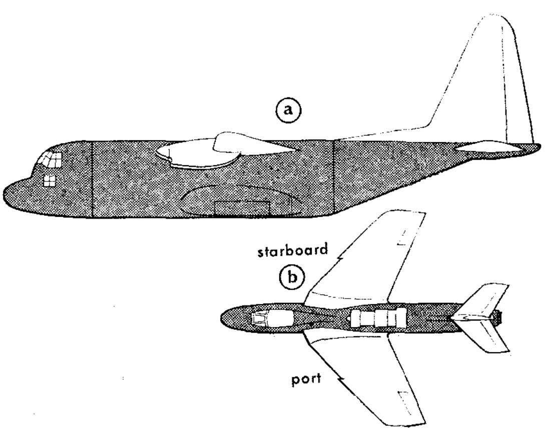


Fig 1 Fuselages

Main Planes

3. The primary purpose of the main planes is to support the aircraft in flight. They are often also used to support or contain the propulsion units, fuel tanks and armament.

Port and starboard mainplanes can be fitted directly to the fuselage as in Fig 2a, or attached to a centre section formed on the fuselage as in Fig 2b.

The front edge of the mainplanes is always called the 'leading edge' and the rear edge the 'trailing edge'. The point of attachment of the fuselage to the centre section is known as the 'wing root' and the opposite (outer) end of the wing as the 'wing tip'. When the leading edges of the mainplanes are inclined rearwards as in Fig 2a these mainplanes are known as 'sweep back' wings.

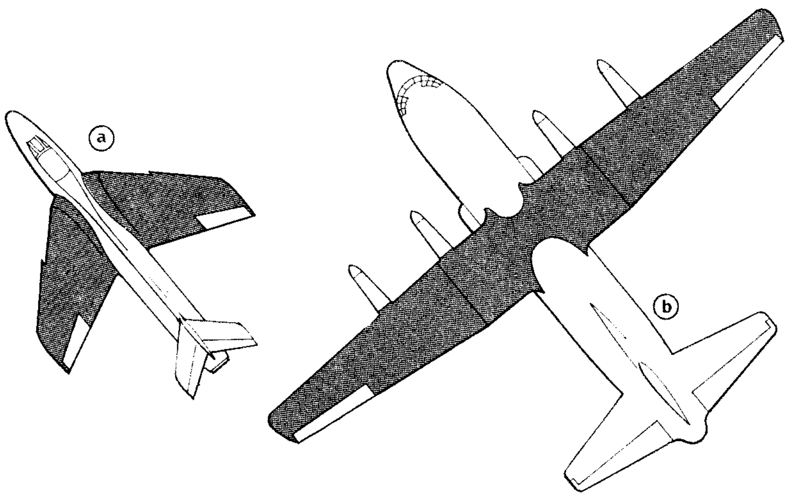


Fig 2 Main planes

Tail Unit

4. The tailplane and the fin form the main parts of the tail unit.

5. **The tailplane.** The tailplane is required to hold or steady the aircraft in flight to prevent 'pitching', that is, the nose going up and down. Port and starboard tailplanes are secured to the rear end of the fuselage (Fig 3a). Some high speed aircraft have the tailplane secured about the top of the fin (Fig 3b). The tailplane is sometimes made adjustable and then it also performs the function of a flying control.

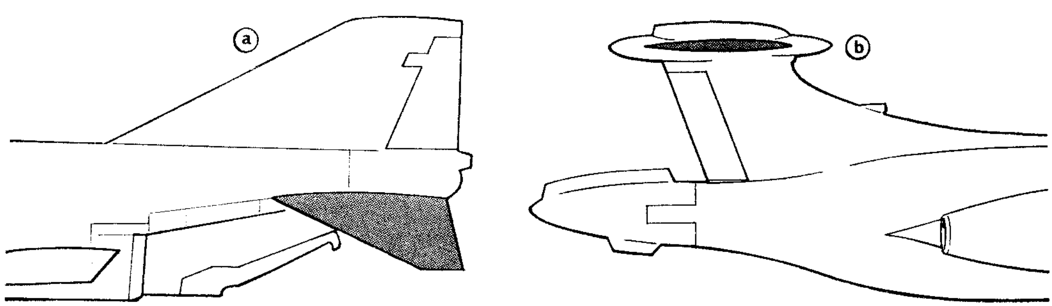


Fig 3 Tailplanes

6. **The fin.** This is a vertical member secured to the rear end of the fuselage (Fig 4). Its main purpose is to provide directional stability; that is, the fin holds the normal line of flight of the aircraft to a straight line. The fin also provides a mounting for the rudder.

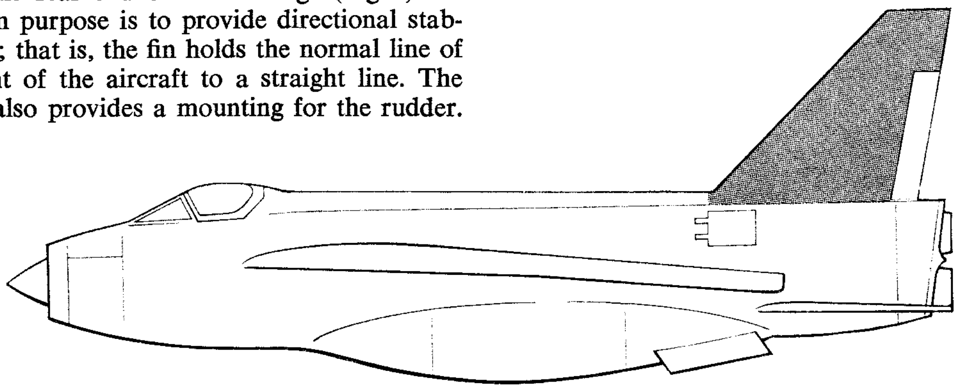


Fig 4 The fin

Landing Gear

7. The undercarriage or 'landing gear' is an essential part of any landplane, although it is a 'dead weight' when the aircraft is flying. The landing gear must:

- Support the aircraft while on the ground.
- Absorb the shock of all landings.
- Provide smooth taxying.
- Be as light as possible.
- Permit or assist with steering.

The landing gear normally consists of a port and starboard undercarriage unit and a nose or tail wheel (Fig 5). When a nose wheel is used it may be steerable, from the cockpit, to assist in manoeuvring the aircraft on the ground. A modern version using central main and nose wheels with wing tip steadying wheels is shown in Fig 5b.

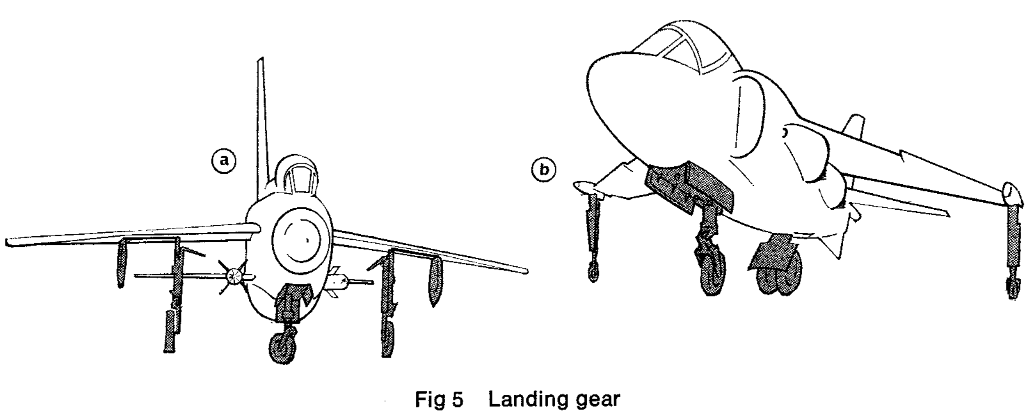


Fig 5 Landing gear

Flying Controls

8. Just as a motor car must be capable of controlled manoeuvre on the ground so an aircraft must be controlled in manoeuvre in the air. This is made possible by the 'flying controls'. These are:

- The ailerons — to control roll.
- The elevators — to control dive and climb.
- The rudder — to give directional control.

In addition, an aircraft may be fitted with:

- Flaps — to enable it to fly at a slower speed.
- Airbrakes — to slow it quickly in the air.

We shall now take a closer look at each control and see how it achieves its aim.

9. **Ailerons.** The ailerons form part of the outer ends of the trailing edges of the mainplanes (Fig 6). They are hinged on to the main structure of the mainplanes and connected to the control column in the cockpit. They are operated from the cockpit by a side to side movement of the control column, or a rotary movement of a control wheel. They are inter-connected so that as the port aileron moves upwards the starboard aileron goes down. This movement in flight would cause the aircraft to roll to port; the reverse movement would cause a roll to starboard.

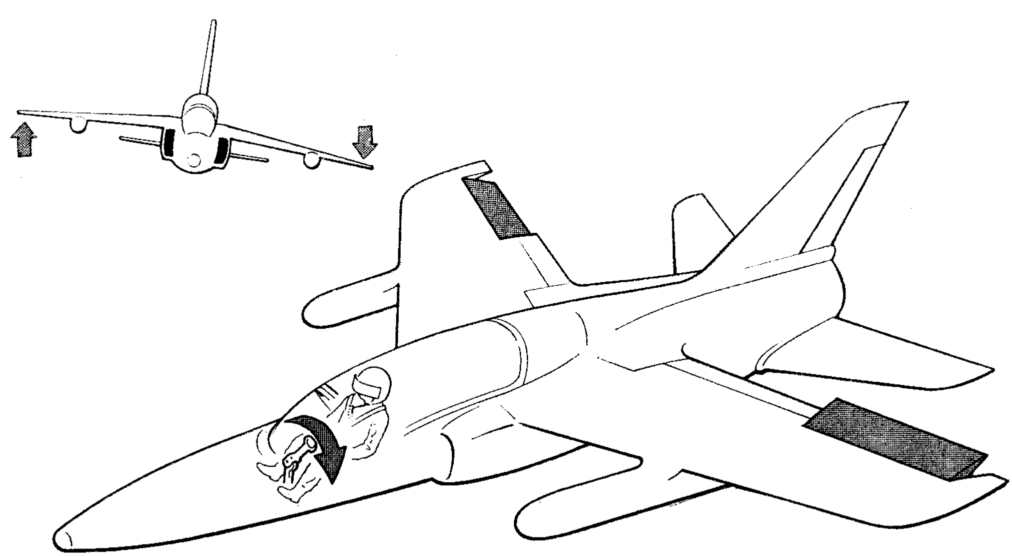


Fig 6 The ailerons

10. **Elevators.** The elevators are control surfaces hinged to the rear edge of a stabilizing surface called the tailplane. They are joined together so that they operate as a single control (Fig 7a). Movement of the elevator is affected by movement of the control column in the cockpit. A forward movement of the column causes the elevator to move downwards and the aircraft will dive, whilst a backwards movement causes the elevators to go up and the aircraft will climb (Fig 7b). Aircraft without a separate tailplane (the so-called tail-less type) use the movable tips or rear portion of their swept back wings to carry out the functions of the tailplane and elevators (Fig 7c).

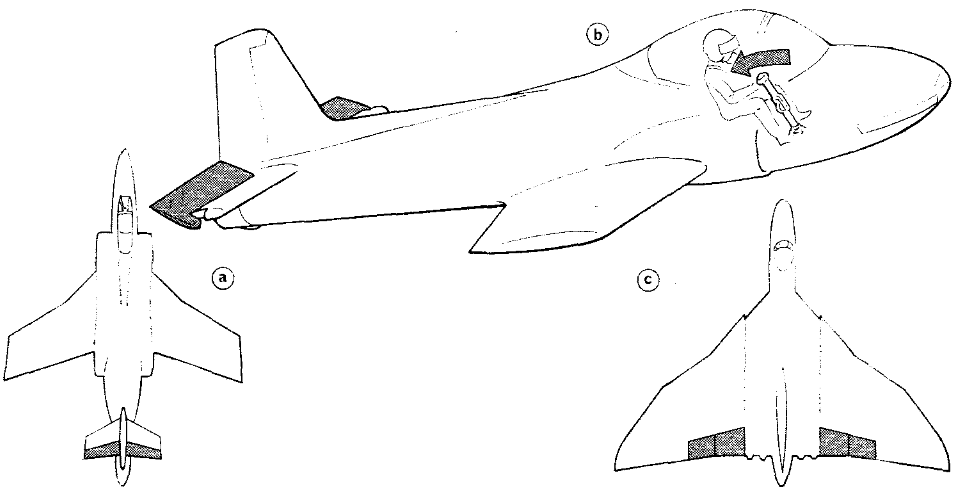


Fig 7 The elevators

11. **Rudder.** The rudder is a movable control surface, hinged to the rear edge of a part of the main structure called the fin (Fig 8). The rudder is connected to, and operated by, a foot control in the cockpit. This control is the rudder bar and pushing the left food forward on the bar pedal causes the rudder to move to port. In flight this causes the aircraft to turn to port. Right foot forward on the pedal would cause a turn to starboard.

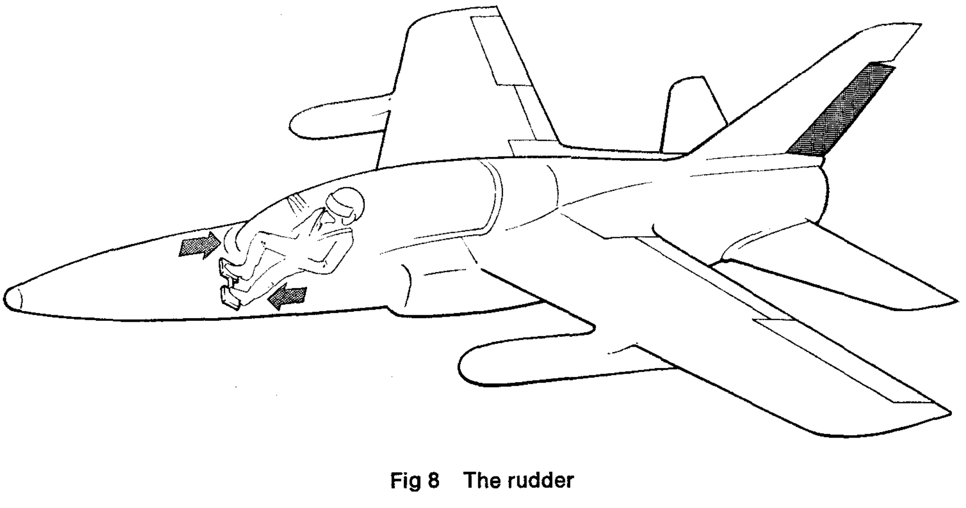


Fig 8 The rudder

12. **Flaps.** The flaps may form part of the inner ends of the trailing edges of the mainplanes (Fig 9). They are movable control surfaces forming part of the mainplane. Unlike the ailerons, port and starboard flaps, when operated, move only from neutral to down and back to neutral. A separate lever in the cockpit causes both flaps to move together in the same required direction at the same rate of movement. When partially lowered for aircraft 'take-off', the flaps increase the 'lift' of the mainplanes and the aircraft climbs at a greater rate (Fig 9a). When fully lowered, for 'landing', wing 'lift' is again increased and the aircraft descends more slowly and at a steeper angle (Fig 9b).

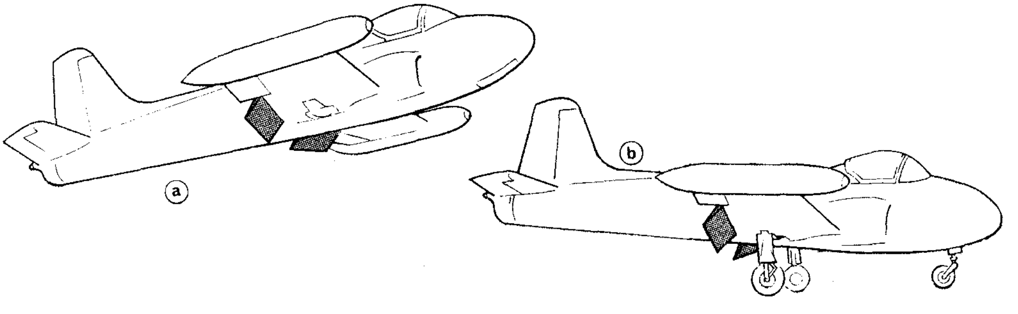


Fig 9 Flaps

13. **Airbrakes.** High speed aircraft with a high weight tend to retain their speed for a considerable time after the engine has been 'throttled back'. When the desired lower speed has been attained any slightly downward flight path causes an increase in speed. To control the angle and speed of descent the 'airbrakes' may be extended by operating a special lever in the cockpit (Fig 10).

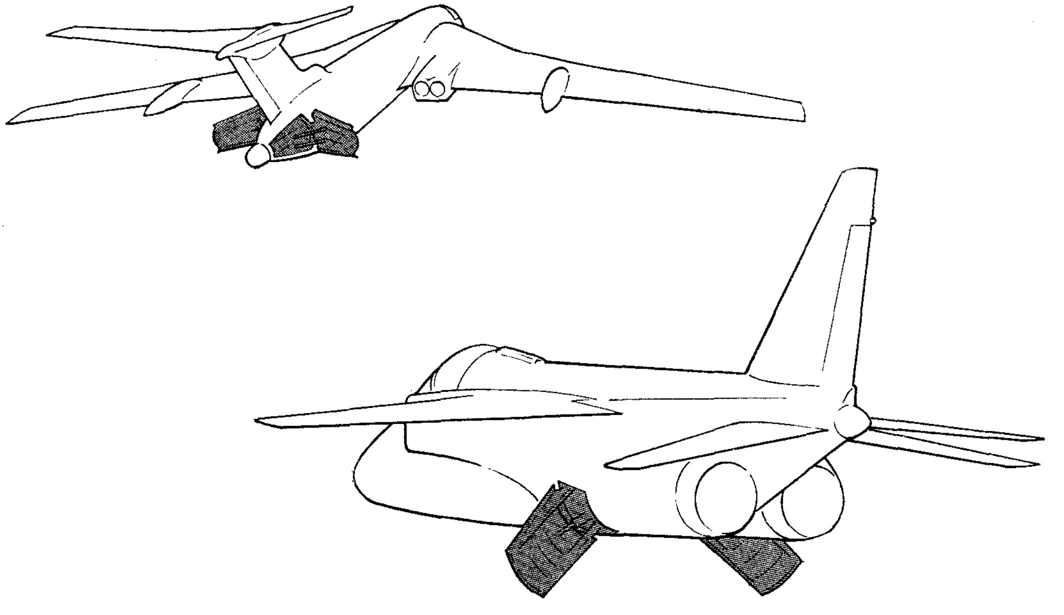


Fig 10 Airbrakes

CHAPTER 9

THE HELICOPTER

Introduction

1. The main flying characteristic of the helicopter is its ability to ascend and descend vertically or to remain stationary (hover) in the air. It can also fly sideways or backwards; in fact, it can fly in any direction whilst facing in another. The helicopter does not need prepared landing grounds with special runways; the surface of the landing area is relatively unimportant.

Main Rotors

2. An important feature of the helicopter is the main rotor. It provides the 'lift' to keep the machine in the air and also the 'Propulsive thrust' for flight. The main rotor may have two, three, four or more blades with an overall diameter of 50 feet or more. The blades are attached to the hub in a special manner using 'flap' and 'drag' hinges. During rotation the blades rise (flap) upwards at the tip forming a cone, the cone angle being maintained by lift and centrifugal forces (Fig 1a). When the helicopter is at rest on the ground, with the engine stopped, the main rotor blades droop under their own weight (Fig 1b).

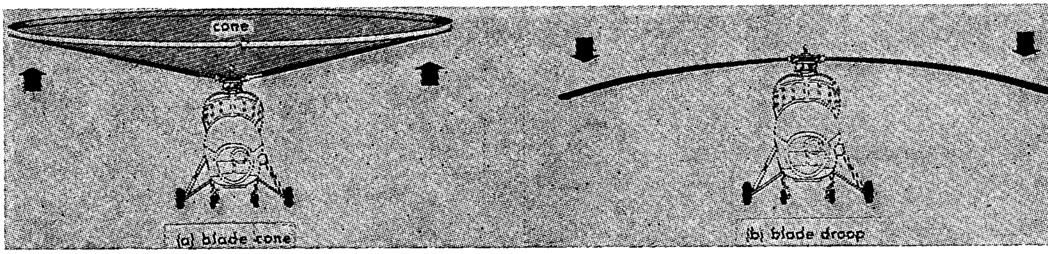


Fig 1 Main rotor

Main Rotor Drive

3. The rotor is power-driven from either a piston engine or a gas turbine engine and included in the drive are:

- A clutch unit, which allows the engine to run without turning the rotor. This makes engine starting easier because the rotors do not turn during the engine starting cycle.
- A free-wheeling device, which allows the rotor to windmill without turning the engine (autorotation). This provides limited control for landing the helicopter if engine power fails.

Lift and Forward Speed

4. The total lift and thrust produced by the main rotor of a helicopter is, like the lift of a fixed wing aircraft, dependent upon the speed of the airflow over it. The forward speed of a helicopter affects the lift of the main rotor blades. It tends to produce unbalanced lift because the speed of air flowing over the blades varies as the blades revolve from one side of the machine to the other (Fig 2).

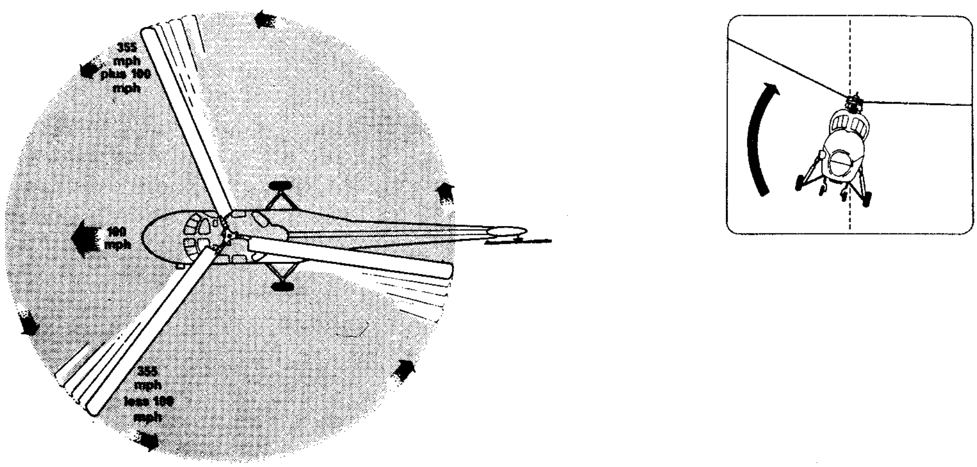


Fig 2 Effect of forward speed

5. To overcome the roll tendency the helicopter is designed so that the 'advancing' blade has a reduced angle of attack whilst the angle of attack of the retreating blade is increased. This change in blade angle is made automatically (Fig 3).

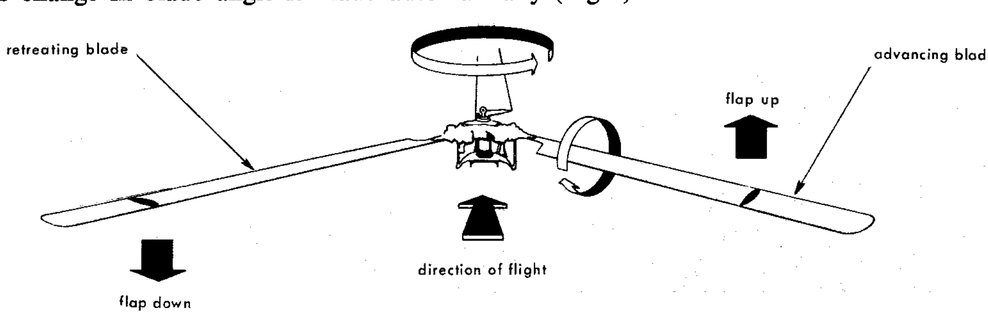


Fig 3 Changing blade angle

Directional Control

6. Helicopters with a single main rotor set up a directional control problem. This is because the engine power used in turning the main rotor shaft creates a force—torque reaction—that tends to rotate the aircraft in the opposite direction. This force is countered by driving a tail rotor (Fig 4).

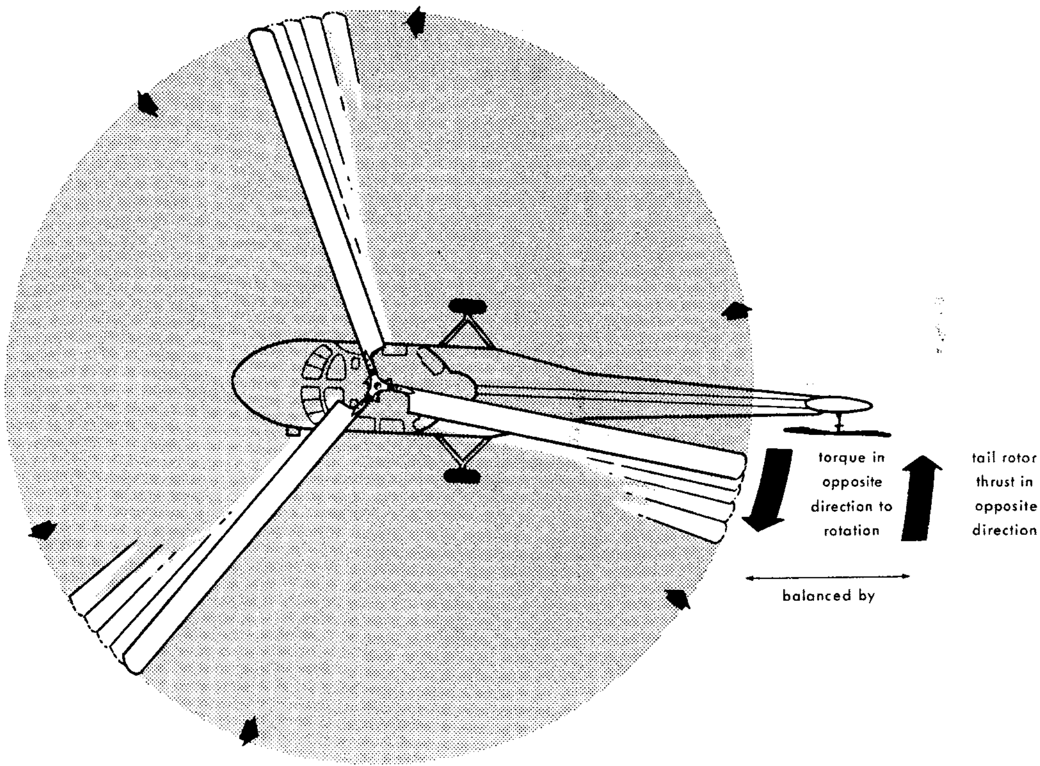


Fig 4 Rotor torque

7. **Tail rotor.** The tail rotor is a much smaller rotor mounted vertically at the rear of the tail cone. The thrust produced by the tail rotor balances the torque of the main rotor and gives directional control. The pitch angle of the tail rotor blades can be varied, varying the thrust produced. In this way it provides a means of turning the helicopter around its vertical axis. Like the rudder of a conventional aircraft the tail rotor blade angle is controlled by the pilot's feet on a conventional rudder bar or on pedals.

Ground Handling

8. Because of the blade length (typically over 25 feet), and because the blade may come to rest in any position, great care is needed to avoid damage to the main rotor when handling the helicopter on the ground. If you must handle the rotor blades, ensure that they are moved downwards the smallest amount possible from the normal droop position. Any greater movement will overstrain the blade root assembly and can cause failure.

Care of Rotor Blades

9. Rotor blades should be moored, if possible, when the helicopter is parked; even light gusts of wind may damage blades which are free to flap. Rotor blades are moored with one blade aligned along the tail cone and the tail rotor vertical (two bladed types). Special blade tip mooring covers, complete with rope, are used to secure the blades (Fig 5). The ropes are tied to anchorage points on the helicopter and should be tightened to prevent flap but not so tight as to strain the blades. When the blades are positioned for mooring the collective pitch control lever must be locked in the fine pitch position and the rotor brake applied.

Always use the correct mooring covers; rope by itself must never be used when mooring or handling rotor blades.

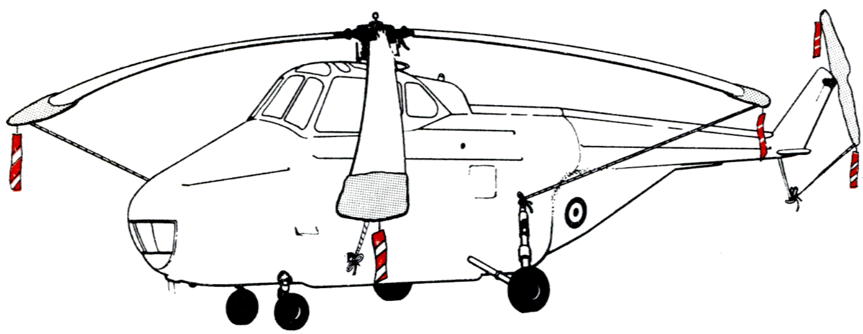


Fig 5 Moored blades

10. **Protective Covers.** Special covers are provided for both main and tail rotor blades (Fig 6). These covers should be fitted, to protect the rotor blades from heavy rain or strong sunlight, during long periods of parking. When fitting blade covers ensure that the warning pennants hang free.

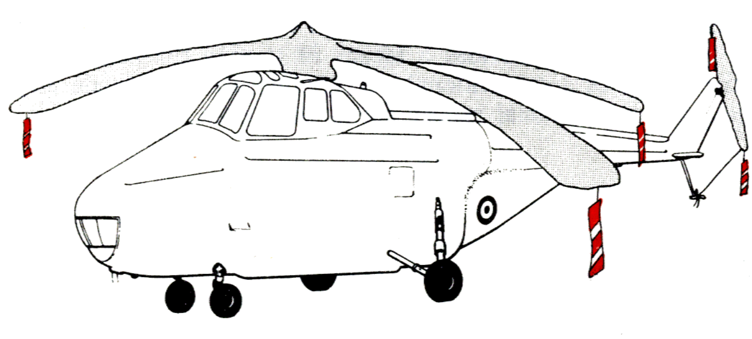


Fig 6 Protective covers

SECTION 3

TECHNICAL ORGANIZATION

NOTE TO READERS

Section 3 contains general information on the organization and administration of the Royal Air Force technical services. This information is for training use only and is intended to be of value to students at schools of technical training and to tradesmen studying for promotion examinations. The information given is not mandatory and reference should always be made to one of the publications listed below which contain full details and mandatory orders.

AP 3158		— Technical services manual.
	Vol. 1	— Organization and administration.
	Vol. 2	— Technical orders and instructions.
AP 3224		Manual of signals organization.
AP 830		Royal Air Force equipment regulations.
AP 1301		Manual of organization.
DCIs		Defence Council Instructions.

CHAPTER 1

EQUIPMENT PROCEDURES

List of Contents

Introduction

1. The regulations governing the handling and accounting procedures to be used for RAF equipment are set out in full in AP830. Most of these regulations are the concern of the equipment tradesman only, but all tradesmen must have a background knowledge of equipment procedures to enable them to carry out their work efficiently.

2. Spare parts which are used only on a particular aircraft or equipment are listed in the volume 3 of the appropriate air publication, but they are handled in the same way as all other items. Parts of more general application and all RAF equipments are listed in the AP1086—'Catalogue of General RAF Equipment'. Each item is identified by a number (its stock number) and by name (its nomenclature). The equipment accounting class of the item is also given in AP1086 (*see* para 3). Items can only be obtained in the quantities given in AP1086 or in multiples of these quantities.

Classes of Equipment

3. All items are classified for accounting purposes as 'A', 'B', or 'C' equipments. This classification depends mainly on the value of the items and on the approved method of disposal when the item becomes unserviceable.

a. Class 'A' equipment. This class consists of items of fairly high value which are capable of repair. When they become unserviceable they are repaired by the engineering wing, but if this is not possible they *must be returned* through the supply squadron to a *repair depot* (Maintenance Unit) or to the manufacturer. Power operated tools, radio equipments and test sets are typical examples of class 'A' items.

b. Class 'B' equipment. These items, which for technical or other reasons cannot be economically repaired other than at unit level, are returned by the user to the supply squadron for local disposal. Most barrack equipment and wooden furniture are class 'B' items, as are many tools.

c. Class 'C' equipment. Class 'C' contains all items which cannot be classified 'A' or 'B'. These items are *not accounted for whilst in use*, but should be repaired by units if economically possible. The class consists of low value items such as nuts, bolts, some spanners and small tools, and items which are consumable such as solder, wire and paint.

4. **NIV items.** Sometimes articles such as test benches are made by local manufacture and have a value such that they must be taken on charge and accounted for whilst in use. This is done by giving the item a local reference number and treating it as a class 'B' equipment. The number is preceded by the letters NIV which means that the item is not listed in AP1086 (which used to be called the vocabulary of equipment). A register of NIV items is maintained by the supply squadron.

5. **Valuable and attractive (V & A) items.** These are small attractive items of high value which experience has shown are liable to be stolen. Typical examples are stop watches, cameras and binoculars. Special arrangements are made for the custody of V & A items in the supply squadron and *at user level they are kept in a locked steel cupboard when not in use.* All vouchers and documents relating to V & A equipment are annotated V & A across the top in red ink. If the item has an RAF serial number this must also be shown on all documents. The Commanding Officer has the power to classify some items as local V & A *for security purposes at user level,* and this is often done with AVO multimeters.

Inventories

6. All class 'A' and 'B' items issued to a section are taken on charge by an officer or senior NCO who is responsible for their safe custody. The items and quantities are listed in an inventory (RAF form 37) which is kept up to date by a system of periodic checks. A master copy of each inventory is also maintained by the supply squadron as a record of all transactions.

7. **Inventory checks.** Inventories are checked on the following occasions and are brought up to date immediately before the check by the Supply Control and Accounting Flight (SCAF) of the supply squadron.

a. On change of inventory holder they are checked by the individual taking over in the presence of the person handing over.

b. All inventories must be checked at least once in each three year period commencing on April 1st. This check is usually carried out by planned change of the inventory holder as in *sub-para a.* above. Where this is not possible the inventory will be checked by an independent officer or senior NCO appointed by the Commanding Officer.

c. An annual check of all V & A items on the unit is carried out during the period April 1st to March 31st by the supply squadron.

8. **Loans to individuals.** Any items of 'A' or 'B' equipment on loan from the inventory holder to an individual must be signed for on the appropriate form:

a. F668—Record Card, Loans to Individuals in Units. Any item which is to be kept for more than 24 hours is signed for on F668. The inventory holder keeps a record of all F668s on the appropriate pages of his inventory and carries out physical checks of the items periodically (normally monthly). A separate F668 is used for each tradesman who inserts the date and his signature against *each item* of equipment recorded. It is the tradesman's responsibility to ensure that items on his F668 are deleted by the inventory holders signature when they are returned.

b. *F108—Receipt for Equipment on Temporary Loan.* F108 is used for short term loans of less than 24 hours, the item on loan being returned to the inventory holder's lock-up at the end of the working day. It is the tradesman's responsibility to ensure that his F108 is destroyed when the equipment is returned. If an item on temporary loan is drawn from a section sub-store a counter book is sometimes used to record issues and receipts from this store. It is still the tradesman's responsibility to make sure the item is 'signed-in' on its return.

9. **Loss or damage due to negligence—F664B.** The cost of an item which is lost or damaged may be recovered from an individual by F664B action. The vouchers are raised by SCAF and signed by the individual as accepting responsibility for the cost. Action can then be taken to replace the item or have it struck off the inventory.

Supply Organization

10. **Automatic Data Processing Supply System (ADP).** Provisioning of equipment for the whole of the RAF entails the supply of a vast number of different items of equipment, all of which have to be held on account. Central records are now kept on a computer and information is fed to and from user units over a form of teleprinter link with the supply squadron (SCAF).

11. **Unit organization.** The supply squadron is sub-divided into a number of flights, each of which is responsible for a particular aspect of the units requirements. The main flights are:

a. Supply Control and Accounting Flight (*SCAF*). This flight is responsible for the provisioning and accounting of all equipment used on the unit. They hold a record of every transaction carried out, both internal and external. A master copy of each inventory on the unit and a master list containing all 'Articles in Use' on the unit (the A in U ledger) are compiled and maintained up to date by this section.

b. Receipt and Dispatch (*R & D*). This section is responsible for receipt of all items into the unit and their distribution to the correct stockholding group. It also prepares and packages all items for dispatch by the unit and organizes their transit.

c. Stockholding Groups. These sections are organized to hold stocks of a particular type of item and to issue these items to the user as and when they are required. A typical breakdown would be:

(1) Barrack. All furniture and domestic equipment.
(2) P.O.L. Petrol, oils and lubricants.
(3) Clothing. All items of personal kit.
(4) Technical. This section is often divided into sub-groups such as electronic, V & A items, security graded equipments etc., all of which operate from a common office.

12. **Forward Supply System.** When equipment is to be demanded or returned the supply squadron (SCAF) is informed either by telephone or in writing. All voucher preparation is completed by SCAF and the required items are delivered to the user section by the forward supply truck. The inventory holder or his deputy must be available to receive the equipment and sign the vouchers. A copy of the voucher is handed over and this enables the holder to keep a running check on his inventory. The main objects of the forward supply system are to:

a. Eliminate the time used by skilled tradesmen in the preparation of vouchers and in the collection and delivery of items from or to the stockholding groups.

b. Ensure efficiency and economy in the use of equipment by retaining direct control of the allocation of spares holdings.

c. Provide accurate consumption data upon which unit provisioning action can be based.

Transaction Procedures

13. **Internal ADP voucher F676.** To enable the demands clerk in SCAF to complete the F676 the following details must be given when making demands, exchanges or returns:

a. All Transactions.

(1) Flight or section and inventory number.
(2) Section, reference number and quantity of the item.
(3) Whether for demand, exchange or return.
(4) Date and time required if the routine delivery by forward supply truck is unsatisfactory.

b. Exchanges and returns.

(1) The condition of the item being replaced or returned.
(2) When the item will be available for return.

14. **'C' class items.** Class 'C' items for which there is a recurring demand are delivered automatically by the routine runs of the forward supply section. Flight lock-ups normally hold 14 days supply of class 'C' items and this stock should not be allowed to run down or accumulate. Demands for extra 'C' stores are made to SCAF in the normal way, stating the reason for the demand and confirming that the quantity demanded is not in excess of requirements. If stock runs down or accumulates the officer i/c section will arrange a review of the section stock holdings with the supply officer.

15. **Priority demands.** When the time taken to obtain spare parts or equipment is likely to be so long as to reduce squadron efficiency the demand can be given special priority. A list of priorities is published from time to time in DCIs and authority to raise a priority demand must be given by the OC Engineering Wing or by a Command Staff Officer.

16. **Direct supply scheme.** This scheme applies to selected items of equipment which are in commercial use and was introduced to improve supply efficiency and reduce storage and handling costs. Details of the items available under this scheme are distributed to the unit equipment section. Demands are made *by the user in the normal way* to the supply squadron which makes arrangements to purchase the item from a local trade source.

17. **Equipment label (RAF Form 6812).** All equipment to be exchanged or returned must be assessed for condition and have an equipment label attached. The appropriate condition certificate block on the label must be signed by an authorized trade specialist. In the interests of flight safety, any equipment which does *not* have a 'serviceable' condition certificate signature on the equipment label *must be regarded as unserviceable.*

Note: Where MOD servicing records are in use on the unit, the equipment label (MOD Form 731) forms part of the job card (see Sect. 6, Chaps. 2 & 3). These two labels are identical except for the computer input information on the MOD Form 731.

18. **Scrap label (RAF Form 3910C).** This is a yellow label and indicates that the item is impossible to repair or is beyond economical repair. The certificate on the label must be signed by an authorized trade specialist officer.

CHAPTER 2

SOURCES OF TECHNICAL INFORMATION

List of Contents

Introduction

1. Technical air publications (APs) are the official authority for the servicing and repair practices to be used in the Royal Air Force and are mandatory. They may be over-ridden in part by the issue of later orders promulgated as Defence Council Instructions (DCIs); or they may be adapted slightly to suit the operational requirements of a particular command by Command Engineering Staff Instructions (C Eng S Is).

2. Information and orders of a general character may be found in:

a. AP3158—Technical Services Manual. This AP consists of two volumes; Volume 1 contains information on organization and administration of the RAF technical services, and Volume 2 contains mandatory technical orders and instructions.

b. AP3224—Manual of Signals Organization. This AP contains information on the organization and responsibilities of signals and related electrical engineering staffs.

c. AP1464—RAF Engineering. One part of this manual AP1464B—General Engineering, contains general engineering principles and workshop practices.

Note. Technical information and orders for a particular type of aircraft or equipment will be found in the AP specifically written for the purpose.

3. **Amendments.** All publications are kept up to date by amendment lists (ALs) issued from time to time. They are authorized by the Ministry of Defence and their issue is announced in the Publications Supplements to Defence Council Instructions (RAF). The holder of an Air Publication is personally responsible for keeping it full amended. Amendment lists should be incorporated as soon as possible after receipt and their incorporation signed for on the amendment record sheet at the front of the air publication. Amendment lists are numbered consecutively and are usually issued in sequence, thus enabling the AP holder to check that all previous ALs have been received and incorporated.

4. **Advance Information Leaflets (AILs).** These are leaflets which are used to speed up the publication of urgent, important, technical information. The leaflet is normally inserted to face the appropriate page in the AP and remains there until an amendment list containing the same information (and cancelling the AIL) is issued. To emphasize the importance of AILs, and to attract the readers attention to them, they are printed on blue paper.

5. **Command temporary amendments.** A Command temporary amendment may be issued to Air Publications when corrective action is required *immediately*. They are only an interim measure and are withdrawn as soon as official amendment action is taken by the Ministry of Defence.

6. **Manufacturers information.** A large number of manufacturers handbooks are used in the service, particularly for radio equipment and electronic test equipment. Most of these are given an official AP number and are then kept up to date, and amended in the light of service experience, in the same way as a normal Air Publication. Those handbooks which do not have an AP number should be regarded as *informative* only, and all servicing must be carried out in accordance with official servicing schedules. When information is received from a manufacturer which conflicts with an AP an unsatisfactory feature report must be raised so that the matter can be investigated and the AP amended if necessary. The permission of Command HQ must be obtained before direct use is made of manufacturers information.

7. **Unsatisfactory features reports.** Any errors found in technical air publications should be reported on RAF form 6734. Suggested improvements are also readily accepted and help towards a continuing improvement in the standard of technical air publications.

8. **Security.** All APs are classified in accordance with the security rating or grade of their contents. This rating is printed on each page and is also indicated by the colour of the cover label. Material classified as restricted or above must never be left unattended and must be kept in a locked safe or steel cupboard when not in use.

Top Secret material has a deep red cover.
Secret material has a red cover.
Confidential material has a green cover.
Restricted material has an orange/buff cover.
Material 'For Official Use' has a blue cover.

Technical Air Publications

9. **The six volume scheme.** This layout was introduced to provide a flexible framework for the standardization of air publications. Each publication is allotted a number, *eg* AP2534—Tacan and may have a suffix to show that the publication deals with a specific mark or type of equipment only, *eg* AP2534L—Tacan (Surface). These numbers were allotted in sequence from a block allocated to technical APs and are of themselves meaningless. This system of numbering was replaced in 1965 by a coding system suitable for computer indexing.

10. **The six volume layout.** The actual contents of a particular AP are shown in a layout tree in volume 1 of the publication, but most equipment APs are divided in the following manner. Each volume, part or section is not necessarily issued for every equipment.

a. Volume 1. 'General and Technical Information'. This volume gives a general description of the equipment, followed by technical information, fault diagnosis and testing after installation.

b. Volume 2. 'General Orders and Modifications'. These are listed in leaflets issued as amendments to volume 2 which must be kept up to date by the holder.

c. Volume 3. 'Equipment Schedules and Scales'. This volume contains a schedule of spare parts for the equipment and lists the scales of unit equipment and servicing spares which may be held by a user unit.

d. Volumes 4 and 5. 'Servicing Schedules'. These volumes contain all safety and servicing instructions needed for servicing the equipment at unit level. For new equipments coming into the service, provisional schedules are issued by the responsible authority.

e. Volume 6. 'Repair and Reconditioning Instructions'. This volume is normally used for fourth line servicing and reconditioning at the manufacturers but may have some applications at Maintenance Units.

11. **Coded AP numbers.** The coded AP is the modern form of technical publication and all technical information required by the RAF is now issued in this format. The codes have a meaning (see figure 1) and the contents of a coded publication can thus be identified from the number. The big advantage of the coded system of issue is that much information which was previously only available in *bulky* manuals such as AP4343 (Electrical Manual) is now issued in smaller 'units'. Each of these units, no matter how small, is a complete individual publication with its own code number, title page and amendment record sheet. To assist the user to select the coded APs which he requires, a separate catalogue of coded publications is kept at Air Publications and Forms Store (APFS). This catalogue also contains 'master lists for aircraft' which show the user of a particular aircraft type which publications he needs to order to maintain the aircraft, its ground equipment and all removable installations.

CODED AP No. 113E-0129-1 Formerly AP 4343D, Vol 1, Book 4, Sect 21, Chap 27.

113E - 0129 - 1

1st ELEMENT		2nd ELEMENT		3rd ELEMENT
GROUP	SUB-GROUP	CLASS	ITEM	TOPIC NUMBER (Based on 6 Vol scheme)
113 Electrical Equipment	E Rotary consumer equipment	01 Actuators, linear	29 AILERON TRIM STRUT, Plessey type 500/1/00299	1 VOLUME 1 General and Technical Information

CODED AP No. 101B-0101-1A

101 Aircraft	B Fixed wing	01 BELFAST C	01 Mark of aircraft Mk1	1 VOLUME 1	A BOOK 1

CODED AP No. 116B-0203-2

116 Radio Equipment	B Navigational and landing aids (airborne)	02 Radio Altimeters	03 RADIO ALTIMETER Mk7	2 VOLUME 2 General Orders and Modifications

Fig. 1 Structure of the AP code

Orders and Instructions

12. **Defence Council Instructions (DCIs).** These instructions are promulgated by the Defence Council and are published weekly; DCI (General) apply to all the armed services. DCI (RAF) are issued in two parts; Standing Instructions (DCI-'S') which are valid for three years, and Temporary Instructions (DCI-'T') valid for one year. Both parts are of equal importance and provide a means of publishing up to date information prior to the amendment of the appropriate air publication. They contain general orders and instructions including administration, flying, training, equipment and servicing orders. DCI (T) also contains a publications supplement giving information on new and obsolete APs, forms and air diagrams and on the issue of amendments to existing publications. An index to current Defence Council Instructions is published annually (January).

13. **Command Engineering Staff Instructions (C Eng SIs).** These instructions are issued to groups and units by the engineering branch of their command headquarters. Their purpose is to promulgate command orders, special instructions and command modifications, to personnel within the command. They give more detailed interpretations and command applications of the general orders and instructions mentioned in para 2, and form the basis from which Unit Servicing Orders are compiled. Particular orders are preceded by two or three letters indicating the command of origin *eg* TC Eng SI (issued by Training Command).

14. **Unit Servicing Orders (USOs).** The purpose of unit servicing orders is to describe the technical organization of the unit and to define individual responsibilities for the servicing of aircraft and other technical equipment. The orders are prepared by the OC Engineering Wing and are then promulgated by the Station Commander. The orders laid down will vary according to the type of unit and its servicing task; where necessary, reference will be made to Queen's Regulations (QRs), DCIs, and C Eng SIs. In general the subjects covered are:

a. Statement of the object of the orders.

b. The method of publication and amendment.

c. Duties and responsibilities of engineering wing personnel.

d. Responsibilities of aircrew:
(1) engaged in flight testing.
(2) employed on aircraft servicing.

e. Division of work between various parts of the unit servicing organization.

f. Servicing of visiting aircraft.

g. Servicing of technical equipment other than aircraft.

h. Ground handling of aircraft on the unit.

j. Routine orders for duty personnel e.g.:
(1) Duty Engineering Officer.
(2) Duty ground crew.

15. **Technical Order Books.** An order book is normally maintained by all self-contained flights or sections. It includes all orders specific to the section and defines the responsibilities delegated to section personnel. A special cover (RAF form 5642), set of six spacer cards (F3559A) and individual order and signature sheets (F3559B) are available, and where necessary a second set of spacer cards could be used. A typical Electronics Servicing Squadron order book would contain:

a. Part 1. General orders which apply to all electronics personnel irrespective of their section or task, including:
(1) Allocation of responsibility to Officers and SNCOs i/c sections or servicing bays.
(2) Security orders.
(3) Safety precautions and regulations.
(4) Discipline.

b. Part 2. Technical and servicing orders of a general nature which are applicable to all sub-sections or bays.

c. Parts 3—6. Technical orders—each part containing the orders relevant to a particular sub-section or servicing bay.

Each sub-section should hold only those parts of the orders which are applicable *eg* parts 1 and 2 and one of the other parts. Officers i/c sections should hold a full copy and a master copy is retained by the squadron commander. It is important that all tradesmen keep themselves constantly aware of the book as it is continually amended as orders are varied. *Each loose leaf order is signed* by all tradesmen to which it applies to record that they have read and understood the order on that leaf.

16. **Modification Leaflets.** The modification of an equipment is a process adopted to improve reliability or to adapt the equipment to some new function. Modifications are also introduced when found necessary to make servicing easier and thus save man-hours. Information that a modification has been approved is issued to Commands in the Air Force Department monthly list of modifications. A modification leaflet is issued to the user in the form of an amendment to volume 2 of the equipment AP. This leaflet details the work sequence to be followed and also sets a limit on the time period allowed for embodiment action. Modifications to avionic equipments, *eg* electrical, instrument and radio equipments fitted to aircraft, are normally embodied by a repair depot (MU) or the manufacturer. For these modifications, an information leaflet is issued for the volume 2 which omits the working sequence.

17. **Special Technical (STI) and Servicing Instructions (SI).** Serious defects may require quicker remedial action than is possible by normal modification procedures. Instructions are issued in the form of signals or memoranda and are known as STIs, SIs or preliminary warnings. An STI is issued where action is urgent and non-recurring; and finally results in modification action. An SI is issued where the action required is recurring and remains in force until the instruction is introduced as a permanent item in a servicing schedule, or until a modification is introduced to rectify the fault and render the SI unnecessary. Preliminary warnings are instructions of immediate importance issued when evidence available is insufficient to compile an STI or SI. They consist of serially numbered signals and no standard form is laid down.

CHAPTER 3

ASPECTS OF SERVICING

List of Contents

Introduction

1. This chapter contains general servicing information and information on aircraft servicing. The system of servicing ground radio equipment is described in Chap 4. Before servicing any aircraft or equipment the Air Publication for the relevant work must be consulted, and the work sequence followed must be that laid down in the vol 4/5 (Servicing Schedules).

2. The term *serviceable* is used to describe the condition of materiel that is fit for its intended use. Servicing is therefore the engineering and other activities necessary to keep an item in a safe, operationally effective and serviceable condition.

a. *Inspection.* Inspection is the process of measuring, examining, testing, gauging and otherwise comparing material, processes and workmanship with the applicable quality requirements.

b. *Repair.* To repair an item is to restore it to a specified condition *eg* serviceable. It may be done by:

(1) Replacing damaged or deteriorated parts by serviceable parts.

(2) Making parts good by the use of suitable tools and materials.

(3) Adjustment to restore it to the specified condition.

c. *Reconditioning.* Reconditioning is the process under which an item is completely overhauled, renovated, reassembled and inspected to specified quality requirements. After reconditioning; equipment, with the exception of airframes, normally starts a new life.

Signing Servicing Documents

3. In the interest of safety there must be a chain of individual responsibilities for servicing work, and a recording system which ensures that the individuals can subsequently be identified. A system of successive signatures on the appropriate servicing document is used:

a. *The signature of the tradesman* certifying that he has completed the job in accordance with the instructions given to him. On some records the tradesman initials individual job entries and signs one certificate covering the whole document.

b. *The countersignature of the Non-commissioned Officer* (*Trade NCO*) certifying that he is satisfied with the completeness and quality of the work for which the tradesman has signed.

c. The co-ordinating signature of the NCO-in-charge of the flight or section. The co-ordinating signature certifies:

(1) In the case of a fitness for flight certificate that all the work necessary to prepare the aircraft for flight has been completed, certified and countersigned by authorized personnel.

(2) For all other servicing that the servicing documents adequately describe the range of work and the mandatory checks necessary to complete the servicing or to make good the repair. And that the servicing documents are properly completed and exhibit the signatures of tradesmen and the countersignatures of the trade NCOs.

Note 1. The completion of any servicing record form, together with signature or initials as appropriate, constitutes a certificate under the Air Force Act.

> "By the Air Force Act it is a punishable offence to sign any certificate knowing it to be false (sect 62) or to sign any certificate in relation to aircraft or aircraft materiel without ensuring the accuracy thereof (sect 50)."

Note 2. All entries are to be made in ink or indelible pencil. Errors are not to be erased, but should have a line drawn through them and be initialled by the person making the correction.

Servicing Terms

4. To ensure that servicing instructions are not misunderstood, a limited number of verbs are used. These verbs, which should be memorized, include the following:

a. Check. Make a comparison of a measurement of voltage, pressure or other quantity with a known required figure for that measurement.

b. Examine. Scrutinize the materiel to determine its condition. The things to look for would include insecurity of attachment, cracks or fractures, corrosion, loose or missing rivets, faulty or broken locking devices, loose or damaged plugs and sockets, any chafing, fraying or scoring, discoloration due to overheating.

c. Fit. Correctly assemble one item to another.

d. Refit. Fit *the same item* which had previously been removed.

e. Replace. Remove an item and fit another of the same kind.

f. Replenish. Refill container to a predetermined level, pressure or quantity.

g. Test. The trial of materiel to determine properties and characteristics or to check functioning or operation.

Aircraft Component Servicing

5. **Policy.** To reduce the time during which an aircraft is unserviceable, aircraft components are serviced by replacement whenever possible. Normally, components will only be replaced when their in-use performance falls below the required standard. The component removed because of defect will be bay serviced (where appropriate) and returned to use as a servicing spare. A policy of lifing, or routine bay servicing, will only be used for critical components which, should they fail, would constitute an immediate danger to the aircraft.

COMPONENT SERVICING SHEET

A.P.	VOL.
PART.	BOOK.
LEAFLET No.....	A.L. No.....
Sheet of Sheets	

① Name...TRANSMITTER RECEIVER, part of ARI 23159 Standby U.H.F. D403............

Ref No Not issued. Pt./Drg No....N/A.. N.A.T.O. No. 5821-99-952-8931 Other Pt. No....N/A...

Manufacturer(s) Ultra Electronics M.O.D. BRANCH Elect Eng.14. M.O.A. BRANCH.............. A.E.C. No ....

C.S.D.E. Ref.

② AIRCRAFT :- Phantom Mk F, F.4M

③ Also fitted to:- PHANTOM MARK F-/J RF.4

④ INSTALLATION DATA

a. System	b. No/System	c. Function	d. Location	e. Accessibility
U.H.F. Stand/by ARI23159	1	Emergency U.H.F. Intercommunication	Nosewheel bay compartment, Access Panel 58	Good

SPEC/TRADE

⑤ SIGNIFICANT LEADING PARTICULARS

a. Frequency 238 - 248 Mc/s Normal - 243 Mc/s.
Power:- 24 Volts DC. 1.8 Amps maximum. 40 Watts (Aircraft load)
Transistorised. Semi-Modularised construction

b. NOMINAL COST £ Not Known

NAMDU Ref.

⑥ ALTERNATIVE COMPONENTS: Nil

⑦ EQUIPMENT INFORMATION

Class of Store:- P.I.L. Scales:-

Turn Round Spare:- Yes/No

Initial Lead Time:- Nil Months

⑧ REFERENCES

Publications. A.P.116D-0107-1 ARI23159..........
.... Manufacturers Handbook

M.E.A.R. No ....

Mag. No ....

Line No ....

System M.E.A.R. Nos .63100..........................

SERS Ser. Nos..........................

A.L.No. Page

⑨ ADDITIONAL INFORMATION

1. ECP 9017 Action - to fit this item to F4K in lieu of Radio Rx (Aux) R1286/ARR 19
2. Access problem:- This item removed on replacement of Amplifier Relay Assembly (ADF) AM 3624/ARA 50

Part..........
....
....
Section....
....
....
System.....
....
....
P.U.(21)

Fig 1. Component servicing sheet

(10) LIFING DETAILS	a. [redacted]/NON CRIT	b. MANDATORY LIFE:- Nil.	c. MANDATORY SERVICING (REMOVED)	d. ESTIMATED LIFE ....to Scrap/Recondition
	e. SAMPLING PROGRAMME Nil			

	OUTLINE OF SERVICING	A	B	SPECIAL TOOLS & TEST EQ.	TRADES	INFORMATION	SPARES
(11) IN-SITU ROUTINE	a. Aerial - Visually ensure intact. Periodic test of emergency facility.			b. Contained in:- C.S.D.E. Provisional Schedule Parts 1 - 4 1st Edition November 1965	c. A.R.F. A.W.F.	d. A.P.116D-0107 -1 and C.S.D.E. Provisional Schedule	e. YES/[redacted] R.O.S. A.P.116-0107-3A
(12) IN-SITU REPAIR	a. Replacement of defective units and functional test of A.R.I. Estimated M/hr Cost/1000 hrs:- 1.25	5	0.25	b. Contained in:- C.S.D.E. Provisional Schedule Pts 1 - 4 1st Edition November 1965	c. A.R.F. A.W.F.	d. A.P.116D-0107 -1 and C.S.D.E. Provisional Schedule Parts 1 - 4	e. YES/[redacted] R.O.S. A.P. 116D-0107-3A
(13) REMOVED ROUTINE	a. Nil Estimated M/hr Cost/1000 hrs:-			b. Nil	c. -	d. -	e. [redacted]/NO R.O.S. A.P.
(14) REMOVED REPAIR	a. Changing of complete modules, valves and chassis mounted components. Estimated M/hr Cost/1000 hrs:-	5	1	b. Contained in:- C.S.D.E. Provisional Schedule Part 6. 1st Edition November 1965 and A.P.116D-0107-4F when available.	c. A.R.F. A.W.F.	d. A.P.116D-0107 -1 and C.S.D.E. Provisional Schedule for Bay Servicing.	e. YES/[redacted] R.O.S. A.P. 116D-0107-3A
							f. YES/[redacted] R.O.S.
(15) 3rd LINE (DEPOT) RECONDITIONING	a. YES/[redacted]		b. E.C.O. £	c. Master Work Sheet	d. Radio Technician	e. Master Work Sheet	A.P.116D-0107-3A
(16) 4th LINE (CONTRACTOR) RECOND.	a. YES/[redacted]			b. N/A	c. N/A	d. N/A	e. YES/[redacted]
(17) APPROVAL NAMDU CSDE PROJECT:- 6 Mar 66 SPECIALIST:-				M.O.D.:-			C.R.S.P.

C.S.D.E. Ref.

NOTE:- A Estimated Arising per 1000 hrs. B Estimated Manhours per Arising

P.U.(21A)

Fig 1. Component servicing sheet

6. **Component servicing sheets.** These sheets indicate the depth of servicing to be carried out at units on all components of either cost or servicing significance. They will be compiled by the Central Servicing Development Establishment and published as part of the aircraft AP for new aircraft coming into service. A specimen sheet is shown in fig 1 and contains:

a. Component location and access details.
b. Leading particulars.
c. An outline of servicing at different lines.
d. A list of special tools and test equipment needed.
e. The AP references required for servicing and for spares.

7. **Aircraft servicing form (MOD F700 series).** All servicing carried out on an aircraft must be recorded in the appropriate part of the MOD Form 700 for that particular aircraft. The certificates in the form which are of concern to the electrical and electronic trades are described in sect 7 chap 1. Full instructions on the completion of these forms are given in MOD Form 799 in the front of the book.

8. **Electrical and electronic installations.** These aircraft installations can be divided into two main categories for the purpose of servicing:

a. Fixed fittings. Items such as wiring, connectors, switches, certain aerials and other simple robust parts which do not lend themselves to easy removal from the airframe. These parts are not scheduled for bay servicing and for all practical purposes are considered to be part of the aircraft.

b. Removable fittings. These items consist mainly of 'black boxes' and are mounted in such a manner as to permit easy removal. They can only be serviced in a servicing bay or maintenance unit where the necessary test equipment and skilled tradesmen are available. The aircraft is made serviceable by replacement of any of these items which become defective and they are often known as 'line replacement units' (LRU).

1st/2nd Line In-situ Servicing

9. This type of servicing includes all work which can be successfully completed without removing any items from the aircraft and also aircraft servicing by the replacement of LRUs. It is carried out mainly by semi-skilled tradesmen, supervised by a small nucleus of technicians and NCOs. As it is carried out on an aircraft the work is recorded in the MOD Form 700. Typical jobs to be carried out include:

a. Compliance with safety regulations and orders.
b. Visual examination for security.
c. Pressurization checks.
d. Electrical and functional checks or tests for serviceability as laid down in the servicing schedules.
e. Simple adjustments of specified controls to achieve serviceability.
f. Replenishments.
g. Completion of the necessary servicing records and labels.
h. Any repairs required on fixed fittings and replacement of LRUs.
j. Incorporation of authorized SIs, STIs and Modifications.

10. **Non-routine or defect servicing.** When an assembly or LRU is replaced the associated fixed fittings such as mounting trays, racks, and adjacent connectors are to be examined for serviceability. After any part of the system has been electrically disturbed (*ie* by replacing an LRU)

a full functional test is carried out before the system is certified as serviceable. Details of the repair are entered in the MOD Form 720B (part of the aircraft's MOD Form 700).

11. **Routine flight servicing.** These servicings are carried out in accordance with the servicing schedule issued as vol 4/5 part 2 of the aircraft AP. The work covers final preparation for flight and examination after flight. Completion of the servicing is recorded in the Flight Servicing and Replenishment Certificates of MOD Form 700. Any defects found are reported to the trade NCO and entered in the MOD Form 720B part of MOD Form 700. Flight servicing is divided into three parts:

a. Before flight. The servicing necessary when an After Flight servicing has previously been carried out and the aircraft is required for flight. It must be done as late as practicable, and within 8 hours of flight.

b. After flight. Replenishment and servicing required after flight to ensure that the aircraft is serviceable and ready for further flight subject to a before Flight servicing being carried out. An After Flight must be carried out on the following occasions:

(1) After every flight unless a Turn Round servicing has been carried out.

(2) When a Turn Round has been carried out and subsequently the aircraft did not fly within the 8 hour period.

(3) If more than 72 hours have elapsed since the last After Flight servicing was carried out.

c. Turn Round. This servicing combines certain items of the After and Before Flight servicings and may be used in lieu of these when the aircraft is expected to fly again within 8 hours of landing.

12. **Routine planned servicing.** These servicings take place at set intervals established on a flying hour basis and various systems have been adopted to suit the operational requirements of individual Commands. The work done is of the type listed in para 9, and the servicing done by an individual tradesman is itemized and issued as part of the aircraft servicing schedule. The items are recorded individually by the tradesman's initials on F2988A (Fig 2). Any defects found are to be reported to the trade NCO who will make the necessary entries in the MOD Form 720B. For some aircraft, expendable servicing schedules have been produced. As part of these schedules the tradesman is issued with a consumable work card on the back of which is printed a F2988A (substitute). Items of work are recorded in the same way as on F2988A.

2nd Line Bay Servicing

13. Bay servicing is carried out on equipment which cannot be tested or repaired in-situ because of the complexity or expense of the test equipment required. It is also limited by the same factors, and many equipments or assemblies can be serviced only at Third Line maintenance units where more complex test equipment or factory processes are available. (An example of this is alignment of receiver IF strips). Instructions for bay servicing can be found in the equipment AP vol 4 part 6; or for new equipments in a provisional bay servicing schedule issued by CSDE. Typical jobs to be carried out include:

a. Compliance with safety regulations and relevant orders.

b. Functional tests.

c. Repair by replacement of sub-assemblies or of components specified as 2nd line spares in the equipment AP vol 3.

d. Setting up or alignment.

e. Cleaning and lubrication.

f. Modifications, SIs or STIs specified as for 2nd line embodiment.

g. Completion of the necessary servicing records and labels.

SERVICING RECORD R.A.F. FORM 2988A

AIRCRAFT No..............A.P. No.........Vol........Part......Bk......Edit.....

Trade(s)................. ....Card No............A.L. No..........

Scheduled Servicing		Details of Defects Found		Immediate Rectification		Support Rectification
Block (1)	Initials (2)	Schedule Ident. Code (3)	Defect (4)	Initials (5)	Man Hrs. (6)	A/C Job Card No. (7)
1						
2						
3						
4						
5						
6						

TRADESMAN. I CERTIFY THAT:-

(a) I have read Safety and Servicing Notes. (Pt.1, Bk.2, Sect.1.)

(b) I have completed the scheduled servicing blocks for the Card No. quoted above for which I have put my initials in Col.(2) above.

(c) I have entered details of all defects found, in Cols. (3) and (4) above.

(d) I have placed a cross in Col.(5) where I have been unable to rectify a defect.

(e) I have rectified those defects against which I have put my initials in Col.(5).

NAME ....INITIALS ....SIGNATURE ....DATE ....
(BLOCK CAPITALS)

NAME ....INITIALS ....SIGNATURE ....DATE ....
(BLOCK CAPITALS)

NAME ....INITIALS ....SIGNATURE ....DATE ....
(BLOCK CAPITALS)

TRADE N.C.O./TECHNICIAN. I CERTIFY THAT the scheduled servicing blocks for the Card No. quoted above have been completed as indicated below:-

BLOCKS	NAME	INITS.	RANK	SIGNATURE	DATE

N.C.O. i/c SERVICING OR TRADE N.C.O./TECHNICIAN. I CERTIFY THAT:-

(a) All the necessary entries have been made in F.700.

(b) All aircraft job cards have been raised as indicated in Col. (7) above and registered in F.700.

NAME ....INITIALS. ....SIGNATURE ....DATE ....
(BLOCK CAPITALS)

Fig 2. Servicing record F2988A

14. **Non-routine repairs.** Whenever possible, assemblies are repaired by the replacement of a sub-assembly which can then be sent to a Maintenance Unit for third line repair under the direct exchange scheme. The remainder of the equipment is examined for cleanliness, mechanical wear, or component damage without disturbing any other sub-assemblies or components. The repaired equipment is to be functionally tested in accordance with the bay servicing schedule before being classified as serviceable for use. When an assembly cannot be broken down into sub-assemblies it is serviced and tested in accordance with the appropriate bay servicing schedule.

15. **Repair and calibration of test equipment.** Repairs at unit level are confined to such operations as the replacement of fuses, indicator lamps, switches, knobs and valves that do not affect the calibration of the equipment. The spares concerned are listed in vol 3 of the appropriate AP. Other repairs are normally carried out by industry. Calibration of test equipment is carried out at routine intervals in order to maintain the required degree of accuracy. This is carried out by the Electronic Calibration Centre and equipment is collected by them on a routine run of their direct delivery service. Requests for calibration are submitted on F3811; the maximum period between calibrations is listed in current DCIs.

Third Line Servicing

16. Third line servicing includes all servicing that cannot be carried out at units because of the wide range of spares and special test equipment which is required. It is centralized at selected Maintenance Units; but exceptionally may be carried out on a selected unit when an equipment is exclusive to one Command or when only a small number of equipments were bought for service use. Items are serviced as below:

a. Testing and servicing to the standard specified in vol 6 of the AP.

b. Fault diagnosis and rectification of defects.

c. Embodiment of all Modifications not classified as second line for safety reasons.

d. Classification of all items beyond third line capacity.

e. Manufacture of component spares if necessary, or the substitution of alternate components within the limits specified.

f. Maintenance of servicing records and the submission of technical reports for defect investigation.

17. **The direct exchange scheme.** The majority of radio sub-assemblies are available on a direct exchange scheme from No 30 MU which operates a specially fitted out vehicle on a regular weekly routine to all major user units. For high reliability equipments, the line replacement unit (LRU) is usually sent for servicing to the MU under this scheme. A signal listing the equipment for exchange is sent weekly, showing the task number of all items and the quantity of each for exchange. No supply squadron action is required as the scheme operates on a one for one basis. All equipment transferred to 3rd line must have an equipment label (MOD Form 731 or RAF Form 6812) attached to it giving details of the defect.

CHAPTER 4

GROUND RADIO SERVICING

List of Contents

Introduction

1. This chapter describes the ground radio servicing methods in use by the RAF. The definition of servicing and the terms used for specific operations are set out in the early paragraphs of chapter 3 and these should be studied before reading this chapter.

2. The range of equipment covered by the ground radio servicing organization includes ground radar equipments—fixed, mobile and air transportable; and all ground wireless, landline and cryptographic equipment including aerials and masts. Exceptions are items of telephone equipment serviced under GPO arrangements in the UK and by the army overseas, and certain towers and masts which are the responsibility of the Department of the Environment (DOE).

Policy

3. To obtain maximum serviceability of the equipment, routine servicing has been reduced to a minimum and a policy of fault clearance by replacement has been adopted wherever possible. The repair of faulty assemblies or sub-assemblies is carried out at second or third line depending on the manpower and test equipment resources established at these lines. Third line servicing has been centralized under the Ground Radio Servicing Centre (GRSC) at North Luffenham which can obtain general engineering support from the Radio Engineering Unit (REU) at Henlow if necessary.

4. The division of the servicing task for an actual equipment depends on a number of factors such as operational requirements, number in use, deployment, reliability, cost and size. For this reason a detailed servicing policy is issued *for each equipment* by the appropriate branch of the Air Force Department at MOD. This policy details the lines of servicing into which various operations fall.

First/Second Line Servicing

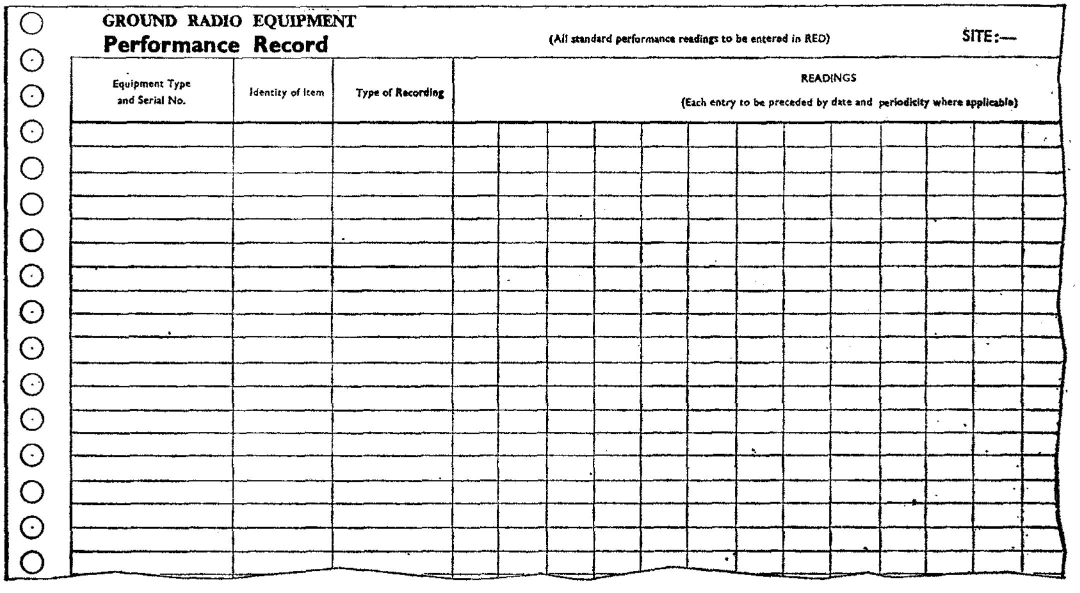
5. First and second line servicing is undertaken by all Royal Air Force Units. First line servicing consists of those tasks which can be carried out by the tradesmen established to maintain the equipment in its operational state. It is normally limited to performance checks, adjustments and repair by replacement of assemblies (or sub-assemblies). Second line servicing covers all other tasks, including modifications, which can be carried out within Unit resources but which are beyond first line capabilities. The actual depth of servicing at second line varies widely with different equipments. Typical first and second line tasks are:

a. Servicing in accordance with the appropriate schedules, including lubrication, cleaning, and any electrical or mechanical adjustments found to be necessary.
b. Repair of installations by the replacement of assemblies or sub-assemblies.
c. Repair by the replacement of components specified in vol 3 of the appropriate AP.
d. Incorporation of specified modifications and Special Technical Instructions.
e. Maintenance of essential servicing records.

6. **Routine servicing.** Routine servicing of equipments is carried out on a periodic basis in accordance with the servicing schedules issued as part of the equipment AP. Two systems of servicing are used:

a. Calendar. A basic servicing is carried out daily, and more complete inspections are carried out weekly and monthly. The disadvantage of this type of servicing is that the equipment has to be withdrawn from operation for a considerable time each month to enable the servicing to be carried out.

b. Progressive. The more complex servicings are broken into small groups of tasks which can be done daily without interfering with the equipment's operational periods. These servicing tasks are numbered in the schedule, which is arranged so that every item is still serviced with the same periodicity as it would have been on calendar servicing.


GROUND RADIO EQUIPMENT
Performance Record
(All standard performance readings to be entered in RED)
SITE:—

Equipment Type and Serial No.	Identity of Item	Type of Recording	READINGS (Each entry to be preceded by date and periodicity where applicable)

Fig 1. Performance record card F6632

7. **Performance Record Card—F6632.** The purpose of F6632 is to ensure that the performance of equipment is checked and evaluated *against standard figures* at regular intervals. The form is used to record performance and servicing figures and aerial insulation tests and may also be used to record 'hours run'. Performance and servicing figures are defined as follows:

a. Performance figures. Performance figures are those parameters which are critical to the performance of the equipment. They are identified by an asterisk (*) and have stated limits. Readings within these limits *must be obtained* before the equipment can be categorized as serviceable to engineering standards. These performance figures are mandatory.

b. Servicing figures. Servicing figures are a range of figures, typical of a serviceable installation, which are given as aids to servicing or fault location. These figures are not mandatory but are recorded for comparison with those recorded by the installation party, or the most recent third line servicing, to indicate any general deterioration in the installation.

8. **Completion of F6632.** Performance and servicing figures obtained from the appropriate AP, or authorized test specifications, are to be entered in the first column of F6632 in red ink. This column is to be headed 'Appendix F'. The performance and servicing figures obtained by the installation party are recorded in red ink in the second column titled 'Inst Figures'. The authority for any concessions must be recorded and shown continuously on F6632. The appendix F and installation figures are to be recorded as the first and second column entries of each subsequent F6632 raised for the installation. Figures recorded by second line personnel in accordance with the 2nd line servicing detail are to be in blue or black ink. Recording, as distinct from checking, should not be more frequent than weekly under normal circumstances. Figures obtained at third line servicing are to be recorded in red ink and the column is to be headed '3rd line'. During use the form is kept in a multi-ring binder which permits the visi-edge display of up to 18 cards. Completed forms are transferred to a 2 ring binder and are retained for two years after the date of the last entry.

9. **Non-routine (unscheduled) servicing.** This type of servicing consists mainly of the rectification of defects and the incorporation of modifications. Whenever possible, defects are repaired by the replacement of sub-assemblies to keep to a minimum the equipment non-operational time. All work done on unscheduled servicing is recorded on the MOD Form 720 series of job cards (*see* section 6 chapters 2 and 3 of this book).

GROUND RADIO EQUIPMENT

Control Log of Unscheduled Servicings Station —

Job No. (a)	Date/Time Reported Date/Time Released to Tradesmen (b)	Identity of Equipment and Serial No. (c)	Nature of Defect or Task (d)	Operational Status (e)	Tradesman Detailed for Task (f)	Date/Time Facility Restored (g)	Job Card Raised (h)	Action Taken Note :— Defect Reporting Action taken to be entered in RED (i)	Certified Job Completed (k)

Fig. 2 Control log of unscheduled servicings F6633

10. **Central servicing control.** When a central servicing control point is in use on a site, all defects are recorded on a control log to assist local management. Either RAF form 6633 (fig 2) or MOD form 717 series may be used to record detail taken from the job card (MOD form 720 series).

a. The entry in column e for 'operational status' is decided in liaison with the operational staff and entries are one of the following:

(1) 'Inoperable'.

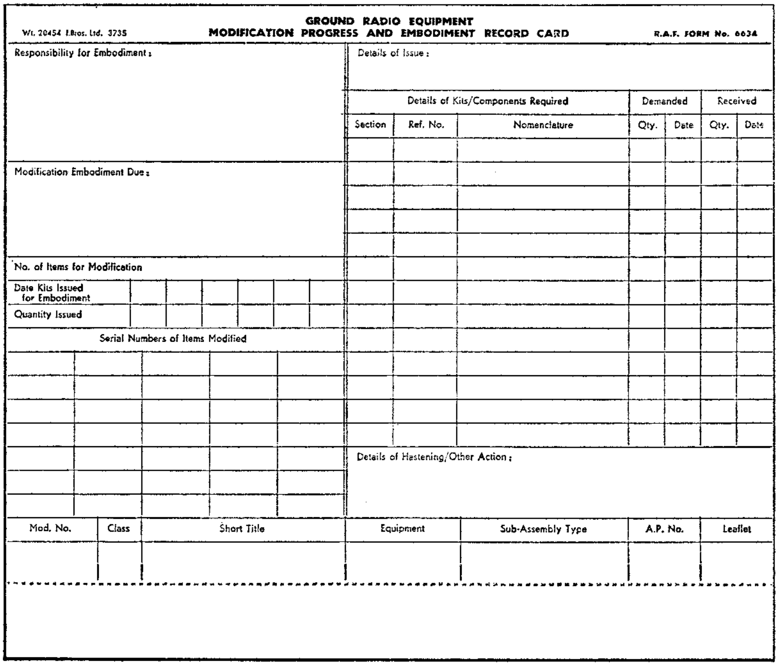
(2) 'Major'. Major reduction in capability and/or efficiency.

(3) 'Minor'. Minor reduction in capability and/or efficiency.

(4) Nil effect.

b. The entry in column h is to show the reference number of the MOD form 720 job card.

c. The certificate in column k certifying that the job is completed is to be filled in when all work arising from the original defect or task is completed satisfactorily and the job card has been actioned by an NCO.



Wt. 20454 I.Bros. Ltd. 3735
GROUND RADIO EQUIPMENT
MODIFICATION PROGRESS AND EMBODIMENT RECORD CARD
R.A.F. FORM No. 6634
Responsibility for Embodiment:
Details of Issue:
Details of Kits/Components Required | Demanded | Received
Section | Ref. No. | Nomenclature | Qty. | Date | Qty. | Date
Modification Embodiment Due:
No. of Items for Modification
Date Kits Issued for Embodiment
Quantity Issued
Serial Numbers of Items Modified
Details of Hastening/Other Action:
Mod. No. | Class | Short Title | Equipment | Sub-Assembly Type | A.P. No. | Leaflet

Fig. 3 Modification record card F6634

11. **Modification Progress and Embodiment Record Card—F6634.** A separate F6634 is raised for each modification to be carried out on equipment held by a unit. The form remains in the 'in-use' Kardex wall panel until all equipment has been modified. It is then transferred to a 'completed modifications' folder and retained for the life of the equipment concerned. Replacement equipment will require outstanding modifications to be recorded and where appropriate completed. This may entail withdrawing the F6634 from the 'Completed Modifications' folder for actioning. The card is sub-divided into eight sections:

a. Responsibility for Embodiment. Details of the level of servicing at which the modifications is to be embodied are entered *eg* 2nd Line.

b. Modification Embodiment Due. Instructions concerning the time of embodiment are entered *eg* on failure—on repair—on receipt of spares, *etc.*

c. Number of items for Modification. The total number of equipments of the type to be modified is entered. If a replacement equipment requires modification by the unit its serial number is entered in this section.

d. Date kits issued for embodiment and quantity issued—self explanatory.

e. Serial Numbers of Items Modified. These are obtained from completed forms MOD 720C and entered in the panels provided.

f. Details of issue. Details of the arrangements for the supply of kits or components are entered *eg* Issue Order—supplied by contractors—local resources.

g. Details of kits/components required. Details of the items demanded with quantities and dates are entered.

h. Details of Hastening/Other action. Signal references and other measures taken to expedite the supply of kits are to be recorded.

Third Line Servicing

12. No 90 (Signals) Group is responsible for the third line servicing of specified ground radio installations and equipments in the UK, Gibraltar and other units abroad as directed by MOD (Air). Overseas commands make their own arrangements for third line servicing in accordance with Air Force Department policy. Third line servicing consists of those tasks which are required to maintain the equipment in an operable condition but which require the resources of a centralized servicing base. Tasks may be undertaken at the unit by a repair party from the third line base but most tasks are carried out at the Ground Radio Servicing Centre (GRSC). The following facilities are provided by the GRSC:

a. "*RADFAULT.*" Fault diagnosis and rectification on site for specified equipments where it is beyond the capacity of the user to diagnose or repair the fault owing to lack of skill or special test equipment.

b. "*RADREPLACE.*" Servicing by replacement of main assemblies or subassemblies for specified equipment where the user unit has diagnosed the cause of the unserviceability to a replaceable assembly or subassembly but is unable to rectify the fault. It is vital to the operation of the RADREPLACE scheme that units return unserviceable assemblies and subassemblies *without delay.* Assemblies delivered in special transit cases must be returned in the case supplied and every care is to be exercised to avoid damage in transit.

c. Periodic servicing of main radio installations called for by the appropriate servicing schedule.

d. Third line modification of specified equipments in accordance with priorities allocated by the Ministry of Defence, Air Force Department, in conjunction with the user Commands.

e. Workshop repair of unserviceable assemblies and sub-assemblies returned to GRSC following RADREPLACE action.

13. **Flight checking aircraft.** These specially equipped aircraft are responsible for flight checking ground radio navigation and approach aids, Air Defence and Air Traffic Control radars. Checking is done on commissioning, periodically as prescribed or on request when performance is suspect.

14. **Special Signals Unit.** Servicing of specified cryptographic sub-assemblies is undertaken by a special signals unit. These sub-assemblies are not dispatched through normal equipment channels. A secure means of delivery is used.

15. **Fourth line servicing.** Equipment beyond third line repair is returned to a Maintenance Unit, and is either contracted out to industry or repaired within the RAF at the Radio Engineering Unit, Henlow.

SECTION 4

ELECTRICAL AND ELECTRONIC MEASUREMENTS

NOTE TO READERS

Although this section deals with the methods of making electrical measurements in general terms, references have been made to specific items of test equipment as typical examples of their type. Wherever possible, preferred 'common user' items have been used as the example. Inclusion of these references to specific items of test equipment does not constitute authority for demanding the items.

Where the method of making a specific measurement is laid down in a servicing schedule or equipment AP that method is mandatory. When a servicing schedule or leaflet contradicts any portion of this publication, the servicing schedule or leaflet is to be taken as the overriding authority.

For concise details of a wider range of 'common user' test equipments reference should be made to:

AP4837B Concise Details of Radio 'Common User' Test Equipment.

CHAPTER 1

RESISTANCE MEASUREMENTS

List of Contents

Introduction

1. Practical measurement of resistance values is of considerable importance in the work of a tradesman, both in routine servicing procedures and in the diagnosis of faults, as these measurements can be made without power being applied to the equipment under test. Test equipments used for the direct measurement of resistance values are basically some form of current meter associated with a source of electrical energy such as a dry battery. The energy source drives a current through the resistance under test and the meter, and this current provides the deflecting force to move the instrument pointer over a scale calibrated directly in ohms (or multiples of ohms). There are many different types of ohmmeter available, each of which is well suited to a specific range of resistance values; none of them are even approximately suitable for all purposes. It is part of a tradesman's knowledge to be able to *select the appropriate equipment* for the job in hand and to use it in the *most effective* manner possible.

2. The measurements to be made fall roughly into three classes, but there is no clear dividing line where one class may be said to finish and the next begin.

a. Conductors. As the power lost in a circuit is proportional to the resistance, it is essential that the resistance of a conducting circuit should be kept to an absolute minimum. Where an equipment is bonded to earth or connected to the airframe, the value of resistance would normally lie between zero and 0·1 ohm. These extremely low values can only be measured with special instruments designed for the purpose, such as bonding testers or low resistance bridges.

b. Resistors. These components are used to regulate the flow of current in a circuit to the desired level and are made to preferred values of resistance. These values normally fall in the range 10 ohm to 10 Megohm and can be measured to within manufacturers tolerance on normal multimeter resistance ranges. If measurement of a precision resistor is to be made, a bridge type of instrument must be used.

c. Insulation. The purpose of insulation is to prevent the flow of current from one part of the circuit to another. The resistance value is normally greater than 10 Megohms and must be greater than the minimum level specified in the servicing schedules. As the purpose of an insulator is to prevent the flow of current *under working conditions*, insulation measurements must be made at a voltage equal to or higher than that at which the component is used. For these measurements a 'Megger' or an EHT insulation test set must be used.

3. **Safety Ohmmeters.** A special range of 'safe' meters has been developed for use on armament circuits. These meters have built-in voltage and current limiting facilities. Where the use of these meters is specified in the servicing schedule they are the *only* instruments which may be used.

RESISTANCE MEASUREMENTS

Multimeters

CT 511 — Avo Multiminor Model 2 Multimeter (6625-99-943-2134)

Range	Scale Limit	USEFUL RANGE	Scale Limit	Source Volts
x1	0	12·5Ω–1250Ω	20kΩ	1·5V
x100	0	1250Ω–125kΩ	2MΩ	1·5V

CT 498 — Avometer Model 9SX Multimeter type 12889 (5QP 17447)

Range	Scale Limit	USEFUL RANGE	Scale Limit	Source Volts
Ω÷100	0	2Ω–200Ω	2kΩ	1·5V
Ω	0	200Ω–20kΩ	200kΩ	1·5V
Ωx100	0	20kΩ–2MΩ	20MΩ	15V

CT 471C — Electronic Multimeter (6625-99-972-0247)

Range	Scale Limit	USEFUL RANGE	Scale Limit	Source Volts
Ω	0	·2Ω–20Ω	100Ω	·08V
Ωx100	0	20Ω–2kΩ	10k	2·5V
kΩx10	0	2kΩ–200kΩ	1M	2·5V
MΩ	0	200kΩ–20MΩ	100M	2·5V
MΩx10	0	2MΩ–200MΩ	1000M	2·5V

Fig. 1. Multimeter resistance ranges

4. **Useful ranges.** A comparison of the resistance ranges available on the three preferred 'common-user' multimeters is shown in Fig 1. All multimeters give the most accurate resistance readings at half scale deflection and the useful range of the instrument lies between one tenth and ten times the centre scale value. The normal mid-scale accuracy of a multimeter is about ±5%, falling to ±10% or worse towards the ends of the scale which are cramped and difficult to read. The meter selected for a particular measurement, and the range used on that meter must be chosen so that the reading obtained lies between the limits of the centre scale accuracy band of the meter.

CT 511—Multimeter (Avo multiminor model 2)

set 'zero ohms'

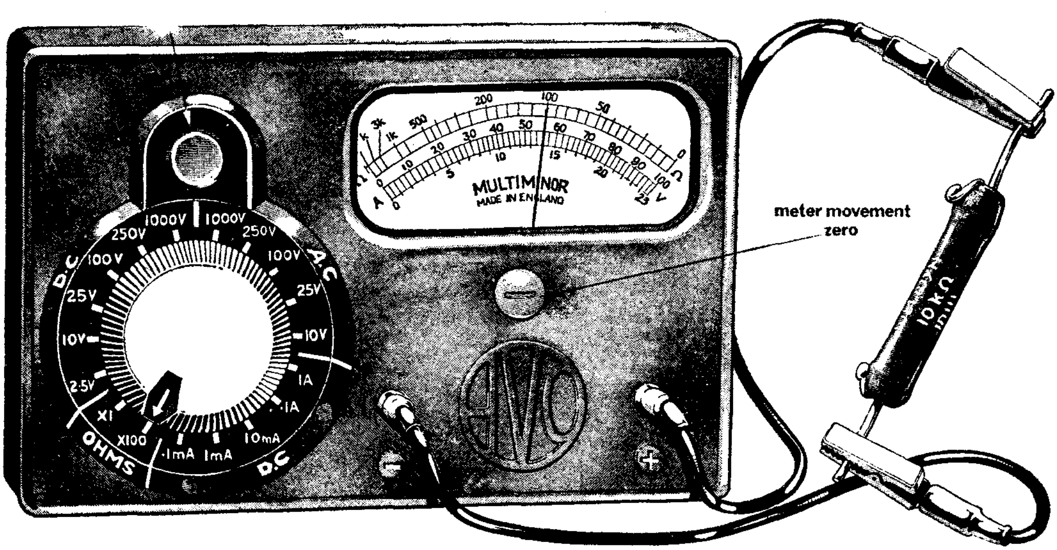


Fig. 2. Multimeter CT511

5. **Circuit.** The simple circuit of the ohmmeter section of the CT 511 multimeter is shown in Fig.3. The selector switch enables two ranges of measurement to be made by shunting the meter on the low range (X1), and by adding a series resistor on the high range (X100). The energy source used is a 1·5V cell and the meter is zeroed by adjusting the proportion of the total current flowing through the movement and the shunt by means of a potentiometer (set zero ohms). This arrangement makes the meter less dependent on battery voltage than the simple series type described in para. 1. The swamp resistor in series with the meter movement is to minimize the effect on the accuracy of the instrument due to the changing resistance of the meter coil with temperature when in use.

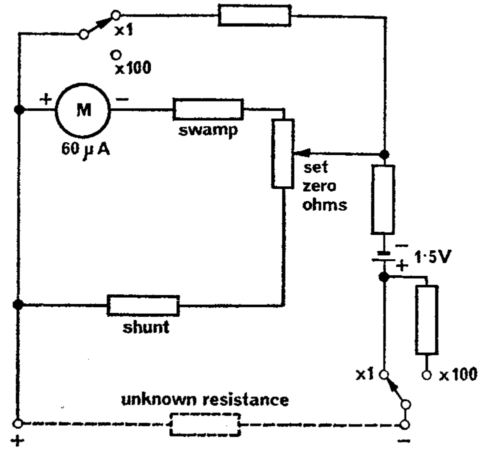


Fig. 3. Simplified circuit CT511

6. **Set zero control.** Before use the meter must be set to read zero ohms on the range on which the measurement is to be made. This is done by selecting the required range and joining the meter leads together to form a short circuit. The set zero control is then adjusted to give full scale deflection (zero ohms). If the meter will not adjust to f.s.d. or if the position of the pointer fluctuates, the dry battery is exhausted and must be replaced. Never leave an exhausted cell in the meter as it may leak and cause corrosion. Do not leave the meter selector switch on the ohms ranges when not in use as the test leads may become short circuited and run down the battery.

7. **Testing current.** When making resistance measurements the current required is drawn from the internal battery of the meter. Consequently the circuit under test must be de-energized completely, and any components likely to be damaged by the current from the meter must be removed or disconnected. The short circuit current delivered by the meter can be calculated very simply:—

$$\text{Short circuit current} = \frac{\text{Battery voltage}}{\text{Centre scale reading}}$$

e.g. on the X1 range of the CT 511.

$\text{Short circuit current} = \frac{1 \cdot 5\text{V}}{125 \text{ ohms}} = 12\text{mA}$ and any components which would be damaged by this current must be removed. Maximum short circuit currents are normally delivered on the *lowest* ohms range of a multiple range meter.

8. **Operating procedure.** Never attempt resistance checks on a live circuit.

a. Place the meter face upward on a horizontal surface.
b. If necessary, zero the meter movement (see Fig 2).
c. Select the ohms range needed to obtain a centre scale band reading.
d. Short circuit the leads and adjust the set zero ohms control (see para. 6).
e. Separate the leads and connect them across the circuit or component to be tested.
f. Read the resistance on the ohms scale. If the X100 scale is selected, multiply by 100.
g. If the result obtained differs from that expected, repeat *e* and *f* with the leads reversed as a cross check. If these two readings are different, either the component's resistance depends on the polarity of the voltage, or something is wrong and the whole check sequence should be repeated carefully.

h. When checking polarised components such as diodes or electrolytic capacitors it must be remembered that the positive supply from the internal battery is connected to the negative terminal of the instrument (see Fig 3).

Note. Do not change resistance ranges with a component connected across the leads. Start again and re-zero the meter on the correct range for the component being tested.

CT 498—Multimeter type 12889 (Avo 9SX)

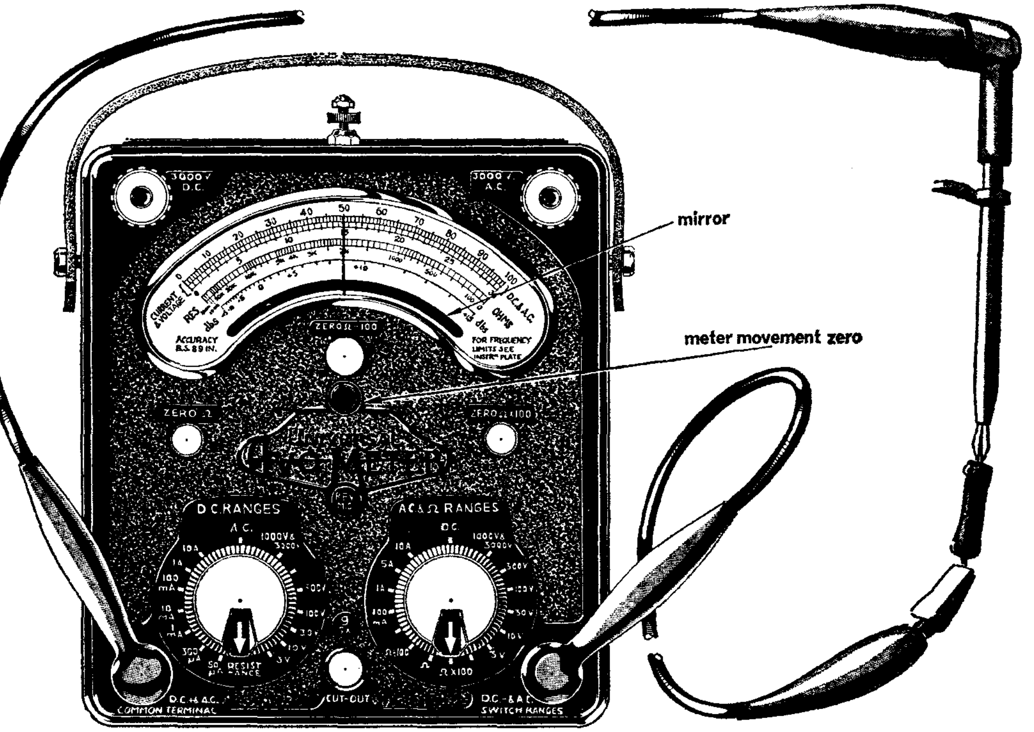


Fig. 4. Multimeter CT498

9. **Basic operating procedure:**

a. For accurate results the meter should be operated face upward on a flat surface.

b. If necessary the movement may be zeroed using the screw shown in figure 4.

c. The meter should be read from directly above, using the mirror to prevent errors.

d. Ensure that the cut-out is set, i.e. pressed back against the panel. If the cut-out operates while a reading is being taken, *disconnect* the meter before resetting the cut-out, and correct the error which caused the overload *before reconnecting* the meter. It should be noted that mechanical shock may also cause the cut-out to trip.

e. Set the left hand switch to resistance, and the right hand switch to the required ohms range. Connect the leads to the meter terminals shown in figure 4.

f. Connect the test leads together and adjust the resistance zero by means of one of the knobs marked zero $\Omega \div 100$, zero Ω, or zero $\Omega \times 100$, according to the range selected.

g. Connect the unknown resistance between the leads and read its value on the scale.

10. **Ohms $\div$ 100 range.** The short circuit current delivered by the meter on this range is 75mA, so any component likely to be damaged by this current must be disconnected before attempting to make any measurements.

11. **Ohms × 100 range.** This range can be used accurately up to 2Mohms and for approximate use up to about 20Mohms. When making these readings care must be taken not to shunt the resistance under test with the fingers or the body. If it is suspected that the 15V battery is flat, it may be tested for short circuit current on the 100mA d.c. range (should give over 5mA).
Caution. Never leave the selector switches in the ohms position when not in use; inadvertent connection of the meter to a voltage source could cause very severe damage to the meter.

CT471C—Electronic Multimeter

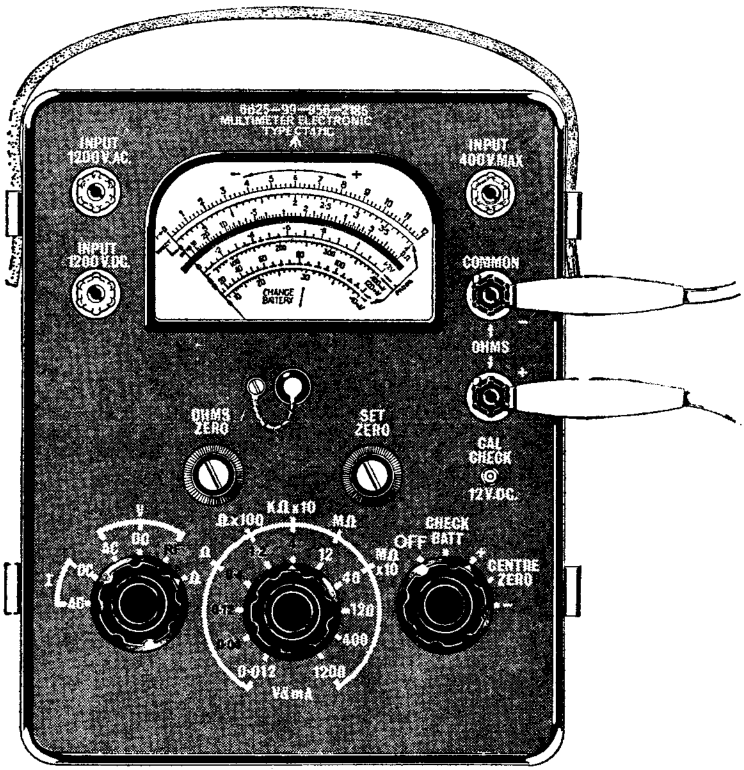


Fig. 5. Multimeter electronic TC471C

12. **Basic operating procedure:**

a. For accurate results, the meter should be operated face upwards.
b. Read the pointer from directly above, using the mirror to prevent errors.
c. Adjust the movement zero if necessary, using the screw shown in figure 5.
d. Switch to the check battery position of the right hand selector knob and ensure that the pointer comes to the line marked on the bottom of the scale.
e. Connect the meter leads to the terminals shown in figure 5 and join the ends together. Switch to a d.c. current range with the right hand selector switch on +. Adjust the knob marked 'set zero' to align the pointer with the left hand limit of the scale.
f. Switch to the required ohms range and adjust the 'ohms zero' control to align the pointer with the right hand limit of the scale (0 ohms).
g. Connect the component to be measured between the leads, and if necessary re-adjust the range selector to obtain a reading within the mid-band accurate region of the scale.

h. If the range selected is different from that used to zero the ohms range, the zero should be checked and if necessary re-adjusted if an accurate reading is required.

j. Select a high voltage range and turn the meter off immediately after use to reduce the risk of damage and to prevent the batteries from running down.

When measuring resistances on the higher ohms ranges of this meter care must be taken not to shunt the component being measured with the fingers, or by any dampness on the test bench. It is good practice to check the meter reading on open circuit with the leads placed approximately in the position in which they are to be used.

Bridges

13. Bridges are used when an accurate measurement of resistance has to be made on precision components or when very low or very high values of resistance are to be measured. The basic circuit of a Wheatstone bridge is shown in figure 6, but modified forms are often used in practical instruments. When the variable resistor Rv is adjusted to give zero deflection in the meter (null) the bridge is balanced and it can be shown that:

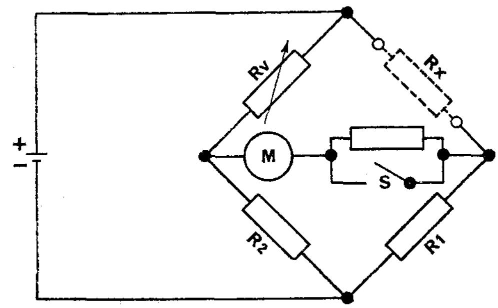


Fig. 6. Wheatstone bridge

$$Rx = \frac{R1}{R2} \times Rv$$

The ratio R1/R2 is adjusted by the range selector switch. A spring loaded sensitivity switch, or button, is usually provided enabling the meter protection resistor to be shorted out to increase sensitivity and give a more accurate null reading. More complex bridges use an a.c. source and null detector system; they measure *reactance* and can therefore be used to determine capacitance and inductance values as well as resistance. (Mainly 3rd line).

Megohmeter Set (6625–99–945–9195)

Use multiplier switch to obtain a reading as near mid-scale as possible			
Range Multiplier	RANGE LIMIT	Accuracy	Source Resistance
x0·1	0·05Ω – 5Ω	2%	6Ω
x1·0	0·5Ω – 50Ω	0·5%	11Ω
x10	5Ω – 500Ω	0·5%	55Ω
x100	50Ω – 5kΩ	0·5%	500Ω
x1K	500Ω – 50kΩ	0·5%	5kΩ
x10K	5kΩ – 500kΩ	0·5%	50kΩ
x100K	500kΩ – 5MΩ	2%	500kΩ

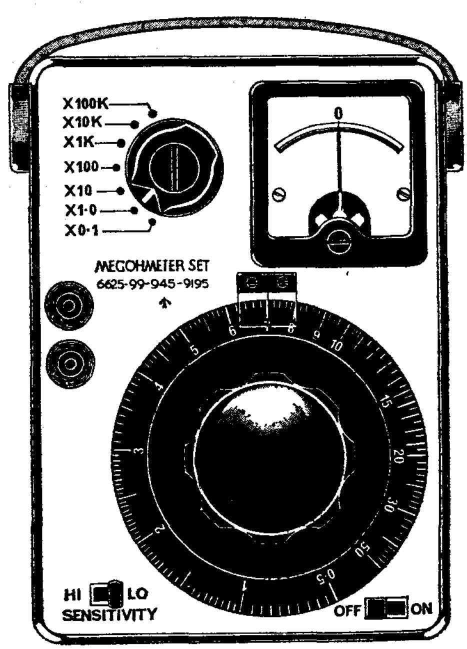


Fig. 7. Megohmeter set

14. **Basic operating procedure:**

a. Place the instrument face upwards on a flat surface.
b. Connect the leads and the component to be tested between the two terminals.
c. Select the correct range and set main dial to the approximate value expected.
d. Ensure that the sensitivity switch is in the LO position and switch the meter ON.
e. Adjust the main calibrated dial to obtain a zero meter reading.
f. Hold the sensitivity switch in the HI position and readjust the main dial to obtain the accurate zero point on the meter.
g. Return the sensitivity switch to the LO position and switch OFF the instrument.
h. Read the resistance value from the calibrated dial and multiply by the factor shown by the range selector switch.

CONDUCTORS

Bonding Tester

15. The bonding tester is designed for the accurate measurement of resistance values in the range of 0–0·1 ohm. It is used mainly for testing the continuity of bonded connections or of metallic structures. The scale is graduated in divisions of 0·002 ohm so the meter can also be used for general low resistance measurements. The complete equipment consists of a ratiometer type ohmmeter and a 1·2V alkaline cell housed in a teak case, a 60ft. length of twin flexible cable (the B lead) fitted with a single spike probe, and a 6ft length of similar cable with a double spike probe (the A lead). Plug and socket connectors provide quick action non-reversible connection to the instrument case. The double probe acts as a switch for interrupting the current unless the tester is actually in use and thus protects the alkaline cell from accidental discharge.

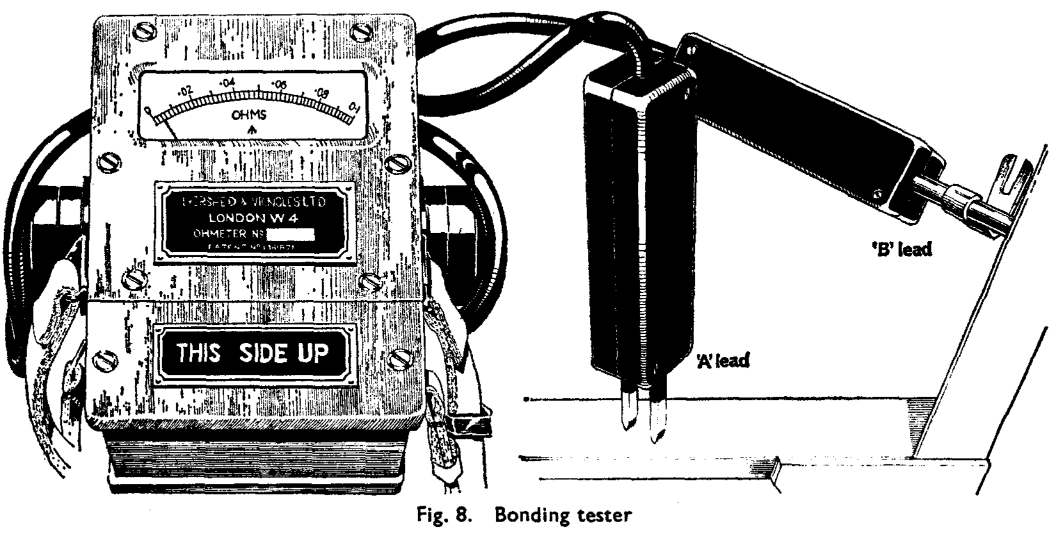


Fig. 8. Bonding tester

16. **Operating procedure:**

a. After plugging in the cables to the instrument case, place the single spike of the B lead across both spikes of the A lead; the pointer should align with the zero mark on the scale.
b. If testing bonding or frame continuity, secure the probe of the B lead to a suitable point on the structure by means of the spade terminal lug. Check for effective contact at this point by touching both spikes of the A lead probe to a metal surface in the immediate vicinity of the connection—the meter should read zero. It is most important that the B lead (single probe) *is connected first;* if the double prongs of the A lead are brought into contact with a conducting

surface before this connection has been made there is a grave risk of damaging the meter.

c. Apply both prongs of the A lead probe to selected points on the structure. Note the values of resistance between the A and B probes indicated on the meter scale.

d. If an unduly high resistance value is indicated, repeat the test with the A probe applied to another point adjacent to that originally selected to eliminate any error arising from indifferent surface contact.

17. **Accuracy checks.** The accuracy of the bonding tester should be checked periodically by measuring the resistance of standard test resistors. Three such resistors (0·02 ohm, 0·06 ohm and 0·1 ohm) are supplied for this purpose and the readings obtained should be within 10% of the stated value of the resistor.

INSULATION

18. **General.** Insulation testing is *not* simply a matter of measuring the resistance, in ohms, between two points that are not supposed to be connected. Under working conditions the insulation of an electrical installation is subjected to electrical stresses which can cause a reduction in the effective resistance between the points concerned. It is most important that similar conditions of stress are established during testing. Any ohmmeter used for measuring insulation resistance must have a power supply source with an output voltage at least equal to, and preferably greater than, the working voltage of the installation, circuit or component under test. Most practical insulation testers consist of a ratiometer type indicator connected through suitable resistors to a hand-driven generator. The generator output voltage for general purpose insulation testers is 250V, 500V or 1000V according to type. Low voltage generators are used in special 'safety ohmmeters' supplied for testing armament circuits. The basic circuit used in these meters is similar to that shown in figure 9.

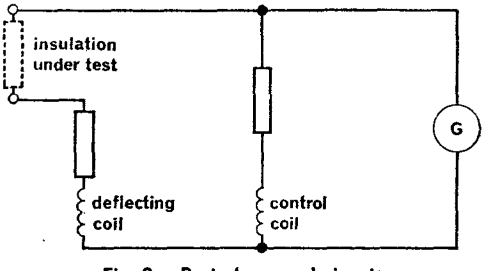


Fig. 9. Basic 'megger' circuit

Megger—Tester Insulation Resistance Type A

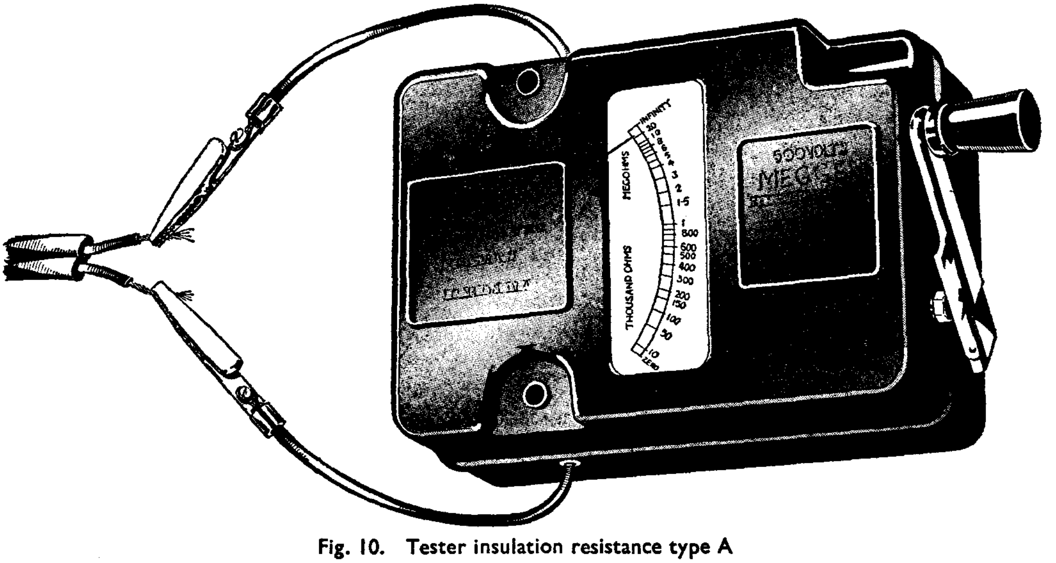


Fig. 10. Tester insulation resistance type A

19. The type A insulation tester is supplied for general purpose testing of installations and components that operate in the 200V-250V range.

20. **Preliminary checks**

a. Remove the flexible leads from the tester terminals and place the tester, scale uppermost, on a flat surface where the handle can be turned conveniently.

b. Turn the handle steadily at the rated speed for a few seconds (type A at 160 r.p.m.). The pointer should take up and hold a position over the infinity mark on the scale.

c. Connect the test leads to the tester terminals, twist the leads together, ensure that the exposed ends are not in contact and repeat *b.*

d. Touch the ends of the leads together and turn the handle slowly, the pointer should immediately move across the scale to the zero position.

21. **Insulation tests**

a. Readings oı infinity should always be regarded with suspicion. Check the connections, the test leads, and the meter itself, and then repeat the test for confirmation.

b. The acceptable values specified in the servicing schedules are minimum values. If the test result is even slightly less it must be regarded as unserviceable.

c. Accept only steady readings obtained after continuous turning of the handle at the rated speed for at least 5 seconds. Unstable readings are often signs of insulation weakness that may lead to a breakdown in the near future.

d. Readings that fall as the rate of turning the handle is increased are often a sign of moisture in the installation and the test should be repeated after attempted drying.

CT 318—Test Set Insulation

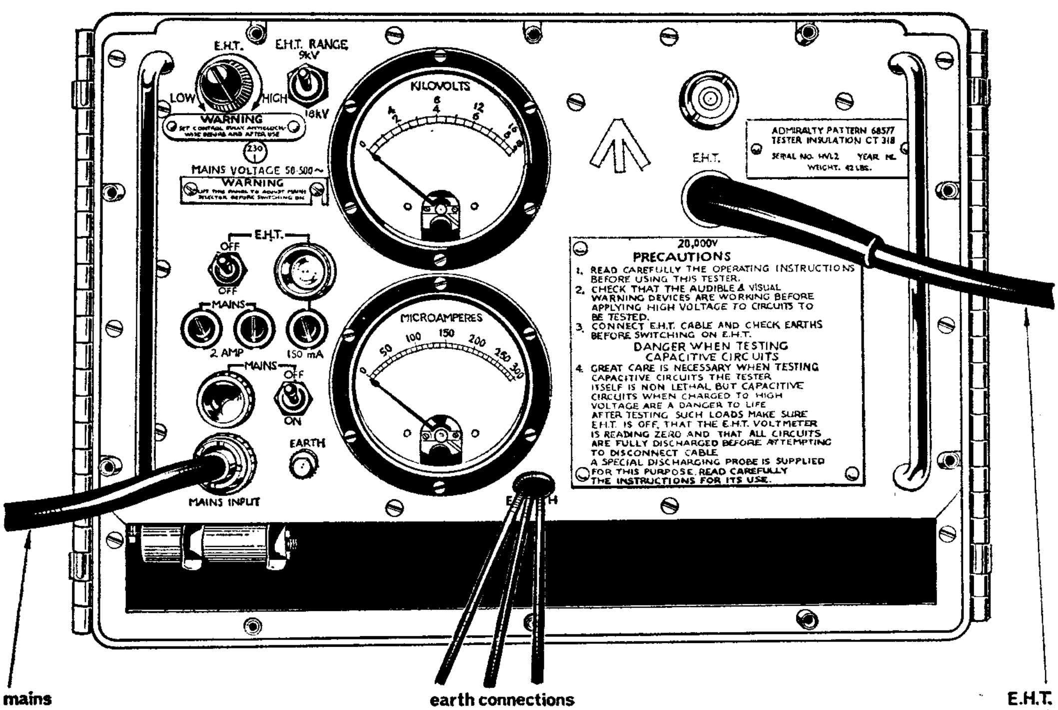


Fig. 11. Test set insulation CT318

22. This test set is designed to test components or installations subject to high voltage stress. Insulation resistance is not measured directly but may be calculated if required by Ohm's law from the direct voltage and current readings on the meters. The maximum output current is 300 μA, at a maximum voltage of 15KV.

23. **Operating.** The voltages used by this test set are a source of personal danger to the operator, particularly when measurements are being made on capacitive circuits. The instructions for use given in the equipment handbook, BR1771 (21), should always be followed and all relevant safety precautions taken. A discharge probe is provided with the set and must be used before attempting to disconnect the leads.

COMPONENT CHECKS

24. The failure of many different types of components can often be detected by properly applied resistance or insulation tests. These consist mainly of the detection of short or open circuits and of the comparison of resistance readings obtained on the suspect component with those obtained on a serviceable component. Many equipment handbooks and American servicing publications quote the resistance readings which should be obtained at given points of the circuit. These have been measured on a specified meter and any reading to be compared must be taken on the same meter and the same range if it is to have any meaning.

25. **Fuses.** Many modern fuses are encapsulated in an opaque tube and can only be tested by measuring their resistance for zero. Before carrying out this check the current delivered by the meter through a short circuit must be known (see para. 7). If this current exceeds the rating of the fuse any attempt to measure resistance will only rupture the good fuse.

26. **Diodes.** Although most test meters cannot drive a diode into full conduction a rough indication of serviceability can be obtained by measuring the resistance and then repeating the measurement with the meter test leads reversed. If these readings do not differ by a factor of at least ten to one the diode is unlikely to be serviceable. Faulty diodes usually go open circuit due to mechanical damage or short circuit due to 'burn out' and both of these conditions are easily detected. Low power signal diodes should only be tested on a diode or transistor tester which has built-in current limiting facilities.

27. **Capacitors.** Before attempting resistance checks ensure that the capacitor to be checked has been discharged. If it is an electrolytic capacitor ensure that the positive terminal of the capacitor is connected to the negative terminal of the meter. When first connected to the meter the resistance obtained will be low and will gradually increase as the capacitor charges. A short circuit capacitor will read zero and is obviously u/s, an open circuit capacitor will not 'kick' to a low reading when connected and will read infinity.

28. **Inductors/transformers.** The two most common faults are open circuit windings or a short circuit between the windings or between some of the turns of one winding. Measure the resistance of each winding in turn and make a note of the readings obtained; an open circuit will be obvious. Carry out an insulation test between each winding, the case, and all other windings; a short circuit will be obvious. If a serviceable spare is available check the resistance of its windings and compare the readings obtained with those of the suspect component. If there is any significant difference between these sets of readings it is likely that there is a short circuit between some of the turns of that winding.

29. **Cables.** Connect the remote ends of two cores together and measure the resistance of the two cores in series as a continuity check. Separate the remote ends and carry out an insulation check between them with a 'megger'. Repeat these checks until the continuity of all cores and the insulation of each core from all other cores has been checked. If the cable run is fastened to a conducting surface such as an airframe or aerial tower a further insulation test between each core and the airframe should be carried out.

SUMMARY

Can YOU answer YES to ALL these questions?

Is all power removed from the equipment to be tested and are all capacitors discharged?

Are you using a suitable instrument for the test to be carried out?

Is it serviceable, calibrated and properly adjusted?

Have you carefully read and understood the operating instructions?

Are you sure the meter test current will not damage the equipment or its components?

Are the test leads connected tightly to the correct terminals?

Have you selected the correct meter range for the expected result?

Are you using the meter properly?

Have you checked that the resistance being measured is not shunted by another resistance or by your body?

Did you carry out a cross check on an unexpected result?

Have you left the meter controls in a 'safe' position, or turned 'off' as appropriate?

CHAPTER 2

VOLTAGE AND CURRENT MEASUREMENTS

List of Contents

Introduction

1. The voltage and current in a d.c. circuit are related to each other and to the circuit resistance by the equation V = IR (Ohm's law). The measurement of resistance has already been considered in chapter 1 and if either voltage or current is measured as well as R, the other can easily be calculated. To measure voltage the meter is connected across (in parallel with) the component concerned. To measure current the meter must be inserted in series with the component and this involves disconnection, probably by unsoldering. Current measurements are therefore seldom made as current flow can be calculated from voltage measurements provided the circuit resistance is known or measured.

2. This chapter is concerned primarily with the techniques of measuring voltages, but current measurements have also been included as most items of test equipment include provisions for both types of measurement. It should be noted that voltage measurements can be obtained sufficiently accurately for many fault-finding purposes from an oscilloscope and this method of measurement is considered separately in chapter 3.

CURRENT MEASUREMENT

3. **Direct current.** Figure 1 shows the circuit diagram of the ammeter section of a typical multimeter. The full-scale sensitivity of the movement is 37·5 µA. The shunt used is a tapped type called an Ayrton shunt. The current flow through the instrument takes two paths, one direct through the shunt resistors to the left of the tapping selected by the switch, and the other to the right through the remaining resistors and the meter movement. The total shunt resistance is such that it passes 12·5 µA with 37·5 µA passing through the meter, giving a practical sensitivity of 50 µA. As the selector switch is moved towards the higher current ranges, the resistance of the shunt portion decreases, so bypassing an increasing and proportionate amount of current away from the meter movement. Theoretically, an ammeter should have an internal resistance of zero ohms so that its insertion in a series circuit does not affect the current flow. With a practical multimeter some 'loading' occurs.

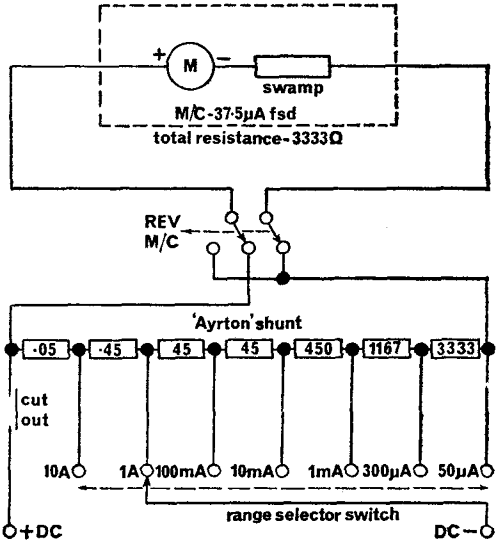


Fig. 1. Simplified amps circuit CT498

4. **Circuit loading effects.** The resistance of the meter will cause a voltage drop across the meter terminals which may affect the current flowing in the circuit under test. Figure 2 shows the voltage drop across the three normal multimeters at full-scale deflection (fsd). As the meter is a resistive circuit, the voltage drop for a given reading is proportional to the deflection i.e. at a reading of ½fsd, the voltage across the meter will be half that given in figure 2 for fsd. This voltage drop makes it impossible to measure the current through a valve or transistor by inserting a multimeter in the cathode or emitter circuit as the meter voltage will act as extra bias and may considerably reduce the normal current flow. Current readings are mainly used to determine the current consumed by a component or a circuit and the multimeter must be inserted at a point in the circuit such that the meter voltage does not appreciably affect the current flow.

CT511 Accuracy ±2% fsd.			CT498 Accuracy ±1% fsd.			CT471C Accuracy ± 2% fsd. up to 400mA (±3% fsd. on 1·2 A range)		
Scale Limit	USEFUL RANGE	Volts Drop fsd.	Scale Limit	USEFUL RANGE	Volts Drop fsd.	Scale Limit	USEFUL RANGE	Volts Drop fsd.
						0	2µA – 12µA	40mV
			0	10µA – 50µA	125mV	0	12µA – 40µA	40mV
0	30µA – 100µA	100mV				0	40µA – 120µA	40mV
			0	100µA – 300µA	500mV	0	120µA – 400µA	40mV
0	300µA – 1mA	250mV	0	300µA – 1mA	500mV	0	400µA – 1·2mA	40mV
						0	1·2mA – 4 mA	40mV
0	3mA – 10mA	250mV	0	3mA – 10mA	500mV	0	4 mA – 12 mA	40mV
						0	12mA – 40mA	40mV
0	30mA – 100mA	250mV	0	30mA – 100mA	500mV	0	40mA – 120mA	120mV
						0	120mA – 400mA	120mV
0	300mA – 1A	250mV	0	300mA – 1 A	500mV	0	400mA – 1·2 A	120mV
			0	3A – 10 A	500mV			

Fig. 2. Multimeter d.c. current ranges

5. **Using a multimeter to measure current.** Ensure that the meter selected is suitable for the measurement to be made and that it is serviceable and properly adjusted. Place the meter in its best working position and make sure that the test leads are tightly connected to the proper terminals. Adjust the meter to zero if necessary.

a. Switch off the equipment to be tested.

b. Connect the meter in series with the current path to be measured and set the range selector switches to a higher range than the expected result.

c. Switch on, take an approximate reading and switch off the equipment.

d. Select the correct current range so that the reading obtained will lie above ⅓fsd.

e. Switch on the equipment and take an accurate reading from the meter.

f. Switch off the equipment before disconnecting the meter.

g. Never leave the meter selector switches on a current range, as accidental connection to a voltage source could damage the movement. Switch to a high voltage or a non-connected position as appropriate.

Warning. Never alter the current range selected when current is flowing through the meter. This could cause arcing of the meter selector switch contacts, and if there is any capacitance in the circuit a sudden surge of current as the new range is selected may damage the meter movement.

6. Alternating current. The basic waveform is the sine wave, from which all other more complex waveforms are developed by adding harmonics of this fundamental waveform to produce, for example, square or sawtooth waveforms. A pure sine wave is symmetrical and free from harmonics. For the purposes of measurement, the following values have been established:

a. Peak value. As the name implies this is the highest value that the sine wave attains. It is not normally used as a method of recording a.c. values; but the peak-to-peak voltage value of a waveform is often used for convenience when using an oscilloscope to measure the amplitude of a complex waveform, (see chapter 3).

b. RMS value. This is sometimes called the effective value and is 70·7 per cent ($1/\sqrt{2}$) of the peak value. It is numerically equal to the value of direct current that would produce the same power dissipation or heating effect in a resistance. Thermally operated meters measure the r.m.s. value directly.

c. Average or mean value. This is the *actual* meter response to a rectified a.c. waveform, such as the succession of half-cycles from a rectifier. With full wave rectification it is equal to 63·6 per cent of the peak value; with half-wave rectification it is 31·8 per cent. Most rectifier meters are *calibrated in r.m.s.* and will therefore only give a true reading if the input waveform is sinusoidal.

7. Multimeters. The a.c. input is fed through a current transformer so that the same current is passed through the bridge rectifier and meter movement irrespective of the range selected. The moving coil meter responds to the average value of the rectified waveform, but the scale is calibrated to read the r.m.s. value directly. This means that the meter can only be used to measure the value of sinusoidal inputs, unless the form factor of the input waveform is known and a correction factor applied. These meters are designed primarily for the measurement of power frequency a.c. but will give a reasonable reading at audio frequencies up to about 20kHz. At higher frequencies the rectifier becomes non-linear and thermal meters must be used.

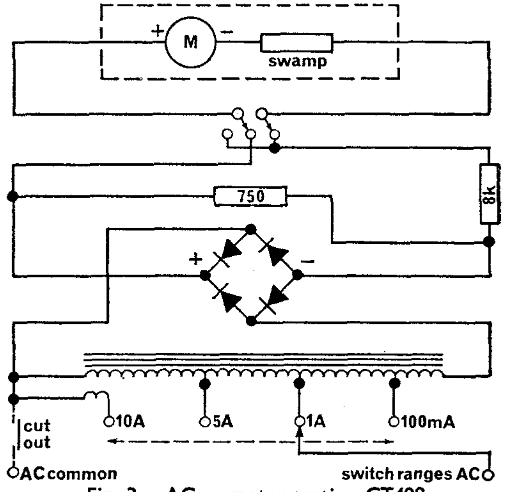


Fig. 3. AC ammeter section CT498

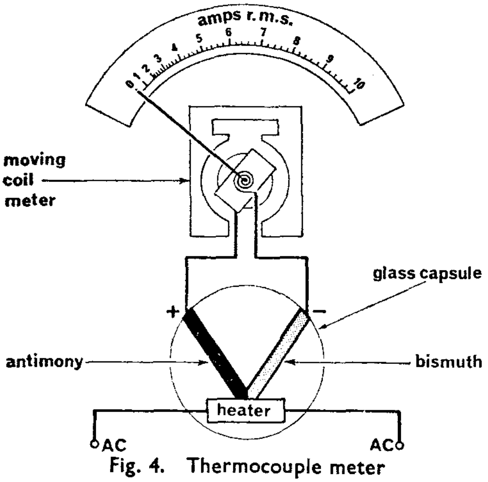


Fig. 4. Thermocouple meter

8. Thermocouple meters. Two dissimilar metal strips (usually antimony and bismuth) form a thermocouple which is heated by passing the current to be measured through an adjacent resistive heating element. The small d.c. voltage produced by the thermocouple is used to operate a sensitive moving coil meter whose scale is calibrated directly in a.c. amps. As the heating element is resistive the instrument can be used on several ranges by using normal 'shunts'. The meter is sluggish and time must be allowed for the heating element to attain a steady temperature before a reading is taken. The meter will respond to all frequencies from d.c. to r.f., but is very easily damaged by shock or overloads even as small as 50% over f.s.d.

VOLTAGE MEASUREMENT

9. Voltage is measured by placing the meter in parallel with the component or circuit to be tested and does not require any disconnections to be made. As the measurement is made with the circuit 'live' it is the easiest method of testing many equipments and forms a major part of an electrical or electronic tradesman's normal work. Point-to-point voltage measurements, compared with known nominal voltages as given in voltage charts or tables, provide invaluable aid in locating trouble quickly and easily. However, if the sensitivity of the test meter differs from that used in preparing the tables of data, the measurements made must be 'corrected' before a comparison is made. The tradesman should also keep in mind that in certain circuits a voltmeter, particularly one of low sensitivity used on a low range, may alter the circuit conditions to such an extent as to render the circuit inoperative.

10. **Multimeters.** A voltmeter should theoretically have an infinite internal resistance so that it would absorb no energy from the circuit under test and would therefore measure the true circuit voltage. In practical meters some loading effect is unavoidable, but it is minimised as much as possible by using highly sensitive meter movements in conjunction with very high value series resistors (see Fig 5). An even better method is to use a thermionic valve as the input stage to a more robust meter to form a 'valve voltmeter'.

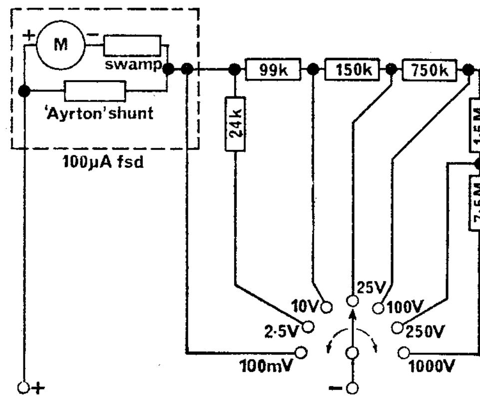


Fig. 5. Simplified volts circuit CT511

11. **Sensitivity.** The basic sensitivity of a meter movement is given in terms of the current needed to cause full scale deflection of the pointer. To make the expression of sensitivity more informative, for use as a voltmeter it is given as the number of ohms present in the meter circuit for each volt of the meter range (ohms per volt). This is found by dividing the current needed for f.s.d. into 1 volt. Knowing the sensitivity in ohms per volt, the shunting effect of the multimeter can be found simply by multiplying the sensitivity by the range setting on the meter. For example the shunting effect of the meter shown in figure 5 (CT 511) on the 25V range is 25V × 10,000 ohms/v or 250,000 ohms.

CT511 — Basic Sensitivity 10 kΩ/V, Accuracy ± 2% fsd

Scale Limit	USEFUL RANGE	METER RES. (OHMS)
0	25mV – 100mV	1 K
0	1V – 2·5V	25 K
0	2·5V – 10V	100 K
0	10V – 25V	250 K
0	25V – 100V	1 M
0	100V – 250V	2·5 M
0	250V – 1000V	10 M

CT498 — Basic Sensitivity 20 kΩ/V, Accuracy ± 1% fsd

Scale Limit	USEFUL RANGE	METER RES. (OHMS)
0	1V – 3V	60 K
0	3V – 10V	200 K
0	10V – 30V	600 K
0	30V – 100V	2 M
0	100V – 300V	6 M
0	300V – 1000V	20 M
0	1000V – 3000V	60 M

CT471C — Basic Sensitivity 10MΩ/V, Accuracy ± 2% fsd (± 3% on 1200 V

Scale Limit	USEFUL RANGE	METER RES. (OHMS)
0	2mV – 12mV	120 K
0	12mV – 40mV	400 K
0	40mV – 120mV	1·2 M
0	120mV – 400mV	4 M
0	400mV – 1·2V	12 M
0	1·2V – 4V	40 M
0	4V – 12V	110 M
0	12V – 40V	110 M
0	40V – 120V	110 M
0	120V – 400V	110 M
0	400V – 1200V	110 M

Fig. 6. Multimeter d.c. voltage ranges

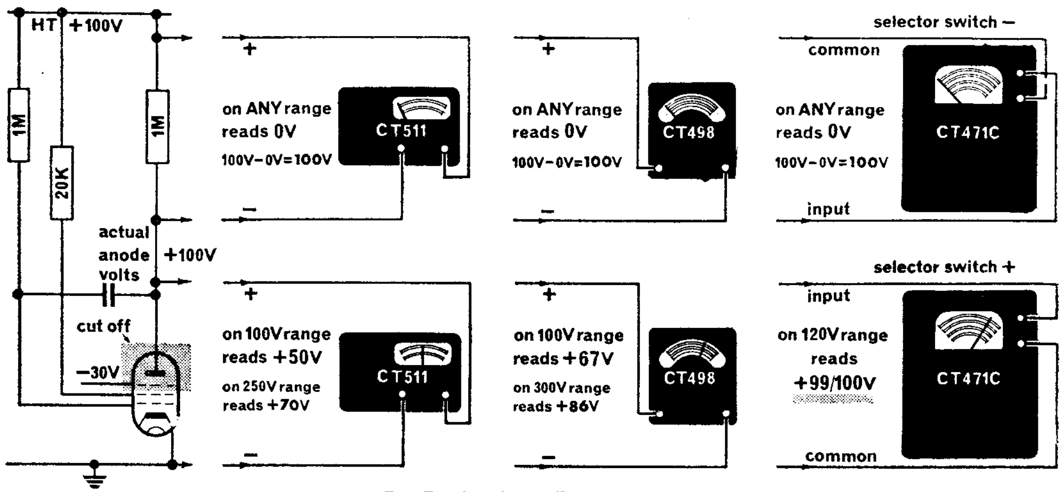


Fig. 7. Loading effects (para 12)

12. **Circuit loading effects** (Fig 7). It can be seen from figure 7 that voltage measurements do not always give the correct reading when taken against earth using a low sensitivity meter. The actual circuit shown is part of a timebase; the valve is 'cut off' and therefore no current flows through the 1MΩ resistor, leaving the anode at 100V. Connecting a meter between anode and earth causes a current to flow which depends on the meter resistance and will give a false reading of anode voltage. To get a *reasonable practical* reading (within 5%) the meter resistance must be at least 20 *times* that of the circuit *series* resistance i.e. $20 \times 1M\Omega = 20M\Omega$. Only a valve or digital voltmeter will give a reasonable reading under these conditions. The top row of readings in the diagram show the value of doing a *cross-check* on any doubtful results obtained, as this method will produce the correct reading regardless of the meter resistance when there is no current flowing in the circuit.

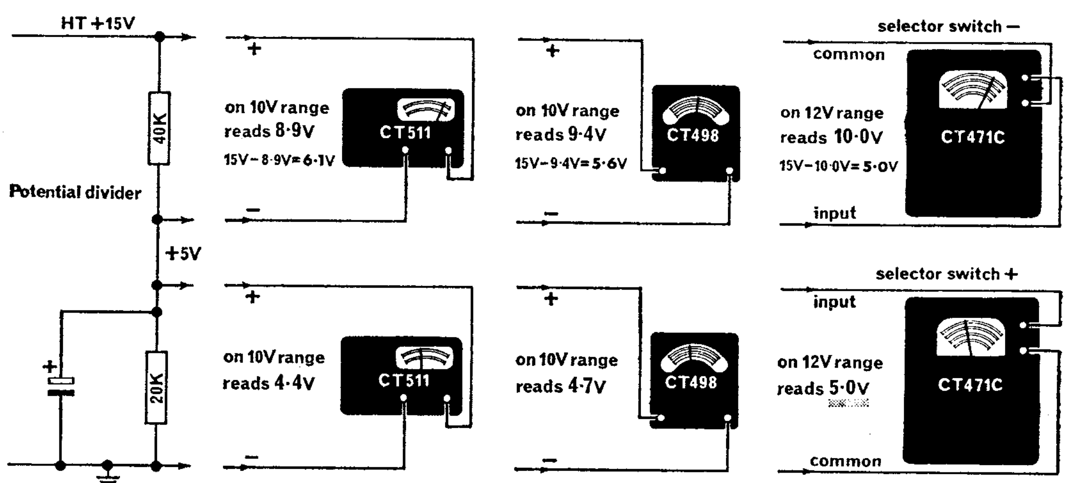


Fig. 8. Loading effects (para 13)

13. **Circuit loading effects** (Fig 8). The loading effect obtained by connecting meters in parallel with a circuit resistance is shown in figure 8. To obtain a reasonable practical reading the meter

resistance should be *at least* 10 *times* that of the circuit resistance in *parallel* with it. The value of cross-checks can again be seen. Remembering that the loading effect across a high resistance is greater than that across a low value, an estimate of the true voltage can be obtained by simple calculation from the two readings.

14. **Using a multimeter to measure voltage.** This paragraph applies mainly to the CT 498, but the points covered can be regarded as common to all multimeters.

a. Place the meter in its best operating position (normally face upwards), and set the meter movement to zero using the slotted screw immediately below the zero Ω ÷ 100 knob.

b. Ensure that the cut-out is set. If the cut-out operates while a reading is being taken, disconnect the meter from the external circuit before re-setting it, and correct the fault which caused the overload before re-connecting the meter. To reset the cut-out press the button firmly back against the panel, without twisting the button; the meter should be face upward while this is being done.

c. Attach the test leads, with prods or clips fitted as required, to the appropriate terminals; i.e. to the DC+/AC common and the DC/AC switch ranges terminals for all voltage measurements up to 1000 volts. Connect the earth lead of the meter first and then work one-handed if at all possible.

d. When in doubt as to the value of voltage to be measured, start at the highest range reducing gradually by means of the range switch until the appropriate range is reached. Always use a range which gives a reading *greater* than ⅓ f.s.d. (if possible) to reduce the meter error. There is no need to disconnect the leads as the switch position is altered when measuring voltages, but the meter should never be switched off by turning a range switch to a blank position.

e. Great care is necessary when connecting the meter to a live circuit, and this procedure should be avoided whenever possible. Where high voltages are present in an equipment under test (i.e. voltages over 50V d.c. or 30V r.m.s. a.c.) two persons should always be present when these voltages are exposed.

f. To measure voltages between 1000 and 3000V one lead is connected to the DC+/AC common terminal and the other to the appropriate terminal for d.c. or a.c. at the top of the instrument, and the appropriate 1000V range should be selected on the switches. Always *turn off* the equipment and allow time for capacitors to discharge before connecting or disconnecting the meter.

g. When using the CT 511 (multiminor) to measure a.c. voltages in the presence of d.c. a blocking capacitor must be used in series with the meter lead. A ·5μF paper capacitor of adequate working voltage is suitable for most measurements. Always discharge this capacitor through a suitable resistor after taking a measurement as it is dangerous both to personnel and equipment to leave it in a charged condition.

15. **Using a valve voltmeter to measure d.c. voltage.** The input impedance of valve or transistorized voltmeters is extremely high and they therefore have very little loading effect on the circuit to which they are connected. A valve voltmeter is provided at most bench servicing positions for electronic equipments and it should be used wherever possible in preference to normal multimeters.

a. If the meter has been moved, the movement zero must be adjusted using the slotted screw immediately below the meter. This adjustment must be made before the meter is turned on.

b. Turn on the meter and allow sufficient time for the valves to warm up and settle to a steady zero reading. If the meter is battery operated these must be checked by switching to the battery check position.

c. The scale zero must be adjusted with the meter turned on and with zero input. This is usually done by short circuiting the leads together and adjusting the 'set zero' control. Some meters have a 'check zero' switch position which selects zero input internally before the set zero control is adjusted.

d. Because of the internal circuit arrangements the terminals of most valve voltmeters are not reversible and the meters are therefore fitted with a polarity reversal switch. The input terminals are usually marked 'low' and 'high' but are sometimes called 'common' and 'input'.

e. The 'low' or 'common' terminal is the terminal which has the lower impedance to earth inside the meter, and it must always be connected to the *low impedance* point on the circuit to be measured. For example, in figures 7 and 8, when measurements are to be made between the anode of a valve and the HT line the low impedance terminal is connected to the HT line and the anode voltage is measured as a negative voltage with respect to the HT line.

f. The high or input terminal has a high impedance to earth inside the meter and is always connected to the high impedance point of the circuit to be measured. The polarity of the point to be measured, with respect to the low impedance terminal is selected by setting + or − on the meter selector switch. This function is very useful in practice as most circuit measurements are made against earth and the low impedance terminal can be left connected to earth when measuring either positive or negative voltages.

g. Unless the meter is required again almost immediately it should be turned off after use. In any case the range selector must be returned to a high voltage position to prevent the risk of damage to the meter by inadvertent connection to a high voltage.

16. **EHT measurement.** If the voltage to be measured is greater than 300V the prods supplied with most meters must not be used and special safety precautions must be observed, particularly in circuits containing capacitors which may be charged to a lethal voltage.

a. Switch off the circuit power supplies, discharge any capacitors through a suitable insulated resistive probe, and temporarily earth the point to be measured.

b. Connect the 'earthy' lead of the voltmeter first; if this lead is connected to any point other than earth the precautions in para. *a.* must be carried out.

c. Connect the high impedance lead to the point to be measured using a clip.

d. Move away from the voltmeter and leads, switch on the circuit power supplies and then read the voltmeter—do NOT touch anything.

e. Switch off the power supplies, allow time for the meter to return to zero volts or use a discharge probe *before* removing either of the meter leads from the circuit.

Voltages in excess of 3000 volts cannot be measured with any of the normal multimeters unless an external multiplier (special to type) is used. These voltages are normally only measured with an electrostatic voltmeter which must be connected to the circuit in the manner already described in this paragraph.

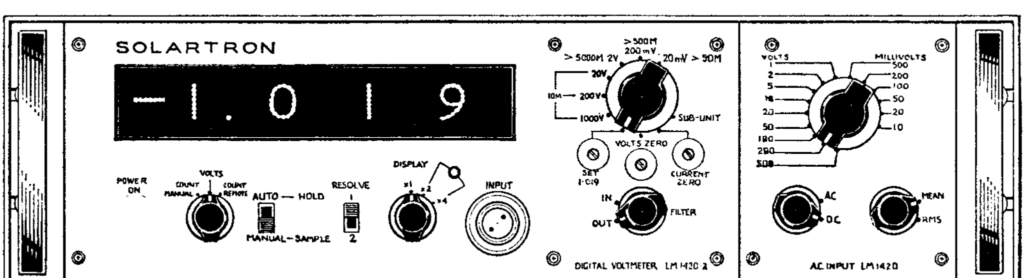


Fig. 9. Digital voltmeter LM1420. 2BA

17. **Digital voltmeters.** The numerical read-out eliminates reading errors, and can usually be printed out automatically or used to provide a remove print-out facility. They have a high sensitivity (2·5 μV) and a high accuracy (± 0·5% on d.c.) due to the use of an internal standard cell. On the LM1420·2BA, the true r.m.s. readings are taken using built-in thermocouples and

are accurate to $\pm$ 0·25% up to 20kHz irrespective of the waveform shape. The input impedance is extremely high (greater than 500MΩ on d.c.) and this allows the meter to be used on almost any circuit without introducing loading errors. The mode of operation (a.c. or d.c.) and the range setting (the decimal point) are automatically indicated on the numerical display to prevent operating errors.

ALTERNATING VOLTAGE

18. The majority of alternating voltage measurements are made at power frequencies, i.e. from 50Hz to 1600Hz for some aircraft supplies. At these frequencies the usual measuring instrument is the moving coil meter, fed with a rectified input. The meter measures the average voltage from the rectifier, but the scale is calibrated in r.m.s. and assumes that the input is a sine wave. Most multimeters are rectifier instruments and are only usable at low frequencies, up to about 10kHz. If the wave form to be measured is non-sinusoidal, a true r.m.s. meter must be used. The most common meter of this type is the thermocouple meter which is usable from d.c. to about 100MHz; good meters of this type have an accuracy of about 0·5% as compared with the rectifier meter accuracy of about 3%.

CT511 — Power Frequencies Only

RANGE	INPUT IMPEDANCE (OHMS)
0 – 10V	10K
25V	25K
100V	100K
250V	250K
1000V	1M

Basic Sensitivity 1kΩ/V
Accuracy ±3% fsd

CT498 — 25Hz – 10kHz

RANGE	INPUT IMPEDANCE (OHMS)
0 – 3V	100
10V	1K
30V	10K
100V	100K
300V	300K
1000V	1M
3000V	3M

Basic Sensitivity 1kΩ/V
Accuracy ±2·5% fsd
(some loss of accuracy over 3kHz)

CT471C — AC (normal) 40Hz – 20kHz

RANGE	INPUT IMPEDANCE (OHMS)
0 – 12mV	12K
40mV	40K
120mV	120K
400mV	400K
1·2V	1·2M
4V	1·2M
12V	1·2M
40V	1·2M
120V	1·2M
400V	1·2M
1200V	3M

Basic Sensitivity 1MΩ/V
Accuracy ±3% fsd

CT471C — RF/AC (probes) 20kHz – 1500MHz

NEVER apply any d.c voltage to the probes

RANGE	INPUT IMPEDANCE (OHMS)
0 – 40mV	200K in parallel with 2pF
120mV	200K in parallel with 2pF
400mV	200K in parallel with 2pF
1·2V	200K in parallel with 2pF
4V	200K in parallel with 2pF

note:
Terminated probes of 50Ω and 75Ω impedance are available
A 40dB divider (÷100) is available for use with the unterminated probe on voltages up to 400V below 100MHz

Accuracy ±5% fsd
(some loss of accuracy over 1000MHz)

Fig. 10. Multimeter a.c. voltage ranges

19. **AC measurement.** The general principles of measurement are the same as for d.c. voltages, but the special points listed below must also be considered when making a.c. measurements. It should also be remembered that for fault finding purposes the voltage calibrated oscilloscope is the normal method of measuring a.c. voltages (see chap. 3).

a. Frequency. The frequency, and waveshape, of the waveform to be measured must be known to enable a meter to be selected which is capable of making the required measurement with reasonable accuracy.

b. DC isolation. Some multimeters are not transformer coupled internally (CT 511), and will respond to d.c. when switched to their a.c. ranges. A quick check is to repeat the reading with the leads reversed; if a different reading is obtained, the circuit d.c. level is affecting the reading and a suitable blocking capacitor must be inserted in series with the meter lead. Always discharge this capacitor immediately after taking the reading as a safety precaution.

c. DC loading. Some multimeters (e.g. CT 511 and CT 498) are not capacitor isolated on their a.c. voltage ranges. As the input impedance of these meters is usually fairly low on their a.c. voltage ranges it may affect the d.c. bias or voltage levels in the circuit to be measured. This effect is also eliminated by using a blocking capacitor of suitable size (about 1 μF paper 500V working).

d. 'Pick-up'. On the a.c. voltage ranges all meters will respond to stray fields, and pick-up some voltage without being connected to anything. This is more marked with a high input impedance meter such as a valve voltmeter. These voltages are caused by the intersection of the leads by magnetic fields in the vicinity of power cables, transformers, transmitters and other high power devices. The effect can be minimised by routing the meter leads close together so that they do not form a loop. When making measurements on small voltages it is advisable to earth the meter as close to the point being measured as possible. At the higher frequencies a special probe and screened lead are used.

e. Meter capacitance. The upper frequency limit at which a meter will give a reasonable reading is usually determined by the parallel capacitance of the meter leads and input circuitry. The CT 471C, with unterminated probe, has an input capacitance of 2pF and can be used up to about 1500MHz. Most meters have a capacitance of 20pF or more and are therefore limited to about 200MHz. The effect of this capacitance must always be considered before attempting radio frequency measurements, particularly on tuned circuits or oscillator stages.

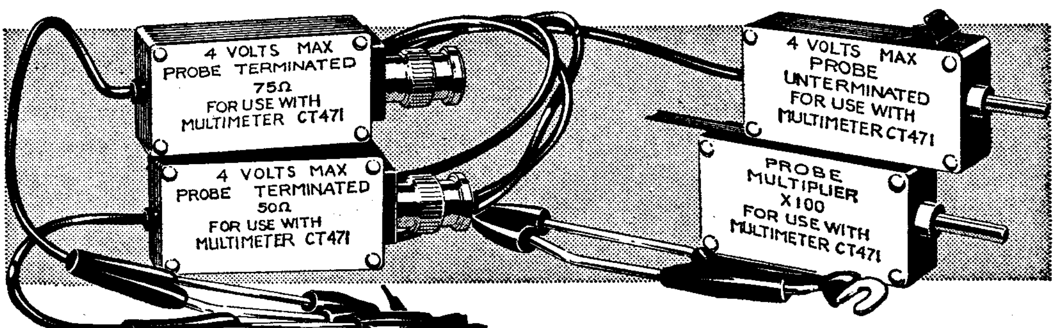


Fig. 11. Probes—multimeter CT471C

20. **Probes for r.f. measurements.** To enable valve voltmeters to be used to measure radio frequency voltages some form of external probe is normally supplied. This probe contains the germanium or silicon rectifier for the meter and its associated circuitry. As it is only used to measure r.f. the capacitors in the rectifier circuit can be small values and still present a low series impedance. The probe thus isolates the lead and meter input capacitance from the circuit being measured and enables readings to be taken at much higher frequencies than would otherwise be possible. The r.f. range of the CT 471C allows voltages up to 4V to be measured at the probe, but a divider attachment is supplied to enable up to 400V to be measured at frequencies below 100MHz. The unterminated probe can be used up to 1500MHz but there is a slight loss of accuracy over 1000MHz. Terminated probes of 50 ohms and 75 ohms impedance, fitted with coaxial connectors are supplied to enable measurements to be made on normal transmission lines without introducing a mismatch.

21. **Decibels.** It is often convenient to make audio frequency measurements in decibels as the reading obtained gives a measure of the sound intensity on the human ear. A difference of one decibel is about the smallest difference which can be detected by ear when comparing the intensity

of two sound sources. The multimeter CT 498 has a decibel scale, calibrated both positive and negative from an arbitrary reference point. The difference in value between a negative value and a positive one is the sum of the two i.e.

$$-3 \text{ dB and } +5 \text{ dB is } 3 + 5 = 8 \text{ dB}$$

When comparing readings on two different a.c. voltage ranges of the meter add 20 dB to the reading for each increase of 10 times on the meter range; successive voltage ranges on the meter correspond to a change of approximately 10dB.

22. **Pulse measurements.** Most valve voltmeters of the type described in the previous paragraphs are calibrated in r.m.s. on the a.c. ranges, even though the diode rectifier system gives an output practically equal to the peak value of the input. Some meters are made which exploit this characteristic to measure peak values of pulses directly. As the calibration of these meters is affected by the pulse width, the pulse rise time, and the pulse repetition frequency they are more in the nature of a test set than a general purpose instrument. For general purpose measurements on pulse waveforms the standard general purpose instrument is the voltage calibrated oscilloscope which is considered in the next chapter.

SUMMARY

Can YOU answer YES to ALL these questions?

Are you using a suitable instrument for the test to be carried out?

Is it serviceable, calibrated, and properly adjusted?

Have you carefully read and understood the operating instructions?

If high voltages are exposed are you taking all necessary safety precautions?

Have you selected the correct range (or a high one)?

Are you sure the meter is not loading the circuit being measured in any way?

Did you carry out a cross-check on an unexpected result?

Have you left the meter controls in a 'safe' position or switched 'off' as appropriate?

CHAPTER 3

WAVEFORM MEASUREMENTS—THE OSCILLOSCOPE

List of Contents

Introduction

1. An oscilloscope is used to give a pictorial display of the voltage changes taking place in a circuit. These are applied to the deflecting plates of a cathode ray tube to give vertical displacement of the spot. The horizontal deflecting voltage is obtained from a timebase circuit inside the instrument and is directly proportional to time. The type of display obtained with a sine wave input is shown in figure 1.

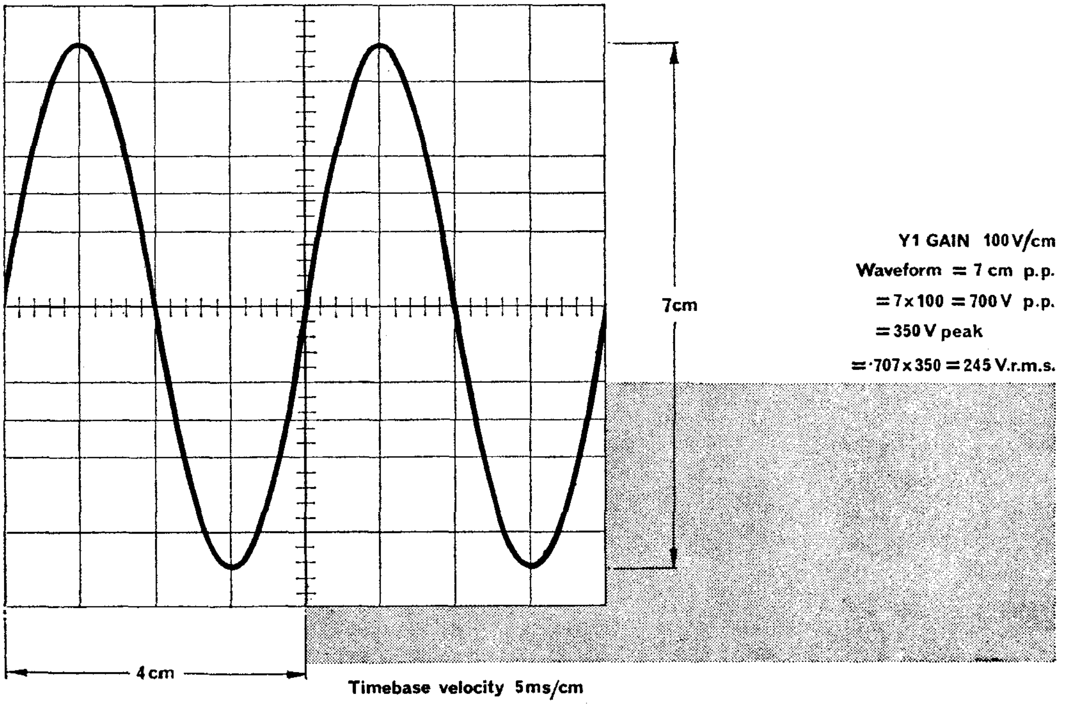


Fig. 1. Display of mains voltage on oscilloscope

2. The biggest advantage of an oscilloscope over a normal meter is that the 'pointer' used is a beam of electrons in a cathode ray tube and has virtually no inertia. It will thus respond to very rapidly changing voltages and can therefore be used to measure accurately very small intervals of time—less than 1 millionth of a second (1 μS).

Oscilloscope Type CT436

3. This oscilloscope is a small general purpose instrument used for first and second line servicing in any part of the world. It is fitted with a double-beam cathode ray tube, which means that two traces are available which are used to compare two separate waveforms against one another and against the built-in timebase scale. The face of the cathode ray tube can be fitted with a squared grid, called a graticule, so that both voltage and time can be measured against the internal calibration of the instrument as selected on the control switches. This graticule is divided into eight 1cm divisions in both the vertical and horizontal axes and may be edge lit by a variable intensity lamp for ease of reading. A viewing hood and polarised filter are supplied with the set to enable the trace to be seen easily in daylight without using excessive brilliance on the c.r.t.

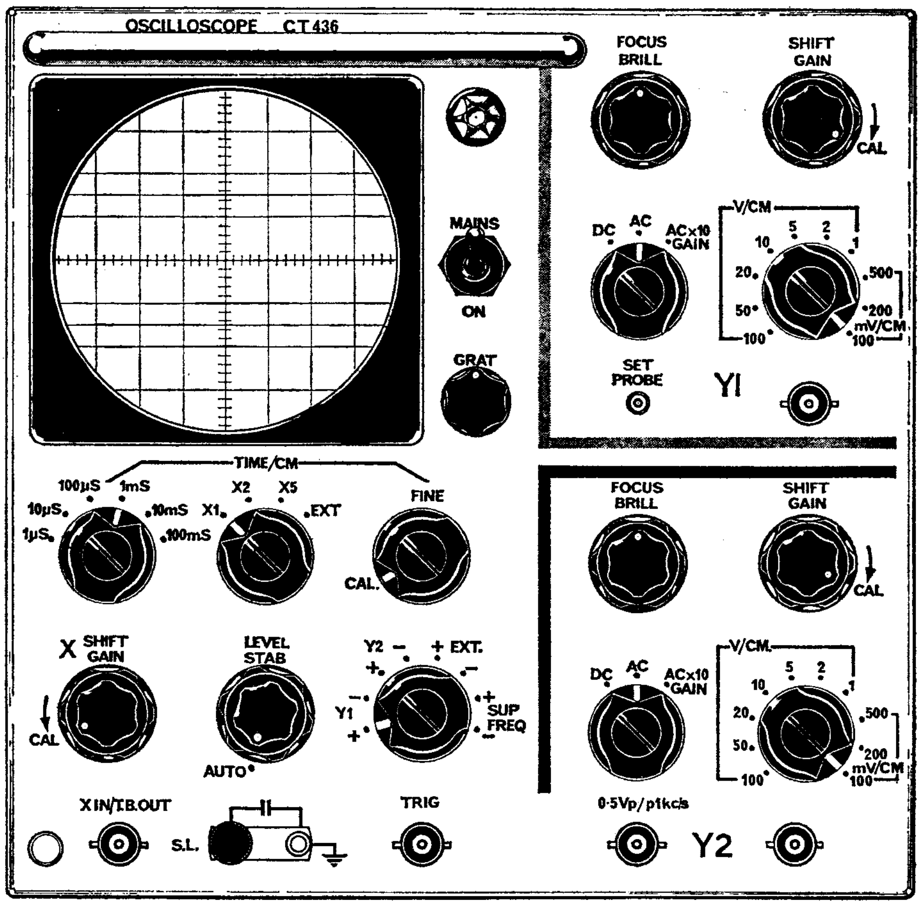


Fig. 2. Oscilloscope CT436

4. **Controls.** The controls of all oscilloscopes are similar in their action and fall into one of four simple groups:

a. Cathode ray tube controls—focus, brilliance, astigmatism, graticule lights, etc.

b. Vertical amplifier controls—sensitivity (V/cm), coupling, shift, gain etc.

c. Horizontal (timebase) controls—velocity (time/cm), shift, gain, etc.

d. Triggering—external, signal (Y1 or Y2), delayed, etc.

5. Vertical amplifiers. The selector panels for the Y1 (upper trace) and Y2 (lower trace) vertical deflection amplifiers are usually fitted with identical controls. Figure 3 shows the Y2 selector panel layout of the CT436 oscilloscope.

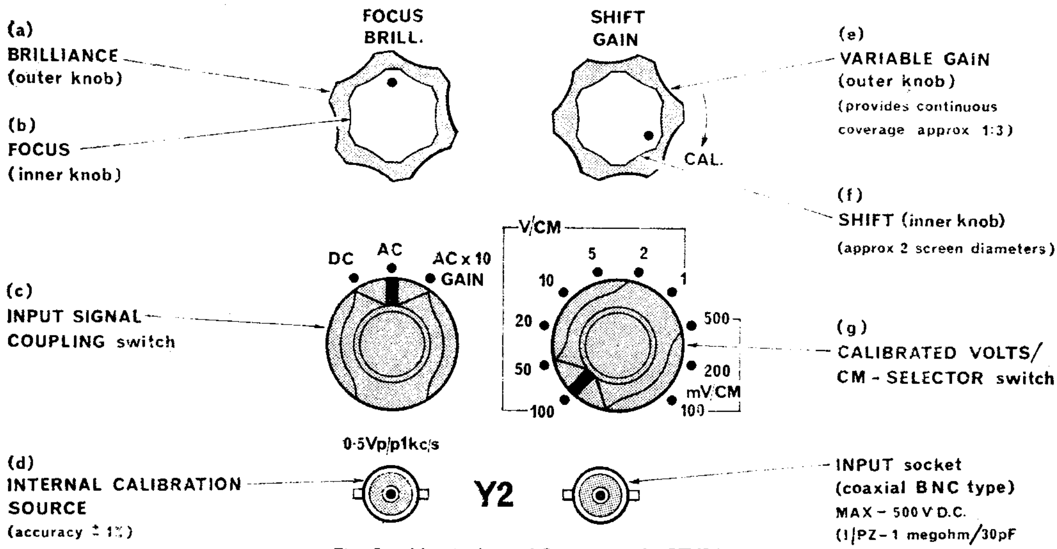


Fig. 3. Vertical amplifier controls CT436

a. Brilliance. This control is used to adjust the intensity of the spot, or trace, by altering the grid/cathode bias applied to the cathode ray tube. In use the level should be set so that the desired waveform is clearly visible. Excessive brilliance should not be used, and care must be taken not to leave a very bright spot stationary on the tube face as this will damage the phosphor coating.

b. Focus. Adjusts the focal point of the electron beam to give a clearly defined spot or trace on the tube face by changing the anode potentials of the c.r.t.

c. Input signal coupling. Connects the coaxial input socket to the input of the d.c. coupled vertical amplifier system either:

(1) DC—directly connected for the measurement of d.c. voltages or of very low frequency a.c. waveforms.

(2) AC—capacitive connection used for normal a.c. and waveform measurements; the bandwidth of the CT436 on AC coupling is 2·5Hz to 6MHz.

(3) AC × 10—connected through a pre-amplifier with a gain of 10× to allow the measurement of small voltages or for use as a null detector.

d. Calibration source. A stable internal oscillator provides a 1kHz square wave of ·5V peak to peak for checking the calibration marks on the selector switches.

e. Gain. Allows continuous adjustment of the vertical amplifier gain between the switched positions. Normally left in the CAL position (fully clockwise) so that the selector switch gives the correct volts/cm. Sometimes used when the vertical gain is calibrated against an accurate external standard.

f. Shift. Used to move the trace up or down the screen, normally to align the bottom of the waveform with a division on the graticule for ease of measurement.

g. Volts/cm. This switch adjusts the gain of the vertical amplifiers in 1 : 2 : 5 steps to display the waveform at a convenient size. The cal. markings are only accurate when the variable 'gain' control is in the cal. position i.e. fully clockwise.

6. **Horizontal (timebase) controls.** On most general purpose oscilloscopes the same timebase is applied to both traces, thus enabling two separate waveforms to be directly compared for timing. Therefore, one set of timing controls will set the time/cm. for both traces. The timing selectors shown in figure 4 are for the CT436 and are typical of most general purpose instruments. More complex oscilloscopes, used for many radar applications, have two independent timebases which may be run at different speeds if required.

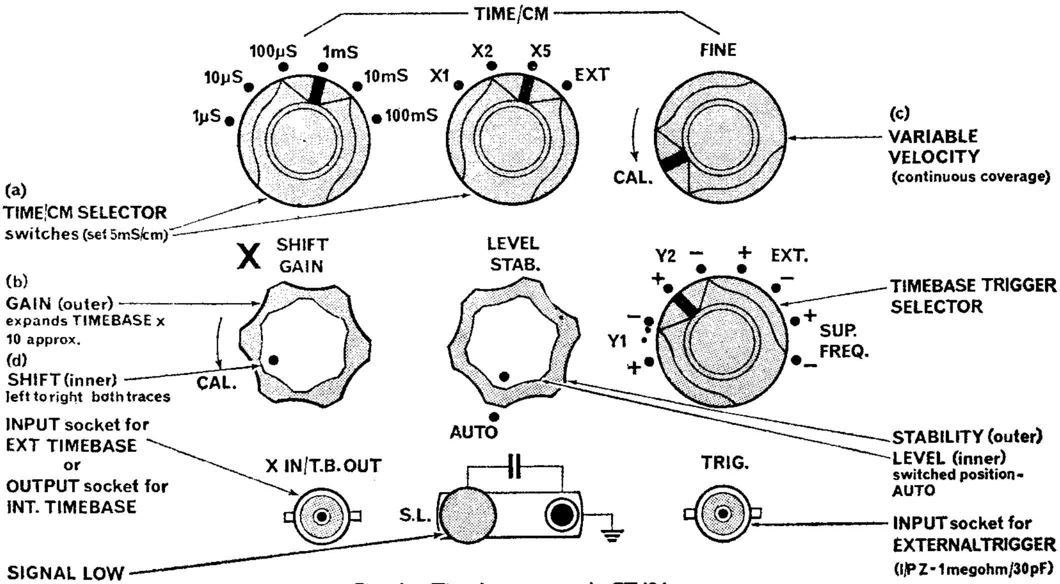


Fig. 4. Timebase controls CT436

a. Time/cm. selector switches. Two switches are used, the basic time selector and a 1 : 2 : 5 multiplier. In figure 4 they are shown in the 1mS × 5 = 5mS/cm. position. These switches provide 18 calibrated ranges from 1 µS/cm to 500mS/cm, but the calibration is correct only when the 'fine' velocity and the X gain controls are in the CAL positions. The multiplier switch has a position marked EXT which switches off the internal timebase generator and allows an external timebase to be fed in to the X IN socket to control both traces. In all other positions the internal timebase may be taken out of this socket and used to drive other test equipment, such as wobbulators, if required.

b. X gain. This control is normally left in the cal. position so that the timings on the selector switches are correct. It may be used to expand the timebase by any amount up to 10 times, thus giving a fastest speed of 0·1 µS/cm when fully clockwise. Always return this control to the cal. position after use to prevent errors.

c. Fine—variable velocity control. This control must also be left in the cal. position for the timings on the selector switches to be correct. It is used in conjunction with the X gain control to set up the time/cm of the traces against an external standard such as a crystal-controlled oscillator.

d. X shift. This control moves both traces from left to right on the screen and is normally used for aligning a selected point on the waveform with one of the lines on the graticule when making time measurements. The adjustment is such that either end of the trace can be centred, even on full timebase expansion.

7. **Timebase delay.** A common feature on many oscilloscopes is the ability to delay either one or both timebases to allow pulse waveforms to be accurately timed. The CT436 has no delay facility but the method is dealt with in a later paragraph on the Hewlett-Packard 180A.

8. **Triggering—Synchronisation.** In order to make any measurements on a waveform, the display on the tube must be stationary. This means that the timebase must run at the same frequency as the input signal or at a sub-multiple of this frequency. In order to do this most oscilloscopes use a triggered timebase system, but one or two of the older types use a free running timebase pulled into synchronisation by the input signal. The CT436 has a triggered timebase which only free-runs when the triggering controls are mis-adjusted.

9. **Triggering controls—CT436.** The three controls used on the CT436 are shown in figure 4, together with the socket used for applying an external triggering signal. The external trigger should be used whenever possible as it enables many related waveforms to be observed without altering the trigger controls and also eliminates any possible confusion over which signal is acting as the trigger source for both traces.

a. Trigger selector switch. This switch selects the source of the triggering waveform supplied to the timebase generator circuits. There are four possible sources, Y1 signal, Y2 signal, EXT fed into the trig. socket, and the supply frequency (normally 50Hz). For each of these sources a positive and negative switch position is available. In the positive position the timebase is triggered by the positive going edge, or half cycle, of the input signal selected. When the negative position is selected, triggering is from the negative going edge.

b. Stability control. This control adjusts the bias which keeps the timebase generator cut-off until a trigger is applied. When it is turned fully clockwise the bias is removed and the timebase will then free-run. In normal use, the control is turned fully anti-clockwise and then turned slowly clockwise until the point at which the trace appears is reached. At this setting the trace is stable and the waveform on display will be stationary. If the control is turned any further in a clockwise direction the timebase will tend to free-run and the display will no longer be stationary.

c. Level control and switch. This control is normally left in the switched position, i.e. on AUTO, in which position automatic level selection allows the timebase to be triggered from any signal up to 0·5MHz without adjustment of the level control. The control may be used to select the point on a complex waveform, such as a stepped waveform, at which it is required to trigger the timebase. The trace should first be stabilised with the level control in the auto position. The level control should then be switched on and turned clockwise until the trace starts at the point on the waveform which is required; on the way to this point the display may pass through several other stable conditions, triggered at different points on the waveform. The level control will select any point on the waveform which lies within $\pm$ 2·5cm of the mean level of the signal and use it for triggering.

10. **Signal low terminal.** When it is required to examine a signal relative to a potential other than earth, the signal low terminal is used as the low impedance, or 'earthy' side of the input connection. This terminal is on the timebase panel (Fig 4) and is normally linked to the chassis terminal (earth) by a metal strap, the insulated terminal being the one used as the signal low. Both the signal input and the signal low terminals may have a potential difference *not exceeding 500V peak* with respect to the chassis when the signal is applied. This method is most often used for examining small signal levels across transformer windings, particularly when these transformers are in the anode circuits of valve amplifier stages.

Typical Use of an Oscilloscope to measure Voltage and Time

11. **Preliminary control settings.** Set the controls as follows:

Both volts/cm. selector switches to 100V/cm.
Timebase selector to 1mS/cm, and X1.
Stab. control fully clockwise, level switched to auto.
Y1 and Y2 input coupling switches to AC.
The four variable controls to their CAL positions.

Adjust the brilliance controls until both traces are at a reasonable viewing level, and then set the focus controls so that both traces are clearly defined. Turn the Y1 and Y2 shift controls until the traces lie over their respective beam centre lines on the graticule (see Fig 5). Turn the X shift until the traces start at the first line on the graticule.

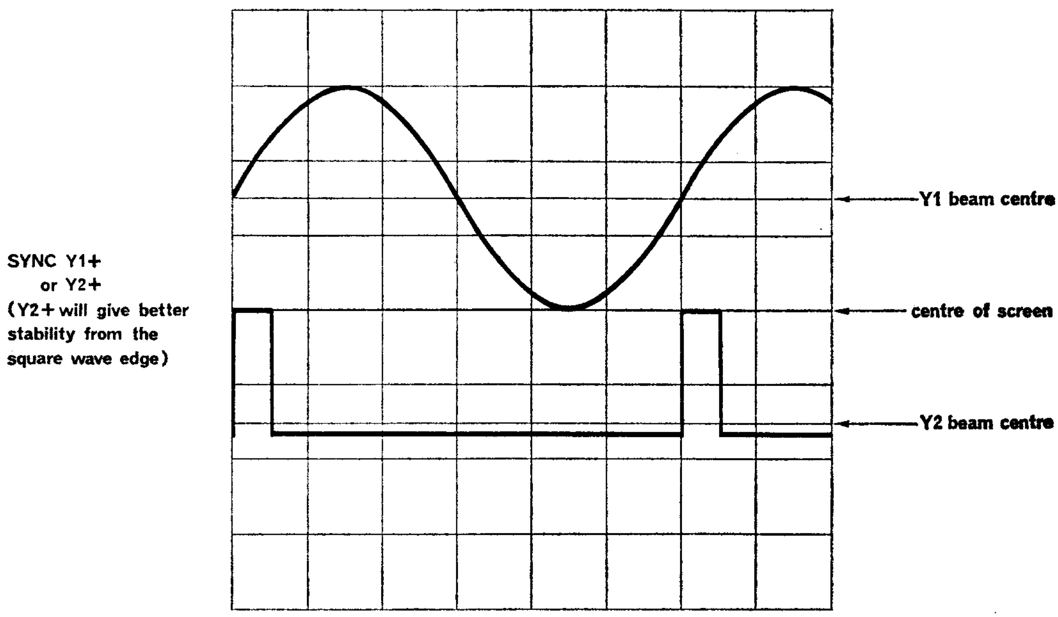


Fig. 5. Typical display

12. The signals shown in figure 5 are the input (sine wave on Y1), and the output (pulse waveform on Y2) of a switching circuit such as a flip-flop. To display these the signals are applied to the Y1 and Y2 input terminals via the 36 in. coaxial leads provided. Take adequate precautions when making connections to avoid electric shock. In particular, connect the earth lead first, *let go of it*, then connect the signal (live) clip—working one-handed if it is possible. Make sure that the clips do not cause a short circuit in the equipment by falling against other leads or components, especially when working on transistorized equipment.

a. Adjust the Y1 and Y2 volts/cm selector switches until each waveform is about 2 or 3 centimeters high on the screen.

b. Select Y2+ on the trigger selector, turn the stab. control fully anti-clockwise, then turn it clockwise until the traces just re-appear; they should be stationary and stable.

c. Turn the time/cm. selector switches until the display shows slightly more than *one complete cycle* across the screen.

13. Interpreting the display. For most fault-finding applications the display shown in figure 5 presents all the information which would be needed and no further control adjustments are necessary. The information obtainable from the display is as follows:

a. The circuit produces one positive pulse from each cycle of the input sinewave. This pulse is timed by the start of the positive half-cycle of the sinewave.

b. The sinewave is 6cm wide; therefore its period is six times the setting of the time/cm selector switches. If these were set at 100 μS/cm and X5 the period would be

$$6 \times 100\ \mu S \times 5 = 3000\ \mu S = 3ms \text{ accurate to } \pm 5\%.$$

from this time measurement the frequency can be calculated

$$f = 1 \text{ sec. divided by } 3mS = 333Hz.$$

c. The positive pulse width is approximately one twelfth of the sinewave period and is therefore 250 μS wide *approximately*. The pulse width cannot be accurately measured on these control settings as it is too narrow to read against the graticule.

d. The sinewave amplitude is *approximately* 3cm; therefore its peak to peak voltage is three times the setting on the Y1 volts/cm selector switch.

e. The pulse amplitude is *approximately* 2cm and its voltage is twice the setting on the Y2 volts/cm. switch.

f. The p.r.f. of the pulse waveform is the same as the sinewave frequency i.e. 333ppS.

14. Voltage measurement. In order to use the accuracy of an oscilloscope to its best advantage, the displayed waveform to be measured must be as large as possible to minimise any error due to inaccurate comparison against the graticule. To measure the sine wave already discussed carry out the following adjustments:

a. Turn the Y2 shift control to remove the trace from the screen out of the way.

b. Turn the Y1 volts/cm. selector switch to obtain a waveform between 5 and 8cm high.

c. Adjust the Y1 shift control until the bottom of the waveform lies exactly on one of the lines of the graticule.

d. Read off the peak-to-peak amplitude of the waveform in centimetres against the graticule and multiply by the setting of the volts/cm switch to obtain the peak to peak voltage with an accuracy of ± 5%.

Note: for this reading to be correct the variable gain control must be in the CAL position.

The amplitude of the pulse waveform on the Y2 trace can be measured in an analogous manner.

15. Time measurement. To obtain reasonable accuracy the width on the screen of the part of the waveform to be measured must be at least 5cm. To measure the pulse width of the waveform already considered on Y2 proceed as follows:

a. Adjust the time/cm selector and the multiplier switches until the pulse is between 5 and 8cm wide.

b. Adjust the Y2 shift control until the part of the pulse to be measured lies along the centre line of the graticule. For square pulses this will usually be the base, but sometimes measurements are made 'between 3dB points' of a sinusoidal pulse.

c. Adjust the X shift until the start of the pulse lies exactly on one of the lines of the graticule.

d. Read off the width of the pulse in centimetres against the graticule and multiply by the setting of the time/cm selector switches to convert this reading to time. The accuracy of direct measurement is ± 5% at timebase speeds greater than 50mS/cm and about 15% at lower speeds.

Note: for this reading to be correct, the fine velocity and the X gain controls must both be in the CAL position i.e. fully anti-clockwise.

16. **Measurement of d.c. voltage.** It is often convenient to use the oscilloscope to determine the voltage present in a circuit on which the oscilloscope is already being used to observe a waveform. This is done by using the d.c. input coupling facility on the Y amplifiers. A reading may be obtained of a d.c. voltage, or of the d.c. level of an a.c. or pulsed waveform. Preliminary adjustment of the oscilloscope controls should be carried out as explained in para. 11.

a. Set the Y1 and Y2 input coupling switches to DC.

b. Connect the signal input leads to earth.

c. Adjust the Y1 shift control until the trace lies over a convenient line on the graticule (normally the centre), and if only one voltage is to be measured turn the Y2 shift until the trace is out of the way.

d. Connect the unknown voltage to the Y1 input and adjust the volts/cm switch until the trace lies on the screen. Note that the shift control must not be moved as it controls the 'zero datum' of the oscilloscope.

e. Measure the deflection of the trace from the original line on the graticule and multiply by the setting of the volts/cm control to obtain the d.c. voltage.

f. Disconnect the input and earth the lead as a cross check on the zero position of the trace.

The accuracy of the reading obtained from a d.c. voltage is about 5% which is adequate for most fault finding purposes. If an a.c. voltage was superimposed on the d.c. level this would appear on the trace displaced from the centre of the screen and the d.c. level must be calculated from the mid-point of the sine or square wave. When an assymetrical waveform is present the time/cm controls should be adjusted until slightly more than one complete cycle is displayed and the d.c. levels of the top and bottom of the waveform measured separately. The mean level of the waveform can be calculated from these levels and the mark to space ratio of the waveform, but this is seldom done as the mean level has no real practical significance.

17. **Loading.** The input impedance of most oscilloscopes is of the order of 1 megohm in parallel with 30 picofarads, irrespective of the control settings. This compares well with most of the multimeters, especially when small voltages are to be measured. Multimeters usually have quite a low input resistance on their a.c. ranges, so the oscilloscope can be used to measure a.c. voltages in circuits which would be excessively loaded by a meter. Very little circuit loading will occur when using an oscilloscope on normal circuits but its effects must be allowed for in circuits with very high anode loads (such as miller timebases). The effect of the oscilloscope input capacitance on tuned circuits at high frequencies sets a limit to the usefulness of the scope unless special probes are used on the input connectors.

18. **Comparison of two voltages.** Two voltages can be compared by applying them to the Y1 and Y2 inputs. The oscilloscope controls are set up as in para. 16 and both traces lined up on the graticule centre line with the inputs earthed. The signals are then applied to the two inputs and the difference between the two traces measured. This method is not very effective as the volts/cm controls are at a fairly high value to keep the traces on the screen. A more effective method is to apply one input to the signal low terminal (see para. 10) and the other to the Y1 input on DC coupling. The 'zero' must be set as before and the shift control left in this position throughout the measurement. The volts/cm control can be used in a sensitive position as the effective input to the scope is the *difference* between the two voltages, and the trace is centred when this difference is zero.

19. **Use of the oscilloscope as a null detector.** One of the normal jobs of a null detector is to determine the point of balance of a bridge circuit. The supply to the bridge may be either a.c. or d.c. and the input coupling controls must be adjusted accordingly. As there is no true earth on

the bridge arms, the two voltages must be compared as in the last paragraph and the bridge adjusted until they are equal. The normal servicing checks on many servo systems and components, such as synchros, require the position at which there is zero output to be found for setting up purposes. The output is usually w.r.t. earth and so may be applied to the Y input with the volts/cm control in its maximum sensitivity position. The synchro can then be turned until the waveform (or voltage) on the scope is zero. The accuracy of this position reading depends on the mechanical drive assembly of the device as the oscilloscope will easily detect voltages as small as two or three millivolts. Care must be taken when using an oscilloscope on small a.c. voltages not to get confused by stray pick-up, particularly from the domestic mains.

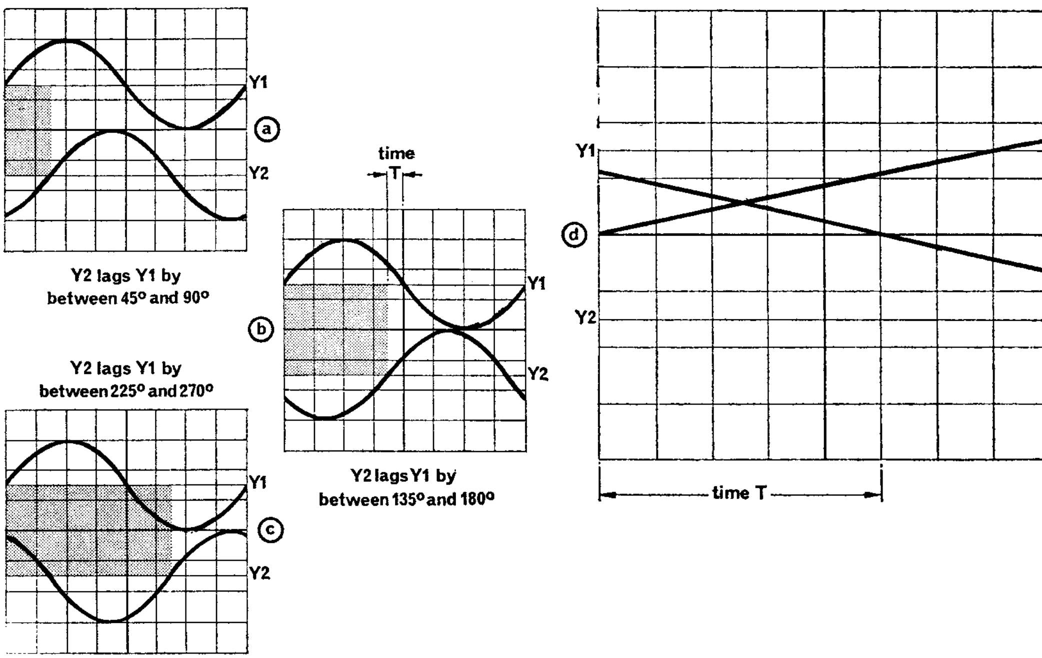


Fig. 6. Phase measurement

20. **Phase measurement.** The two signals are applied to Y1 and Y2 in the normal way, and the scope controls adjusted to give a display similar to those shown in figures 6a, b, and c. By inspection of the display at b it can be seen that the waveform on Y2 lags that on Y1 by between 135° and 180°. To find the exact phase lag the time T must be measured. Time measurements on a sine wave are always made at the *zero cross-over points* as this is its greatest rate of change of voltage and therefore gives the highest accuracy. Adjust the volts/cm and Y gain controls until each waveform is 6cm high on the screen and the Y1 and Y2 shift controls until both waveforms are centred about the horizontal centre line of the graticule. Switch the trigger selector to Y2+ and adjust the time/cm controls to obtain the waveform shown in figure 6d. Measure the time interval T (X gain and fine velocity at CAL). The phase angle of this time interval is given by

$$\theta = \frac{T}{\text{period}} \times 360^\circ$$

From this angle and the original inspection b of the waveforms: the waveform on Y2 lags that on Y1 by 180 − θ°.

Lissajous' Figures

21. When a sinewave is applied to the X plates, instead of the oscilloscope timebase, its phase can be compared with that of another sinewave of the same frequency applied to the Y plates. This method of display forms a trace pattern known as a Lissajous figure. A similar method can be used to compare the frequencies of two sinewaves; or to find the frequency of an unknown sinewave by comparing it with the output of a calibrated oscillator or signal generator.

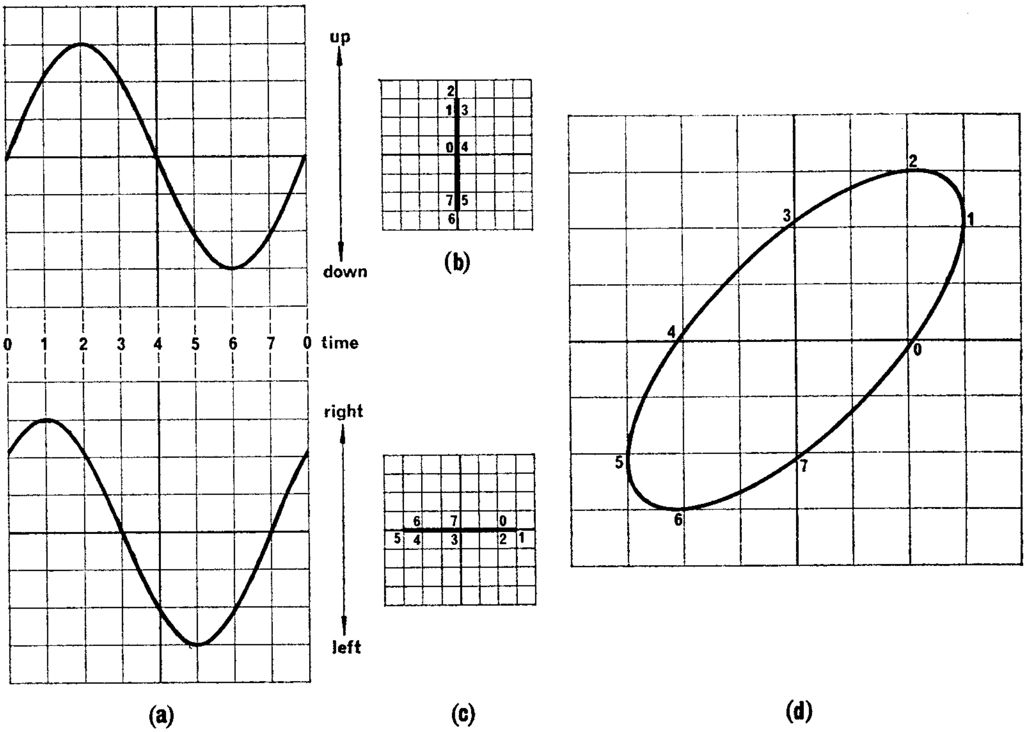


Fig. 7. Formation of a Lissajous figure

22. **Phase comparison.** The method of comparing two waveforms with a phase difference of 45° is illustrated in figure 7. The two waveforms should be displayed normally on Y1 and Y2 to obtain the approximate phase relationship, and to determine which of the waveforms is leading. Disconnect the oscilloscope inputs, and switch off the timebase by turning the time/cm multiplier switch to the EXT position. Adjust the X shift and the Y1 shift controls until the spot on the tube face lies over the centre of the graticule. Apply the input to Y1 and adjust the volts/cm and Y1 gain controls until the trace line on the screen is 3cm either side of the graticule centre line (Fig 7b). Disconnect this input, and apply the other waveform to the Xin/TBout socket. Adjust the X gain control until the trace is 6cm long (Fig 7c). Reconnect the first input to Y1 and the waveform shown at figure 7d will be obtained. This method is most useful at low frequencies as most oscilloscope timebases lose their accuracy at low speeds (e.g. CT436 drops to 15% below 20cm/sec.). The patterns obtained from waveforms with common phase differences are shown in figure 8 and these provide a quick method of checking that the phase relationship is correct; e.g. the inputs to a two-phase induction motor have a 90° phase difference and will produce a circle when applied to the X and Y plates of a scope. The actual phase angle can be measured as shown in figure 8, where θ is the phase angle between the two signals.

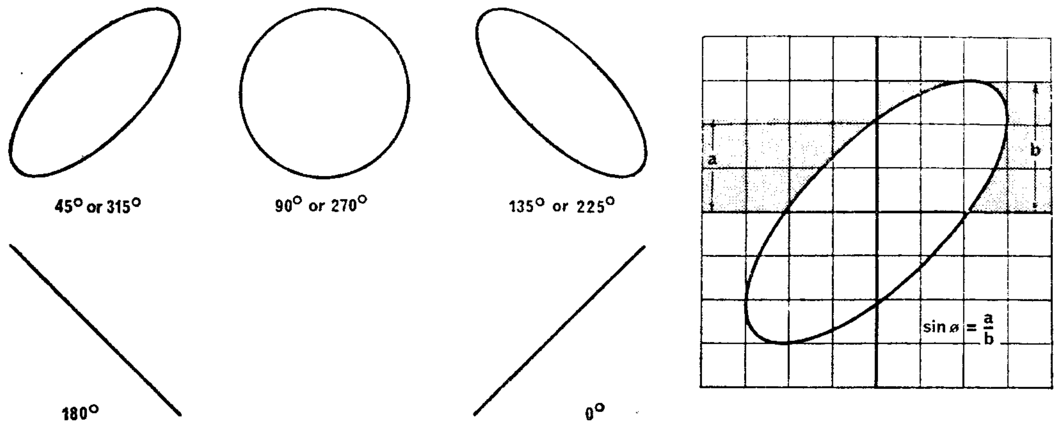


Fig. 8. Phase comparison

23. **Frequency measurement.** Two waveforms of different frequencies can also be compared by their Lissajous patterns. The oscilloscope controls must be adjusted separately for each signal as in para. 22 and figures 7b and 7c. This preliminary adjustment for equal amplitude of deflection is most important as the pattern would otherwise appear distorted. The shapes obtained for common frequency relationships are shown in figure 9; the method is limited to frequency ratios of about 10 : 1 because of the difficulty of counting the number of loops on the display. A very common use of the method is for the adjustment of the output frequency of a 400Hz inverter by comparison with a 800Hz tuning fork to obtain the 'figure of eight' pattern shown in figure 9. The ratio of any two frequencies can be found from the formula:

$$\frac{\text{Frequency on X input}}{\text{Frequency on Y input}} = \frac{\text{Number of loops on side of pattern}}{\text{Number of loops on top of pattern}}$$

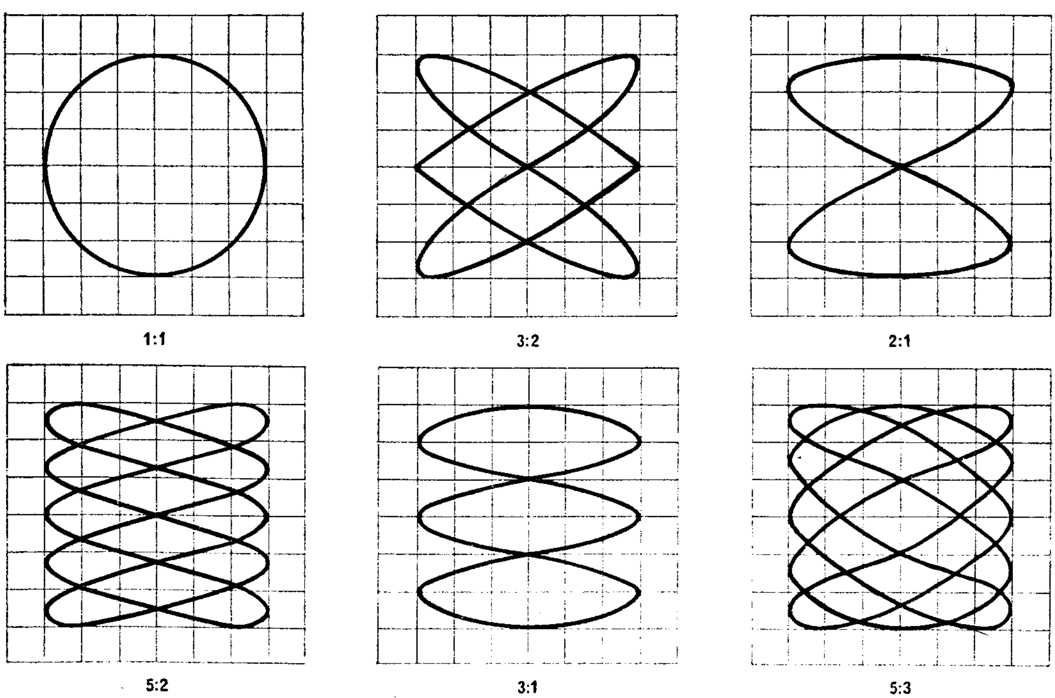


Fig. 9. Frequency comparison X : Y

Amplitude Modulation

24. **Percentage modulation measurement.** The percentage modulation of an amplitude modulated transmitter can be conveniently measured on an oscilloscope if a built-in monitoring system is not provided. The unmodulated carrier wave is applied to the Y input of the oscilloscope with the timebase turned off. The trace produced is then adjusted with the volts/cm and Y gain controls until it is a convenient height (e.g. 4cm on the graticule). The modulator is then switched on and its output fed to the X input socket of the scope. This produces a display pattern of the type shown in figure 10. One hundred percent modulation will produce a triangular pattern and any extra modulation will cause a tail to form on the pattern.

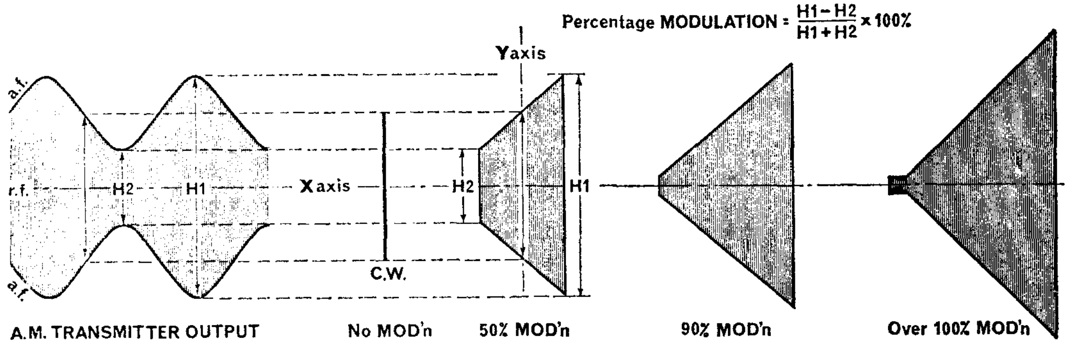


Fig. 10. Amplitude modulation

Accurate Measurements by External Calibration

25. **Use of built-in calibration oscillator on CT436.** A socket on the front panel provides a 1kHz square wave of 0·5V peak to peak with an accuracy of $\pm$ 1%. This can be applied to the Y input with the volts/cm control in the 100mV/cm position and the Y gain control adjusted until the waveform is 5cm high on the screen. This control position is then the CAL position and it must not be altered during measurements. By this method, small voltages can be measured with an accuracy of about 2%. In a similar manner the X gain and fine velocity controls can be adjusted to calibrate the timebase against the square wave. Time measurements of the order of milliseconds can then be measured with an accuracy of about 2%.

26. **Use of an external time standard.** A crystal controlled calibrator unit is available which produces pips at 100kHz and at 1MHz (i.e. 10 μS and 1 μS apart). This unit is used to calibrate the oscilloscope timebase when accurate time measurements are required for alignment of radar systems. Before carrying out these measurements an adequate time must be allowed for the system, the oscilloscope and the calibrator unit to warm up and attain stability; this usually takes about half an hour. The output from the calibrator is then applied to the Y input of the scope and the timebase controls adjusted until the pips are an exact number of centimetres apart. Once this adjustment has been carried out, the timebase controls must not be moved until the alignment procedure is completed. On completion of the alignment it is good practice to check that the oscilloscope calibration is still correct. If it is not the measurements are meaningless and the whole procedure must be repeated. The use of an oscilloscope to measure time or voltage by external calibration against a crystal, or other standard for the type of measurement, results in a much greater accuracy than could otherwise be achieved with a general purpose oscilloscope. An oscilloscope used in this way is sometimes called a 'transfer standard'.

27. **Z modulation by an external time standard.** For some adjustments, such as pulse width, the external standard is triggered by the leading edge of the pulse from the equipment. The pips produced by the calibrator are then applied between the grid and cathode of the cathode ray tube (Z mod) so as to cause the display to have bright spots at the selected time intervals. The pulse width can then be adjusted until the lagging edge lies on the bright spot associated with the correct pulse width.

28. **Use of an external voltage standard.** Standard voltage sources are not normally available except at special calibration centres, so a high accuracy meter is used to calibrate the vertical amplifiers of a general purpose oscilloscope. Use the oscilloscope on d.c. coupled, earth the input terminal, and adjust the Y shift control to 'zero' the trace. Connect an adjustable d.c. voltage source and the accurate meter in parallel to the Y input. Adjust the voltage source to a convenient value on the meter (*eg* 10 or 100 volts). Adjust the volts/cm and Y gain controls until the oscilloscope trace lies exactly on one of the graticule lines which then represents the voltage applied. Note the deflection from zero and calculate the volts/cm of the scope; do not move the controls. Disconnect the voltage source and the meter and apply the waveform to be measured to the Y input. Read off the peak to peak value against the graticule. The accuracy obtained by this method should be about 2% when using a 1% meter. Recheck the calibration of the oscilloscope to confirm the measurements. This method enables a.c. and pulse measurements to be made against an accurate d.c. meter by using the oscilloscope as a transfer instrument.

Signal Leads and Accessories

29. The oscilloscope type CT436 set is supplied with three 3-ft coaxial leads, fitted with crocodile clips at one end and a BNC plug at the other. These leads should be used as the input leads whenever possible as the coax minimises the chance of stray voltage pick-up from nearby radio frequency fields and from the domestic mains. When in use, the earth clip should be connected as near as possible to the signal pick-up clip so as to prevent the formation of an earth loop. Care must be taken by the operator to avoid electric shock when connecting or disconnecting the leads. Connect the earth clip first, *let go of it,* then connect the signal clip. When disconnecting, remove the signal clip *first* and then the earth clip. Four thin wire leads are also supplied, terminated with free plugs for making input connections directly to the cathode ray tube panel on top of the instrument. If longer leads are required for a particular task, they can be connected to the normal input sockets using the terminal adaptors supplied (BNC to screw terminal).

30. **Passive probe** (6625-99-945-0506). This probe is available for use with the CT436 but has to be demanded separately as an accessory. It is of the voltage divider type of probe for use in high frequency or high impedance circuits. A high value resistance is connected in series with the input at the point of the probe. This increases the oscilloscope input resistance to about 10MΩ and isolates the capacitance of the input lead from the circuit being tested. The effective input capacitance when using the probe is about 10pF. The signal actually applied to the oscilloscope is attenuated by this probe by 20dB, which means that any readings taken through the probe must be multiplied by 10 to obtain the actual voltage value present at the probe tip. When accurate measurements are required they should be made without the probe, if possible, as the 20dB attenuation factor is only approximate and introduces a possible additional error.

Oscilloscope Type CT531 (6625-99-199-2562)

31. The oscilloscope type CT531 is a typical example of a slightly more complex modern oscilloscope, such as would be used by electronic tradesmen for aligning radars or navigational equipments. It is fully transistorized except for the cathode ray tube which has an 8cm by 10cm rectangular face with an illuminated graticule. The controls on the front panel are grouped for operator convenience and are labelled in the usual way so that any tradesman who is proficient at operating the CT436 should have very little difficulty in learning to use them. In addition to the general-purpose uses already discussed for the CT436, a number of extra facilities are available and these are summarized in the following paragraphs.

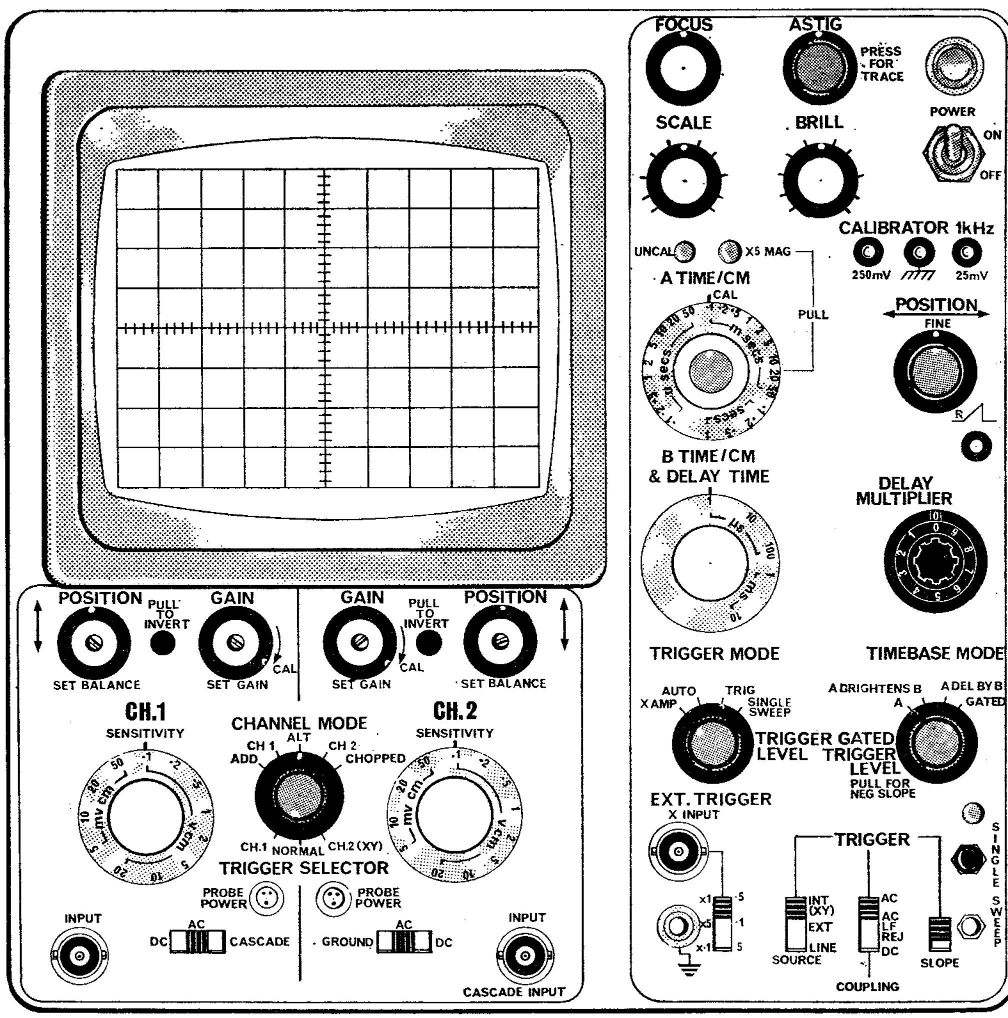


Fig. 12 Oscilloscope CT 531

32. **Beam finder.** This device is a red button labelled 'Press for Trace' and is fitted on top of the astigmatism control. Operating the button partially overrides the brilliance control and both the vertical and horizontal shift controls. This produces a bright trace on the face of the tube which can be centred using the shift controls. On releasing the button a normal trace should appear at the centre of the screen. If it does not do so, the brilliance control may have to be turned up.

Vertical Amplifiers

33. There are two identical vertical amplifiers for the channel one and channel two inputs. They have a maximum sensitivity of 5mV/cm and a bandwidth of 35MHz, thus enabling small waveforms at fairly high frequencies to be displayed. Switched sensitivity controls, using a 1—2—5 sequence, enable signals of any amplitude from 5mV/cm to 20V/cm to be displayed at a convenient size. A variable gain control on each channel covers between these steps for external calibration and also allows signals up to 50V/cm to be displayed. These variable controls are normally left in the CAL position (fully clockwise) so that the sensitivities marked on the switched controls are correct.

34. **Cascade.** The cascade position of the channel one coupling selector switch internally connects channels one and two in cascade to provide an increased input sensitivity of 1mV/cm by using channel two as a pre-amplifier. The input signal must be applied to the channel two (pre-amplifier) input when cascade is selected. The channel mode and trigger selector switches should be in the channel one position (main amplifier) and the trace can be shifted by using the channel one shift control.

35. **Polarity switch.** Both the channel one and the channel two amplifiers have a 'pull to invert' switch which enables any waveform to be displayed negative-up if required. This facility is very useful when working on pulse circuits containing p n p transistors as it allows the waveforms to be displayed in an easily recognisable form.

36. **Display selector switch.** The cathode ray tube used in the CT531 has a single electron gun and deflection system. To obtain a double trace display, the two inputs are switched into the crt system by a five position selector switch labelled 'channel mode'.

a. ADD position (single trace). A single trace display is obtained by addition of the two separate signal inputs on channels one and two. This display method provides a convenient method of adjusting the outputs of a paraphase amplifier system. When the two outputs are equal the display obtained will be a straight line ($CH_1 + CH_2 = 0$). Either channel one or channel two may be inverted by its pull to invert switch to display either $CH_1 - CH_2$ or $CH_2 - CH_1$. This mode allows the oscilloscope to be used as a null detector on an a.c. bridge. Both inputs present a high impedance (1MΩ) to the bridge circuit and this eliminates any loading problems. As the maximum sensitivity is 5mV/cm this method will give reasonable accuracy for most fault-finding or general measurement purposes.

b. CH1 position (single trace). A single trace display is obtained showing the input to the channel one amplifier. Timebase triggering can also be derived from this signal by selecting CH1 on the concentric trigger selector control. Channel sensitivity can be checked by displaying the calibrator output signal, a 1kHz square wave either 25mV or 250mV peak to peak. This signal has an accuracy of 1% and may be used to adjust the set gain preset so that the calibrations of the sensitivity control are correct. If accurate measurements are to be made, the preset gain controls should be adjusted using a digital voltmeter as the standard. Normal accuracy of the volts/cm switch is $\pm 3\%$. The CH2 position of the channel mode switch gives a single trace display of the identical channel two amplifier and can be used to cross check measurements.

c. ALT position (dual trace). A double trace display is obtained by displaying the channel one and channel two signals on *alternate sweeps of the timebase*. It is the recommended method of using the oscilloscope for frequencies above 10kHz. This method cannot be used at very slow timebase velocities because of the tendency of one trace to fade out while the other is being painted. Another disadvantage of the alternate sweep method of obtaining a double trace is the time 'delay' between the signal on trace one and that on trace two. This time delay is a multiple of the periodic time of the triggering signal which starts each sweep (see figure 13), and is of little practical importance as most signals being examined are repetitive in nature.

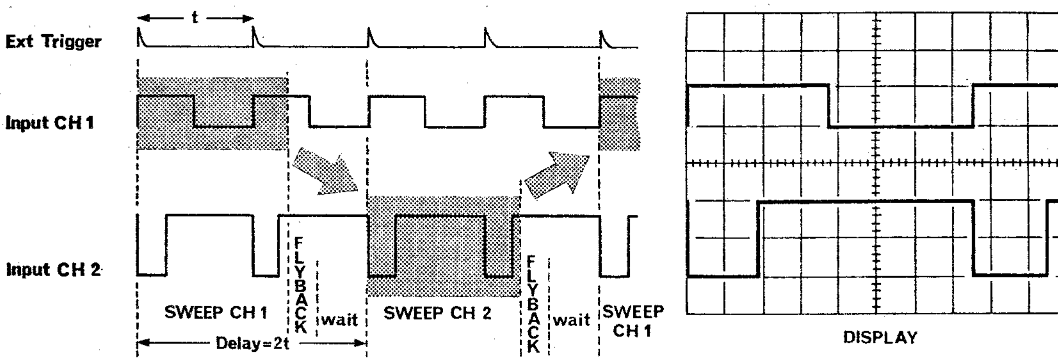


Fig. 13 Dual trace—Alternate sweep method

d. CHOP position (dual trace). A double trace display is obtained by switching the input to the cathode ray tube rapidly from the channel one amplifier to channel two and back with an electronic switching circuit operating at 500kHz (see figure 14). It is the recommended method of using the oscilloscope for frequencies below 10kHz. The CHOP method of switching means that there will be small 'gaps' (1μS wide) in the trace on *each* sweep, but as the chopper oscillator is not synchronized to the timebase trigger these gaps will only result in a variation of brilliance on the display. The presence of gaps only becomes serious when trying to examine narrow (μS) pulses at low p.r.f.s. (less than about 10 per second.) For this, a single trace display should be used to examine each signal separately and the chop position can then be used to examine the relative timing of the two signals. The main advantage of the chop method is that two signals can be examined at the *same time* i.e. without the trace time delay caused by the ALT method. This enables 'once-only' events to be examined using the single sweep timebase facility (see para 47).

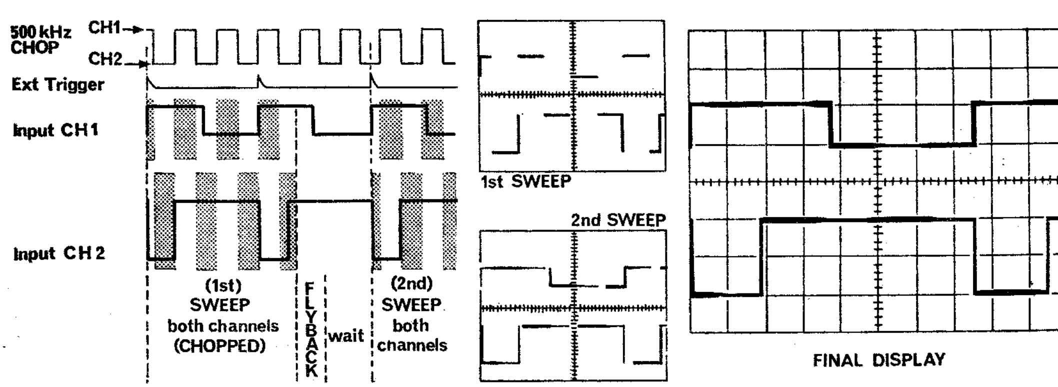


Fig. 14 Dual trace—Chopper switched method

37. **Trigger selector.** There is a three position trigger selector switch mounted concentric with the channel mode switch. This switch controls the timebase triggering when the timebase trigger source switch is set to INT (XY). In the channel one, CH_1, position the trigger for both traces is derived from the channel one signal. In the NORMAL position the channel one trace is triggered from the channel one signal and the channel two trace from the channel two signal. In the channel two, CH_2, position the trigger for both traces is derived from the channel two signal.

38. **XY operation.** This instrument has a very versatile XY display facility which can be used for phase or frequency comparison by the Lissajous' figures method (see paras 21-23). Because of the high input sensitivity of the channel one and channel two amplifiers it can also be used to plot characteristic curves, such as $V_{\hat{c}}$ against $V_{\hat{b}}$ for a transistor amplifier. There are two methods of obtaining an XY display:

a. Using the X input socket. The Y signal is applied to either the channel one or channel two input in the normal way. The X signal is applied to the X input socket with the adjacent sensitivity switch controlling the gain. The trigger source must be switched to EXT and the trigger mode switch to X amp.

b. Using channel two as a pre-amplifier. The Y input is applied to channel one and the X input to channel two with the trigger selector switch on CH_2 (XY). The trigger mode switch must be on X amp and the trigger source switch on INT (XY). The X gain is now controlled by the channel two amplifier to give calibrated horizontal deflections from 5mV/cm to 20V/cm. The maximum input frequency using this mode is 3MHz.

Timebase Triggering

39. **Trigger mode switch.** On the AUTO position of the trigger mode switch, the timebase will free run to give a horizontal line display until a vertical signal greater than 1 cm appears on the display. The timebase will then trigger automatically from this signal. In the TRIG position the timebase does not operate until a suitable trigger signal is applied and therefore the screen will be blank in the absence of such a signal.

40. **Trigger source.** This is a three position switch used to select the signal source from which the timebase will be triggered. When switched to line the timebase is triggered from the power supply frequency which is normally 50Hz mains; but the instrument can be used on other supply frequencies between 45 and 440Hz if required for field use. When switched to EXT the triggering signal is applied to the socket marked EXT TRIGGER/X INPUT. A signal greater than 200mV peak to peak is required for stable triggering and the level needed rises to about 1V at 35MHz. On INT(XY) the triggering signal is derived from the Y amplifier channels and is controlled by the trigger selector switch concentric with the channel mode switch.

41. **Trigger coupling.** There are three coupling methods:

a. DC. The timebase is started when the external triggering signal exceeds the d.c. level set by the trigger level control and is of the correct polarity as set on the slope (+ or −) switch.

b. AC. This is a wideband input used for almost all normal triggering signals. The point on the waveform selected for triggering is determined in the usual way by the setting of the slope and level controls.

c. AC LF REJ. The a.c. low frequency reject position allows stable triggering from a high frequency waveform when mains hum or other low frequency noise is present.

42. **Trigger level.** The trigger level control allows any point on a waveform to start the timebase. It is variable over the full screen height when internal signals are used or over the range ±20V from an external triggering signal.

Timebase System

43. **'A' sweep mode.** When position A is selected on the Timebase Mode Switch the timebase velocity is controlled by the A time/cm control. This gives a 1:2:5 sequence of velocities from 0·1 μS/cm to 1S/cm in twenty two steps. The timebase accuracy is ±3% provided that the variable control is in the CAL position. This variable control (concentric) may be used to cover velocities between the steps (for external calibration) or to extend the slowest range to 2·5S/cm. A front panel warning light immediately above the control indicates that an uncalibrated sweep rate is selected. By pulling out the variable control knob a ×5 multiplier is brought into operation and can be used to extend the fastest sweep rate to 20nS/cm. As all other sweep rates are also multiplied by 5 there is a warning light to show that the ×5 multiplier is in operation.

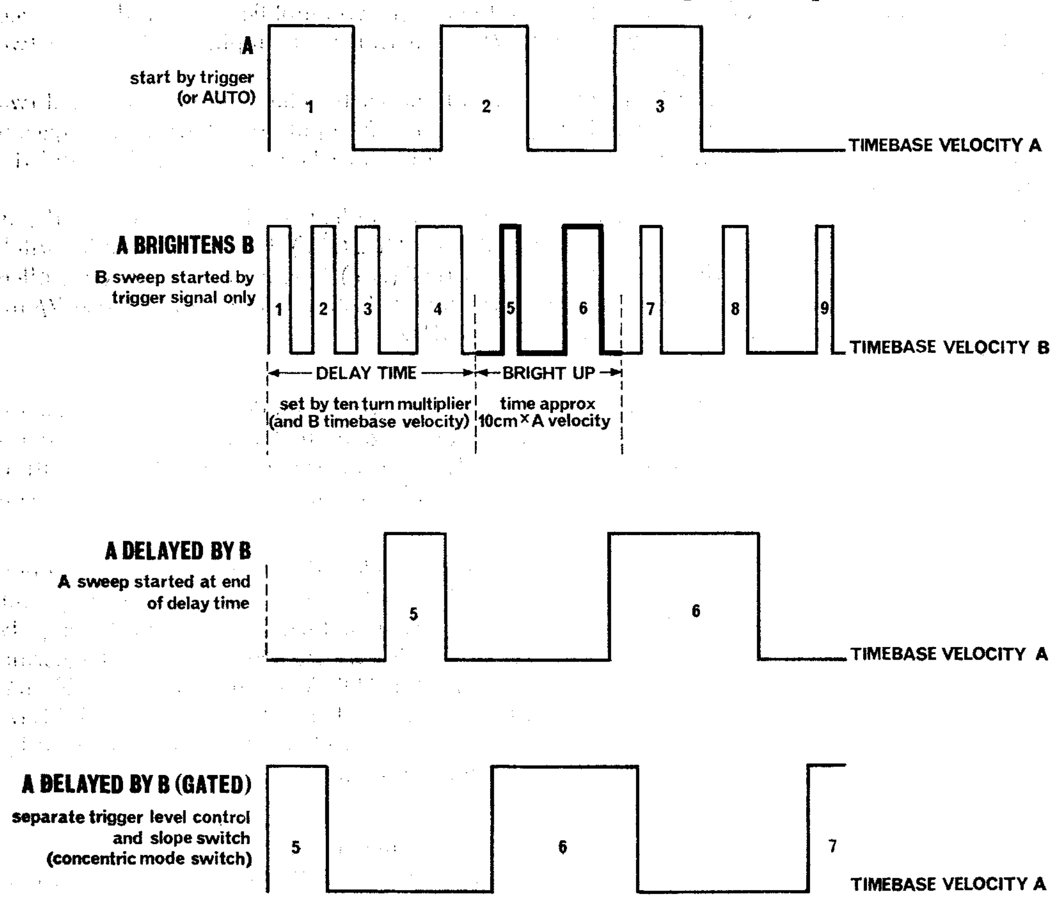


Fig. 15 Timebase modes

44. **'A' brightens 'B' mode.** In this mode the timebase velocity is controlled by the B time/cm control which gives a decade sequence of velocities from 1μS/cm to 10mS/cm in five steps with an accuracy of ±3%. The sweep is started by a trigger signal, the Auto position being inoperative. The trigger source, coupling and slope controls are set to trigger the B timebase. Part of the trace will be displayed 'brightened' (see figure 15). The width of this bright-up is controlled by the A timebase velocity and its position along the trace by the delay multiplier control. When these controls have been adjusted so that the required part of the waveform has been brightened up the timebase mode switch can be turned to the A delayed by B position (A DEL BY B).

45. **'A' delayed by 'B' mode.** The part of the trace selected above is now displayed across the full width of the screen with the timebase running at the A time/cm velocity. The trace is started at the end of a *known delay time* which was set by the B time/cm switch and the delay multiplier control. This facility is very useful for examining selected parts of pulse trains for position or width as well as its general purpose use as a timebase delay. The delayed timebase is often used when setting up radar equipments *eg* to adjust a pulse width to 62μS; a 60μS delay is used and the final part of the pulse adjusted to be 2μS wide using an A timebase velocity of 1μS/cm to obtain good accuracy.

46. **'A' delayed by 'B' (gated).** If the signal being examined on a delayed timebase has excessive 'jitter', the trace can be stabilized using the A delayed by B (gated) mode. The timebase sweep now starts at the first input signal which occurs *after the end of the selected delay time period. Separate trigger* level control and slope switches are provided concentric with the timebase mode switch. (These are needed as the normal triggering controls are being used to start the B timebase to control the time delay period.)

47. **Single sweep operation.** Operation of the single sweep push button when the trigger mode switch is set to single sweep will produce only one sweep of the trace provided the triggering level is correctly set. If the button is operated when no triggering signal is present, the A timebase is primed and a neon indicating lamp above the button will glow. As soon as a signal is applied, one sweep of the A timebase will take place and the neon will go out. This function is mainly used for recording with a high speed camera attached to the tube face to take a photograph of the single sweep.

Inputs Direct to the Cathode Ray Tube

48. **Z modulation.** An access panel on the top of the instrument allows signals to be applied direct to the cathode ray tube. The Z switch must be moved from INT to EXT and the signal is then applied to the adjacent input sockets. The sockets are a.c. coupled and a signal of about 10V is required to modulate the trace.

49. **X or Y plates.** Similar switches and sockets give access to the X and Y plates. When using the Y sockets for direct access, input signals *must not be applied* to either the channel one or channel two amplifiers.

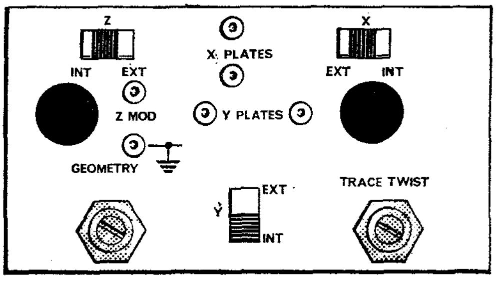


Fig. 16 Direct input panel

Conclusions

50. **Other oscilloscopes.** All modern oscilloscopes have controls similar to those discussed in this chapter. Great care must be taken when using an unfamiliar instrument to ensure that any continuously variable controls are in the correct calibrated position. The handbook is provided to explain how to get the *best results* from an instrument and should be read at frequent intervals until its contents are fully understood and memorized.

51. **Accurate measurements.** Although measurements made with an oscilloscope are accurate enough for many applications, more accurate measurements are sometimes needed *eg* for calibration. Precision measurement is outside the scope of this book but the most accurate voltage measurements are made using a digital voltmeter with a built-in standard cell. The most accurate frequency measurements are made using a frequency counter of the digital type as discussed in the next chapter.

CHAPTER 4

THE ELECTRONIC FREQUENCY COUNTER/TIMER

List of Contents

Introduction

1. The general purpose electronic frequency counter is capable of measuring frequency to an accuracy of 1 part in a million, i.e., to 1Hz in 1MHz or better. It will make these precise measurements in a matter of seconds, without ambiguity and with a virtually foolproof readout system which eliminates operator errors. The control settings and the connections made to the counter are extremely simple, thus allowing precision measurements to be made by relatively unskilled personnel. Most general purpose counters will measure frequencies up to about 10MHz directly and can be used with external converter units to measure much higher frequencies. These converters employ heterodyne techniques, which is a method often used in frequency measurements. A counter may also be used to measure time intervals (or waveform periods) down to about one-fifth of a microsecond. The accuracy obtained will tend to be lower as a timer than as a frequency counter, but as this depends on the measurement being made it will be considered later in this chapter.

2. **Frequency measurement.** To measure frequency, the instrument counts the number of cycles which pass through a gate in a given period of time, usually 1 second. This number is displayed on a digital readout with automatic positioning of the decimal point as different gate periods are selected. The accuracy of the gated time period determines the final accuracy of measurement so a highly accurate 'clock' is required. The usual method of obtaining high accuracy is to use a high quality crystal oscillator in a controlled temperature environment. These oscillators have a stability of one part in ten million over very long times (weeks or months).

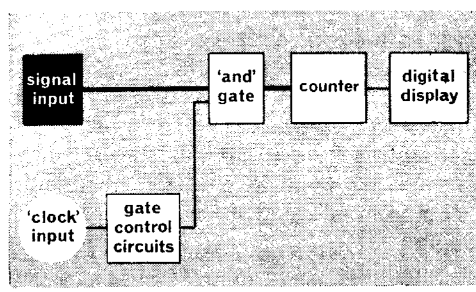


Fig. 1. Use as a frequency counter

3. **Time measurement.** To measure time, the inputs used for frequency measurement are connected as shown in figure 2. The instrument then counts the number of clock pulses which pass through the gate in a time period controlled by the input signal, usually one complete cycle. The clock is normally arranged so that pulses are generated at intervals of one-tenth of a microsecond minimum. A selector switch enables other clock pulse rates to be used, usually in decade steps from the master oscillator frequency. As all these rates are produced by division from the master oscillator their accuracy is the same.

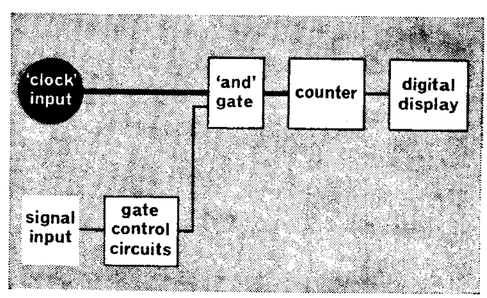


Fig. 2. Use as a timer

PRINCIPLES OF OPERATION

4. In order to appreciate the versatility of a counter/timer it is necessary to understand the basic principles of its operation. Some measurements are best made by using the instrument as a counter, some as a timer; others are borderline cases where one method is quicker but the other method is more accurate. The following paragraphs consider in very simple form the action of a typical instrument and point out some of the extra facilities available on the complex models which are often used at third line units.

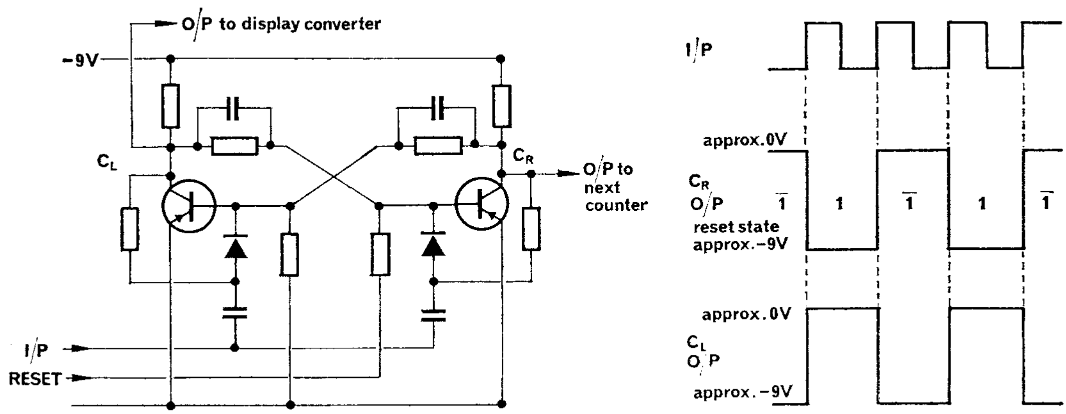
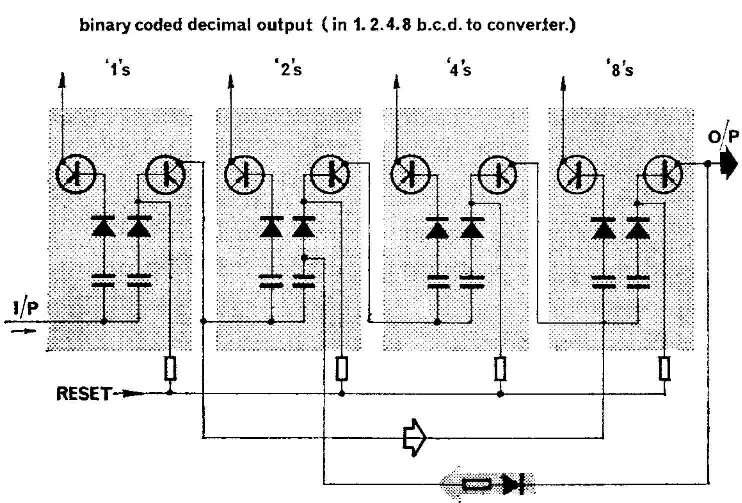


Fig. 3. Eccles-Jordan bistable as a binary counter

The Counter Unit

5. **Bistable as a binary counter.** The basic circuit action of an Eccles-Jordan bistable circuit was dealt with in AP 3302 (Pt. 3, p127). Inclusion of the two diodes in the base input leads means that the circuit will only change states on a positive going edge of the trigger input, i.e., once per cycle (see figure 3). Thus for two cycles of input the bistable will change states twice, i.e., from $\bar{1}$ to 1 and then from 1 to $\bar{1}$, producing one cycle of output. This means that the circuit is dividing or counting by two and it is therefore called a binary counter. Before the count begins all bistables are 'reset' by momentarily open circuiting the reset line (normally earthed). This causes a negative voltage at the base of the right hand transistor causing it to conduct and its collector



'1's	'2's	'4's	'8's	No.
$\bar{1}$	$\bar{2}$	$\bar{4}$	$\bar{8}$	0
1	$\bar{2}$	$\bar{4}$	$\bar{8}$	1
$\bar{1}$	2	$\bar{4}$	$\bar{8}$	2
1	2	$\bar{4}$	$\bar{8}$	3
$\bar{1}$	$\bar{2}$	4	$\bar{8}$	4
1	$\bar{2}$	4	$\bar{8}$	5
$\bar{1}$	2	4	$\bar{8}$	6
1	2	4	$\bar{8}$	7
$\bar{1}$	$\bar{2}$	$\bar{4}$	8	8
1	$\bar{2}$	$\bar{4}$	8	9
$\bar{2}$ can't change when 8 present			on 10th I/P pulse	
$\bar{1}$	$\bar{2}$	$\bar{4}$	$\bar{8}$	0

Fig. 4. Decade counter unit

to be at approximately zero volts. This is known as the NOT 1 condition and is normally written as $\bar{1}$. A positive edge is produced at the output every time the bistable changes over from 1 to $\bar{1}$ and this is used to trigger the next bistable in the counter line.

6. **The decade counter.** The purpose of a decade counting unit is to divide the input by a factor of ten, i.e., to give *one* cycle output for *every ten* cycles input. To obtain a decade counter four binaries are connected in cascade so that the output of each binary acts as the input to the next one (see figure 4). This system would count by sixteen ($2 \times 2 \times 2 \times 2$) in its normal form and two feedback loops are required to make it count by ten.

a. A d.c. bias is fed back from the 8 counter to prevent the 2 counter changing states when 8 is present. This feedback has no effect when the eights counter is in the $\bar{8}$ state as the collector of the right hand transistor is at approx. earth. When 8 is present this collector is at a negative voltage which is fed to reverse bias the input diode of the two's counter and will keep it in the $\bar{2}$ state (see table in figure 4).

b. The output of the ones counter is also fed as an input to the eights counter. This input will have no effect when the counter is in the $\bar{8}$ state as the left hand transistor is already cut off. When the eights counter is in the 8 state this input will change it back to $\bar{8}$. This will occur on the tenth input cycle to the complete decade counter, and will restore it to the zero or reset condition (see table in figure 4).

Two outputs are taken from each decade counting unit; an output from the eights counter is used as the input to the next decade counting unit in the chain, and a four-lead output from the binaries in the counter is used to provide a 1.2.4.8. binary coded decimal number to operate the display converters.

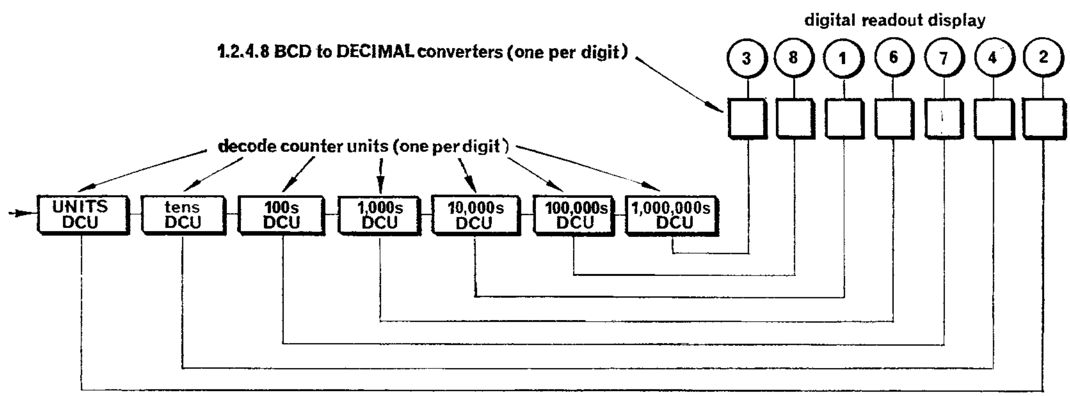


Fig. 5. Complete counter chain and display unit

7. **The complete counter and display unit.** A block diagram of the complete chain of decade counter units and the display system is shown in figure 5. There is one decade counting unit for each digit of the display and each counter is driven by the output from the previous counter so as to divide the input successively by stages of ten. The output from the counters is in 1.2.4.8. binary coded decimal and this is often fed to a multi-way output socket to act as the drive for a remote display or printing unit. To drive the instrument internal display digits a 1.2.4.8. b.c.d. to decimal converter must be used between each counter and its associated display digit. There are many different methods of conversion and display in use in commercial counters and a description of their operation is beyond the scope of this book.

8. **Counting.** As the counters are basically bistable circuits, the input used does not have to be periodical or symmetrical. The counter will in fact count pulses applied *at random* to the input provided that they do not occur at intervals too short for the counter circuits to change stable

states between them. Most good quality instruments will accept pulses up to about 10MHz, i.e., one-tenth of a microsecond separation. A counter is also unable to see a pulse pair as a pair if the two pulses in the pair are not separated by more than this time. To operate the counter a steep leading edge is required on the input pulse, and as the most common measurements are made on sine waves pulse shaping circuits are needed between the instrument input terminal and the counter input.

The Clock Unit

9. **The master oscillator.** The master oscillator is the time reference against which all measurements are made and therefore controls the accuracy limits of the whole instrument. The type of circuit used to obtain the master frequency depends on the purpose of the whole instrument and on its cost. The order of accuracy obtainable from the more common references is as shown in the table below. General purpose counters of the types used in the service use a high stability crystal controlled oscillator, usually of the Butler type (AP 3302 Pt 2). The crystal is kept in a thermostatically controlled oven and the oscillator power supplies are stabilised to prevent loss of accuracy with variations of temperature or supply voltage. Under these conditions a very high quality instrument would have a stability of about one part in 1000 million per day. Orders of accuracy greater than this are possible using an external frequency standard.

FREQUENCY REFERENCE	ACCURACY	USE
Mains (50 Hz)	1 in 10^2 (1%)	Process timers – The 'electronic stopwatch'
LC Tuned circuits Tuning forks	1 in 10^4 1 in 10^5	AF counters – Electronic tuning aids (musical)
Quartz crystal High stability crystal (in oven)	1 in 10^6 1 in 10^9	General purpose counters (up to about 10 MHz)
Transmitted standard frequency Atomic resonance	1 in 10^{10} 1 in 10^{11}	Precision laboratory–calibration standard

10. **External standards.** The external standard normally used for high accuracy work is that of the GPO standard frequency transmissions. These are transmitted by station MSF (Rugby) on 5MHz, 10MHz and 15MHz and by the BBC (Droitwich) on 200kHz. These frequencies are derived from an atomic standard (rubidium gas cell) at Rugby and are accurate to one part in 10000 million. Most counters have an input socket, often at the rear of the instrument, which will accept one or more of these standard frequencies.

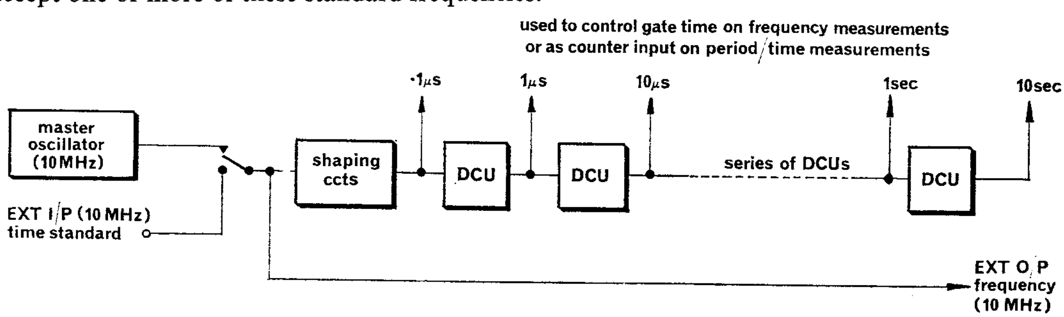


Fig. 6. Typical clock unit

11. **Typical clock unit.** The master oscillator frequency is fed through shaping circuits to a series of decade counting units acting as dividers. These produce pulse trains at decade steps from the master oscillator frequency down to a very low frequency, often one-tenth of a Hertz. These

pulse trains are used to control the instrument gate for frequency measurement or as the counter input when measuring periodic times. They are often available as an output from the instrument and may be used to operate external gates. Frequency outputs, usually at 1MHz and 10MHz are also fed to output sockets and may be used to calibrate a signal generator when measuring extremely high frequencies by heterodyne methods. When an external standard frequency is fed into the counter as the timing reference, sub-multiples of that frequency can be obtained from these output sockets for use as timing signals or synchronising pulses.

The Control Unit

12. **Counter input gate.** As the counter unit makes a total count of all pulses fed into it, the input signal must be fed through a gate. This gate only allows pulses to pass into the counting unit for a period of time determined by the gate control bistable and its input. At the end of this time period the gate is closed and the counter/display will then hold the total number of pulses counted until it is reset.

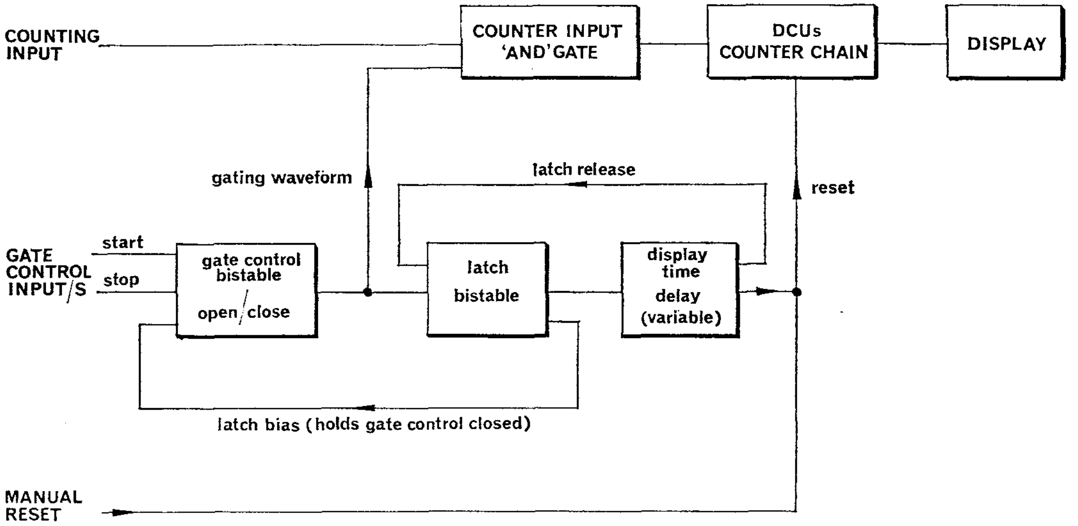


Fig. 7. The control unit

13. **Gate control bistable.** This is usually a Eccles-Jordan bistable circuit which provides the required bias to hold the signal gate closed in one state and open in the other. The input circuit arrangements to the control bistable vary considerably from counter to counter. The main requirements are shaping circuits, an adjustable trigger level control, and a trigger slope selector. Some counters have separate open and close inputs to the gate control bistable, others derive the open and close triggers from the same input. When measuring frequency the gate control bistable input is from the clock unit; one pulse to open and the next to close so that the gate remains open for one period of the time selected.

14. **Latch bistable and display delay.** The latch bistable changes states when the control gate goes to the close position. It provides a feedback bias to the gate control bistable to hold the gate closed. At the same time a pulse is fed to the display time delay circuit (normally a flip flop). This delay is adjustable on the front panel and sets the time for which the display will hold the count just completed. At the end of this time the flip flop reverts to its stable state feeding a reset pulse to return the counter chain to zero, and a trigger back to reverse the latch bistable. Reversal of the latch bistable removes the close bias from the gate control bistable. The next suitable input trigger to the gate control bistable will then open the signal gate and allow the count sequence to restart.

15. **Input period divider.** To enable time period measurements to be carried out more accurately many counters have a facility which enables the clock to be counted over more than one cycle. This is usually done by passing the input into a chain of three decade dividers so that the gate may be opened for 10, 100, or 1000 cycles of the waveform to be measured.

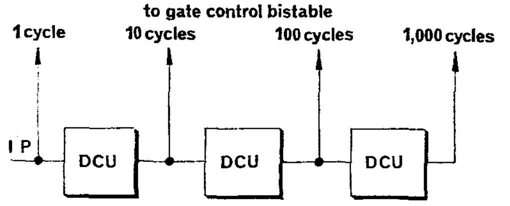


Fig. 8. Input period divider

Accuracy of Counter Measurements

16. The limit of accuracy of any given counter is determined by the stability of the internal clock, unless an external frequency standard is available. Most clocks are crystal controlled and have an accuracy considerably better than 1 part in 1 million. The small error introduced by the clock can therefore usually be ignored unless precision measurements are being made. Of far greater practical importance is the error of ± 1 count which is always present as it is a built-in feature of the counting action. This error means that the least significant digit, i.e., the right hand figure of the display, is always in doubt by plus or minus one. The significance of this accuracy limit depends on the method used to operate the counter and is illustrated in figure 9.

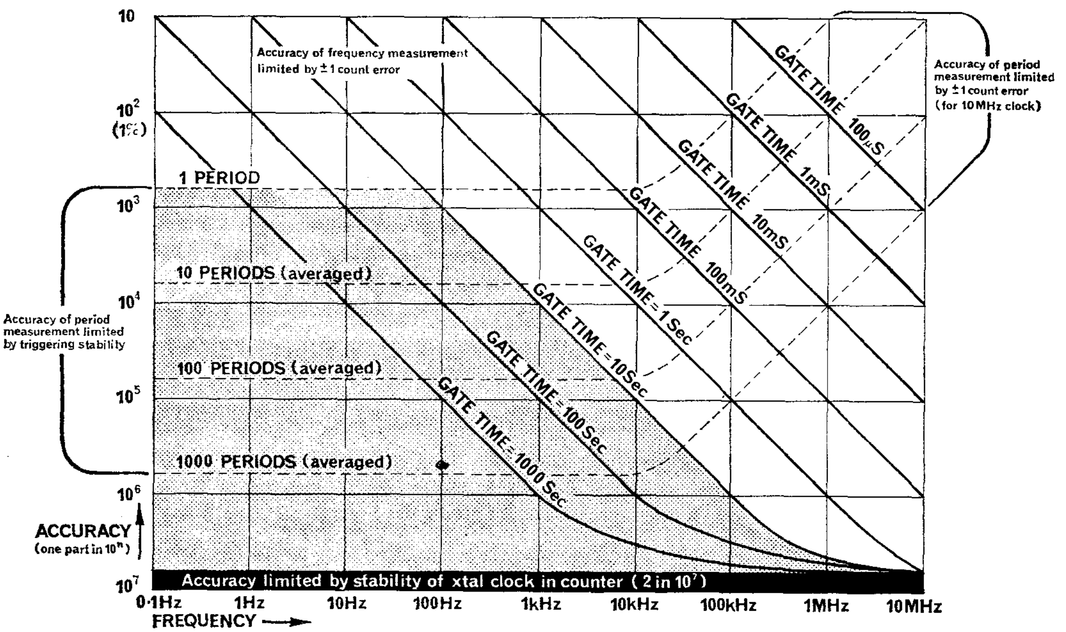


Fig. 9. Accuracy limits of counter/timers

17. **Frequency measurements.** Suppose the frequency to be measured is 1MHz and the counter being used has a seven digit display. Referring to figure 9 it can be seen that choosing a gate time of 1mS will result in a displayed count of 0001000. kHz and as the final digit is in doubt the accuracy of this reading is 1 part in a thousand (1 in 10^3). If a gate time of 1 sec is chosen for the same count, the final display will be 1000000. Hz and the accuracy is now 1 in 10^6. A gate time of 10 secs would result in a display of 000000·0 Hz as the most significant digit is now 'off-scale'. From these results it follows that the gate time chosen should be 1 sec as this gives the greatest accuracy without going off-scale. For all frequency measurements *the gate time used should be as long as possible* to reduce the error caused by the ± 1 count limit of the instrument.

Accuracy of Timer Measurements

18. **Triggering error.** As well as the two sources of error already discussed, there is an additional error due to the uncertainty of the gate operating times when making period measurements. For pulse or square wave inputs this error is small and can usually be ignored. For sine wave inputs the triggering error is of the order of 2 or 3 parts in 1 thousand. If noise is present it may be as high as 2%

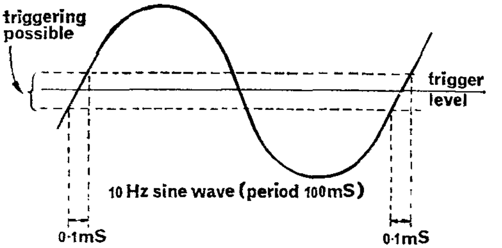


Fig. 10. Triggering error

19. **Period measurements at low frequencies.** When measuring low frequencies, the number of cycles occurring in the gate period is very small and frequency counting becomes inaccurate due to the ± 1 count error. To increase the count either an extremely long gate time must be used or the frequency must be calculated from a period time measurement. Referring to figure 9: a frequency of 10Hz can be measured to an accuracy of 1 in 10^2 by frequency measurement using a 10 sec gate; by period measurement an accuracy of 2 parts in 10^3 can be obtained over a single period and the measurement is made in a much shorter time (one-tenth of a second). The error present on the period measurement is due to the triggering instability (para 18) which has no effect on frequency count measurements. This error can be greatly reduced if the counter used provides facilities for measurement over decade multiples of the input period. If the reading was made over 10 cycles the error would fall to 2 in 10^4 and over 100 cycles to 2 in 10^5; note that these measurements could still be made in 10 secs. for a frequency of 10Hz.

20. **Choice of measurement method.** Whether a particular frequency is measured by a frequency count or by periodic time measurement depends on the characteristics of the instrument used. As an example of this, the Marconi TF1417/2 counter has a maximum internal gate time of 10 secs and will only measure over a single period (see shaded area of figure 9). This means that for frequencies below 100Hz period measurements will be more accurate than frequency counting. It is not advisable to attempt period measurements on a sine wave in the presence of noise as this could result in quite large errors.

21. **Pulse width and time delay measurements.** The most common use as a timer is for the measurement of pulse width or of time delay, usually of the order of 5 to 50 microseconds on radar equipments. For these measurements the highest clock rate available in the instrument is always used; normally this will be 10MHz i.e. pulses at intervals of one tenth of a microsec. The least significant digit counted is thus multiples of tenths of microseconds and a 5 μs pulse can only be measured to one part in 50, because of the ± 1 count error. To adjust the pulse width to 5·0 μs interpolation must be used. The counter is set up to measure pulse width using as short a display time as possible so that measurement is repeated at frequent intervals. The adjusting control is then turned until the counter just starts to read 4·9 and its position is noted; it is then turned the other way until the counter just starts to read 5·1 and this position is also noted. The adjustable control is then placed in the mid-position between these two readings as the optimum position for a 5·0 μs pulse width. Errors due to triggering instability can usually be ignored as they are small compared to the count error.

22. **Cross checks.** As with any other instrument, the first reading obtained should not be accepted as correct without carrying out some form of cross check. The simplest precaution is to allow the counter to repeat the count to see if the same result is obtained. If these readings differ by more

than the expected error for the count being made the instrument must be set-up again and the count repeated.

a. Other instruments. It is good practise to check the waveform being measured on an oscilloscope. An approximate value for the expected reading can be obtained from the graticule and the presence of noise is very easily detected. Some complex counters have an output which allows the gate trigger point to be observed on an oscilloscope while the measurement is being made.

b. Repeated count. If the readings from repeated counts agree to three significant digits and then vary, it is probable that the instrument error will not allow measurement of the fourth figure (e.g. triggering error 2 in 10^3 is present).

c. Different gate periods. All measurements should be tried at more than one gate period in case there are significant digits off-scale.

d. Period and frequency measurements. Where the frequency is such that both period and frequency measurements give similar accuracy they should both be carried out and the results compared.

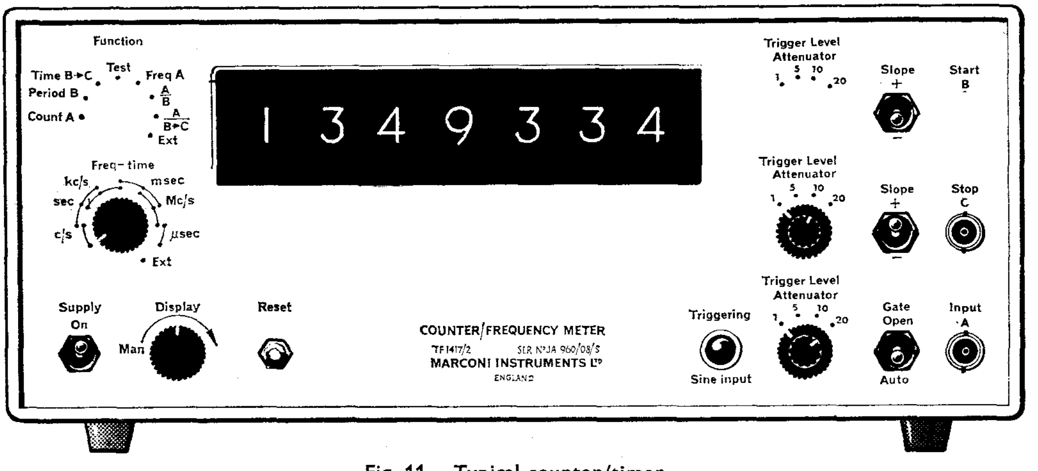


Fig. 11. Typical counter/timer

Typical Electronic Counter/Timer—Marconi TF1417/2 (10S/9331822)

23. **General.** This counter will measure frequency directly up to 10MHz but can be used in conjunction with a converter unit to measure up to 510MHz. Period measurements can also be made up to 5MHz enabling pulse widths as small as 0·2 microseconds to be measured. The internal clock is crystal controlled and has a stability of 2 parts in 10^7 provided it is allowed about an hour to warm up and stabilise. The counter can be used 2 or 3 minutes after switch-on but the stability will be only of the order of 1 or 2 parts in 10^5. Provision is made on the rear panel to allow a 100kHz or 1MHz signal from an external time standard to be used instead of the internal crystal clock. Outputs from the internal clock can also be obtained from the rear panel (0·1Hz to 1MHz) and may be used as time references for other instruments. The input signal required to drive the counter must be greater than 250mV r.m.s. and built-in attenuators enable signals up to $\pm$ 100V to be used. The optimum signal level is 1 or 2 volts after attenuation; note that if the input has a d.c. voltage superimposed a blocking capacitor must be used. The input impedance varies from 4k Ω to 80k Ω depending on the settings of the attenuators and care must be taken not to 'load' the source. The instrument presentation is a seven digit display and an output in 1.2.4.8. binary coded decimal can be obtained from a socket on the rear panel to drive remote readouts or printers.

24. **Self-test facility.** Correct functioning of the instrument is checked by carrying out a frequency count of the 10MHz signal from the internal clock. Set the controls:

main switch—'on' allow to warm up.
function switch—'test'.
gate switch—'auto'.
display control—centre of travel.

The various positions of the Freq-Time switch should then produce the displays shown in figure 12 with an accuracy of ± 1 count.

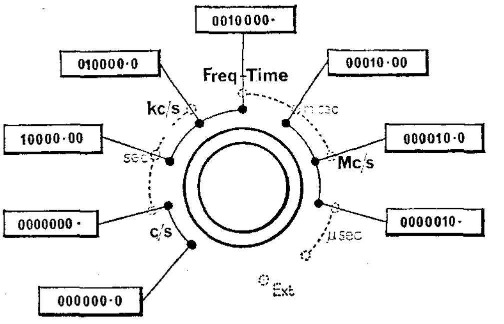


Fig. 12. Self-test readings

25. **Triggering.** A monitor lamp is provided on input A to enable the attenuator and trigger level controls to be adjusted. This lamp can be used to find the approximate control settings for a particular input signal which can then be used on any input socket if the associated controls are set to the same positions as those found for input A.

a. Sine inputs. Set the A attenuator so that the lamp lights over a small range of the trigger level control adjustment. If the setting of the level control is too critical, the input is too small; if triggering occurs over the whole range it is too large.

b. Pulse or square inputs. Set the attenuator so that triggering occurs at about the centre of the level control adjustment but ceases at both ends. Adjust the level control to the centre of the counting range.

26. **Count A.** The instrument makes a total count of the number of inputs applied to A. It can therefore be used to count the total number of random events even when they occur at high speeds e.g. the number of times a radar transponder is triggered in an hour. Set the function switch to count A, the gate switch to open, the display time to manual and the freq-time switch to one of the microsecond positions. Adjust the triggering level of the input A and then press the reset button to zero the display and start the count. To stop set the gate switch to auto.

27. **Frequency A.** The input to be measured is applied to input A and the triggering adjusted with the aid of the lamp. Set the function switch to freq A, the gate switch to auto and the display time as required. The frequency will be read in Hz, kHz, or MHz, with automatic decimal point positioning depending on the setting of the freq-time switch which controls the time period for which the gate is opened.

28. **Extended gate time.** This method can be used for frequency A counts at low frequencies. Set the gate switch to auto and the freq-time switch fully anti-clockwise (10 secs gate). Set the display control to manual and press the reset button to start the count. After 5 seconds on a stop-watch set the gate switch to open. Allow the count to continue until 5 seconds before the end of the chosen period (e.g. 95 secs) and set the gate switch back to auto. The counter will then stop at the next exact multiple of 10 secs from the original start (e.g. at 100 secs).

29. **Period B.** The instrument counts the number of clock pulses occurring during one cycle of the input applied to B to measure the periodic time of the waveform. The decimal point on the display is automatically positioned by the setting of the frequency-time control. Set the function switch to period B, the freq-time switch to the clockwise μs position (10MHz), the gate switch to auto and the display control anywhere but manual. Set the B level control fully clockwise and apply the input to B. If the readout does not read zero, obtain zero by quickly turning the B level

control fully anti-clockwise and back to fully clockwise. Turn the B level control slowly anti-clockwise until counting starts and the input period will then be measured and displayed. If continuous counting occurs, change the setting of the B attenuator and repeat until consistent readings are obtained.

30. **Time B-C.** This position counts the clock for a period of time started by the B input and stopped by the C input. It can thus be used to measure the width of a pulse applied to both inputs (B slope+ and C slope−, or vice versa) or the time interval between two separate events. The B trigger level is adjusted until counting starts (as above) and then the C level is adjusted in a similar way until counting stops. The next complete count sequence will display the time B-C or the instrument will go into continuous count. If this happens, change the C attenuator setting and repeat the C level adjustment until consistent readings are obtained.

31. **Ratio A/B.** The instrument counts the number of cycles of input A which occur during the cycle of input B (the lower frequency of the two) which is used to control the gate. Set the A trigger level as for frequency A measurement and then set the B level as for period B measurement. The counter will then display the ratio required on subsequent counts.

32. **Ratio A/B-C.** This can be used to count the number of cycles of input A occurring during time B-C. An example of use is to apply 83·3kHz to input A, start B with a primary radar transmitter pulse and stop C with a range reply from the receiver. The counter will then read range directly in nautical miles. Set the A triggering controls as for freq A measurement and the B and C triggers as for time B-C.

Heterodyne Converters for High Frequency Counting

33. **The heterodyne principle.** Figure 13 shows a simple heterodyne arrangement often used for frequency measurements. The unknown frequency is mixed with a known frequency derived from a calibrated oscillator (signal generator). The difference frequency produced from the mixer is amplified and fed to a null detector, usually a telephone headset. The frequency of the calibrated oscillator is adjusted until the output to the headset is zero. At this position the difference frequency is zero i.e. the calibrated oscillator is tuned to the unknown frequency. The frequency can be read directly from the oscillator, and will have the same accuracy as the oscillator circuits i.e. about 1 part in 10000 for an LC tuned circuit.

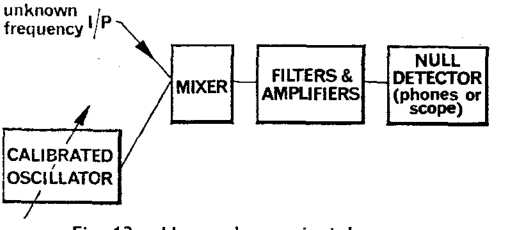


Fig. 13. Heterodyne principle

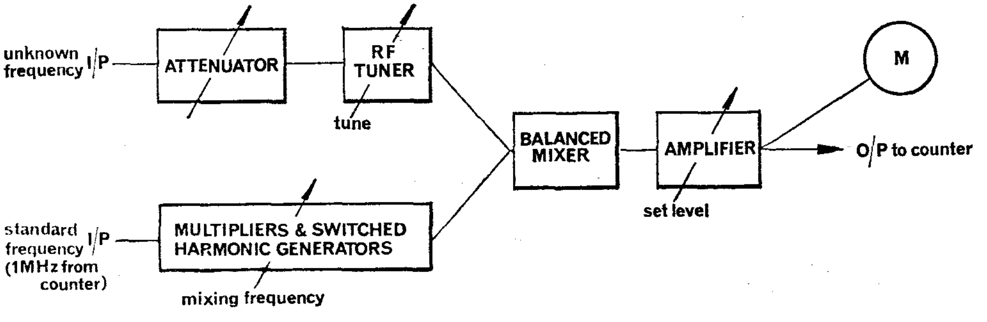


Fig. 14. Typical converter unit

34. **Typical counter converter unit.** Figure 14 shows an adaptation of the basic heterodyne circuit for use with an electronic frequency counter. The calibrated oscillator is replaced by harmonic generators which produce multiples of the standard input frequency to the same accuracy as the input standard (2 parts in 10^7 if the counter clock is used as the standard). This harmonic is mixed with the unknown input frequency to produce a difference frequency which lies within the operating band of the counter unit. After amplitude adjustment this signal is fed to the counter as described in para 27. To obtain the unknown frequency the counter reading is added to the harmonic frequency produced by the switched harmonic generators. The accuracy obtained is that of the harmonic i.e. 1 or 2 parts in 10^7 depending on the accuracy of the counter clock. More accurate readings can be obtained if an external standard frequency, such as the Droitwich transmission, is used to drive both the counter and the harmonic generators. Using this method readings to $\pm$ 1 count can be made up to about 500MHz when required for calibration purposes.

35. **Converters for TF 1417/2 counter.** Two converter units are available to extend the range of the counter up to 110MHz with the TF 2400 converter alone (6625-99-1033677) or up to 510MHz if both converters are used in cascade. Figure 15 shows the two converters mounted in the same instrument case, suitable for standing on top of the counter unit. The standard frequency input socket at the rear of the converters is connected to the 1MHz standard frequency output socket on the rear panel of the counter unit using a special low capacitance coaxial connector. The input signal level required by the converters must not exceed 2V and the output signal is adjustable to provide the optimum level to the counter. This output level is also monitored on a meter and is about 1-2V when the meter reading is in the green band. A built-in wavemeter allows the approximate input frequency to be determined and so enables the harmonic generator controls to be set up correctly (mixing frequency). The harmonic used is *below* the input frequency and the counter reading is therefore *added* to it.

36. **Use as a wavemeter to find an unknown frequency.** The right hand side converter of figure 15 can be used to determine the approximate frequency of an input between 20kHz and 110·5MHz. The input is applied to the socket marked 'input 20Hz-110·5MHz' and the 'set level' control turned fully clockwise. Set the function switch to video and see if a deflexion is obtained on the meter. If a deflexion is obtained the set level control should be adjusted until the meter reads in the green band and the frequency counted normally (it is below 10MHz). If no deflexion is obtained, set the function switch to the wavemeter position and the range switch to the 10-20MHz position. Adjust the tune dial slowly to see if any deflexion occurs; if not alter the range switch and repeat. When a deflexion is obtained, adjust the tune dial until it is a maximum and then the set level control until the reading lies in the green band on the meter. Set the mixing frequency selector switch to the band shown below the red cursor of the tune dial and operate the converter in the tuned mode (see next para).

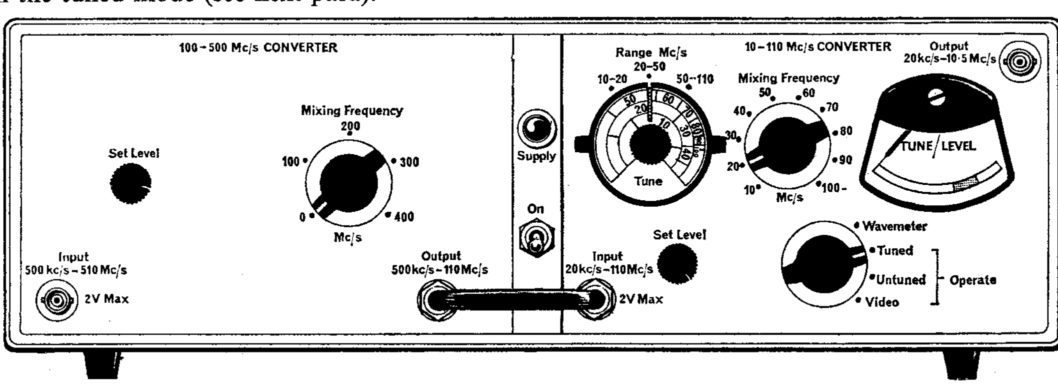


Fig. 15. Converter for Marconi TF1417 counter

37. **Operation in the tuned mode.** This mode of operation enables measurements to be made on signals in the presence of noise. The input to the converter passes through tuned circuits which reject most of the noise component. Set the function switch to the tuned position and the range switch to the correct band for the input frequency. Set the mixing frequency to the harmonic *below* the input signal and adjust the tune dial for maximum meter deflexion. Note that in this position the red cursor of the tune dial will show the harmonic selected on the mixing frequency switch. Adjust the set level control until the meter lies in the green band and operate the counter in the frequency A mode (see para 27). *Add the counter reading* to the harmonic selected on the mixing frequency switch to obtain the input frequency.

38. **Untuned mode.** The range switch and the tune dial are inoperative and the approximate value of the input frequency must be known to enable the right harmonic to be selected on the mixing frequency switch. Set the function switch to untuned and the mixing frequency switch to the harmonic below the input frequency. Adjust the set level control until the meter lies in the green band and operate the counter as above.

39 **Video mode.** The converter acts as an amplifier and shaper for signals between 20kHz and 10·5MHz which can be counted directly. Adjust the set level control until the meter lies in the green band to obtain optimum triggering of the counter.

40. **100-500MHz converter.** Signals above 100MHz are mixed with a multiple of 100MHz from a switched harmonic generator to produce a difference frequency less than 110MHz which can be measured on the counter and TF2400 converter as described above. A switch position (0) allows inputs below 110MHz to pass through without mixing.

41. **Warning.** Counters and converters cannot be used to measure pulsed radio frequences and will not make accurate measurements when the input signal is modulated. This means that transmitters must be switched to carrier wave operation before measurement is attempted. A suitable attenuator must always be used to prevent overloading the instrument.

CHAPTER 5

FREQUENCY MEASUREMENTS

List of Contents

Introduction

1. Frequency measurement is one of the most important routine tasks of radio tradesmen as the correct alignment of transmitters and receivers is essential for effective operation. There are an extremely large number of frequency measuring instruments in service use, but most of them fall into easily recognisable types and examples typical of each type are discussed in this chapter. Before using any unfamiliar instrument, the manufacturers handbook, the operating manual, or the relevant Air Publication should always be studied carefully.

2. **Direct frequency measurement.** This method is used to determine the output frequency of alternating current generators and inverters, oscillators and radio transmitters. The signal to be measured is obtained from the equipment under test and is fed to the test instrument through a suitable attenuator and/or an impedance matching device. The type of test instrument to be used depends on the frequency to be measured and on the accuracy with which the measurement must be made. There is also a requirement for cheap, comparatively low accuracy, test instruments which can be left permanently connected as performance monitors.

3. **Measurement of response frequency.** In many cases the methods and instruments used for direct frequency measurements cannot be used as there is no suitable signal present in the equipment under test. Devices such as tuned amplifiers, bandpass filters and radio receivers are all examples of equipment where a suitably calibrated signal source is required to carry out frequency checks. Such sources are called signal generators and usually also have a calibrated output level to enable sensitivity and gain measurements to be made at the same time as the frequency check. For accurate measurements, e.g. on receivers which use crystal controlled local oscillators, a counter or a crystal controlled frequency synthesiser must be used. The standard frequency transmissions of the GPO are also used when extreme accuracy of measurement is required.

4. **Frequency comparison.** Very often the easiest method of measuring an unknown frequency is to compare it with the output of a signal generator or other known source. This method is normally used for the calibration of frequency measuring equipment from the standard frequency transmissions discussed in chapter 4. As comparison also forms the basis of several methods of measurement, the most common comparison methods will be considered first in this chapter.

5. **Calibration.** In common with other test instruments, frequency measuring equipment is aligned and calibrated at the Electronic Calibration Centre (Henlow) under arrangements published from time to time in DCIs. On some instruments a variable control marked "calibrate" or "corrector" is adjusted as part of the *normal operating sequence*. Other calibration controls, mainly "presets" may only be adjusted at the calibration centre. From the user point of view, some of the calibration procedures mentioned in this chapter are for *checking* the frequency only; if the instrument is found to be in error *the complete instrument must be sent to the calibration centre* for alignment.

Frequency Comparison Techniques

6. **Oscilloscope—the stationary trace method.** The unknown signal is displayed on one input of a double beam oscilloscope and is also used to synchronise the scope timebase. A second signal (the frequency standard to be used) is applied to the second input of the oscilloscope and its frequency is adjusted until a stationary trace is obtained. The standard signal is then at the same frequency as the unknown signal and this frequency can be read from the calibrated dial of the signal generator. A stationary trace will also be obtained with any multiple of the signal generator frequency or of the unknown frequency and a visual check must be made to make sure that the two signals displayed have the same periodic time. When the two frequencies are not equal the trace will drift across the screen; to the left when the signal generator frequency is higher than the unknown frequency, or to the right when it is lower. Frequency differences as small as 1Hz are easily detected by this method but the overall accuracy of measurement is only as good as the signal generator calibration, usually about one part in 1000. The method is normally used for comparing low frequencies and its upper limit is determined by the timebase maximum velocity, usually about 10MHz on a good scope. Frequencies higher than this can be compared on an oscilloscope using Lissajous' figures as discussed in chapter 3.

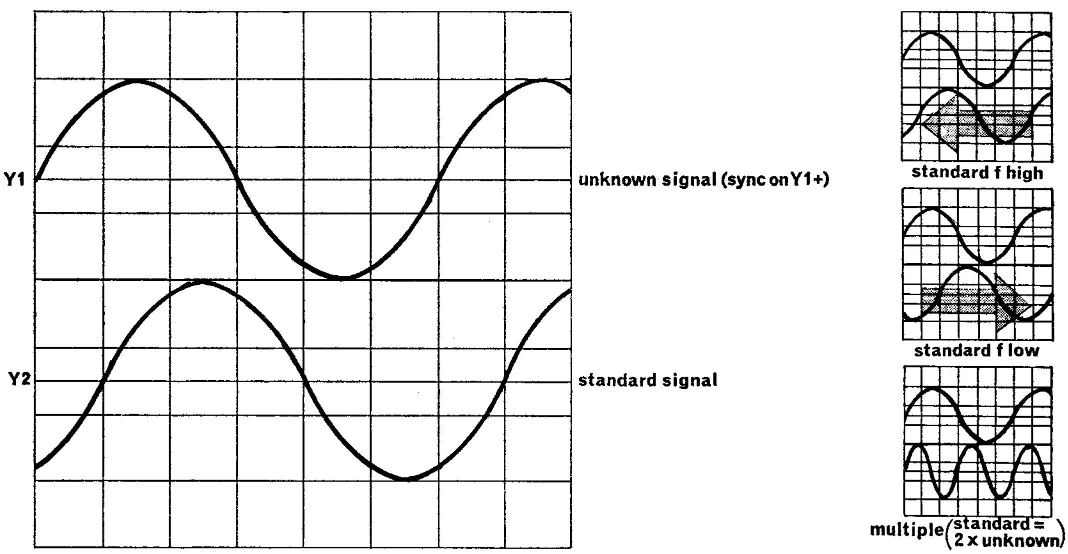


Fig. 1. Frequency comparison on an oscilloscope

7. **Earphones—heterodyne method.** Very much higher frequencies can be compared by feeding the unknown frequency and the standard frequency into a mixer and applying the audio output through an amplifier to a telephone headset. The standard frequency is adjusted until the audio note disappears (zero beat) and at this point the frequency of the signal generator is the same as that of the unknown signal. A zero beat can also be obtained from harmonics of either signal and care must be taken to ensure that it is the fundamental which is being measured. Some instruments deliberately use harmonics of the signal generator as a method of obtaining a greater range of operating frequency. As audio frequencies below about 15Hz are difficult to detect by ear the method cannot be used for low frequency comparison which is usually done on an oscilloscope. A zero beat error of 10Hz on signals above 1MHz is equivalent to an error of 1 in 10^5 and is not usually significant unless precision measurements are being made. An alternative heterodyne method using an electronic frequency counter for very accurate measurements was discussed in chapter 4.

8. **Instrument calibration checks.** Many instruments are calibrated immediately before use as part of the normal operating procedure. This is done by comparing their variable oscillator frequency with that of a built-in crystal calibrator at a series of check points formed by the harmonics of the crystal frequency. These checks are normal heterodyne comparisons and a socket for earphones is usually provided on the front panel of the instrument. A "corrector" control is then adjusted for zero beat at the check point nearest to the frequency to be measured. Where a built-in calibrator is not provided an external calibrator unit such as the CT 432 may be used to provide accurate spot frequencies.

9. **Calibrator frequency CT 432 set.** This instrument provides crystal controlled fixed frequencies up to the fiftieth harmonic of its internal 100kHz, 1MHz, and 10MHz crystals. This gives a series of check points at 100kHz intervals from 100kHz to 5MHz, another series at 1MHz intervals from 1MHz to 50MHz, and a third at 10MHz intervals from 10MHz to 500MHz. The accuracy of the output frequency is better than 1 part in 10^4 so the instrument may be used for calibrating most signal generators (1 in 10^3), absorption wavemeters (1 in 10^3) and oscilloscopes (1 in 10^2). The usual heterodyne/earphone comparison method is used to compare sinusoidal frequencies. For ease of calibration of oscilloscope timebases two pulse forming networks (short CR circuits) are provided which give a series of pips at 10μs (100kHz) or at 1μs (1MHz) intervals when connected to the calibrator output. Four sockets are provided to enable external crystals at other fundamental frequencies between 100kHz and 10MHz to be used.

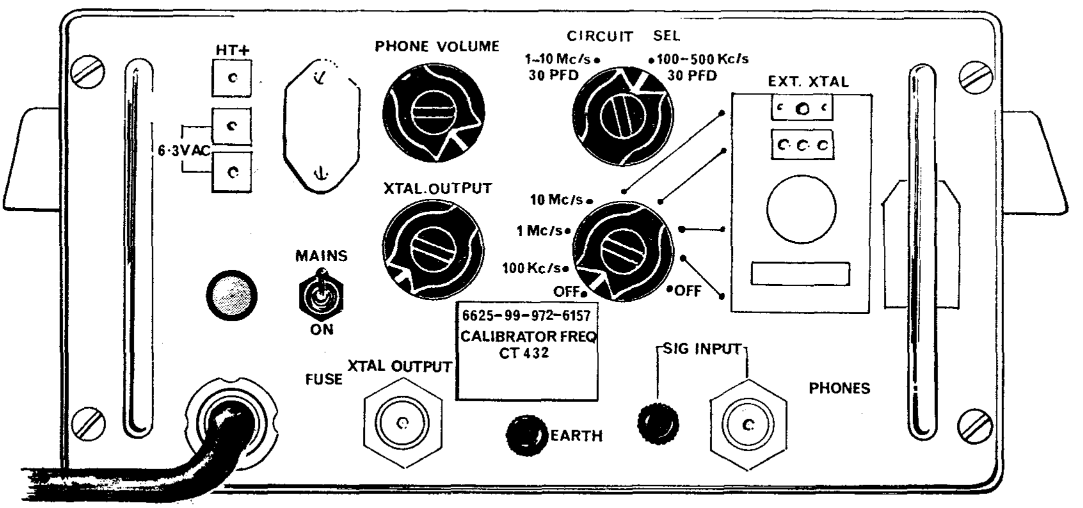


Fig. 2. Calibrator frequency CT432

10. **Typical uses of the calibrator frequency CT 432 Set**

a. Wavemeter checks. The output from the "xtal output" socket is fed into the wavemeter to be checked. The wavemeter dial is set to the check point required and the corrector control is then adjusted for zero beat. This control must be left in the zero beat position while measurements are made.

b. Signal generator checks. The output from the signal generator is fed to the "sig input" socket and a headset connected to the phones socket. The main dial of the signal generator is set to a check point and the "fine" control adjusted for zero beat.

c. Timebase checks. One of the pulse forming networks is connected to the "xtal output" socket and its output taken to the scope vertical input. The timebase variable (cal) control is then adjusted until the pips are correctly spaced on the graticule (see chapter 3).

d. External crystals. Any external crystal designed to work with a circuit capacitance of 30pF can be plugged into an "ext xtal" socket. The output from the "xtal output" socket can be counted to check the crystal. If a frequency such as 83.3kHz is used the output can be used to check nautical mile markers on a radar display system.

Direct Measurement of Frequency

Power and Audio Frequencies

11. The frequency band covered by this type of measurement is from about 10Hz to about 20kHz, but most instruments can be used on frequencies up to about 100kHz. General measurements in the laboratory are usually carried out by measuring the waveform period on an oscilloscope or, where greater accuracy is required, by using an electronic frequency counter/timer as described in previous chapters. There is however a common requirement for monitor instruments directly calibrated in frequency and these devices usually rely on capacitor reactance or CR discharge time for their operation. Where the frequency band to be monitored is very small a system of vibrating reeds of different lengths is sometimes used. The reed whose natural resonant frequency is nearest to that of the applied voltage will vibrate most violently, thus indicating the supply frequency.

12. **Frequency meter type S109.** This meter relies on variation of capacitor reactance with frequency (see figure 3) and is used to monitor the output frequency of aircraft a.c. supplies at 400Hz. The accuracy of measurement is about 1% and as the nominal frequency is usually 380–420Hz (400Hz$\pm$5%) the output frequency of inverters can be adjusted to 400Hz using the meter. A preset calibration control is incorporated to correct the meter reading but this should only be adjusted as authorized when a source of 400Hz accurate to 1 in 10^3 or better is available. The meter movement is a ratiometer whose two coils are fed through rectifiers to obtain the required d.c. The current through the deflecting coil is controlled by a capacitor and that through the control coil by a resistor. As the frequency increases, the capacitive reactance falls and a greater current will flow through the deflecting coil thus giving a higher meter reading. When the supply is removed the needle will take up any position on the scale; some models are however fitted with a *very low torque* spring so that the pointer is pulled off-scale behind a blanking flag when the supply is switched off. Many of these meters are fitted with a bandpass filter in the input leads to prevent false high readings being produced by harmonics of the supply frequency.

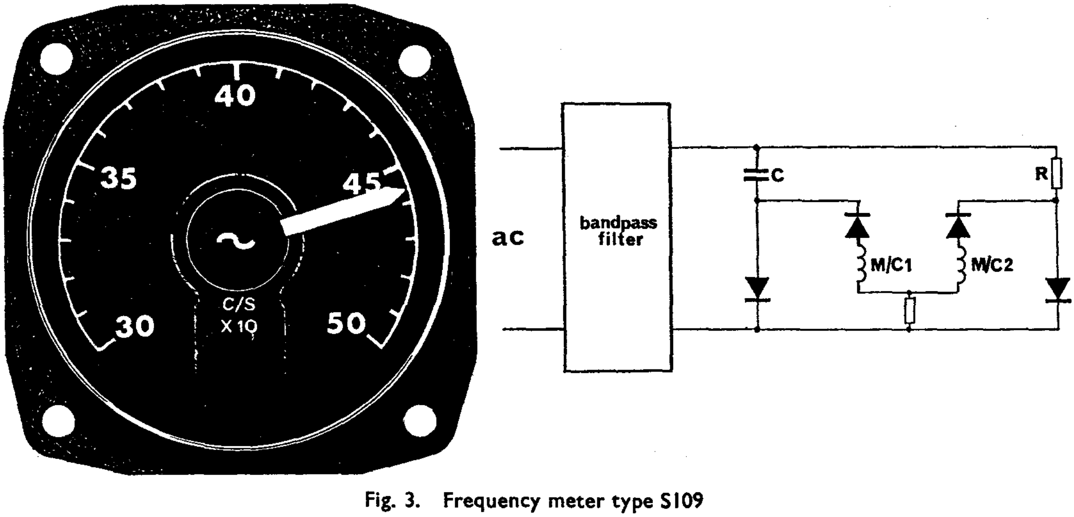


Fig. 3. Frequency meter type S109

13. **Capacitor discharge meters.** The circuit shown in figure 4 is only one of many possible capacitor discharge meter circuits in common use (see AP3302 "diode counters"). The instrument operates by charging C1 quickly through the diode D1 during the positive half cycles, and discharging it at a rate controlled by the time constant C1 × R1 during the negative half cycles. The charge built up on C1 is therefore proportional to the input frequency and after smoothing it can be used to operate a milliammeter calibrated in frequency (non-linear scale).

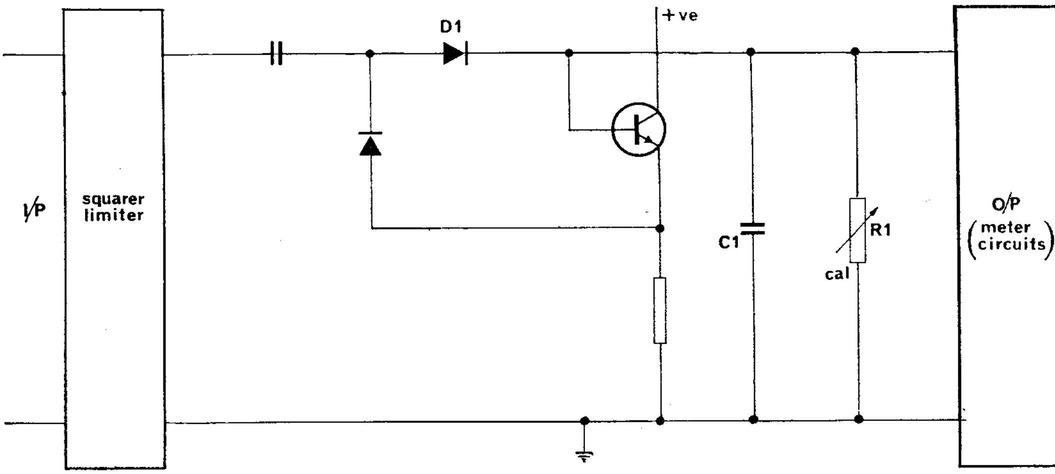


Fig. 4. Capacitor discharge circuit (STR40)

The actual circuit shown in figure 4 is part of Radio Altimeter STR40; the ammeter used is calibrated directly in feet and the equipment has an overall accuracy of ±3% mainly due to errors in the counting circuits. Most instruments of this type are fitted with a calibrator preset control (R1 is variable) so that the reading can be adjusted against a known source such as a signal generator (accuracy 1 in 10^3 or better). Another extremely common use of the capacitor discharge (diode counter) type of circuit is as p.r.f. monitors for pulsed radar transmitters. These meters are calibrated directly in p.r.f. and the circuit is sometimes arranged so as to "rest" the transponder if the p.r.f. exceeds a given value.

14. **Discriminators.** Several types of discriminator circuit are discussed in AP3302. They produce a voltage proportional to the amount by which the applied frequency differs from the frequency to which the discriminator circuits are tuned. This voltage can be fed to a centre zero voltmeter which can be calibrated either in frequency error (from the centre) or directly in frequency (where the centre reading is the required frequency). Such indicators are commonly used as aerial speed monitors or as audio tone indicators. The output can also be used to drive a servo loop so as to automatically correct the input frequency to the required value (zero discriminator output). This is the basis of receiver automatic frequency control systems and of many aerial rotation control equipments.

Radio Frequencies

15. Measurement of radio frequencies includes all usable frequencies from about 100kHz to microwaves at 50GHz or more. Due to this wide frequency variation the physical appearance of many instruments which use the same operating principle varies greatly and the type of an instrument can usually only be decided by studying the operating controls. It is possible to "load" an r.f. equipment and pull it off frequency by connecting unsuitable test equipment. Care should

therefore be taken to select test equipment which has an input impedance to match that of the equipment under test. A large variety of attenuators and sampling devices are available to reduce the power output of the equipment under test to a level acceptable to the measuring equipment. The measurement method to be used depends on the accuracy required and these methods are considered in the following paragraphs with examples typical of each type of test instrument in common use.

16. **Transmitters.** Before commencing frequency checks or alignment the transmitter should always be switched to carrier wave (CW) operation if this is possible. When a transmitter cannot be switched to CW an averaging method of measurement must be used, such as a transfer oscillator and an electronic counter. The different types of transmitter and the measuring methods appropriate to each type are listed below:

a. Master oscillator. A master oscillator type of transmitter usually has a relatively low frequency accuracy and either a good quality absorption wavemeter (1 in 10^3) or a simple heterodyne wavemeter (1 in 10^4) is sufficiently accurate for normal frequency measurements. Where the output frequency is being set up as well as measured the heterodyne meter is the preferred instrument because of its greater accuracy.

b. Crystal calibrated master oscillator. In this type of transmitter the master oscillator frequency is set to beat with a harmonic of the crystal frequency or one of its sub-multiples. As the crystal frequency is more accurate than most wavemeters, an accurate check must be carried out. The usual method is to count the crystal on an electronic frequency counter, and to check any divider stages from the crystal frequency by Lissajous figures. The transmitter output frequency can then be checked on a heterodyne wavemeter to ensure that the master oscillator is tuned to the correct harmonic of the crystal frequency.

c. Crystal controlled oscillator. In this type of transmitter the output frequency is generated by a crystal or by a series of frequency multipliers from a crystal. Because of the high accuracy a counter must be used to check the crystal frequency. If the output frequency is too high to count directly, the crystal frequency may be counted and the ratio of the multiplier stages checked on a heterodyne wavemeter. In many cases the crystal used is a simple plug-in unit and it may be easier to remove it for checking on one of the special crystal check units available at all major measurement centres.

d. Frequency synthesizers. Many modern transmitters derive their output frequency by synthesis from several high accuracy crystal oscillators. In this case all the stable frequencies must be checked with a counter unless the output frequency lies in the range where it can be counted directly. Most single side band and independent side band sets are of this type, as are many microwave links. The only alternative to counting is to compare the output frequency with one of the GPO standard frequency transmissions.

e. Frequency modulated transmitters. These must be checked for carrier frequency in the unmodulated condition using one of the methods described above. Further tests to determine the carrier deviation in the modulated condition are then carried out using a special test set such as the tester carrier deviation CT219.

f. Radar transmitters. Most radar transmitters have a comparatively low accuracy unless designed to work with a ground beacon. Primary radars can normally be checked with an absorption or heterodyne wavemeter. Secondary radars are checked by one of the above methods, depending on the accuracy of the transmitter oscillator.

Wavemeters (usual accuracy about 1 in 10^3 i.e. 0·1 %)

17. Wavemeters are of two basic types, the reaction wavemeter and the absorption wavemeter, but both types rely on the principle that a tuned circuit will absorb maximum energy when it is tuned to resonance. Both instruments take power from the equipment being tested, but the reaction wavemeter absorbs much less power and is therefore sometimes preferred for special tests on very low power signals. The absorption type is much more common for general use.

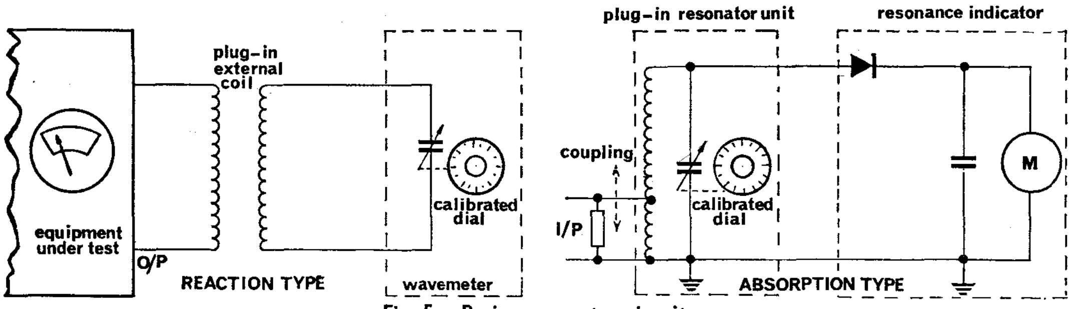


Fig. 5. Basic wavemeter circuits

18. **Reaction wavemeters.** The circuit of a simple reaction wavemeter is shown in figure 5. The coil, one of a range which is mounted externally to the meter, is loosely coupled to the output of the circuit whose frequency is to be measured. The tuning capacitor is varied until an indicator in the equipment under test shows resonance. This may be a maximum or minimum, depending on the position of the meter in the equipment circuit. When the wavemeter reaches resonance (max loading on the equipment under test) it is important that the coupling is reduced to the point which produces a barely usable indication. If the coupling is not reduced a sharp resonance point cannot be determined and the reading obtained may be in error. The frequency is read off a calibrated dial on the variable capacitor, often fitted with a vernier scale to enable more accurate readings to be obtained. It is also important that resonance should always be approached in the direction in which the instrument was calibrated (specified in the handbook) to eliminate errors caused by backlash in the dial drive. Some wavemeters are not calibrated in frequency and the reading on the dial must be converted by reference to a calibration chart or graph supplied with the instrument. Always check that this chart bears the serial number of the actual instrument being used before accepting the reading.

19. **Absorption wavemeters.** The absorption wavemeter is basically similar to the reaction type but contains its own resonance indicator (lamp, magic eye, or meter). The instrument is tuned until a maximum reading is obtained (resonance) and the frequency determined as above. The coupling should be adjusted to keep the indicator reading as low as possible to prevent excessive loading of the equipment under test.

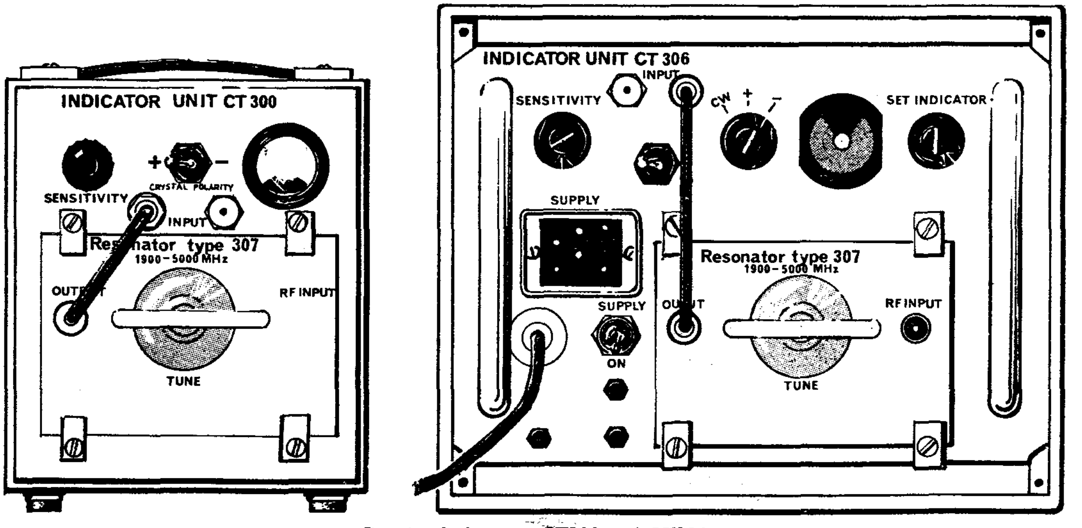


Fig. 6. Indicators CT300 and CT306

20. **Indicator (meter) CT300—indicator (magic eye) CT306.** These indicators form absorption wavemeters by the addition of one of fifteen available resonator units. These resonators cover the band 18MHz to 40GHz in fifteen ranges e.g. the resonator CT307 shown in figure 6 covers from 1900MHz to 5000MHz. The indicator CT300 contains a microammeter to indicate resonance and requires no external power supplies, thus making it very convenient for first line use in the field. Indicator CT306 contains an amplifier and magic eye resonance indicator and is more sensitive than the CT300, it requires a power supply to drive the amplifier but will operate from any normally available a.c. supply (80V–1600Hz, 115V–400Hz or 1600Hz, or 250V mains). Care should be taken to check the supply voltage selector before use as accidental misconnection will damage the instrument.

21. **Wavemeter operation.** To use the instruments as absorption wavemeters, the unknown signal is applied to the r.f. input socket on the resonator unit. The tuning dial is then turned until the indicator shows resonance and the unknown frequency read from the calibrated dial of the resonator. Care should be taken to ensure that the reading obtained is the input frequency fundamental as the instrument will also respond to harmonics if they lie within the resonator range. The meter reading obtained at resonance from the fundamental will be very much greater than the reading obtained from any harmonic. Both indicators have a sensitivity control to assist in finding the exact point of resonance.

If the equipment being tested is fitted with a suitable indicating system the resonator units can be used without the indicator units and will then act as reaction wavemeters. Under these conditions a reading can often be obtained from a frequency source which cannot produce sufficient power to operate the instruments as absorption wavemeters.

Heterodyne Frequency Meters (usual accuracy about 1 in 10^4 or better)

22. The comparison of two frequencies by the heterodyne method was discussed in para 7. A class of frequency meters using this technique have been used for many years as the normal method of measuring transmitter frequency. The main disadvantage of heterodyne meters is that the measurement accuracy depends on the accuracy of the built-in oscillator. It is very difficult to make a continuously variable-frequency oscillator with a high frequency accuracy, so most practical meters have a built-in crystal calibrator against which the oscillator may be checked immediately prior to use. Heterodyne wavemeters usually contain audio amplifiers to enable measurements to be made on low level signals. This sensitivity enables meters to be used outside the stated operating band by comparing the unknown signal with the second or third harmonic of the wavemeter oscillator. The simple type of heterodyne meter contains a fairly stable variable oscillator and a crystal calibrator which give the instrument an overall accuracy of about 1 part in 10^4. More complex types are available with greater accuracy, but due to the advantages of digital counters these meters are no longer in common use.

Fig. 7. Heterodyne frequency meter

23. **Using a heterodyne frequency meter.** The meter illustrated in figure 7 is capable of measuring frequencies between 5MHz and 1000MHz with an accuracy of better than $0{\cdot}01\%$. To find the approximate frequency of an unknown signal, it is applied to the mixer input socket with the function switch at "input". The frequency dial is then adjusted until the "zero beat" position is heard in the headphones. The approximate frequency is noted and the function switch turned to the "xtal cal" position. The main frequency dial is then set at the spot check frequency nearest to the frequency to be measured. The 'corrector' knob is then adjusted for zero beat and must be left in this position during the final measurement. Turn the function switch back to the input position and adjust the main frequency control for zero beat, using the sensitivity control to assist in finding the exact zero point. The frequency of the unknown signal can be read off from the main frequency dial. If the approximate frequency of the signal to be measured is known the first step can obviously be omitted.

An oscillator output socket is often provided on heterodyne frequency meters. This enables the instrument to be used as a signal generator to carry out frequency checks on receivers. The accuracy of the frequency output is still about 1 part in 10^4, provided that the internal crystal has been used to calibrate the variable oscillator as described above.

Frequency Counters—Digital Frequency Meters (usual accuracy about 1 in 10^7 or better)

24. **Counter.** The operation of counter/timers was discussed in chapter 4 but an example of a typical modern counter instrument is illustrated in figure 8. This instrument is the Racal 801 digital frequency meter which is capable of direct measurement of frequencies up to 100MHz. The input impedance is 1MΩ in parallel with 15pF so no appreciable loading of the source occurs.

Input signal levels between 0·05V and 250V rms may be used, depending on the setting of the sensitivity switch. The accuracy obtained depends on ageing since the instrument was calibrated but will be better than 1 in 10^7 using the internal crystal. There is a socket provided on the rear to allow the use of an external 1MHz frequency standard to increase the accuracy when necessary to a maximum of about 1 in $10^9 \pm 1$ count.

Operation of the counter is completely automatic and it is only necessary to adjust the sensitivity switch to the position required by the input signal level. There is a choice of gate time and the eight digit display has automatic decimal point positioning controlled by the gate time selector switch. This makes the reading virtually "idiot proof" and thus allows the counter to be operated by semi-skilled personnel.

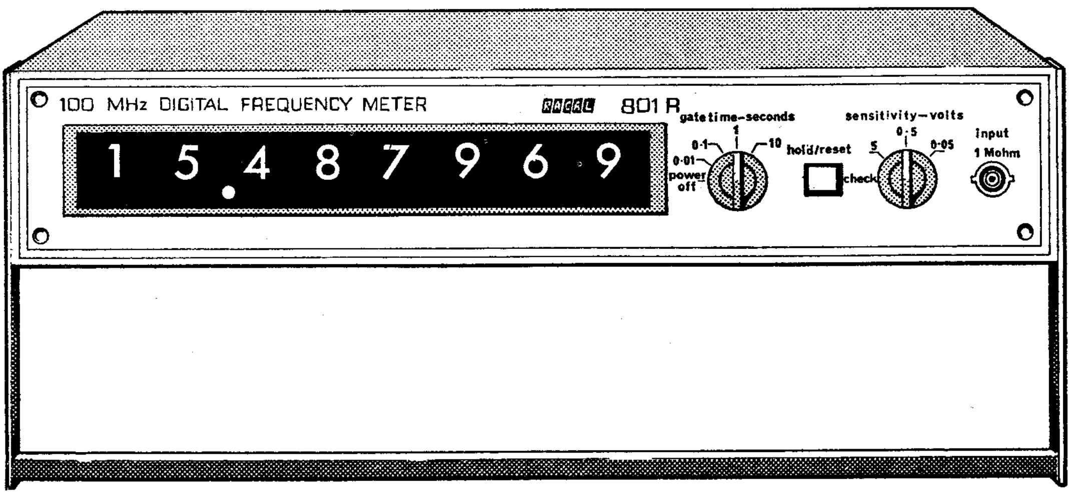


Fig. 8. Digital frequency meter

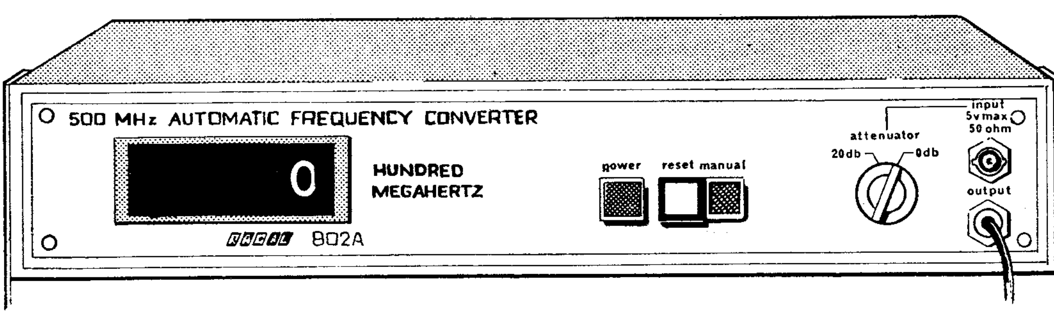


Fig. 9. Converter (Racal 802)

25. **Converter (Racal 802).** This converter, illustrated in figure 9, extends the range of the counter up to 500MHz. It operates as a heterodyne frequency changer and has automatic selection of the harmonic to be used. This harmonic is displayed as a numeral (in 100MHz) by a cold-cathode tube on the front of the instrument. In use the converter is fed with a 1MHz frequency standard obtained from the counter 801. The signal input will accept signals from 0·1V to 5V rms and has an impedance of 50Ω to match normal radio frequency lines. The output supplied to the counter is about 50mV rms and the counter input switch should therefore be used in the 0·05V position. Accuracy of the instrument is the same as that of the counter, but the measurement takes about half a second longer to enable the converter to select and lock on to the correct harmonic.

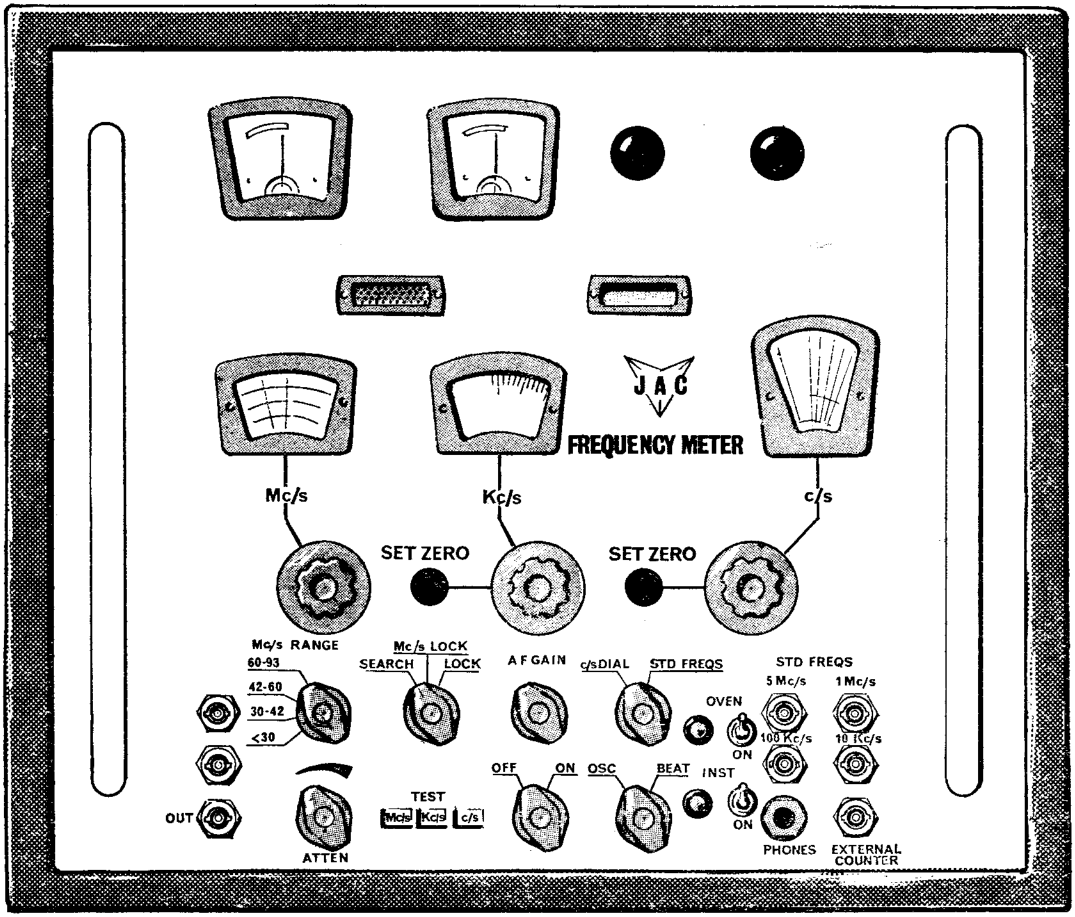


Fig. 10. Frequency meter CT551

Standard Frequency Comparators

26. The most accurate method of measuring frequency is to compare the unknown frequency with one of the standard transmitted frequencies such as Droitwich. This may be done directly or by using an extremely stable oscillator (or frequency synthesiser) as a transfer standard. Equipments capable of this type of measurement are really beyond the scope of this book, but an example has been included for the sake of completeness and is illustrated in figure 10.

27. **Frequency meter CT551.** This instrument is basically a heterodyne comparator using either a magic eye or earphones to detect zero beat. To achieve accuracy and stability, the "variable oscillator" used is a crystal controlled frequency synthesiser with a built-in digital counter on the last four digits. This enables the frequency to be measured to ± 1Hz at full crystal accuracy. The absolute crystal accuracy depends on its initial alignment against a reliable frequency standard such as Droitwich or MSF (Rugby); but once aligned the stability is better than 1 part in 10^9 per day. The instrument is capable of measuring frequencies up to 93MHz using the synthesiser fundamental frequency and up to 3000MHz using harmonics. It can also be used as a signal

generator to provide an accurately known frequency source up to 3000MHz. The crystal and divider frequencies are also available from sockets on the front panel and may be used to check the accuracy of external counters.

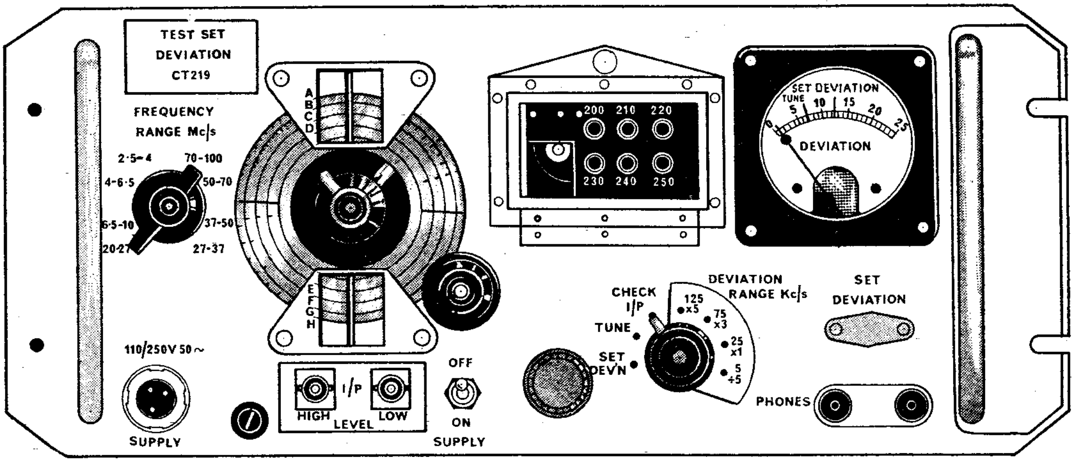


Fig. 11. Tester carrier deviation CT219

Carrier Deviation Measurement

28. **Tester carrier deviation CT219.** These instruments are used to test the frequency deviation of FM transmitters under working conditions i.e. modulated by an audio tone. The basic carrier frequency range of the CT219 is from 2·5MHz to 100MHz, in eight bands, but it is normally used up to 200MHz by working on the second harmonic. The deviation measurement is made on one of four ranges 0–5kHz, 0–25kHz, 0–75kHz and 0–125kHz. An independent audio output at the deviation frequency is also provided to enable an external measuring instrument such as a scope or counter to be used. The accuracy of the deviation readings from the built-in meter is about 3%.

29. **CT219 operation.** The deviation meter must first be adjusted by switching the operating control to the "set deviation" position. If the meter does not deflect to the "set deviation" mark, adjust the pre-set control below the meter. Switch to "tune" and connect the source to the appropriate input socket. Adjust the frequency band selector and the main frequency dial to the approximate frequency of the carrier. Slowly turn the main tuning dial, or the fine control if required, through the signal carrier. Two maxima will be indicated by the meter—one below and one above the carrier frequency; these are separated by a central point of zero response at which the carrier and the instrument oscillator frequencies are the same. Working from this centre point, slowly turn the fine frequency control towards either of the maxima until the meter deflects to the "tune" mark. Take care not to pass the maximum reading as the instrument will only operate correctly on the side of maximum *adjacent* to the zero reading. Switch to "check input" and check that the meter deflects above the "tune" mark. Switch to the required deviation range, read the meter and multiply by the appropriate factor given by the range switch setting.

CHAPTER 6

MEASUREMENT OF RESPONSE FREQUENCY SIGNAL GENERATORS

List of Contents

Introduction

1. In order to check the frequency to which a tuned circuit or a receiver equipment will respond a suitably calibrated signal source is required. Such sources are known as *signal generators* and may be divided into two general classes. Servicing signal generators produce a reasonable signal which may be used to drive an equipment during fault tracing and repair. Laboratory standard signal generators produce more stable signals of low distortion and are used for equipment alignment and distortion measurements. Most laboratory signal generators also provide a calibrated output level which enables them to be used for receiver sensitivity or gain measurements in conjunction with one of the power measuring instruments discussed in the next chapter. The important features of signal generators are discussed first in this chapter, followed by examples of typical instruments which are in common use.

2. **Frequency accuracy.** It must be remembered that the absolute frequency accuracy of most signal generators is *poor* compared to the frequency measuring instruments discussed in the last chapter. Servicing signal generators commonly have an accuracy of only 2 or 3 per cent and even good laboratory instruments are only accurate to 1 part in 10^4. To obtain greater accuracy than this either a crystal controlled frequency synthesizer may be used, or a *high stability* signal generator can be used as a transfer standard to an electronic counter.

3. **Frequency stability.** This is a measure of the instruments ability to maintain the frequency to which it has been set. Usually the short-term stability is quoted and on laboratory instruments it is normally 2 or 3 parts in 10^5 for 10 minutes. This means that a signal generator used as a transfer standard to a counter will maintain the set frequency to an accuracy of 2 or 3 parts in 10^5 for long enough to carry out most normal alignment checks without having to be readjusted.

4. **Spot frequency generators.** Many test sets are made for checking specific receivers or radar equipments and generate signals only on given spot frequencies. These instruments are usually *crystal controlled* and provide much greater accuracy and stability than a variable frequency signal generator. Typical figures would be accuracy 1 in 10^5 or better and a short term stability of about 1 in 10^7, or better if a crystal oven is used.

5. **Output level.** The output level of a signal generator can be quoted either as a source emf in series with the specified source resistance of the instrument, or as the output voltage which the instrument will deliver to a specified load resistance (matched). As there is a considerable difference between these types of reading it is always advisable to consult the instrument handbook unless working to levels laid down for the instrument in a servicing AP.

a. EMF. Most 'audio frequency' signal generators (DC to 100kHz approx) have output controls calibrated to read the generator emf (Eg) in series with the source impedance (Rs) which is usually 600 ohms. Some instruments call this emf the open-circuit output voltage. To calculate the actual output delivered into a given load (R_L) the formula $\text{Vout} = \dfrac{\text{Eg} \times R_L}{\text{Rs} + R_L}$ should be used. For example with a 600 ohm load R_L and a 600 ohm source impedance Rs the actual output voltage is only half that indicated on the instrument output controls. The power being delivered to the device under test is equal to $V^2\text{out}/R_L$ and is equal to one quarter of the value which would be *wrongly* obtained if the instrument calibration method was confused. Some of the lower frequency radio frequency generators designed for general laboratory work are also calibrated by this method—when in doubt, read the handbook.

b. Vout. RF generators designed for receiver tests are calibrated directly in output voltage across *a stated value of load* (R_L) which is usually 50 ohm or 75 ohm. In some cases the output controls have calibrations for both impedances and a special matching pad is supplied to convert the output from one value to the other. The reading is sometimes given directly as a voltage and in other cases is quoted in dB with respect to 1 μV. Many special to type test sets and high frequency generators quote the output power delivered to the specified load in dBm (dB below 1mW reference level). This type of calibration is particularly common on radar test sets where the sensitivity is checked by ensuring that the equipment will lock on and process an input signal of given level.

6. **Output impedance.** In order to transfer maximum power from the signal generator to the equipment under test it is essential that their impedances should be matched. This means that Rs and R_L should be equal, or where this is not possible a matching pad (impedance transformer) should be used. Any external impedance which is added to a signal generator to simulate the aerial impedance of a receiver is known as a *dummy aerial.* It ensures that the signal current to the input circuits of the receiver is the same as would appear with the known signal level induced in an ideal aerial. The circuit shown in figure 1 will match a low impedance signal generator output (50 ohms) to the high impedance input of an ordinary domestic broadcast receiver.

It must be enclosed in a properly designed earthed screening can to prevent stray radiation from causing false results. If the input impedance of the receiver being tested is not known, it is essential that the appropriate equipment AP is consulted to find the correct aerial matching conditions and the proper test frequencies for sensitivity tests.

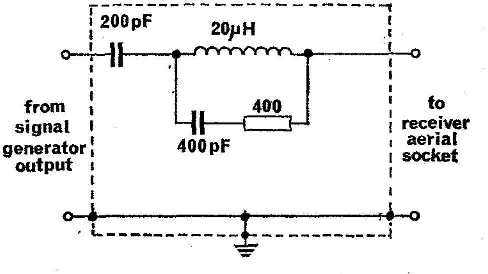


Fig 1. Dummy aerial

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7. **Modulation.** As radio frequency generators are used mainly for receiver testing and alignment, they are normally provided with a means of modulating the carrier frequency produced so that the receiver system may be tested as a whole. Servicing type instruments usually have a fixed depth internal modulation (amplitude modulation) which can be switched off if the generator is to be used for c.w. tests. This modulation is usually 30 or 40% depth at a fixed frequency of either 400Hz or 1kHz. Laboratory instruments usually provide variable depth and variable frequency amplitude modulation to enable receiver fidelity tests to be carried out. Where this facility is not built-in, there is usually provision for applying a variable external modulation from an audio frequency signal generator. Many modern radio frequency instruments also provide frequency modulation and frequency shift keying facilities either built-in or via an external socket.

As audio frequency generators are used for testing amplifiers, many of them provide a square wave output which can be used to check the response of video amplifier systems. Some r.f. generators will accept pulse modulation and can be used for overall testing of video receivers.

8. **Practical points.** The more important aspects of using signal generators are listed. ALL of these points should be considered whenever a signal generator is to be used.

a. Power supply. Ensure that the instrument mains tap is in the proper position for the supply being used and that the instrument itself is adequately earthed. The importance of a *good earth* cannot be overstressed, particularly when working at low signal levels and at low frequencies as mains hum can cause completely erroneous readings.

b. Warm-up time. Allow time for the instrument to warm up and stabilize its output frequency. On transistorized instruments 2 or 3 minutes is often adequate but most valve operated instruments require at least half an hour. Where some form of temperature control such as a crystal oven is used, a considerable warm-up period may be required and the instrument handbook should always be consulted.

c. Frequency calibration. Always check the frequency calibration of an instrument (or adjust the scale zero) *after* the instrument has warmed up and immediately prior to use. If a more accurate frequency measuring instrument such as a counter is readily available, carry out a cross check of the dial reading. Backlash of the tuning mechanism and of the dials on the receiver under test must be allowed for; the handbook usually specifies tuning in one direction only to avoid these effects.

d. Output level. On most instruments the carrier output level must be adjusted (set c.w.) before the modulating signal is applied. The correct sequence of control adjustments is often important —consult the handbook. Care must also be taken to avoid confusion between different methods of calibrating the output controls.

e. Connectors. Stray radiation and pick-up in connectors can cause errors, particularly when working at low signal levels. Always check that the connector is suitable for the instrument being used and does not cause an impedance mismatch. When working at low frequencies using open wire connectors, the earth lead must be connected as near as possible to the signal input point to avoid pick-up from an "earth loop".

f. Distortion. The effects of distortion are very difficult to measure. Always use as low a signal level as possible to avoid overdriving causing limiting in amplifier circuits. Remember also that harmonic distortion increases as the depth of modulation is increased. Do not use a generator at the extremes of its frequency range as the amount of distortion and frequency error may become excessive.

Audio Frequency Measurements

9. **Signal generator type 16728.** This instrument is a good general purpose audio signal generator, using a stabilized Wien-bridge oscillator as the source. The frequency range is in four decade bands from 20Hz to 200kHz. Frequency accuracy is $\pm 1\%$ from 20Hz to 20kHz (the true audio band) and $\pm 1\frac{1}{2}\%$ from 20kHz to 200kHz. After warm-up the stability is better than 2 parts in 10^3. Distortion of the output waveform is less than 1% at any frequency and is less than $0{\cdot}5\%$ over the band 20Hz to 50kHz. In addition a built-in filter can be brought into the output circuit by linking terminals on the front panel to provide a signal at 1kHz with less than $0{\cdot}1\%$ distortion. This signal is very useful as an external modulating signal for radio frequency signal generators when carrying out quality tests on receivers. The instrument output impedance is 600 ohms and the calibration of the level controls shown in figure 2.

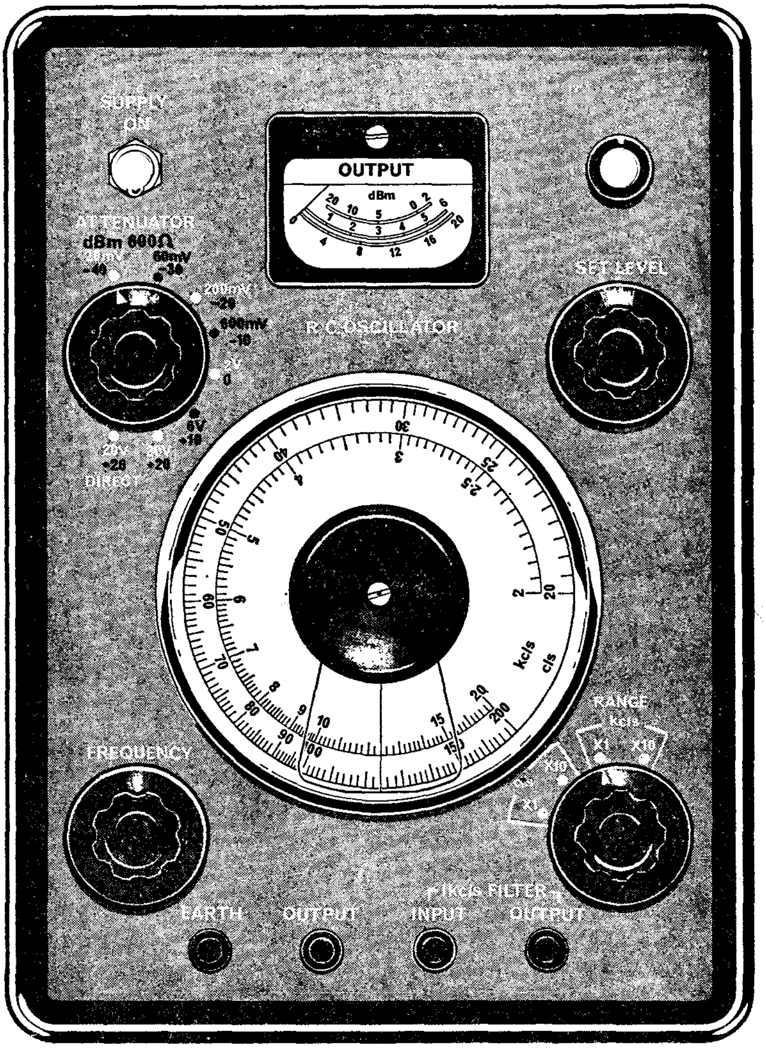


Fig. 2. Signal generator type 16728

10. **Testing open-wire transmission lines.** The standard nominal impedance of open-wire transmission lines is 600 ohms and they will thus act as a matched load for the signal generator type 16728, provided that the line is also terminated with a load of 600 ohms. The performance of an open-wire line can be measured with the simple arrangement shown in figure 3 for determining the power lost along the line at a given operating frequency (usually 1kHz for voice circuits). One set of calibration marks on the output attenuator of the signal generator is calibrated in terms of the *power delivered to a* 600 *ohm load,* directly in dBm (dB with respect to 1mW reference level). The reading of the dBm scale on the meter and decade settings of the attenuator provide output powers from —60dBm to +22dBm. When using this scale, the meter reading should be kept in the —10dBm to +2dBm region by suitable adjustment of the attenuator switch to avoid using the cramped part of the meter scale. The method of carrying out tests on a particular equipment is laid down in the equipment servicing schedules. A typical method is to adjust the signal generator output level (line input) until the line output is 1mW (0dBm), and read the line input from the signal generator to find the line loss.

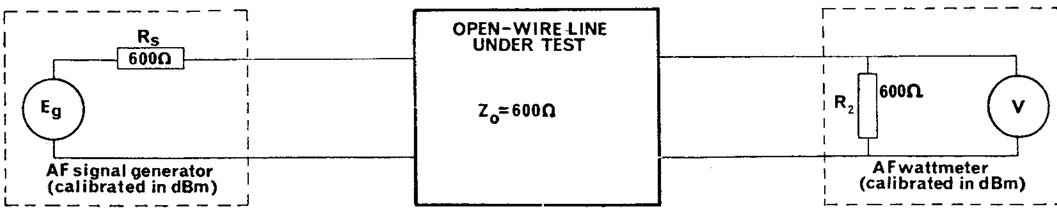
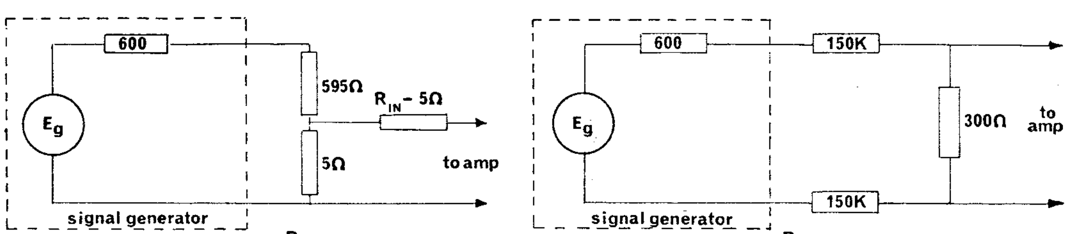


Fig. 3. Testing a transmission line

11. **Amplifier gain/sensitivity tests.** Although amplifier gain and input sensitivity voltage have a precise meaning (British Standard 3860), these quantities are very rarely measured by the technician because of the amount of calculation involved in correcting for impedance matching network losses. In practice an *overall performance* test is specified in the AP and the output and input levels quoted in these tests allow for the effects of the coupling networks *specified* for the tests. Two input networks typical of those used for performance tests are shown in figure 4. When carrying out the tests, the signal generator level is adjusted until a specified amplifier output is obtained. The signal generator e.m.f. must be less than a given figure for this output or the amplifier is classed as unserviceable. The frequency at which the performance test is carried out is also specified in the AP and is the centre frequency of the amplifier response band. The open-circuit voltage (Eg) calibration of the signal generator is used for these tests and the e.m.f. available on the type 16728 is up to 20V r.m.s. on seven overlapping ranges.



(a) amplifier input resistance = R_{IN} (b) balance input amplifier (R_{IN} = 300ohm)

Fig. 4. Impedance matching networks

12. **Frequency response/bandwidth tests.** Although the term bandwidth has a precise definition it is seldom measured for the reasons given above, and also because plotting a gain/frequency graph is time consuming. In practice, the performance test described above is repeated at *two* other specified frequencies; one either side of the centre band frequency used for the gain tests. For the

amplifier to be serviceable, the input level at these frequencies must also be below the figures quoted in the equipment AP. The frequency response of filter networks can be checked in a similar manner by carrying out performance tests at specified frequencies.

Signal Tracing

13. The use of a signal generator for fault finding by the signal substitution method provides a rapid means of isolating the trouble in a receiver, or amplifier, to a single stage. It is the only suitable method of fault finding where a receiver is working more or less normally but has a lower power output than is acceptable as serviceable. In this method, a signal is applied successively to the various stages of the receiver circuit, starting with the audio output stages and working back to the input. Tables giving stage gain and the signal levels to apply to a receiver are given in the servicing information section of the equipment Air Publication (Vol. 1). An example of this type of test is given in the following paragraphs for the tone receiver shown in block diagram form in figure 5.

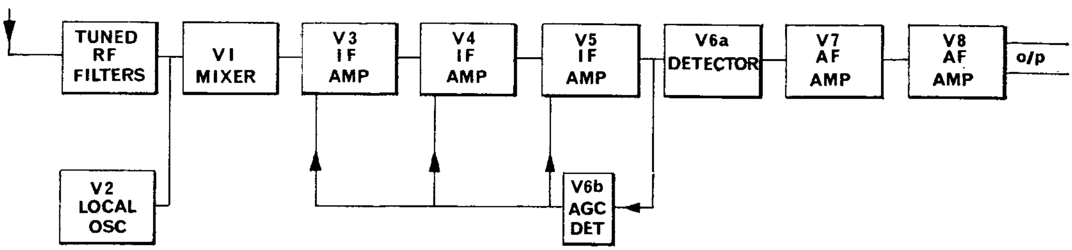


Fig. 5. Tone receiver block diagram

14. **Audio frequency stage gain checks.** These checks are made with a standard level input signal, 2V r.m.s. at 1300Hz, applied between the grid of valve 7 and the chassis (earth). Readings are taken with a valve voltmeter set to the appropriate a.c. voltage range. A table in the AP gives the voltages to be expected from a typical serviceable receiver at various points in the audio circuits (see figure 6).

Test point	Typical Reading
V7 pins 3 and 8 (cathode) to chassis	1·7 V ac
V8 pin 2 (grid) to chassis	11 V ac
V8 pin 1 (cathode) to chassis	6·8 V ac
V8 pin 7 (anode) to chassis	94 V ac
Output plug P1 pole 7 (live) to pole 8 (earth)	5·4 V ac

Fig 6 audio frequency gain check

15. **Radio frequency and intermediate frequency checks.** These checks are made with an input signal of the correct frequency applied at various points in the receiver circuit. The signal generator output level is adjusted to produce a standard output from the receiver e.g. 4V on the valve voltmeter measured across the stated output load. A table in the AP gives typical input levels to be expected at each stage of a serviceable receiver; but it should be noted that the readings obtained from different receivers may vary by as much as 2:1 due to minor differences in valve characteristics. A typical table is shown in figure 7.

Test point	Frequency	Modulation	Typical input level	Meter O/P
V1 pin 1 (grid)	75 MHz	95% a.m. at 1300 Hz	50 μV	4 V
V1 pin 1 (grid)	4·5 MHz		50 μV	4 V
V3 pin 1 (grid)	4·5 MHz		220 μV	4 V
V4 pin 1 (grid)	4·5 MHz		5 mV	4 V
V5 pin 1 (grid)	4·5 MHz		120 mV	4 V

Fig 7 RF and IF stage gain check

16. **Valve-pin voltage measurements.** The stage by stage tests carried out as described above will indicate which stage of the receiver is unserviceable or has a stage gain which is not acceptable. To localize the fault to a component for repair, extra readings are necessary in the faulty stage and possibly in the output of the previous stage or the input of the following stage. To assist the technician, a table giving the voltages on all valve pins in the receiver is also given in the servicing Air Publication. These readings are typical values obtained from a serviceable receiver operated *under standard operating conditions*. In the case of the receiver shown in figure 5:—set the automatic gain control adjustment to the centre of its travel, connect an r.f. signal generator to the aerial socket and adjust its output level until a valve voltmeter shows 4·5V at the audio output, adjust the a.g.c. for a valve voltmeter reading of 3·15 volts. The valve electrode voltages under these conditions of operation are then as shown in the table (see figure 8). The meter used to obtain these readings is *specified* at the bottom of the table. If a different type of meter is used an allowance must be made for any circuit loading due to differences in meter impedance.

valve base- pin number		1	2	3	4	5	6	7	8	9
V1	electrode	G1	K	H	H	A	G2	G3		
	voltage	−4·6*	2·3	0	6·3	180	107	−4·3*		
V2		G1	K	H	H	A	G2	K		
		−2·4*	0	6·3	0	170	53	0		
V3		G1	K	H	H	A	G2	G3		
		0	2·1	12·6	6·3	185	105	−0·54*		
V4		G1	K	H	H	A	G2	G3		
		0	2·1	12·6	18·9	185	105	−0·54*		
V5		G1	K	H	H	A	G2	G3		
		0	1·75	25·2	18·9	170	115	−1·75*		
V6		K (agc)	A (det)	H	H	K (det)	screening	A (agc)		
		14·6*	−4·5*	12·6	6·3	0	0	−5·1*		
V7		A1	G1	K1	H	H	A2	G2	K2	H
		140	−3*	1·65	12·6	12·6	140	−3*	1·65	18·9
V8		G3	G1	K	H	H	G2	A	K	G2
		12	0	12	18·9	25·2	245	240	12	245

Note: All readings taken with multimeter CT 498 except where marked *
Readings marked * must be taken on a high impedance valve voltmeter

Fig. 8. Valve electrode test voltages

Radio Frequency Measurements

17. The main use of r.f. signal generators is checking the frequency response and sensitivity of radio receivers. The type of instrument which may be used on a particular receiver depends on the accuracy of the local oscillator in a similar manner to that discussed for transmitters in the last chapter. Where high accuracy receivers are to be tested a precision frequency source such as a crystal frequency synthesizer is required, or an electronic counter may be used to count the local oscillator (or other receiver crystal frequencies). Some modern ground communications receivers derive their frequencies from the GPO standard frequency transmissions and these equipments can only be checked using the standard transmissions as the reference frequency standard.

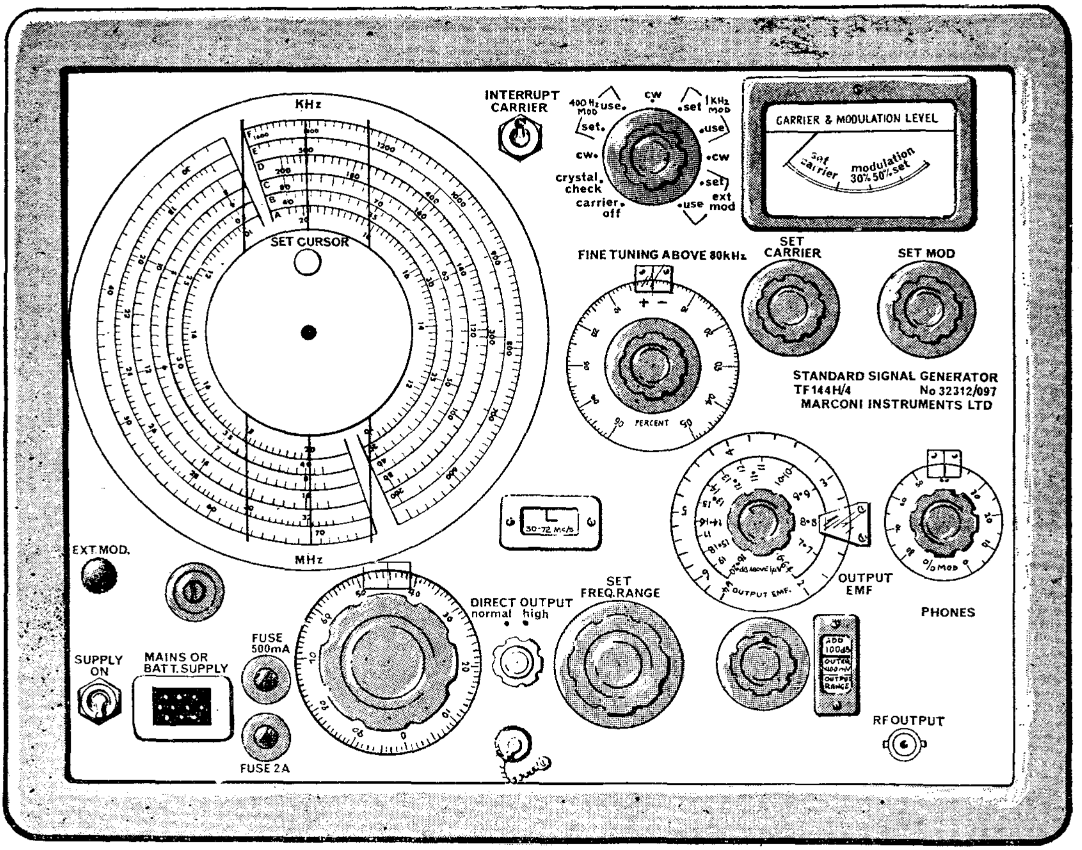


Fig. 9. Signal generator CT452A

Signal Generator type CT452A

18. This is a general purpose signal generator suitable for all normal measurements and tests on receivers in the 10kHz to 72MHz frequency range (the m.f. and h.f. bands). The output frequency is accurate to about 1% due to difficulty in reading the scale, but a built-in crystal check facility may be used to obtain maximum accuracy. A high level output socket is provided and may be used to monitor the frequency on an external electronic counter, thus making full use of the instruments stability (1 part in 10^5) to obtain greater frequency accuracy. The generator output impedance is 50 ohms which allows direct connection to the aerial socket of most receivers; a matching pad is available to convert the output impedance to 75 ohms for use when the receiver under test has an input impedance of 75 ohms.

Provision is made for amplitude modulating the r.f. output at either 400Hz or 1kHz from the instrument; if required an audio frequency signal generator may be used to supply modulation at other frequencies to the external modulation sockets. Modulation depth is variable up to 80%, but there are lower limits at the low carrier frequencies and these are listed in the handbook. The output level from the instrument is quoted as a voltage (the generator e.m.f.) and is variable between 0·2μV and 2V; dial readings are also given in dB above 1μV with an accuracy better than $\pm$1dB at all frequencies.

19. **CW operation.** Refer to figure 10. Check the meter zero and adjust —1. Connect supply —2, switch on —3, and allow to warm up (about 20 mins). Set required frequency range —4. Adjust "set cursor" control —5 to bring the upper cursor to the arrow —6. Turn the fine frequency control —7 to zero. Adjust main frequency dial —8 as required. Switch —9 to crystal check and plug headphones into jack —10. Readjust —8 for zero beat at the nearest check point to the frequency required. Reset cursor —5 to correct dial reading. Turn —8 to the required frequency. Switch —9 to CW and adjust the "set carrier" control —11 to bring meter to "set c.w.". Adjust the level controls —12 for the required output voltage.

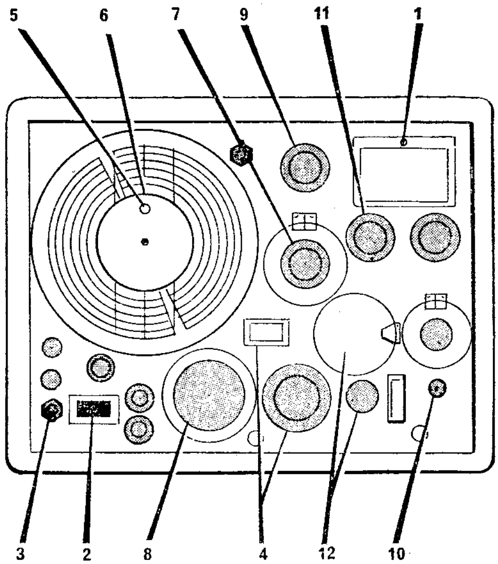


Fig. 10. CW operation

20. **Amplitude modulated (internal).** Set the instrument as in paragraph 19, and then refer to figure 11. Switch —9 to 400Hz MOD SET or to 1kHz as required and adjust the "set mod" control —13 to bring the meter from the set c.w. to the set mod position —14. Switch —9 to the adjacent "use" position. Adjust the percentage mod control —15 to the required modulation depth.

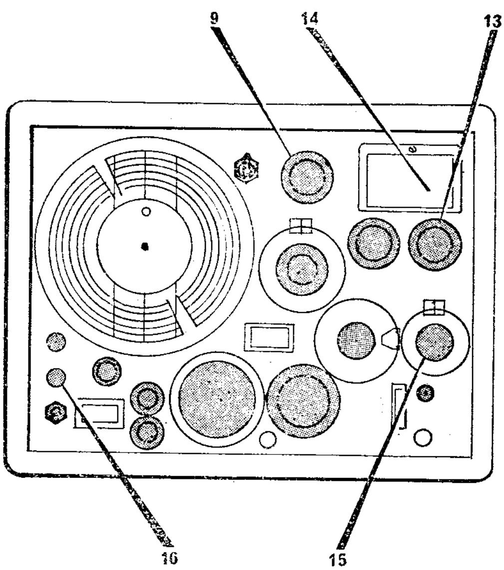


Fig. 11. Amplitude modulation

21. **Amplitude modulated (external).** Set the instrument as in paragraph 19, and then refer to figure 11. Switch —9 to EXT MOD SET. Connect the modulating signal to the ext mod sockets —16 (about 6V is needed). Adjust the set mod control —13 to bring the meter to the set mod mark —14. Switch —9 to EXT MOD USE. Adjust the percentage mod control —15 to the required modulation depth.

Receiver Tests

22. **Response frequency.** As well as finding the exact frequency to which a receiver is tuned, it is often necessary to adjust the tuning of the receiver to one or more specified frequencies. Exact instructions for a particular receiver are given in the equipment AP so only a general outline is given here. A suitable r.f. generator should be connected to the receiver aerial socket and some form of output meter, if required, connected to the receiver output. Adjust the tuning controls of the signal generator to obtain maximum output from the receiver; beware of harmonics or image channel reception. In order to obtain a "sharp" response the signal from the generator should be reduced to as low a value as possible while still maintaining an adequate output reading. Readjust the generator tuning controls to obtain the exact point of response, remembering to allow for the effects of backlash, and read the frequency from the signal generator calibration.

Where the receiver frequency is to be adjusted, the signal generator output frequency should be set up to the required frequency as accurately as possible using the crystal calibrator or an external counter. Where manual adjustment of dial mechanisms or of "click-stop" systems is involved the direction of final adjustment is specified in the AP to avoid the presence of backlash. On "autotune" motor driven systems adjustment is made to stop the motor at the correct point and it is usually good practice to change channels and reselect the one being adjusted, thus avoiding servo "dead-spots". Adjustment of the local oscillator frequency and associated trimmer and padder controls must always be carried out at the frequencies specified in the equipment AP.

23. **Receiver sensitivity/gain.** There are numerous methods of making sensitivity checks on receivers and the equipment handbook should always be used to find the correct test frequencies and levels. This paragraph contains a general description of an A3 sensitivity test for an amplitude modulated receiver. Set the r.f. and i.f. gain controls at maximum and switch off the a.g.c. system. With signal generator on carrier wave output, adjust the generator output level and the receiver audio gain controls to get a receiver noise output level of, say, 60μW as measured on an a.f. wattmeter. Switch on the signal generator modulation and readjust the signal generator output level to give a signal plus noise output of, say 6mW (20dB up). The receiver sensitivity voltage is then the difference between the two voltages. The output levels given here are only typical for a low power receiver and are not generally applicable. At each setting of the signal generator output level make sure that a further slight increase in level gives a corresponding increase in receiver output as a check that limiting is not occurring at some stage in the receiver.

24. **Automatic gain control performance.** At the conclusion of the sensitivity check the receiver a.g.c. should be switched on. The output level from the signal generator is then increased slowly from a few microvolts to a few millivolts to observe the effect on the output. With most a.g.c. systems the increased output obtained will be less than twice the original level, thus proving that the a.g.c. is working properly.

25. **Selectivity.** To check receiver selectivity, the test used for sensitivity is first carried out to determine the input level required to obtain the receiver "standard output". The signal generator frequency is then altered and the level adjusted to maintain standard receiver output. A graph is plotted of receiver input against frequency at both sides of the centre response frequency. As plotting a selectivity graph is time consuming, it is more usual to check that the receiver input (for standard output) at two specified frequencies either side of maximum response lies within permitted levels. Another easy method is to increase the signal generator output by 6dB (power doubled) and then detune the generator to find the frequency limits over which standard output can still be obtained.

26. **Image channel rejection.** After carrying out the sensitivity tests the signal generator is tuned to the receiver image frequency i.e. twice the intermediate frequency away from resonance on the

same side as the local oscillator. The generator output level is then increased until standard receiver output is obtained. This level will be 50 or 60dB above the sensitivity voltage on most communications receivers.

Frequency Synthesis—generator signal 6625–99–913–2933

27. This instrument generates signals with a frequency accuracy better than 1 part in 10^6 by synthesis from a master reference crystal in a controlled temperature environment. It is used for the testing and alignment of high accuracy single sideband receivers such as ARI 18179. The frequency range covered is from 50kHz to 26·499MHz in steps of 1kHz and the output frequency is selected by five decade selector switches. The long-term frequency stability is one part in 10^6 after allowing half an hour warm-up. The output level is controlled by two stepped attenuators and provides signals from 1μV to 10mV (0dB to 100dB), with a level accuracy of within 0.5dB. A high level output is also available (4V at high Z) and may be used to operate a counter or for comparison on an oscilloscope with frequencies generated by the equipment under test. The low level attenuated output has the normal 50 ohms impedance for connecting directly to receiver aerial sockets.

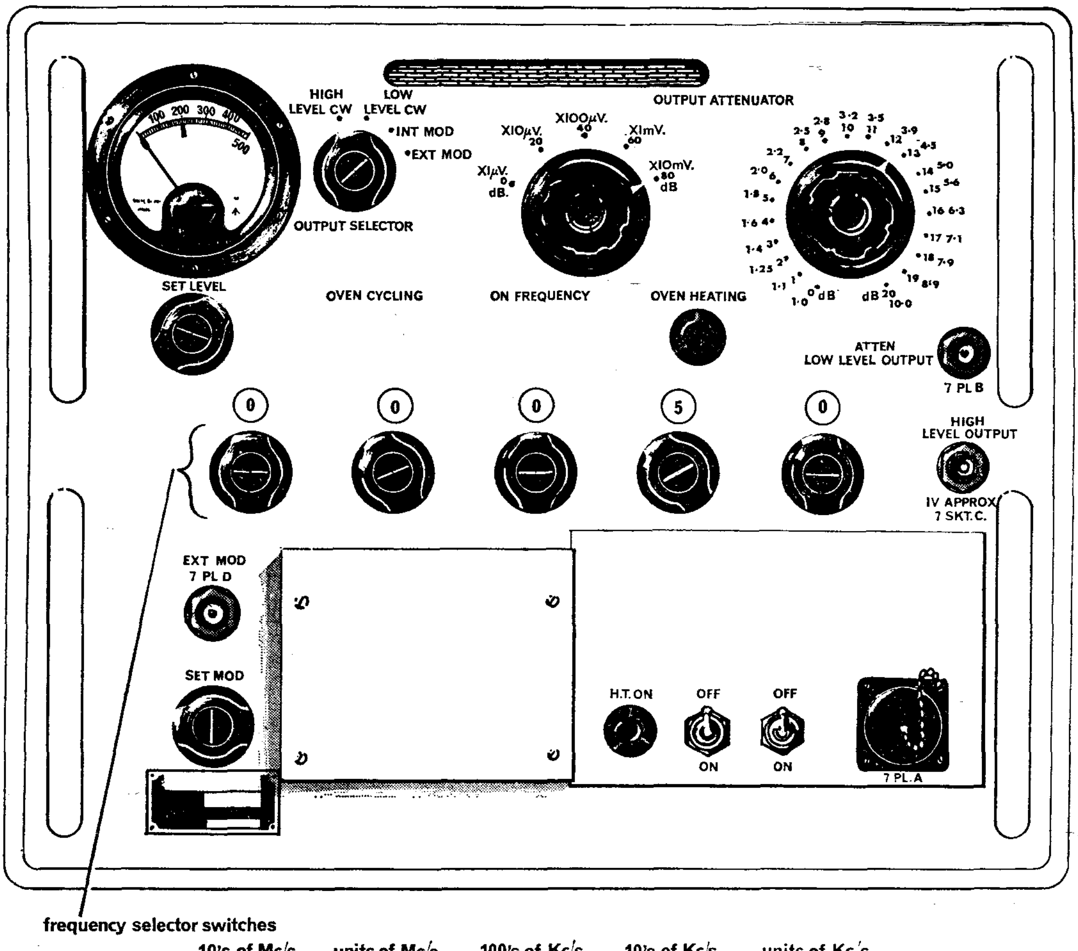


Fig. 12. Generator signal 6625–99–913–2933

Frequency Modulated Signal Generators

28. Various types of frequency modulated signal generators are available, but they are mostly special to type test sets designed for the checking and alignment of a particular type of receiver. They produce a signal in which the output frequency varies above and below a given centre frequency. The overall frequency variation is known as the frequency deviation, and the rate at which this deviation recurs is controllable at any audio frequency rate for which the particular signal generator was designed. In most cases the modulating signal is either fixed frequency (1kHz) or is applied to external modulation terminals from a separate a.f. signal generator. The frequency of this generator controls the rate at which the f.m. signal frequency varies and the a.f. amplitude controls the amount of frequency deviation.

29. **Sweep generators.** (Frequency swept oscillators). Sweep generators are widely used for the observation of tuned circuit response characteristics and for the visual alignment of tuned circuits, particularly in wide-bandwidth receivers where stagger tuning is often employed. This type of instrument "set-up" is colloquially known as a "wobbulator". The frequency of these generators is caused to vary by the application of a sawtooth voltage, usually obtained from the timebase circuits of the display oscilloscope. On the display the horizontal axis then represents frequency and if the circuit output is connected to the Y output a graph of circuit response is automatically displayed. In order to assess this graph in respect of centre frequency and bandwidth it is also necessary to display a spot-frequency marker pip, usually obtained from the generator itself by means of a built-in variable frequency oscillator with an accurately calibrated dial.

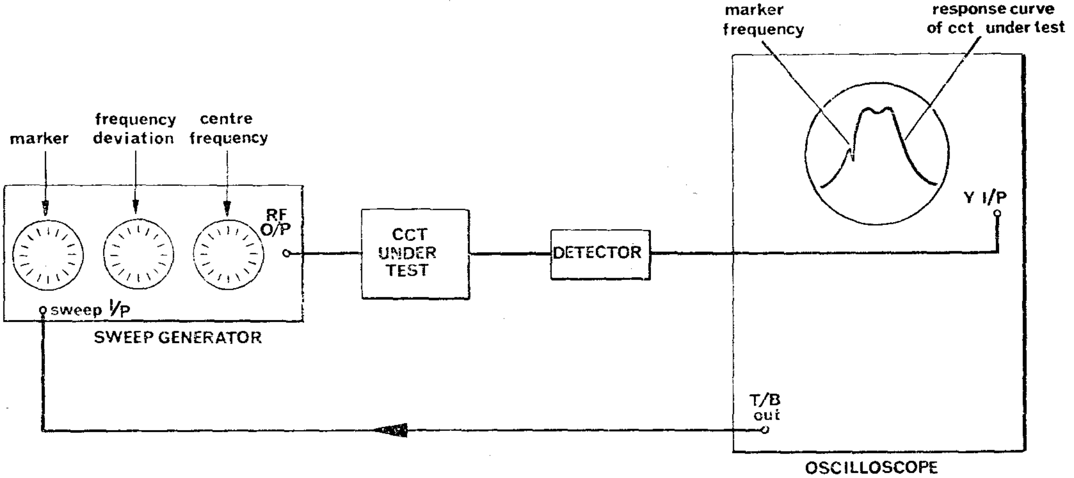


Fig. 13. Wobbulator

30. **Tuned circuit alignment.** The basic "wobbulator" set up is shown in figure 13. To align the tuned circuit the centre frequency of the sweep generator is adjusted to the response frequency of the circuit under test. The frequency deviation is adjusted to a convenient figure slightly greater than the expected bandwidth of the circuit under test. The marker frequency is adjusted to the centre of the tuned circuit theoretical response and should then appear at the centre of the displayed curve on the oscilloscope. If it does not, the circuit under test is retuned until the pip lies at the centre. The pip can now be moved to the 6dB points, the base of the curve, or to the "humps" as required by tuning the marker oscillator. The circuit response is thus evaluated and the coupling can be adjusted until the required response curve is obtained on the display.

31. **Polyskop wobbulator (210S/10060).** This instrument (figure 14) provides a self contained test set-up similar to that shown in figure 13. The sweep signal generator is adjustable to centre on any frequency between 500kHz and 400MHz and the frequency deviation to any figure from ±200kHz–±50MHz. Crystal controlled spot frequency markers are also generated in the oscillator section of the instrument and provision allowed for the use of external markers. The display side provides a twin-beam oscilloscope display whose timebase is used to drive the oscillator sweep. Connection from the circuit under test to the display may be either by coaxial cable or through a low capacitance diode detector probe. Using the twin display allows the response characteristics of two adjacent tuned circuits to be displayed superimposed on one another to facilitate the overall alignment of interacting circuits.

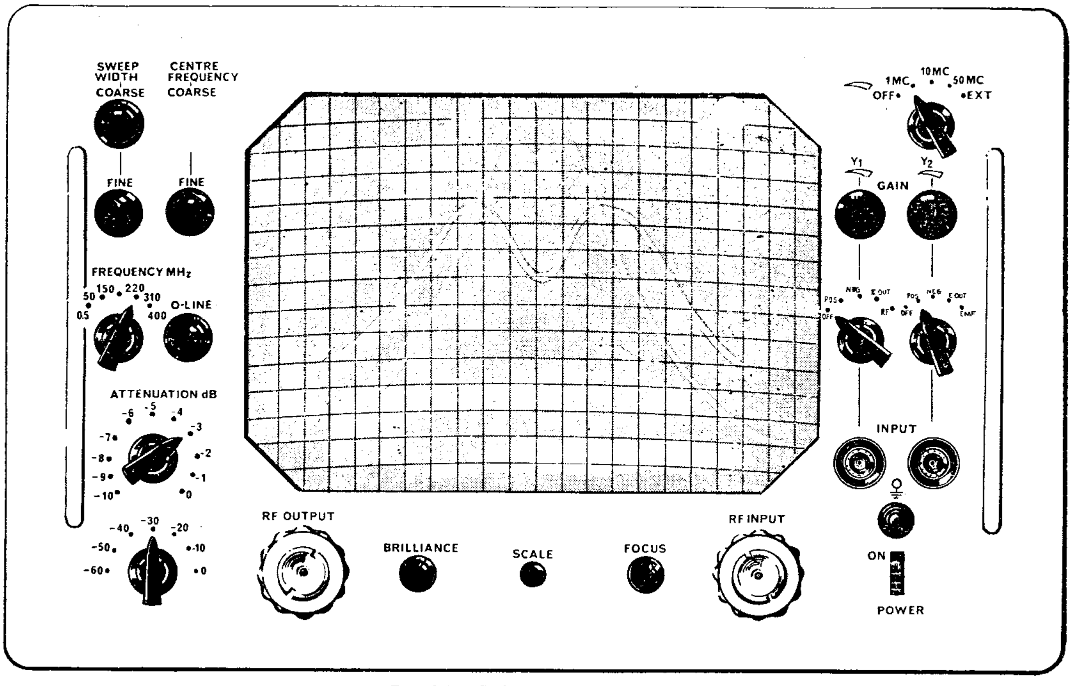


Fig. 14. Polyskop wobbulator

Pulse Generators

32. Pulsed waveforms have been used for many years in radar fault finding and they are now coming into general use for other equipments. Communication systems using pulse code modulation (PCM) are now common and all digital computers depend for their operation on pulse circuitry. The basic test equipment required is a pulse waveform generator with controls to vary the duration of the pulse (pulse width) and the pulse repetition frequency (P.R.F.). Modern amplitude modulated signal generators include provision for external pulse modulation of the r.f. signal so that the aerial input of radar systems can be simulated.

33. **Pulse generator CT564.** This test instrument is a versatile general purpose pulse generator. Provision is also made for the generation of accurately spaced double pulses which are often required for testing "coded" circuitry such as the Tacan and IFF systems. The output may be selected as either positive or negative pulses with the base line reference in either case of zero volts (earth). The output circuit is d.c. coupled to prevent sag on long pulses and has an output impedance of 100 ohms.

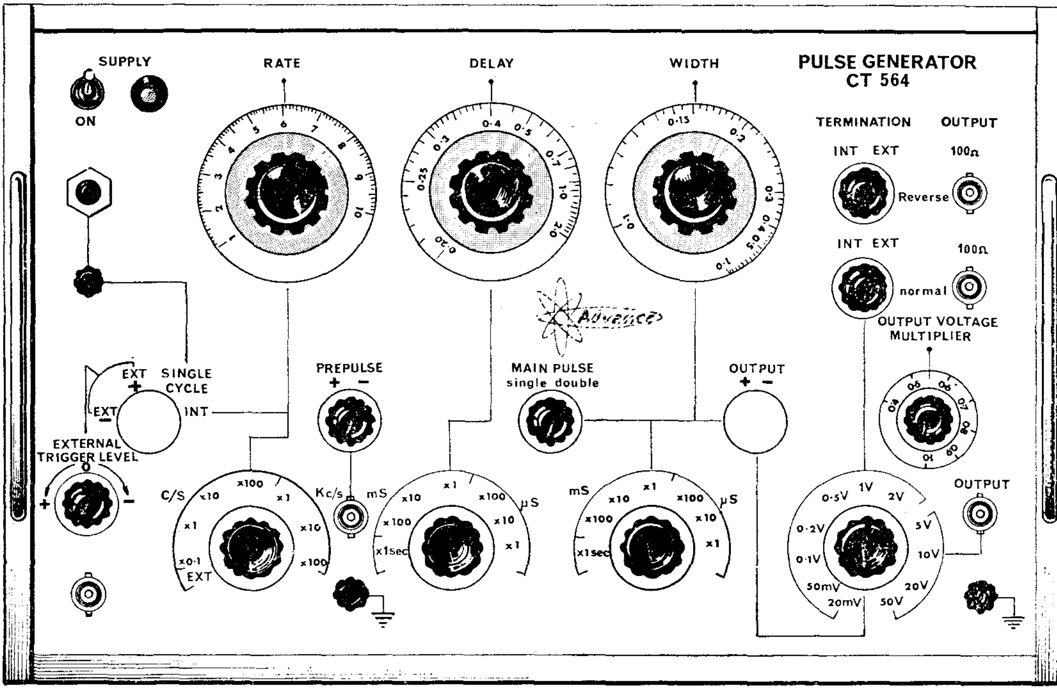


Fig. 15. Pulse generator CT564

34. **CT564 controls.** In addition to the normal pulse generator controls the CT564 is fitted with a calibrated pulse delay control. The output waveform is shown in figure 16.

a. PRF. Using the internal oscillator, any p.r.f. from 0.1c/s to 1Mc/s may be selected on the calibrated rate controls. External triggering can be selected and a variable level control enables any part of the input waveform to be selected as the triggering point in a similar way to the normal oscilloscope trigger controls (see chapter 3). The trigger selector switch can also be set to single cycle for "one-shot" operation.

b. Pulse width. Any pulse width between 0.1 microseconds and 1 second can be selected with an accuracy of $\pm 5\%$. By selection of p.r.f. and pulse width the output can be a square wave with any required mark/space ratio e.g. with p.r.f. at 1kc/s and pulse width of 500μS a symmetrical square wave will be obtained.

c. Pre-pulse. A 15V positive or negative prepulse is provided to trigger other test equipment such as an oscilloscope. This pulse occurs at least 40 nanoseconds before the main pulse to give the oscilloscope timebase a start so that the leading edge of the generator main pulse is visible.

d. Delay. The main output pulse may be delayed from the prepulse by any time from 0·2μS to 2 seconds with an accuracy of $\pm 5\%$. When the double pulse mode is selected this delay time sets the time between the leading edges of the two pulses.

A width 0·2 μs
B amplitude 15 V positive or negative
C rise-time 0·035 μs
D width 0·1 μs to 1 sec
E delay 0·2 μs to 2 sec
F amplitude 8 mV to 50 V positive or negative
G residual delay 0·04 μs
H rise-time 0·012 μs up to 2V

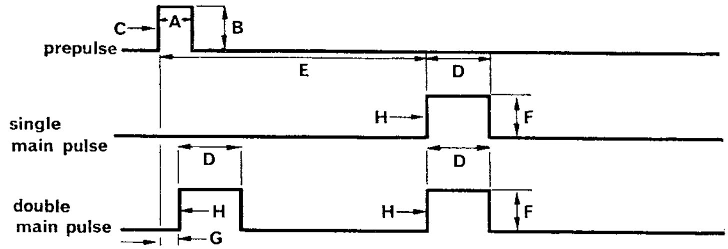


Fig. 16. Output waveforms CT564

CHAPTER 7

POWER MEASUREMENTS

List of Contents

Introduction

1. Power measurements made in the electrical and electronic trades can be conveniently divided into three separate types:

a. Primary power supply measurements. This type of measurement is carried out on the normally used power supplies. These are d.c. 28V, a.c. 400Hz, a.c. 1600Hz and the domestic mains supply at 50Hz. The powers measured are normally fairly large and most special power measuring instruments read in kilowatts.

b. Audio frequency measurements. These are normally carried out to measure the output of amplifier systems or of radio receivers. The frequencies measured range from 10Hz to about 30kHz. The power levels measured are usually fairly small and most instruments are calibrated in milliwatts. Some instruments are calibrated in decibels, usually using 1mW as the reference level.

c. Radio frequency measurements. The power output of radio transmitters is measured as an overall indication of performance. The frequencies involved cover the whole of the usable band, but as special instruments are needed for microwave measurements and for most radar measurements these will be considered separately.

POWER SUPPLY MEASUREMENTS

2. **Direct current.** Direct power measurement on d.c. power supplies is extremely rare. The power is usually calculated from voltage and current measurements as shown in figure 1 using the equation: **Power** (watts) = **Voltage** (volts) × **Current** (amps).

In most normal power supply checks it is usual to ensure only that the supply is capable of maintaining its rated voltage output under specified load conditions. Many generators are thus checked on test benches which simulate a resistive load greater than that which the generator would normally be expected to drive during use.

Where very high power levels are involved the power can be measured directly using a dynamometer wattmeter similar to that discussed under a.c. measurements.

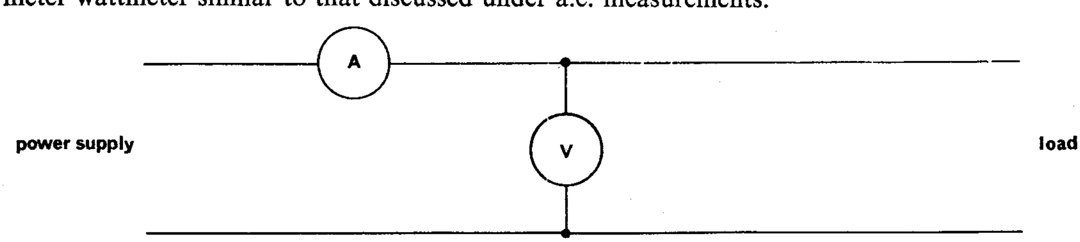


Fig. 1. Measurement of voltage and current

3. **AC power terms.** A full explanation of the terms used in a.c. power measurements will be found in AP3302 and AP3275 and the main terms are summarized below to prevent confusion.

a. True power or real power. This is the power in the circuit which is consumed by the resistive components of the circuit. Like d.c. power it is measured in watts and in a purely resistive circuit it is the product of the r.m.s. voltage and the r.m.s. current. In circuits containing both resistance and reactance it is the product of the r.m.s. voltage and the r.m.s. value of the *current component in phase with the supply voltage.*

b. Apparent power. In a.c. circuits containing both resistance and reactance the apparent power is the product of the r.m.s. voltage and the r.m.s. current and is measured in volt. amps. Some of this power is returned to the supply and is called the reactive power. The rest of the power is available to do work and is the true power. Apparent power is important in practical circuits as all leads, fuses and other components have to carry the total r.m.s. current flowing in the circuit whether it is doing work or not.

c. Reactive power. This is the part of the power which is returned to the supply. As it is due to reactive components he voltage and current are out of phase by 90°. It is often measured in vars (volt. amps-reactive).

d. Power factor. Power factor is the ratio of true power over apparent power and is always less than 1 in mixed circuits. In purely resistive circuits all power is consumed by the resistance so the power factor equals 1 and the apparent power is equal to the true power.

4. **Dynamometers.** Dynamometers are two-coil instruments used for the direct measurement of power in a circuit. The moving coil is connected across the circuit to be measured and is therefore known as the voltage coil. The fixed field coil assembly of the instrument is in series in the circuit and is known as the current coil. The reading obtained is proportional to the product of the voltage applied to the voltage coil and the component of current in the field coil which is *in phase with* the voltage applied to the moving coil. When measurements are made with a dynamometer the reading obtained is therefore the *true power* in the circuit.

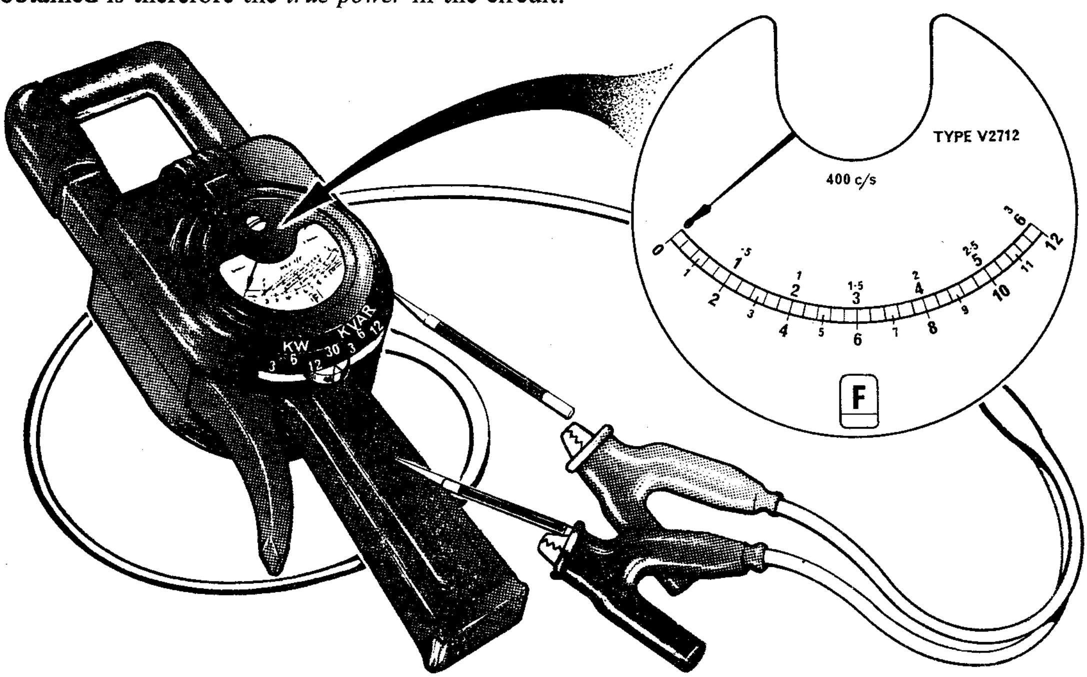


Fig. 2. Watt-varmeter (5QP/25748)

5. **Watt-varmeter (5QP/25748).** This instrument is a clip-on dynamometer wattmeter and was designed to measure loadings on normal 200V–400Hz aircraft electrical systems. It will measure the real and reactive loadings on three phase systems and the real loading of any single phase of these systems or of a single phase supply. The different ranges of the instrument are selected by means of a thumb-wheel rotary switch giving an overall measuring range from 0–30kW real power and from 0–12kVar reactive power. The instrument accuracy on all ranges is $\pm 5\%$ of full scale value at 400Hz, but the instrument is frequency sensitive and an additional error will be present if the frequency is not 400Hz. Cartridge fuse links (5A) are fitted in the clips of the voltage leads to protect the instrument from overload damage.

6. **Real power measurements (kW)**

a. Single phase—2 wire. Set the range selector to the 30kW position. Open the core by pressing the trigger and clip the instrument round the line conductor. Connect the voltage clips (or probes) across the supply. A reading of true power taken by the load will be obtained. If the reading is too small select a lower range. If a reverse reading is obtained, correct by reversing the current core. Most accurate results will be obtained if the line conductor is held central in the current core aperture.

b. Three phase—3 wire. Connect the wattmeter to the red line as shown. If a reverse reading is obtained, correct by reversing the current core. Note the direction of the line conductor through the core and meter reading W1. Transfer the meter to the blue line, taking care that the line passes through the current core in the same direction as for the red line. Note the reading W2. If a reverse reading was shown, reverse the current core. If W2 was obtained without reversing the meter, the total power is W1 + W2. If the meter had to be reversed, the total power is the difference between readings W1 and W2.

c. Three phase—4 wire. Obtain a reading for each of the lines as before. The total power consumed will be the sum of these three readings in any system. For a balanced system, any one of these readings can be multiplied by three to obtain total true power. A supply system can be checked for balance by comparing the three line-power readings obtained.

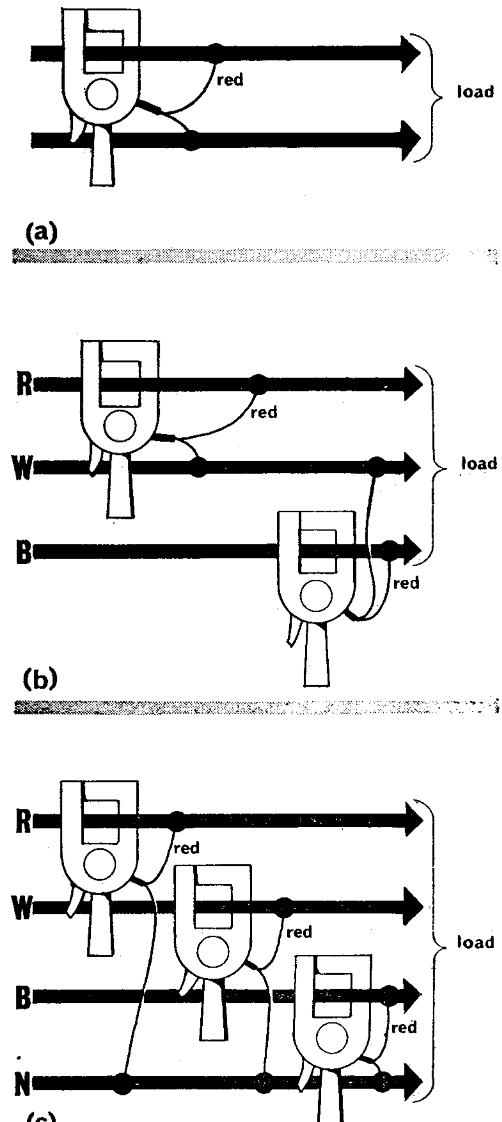


Fig. 3. Real power measurements

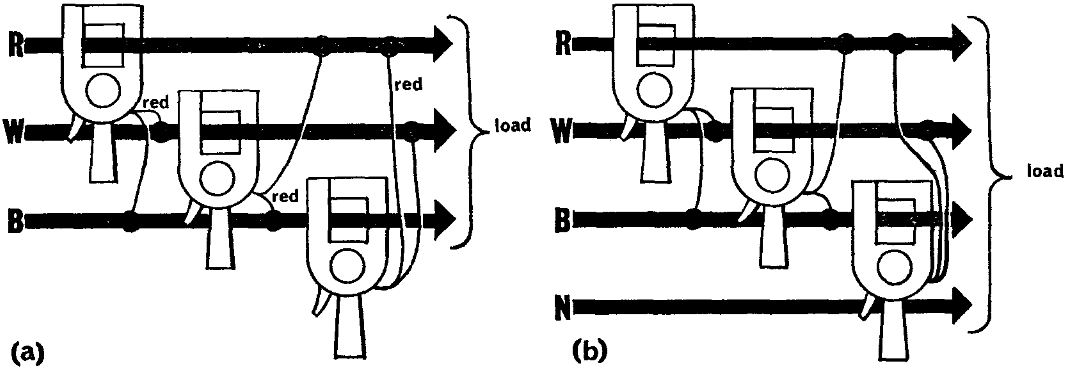


Fig. 4. Reactive power measurements

7. **Reactive volt-ampere measurements.** Normally three phase reactive volt-amp measurements are made with the current coil in the line conductor (say red) and the voltage leads are connected across the *other two* conductors (white and blue). This means that the potential difference across the voltage coil is *in phase* with the reactive component of the current in the red line, and the meter will measure reactive power (kVar). An extra resistance is automatically introduced in the voltage leads when switched to kVar to correct for the increased voltage obtained by connecting across two phases ($\sqrt{3} \times$ line volts). The meter will read reactive power directly in kVar when connected as shown in figure 4.

AUDIO FREQUENCY POWER MEASUREMENTS

8. **Decibels.** Because the human ear responds more readily to ratio changes than to absolute changes a unit known as the bel (B) was originated for audio power measurements. Measurements are normally made in terms of a smaller more practical unit, the decibel (dB), which is one tenth of a bel. Decibels indicate a ratio change of power and are therefore very useful as a measure of how an electronic device affects the transmission of energy through itself, i.e. of the devices efficiency. If a certain amount of power Pin is injected at the input terminals and, as a consequence a power Pout is then available at the output terminals:

$$\text{Power GAIN} = 10 \log_{10} \frac{\text{Pout}}{\text{Pin}} \text{ decibels} \quad \text{or} \quad \text{Power LOSS} = 10 \log_{10} \frac{\text{Pin}}{\text{Pout}} \text{ decibels.}$$

If the network provides a loss (e.g. an attenuator), the second equation above can be used to avoid the complications of negative logarithms; in this case a loss is expressed as a negative gain e.g. as -10dB. Since the decibel is a logarithmic unit, the gains and losses of complicated circuits can be added algebraically to determine the overall circuit performance.

9. **Reference level.** It should be clearly understood that the term decibel does not, in itself, indicate power but only a ratio between two power levels. It is often desirable to express an absolute power level in terms of decibels using a fixed power level as the reference. To simplify calculations a standard reference level of 1 milliwatt has been adopted and the unit dBm is used for power ratios with respect to 1mW. A few commonly encountered values are included for clarification:

A change of 3dB just about doubles or halves the power.

A change of 10dB equals 10 times (10dBm equals 10mW, -10dBm equals 100μW).

A change of 20dB equals 100 times (20dBm = 100mW).

A change of 30dB equals 1000 times (+30dBm = 1W, -30dBm = 1μW).

It should also be borne in mind that in any *given load* power is proportional to the square of the voltage across the load; therefore a power gain of 20dB means a power gain of 100:1 which, in terms of voltage, is a voltage gain of 10:1.

Absorption Wattmeters

10. Dynamometer wattmeters of the type discussed in the previous paragraphs can not be used for general measurements because of the changes in coil reactance with frequency. To overcome this disadvantage an indirect method of power measurement using a resistive load and a voltmeter (or ammeter) must be adopted. This class of instruments are known as direct reading absorption wattmeters and normally measure the voltage across a known value of load resistance (internal) with the meter calibrated directly in power to eliminate calculation ($P = v^2/R$).

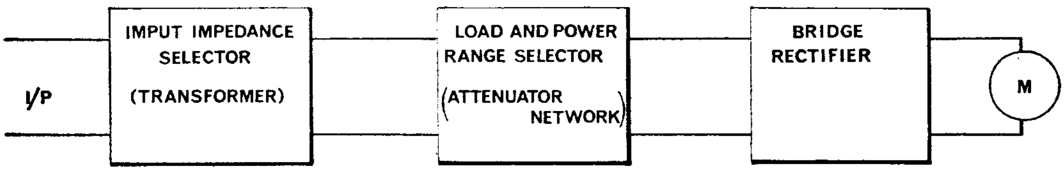


Fig. 5. Absorption wattmeter

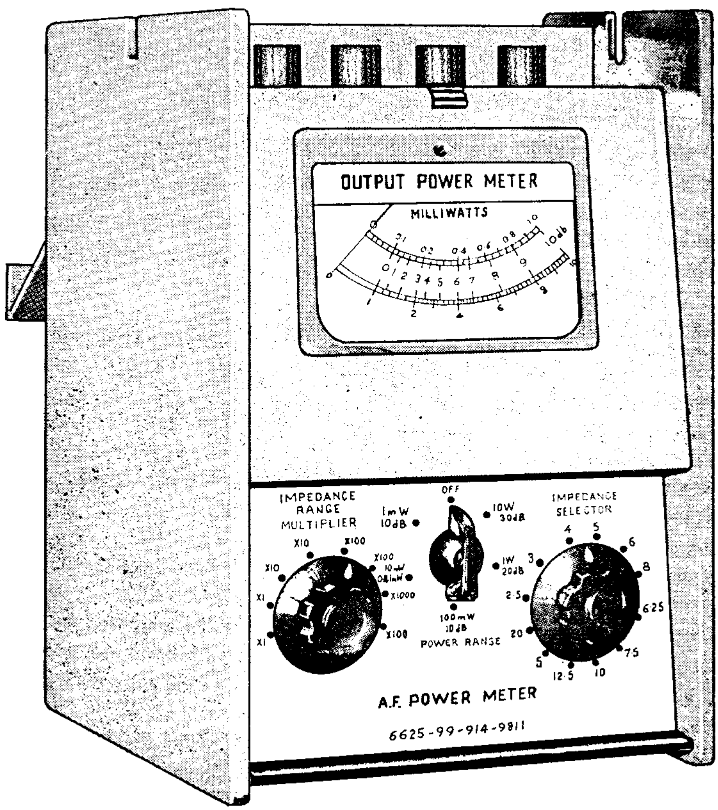
11. A simplified block diagram for an audio frequency absorption wattmeter is shown in figure 5. Similar instruments designed for radio frequency measurements are also available and will operate from d.c. to about 500MHz.

a. Input impedance selector. During a.f. power measurements the wattmeter takes the place of the normal output load of the device under test. It must therefore be provided with an adjustable input impedance so that a "matched" load can be selected. This is usually obtained with a tapped transformer and/or resistance network and impedance values from about 1 ohm to 25 kilohms are normally available. Because of the transformer inductance, the frequency band over which a.f. wattmeters will operate is restricted usually to 20 or 30kHz. As radio frequency absorption wattmeters are used to measure the output power of transmitters the impedance selector stage is normally omitted and a fixed load of either 50 ohm or 75 ohm impedance is used.

b. Attenuator network. Most a.f. wattmeters are multirange instruments capable of measuring powers from about 1mW to 10W in five or six ranges. This range switching is carried out by a resistive attenuator network which also supplies suitable series resistors (multipliers) to correct the voltmeter reading for the different ranges available. In r.f. wattmeters the attenuator section is omitted and a specially designed fixed load (50Ω) is used which has a suitable tapping point for the meter connection.

c. Meter circuit. A moving coil meter fed from a bridge rectifier circuit is normally used in a.f. wattmeters operating only over the frequency band below 20kHz. In radio frequency instruments a wide-band thermocouple type of meter is more common; and on double range r.f. wattmeters the meter reading is corrected by suitable multipliers. In general the measurements obtained from absorption wattmeters are accurate to about 3% of the full-scale deflection reading.

12. **AF absorption wattmeter.** The instrument shown in figure 6 is a typical example of a general purpose a.f. absorption wattmeter. It is completely portable, no power supplies are required, and all power fed to the instrument is dissipated in the internal load. Readings are given in watts and in dBm; to obtain a dBm reading the scale reading is added to the dB number shown on the range switch. For any reading to be true the impedance selector switch must be set to the position which matches the output impedance of the device under test. The input waveform must also be *sinusoidal* for the meter calibration to be accurate and it is often prudent to monitor the input on an oscilloscope to ensure that distortion is not excessive, and that the waveform remains sinusoidal under load conditions.



Frequency range 20Hz–35kHz

Power ranges 0 – 1mW f.s.d.
0 – 10mW
0 – 100mW
0 – 1W
0 – 10W

Accuracy
±2½% f.s.d.(readings under ½ scale)
(or ± 5% of readings above ½ scale)

Impedance range 2·5Ω – 20,000Ω
(using input centre tap gives one quarter of the impedance selected)

Fig. 6. Wattmeter absorption AF (6625–99–914–9811)

RADIO FREQUENCY MEASUREMENTS

13. **Aerial excitation monitors.** At radio frequencies up to about 60MHz it is possible to measure the transmitter power by measuring the current flowing into a resonant aerial system, provided that the effective resistance of the aerial is known ($P = I^2R$). Although this method is not a very easy way of measuring absolute power output, it does enable a very simple routine monitoring system to be permanently connected to m.f. and h.f. transmitters. A thermocouple ammeter and shunt is connected in series in the earthy side of the aerial feed, or in series with the feeder transmission line to the aerial, and gives a direct reading of aerial excitation current. As well as acting as a performance monitor the meter enables the aerial coupling circuits to be set up for maximum power output after the transmitter has been retuned. Where a meter is fitted in each line of a balanced aerial feed the currents can be adjusted for equality as a method of maintaining line balance.

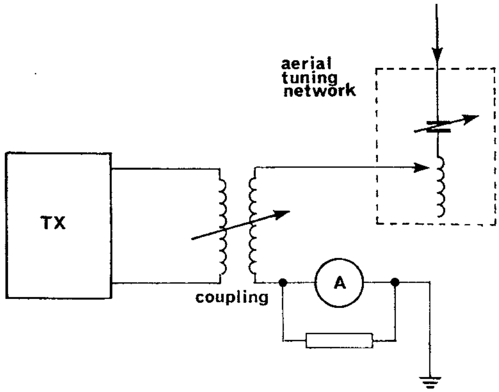


Fig. 7. Aerial current monitor

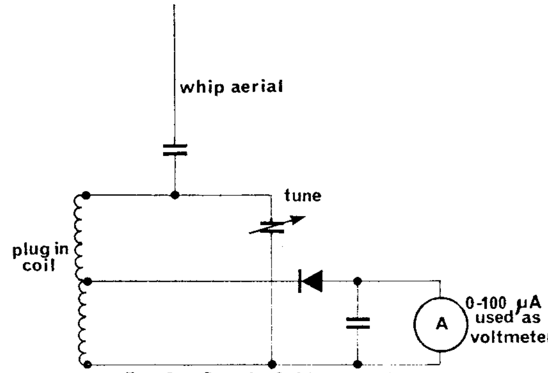


Fig. 8. Simple field strength meter

14. **Field strength meters.** Field strength is measured in volts per metre. Since most field intensities are very small it is usually more convenient to measure in terms of microvolts or millivolts per metre. Thus a 1mV potential difference would exist on a whip aerial 1 metre long in a 1mV/metre field, assuming that the direction of the aerial lies in the direction of the greatest rate of potential change of the field. Simple instruments of the type shown in figure 8 are often used to make routine relative field measurements as a check on the performance of the complete radio system including the aerial installation.

15. **Radio frequency absorption wattmeters.** These instruments operate on the principle described in para. 11 and contain a specially designed r.f. load. They usually operate over the whole band from d.c. to about 500MHz and do not require any external power supplies. As the whole of the transmitter output is absorbed by the internal load they should not be left connected for longer than is necessary to make the power measurement. The instruments shown in figure 9 are typical examples of portable transmitter output power meters; the CT418 is a dual range instrument capable of measuring powers up to 25 watts, and the larger CT401 will measure up to 500 watts provided the maximum input voltage is less than 500V.

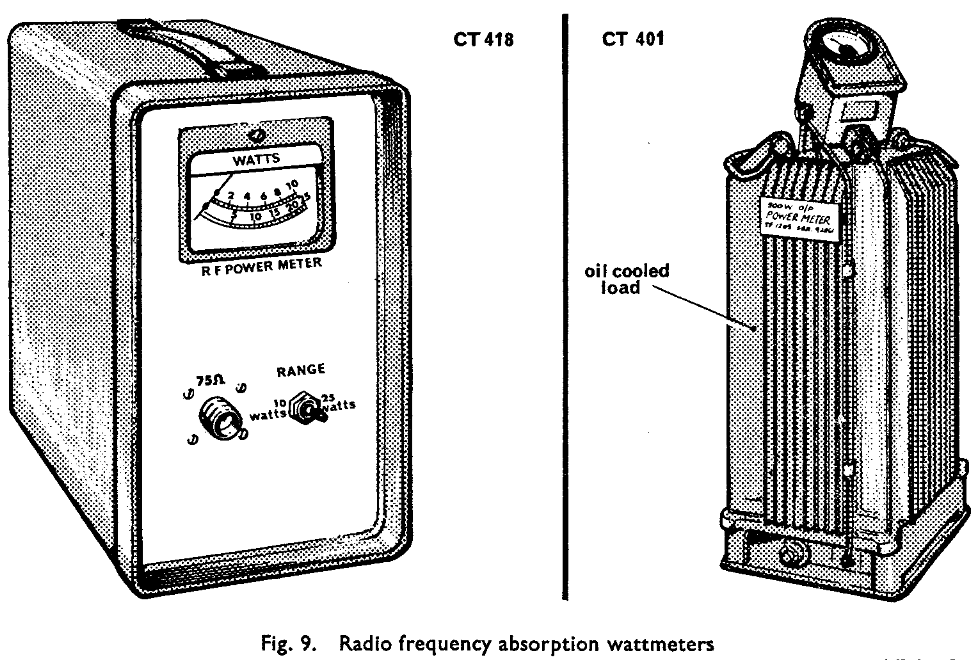


Fig. 9. Radio frequency absorption wattmeters

16. **Modulation depth measurement.** As the meter used in most radio frequency wattmeters such as the CT418/CT419 is a thermocouple instrument, the reading obtained will be the true mean power irrespective of the input waveform shape. The meter will therefore respond to the change in power level when amplitude modulation is applied to the input signal. The modulation depth can be calculated as follows:

a. Measure the output power of the source with the signal unmodulated. Let this reading be P_{cw} watts.

b. Modulate the signal and again measure the output power. This reading is P_m watts.

c. Calculate, using log tables

$$\text{Modulation depth} = \sqrt{\frac{20000\,(P_m - P_{cw})}{P_{cw}}}\ \%$$

UHF AND SHF MEASUREMENTS

17. **Thermal measurements.** At these high frequencies, current and voltage values depend on the point of measurement along a transmission line or waveguide. They are almost impossible to measure with any accuracy as any measuring device used affects conditions on the line to a certain extent (see AP3302—standing waves). Power, on the other hand, is independent of the measuring position and is therefore the fundamental measurement at these frequencies. It is normally measured by the use of a thermally sensitive element in a specially designed "head" or "mount" coupled directly into the line or waveguide. The temperature rise is caused by absorption of the incident r.f. power at the element. This type of device is only suitable for the measurement of *low power* levels, up to about 5mW; but the instruments are commonly used in conjunction with attenuators and samplers for the measurement of all except the very highest power levels. For measuring extremely high powers a calorimeter must be used in which the r.f. power is used to heat up a dummy load, such as a water bath. The power level is then calculated from the temperature rise in a given time.

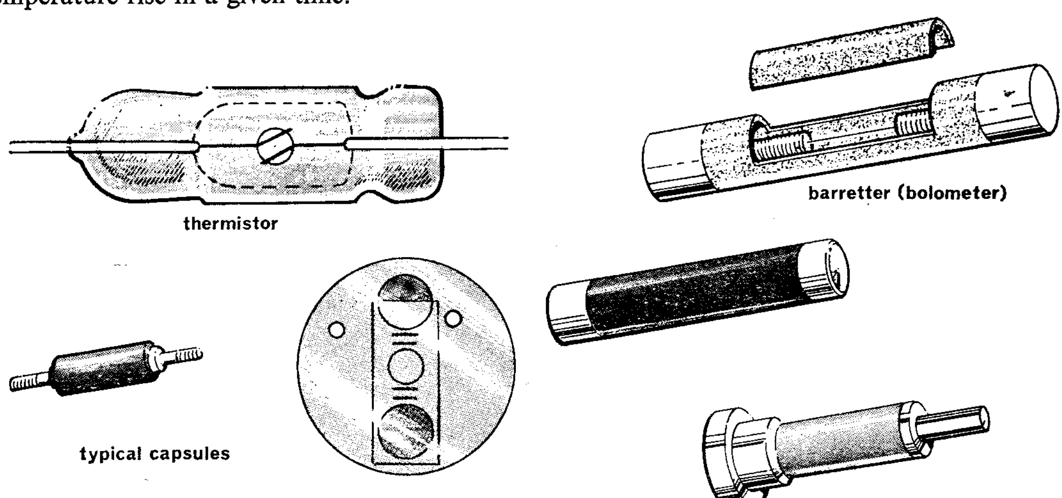


Fig. 10. Thermal elements

18. **Thermal elements.** The two thermal elements in common use are the thermistor and the bolometer (see figure 10), both of which depend on the change in resistance of the element with temperature. Some test instruments also make use of specially designed thin-film thermocouple elements mounted directly in a waveguide section to measure either average or peak pulsed powers, depending on the instrument circuit arrangement.

a. Thermistors. Thermistor elements are used almost exclusively for the measurement of average powers. The active part is a small bead of semiconductor/ceramic material, mounted on fine wires inside a glass or ceramic capsule. They have a negative temperature coefficient of resistance i.e. as they heat up their resistance decreases, typically by about 5 ohms for 100 microwatts of incident power. They have a long time constant, typically about 100 milliseconds. Thus the resistance change depends only on the average r.f. input power and they are used to measure c.w. powers or mean powers of pulsed sources.

b. Bolometers. Bolometers consist of a very fine strand of platinum or tungsten wire mounted in a ceramic capsule. They have a positive temperature coefficient and their resistance increases by typically 2 or 3 ohms for 1mW of incident r.f. power. They have a much shorter time constant than thermistors, typically about 200 microseconds, but are less rugged and therefore not so commonly used. The circuit arrangement normally used is a resistance bridge for measuring mean powers. Instruments are made for direct measurement of peak power using bolometers with differentiating amplifiers and peak-reading valve voltmeter circuits. The alternative name for these devices is barretters.

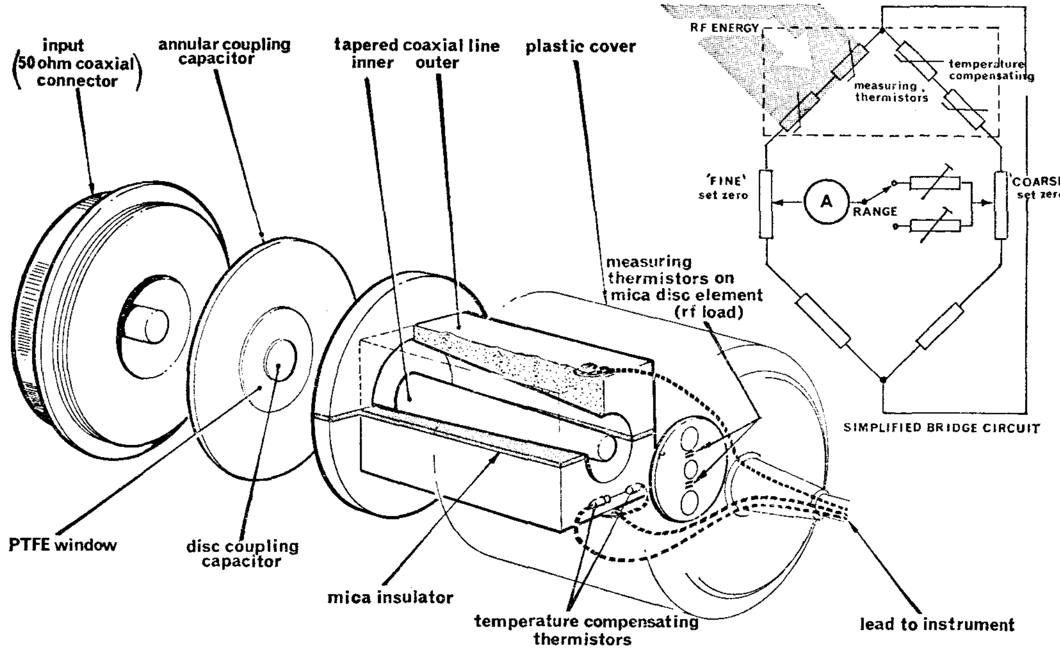


Fig. 11. Typical thermistor mount

19. **Typical mount.** Figure 11 shows a typical thermistor mount. The measuring element is a mica-disc capsule containing two thermistors, each of which has a "normal" resistance of 100 ohms with the bridge balanced at room temperature. To the incident r.f. these are mounted in parallel between the inner and outer conductors of a tapered coaxial line and thus present a matched load of 50 ohms. To the measuring instrument they are in a series and give a bridge arm resistance of 200 ohms. Also in the mount are two temperature compensating thermistors which form another arm of the measuring bridge. These thermistors are not affected by the r.f. but will change resistance with ambient temperature in the same way as the measuring thermistors thus preventing zero drift of the instrument with temperature.

Wattmeter Type 14441

20. This is a portable battery operated thermistor bridge wattmeter which indicates true mean power on a linear scale (see figure 12). Two ranges are provided, from 50 microwatts to 1 milliwatt, and from 0·25 milliwatt to 5 milliwatts with an accuracy of about 5 %. Fixed 30dB attenuators are available enabling powers up to 5 watts to be measured. The frequency range covered by the instrument is from 500MHz to 5000MHz and the impedance presented to the power source is 50 ohms. When the attenuators are used they must be tuned to the frequency of the source and the reading must be corrected by reference to the calibration chart fitted to the attenuator. Only the thermistor head which bears the same serial number as the instrument may be used as the bridge is preset for that particular head.

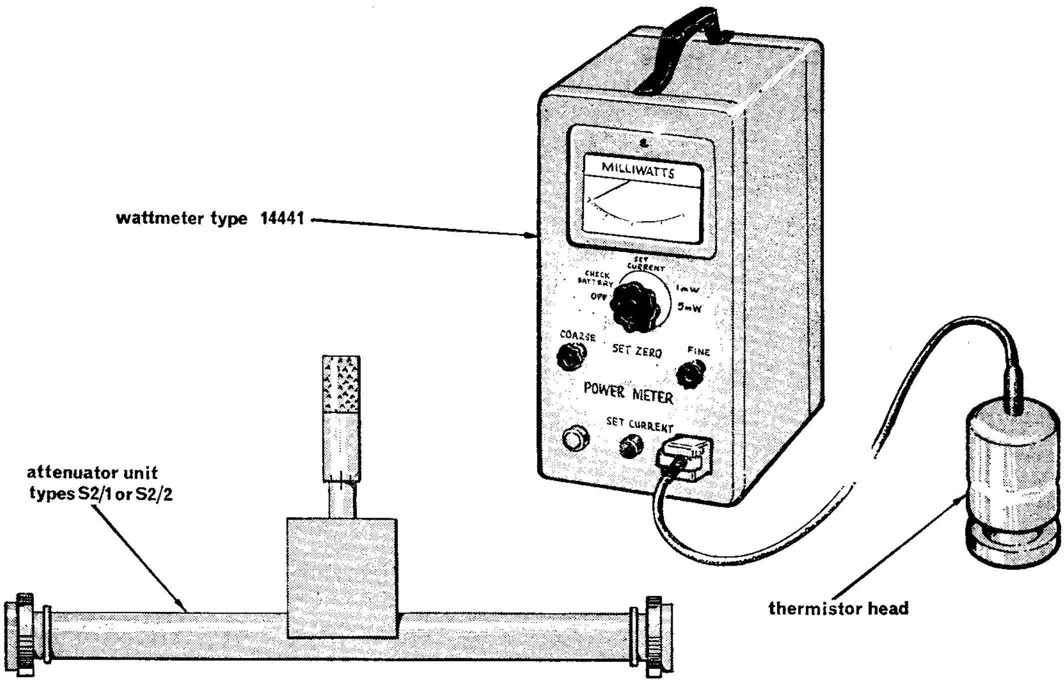


Fig. 12. Wattmeter type 14441

21. **Operation.**

a. If necessary, mechanically zero the meter.

b. Connect the thermistor head to the socket on the meter and check serial numbers.

c. Set the selector switch to the "check battery" position and ensure that the meter is above the "battery limit" mark. If not, change the batteries.

d. Set the selector switch to the "set current" position and if necessary adjust the set current preset potentiometer so that the meter reads between the two lines marked "set current" on the scale. This adjusts the working resistance of the thermistors to give the best possible voltage standing wave ratio.

e. Allow a warm up period of about 10 minutes and repeat *d.*

f. Select the appropriate range and adjust the coarse and fine zero controls for zero reading on the meter.

g. Connect the thermistor head to the power source under test and switch on the power.

h. Read directly from the scale on the 1mW range; multiply by 5 on the 5mW range and apply the correction factor if an attenuator is being used.

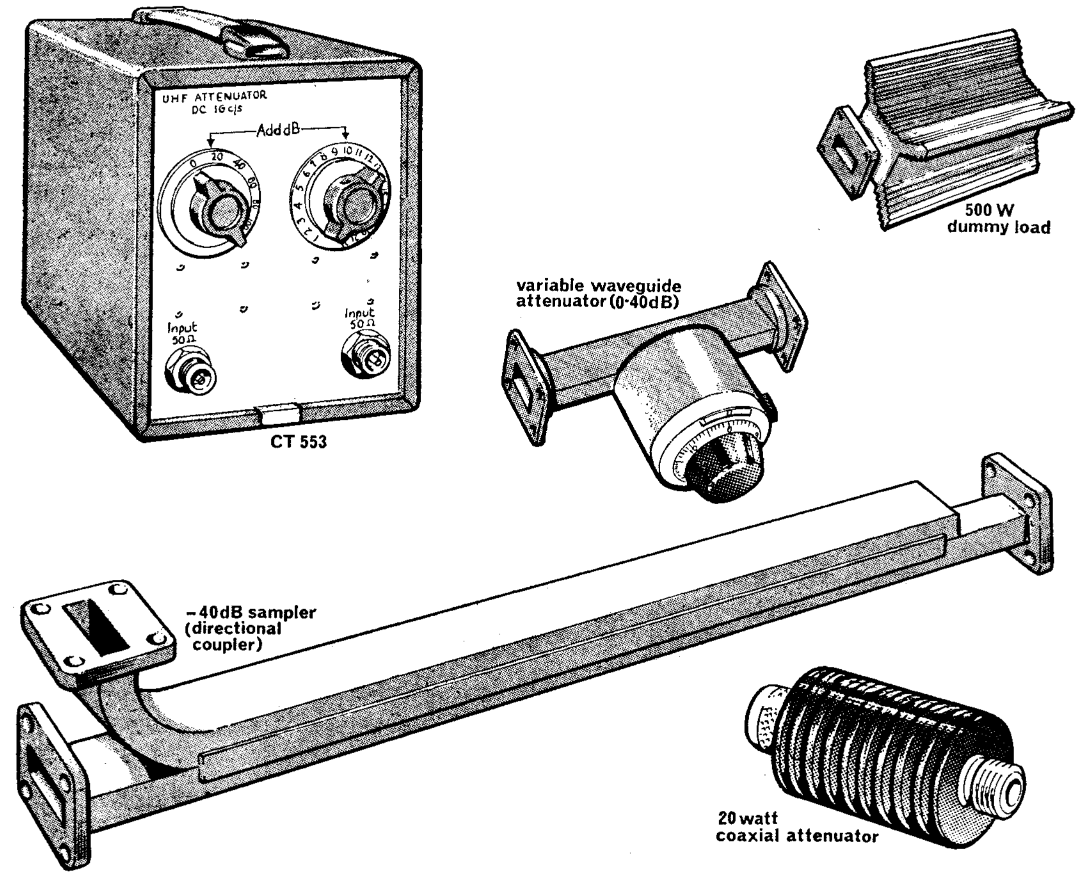


Fig. 13. Attenuators and samplers

Attentuators and Samplers

22. To extend the range of thermal wattmeters, a wide range of fixed and variable attenuators is available. At microwave frequencies, particularly where high power levels are involved, it is usual to use directional couplers to measure a known sample of the power output from the source under test. Typical attenuators and couplers are shown in figure 13. Attenuators dissipate part of the applied power in a built-in load and this sets a limit to the *maximum* power which can be applied, and often to the time for which this power may be applied. The maximum power, both *average* and *peak*, which may be applied to a given attenuator input is always given in the specification and must not be exceeded as severe overheating will almost certainly damage the device. Directional couplers are usually used in waveguide systems and do not suffer from this limitation as the input power is only sampled and the excess is radiated from the aerial or dissipated in a separate dummy load. At the higher microwave frequencies most attenuators and couplers will only work satisfactorily at the frequency for which they were designed, but some are fitted with a tuning mechanism to correct their effective length for use at different frequencies. The accuracy of power measurements made through attenuators or couplers is *less than* direct measurement as the error introduced by the coupler has to be added to the instrument error. Most attenuators and couplers have an error of ±0·1dB up to about 0·8dB which in terms of power uncertainty is from about 2% to about 20%. The switched attenuator shown in figure 13 (the CT553) will provide any attenuation from 0 to 142dB in 1dB steps and has an accuracy of about 5% (±0·2dB) at frequencies up to 1000MHz.

RADAR MEASUREMENTS

23. **Peak power.** The performance of a primary radar system depends mainly on the *peak power* transmitted in a fairly short pulse, but this is difficult to measure directly because of the very high power levels and the very short time intervals involved. It is more usual to measure the average power of a radar transmitter by one of the methods already mentioned, and to calculate peak power from this measurement and separate measurements of pulse width and pulse repetition frequency obtained from a good oscilloscope.

Then:

$$\text{Peak Power} = \frac{\text{Average Power}}{\text{PRF} \times \text{PW}}$$

The accuracy of the peak power calculated in this way is unlikely to be better than $\pm 10\%$, as possible errors in measurement of PRF and PW have both to be added to that of the average power measurement. Because of the high peak powers present in most radar systems it is often necessary to use a directional coupler in the average power measuring system and this can introduce a further error of up to 10%, giving a total uncertainty of about 20%. There are, however, a number of very simple monitoring techniques which enable the performance of a radar to be evaluated without actually measuring peak power. These monitors will be discussed in the following paragraphs as they are in extremely common use. They are capable of reading the absolute peak power directly by initial calibration using calorimetric techniques but they usually only give a "relative" or "go—no go" type of reading.

24. **Detector monitors.** Detectors are the simplest method of monitoring power and are often built-in to radar systems. When connected to a suitable load and milliammeter they can be calibrated to monitor average power. Sometimes shaping circuits and a peak-reading voltmeter are used to monitor the peak power.

a. Crystal detectors. The waveguide crystal detector is already built-in to radar receivers and is often arranged so that the detector current can be monitored as a check on the local oscillator performance. At centimetre wavelengths the sensitivity is about 1mV/mW with the optimum load impedance. The load is critical and if an external meter is used to monitor crystal current it must be of the type specified in the equipment handbook, or be fitted with suitable shunts to present the correct load to the detector.

b. Barretters. Barretters have a fairly short time constant and can be used as detectors in pulsed radar monitors. The output waveform is differentiated, amplified and used to operate a peak reading voltmeter calibrated in peak power. Crystal diodes can be used in a similar way. The power level at which both these devices operate is fairly low and suitable directional couplers must be used to prevent burn-out.

c. Vacuum diodes. Specially constructed vacuum diodes are made for mounting in the waveguide as peak power monitors up to fairly high peak power levels. An output of about 100 volts is obtained for power inputs of about 15kW peak at 10GHz. These diodes are stable over several thousand hours and, if calibrated, will give a true peak power reading.

d. Thermocouples. Fine-wire thermocouples are sometimes used to monitor high power levels. The thermocouple itself forms a small loop coupled to the magnetic field in the waveguide and the output is used to drive a low resistance meter, calibrated directly in power. Thin film thermocouple elements are being developed to operate peak reading power meters similar to the average reading meter described in paragraph 20. Experiments are also being carried out using thermoelectric cooling of a waveguide termination to balance out the heat produced by the incident microwave power.

25. **RF radiation hazard.** Many radar installations, particularly those working at microwave frequencies, operate at a power level high enough to be a health hazard. Damage is caused to the body tissues by the production of heat; the eye being particularly sensitive and any prolonged exposure may cause blindness (cataract) without the appearance of acute symptoms at the time of exposure. It is *extremely dangerous* to look into a waveguide or directly into a scanner while the power is switched on. To prevent accidental exposure to RF radiation two types of hazard areas have been defined. An RF danger area is one in which a person may be exposed to radiation in excess of 100mW/sq. cm and entry to such areas is prevented by physical barriers such as fences and locked gates. An RF restricted area is one in which a person may be exposed to radiation exceeding 10mW/sq. cm but not exceeding 100mW/sq. cm. Maintenance of the installation will often involve entry to this area and all personnel must be familiar with the points of greatest hazard and the safety precautions required.

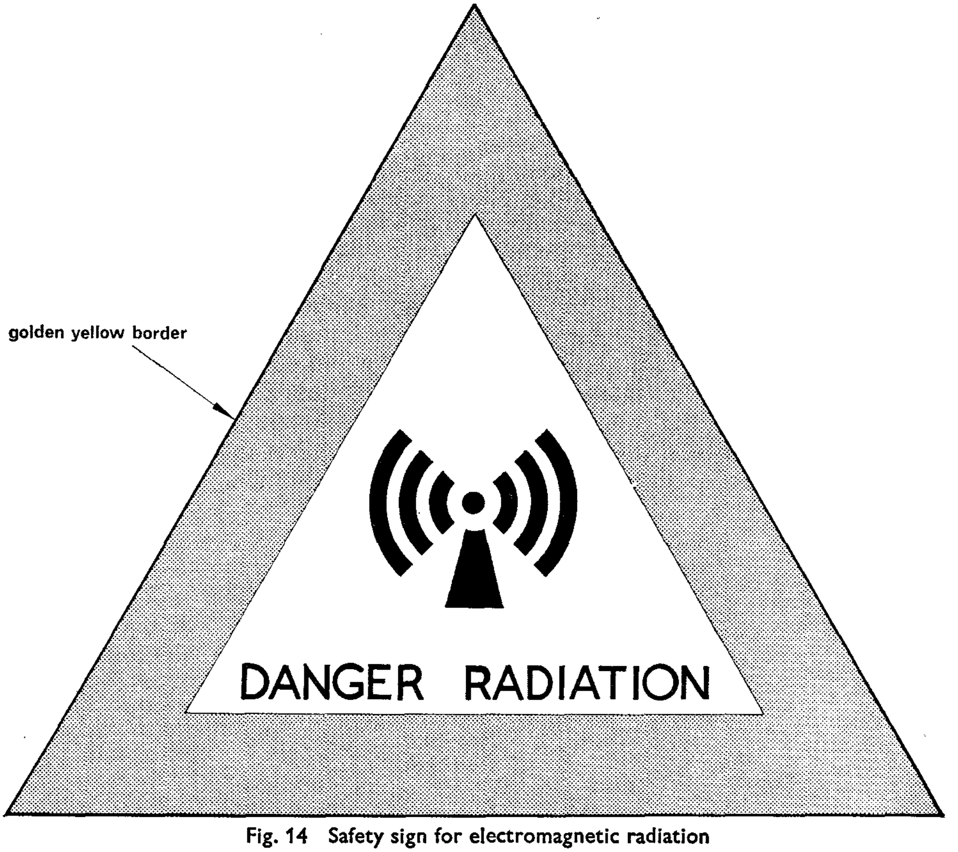


Fig. 14 Safety sign for electromagnetic radiation

26. **Safety sign.** The use of electronic and electrical apparatus which can produce electromagnetic fields at high radio frequencies, or other radiation of a non-ionizing nature, that may affect health, is increasing. Examples of such equipments are high power radio transmitters, microwave radars, infra-red 'searchlights' and lasers. A distinctive sign (*see* Fig. 14) has been produced by British Standards to indicate the actual or the potential presence of such radiation. The symbol and lettering are black on a white background surrounded by a golden yellow triangle.

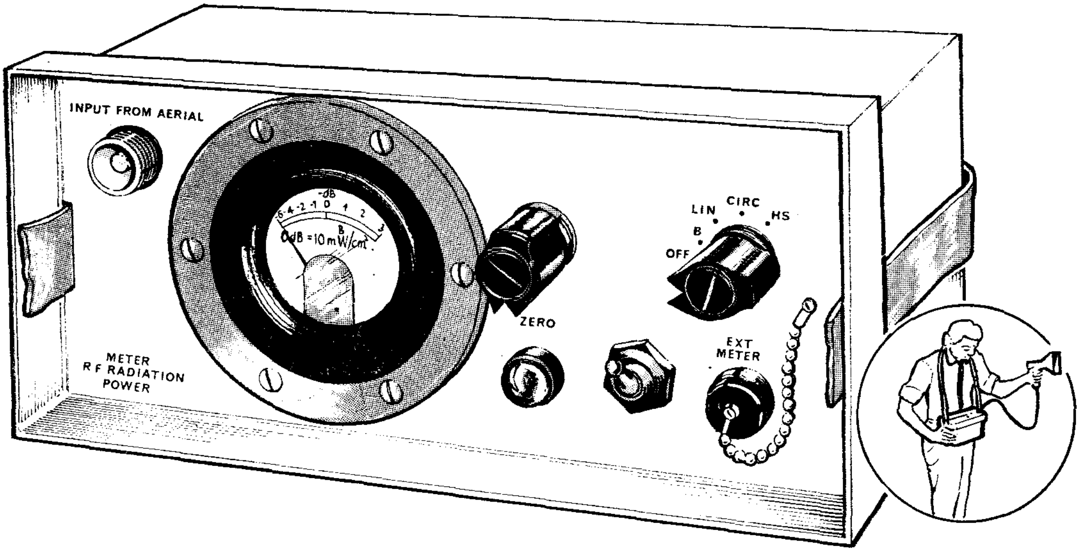


Fig. 15 Radiation hazard monitor CT477

27. **Radiation hazard monitor CT477.** This is a portable radiation power monitor operating on the thermistor bridge principle. It is designed to measure intensities between 2mW/sq. cm and 20mW/sq. cm and can thus be used to check the boundaries of an RF restricted area. Aerials are available for the L, S and X bands and are connected to the meter through special connectors which compensate for the aerial size. The meter normally has a time constant of one second to enable average readings to be taken on rotating aerial systems, but this can be switched out by the operator to assist in aerial orientation. A high sensitivity position is also available to assist in finding weak fields.

SECTION 5

TESTING AND SERVICING

CHAPTER 1

ALUMINIUM ANODE FOIL ELECTROLYTIC CAPACITORS

List of Contents

Introduction

1. Aluminium anode foil electrolytic capacitors have their positive and negative electrodes made from aluminium foil. These are normally separated by paper impregnated with a suitable conducting liquid, or paste, which forms the electrolyte. The dielectric is a thin film formed on the positive electrode by electrolytic action. Deterioration of this film, usually during storage, will allow an excessive leakage current to flow through the capacitor when it is put into use. This will cause overheating of the component and in extreme cases may cause it to explode. To prevent this happening, electrolytic capacitors are reformed prior to issue by MUs and ARSUs. Equipment in which they are installed is issued with a label attached stating the date on which power was last applied to the equipment.

2. **Leakage Current.** The maximum value of leakage current which should flow through a serviceable electrolytic capacitor can be calculated from the formula:

Leakage current (microamps) $= 0{\cdot}15CV$ Where C is in microfarads and V is in volts (working voltage).

During reforming the leakage current flowing through the capacitor will gradually decrease to this value, and the reforming can then be said to be complete.

Servicing Regulations

3. The regulations governing the servicing and reforming of electrolytic capacitors are laid down in AP 3158, Vol 2, leaflets H13 and H14. The major points are below:

a. If piece part capacitors have been stored or unused for a period exceeding 5 years they are beyond reforming. Such capacitors must be mutilated and scrapped to prevent accidental use by any other tradesman.

b. Piece part aluminium anode foil capacitors which have been stored for a period of one year or more since the date of manufacture must be reformed by MUs and ARSUs prior to issue, and the date of reforming must be attached to the capacitor.

c. Components containing aluminium anode foil capacitors need not be specially tested prior to issue but must have a label attached stating when power was last applied.

d. The date of manufacture is marked on capacitors in a simple date code. A four digit figure is used where the first two digits represent the year of manufacture, and the second two digits the week of that year, *eg* 7004 = 1970, fourth week.

4. **Safety.** Old electrolytic capacitors may explode when power is first applied. Great care must be taken to avoid operator injury when switching on equipment which has been stored. During reforming, the capacitor should be shielded, preferably by the lid of the special reforming unit.

Reforming Methods

5. **Method.** In order to reform an electrolytic capacitor a d.c. current of the correct polarity must be passed through it for a period of time depending on the condition of the capacitor. This current should be as low as possible and must be carefully controlled to prevent overheating the component. A suitable reforming circuit is shown in figure 1. The value of the variable resistor is gradually reduced during the reforming, keeping the leakage current less than the permitted maximum. The resistor should not be reduced beyond the point where the voltage across the capacitor reaches the working volts. The leakage current indicated on the ammeter with the working voltage applied must be less than the value calculated from the formula in para 2 or the capacitor is unserviceable.

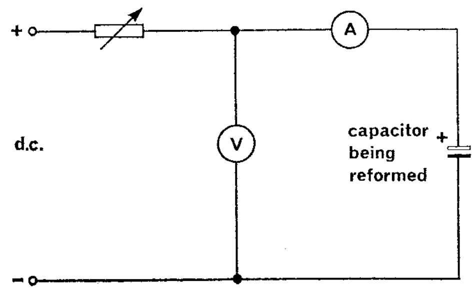


Fig 1 Reforming circuit

6. **Reforming unit, electrolyticc apacitor, number 1.** This is a test set supplied to measure the leakage current flowing through an electrolytic capacitor and if necessary to reform the dielectric.

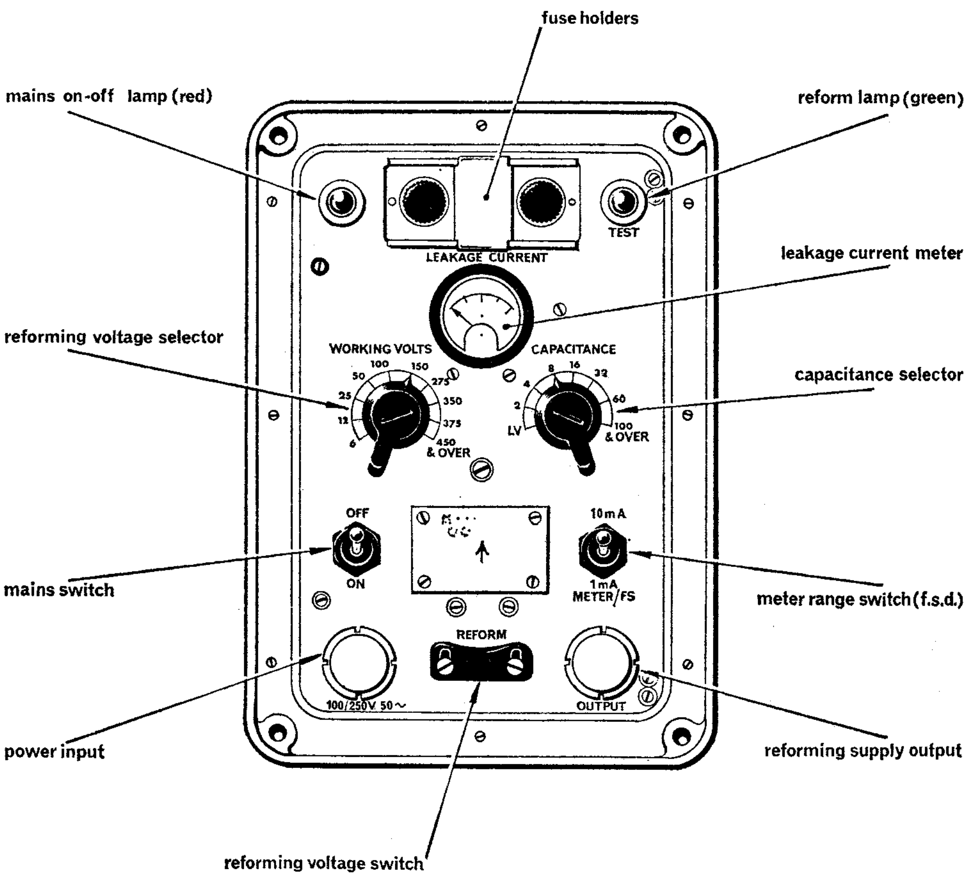


Fig 2 Reforming unit, electrolytic capacitor, number 1

Only one capacitor may be serviced on the unit at a time. The lid of the test set has special compartments into which the capacitor may be fitted during testing. These are designed to act as blast shields and thus prevent personal injuries to the operator in the event of an accidental explosion.

Testing—Leakage Current

7. The capacitor to be tested must be placed in the lid of the test set and connected to the output socket using the leads provided. It is essential that the red crocodile clip is connected to the positive terminal of the capacitor and the black clip to the negative terminal. If the capacitor is installed in an equipment, all other connections to the capacitor must be disconnected before the test leads are connected. If the d.c. working voltage of the capacitor is 150V or more turn the 'capacitance selector' switch to the capacitance in microfarads; if it is less than 150V set the selector in the 'LV' position. Set the 'working voltage' selector to the rated working voltage of the capacitor. Turn on the mains power supply switch and the red indicator lamp should come on. Depress the spring loaded 'reform' switch and the leakage current will be shown on the meter (10mA f.s.d.). If this reading is less than 1mA, press the meter f.s.d. switch to obtain a reading.

Maximum permitted leakage current (in mA) for reformed capacitors with working voltages of:-

less than 150V
TABLE 1

C (μF)	6v.w	12v.w	25v.w	50v.w	100v.w
3	0·10	0·10	0·10	0·10	0·10
5	0·10	0·10	0·10	0·10	0·10
10	0·10	0·10	0·10	0·10	0·15
12	0·10	0·10	0·10	0·10	0·18
20	0·10	0·10	0·10	0·15	0·30
25	0·10	0·10	0·10	0·19	0·38
50	0·10	0·10	0·19	0·38	0·75
100	0·10	0·18	0·38	0·75	1·50
250	0·22	0·45	0·94	1·88	3·75
500	0·45	0·90	1·88	3·75	7·50
1,000	0·90	1·80	3·75	7·50	15·00
1,500	1·35	2·70	5·63	11·30	22·50
2,500	2·25	4·50	9·40	18·70	37·50
3,000	2·70	5·40	11·30	22·50	45·00
5,000	4·50	9·00	18·70	37·50	75·00

150V or more
TABLE 2

C (μF)	150v.w	275v.w	350v.w	375v.w	450v.w
2 & less	0·10	0·10	0·10	0·11	0·14
4	0·10	0·16	0·21	0·25	0·27
8	0·18	0·33	0·42	0·45	0·54
16	0·36	0·66	0·84	0·90	1·08
32	0·72	1·32	1·68	1·80	2·16
60	1·36	2·46	3·15	3·37	4·05
100 & above	2·25	4·10	5·23	5·62	6·75

8. **Interpreting the reading obtained.** If the reading is equal to or slightly less than the value quoted in the table, or the calculated value, the capacitor is serviceable and may be used. If no leakage current at all is indicated, the capacitor is open circuit and must be mutilated and scrapped. If the reading is greater than the value quoted, continue to hold down the reform switch to observe whether or not the leakage current decreases.

(*a*) If the leakage current increases, the capacitor is unserviceable and must be rejected, mutilated and scrapped.

(*b*) If the leakage current decreases steadily, the reform of the capacitor is proceeding satisfactorily (see para. 10). Once this has been ascertained the capacitor would continue to reform in use but there is no guarantee that the final leakage current would be less than the value given in the table.

9. **Disconnecting.** Release the reform switch; this automatically applies a discharge resistor across the capacitor terminals. As the discharge takes place through the interruptor relay, the green lamp will flash until the discharge current falls below 0.5mA. The capacitor should not be disconnected until a few seconds *after* the green lamp stops flashing to allow it to discharge completely. *Charged capacitors are dangerous* to personnel; if in doubt apply a resistive probe across the capacitor before handling.

Reforming

10. The capacitor is connected to the unit in the same way as for the leakage tests (para. 7). The reform switch is depressed and held down until the leakage current has fallen to the appropriate value and reforming is complete. When the capacitor is satisfactory, or rejected, release the reform switch and disconnect the capacitor as in para. 9.

11. **Interrupter circuit.** The leakage current in an electrolytic capacitor depends on the applied voltage, the temperature and the condition of the capacitor being reformed. When voltage is first applied to a capacitor after a period of disuse the leakage current is initially high, but rapidly falls as the dielectric film is reformed. In the reforming unit number 1 the reforming voltage on the lower ranges (below 150V) is applied directly to the capacitor. On the higher ranges (150V or more) direct application of the voltage could cause a heavy leakage current to flow in the early stages of reforming. This current might not fall sufficiently rapidly to prevent the capacitor overheating with a consequent risk of explosion. To prevent this happening an interrupter circuit in the unit causes the voltage to be applied as a series of pulses; the mean current is low enough to prevent overheating. A green lamp flashes in time with the current pulses to indicate that the interrupter circuit is operating. The interrupter automatically cuts out at reform currents less than 0.5mA, but for large values of capacitance with high leakage currents it will continue to flash throughout the whole reforming process.

CHAPTER 2

ELECTRICAL MACHINES

List of Contents

Introduction

1. A very large number of electrical machines of various types are in use in aircraft and on the ground; the routine servicing of most of these machines is the responsibility of one of the electrical or electronic trades. Normal routine servicing consists mainly of cleaning, lubrication, and visual examination with the minimum of dismantling. It is concerned with the prevention of trouble and with the detection of minor faults in their early stages to prevent complete breakdowns.

2. The essentials of good preventive servicing are constant attention to the following points:—

a. Absolute cleanliness. Grit or dirt in a machine which is rotating at very high speeds will find its way into the bearings, causing an increase in friction, overheating, and eventual disintegration of the bearing. Excess grease or oil in a motor attracts carbon dust and causes insulation breakdown, particularly at the commutator.

b. Mechanical security. Due to normal vibration there is a tendency for nuts or bolts to work loose during use. To prevent this happening the majority of nuts are locked in position during assembly. All nuts must be checked periodically, particularly those of the electrical connections to the machine.

c. Lubrication. The type of lubricant to be used on a particular machine is specified in the servicing schedule. Care must be taken to ensure that the lubricant used is of the correct type, is *clean* and is applied in the right quantity. Overlubrication of bearings may cause them to overheat and will almost certainly result in lubricant being thrown out of the bearing housing, possibly on to the commutator or brushgear.

d. Cooling. The windings and metal parts of the machine get hot during use and must be adequately cooled. Large machines are often oil cooled and merely require the oil level in the reservoir to be maintained. Smaller machines are air cooled, requiring a free flow of air usually through a filter which must be cleaned regularly.

e. Insulation. Machines which have been stored or have not been used for some time have a tendency to absorb moisture which may affect their insulation. Before such machines are put into use they must be given an insulation test. A low test reading can often be brought up to standard by drying out the machine using a hot air blower. Insulation tests should be carried out periodically during drying; when three or four tests give the same reading the drying out process is complete.

3. **Tools.** Special tools are often required to dismantle scanner systems and other electrically driven machinery. No attempt to carry out dismantling or servicing should be made unless these tools are available. Do not use excessive force to separate or assemble components as any distortion will almost always ruin the component, making it fit only for scrap. Careful note must be taken of the position of shims or packing washers and they must be replaced in the same position. Torque loadings of nuts must never be exceeded and particular care should be taken when assembling brass or copper threads.

Cleaning

4. The commonest cause of trouble in electrical machines is carbon dust which is formed by wear of the brushes during normal service. This dust is a conductor and if it is allowed to accumulate on the commutator or around the brush holders will lead to insulation breakdown. The problem is aggravated by seepage of lubricant from bearings which collects the loose carbon dust to form a conducting film. Because the dust is formed during normal use, the only effective servicing precaution is regular careful cleaning.

5. The usual method of removing dust is to blow it clear of the machine with air from a compressed air line or from bellows. Before using an air line the valve should be opened for a few seconds to allow any moisture due to condensation in the pipes to escape to the open air. Blow out all loose dust from the brush gear and commutator, and from any other part of the machine which is accessible. Wipe off all oily dirt with a dry non-fluffy rag, taking care to remove any grease or oil forced from the bearings. Dirt between the commutator segments is removed with a short-bristle brush similar to a nail brush. Dirt on the surface of the commutator is wiped off with a non-fluffy rag moistened with cleaning fluid. The recommended fluid for cleaning electrical equipment is *trichloroethane*; other cleaning fluids are liable to have an adverse effect on synthetic insulating materials and may only be used if they are specified in the servicing instructions for the particular machine.

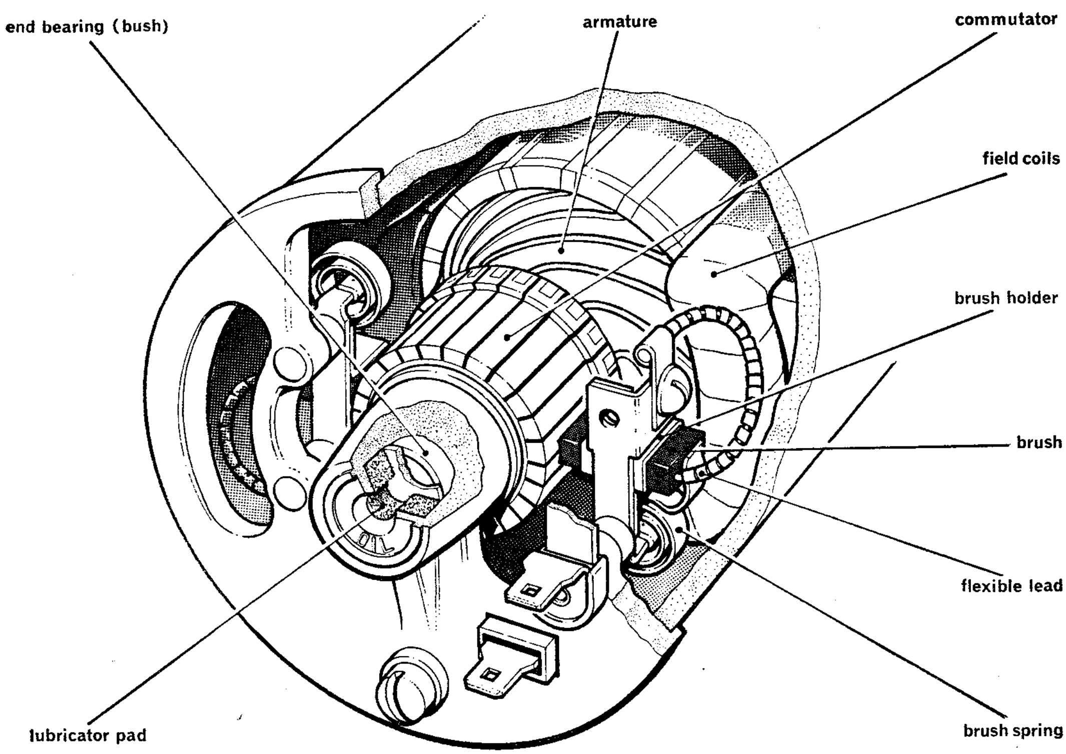


Fig. 1 Typical machine (12V d.c. car generator)

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Inspection

6. After the machine has been thoroughly cleaned, inspect the following:—

a. *Commutator*. The surface of the commutator should be dead smooth, free from any signs of pitting or burning, with the mica below the surface of the commutator segments. The portion of the commutator surface swept by the brushes should be of a uniform colour (dark brown with a distinctive bluish sheen) and have a very high gloss.

b. *Brushes*. The length of brush remaining should be well over the minimum permitted length, as given in the appropriate Air Publication, and the edges in contact with the commutator must show no signs of chipping or burning. The contact face of each brush must bear on the commutator surface over its full area. Every brush must be an easy sliding fit in its holder, yet have no tendency towards side play or wobble.

c. *Brush holders*. All insulating surfaces must be clean and free from any signs of charring. Flexible connections to the brushes must be firmly connected to the brushes and to the brush holder or terminal post. The action of the brush springs should be checked by raising each brush against its spring; on releasing the brush it must slide smoothly into contact with the commutator. All nuts, bolts, etc. must be examined for tightness, and if the brush gear is of the rocker type the index marks on the end of the yoke and on the rocker ring must be checked to see that they coincide.

d. *Bearings*. The armature should be turned by hand in the normal direction of rotation. It should rotate freely without any sign of end play. Ensure that an adequate supply of the correct lubricant is present in the oil reservoir or grease cup.

e. *Electrical connections*. All contact surfaces should be clean and bright and all connections to terminals tightly connected. The conductor should not have any broken strands and all cables should be inspected closely for any signs of damaged insulation caused by rubbing against moving parts.

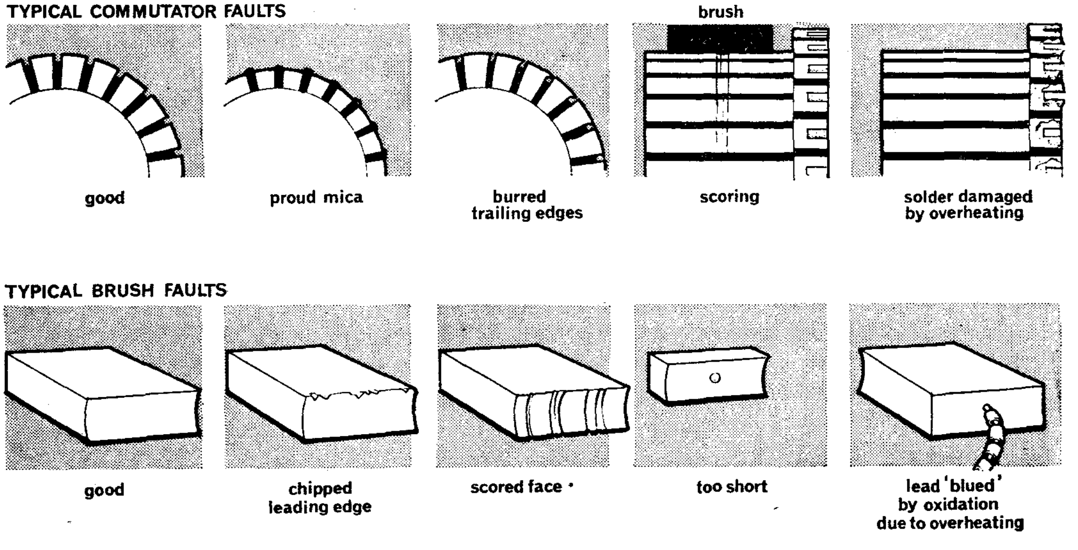


Fig. 2 Some common machine faults

7. On completion of the stopped inspection, run the machine at normal load and speed for an operational check:—

a. *Commutator.* With the commutator cover removed, note the tendency to sparking shown at the commutator surface. 'Pin-point' sparking is generally permissible at half load or over provided it is evenly distributed. Excessive or irregular sparking must be corrected immediately as it can cause serious interference to radio equipments.

b. *Brushes.* There should be no perceptible motion or chatter of the brushes.

c. *Ventilation.* Replace the commutator cover and check that air is expelled from the ventilation grilles or pipes at a satisfactory rate.

d. *Mechanical trouble.* Listen carefully for unusual or irregular noises when the machine is running at full load. Bearing noises can be studied if the handle of a screwdriver is placed against the ear and the blade on the bearing housing. Scraping noises can often be heard in the early stages of bearing trouble or rotor distortion.

Brush Replacement

8. If the original brushes are to be removed from a machine for cleaning and are then to be refitted, each brush must go back in its original holder *and* into the same position as it originally occupied in that holder. Thus if apparently serviceable brushes are removed, they should be laid out carefully on a piece of clean paper marked so that they can be replaced in their original positions.

9. **Tight brushes.** Intermittent sparking, or sparking concentrated on individual brushes, is usually a sign of a defective brush or brush holder. Brushes must always be a free sliding fit in their holders, without side play, and the spring pressure exerted must be sufficient to hold the brush in good contact with the commutator surface. Tight brushes should be removed from their holders and the inside of the brush holder and the sides of the brush should then be cleaned with a non-fluffy rag *moistened* (not soaked) in lead free gasoline. If this does not remedy the tightness, the face of the brush concerned must be gently rubbed down on fine glass paper (Grade 00) supported on a flat surface until it is a correct sliding fit in its holder. Under no circumstances may the inside of the brush holder be scraped out, nor any lubricant of any type be placed on the sides of the brush or in the holder. Loose brushes, or those which have been worn down so much that they are no longer effective must be replaced by new brushes of the correct size and grade, as specified in the appropriate AP.

10. **New brushes.** Although the minimum permissible length of brush varies with different machines, a good working rule is to renew a brush whenever it has worn down to half the original length. This can easily be checked by comparing the brush with a new one. It is also advisable to renew *all* the brushes of a machine at the same time, even if some of them appear to have useful service left in them. Many types of brushes are supplied with the contact faces already shaped to fit the commutator. When installing these brushes, it is only necessary to fit them into the brush holders, easing the sides of the brush if necessary, and then running the machine at minimum load for about a quarter of an hour to polish the contact face. After several hours normal service, newly fitted brushes should be re-examined to ensure that they are still free in their holders.

11. **Bedding-in.** When unshaped brushes are supplied they must have their working face bedded to the contour of the commutator by one of the methods described below:—

a. *Method A.* This method is the quickest way to bed new brushes and is generally used for motors and for machines which have a large commutator diameter where accurate position of the brush leading edge is not critical.

(1) Cut a strip of fine glass paper (Grade 00) of the same width as the commutator and long enough to pass completely round it with a considerable overlap.

(2) Wrap the strip of glass paper, abrasive side outwards, round the commutator in a direction opposite to the normal direction of rotation of the armature (Fig 3).

(3) Fit the brushes into their holders, and adjust the spring pressure to its normal running value (if adjustable). Normal brush pressure will hold the glass paper in place round the commutator.

(4) Turn the armature by hand in the normal direction of rotation until the contact surface of all brushes is worn to approximately the same contour as the commutator.

(5) Remove the glass paper and blow all loose carbon dust from the machine. Run the machine at minimum load for about a quarter of an hour to polish the working faces of the brushes.

(6) Remove and examine each brush in turn, making sure that there are no high spots and that each brush is a free sliding fit in its holder. Any high spots should be eased by re-bedding that brush using method B.

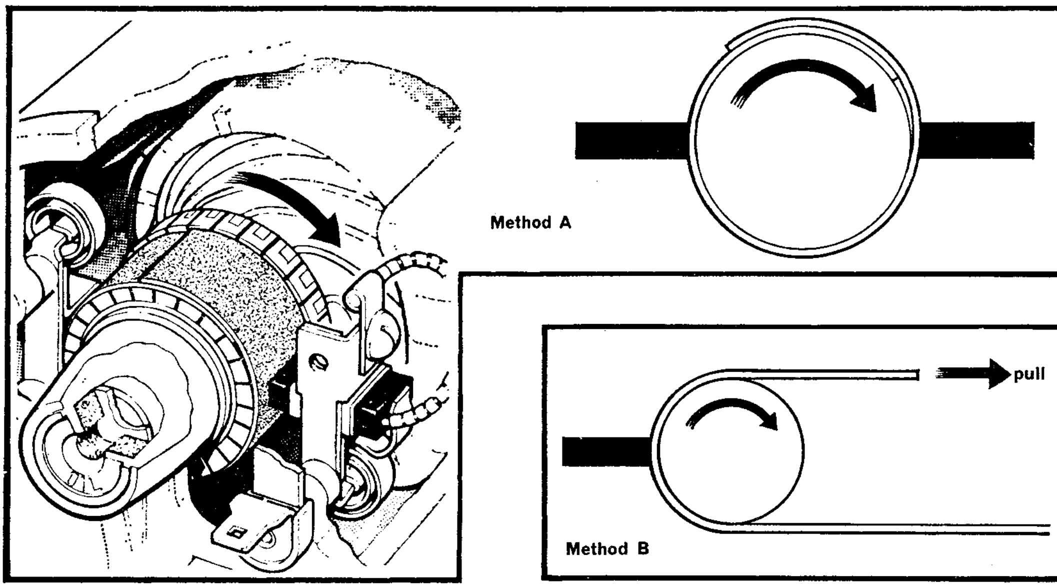


Fig. 3 Bedding in methods

b. Method B. This method produces a more accurate contour than method A, but is very much slower as only one brush can be bedded in at a time. It is often used for bedding brushes for machines with small armature diameters and for servo 'pick-off' machines where the accurate position of the brush is critical.

(1) Cut a strip of fine glass paper of the same width as the commutator and of as great a length as possible.

(2) Pass the end of the strip over the commutator, abrasive side outwards, as shown in figure 3. Hold the ends of the strip so that the paper is in contact with the commutator for at least 180°.

(3) Fit the brush to be bedded into its holder and pull the strip of glass paper across the brush in the direction of normal armature rotation.

(4) Raise the brush so that it does not contact the paper when drawing the paper back to its starting position. Continue (3) and (4) until the brush is shaped.

(5) Blow out all carbon dust and run the machine as described for method A.

Commutator Cleaning

12. Blackening of the commutator surface is encountered in two forms; localized blackening affecting individual commutator bars, and uniform blackening in which the whole of the surface swept by the brushes is blackened to some extent. Localized blackening is probably caused by a short circuit in the armature windings and the machine should be returned to a suitably equipped workshop for repair. Uniform blackening is usually due to the normal action of the brushes coupled with failure to clean regularly and thoroughly and can be easily cured. Remove the brushes and clean the commutator surface by brisk rubbing with a non-fluffy cloth moistened with non-leaded gasoline, finishing off with a soft dry non-fluffy cloth. If this treatment fails to remove hard dirt, a piece of grade 00 glass paper, fixed to a wooden block, should be held against the commutator surface while the armature is rotated by hand. During this process the glass paper should be traversed slowly across the full width of the commutator. All traces of dirt must be removed from the inter-segment grooves before the brushes are refitted. Treatment with glass paper should be avoided whenever possible as abrasive action destroys the protective glaze on the commutator surface. The use of emery or carborundum cloths for commutator cleaning is forbidden.

CHAPTER 3

ELECTRONIC VALVES

List of Contents

Introduction

1. Electronic valves, although more prone to faults than semiconductor devices, are still in common use in a large number of electronic equipments. They are likely to remain in use for many years, particularly at extremely high frequencies and powers and for applications where there is as yet no semiconductor equivalent *eg* the cathode ray tube. In all-valve equipments it has been shown statistically that *about* 50% *of all faults* are caused by valve failures. The ability to detect valve failure rapidly is thus a very important part of the electronic tradesman's normal servicing task. Valves found to be unserviceable are normally replaced, as repair is impossible without special vacuum equipment.

2. **Valve life.** If the average valve is not overrun, nor operated continuously at its maximum rating, it can be expected to have a working life of at least 2000 hours. Valves which have operated for several hundred hours with relatively stable characteristics are more reliable than new valves. In general it is not advisable to replace a valve solely because of 'hours run'; but certain valves are notorious for their limited operating life and details of any periodic valve changes necessary are given in the appropriate equipment AP.

Valve life can be greatly increased if frequent on/off switching of the heater current is avoided as the surge current of the cold heaters is many times the rated heater current. To facilitate this, many equipments are fitted with a 'standby' control position in which heater and bias voltages remain but the HT and EHT is switched off. The correct switching on procedure and the time delay in the standby position are quoted in the equipment AP and must be rigidly followed. Valve life can also be increased by anti-vibration protection and by efficient cooling. Most screening cans for valves are designed with a spring interior for this purpose; care should always be taken to ensure that these devices are properly fitted.

It has also been found that by operating some types of new valve in a test rack for 100 to 300 hours prior to actual use about 80% of the valves that would fail early in life can be eliminated. For this 'running-in' operation, a steady current is passed through the valve so that both anode and screen operate between one half and the full rated dissipation. Valves which survive the first 300 hours with only minor changes in their characteristics are good risks for several thousand hours life. Valves with inherent mechanical defects, poor welds, and other manufacturing faults are usually eliminated during the first 100 hours.

Valve Handling

3. **Glass enveloped valves.** Extreme care must be taken when handling large valves and cathode ray tubes because of the danger of implosion if dropped or knocked against hard objects. This danger cannot be over-emphasized as the total force due to atmospheric pressure on a normal 10 inch c.r.t. is about *two tons*. The face of a c.r.t. should also be kept away from bench tops to

avoid scratching the viewing area and weakening the envelope; this is best done by laying the c.r.t. on a soft clean cloth. All valves must be protected by keeping them in the proper container or package until actually required for use.

The contact pins on the base of a valve are very easily damaged or distorted unless treated with great care. Before inserting a valve the pins should be aligned with the holes in the valve base and the valve then pressed home from directly above. Any bending or twisting of a valve during removal or insertion will distort the pins and may result in an intermittent contact with the valve base, broken pins, or rupture of the wire/glass seal.

When making measurements on a valve base, narrow probes must always be used to prevent shorting the pins together (inadvertent application of HT to the heaters will almost always burn out the valve). Wired-in subminiature valves have their leads very close together and are extremely prone to damage due to carelessness with test prods or clips. This type of valve is also easily damaged by the application of excessive heat during soldering; heat sinks must always be used and must be placed as far from the valve envelope as possible.

4. **VHF/UHF/SHF valves.** At high frequencies the inter-electrode capacitance and lead inductances of the valve have a considerable effect on the tuning of the circuit in which it operates. Valve replacement thus upsets the circuit tuning and complete re-alignment is often required. Many of these valves can only be replaced at third line (*eg* airborne radar IF units) and the equipment AP must be consulted in all cases. At UHF many tuned circuits are formed using the valve, valve leads and 'lecher lines' and these circuits and valves should not be disturbed in any way during routine servicing or testing. Sometimes repositioning of the leads is permitted in the AP to correct the tuning alignment but where this is done the complete tuning procedure must be repeated after moving the leads. At SHF coaxial cavities are often used as tuned circuits. The position of the valve in these cavities is critical to alignment and these circuits must not be physically disturbed in any way as circuit realignment is normally a third line task.

5. **Magnetrons.** Magnetrons depend for their operation on a very powerful magnetic field, usually provided by a permanent magnet, and care must be taken not to impair the efficiency of this field. Some equipments use a packaged magnetron (*ie* valve and magnet form a complete replaceable assembly) while others use a valve and separate magnet. In airborne equipments where weight is important these magnets are almost saturated and are therefore easily damaged. Avoid striking or dropping the magnets or placing them anywhere near a large mass of magnetic material. Special brass or plastic tools are provided for assembly and dismantling and steel tools must *never* be used. Where a separate magnet is used the correct type of soft-iron 'keeper' must be applied to the magnet immediately after dismantling. During storage care must be taken to prevent the interaction between the fields of two or more magnets causing deterioration of their field strengths. In general, stored magnetrons or magnets should be kept not less than twelve inches apart.

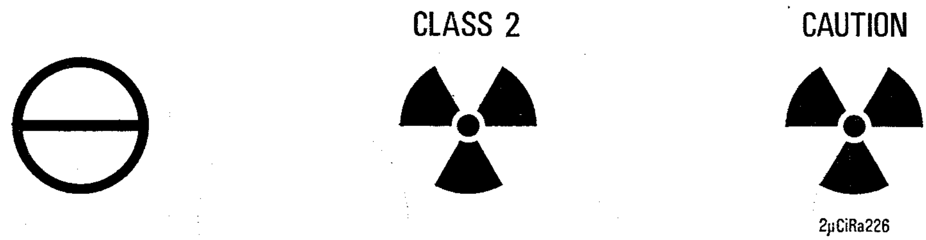
6. **Radioactive valves.** Some valves, such as high speed T/R switches, contain radioactive materials to assist ionization. These valves are a serious hazard to health if broken, and the safety precautions given in AP 4687A, Vol 2 must be strictly observed.

a. The valve must not be removed from its screened carton until immediately prior to fitting it to an equipment.

b. The valve removed from the equipment must be placed in this protective carton immediately after removal of the new valve.

c. *Extreme* care must be used during fitting and removal to prevent breakages.

d. Any protective screening on the equipment must be refitted immediately the valve change is completed.



Theta marking for Class 1 | Marking for Class 2 | Marking for Hazard Grade

Marking of radioactive valves – symbols are black on a yellow background

7. **Mercury vapour diodes.** These diodes must always be kept in an upright position to ensure that none of the liquid mercury comes into contact with the cathode surface. Replacement valves must be allowed to heat up for at least half an hour before application of the high voltage supply. It is essential to the long life of these diodes that the HT delay circuits should be operated correctly and no attempt may be made to 'shorten the delay' when servicing. Both mercury vapour and liquid mercury are extremely poisonous. If a valve containing mercury is broken the room should be evacuated and all doors and windows opened to provide ventilation for at least one hour. Any tradesman who thinks he may have been affected should report sick immediately and *inform the medical officer that he has been exposed to mercury vapour.* Adequate precautions must be taken when cleaning up to prevent poisoning. If any spilled mercury comes into contact with light alloy parts anti-corrosion treatment should be applied as soon as the vapour has been dispersed.

8. **Mercury arc rectifiers.** These valves must never be looked at for more than one or two seconds at a time when the arc is 'struck'. Excessive exposure of the naked eye to the ultra-violet radiation from these arcs can cause permanent damage to the eyesight.

Unserviceable Valves

9. **Repairs.** The cost of repairing or restoring most valves is considerably greater than the cost of a new replacement and is therefore not attempted. It is, however, economical to repair special valves which contain high cost precision assemblies. Examples of such valves are klystrons, magnetrons, cathode ray tubes and some high power transmitting valves. These repairs are carried out by the manufacturer and the valves are returned by the tradesman to the supply squadron for repair or disposal in accordance with current regulations.

10. **Valve defect reports.** A code giving data on the manufacturer and date of manufacture is stamped on the valve envelope. This code consists of a five letter group (*eg* DA—Mullard at Blackburn, PF—1963 June, U—combined US/UK approval) forming the code DAPFU. These letters must be shown on all defect reports raised on electronic valves. Should there be any doubt as to the information required, full details of all the markings on the valve should be included in the defect report on form 1022G.

Valve Pin Location

11. Each electrode in the valve is connected to a pin at the base of the valve. These pins fit into a socket, usually called a valve base, which is permanently wired into the circuit. The valve can be easily removed if it becomes unserviceable, and the tags on the base form convenient points for making circuit measurements during fault finding. It is essential to be able to locate the correct pin of a valve base easily so all pins are numbered clockwise as seen from below the chassis, starting from the gap or the location spigot. The layout of some of the more common bases is shown in

figure 1. Maker's catalogues, valve manuals and equipment APs indicate which pin is connected to which electrode and it is now becoming common practice to show the pin numbers on the circuit diagram.

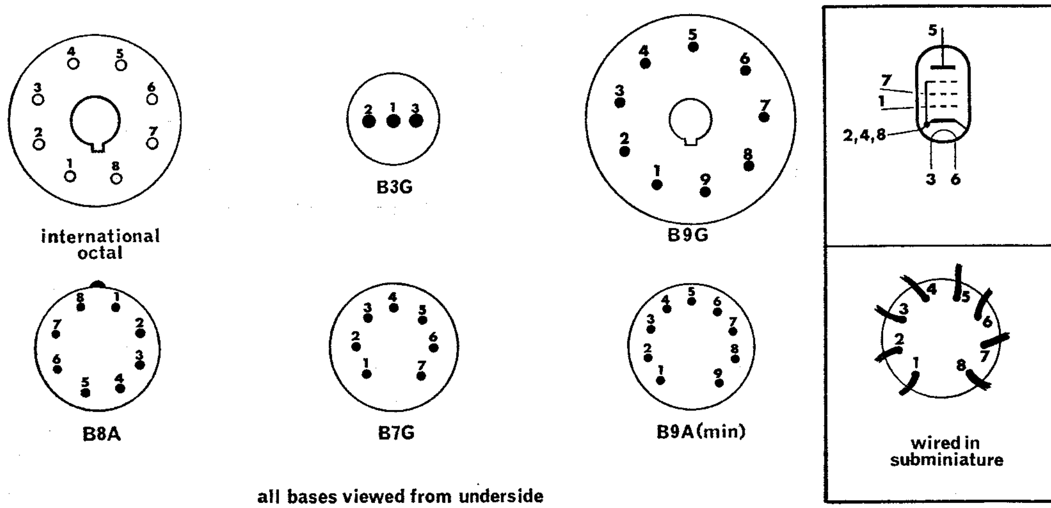


Fig 1 Valve pin location

Common Valve Faults

12. The circuit symptoms shown in the presence of any particular valve fault are not easy to catalogue as they depend mainly on the circuit function for which the valve is used. Some of the more common valve faults are discussed in the following paragraphs together with their general circuit effects and methods of detecting their presence. More detailed information can be found in later paragraphs on valve testing.

13. **Heater open-circuit.** This is probably the easiest valve fault to detect as the valve is not alight and will remain cold. As there is no emission from the cathode when cold the circuit will not function at all. The anode d.c. voltage will be at HT, but care should be taken not to be mislead by voltmeter loading in high resistance circuits (*see* Chap 2 para 12). Heater burn-out is usually a natural result of old age and of frequent switching on and off. It is sometimes caused by the accidental application of high voltages to the heater during testing or by short circuit between the pins of the valve base due to stray solder or bare wires bent out of position. It is good practice to carry out a visual inspection and to check the voltage present on the heater pins before substituting a new valve.

14. **Heater—cathode insulation faulty.** Repeated heating and cooling of the cathode assembly may cause small amounts of the insulation between the heater and the cathode to become brittle and deteriorate, leaving a resistive leakage path between these two elements. This will result in either the a.c. heater voltage appearing on the cathode (mains hum), or the cathode d.c. bias leaking to earth through the heater, depending on the circuit arrangement in which the valve is used. If the cathode and heater are completely short circuited it becomes impossible for the valve to develop any cathode bias and excessive valve current may damage or burn-out the cathode, anode or screen resistors. It is not possible to state a definite rejection figure for heater-cathode resistance unless the circuit operating conditions are known, but in general terms it is better to reject all valves which have an insulation less than 10 Megohms.

15. **Microphony.** Because of the expansion and contraction of the valve electrodes during repeated heating and cooling they may develop a lean or sag. This will cause periodic fluctuations of the anode current due to the mechanical vibration of the electrodes (especially the grid and screen) at their natural resonant frequency, resulting in microphony or 'howling' in a receiver. This type of fault is easiest to detect in situ by *lightly* tapping the valve envelopes with a pencil to cause howling when the faulty valve is tapped.

16. **Inter-electrode insulation.** This type of fault occurs when an electrode has developed so much sag that it comes into contact with one of the other electrodes. Open circuit electrodes and inter-electrode shorts can also be caused by excessive vibration of the equipment breaking a 'grid' or an internal valve lead. Open circuit electrodes cause complete circuit failure and are usually easy to detect from measurements of the valve base voltages. Short circuits can be intermittent and may be quite difficult to detect without the assistance of a valve tester capable of measuring inter-electrode insulation with the valve hot. When there is reason to suspect an intermittent fault the valve should be lightly tapped with a pencil during these tests to see if the insulation reading fluctuates.

17. **Loss of emission.** Low emission is usually an indication that the valve is nearing the end of its useful life and requires replacement. The principal cause of emission loss is deterioration of the cathode coating due to old age or to oxidation caused by defective seals allowing air to leak into the envelope. The normal circuit symptoms are loss of gain or power, accompanied by changes in the d.c. electrode potentials due to the valve current being lower than normal. An emission test on a valve tester measures the condition of the cathode emitting surface to determine whether it can supply sufficient electrons for the valve to operate.

18. **Decrease in mutual conductance.** The term mutual conductance expresses the effect of changes of the grid voltage on the anode current of the valve. By measuring mutual conductance it is possible to evaluate the condition of a valve much more accurately than by emission tests, as the test more closely approximates actual circuit operating conditions. Causes of decreased gm are grid defects due to heating/cooling or vibration; and inability of the grid to control the electron stream, usually due to 'patchy' emission or 'hot spots' on the cathode caused by heater deterioration. The circuit symptoms are not always easy to detect as the principal effect is loss of gain which may not be very obvious when considering a single stage in isolation from the rest of the equipment.

19. **Ionization.** This is caused by the release of occluded gases from the electrode assembly or by defective valve seals. The valve is said to be 'gassy' or 'soft' and a bright purple glow is often present round the electrodes. When gas is present, collision between the electrons and the gas molecules forms positive gas ions which are then attracted to the grid (usually the most negative electrode in the valve). The net effect is to reduce the bias on the grid, causing an increase in standing anode current and distorting the output as the valve is not working at its correct operating point.

Valve Testing

20. Because of the very large number of different power supply voltages required to carry out the simple tests already discussed for differing types of valve, special valve testers are used in which the test voltages and the required valve base connections can be set up on selector switches. The valve tester must provide a simple and quick appraisal of the quality of the valve being tested

to assist the technician in fault diagnosis. It must also be able to measure the characteristics of a valve with sufficient accuracy to enable 'matched pairs' of valves to be selected when required for use in balanced circuits such as push-pull output stages. There are several valve testers in service use but the commonest is the CT160 (fig. 2) which will be discussed in this chapter as it has test facilities for finding all the faults so far described. A full technical description of the CT 160 is given in AP2537F, together with step-by-step operating instructions and valve data charts. These notes are intended to provide background information to enable the technician to understand the various tests and to assist him in the interpretation of the results he obtains.

Caution. Before the valve to be tested is inserted in the correct test socket, make certain that all panel controls are set to the positions listed for that type of valve in the valve data chart. This precaution is essential to prevent excessive voltages from being applied to the valve electrodes, particularly to the heater. When in use high voltages are present on the valve holders and on the various top cap links and adequate precautions should be taken to guard against electric shock.

21. **Parasitic oscillation.** Much trouble can be caused by valves of high mutual conductance going into oscillation when placed in valve tester panels. This effect can be traced to the long leads needed to connect up all the switches and valve base sockets forming lecher lines which act as parallel tuned circuits. The valve tester CT160 has a special wiring system to prevent this effect in which all valve bases are connected in the form of a ring main and ferrite beads and damping resistors introduce severe radio frequency losses. The effect of parasitic oscillation is to give fluctuating readings caused by the oscillator 'squegging', but trouble on the CT160 is likely to occur only when testing special valves whose grid and anode leads are connected to top caps.

22. **Tests on CT160.** The tests are carried out in a logical order so that valves with insulation faults are eliminated at the beginning of the test sequence to prevent them causing damage to the test instrument. If an insulation fault is found, the test sequence must be discontinued and the valve rejected as unservicable.

a. Insulation resistance tests.

(1) Set mains—instrument test voltages are adjusted.

(2) Inter-electrode insulation—valve cold.

(3) Heater continuity.

(4) Inter-electrode insulation—valve hot.

(5) Heater to cathode insulation—valve hot.

b. Emission tests.

(1) Rectifiers and signal diodes.

(2) Other valves—as part of setting-up for the mutual conductance tests.

c. Mutual conductance tests.

(1) At the negative grid voltage given in the data tables.

(2) At the anode current value given in the data tables.

d. Gas tests—measuring grid current due to ionization.

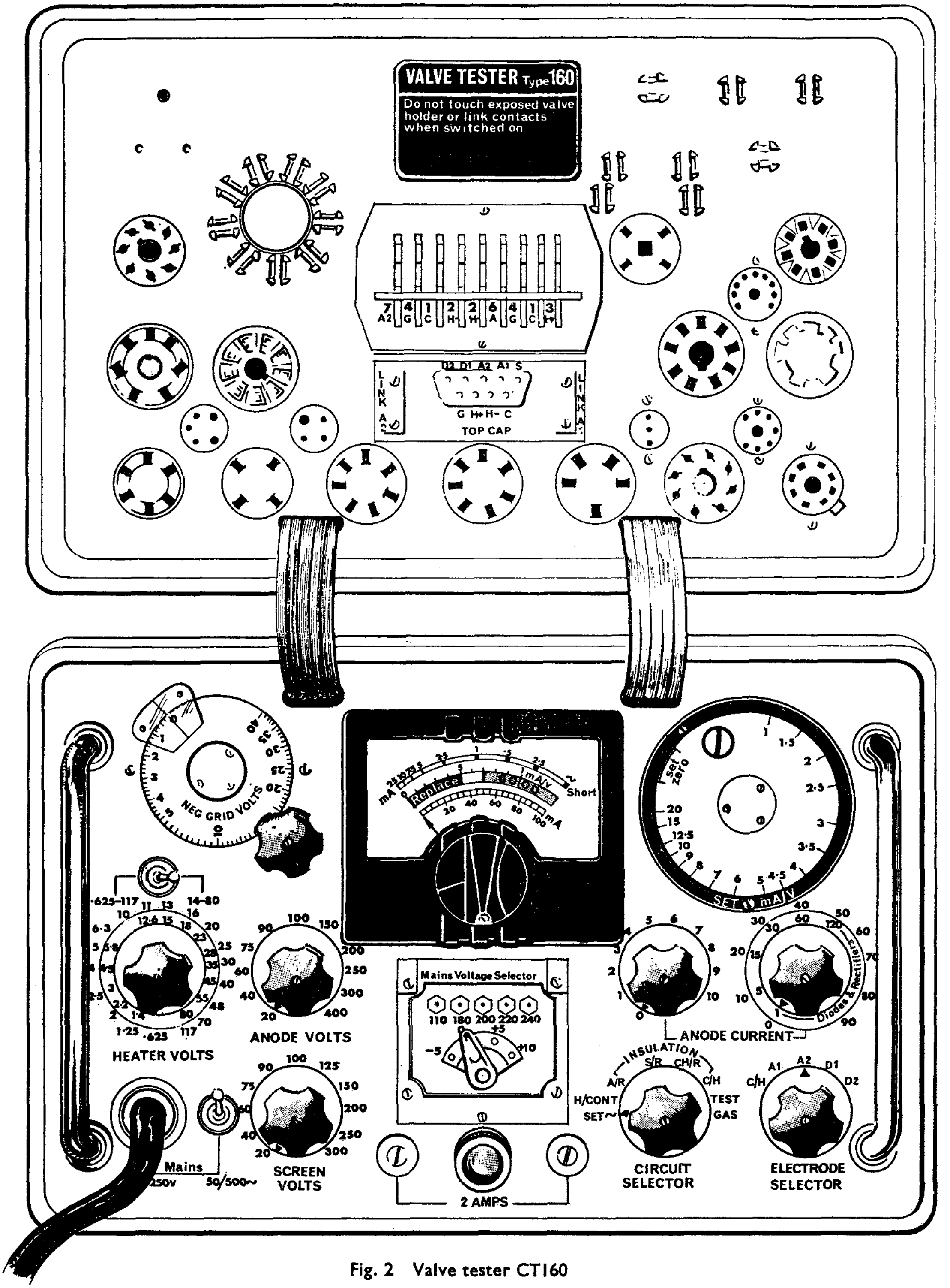


Fig. 2 Valve tester CT160

23. **Insulation tests.** A simplified diagram of the circuits used for the insulation tests in the CT160 is shown in figure 3, and its resemblance to a simple series ohmmeter can easily be seen. The voltage and resistance values in the circuit are such that the first meter indication is given at 25 Megohms, with full scale deflection representing a short circuit. Before using the circuit to measure insulation the zero is adjusted with the instrument at 'set ~'. This puts a short circuit on the test terminals and the mains voltage selector is then adjusted to give full scale deflection (0 ohms). At this setting the circuit test voltages in the instrument are correct as they are all proportional to the voltage used for insulation tests. Insulation tests are then carried out in the order given in para. 22a by following the step-by-step instructions given in AP2537F. If any inter-electrode shorts are found, or the heater is open-circuit, the valve must be rejected. The minimum acceptable value of heater/cathode insulation depends on the circuit operating conditions in which the valve is used, but in general, valves with a heater/cathode resistance of less than 10 Megohms should be regarded as unserviceable.

Note. When carrying out insulation tests with the valve 'hot', adequate time must be allowed for the valve to attain its normal working temperature.

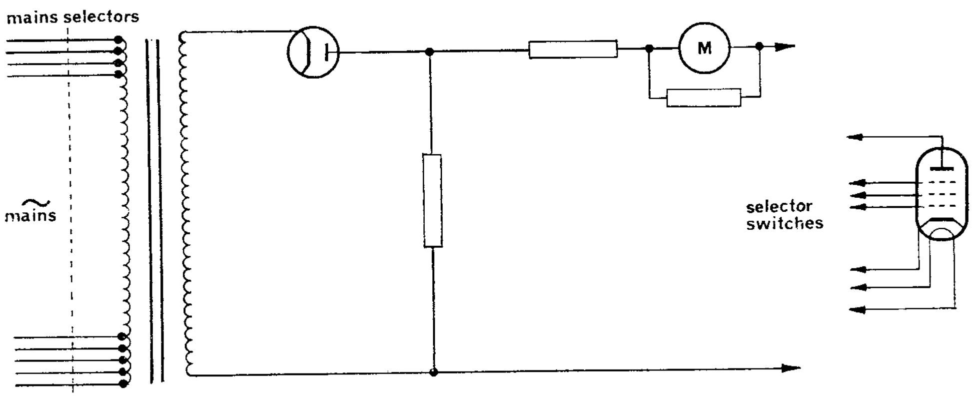


Fig. 3 Simplified circuit for CT160 insulation tests

24. **Emission tests—rectifiers and diodes.** The simplified circuit for this test is shown in figure 4. The rectifier under test is loaded with the resistors Rs and R_L in series and a reservoir capacitor C. An a.c. voltage is applied of sufficient amplitude to operate the rectifier over the linear part of its characteristic so that the circuit will pass a rectified current equal to the maximum load current of the valve. The meter measures this current by reading the voltage developed across Rs and is scaled by the appropriate range resistor so that the current selected on the Ia switch will deflect the pointer to the centre of the 'good' zone of the scale. Switching of the applied voltage and the range multiplier is ganged so that rectifier test currents of 1mA, 5mA, 15mA, 30mA, 60mA, and 120mA, per anode are available. Each anode of a full wave rectifier is tested separately and the 1mA and 5mA positions can also be used to test signal diodes.

The figures for anode current given in the data charts are the standard emission to be expected from the type of valve under test. When testing rectifiers, either this figure can be used or the Ia selector can be set to a figure decided upon from the valve's operating circuit. For example, if a half wave rectifier circuit is supposed to deliver 50mA then a valve test at 60mA (about 20% excess) will be an adequate test of the emission. Valves are normally designed to give full emission with the heater voltage derated by about 10% which allows an extra test to be carried out on 'doubtful' valves. The heater voltage can be reduced from say 6.3V to 5.8V to measure the change in emission as the valve cools. An excessive drop of more than 10% suggests that the valve is nearing the end of its useful life and it should only be used in low current circuits.

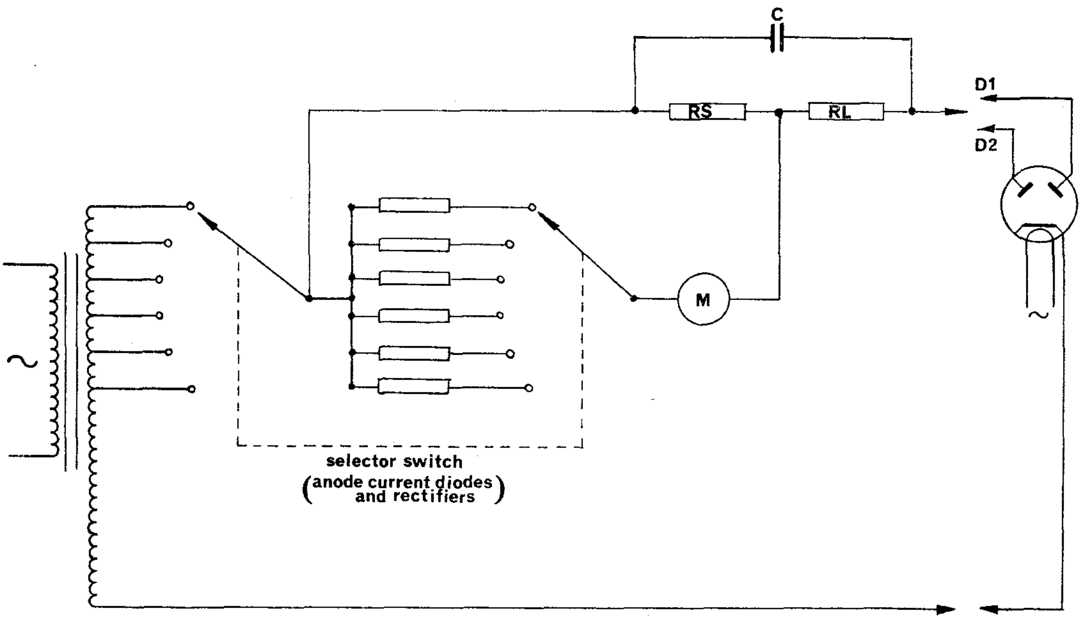


Fig. 4 Simplified circuit for CT160 emission tests on rectifiers

25. **Emission tests—other valves.** Although the CT160 is designed to test amplifying valves by measuring their mutual conductance, there are occasions when more realistic results can be obtained by a form of emission test. Examples of this are where a valve is used in a motor control circuit or as an output stage and is normally operated at peak emission. Some oscillator and pulse circuits also come into this category. The anode current expected under working conditions for these valves is normally given in the servicing information section of the equipment AP. The valve is tested by operating it in the CT160 with a given set of electrode voltages, including the grid bias. The anode current delivered by the valve under these conditions can be measured by 'backing off' the meter reading to zero and reading Ia from the anode current selector switches. If necessary the mutual characteristic Ia/Vg can be plotted by making measurements at various grid bias settings.

Where the equipment AP gives a value for the working anode current of the valve in situ, it should be expected to deliver about 10% more Ia when under test; or to be able to deliver the working anode current with the heater voltage derated by 10%. When the circuit operating conditions are not known, a serviceable valve should be capable of delivering at least 80% of the value given in the valve data charts. The normal tests for mutual conductance should be carried out in addition to these emission tests.

26. **Mutual conductance.** The term mutual conductance is used for the change in anode current produced by a small change in grid voltage, is given the symbol g_m, and is usually expressed in milliamps per volt (mA/V). As it is the gradient, or slope, of the mutual characteristic graph referred to in the last paragraph the term 'slope' is quite often used. In valve data given by American manufacturers the term transconductance is used, expressed in micromhos. The value of transconductance is micromhos equals 1000 times the mutual conductance in milliamps per volt.

27. **Mutual conductance tests.** The mutual conductance test provides a more accurate evaluation of the condition of a valve because it measures its amplification ability under simulated circuit conditions (usually class A bias). A voltage or power amplifier valve is considered defective when its mutual conductance falls below 70% of the rated value. To make this comparison easy the meter scale of the CT 160 is zoned on a coloured scale:

Green from 70% to 130% indicating a good valve.
White from 50% to 70% indicating a failing valve.
Red below 50% indicating a reject.

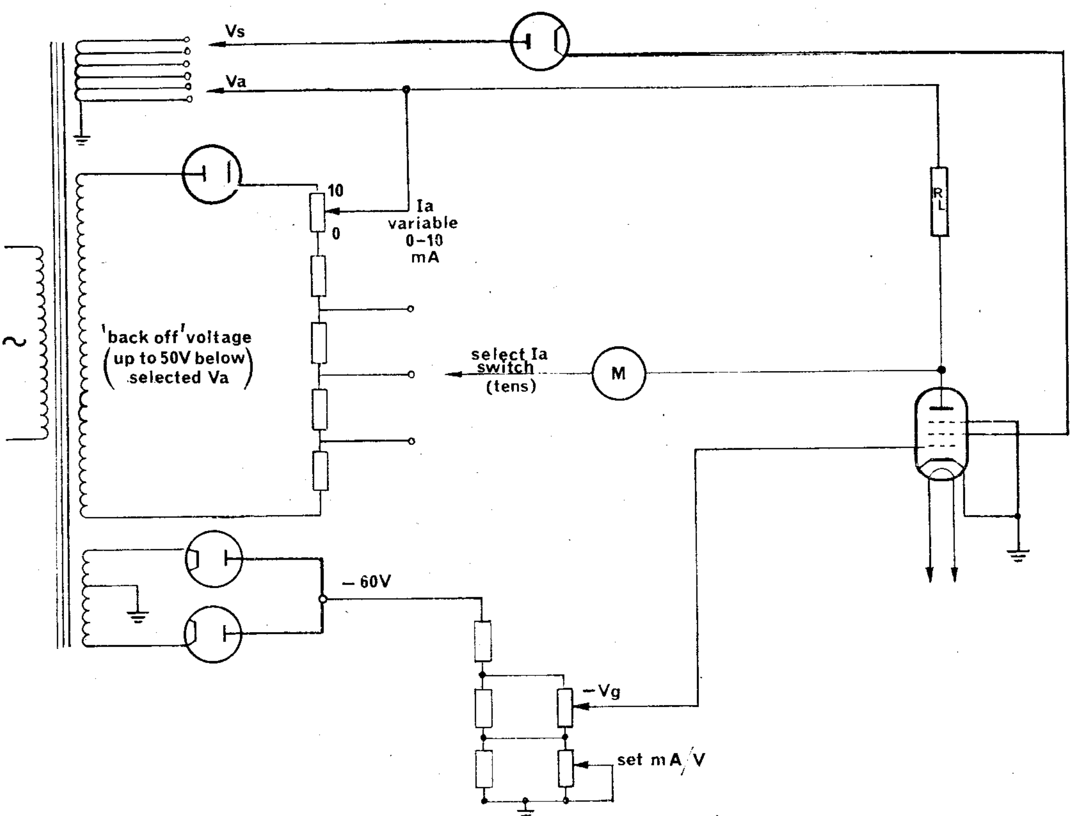


Fig. 5 Simplified circuit of CT160 mutual conductance test

28. **CT160 mutual conductance tests.** The simplified circuit used for mutual conductance testing in the CT160 is shown in figure 5. Anode, screen, grid and heater voltages corresponding to the working point of the valve (class A) are applied and the resulting anode current of the valve causes a voltage drop across the low value resistor R_L. A backing off voltage is applied to the other end of the meter and the controls adjusted until the meter reads zero /these backing off controls are calibrated in anode current as the voltage across R_L is equal to $R_L I_a$). A small incremental voltage, proportional to the expected g_m of the valve, is then applied to the grid by adjusting the set mA/V control. The resulting increase in anode current causes a larger volts drop across R_L and deflects the meter pointer. As the incremental voltage was proportional to g_m all valves should

deflect to the 1mA/V point in the centre of the 'good' band of the scale. This point represents 100% of the rated value of g_m and the quality of the valve can be assessed from the coloured scale. Two basic methods of carrying out mutual conductance tests are possible, depending on the operating conditions of the circuit in which the valve is to be used.

29. **Test g_m at recommended negative grid bias.** Where the grid bias in the operating circuit is obtained from a fixed source such as a voltage divider network the valve should be tested at the recommended value of $-Vg$. If the circuit bias is not class A the value of $-Vg$ used in the operating circuit should be used instead.

a. Set up the valve tester controls to the positions given in the valve data charts.

b. Adjust the anode current controls until the meter reads zero.

c. Slowly rotate the set mA/V control to the set zero position and make the final adjustment to zero using the fine anode current control (0–10mA).

d. *Either*

(1) Rotate the set mA/V control to the expected value of g_m and read off the comparative goodness of the valve from the coloured scale of the meter.

or (2) Rotate the set mA/V control until the meter reads 1mA/V at the centre of the green band and find the actual value of g_m from the calibrations of the set mA/V dial.

30. **Test g_m at recommended anode current.** Where the valve is used in a circuit which develops self bias at the cathode it is better to test for g_m at the recommended value of anode current given in the data chart.

a. Set up the valve tester controls to the positions given in the data charts.

b. Adjust the grid bias voltage until the meter reads zero.

c. Slowly rotate the set mA/V control to the set zero position and make the final zero adjustment using the fine anode current control (0–10mA).

d. *Either*

(1) Rotate the set mA/V control to the expected value of g_m and read off the valve's goodness against the coloured scale of the meter.

or (2) Rotate the set mA/V control until the meter reads 1mA/V and read off the value of g_m from the set mA/V control.

Notes.

(1) The test can be carried out by both methods and the readings used as a cross check.

(2) Some valves are quoted in the data charts with more than one set of operating voltages and in such cases the valve should be tested as near as possible to its actual circuit operating voltages.

31. **Valves with g_m less than 1mA/V.** Valves having a slope of less than 1mA/V cannot be checked against the coloured scale. Using either of the methods described above, rotate the set mA/V control to the 1mA/V calibration on the control and read off the actual g_m from the scale on the meter calibrated from 0.1 to 1mA/V.

32. **Gas test.** The final position of the circuit selector switch, marked 'gas', connects the meter in series with a resistor in the grid circuit of the valve being tested. The meter will then measure ionization current to the grid directly up to 100μA. The point at which a valve becomes useless due to gas current depends on the circuit in which it is to be used. If the circuit is transformer coupled quite large currents can flow through the winding to earth without upsetting the circuit operation. If CR coupling is used between stages, very much smaller amounts of gas current can produce sufficient bias across the resistor to interfere with normal circuit operation, particularly in low frequency circuits where very large CR values are used for efficient coupling.

Note. If the safety relays in the CT160 operate during the mutual conductance or gas tests the tester must be *switched off*, the faulty valve removed, and the tester switched on again before it will operate normally.

Valve Replacement

33. When carrying out repairs to an equipment, replacement of a valve which was faulty is *not* the end of the servicing task. Three vital questions must always be considered:

a. Was the valve fault natural? Such faults are those due to old age such as loss of emission or changes in the mutual conductance.

b. Was the valve fault likely to cause damage to the equipment? Such faults as inter-electrode shorts will often burn out the cathode, or other, resistor.

c. Was the valve fault caused by abnormal circuit operation? Some component faults such as shorted transformers can cause a valve to be over-run and eventual valve failure.

Before fitting a replacement valve, all associated circuit components should be checked for damage and wherever possible the component value should be checked on a multimeter. After fitting the new valve the circuit should be checked for normal operation by measuring the circuit voltages and comparing them with those given in the equipment AP.

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CHAPTER 4

SEMICONDUCTORS

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Introduction

1. Semiconductor devices have replaced electronic valves for all but a few specialised applications, mainly where very high powers or frequencies are involved. They are impossible to repair, and servicing is therefore carried out by replacement. Because they are easily damaged by voltage overloads or by heat, special precautions are necessary when working in semiconductor circuitry. This chapter deals with these precautions and the methods of testing semiconductor diodes and transistors.

Note. If a transistor appears to be faulty, always check that the symptoms are not due to a fault in another component. If a transistor is found to be faulty, before a replacement is fitted, always check that the failure was not caused by the failure of another component such as an interstage coupling capacitor.

Handling

2. **Leads.** The connecting leads on transistors, semiconductor diodes and associated components are necessarily thin and fragile. They should be handled carefully and the lead must not be bent sharply close to the body of the transistor. Crocodile clips should be applied to a tag or terminal post and must not be clipped directly to the device leads. Any component lead which has been 'nicked' through the plating or which has deep indentations or flats must be regarded as unserviceable. Before fitting a transistor into a circuit, the connecting leads i.e. base, collector and emitter, must be positively identified from published data. If the collector and emitter leads are inadvertently interchanged the circuit may still work but the device will quickly become overheated and will then fail.

3. **Paint.** Since transistors are photo-sensitive the paint must not be scratched off those types which are glass encapsulated.

4. **Mica washers.** Some power transistors require thin mica washers to insulate the collector (case) from the chassis. The chassis adjacent to the transistor should be examined and all burrs and sharp edges removed to prevent damage to the mica washer on replacement. The washers themselves are extremely brittle and should be handled with great care; their edges are also very sharp and can cause cut fingers.

Temperature Considerations

5. A transistor is very sensitive to temperature variations, and the temperature of the junctions in the device *must not exceed* a specified maximum value laid down by the manufacturer. If this maximum value is exceeded the transistor will suffer permanent damage or will fail.

a. There may be increased diffusion between the p-type and the n-type materials, causing a change in the current gain of the device and, in many cases, resulting in an increase of noise even after the high temperature is removed.

b. The internal soldered joints of the collector and emitter leads may become loose, resulting in an open circuit device or in intermittent operation.

6. **Operating temperature.** In operation, the junction temperature depends on the amount of heat generated in the transistor and the amount of heat removed in unit time, *ie* on the thermal dissipation through the leads and the case. For most radio frequency and low power transistors convection cooling is sufficient, *ie* transfer of heat to the air flowing past the transistor. For power transistors this type of cooling is inadequate and the excess heat must be removed by conduction to a heat sink. This is done either by clamping the case of the device in a special mounting clip or by bolting the device to the chassis. Where clips are used the equipment must not be turned on unless the clips are in position. Many power transistors have a mica washer to electrically isolate the case from the chassis; a smear of silicone grease is often used to ensure efficient heat transfer from the device to the chassis.

7. **Soldering.** The majority of transistor connections have to be soldered into the circuit. During soldering these connecting points must be far hotter than the maximum permissible junction temperature of the semiconductor device and therefore special precautions are needed to prevent this excessive temperature reaching the p-n junction by conduction along the lead-in wires. The following are the most important points:

a. Heat sink. An efficient heat sink must be used between the soldering point and the body of the semiconductor. There are many forms of clip-on heat sink made from copper and crocodile clips, but some of these may prove too large for easy working on semiconductors. A very effective method is to use long nosed pliers which have had a short length of copper cable-braiding slipped over each of the jaws (see fig. 1). Manufacturers quote a minimum distance between the soldering point and the body of the device. On service equipment the recommended minimum distance is 5mm (0·2 in.).

b. Solder. To keep the joint temperature as low as possible, 'radio grade' solder must be used. The lowest possible melting point of solder is 183°C for the eutectic alloy (63% tin and 37% lead). The alloy normally used for electronic work is 60% tin and 40% lead which melts at 188°C and has a small plastic range. It is supplied as flux-cored wire in various diameters. For work on semiconductors only the thinner types should be used (e.g. 22 SWG) as they enable solder to flow on to the joint in the shortest possible time. When the leads of a semiconductor are to be attached to a tag or terminal post, both the leads and the post must be pre-tinned to enable the joint to be completed quickly.

c. Soldering iron. For efficient alloying of a soldered joint a temperature about 60° higher than the melting point of the solder is required (*ie* about 250°C). For semiconductor work it is best to use a temperature-controlled soldering iron such as the Weller 28V model shown

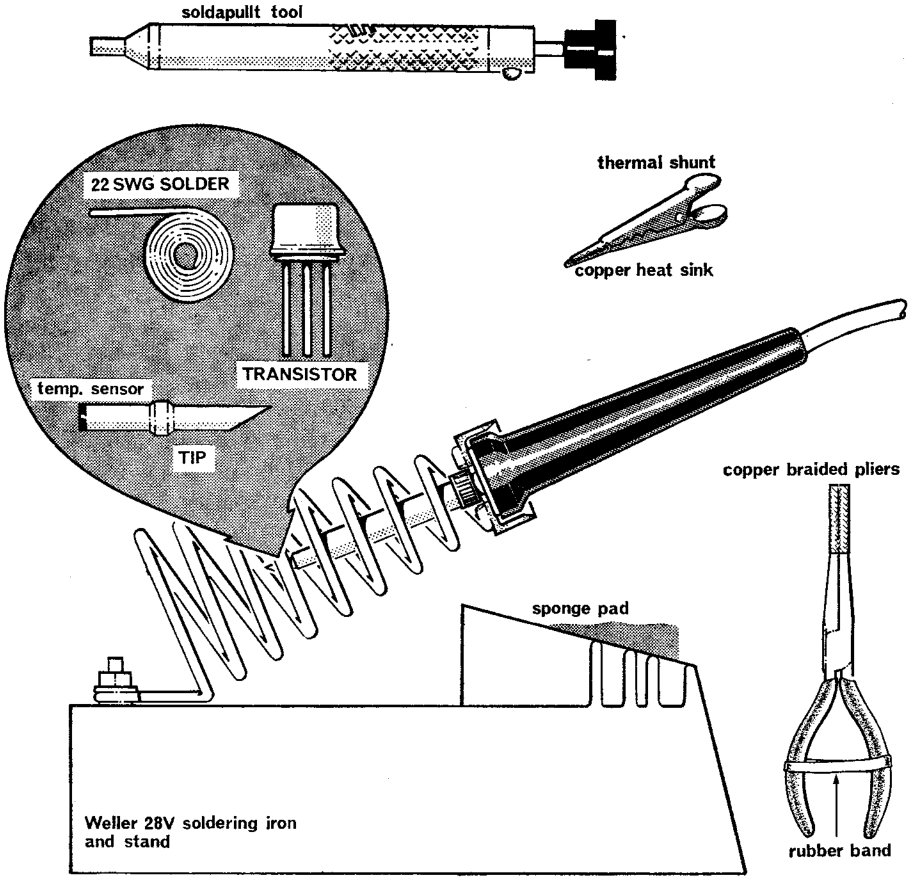

Fig. 1 Soldering

in Figure 1 (1B/1278853). This can be fitted with a range of tip sizes, the most suitable for semiconductor work being a single-flat $\frac{1}{8}$ in tip working at 260°C. Where multi-lead devices are being fitted it is essential to allow a short time (about 20 seconds) between joints to allow the device to cool and the iron to regain the correct working temperature.

d. Desoldering. If the device is to be refitted to the equipment, all the previous points also apply to its removal. The heat sink is still essential. To keep to a minimum the time for which heat is applied, an aspirated desoldering tool must be used. For miniature work, particularly on printed circuits, it is often easiest to use the Weller iron and the Soldapullt tool, thus retaining the advantage of the temperature controlled iron.

Note. Before any soldering or desoldering operations are carried out the equipment must be switched off.

Voltage Considerations

8. Maximum voltage ratings of semiconductors are given by the manufacturer in the device specification. These are absolute maxima, and voltages greater than specified will almost always cause the device to fail.

a. Excessive voltages applied to the base can rupture the crystal lattice and turn the device into an effective short circuit.

b. Excessive drive voltages or voltage transients may cause the maximum power rating of the device to be exceeded, which causes overheating and leads to thermal destruction.

The following paragraphs consider the more important precautions which must be taken when servicing equipments containing semiconductors.

9. **Short circuits.** By far the largest single cause of damage is accidental short circuits with test prods or crocodile clips. Short circuiting the collector lead or the collector-base leads of a transistor can cause very high currents to flow, leading to thermal destruction of the device. Miniature crocodile clips and insulated test prods must be used and great care must be taken to avoid short circuits. The use of small screwdrivers as test prods is forbidden. Power transistors require extra care as the collector is often connected to the case and may be at quite a high voltage with respect to chassis.

10. **Voltage transients.** Care must be taken to avoid the application of d.c. voltages from external sources, e.g. charged input capacitors on oscilloscopes. Earth leads should be connected and the input lead touched to earth before connecting it to the circuit to ensure that any input capacitors are discharged.

11. **Signal generators.** Most signal generators are capable of giving an output of several volts from a low impedance source. This can greatly exceed the maximum specified base-emitter voltage of the transistor and may destroy it. Before a signal generator is connected into a transistorized circuit, the output should be reduced to minimum and then brought up to the required value after connection.

12. **Plugs and sockets.** When removing or replacing plugs or sockets some pins may be connected before others and, if the equipment is switched on, the transistors may be damaged. It is essential to ensure that power supplies are switched off before any plugs or sockets are removed or reconnected. Do not attempt to run transformer coupled output stages with the load disconnected as this allows high primary voltages which may exceed the maximum collector-emitter rating of the transistor.

13. **Insulation testers.** Due to the high voltages at which these instruments work they will destroy any transistors to which they are accidentally connected. For this reason insulation testing of aircraft wiring and installations is not permitted unless specifically called for in the servicing schedule or authorized by the appropriate trade specialist officer. Whenever insulation testing is to be carried out, the type of tester to be used will be specified and the exact method of carrying out the test laid down so that transistors will not be damaged.

14. **Multimeters.** Multimeters often have several resistance measurement ranges which operate at different voltages from internal dry batteries. On the higher ohms ranges most multimeters use a 15V or 22·5V battery which is a high enough voltage to damage a transistor base-emitter junction. In general the range must not be used if it operates from a battery of more than 3V.

Measurements in Semiconductor Circuits

15. **Voltage.** Care must be taken when making voltage measurements to ensure that components are not shunted in such a way as to cause damage to transistors. This is particularly important in d.c. coupled circuits where the application of a voltmeter can affect the bias conditions. Whenever possible a valve voltmeter should be used for all measurements, but if a multimeter is to be used it must have a high sensitivity (better than 10kΩ/V).

16. **Resistance.** Before making resistance measurements on components with the transistors in circuit, the ohmmeter must be checked to ensure that its output voltage does not exceed the maximum permitted levels quoted in the transistor specification. The polarity of the meter leads should be checked on an external voltmeter, and the leads applied in such a way as to *reverse bias* any semiconductor junction in parallel with the resistor being measured. Meter ranges capable of delivering short circuit currents greater than 2mA should not be used because of the risk of damage to semiconductor junctions if they are accidentally forward biased.

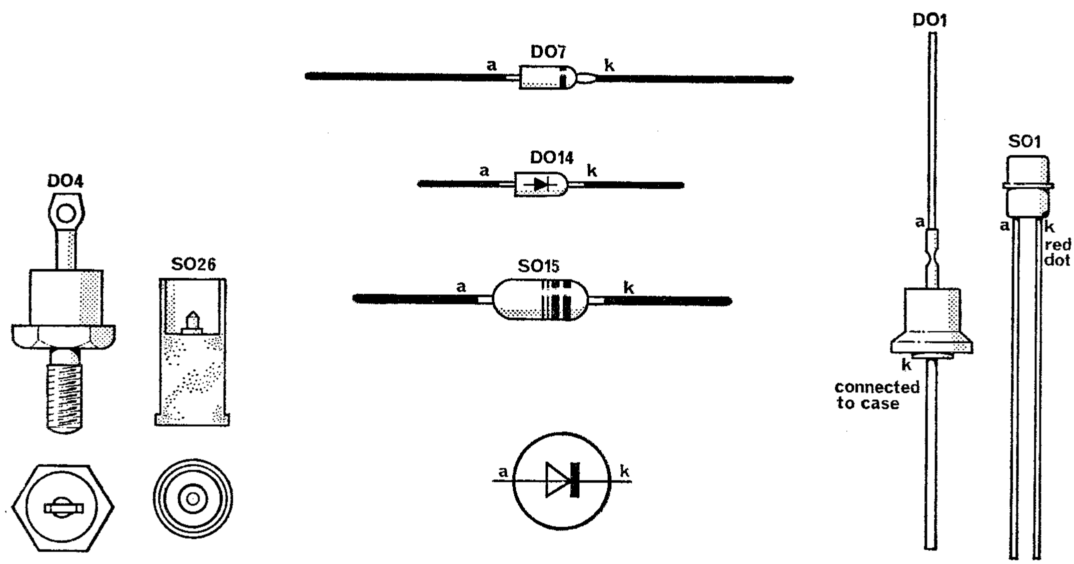

Fig. 2 Diode outlines (actual size)

Diodes

17. **Polarity.** In order for semi-conductor diodes to operate they must be installed with the proper polarity. Reversed polarity could result in damage to the diode or to its associated components. Unfortunately there is, as yet, no standard method of marking diode polarities and different manufacturers use their own methods. It is even likely that spare diodes of a given CV type may be marked differently from those of the same type originally fitted by the equipment manufacturer. Some of the more common diode packages and markings are shown, actual size, in figure 2. The cathode end of the package may be marked with a red, blue or black band (or bands) or it may be coloured red, blue or black. Single-ended packages have a + sign, a red dot or the letter k stencilled near the cathode lead. Where there is any doubt, the polarity of a device can be checked on a multimeter as described in the next paragraph.

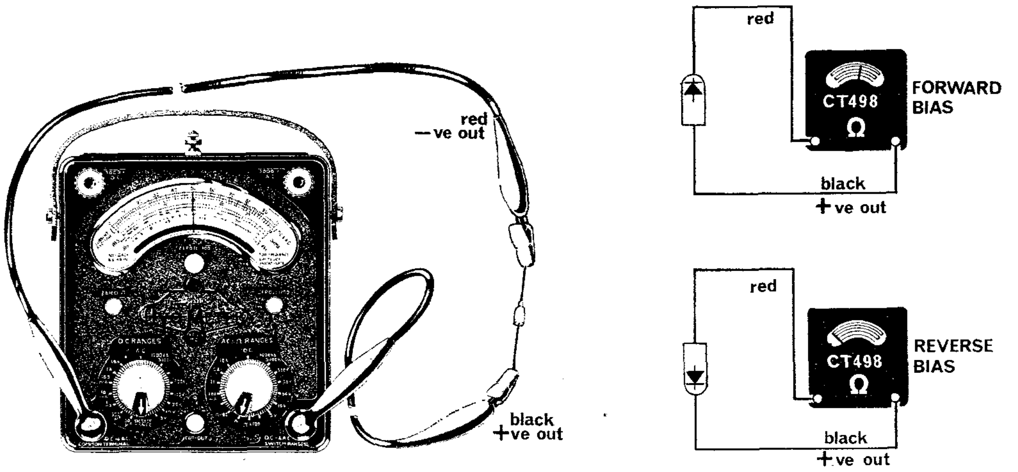

Fig. 3 Diode testing with a multimeter

18. **Multimeter tests.** The more common diode faults can be found by using a multimeter to carry out resistance checks. The diodes backward resistance is first measured with reverse bias, *ie* the black lead of the ohmmeter (positive out) is connected to the cathode end of the device. The resistance reading obtained is noted and the leads are then reversed to measure the forward resistance of the diode. The ratio between the two resistances is known as the back-to-front resistance ratio and is unlikely to be less than 10:1 on a serviceable diode. Most junction diodes will give a ratio of about a thousand to one and point contact types a ratio of about a hundred to one. If during these tests a device reads low resistance both ways, it has lost its rectifying ability and is therefore unserviceable. If a low reading cannot be obtained either way round, the device is probably open-circuit and again is unserviceable. Occasionally a diode will pass these tests but will not perform satisfactorily when connected into circuit. When this happens, more complicated tests will have to be carried out to check the diode against the manufacturers specifications.

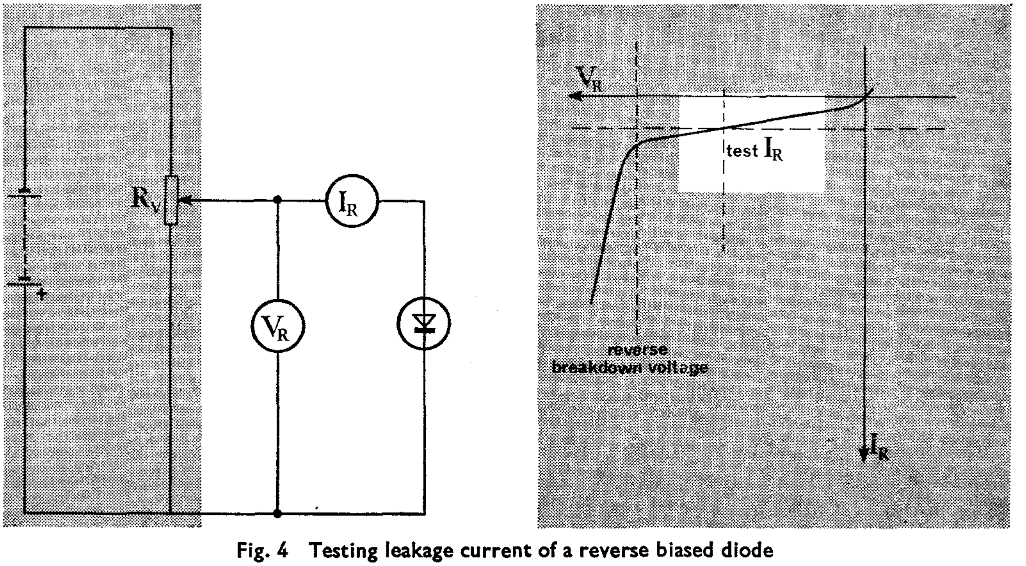

Fig. 4 Testing leakage current of a reverse biased diode

19. **Reverse bias tests.** The basic circuit shown in figure 4 is used to test diode characteristics under reverse bias conditions. Initially the potentiometer R_V is set to apply zero volts to the diode. The voltage is then *carefully* increased while watching the *ammeter reading* I_R. If this leakage current is much higher than quoted by the manufacturer the device is going unserviceable and has probably been damaged by diffusion at the junction, caused by overheating. If the diodes reverse breakdown voltage is to be tested, a graph is plotted of I_R against V_R. When the *rate of change* of I_R begins to increase suddenly, the meter reading V_R is noted and compared with the breakdown voltage quoted by the maker.

Note: These tests may be difficult to carry out on modern silicon diodes where the leakage current is too low to measure on easily available ammeters.

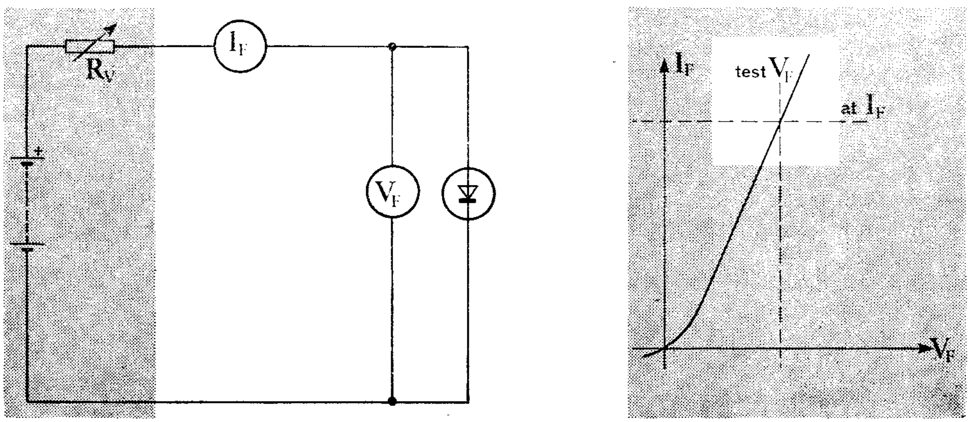

Fig. 5 Testing forward voltage drop of a conducting diode

20. **Forward bias tests.** Because the ohmmeter tests for forward resistance do not drive the diode into full conduction they do not give an accurate indication of its circuit performance. The basic test circuit of figure 5 can be used to drive the diode to its working current. Initially the variable resistor is set to its full value to protect the ammeter if a short-circuited junction is present. The current is then *carefully* increased to the test value given in the manufacturers specification. The voltage drop across the diode is then shown on the voltmeter V_F and can be

TYPICAL DIODE TEST READINGS

CONSTRUCTION/USE	TYPE	I_R at V_R		V_F at I_F	
GERMANIUM - POINT CONTACT General purpose signal diodes or detectors	OA91	75µA	100V	2·1V	30mA
	AA117	4µA	10V	1·2V	10mA
	AAY 54 CARTRIDGE	300µA	40V	<1·0V	2mA
GERMANIUM - GOLD BONDED General purpose and fast switching	AAZ15	10µA	100V	0·7V	250mA
GERMANIUM - X BAND MIXER CARTRIDGE	AAY50	3µA	0·5V	0·5V	9mA
SILICON JUNCTION - General purpose	OA200	20nA	50V	0·9V	30mA
SILICON JUNCTION (PLANAR) - High speed switching	BAX28	<50nA	15V	<1·0V	30mA

compared with that given by the manufacturer. If the reading is too high, the diode is inefficient and should be classed as unserviceable. Because of the various meters and power supplies needed to test different diodes, these tests are normally done on transistor test sets.

Transistors

21. **Outlines and nomenclature (USA).** The oldest standard system in common use is the American "JEDEC" system. This was produced by the Joint Electronic Device Engineering Council (JEDEC) of the Electronic Industries Association in the United States. The system used has a first numeral which indicates the number of junctions in the device. This numeral is followed by the letter N and then the serial number under which the device was first registered. Thus 1N23 was the twenty-third diode registered. Both 1N diodes and 2N transistors now total over 5000 registrations. Any manufacturer can supply devices to JEDEC numbers provided they meet the specification registered by the original manufacturer. Devices made to American military specifications may have their JEDEC number preceded by the letters JAN (joint army-navy).

The JEDEC council also registered the dimensions of preferred cases and encapsulations under DO (diode outline) and TO (transistor outline) numbers. Certain common outlines from this system have now been adopted by most manufacturers and are shown in Figures 6 and 2.

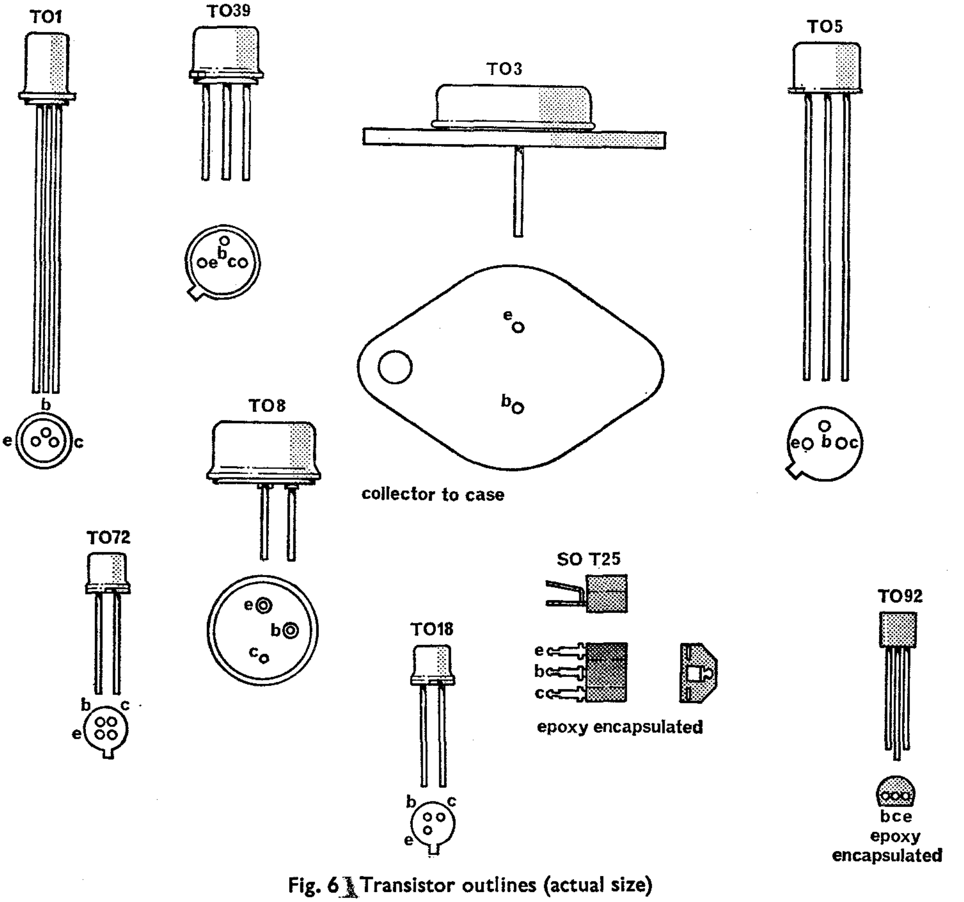

Fig. 6 Transistor outlines (actual size)

22. **Outlines and nomenclature (Europe).** The European system is organized by the Association Internationale Pro Electron and is known as "PRO-ELECTRON". The type number has five places; either two letters and three numbers for entertainment users (e.g. AC151), or three letters and two numbers for professional and industrial users (e.g. ACY23). The first letter shows the semiconductor material used *eg*

A = Germanium   B = Silicon   C = Gallium arsenide

The second letter indicates the application of the device e.g.

A = Signal diode   C = Low frequency transistor   S = Switching transistor

The remaining letter and two figure number form the serial number of the original device registration (Z first, then Y, then X etc). For United Kingdom military use all types of semiconductor device are given a CV number and are listed in AP1186 together with all electronic valves. As was the case for valves, the CV number itself has no meaning.

A standard system of semiconductor outlines (the SO series) have also been registered with the British Electronic Valve and Semiconductor Manufacturers Association. These outlines are related to the JEDEC system which now seems to be in international use.

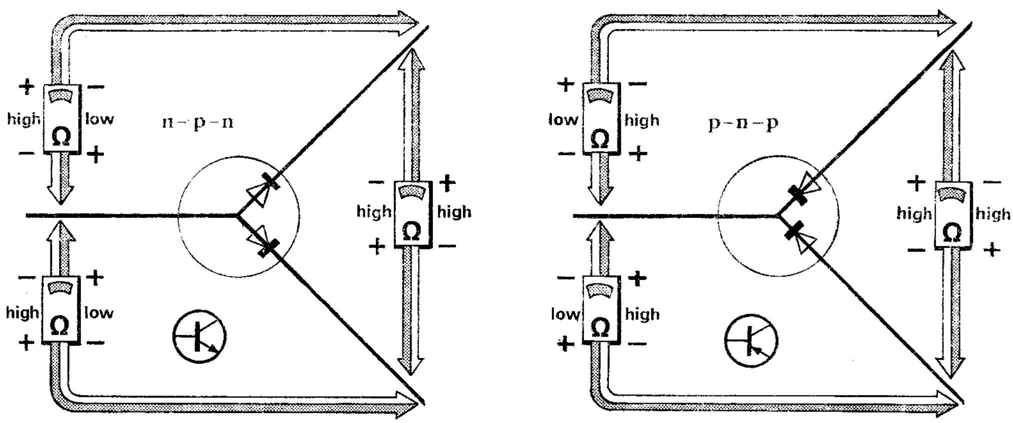

Fig. 7 Transistors—multimeter tests

23. **Multimeter tests.** Before making tests with an ohmmeter, the transistor specification must be checked to ensure that the maximum permitted voltages, particularly V_{EBO} will not be exceeded. To minimise the risk of damage to a transistor during testing, the meter resistance range used should operate with a current of less than 2mA and a terminal voltage of less than 3V. On the multimeter CT 498 these restrictions mean that only the $\Omega\times 1$ range may be used. When testing transistors installed in an equipment, all power supplies must be turned off and allowance must be made for any resistors in parallel with the junction resistance being measured.

The tests shown in figure 7 can be used to check a suspect transistor for open circuits and for short circuited junctions. For the purpose of the test a transistor can be assumed to be a pair of p-n junction diodes connected back to back as shown in figure 7. The back-to-front resistance ratio of each of these diodes is then tested separately. The polarities shown on figure 7 are those actually present on the meter leads. On most direct reading instruments the black lead (negative input lead) will be connected to the positive pole of the internal battery and is therefore the lead marked + in figure 7. When in doubt, both the lead polarity and the output voltage can be checked on a voltmeter.

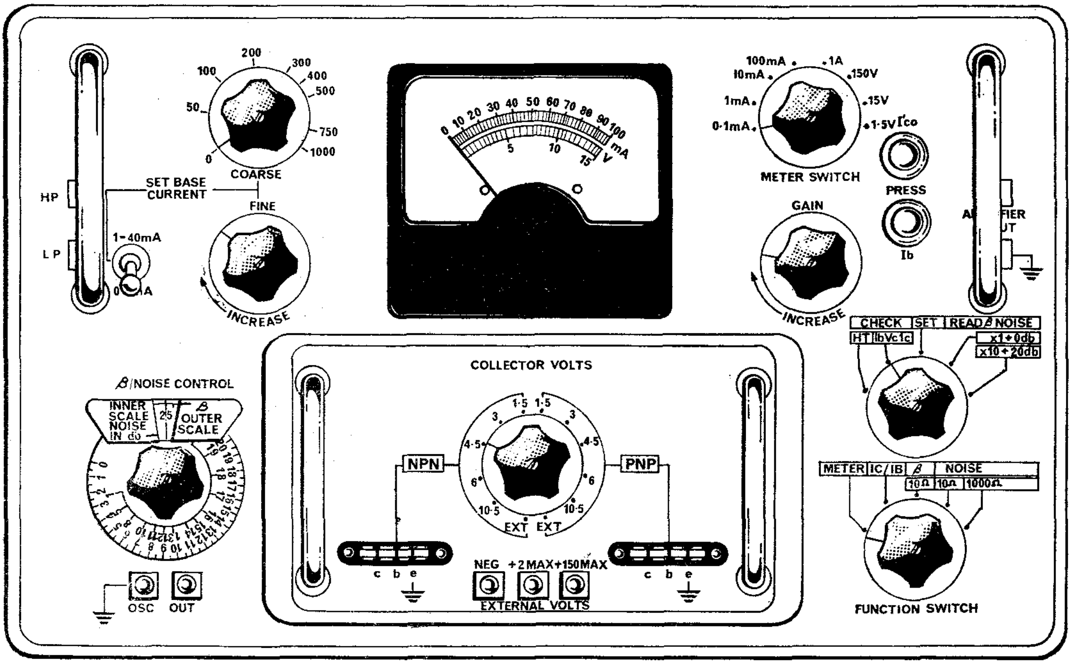

Fig. 8 Test set transistor CT 446

24. More sophisticated tests on transistors are usually carried out only at third line units on special test equipment, such as the test set CT 446 shown in figure 8. The circuitry, batteries and meters needed to carry out standard tests can be selected on the front panel switches. Full details of this instrument can be found in AP2537G which also contains the test data for CV registered transistors. The serviceability of a given transistor can normally be determined by two tests, leakage current and current gain, and the basic circuits for these tests are described in the following paragraphs.

25. **Leakage current I_{CBO}.** I_{CBO} is the sum of the surface leakage current and the minority carrier current which flows across the reverse biased base-collector junction. As the minority carrier current is caused by hole-electron pair formation it is very dependent on junction temperature and will approximately double for every 10°C increase. When testing, do not hold the transistor in the hand (it is warm). Any damage to the crystal lattice structure (caused by previous overheating) will also cause a considerable rise in the value of leakage current which therefore acts as a sensitive indication of the condition of a transistor. In general, a transistor with greater than normal leakage is more defective than one with a lower than normal gain. This is because any I_{CBO} flowing will aid the forward bias in a common emitter circuit, completely upsetting the normal operating conditions and, in extreme cases, causing thermal runaway to occur.

The circuit of figure 9 shows the basic method of measuring leakage current for a p-n-p transistor. For n-p-n transistors the connections to the base and collector must be reversed for proper biasing. Initially the variable resistor is set to apply zero volts to the transistor. The voltage is then increased, taking great care not to damage the ammeter, until the test value of V_{CB} is reached. The leakage current measured will probably be about one fifth of the manufacturer's specified maximum value on a good transistor. Initially a higher value may occur which reduces over a period of 5 or 10 secs. This is due to drift at the junction and sufficient time must be allowed for steady conditions before taking a reading. As moving coil ammeters are not commonly available to measure currents below about 1μA, the leakage currents of low power silicon transistors can only be measured on a special transistor test set.

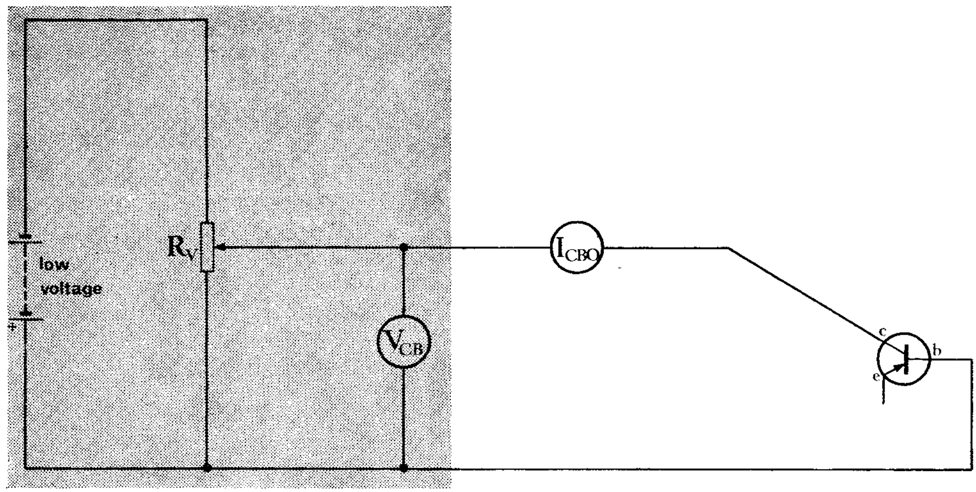

Fig. 9 Testing leakage current I_{CBO}

26. **Gain h_{FE}.** The gain usually quoted in manufacturer's specification is h_{FE}, which is the static value of the short circuit current transfer ratio in the common emitter configuration (i.e. I_C/I_B). It was formerly given the symbol β and is still occasionally called beta. It is usually quoted for a specified collector current I_C and collector-emitter voltage V_{CE}. Under these conditions a base current I_B is needed to allow the collector current to flow. These currents can be measured using the basic test circuit shown in figure 10, and h_{FE} can then be calculated ($h_{FE} = I_C/I_B$), and compared with the specified minimum value for the transistor being tested. Figure 10 shows the test circuit for an n-p-n transistor; for testing p-n-p types the polarity of both batteries must be reversed.

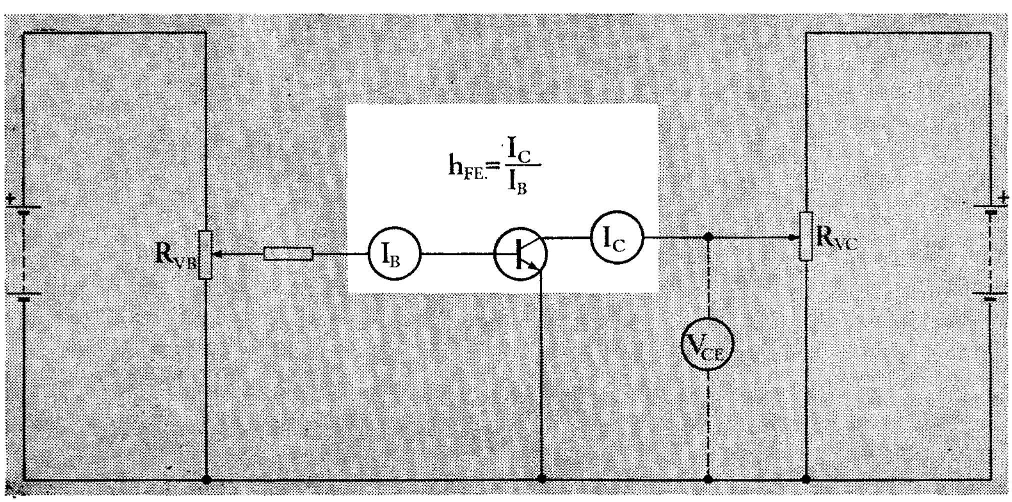

Fig. 10 Testing current gain h_{FE}

CHAPTER 5

PRINTED CIRCUITS

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Introduction

1. This chapter contains repair methods applicable to printed circuit boards and to other sub-miniature equipments constructed by the turret post/laminated baseboard technique. The depth of servicing *permitted on a given equipment* is laid down in the equipment servicing policy and can be found in the appropriate Air Publication. Some of the repair methods described in this chapter are not permitted *at second line level* on equipments serviced by maintenance units under the direct exchange scheme.

2. **Construction.** Simple printed wiring boards are made of a laminated material such as glass cloth bonded with epoxy resin (or PTFE), or paper bonded with a phenolic resin. The copper wiring is extremely thin (about 0·003 inch) and is bonded to the laminate by a layer of adhesive, usually an epoxy resin such as Araldite. The required conductor pattern is then formed by an etching process and holes are drilled (or punched) through the board to mount components. The ends of the component leads are sometimes bent over against 'pads' on the copper conductors. The board is then flow-soldered and a protective layer of varnish or a plastic insulating coating is applied.

The increase in component density caused by the widespread use of transistors and miniature low-voltage/low-wattage components made it difficult to fit the interconnecting wiring pattern on one side of the board and so double sided boards were introduced. The connections between the two sides were originally made by wire links, rivets or 'crinkle' links but as these were not very reliable they were rapidly replaced by the plated-through hole technique and this is now the normal method.

As integrated circuit packs became more common, the very high density interconnection patterns needed could no longer be accommodated on double sided boards. Consequently further layers of conductor patterns were added to form a multiple laminate structure now well known as multi-layer boards. Connections between layers are made by means of through plated holes.

3. **Multi-layer boards.** The amount of manual skill and dexterity necessary to repair modern multi-layer boards is so great that 30 MU personnel are given special on-the-job training before being allowed to carry out repairs on in-use equipments. Some special tools are also required. Unauthorized attempts to carry out local repairs to multi-layer boards *must not be made* because of the high risk of causing *irreparable damage to very high cost items.*

Printed Circuit Board Preparation for Work

4. **Protective coating.** Printed circuit boards have all soldered connections covered with a protective coating of varnish which may have to be removed before tests can be carried out during fault finding. The coating must always be removed from any area in which soldering is to take place. Failure to remove the coating will result in an excess of heat being applied, first to break through the varnish and then to unsolder the component. This could cause lifting of the conductor track or loosening of eyelets resulting in future intermittent open circuits. The board should be cleaned with Trichlorethylene (33C/547) in a well-ventilated room. It is easiest to apply from a spray or a plastic 'squeeze' type bottle. The dissolved varnish and solvent can be brushed off the board with a nylon brush (1A/9432863) and the board can then be dried using an air line. Care must be taken not to damage any sensitive components and the air line must always be pointed away from personnel and any other electronic equipment.

5. **Handling.** Printed circuit boards are particularly susceptible to damage when improperly handled. Foreign materials, such as dirt, dust, filings, solder spots and fingerprints can all cause poor solder connections, electrical breakdown or open circuits. Bending the board will result in the conductor foil being stretched, and as severe strain may fracture the copper can result in hairline cracks in the conductor. These breaks will often result in intermittent faults which are very difficult to trace.

Component Removal

6. When removing components extreme care must be used to avoid lifting or damaging the etched circuitry, and to prevent damage to the base material through excessive application of heat. For most components of the axial lead type, *eg* resistors, first cut the component leads on the component side of the board. Then by careful application of heat, remove the lead ends from the circuitry side of the board as soon as the solder is molten. Many of the low-power transistors have very thin leads which can be broken by twisting the transistor backwards and forwards a few times, the lead ends can then be removed as before.

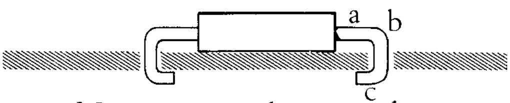
For multiple pin components such as integrated circuit flat packs a different technique must be used. Each lead must be heated individually and the solder removed as soon as it is molten by means of a desoldering tool such as the Soldapullt. Allow time for the printed circuit board to cool before heating the next lead. For complete removal of all residual solder a special flux-impregnated braid can be used which absorbs the molten solder by capillary action. Ensure that all leads are completely free before attempting to remove the component, a sticking lead can be gently eased free with a penknife.

Component Preparation and Mounting

7. All component leads must be cleaned and degreased carefully and then pre-tinned to enable the final soldering operation to take place as quickly as possible. Where insulated leads are to be stripped, thermal stripping tools should be used on leads of 22AWG or smaller to protect them from the stretching and nicking which is so easily caused by mechanical strippers. Any nicks caused during stripping (or bending) must not penetrate the plating, not decrease the cross sectional area of the lead by more than 15%, not be closer together than 0·05 inch and there should not be more than three such nicks on any one lead.

8. **Bending tools.** Use wire-bending pliers (round nosed), or other smooth-edged devices, to form wires and component leads. Long nosed pliers are an acceptable bending tool *provided that the sharp edges of the jaws are covered to prevent damage* to the lead.

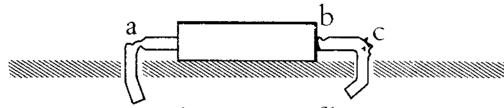
Lead bending. Use extreme care, when forming wire or component leads, to prevent damage or breakage by the bending tools.



a. Minimum straight section between component and bend is 0.06 inch.

b. Bend angle is 90° with a smoothly radiussed bend.

c. Part is held securely with a mechanical clinch; the lead must lie along the printed wiring track.

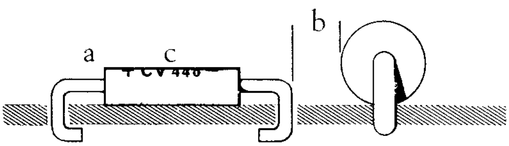


a. Deep indentation or flat is present on lead

b. Lead is nicked through plating.

c. Plating has deteriorated and is flaking off at bends.

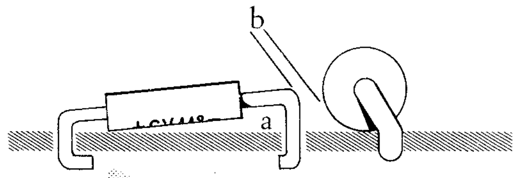
9. **Mounting of axial - lead components**



a. Parts are properly oriented and seated as firmly as possible.

b. Unless otherwise insulated, minimum electrical clearance between parts shall be .025. Exceptions (made necessary by voltage requirements) will be specified in the appropriate A.P.

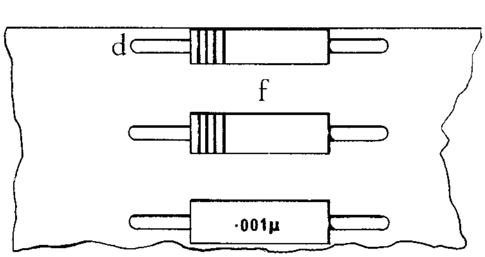
c. Values/rating etc. are clearly visible.



a. Parts are not seated firmly nor properly oriented.

b. There is insufficient electrical clearance between parts.

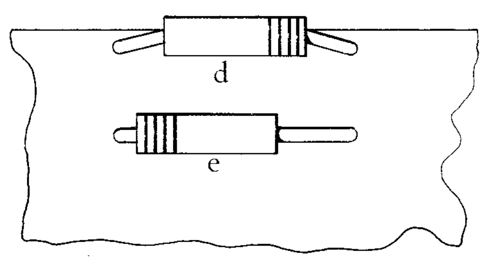
c. Values and ratings are hidden.



d. Part body is flush with or inside board edge.

e. Part is centered between lead holes.

f. All non-polarized parts are in the same 'orientation' for colour code (or identity marking).



d. Part body extends over board edge.

e. Part is not centered between lead holes.

10. **Soldering components with clenched leads.** The component lead should be cut to a length sufficient to permit direct contact with the printed circuitry. The lead end should then be smoothly bent over to lie against the printed circuit track. The lead must not extend beyond the edges of the terminal pad area or of the connecting circuitry. When soldered, the joint should have a smooth, shiny appearance with a clean solder fillet completely around the lead. The *outline* of the lead should still be visible through the surface of the completed soldered connection.

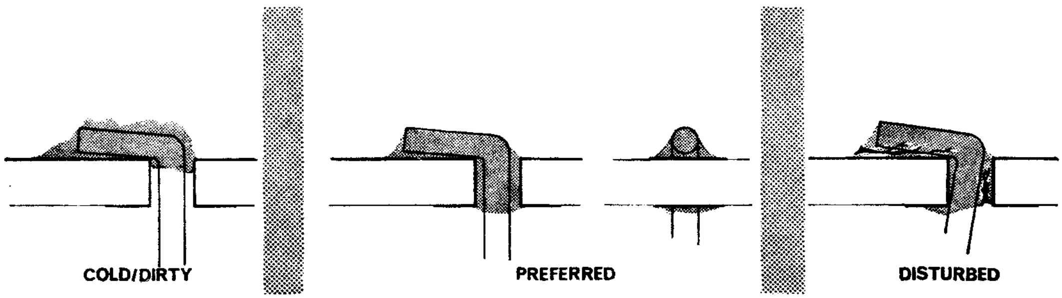


Fig. 1 Clenched joints

11. **Soldered joint definitions.** There are three essential conditions for high quality soldering; absolute cleanliness, the correct iron and the correct solder. For printed circuit and other miniature work, absolute cleanliness means the absence of dirt and surface oxidation and the removal of all traces of grease (even that caused by fingerprints). The size and wattage of the iron depends on the size of the job, but temperature controlled types (such as the Weller) are recommended for printed circuits or semiconductors. The only solder which should be used for electronic equipments is 22 SWG resin cored solder wire. If these conditions are observed, the joint obtained will fit one of the following definitions:

a. *Preferred.* The solder is smooth, bright, and feathered out to a thin edge, thus indicating proper flow and wetting action. There is no bare lead material exposed within the solder joint, no sharp protrusions and no evidence of contamination (or embedded foreign matter). The contour of the component lead wire is visible.

b. *Excessive solder.* As above except that the lead contour is completely obscured. If the excess solder has also overflowed beyond the edges of the terminal pad area or the connecting circuitry the joint is not acceptable.

c. *Insufficient solder.* The component or wire leads show exposed lead or copper material and the absence of a complete solder fillet around the lead. In extreme cases these joints are not acceptable and should be resoldered.

d. *Cold/dirty.* The solder usually appears dull and sometimes has a crystalline or porous surface. The joint usually has a stacked or piled-up appearance and an absence of smooth flow and proper wetting action. There is often a clear dividing line between the two halves of the joint rather than the smooth fillet of the preferred joint. In most cases the cause can be traced to an improper wattage soldering iron or to dirt.

e. *Disturbed.* The solder has a dull porous or crystalline appearance. Under a good magnifying glass the surface will show cracks and fractures. This type of defective joint is caused by movement of the parts during the critical plastic range of the solder which occurs just before solidification.

Where a defective joint has been made, it is usually best to remove all solder using a desoldering tool, thoroughly clean the parts and then resolder the joint.

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12. **Components with straight-through leads.** Multilead components, such as integrated circuit flat packs are mounted without clenching the leads. They are usually manufactured with lead spacing arranged to fit the standard printed circuit matrix, but in some cases the leads may have to be formed to fit the hole pattern. The component should be mounted flush to the printed circuit board and the excess lead trimmed off to form a pigtail not more than one twentieth of an inch long extended through the mounting hole. When soldered, the joint should have a smooth shiny appearance with a clean solder fillet completely around the lead. The *outline* of the pigtail should be visible through the surface of the completed soldered connection.

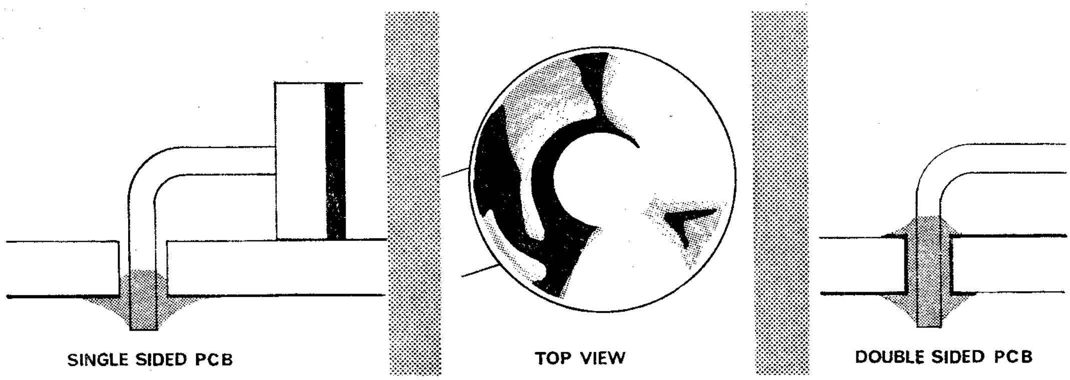


Fig. 2 Straight-through joints

Repair of Damaged Conductor Track

13. The repair of damaged printed circuit conductor tracks is normally a third line task and is carried out in the following sequence:

a. The working area is thoroughly cleaned and degreased.

b. If a gap in the conductor track of less than 0·03 inches exists it is repaired by soldering a bridge of 22 SWG wire across the gap. An 0·25 inch overlap on to the conductor at both sides of the gap ensures good conduction.

c. If the gap is in excess of 0·03 inches a jumper lead of white cable 22 SWG (5E/9453381) is used to effect a new lead from the connected points of the damaged conductor. The jumper lead is soldered between suitable component leads and only enough solder is applied to show the wire contour. The jumper lead must be secured to the printed circuit board and this is normally done with a clear adhesive *eg* Tensol (33H/9436930).

d. If the etched conductor has been raised off the printed circuit board by the application of excessive heat or undue pressure it may be resecured with a suitable adhesive, usually Araldite (33H/9437791). A long stretch of raised conductor is often cut away and replaced by a jumper lead as above.

Treatment after Repair

14. Ensure that all solder splashes, resin spots, wire ends etc. have been removed from the board and then clean and degrease the worked area using trichlorethylene. Inspect the area which has been repaired using an illuminated magnifier (6E/948), to confirm that the work has been carried out to acceptable standards. Place masking tape over male pin connectors etc. and recoat the board with insulating varnish. As using a brushing varnish is a possible source of contamination an aerosol type of spray is recommended by 30 MU. Allow about an hour for the board to dry in clean conditions and then carry out a final inspection of the whole board under the illuminated magnifier.

Turret Post Terminals

15. Some miniaturized equipments are constructed as a 'mother' chassis to which several modules are connected by means of plugs and sockets. These modules often consist of an alloy frame containing a laminated circuit board to which the components are mounted by means of turret posts. Care must always be taken when removing components to avoid pulling the turret posts out of the board, and heat should be applied for the shortest possible time to avoid distortion of the laminate.

16. **Connection of leads to turret posts.** The lead should be long enough to permit one field repair *ie* cutting, restripping and reconnecting. Where more than one lead is attached to a terminal, the largest lead will normally be at the bottom. Leads shall be wrapped between one half and three quarters of a turn round the terminal (without any lead extension) and the contour of the lead should be visible through the completed soldered joint.

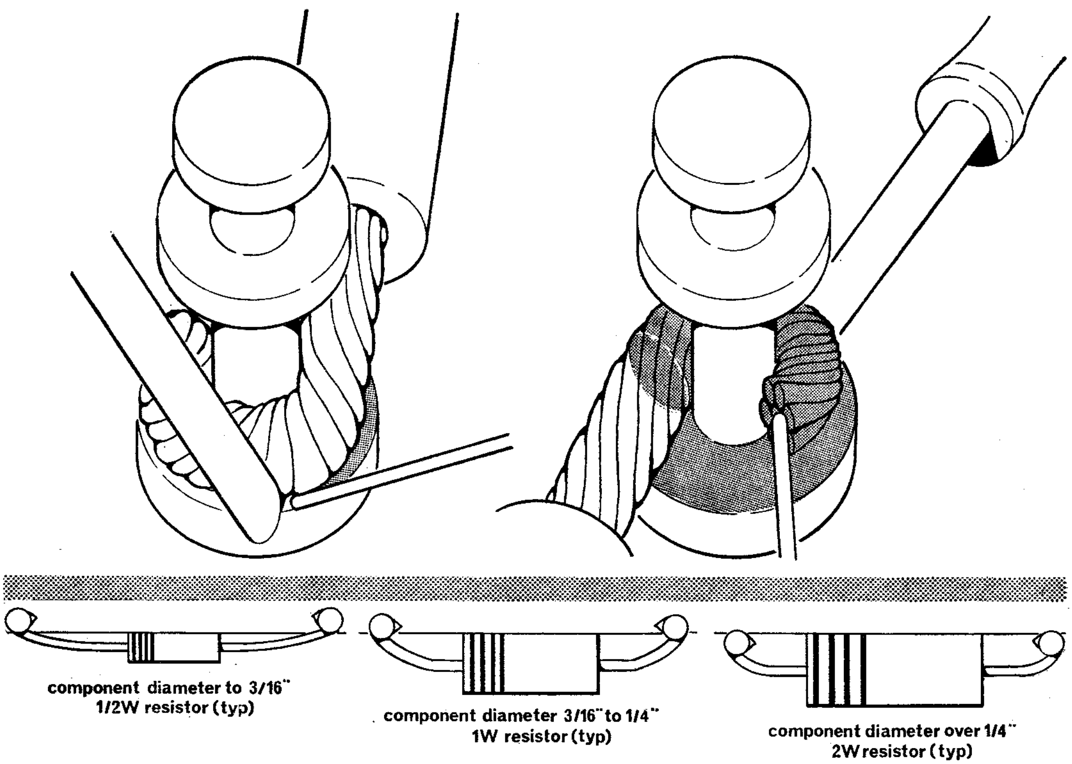


Fig. 3 Turret posts

17. **Connection of components between turret posts.** The components shall be mounted with colour coding, rating and other data clearly visible and unless polarized should read from the left to the right consistent with printed identification marks. Where there is any risk of shorting or grounding, the component leads are covered with insulated tubing (sleeves). Component leads shall be preformed and must not be bent closer than one sixteenth of an inch to the component body, the minimum radius of bend is three times the lead diameter. Expansion radii are slight curves which must be formed in the leads to prevent stress during thermal expansion and contraction (see figure 3).

CHAPTER 6

FAULT FINDING

List of Contents

Introduction

1. There are four main factors which contribute to a tradesman's ability to find a fault in electrical or electronic equipment. These factors are very much inter-related and none of them could be said to be more important than any of the others. They are:

a. *Knowledge of basic electrical and radio theory.* This knowledge is mainly obtained during initial trade training and will gradually develop as a tradesman gains experience and meets a wide variety of different equipments. It is dealt with in detail in AP3275 and AP3302 and will not be considered in this book. During fault finding, theory is mainly used to determine which component is faulty within a circuit which has been proved to contain the fault.

b. *Use of test equipment.* The ability to operate general items of test equipment, such as multimeters and oscilloscopes, is vital in fault diagnosis. Test equipment is the means by which checks are made of the equipment function to narrow down the area containing the fault, and the ability to *correctly interpret* the results is an essential part of the check. The use of general test equipment has already been considered in Section 4 and any further information needed can usually be obtained from the instrument handbook. When making tests at places in an equipment other than built-in test points, the *loading effect* of the test instrument must be considered.

c. *Functional knowledge of the equipment.* This is the knowledge required to understand the operation of the equipment in terms of the outputs available, the inputs, switching arrangements etc and can be obtained from functional diagrams in the equipment AP. A tradesman must also be able to operate the equipment and any special-to-type test equipment in order to carry out functional tests and alignment (setting up). It is the ability to interpret the defect symptoms found during functional tests which forms the basis of a tradesmen's fault-finding strategy and determines the order in which all further tests are to be made.

d. *Knowledge of fault-finding principles.* Fault finding is a logical process of elimination and can only be done effectively by systematically narrowing down the area in which the fault lies. This chapter contains the general rules which can be applied to any fault-finding situation and then considers the application of these rules to some of the tasks normally carried out by the tradesman.

General Rules

2. All the rules are based on the strategy of *considering the full symptom pattern* and then making a check which attempts to *half the area in which the fault could possibly lie.* This method is called the 'half-split' technique and can be shown mathematically to find any fault using the least possible number of checks. In applying the rules, all relevant safety precautions must be observed and the tradesman must avoid taking any action which could result in damage to the equipment or to the test equipment.

3. The rules given often have to be *modified* to take into account the ease of making a check at a particular point, or to take advantage of built-in test points or of the physical boundaries in the equipment under test. The relative probability of failure of certain components, such as fuses, may also be allowed for by an experienced tradesman when deciding on the exact position of his next check. In practice check points should be decided on the basis of:

a. The theoretically best place to test, as determined by the general rules.

b. The ease of making the test at this exact point, compared to making it at a nearby but more accessible point.

c. The probability of failure of components in the two 'halves' which may lead an experienced tradesmen to make his check 'offset from the centre'.

d. The safety of the equipment, test equipment and operator when making the check.

Note. Every effort should be made to keep the *electrical disturbance* of the equipment to an absolute minimum during testing. Plugs and sockets should not be disconnected if a test can be made at a terminal block or other accessible point.

4. **The half-split rule.** When making tests in a linear system which has been proved to contain a fault; *test in the middle first,* and continue halving the possible faulty area on subsequent tests until the fault is located.

Example 1.

The diagram below shows an eight stage linear chain in which all stages have an equal probability of failure. To simplify the example it is shown with F as the faulty stage.

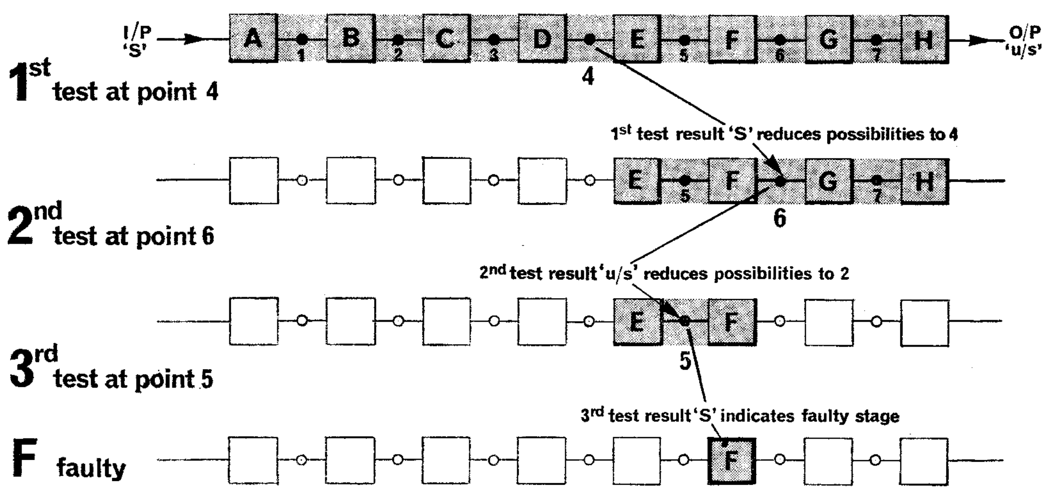


Fig. 1 Example 1 . . . the half split rule

Originally, all that is known is that the input is correct and the output is faulty. The first test is carried out in the middle (point 4) and gives a correct result. This proves that the fault lies in the second half of the chain (stages E, F, G and H). A test is now carried out in the middle of this half (point 6) and gives a faulty result. This proves that the fault lies in stages E or F. A third test is then carried out in the middle of these remaining stages (point 5) and gives a correct result, thus proving F to be the faulty stage. Note that *only three tests* were carried out to locate the faulty stage.

Example 2—The general case

The diagram below shows the general application of the half-split technique to an eight stage chain. It shows that *three tests must locate* the faulty stage of an eight stage chain if these tests are carried out according to the half-split rule. Four tests would be enough to locate the fault in a sixteen stage chain, or five tests in a thirty two stage chain, so the advantage of the half-split technique can easily be seen.

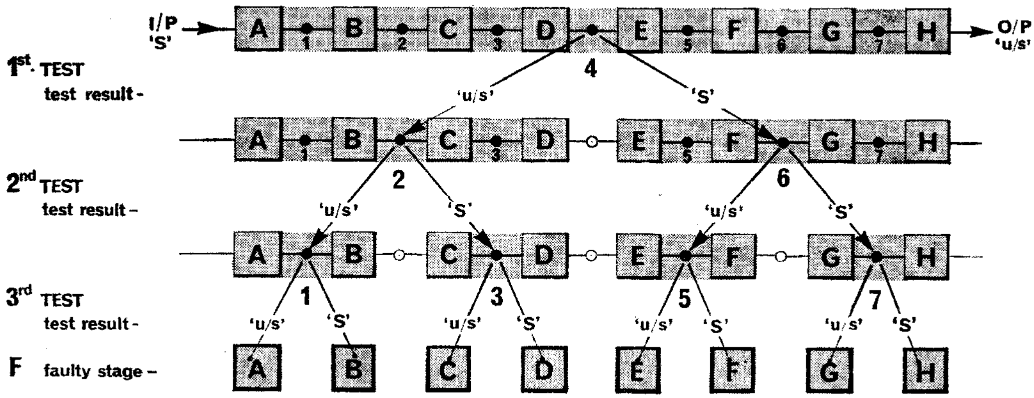


Fig 2. The half split rule . . . general case

5. **Fuses.** Fuses are designed as the 'weak link' in a circuit to protect equipment by blowing when excess current flows in the circuit. After being in service for some time a fuse becomes fatigued and may blow under normal operating conditions, usually at switch-on when there is often a current surge. Thus when there is a fuse in the circuit, it is best to test the circuit as two separate chains, one either side of the fuse.

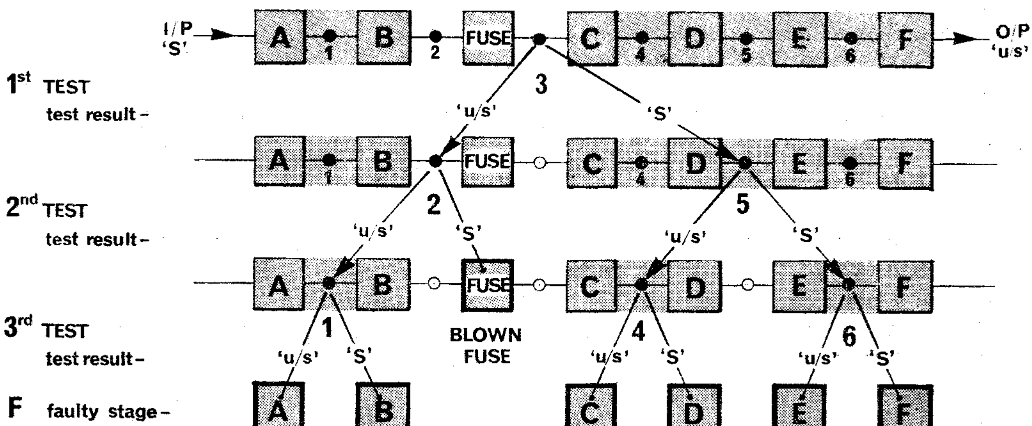


Fig. 3 Half split rule in fused circuits

Example 3—Fused Circuit

If the test sequence shown above proves the fuse has blown, it must be replaced with a new fuse of the correct type. A functional test must then be carried out. If the new fuse does not blow during this test, the equipment is serviceable and the fault was caused by fuse fatigue. If the new fuse blows, there is a fault in stages C, D, E, or F which must be located with the circuit 'dead'. This involves making a visual examination and resistance or insulation tests to find the cause, usually a short circuit.

6. **Divergent circuits.** Divergence occurs when one input is the source of two or more outputs. The simplest case (a divergent point) is where two (or more) output leads are connected to one terminal point *eg* the side and tail lights of a motor car. Divergence can also occur in a circuit, or stage, common examples being paraphase amplifiers and flip-flops. Divergence is extremely important to fault-finding strategy—it enables the faulty area to be narrowed down by deduction, often from the symptoms obtained as part of the equipment functional check. The general rule is to *check the outputs in turn* and then to search in the area common to the faulty output(s) using the half split method.

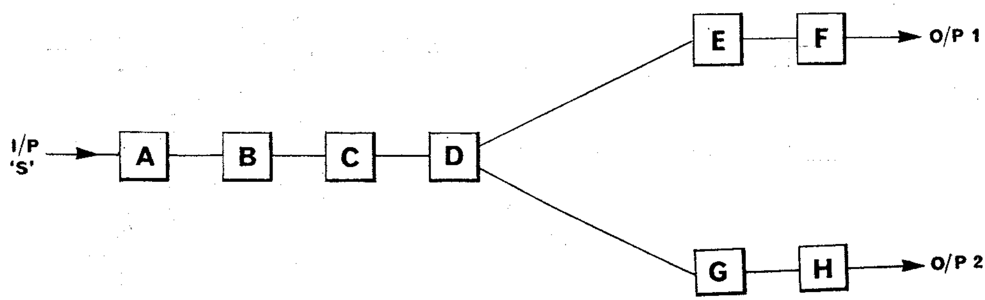


Fig. 4 Divergent circuits

Example 4—Divergent circuit

a. Assuming that output one and output two are 'visible' on a functional check; then by deduction:

(1) If both output 1 and output 2 are 'absent'—the fault lies in stages A to D which can be tested as a linear chain by the half split method.

or (2) If output 1 is 'present' and output 2 is 'absent'—the fault must lie in stages D, G, or H which can be tested as a linear chain.

or (3) If output 2 is 'present' and output 1 'absent'—the fault is in D, E or F.

b. If the outputs are not visible on the functional check they must be tested in turn at convenient access points before deductions can be made as above.

7. **Switching.** Switches are a common means of altering the functional structure of an equipment and are most useful during fault finding because their ease of operation allows tests to be made in a very short time. The important point for fault finding is to know how operation of the switch affects the equipment function. The general rule for switching circuits is to *change the switch position;* then by a deduction process similar to that used for divergence:

a. If the fault symptoms disappear—the fault was in the area switched out.

or b. If the fault remains—it must be in the area common to both switch positions.

8. **Convergence.** Convergence occurs when one output is derived from two (or more) inputs. Functional knowledge of how the inputs act to influence the output is essential. There are two possibilities:

a. First the output may only be produced when *all the inputs are present at the same time.* This is termed summative convergence; common examples are the AND gate in digital computers and coincidence gates in radar strobing or decoding circuits.

b. Secondly the output may be present with *any one input applied.* This is termed alternative convergence and is most often met as the OR gate in digital circuits.

9. **Summative convergence.** The rule for summative convergence is to *check the inputs together* (double beam oscilloscope) to ensure that they are both correct and are present at the same time. Where the circuit has more than two inputs they should be checked in pairs, using one input as the time reference for comparison.

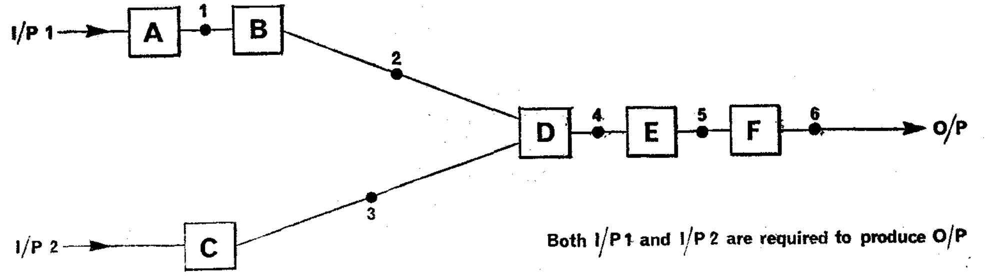


Fig. 5 Summative convergence

Example 5—Summative convergence

Test the inputs at test points 2 and 3. Then by deduction:

a. If any one input is incorrect, search in that input chain using the half split.

b. If all inputs are correct, carry out a check at test point 4. Then if test point 4 is correct search in the output stages using half split; or if test point 4 is not correct search in the convergent stage D using the appropriate circuit techniques.

10. **Alternative convergence.** This type of convergence is less common in radar circuitry than summative, but is much easier to deal with as the faulty area can normally be narrowed down by deduction from the fault symptoms.

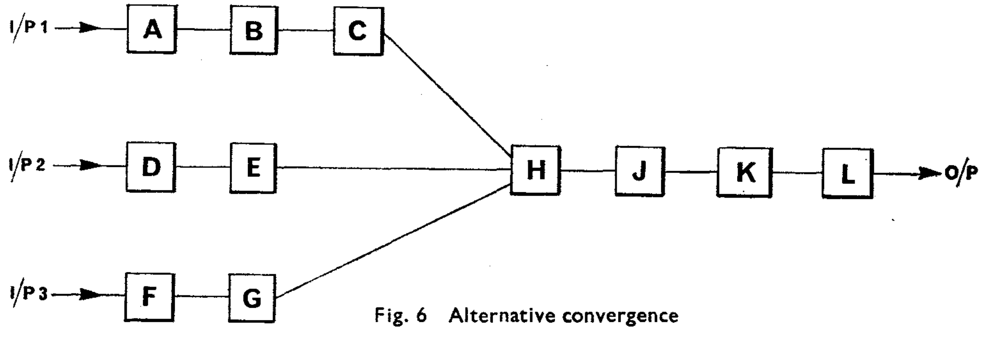


Fig. 6 Alternative convergence

Example 6—Alternative convergence. Any one input will produce an output. By deduction:

a. If there is no output. The chances of all inputs being unserviceable at the same time are extremely small, so the fault must lie in the convergent stage H or the output stages J, K, or L. These four stages can then be tested as a linear chain.

b. There is an output when input 2 or input 1 is applied, but not when input 3 is applied. The fault must lie in number 3 input stages, *ie* the linear chain formed by stages F and G and the input components of the convergent stage H. Similar reasoning can be applied if any other input does not produce an output.

11. **Logic circuits.** In many digital systems there are either logic cards or integrated circuits which perform the complete function of either AND or OR gates and similar related devices. It is only possible to test the inputs, outputs and power supplies and then to clear the fault by replacement with a serviceable item.

12. **Feedback.** Feedback exists where a signal is fed back to an earlier point in its flow path. On a functional diagram the feedback path is marked with arrows from right to left to show the direction of signal flow. There are two main types of feedback, sustaining (positive feedback) and modifying (negative feedback). Positive feedback has limited application and is usually found only in oscillator and pulse switching circuits. Because of the relatively small size of these positive feedback loops, fault finding is usually carried out using the normal techniques for fault finding in a circuit.

Negative or modifying feedback has very wide application and takes many different forms, ranging from simple d.c. loops (such as receiver a.g.c) to the complex a.c. servo loops found in motor control systems. There are no general rules for fault finding in feedback loops as the method to be used in a particular circuit depends on the function of that circuit and is therefore specific to that system. In general the method used is to change the feedback loop; but great care must be taken to ensure that a motor system does not 'run away' and to select a change which does not render the complete system inoperative. Two examples are given below to show typical negative feedback treatments.

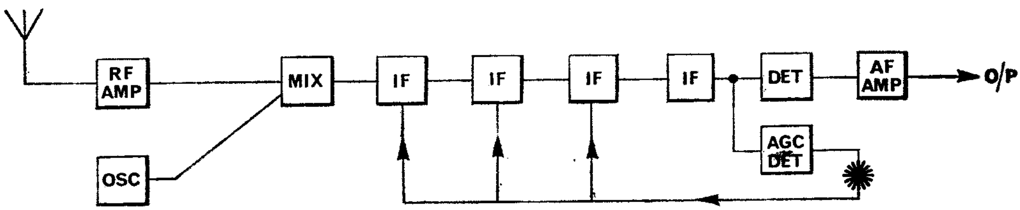


Fig. 7 Feedback . . . example 7

Example 7—Negative Feedback—Automatic gain control (d.c.)

In receiver automatic gain control systems the negative feedback is applied in the form of a d.c. voltage to control the gain of the IF amplifiers. For testing purposes the loop can be broken at the point marked with an asterisk and an artificial feedback voltage can be inserted. This voltage can be varied by the technician to examine the receiver behaviour under simulated overload conditions or to assist him with fault location.

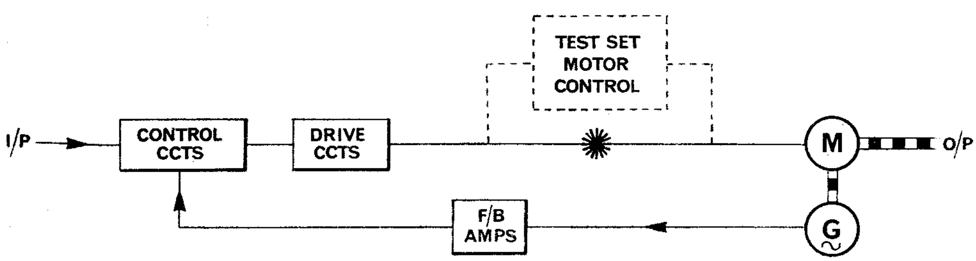


Fig. 8 Feedback . . . example 8

Example 8—Negative feedback—Motor control servo.

The purpose of this type of feedback loop is to apply negative feedback only when the motor is actually running. Thus a high starting torque is developed under 'no feedback' conditions, but the motor speed is controlled under running conditions. Usually the loop cannot be disconnected because of the risk of damage if the motor runs away. The general treatment is to disconnect the motor drive and substitute an artificial drive derived from test equipment (test sets motor control). This enables the technician to examine the actual drive servo performance under various running conditions selected on the test set controls. The same general form of treatment is often applied to remote position control servos, but in this case the drive is disconnected and the position altered by hand.

The general rules for feedback are therefore:

a. To recognize the existance of a feedback loop.

b. To understand the exact function of the feedback in the system being tested.

c. To decide what changes to make to enable tests to be carried out safely and in a manner which provides the maximum information about the circuit behaviour.

Servicing Policy

13. The servicing policy adopted by the Royal Air Force is intended to produce the maximum serviceability of equipment by the most economical use of available resources. This is done by carrying out the minimum of routine servicing and by the replacement of assemblies or sub-assemblies to clear fault conditions.

This *repair by replacement* policy enables skilled manpower, test equipment and spares to be concentrated at centralized servicing points. The amount of centralization possible for a given equipment type depends on a large number of factors such as reliability, cost and size. For this reason, a detailed servicing policy is issued for each equipment by the Ministry of Defence which details the lines of servicing into which various repair tasks fall.

14. **Fault Finding.** In the context of this policy, fault finding could be defined as:

> "Diagnosing and localising a fault through observing symptoms and by performing appropriate checks in a logical and systematic sequence; taking into account any probability information available."

The important words in a practical situation are *localising the fault*. The method of work depends on the degree of localisation required for a given equipment construction. Servicing diagrams in the equipment AP provide the tradesmen with all the information needed for fault location and are produced to the level required by the equipment servicing policy.

Servicing Diagrams

15. **Classes of Diagram.** Servicing diagrams are provided to assist fault diagnosis, rectification and repair. Where the information required cannot be included on the main diagram without loss of clarity, supplementary tables may also be provided. There are three general classes of servicing diagram:

a. Spatial. These are provided to show the physical disposition of an equipment. Line drawings or photographs may be used to locate and identify all items which may be required during servicing.

b. Functional. These are drawn using "detached representation" in which an item is shown in its functional position in the flow path, regardless of its location.

c. Others. Drawings may also be required to show how to do a particular task *eg* dismantling/assembly; or to assist in fault location *eg* waveform charts.

16. **Spatial Diagrams.** Spatial diagrams are produced at any level of complexity required by the servicing task. Examples of the more common types are given in this paragraph. In most modern APs drawings are either full page or double page size.

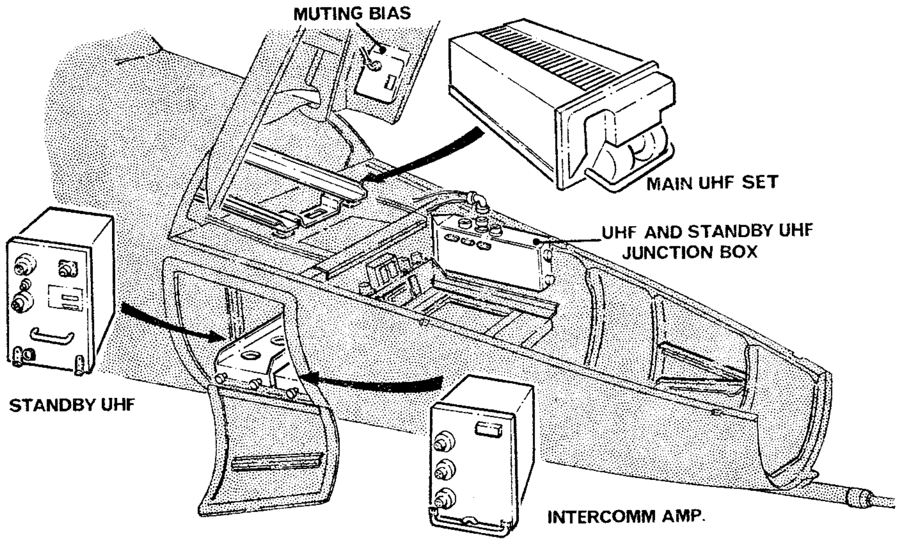


Fig. 9 Major assembly location diagram

a. Major assembly location diagrams. Major assembly diagrams may be either line drawings or photographs. They identify and show the position of all major assemblies, junction boxes and interconnecting cables. They are mainly used as an aid to first line and second line in-situ servicing. Similar diagrams or photographs are used to show the layout of sub-assemblies inside a main assembly to assist in second line servicing by replacement.

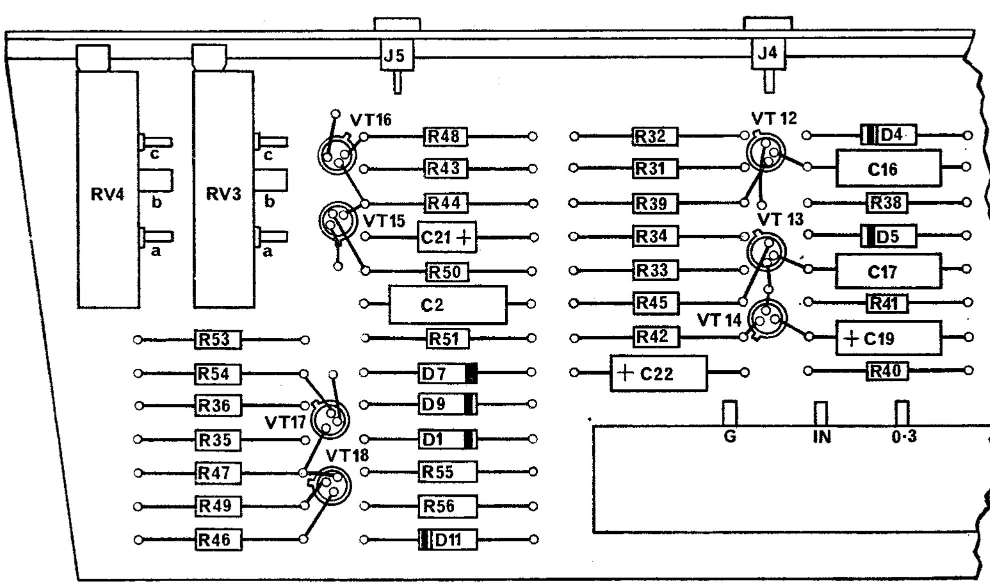


Fig. 10 Component location diagram

b. Component location diagrams. These are normally line drawings and are used to identify components during second or third line servicing. The component circuit reference number is normally printed within the outline of the component. Many components are drawn with wires connected to assist correlation between the diagram and the actual hardware.

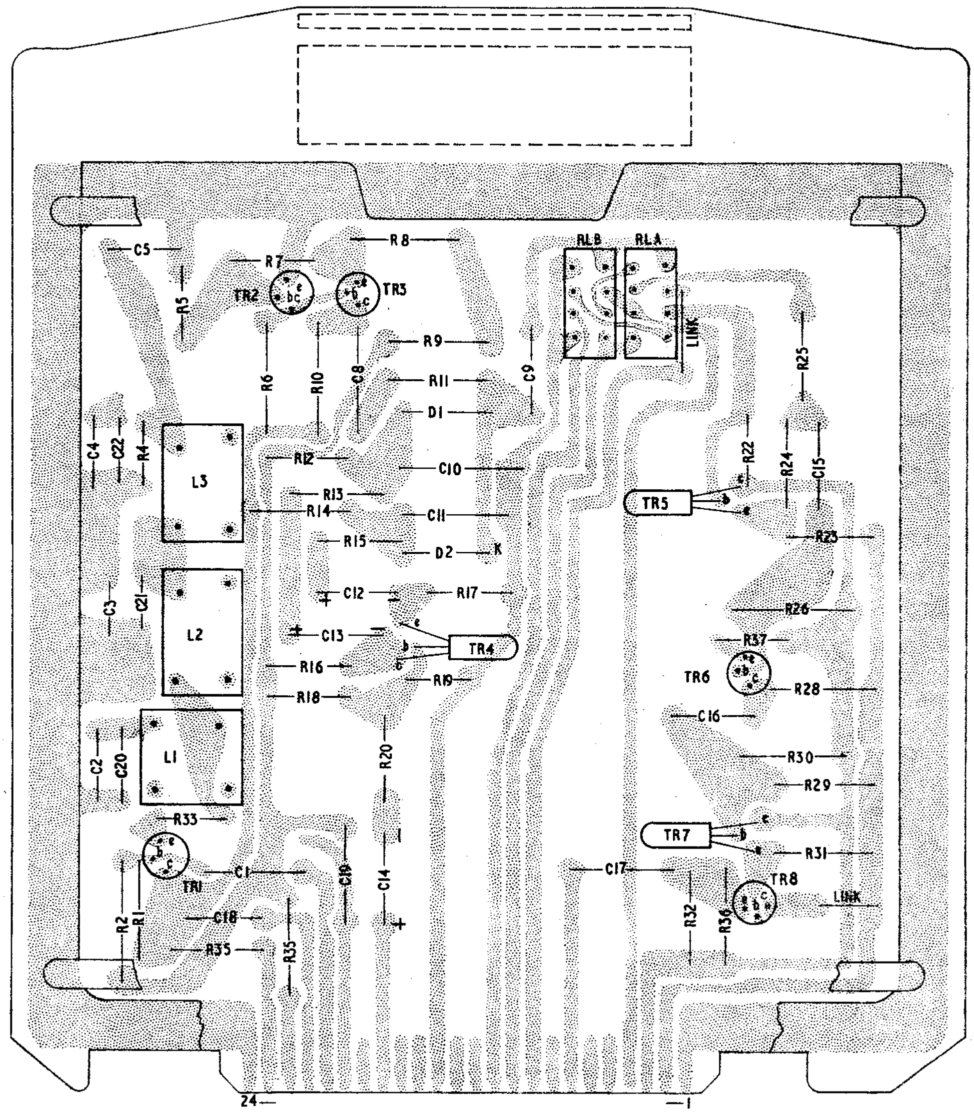


Fig. 11 Printed circuit board layout

c. Printed circuit boards. These layout diagrams are produced so that both the components and the wiring layout are shown. The diagram is drawn looking from the wiring side with the wiring indicated by a light blue wash or tone. In the case of more complex boards *eg* those printed both sides, more than one diagram is often provided to enable both sides to be shown clearly. The component circuit references are printed in position as on ordinary component location diagrams.

17. **Functional Diagrams.** Functional diagrams are the main diagrams used for servicing and fault finding in electronic equipments. There are two basic types:

a. Block diagram. These are provided to assist fault diagnosis where a detailed knowledge of component interconnections is not required. They consist solely of interconnected block symbols but may contain some component symbols where these are necessary to clarify details of the flow path.

b. Circuit diagrams. Circuit diagrams are provided to assist fault diagnosis and repair tasks which require the removal and replacement of individual components. In cases where integrated circuits or potted circuits are used these will be shown on the circuit diagram as block symbols as they are replaced as units.

18. The basic requirements for both types of functional diagram are the same and they should:

a. Emphasize the flow path of each function, irrespective of spatial relationships.

b. Show how the fault diagnosis task can best be carried out. This will usually be done by showing on the diagram the positions of all test points, together with enough spatial information to enable these to be located easily on the hardware. An indication will normally be given of the test parameters to be expected at these test points, the most common method being to use "inset" waveforms (see fig. 12). To enable the main flow path to be traced easily the diagram usually includes routing information such as the pin numbers of all plugs/sockets in the main flow paths.

c. Provide sufficient location data to link with other diagrams.

19. **Block diagrams (functional).** Normal flow paths are from left to right across the diagram. Where feedback occurs it is usually from right to left and the direction of flow will be shown by arrowheads. Test points are marked on the diagram and inset waveforms are shown to assist fault location. The block symbols used may be the functional symbols recommended in British Standards 3939 (see Appendix A) or may be rectangles containing a functional title. Location data is given to enable correlation with spatial diagrams and enough circuit references to enable correlation with full circuit diagrams. The physical boundaries of units and subunits are shown using 'chain-line' of various weights. Leads which go off the diagram are marked with a triangular symbol containing a number and a key is provided on the diagram to link these symbols with those on other diagrams.

20. **Fault location from a block diagram.** The aim is to locate a faulty subassembly or card for repair by replacement; or to isolate the faulty stage as a preliminary step to full repair using the circuit diagram. In the first case tests should be made at the test points most suitable for *physical division* of the equipment into sub-assemblies, using half-split techniques until the defective unit is located. Confirmation of the fault is normally obtained by replacement of the defective unit with a serviceable spare. In the second case tests should be made on the basis of the general rules given earlier in this chapter. The most effective order is usually:

a. Consider the symptoms and any information which can be deduced from divergence.

b. Test convergent stages to obtain further information.

c. Proceed by half-split for the faulty stage in the linear chain decided on as a result of *a.* and *b.* If feedback is involved it is often advisable to carry out further tests using the circuit diagram as a reference.

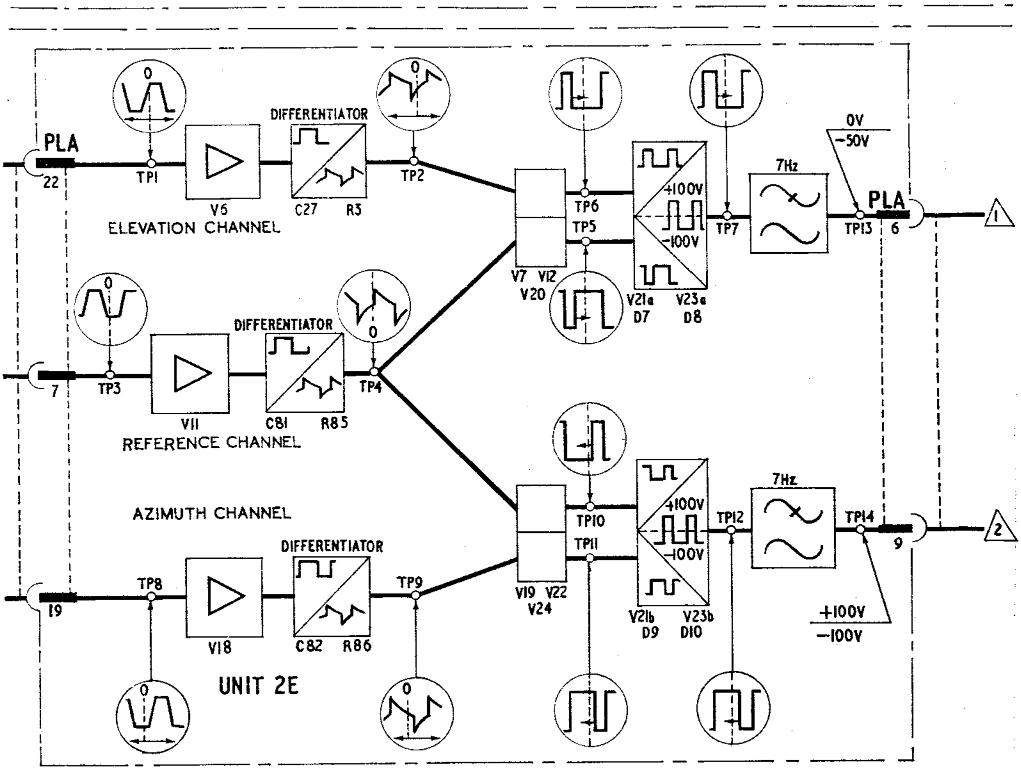


Fig 12 Block diagram (functional)

21. **Logic diagrams.** The use of logic symbols permits complicated switching or computer circuits to be drawn without the use of detailed symbols for individual components. In recent years the widespread use of digital computers has lead to the development of integrated circuit 'logic packages' or 'modules' which are produced in several forms for direct connection to printed circuits. The logic circuit shown in figure 13 uses fourteen lead dual-in-line packages and a key on the diagram shows the pin location. Faults can only be diagnosed to 'module' level and are repaired by replacement of the defective package.

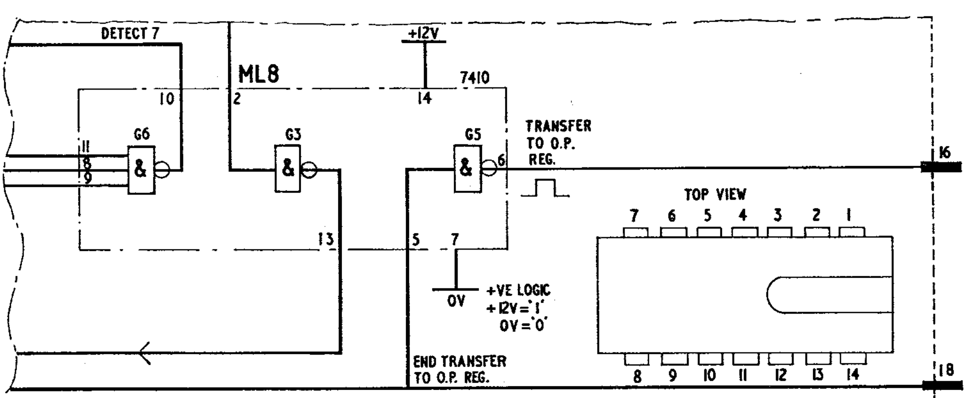


Fig 13 Logic diagram

22. **Circuit diagrams.** The component symbols used on these diagrams are also listed in British Standard 3939. A block symbol is used in preference to several component symbols to represent any module which is *replaced as a complete unit.* To assist correlation with the block diagrams a two or three tone colour wash is often employed. With this method, the components which form a block on the block diagram are contained in pale blue colour compartments. Several of these compartments which form a sub-unit are contained within a pale yellow boundary. The input and output connections are all numbered to show the signal routing.

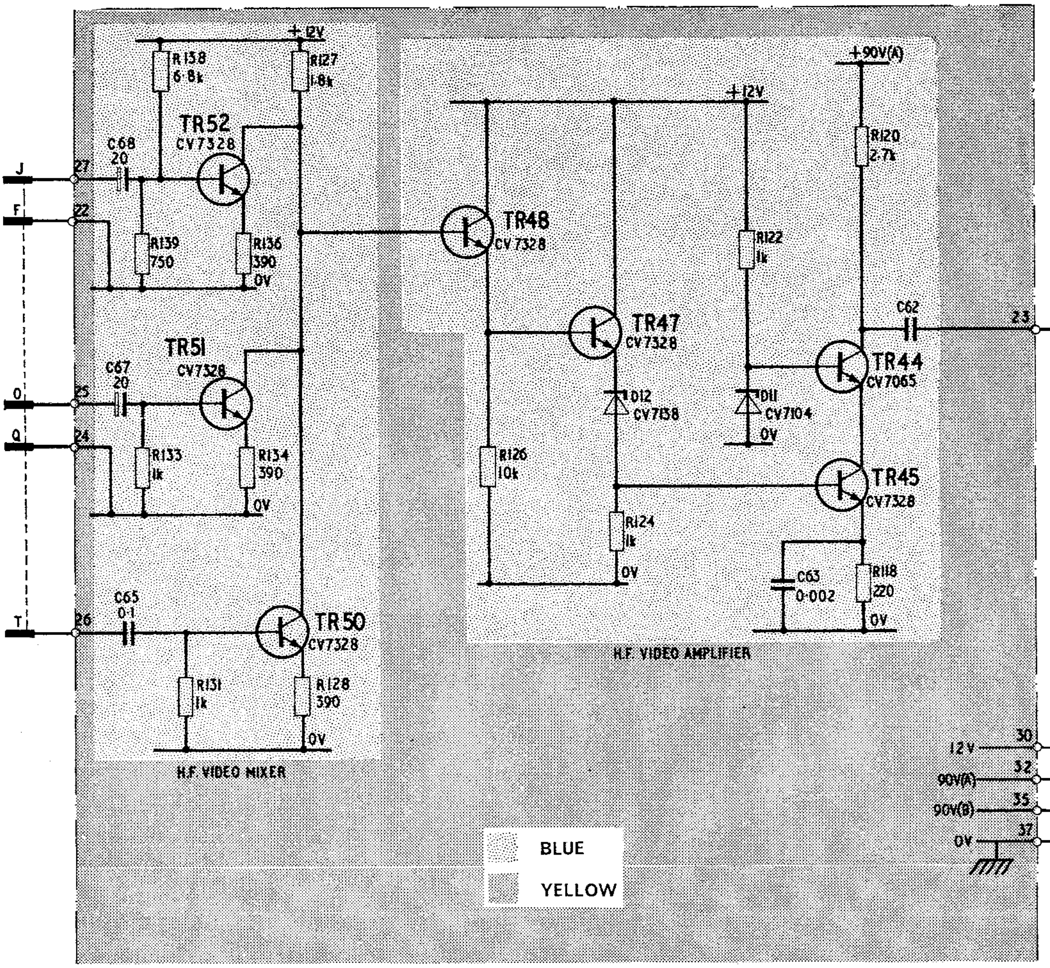


Fig 14 Circuit diagram

23. **Fault finding in a circuit.** Preliminary diagnosis from a block diagram will usually have located the defect to a functional block. The next step is to check all input and output waveforms of this block; which may contain several transistors or valves (*see* the HF video amplifier in figure 14). Make any deductions possible from these waveforms and then make voltage measurements in the part of the circuit considered to be faulty. If the unserviceable component cannot be deduced from these measurements it will be necessary to make resistance measurements to obtain further information.

Other Diagrams

24. **Waveform time-sequence charts.** Time sequence charts are provided where it is required to show the time and phase relationships between waveforms or to show the sequence of waveforms in an equipment. The waveforms are drawn one beneath the other down the page using a common time and amplitude scale if this is possible. Where the common scale cannot be used this is indicated on the affected waveforms. When a sequence is continued on another page, a key waveform is repeated at the top of the next page to emphasize the time relationship with the previous sequence. Line drawings of the waveforms are used and these may sometimes be 'idealised' rather than practical in shape. These charts usually contain all the waveforms in the equipment and are supplemented by *true waveform charts* for main test point waveforms.

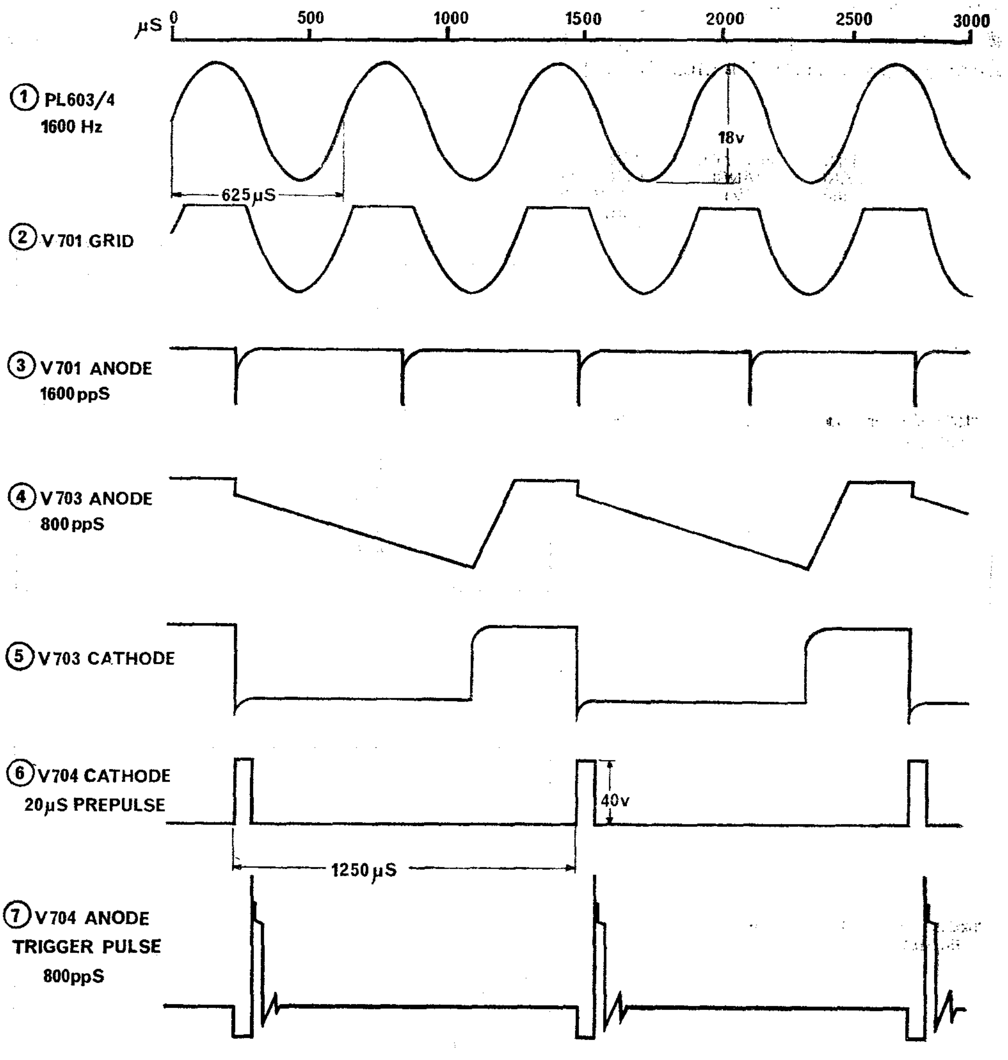


Fig. 15 Waveform time sequence chart

25. **True waveform charts.** The main test point waveforms are provided as a reference standard against which a technician can compare the waveforms he observes on an oscilloscope. True waveform charts are therefore photographs (or accurate facsimile drawings) of actual waveforms observed on the type of oscilloscope scaled for use with the particular equipment. By the side of the photograph a caption gives relevant information such as:

a. The identity of the test point, terminal, or circuit point at which the waveform can be observed.

b. The function or title of the waveform.

c. The settings of the oscilloscope controls on which the waveform was observed. This includes the dimensions of the graticule in volts/cm and time/cm to enable the operator to measure the waveform.

d. Any actions to particular equipment controls which may be necessary to obtain the waveform (*eg* the transmitter must be on).

	TIME RANGE (μs)	VOLTAGE RANGE (V)	SIGNAL GENERATOR ATTENUATOR (dB)
TR3 collector (saturated)	30	3	-24
TR4 collector (linear)	30	10	-44

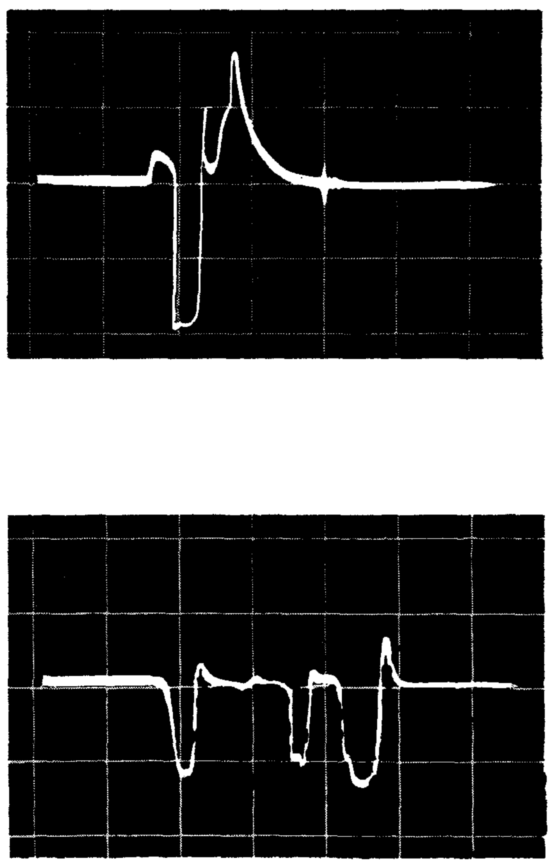
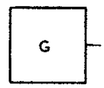


Fig. 16 True waveform chart

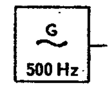
FUNCTIONAL and LOGIC SYMBOLS
(BS 3939)

1. Signal Generators

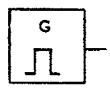
General symbol for non-rotating generator.



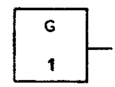
Sine-wave generator of frequency 500Hz.



Pulse generator.

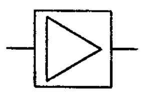


Logic ONES generator.

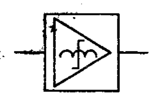


2. Amplifiers

General symbol.

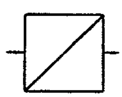


Magnetic amplifier.

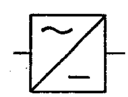


3. Changers

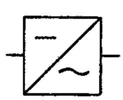
General symbol.



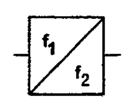
Rectifier.



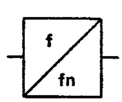
Inverter.



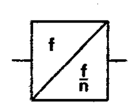
Frequency changer from f_1 to f_2.



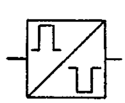
Frequency multiplier.



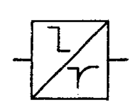
Frequency divider.



Pulse inverter.

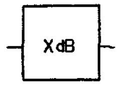


Differentiator.

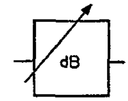


4. Two-Terminal Networks

Attenuator (fixed loss of XdB).

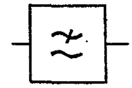


Attenuator (variable loss).

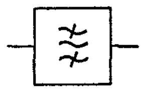


High- pass filter.

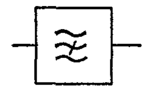
Low-pass filter



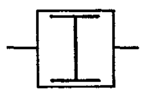
Band-pass filter.



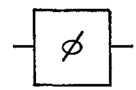
Band-stop filter.



Artificial line.

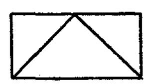


Phase-changing network.



5. Modulators

General symbol.

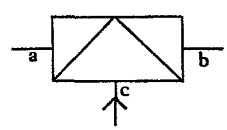


Modulator, demodulator
or discriminator.

NOTE.

For a modulator

a = modulating signal input
b = modulated signal output
c = carrier input

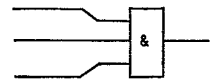


For a demodulator or discriminator

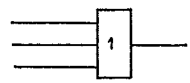
a = modulated signal input
b = modulation frequency output
c = carrier input, if required.

6. Logic Elements (Gates)

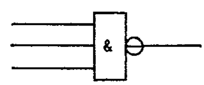
AND element.



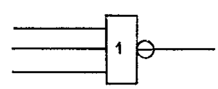
OR element.



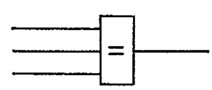
NOT-AND element.



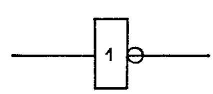
NOR element



Identity element.



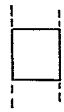
Negator.



7. Multistate Elements

A multistate element is an element which can exist in two or more states. Each state is represented by a single square and only one state may have an output signal representing 1 at any particular time.

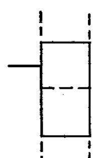
Stable states are shown thus:



Quasi-stable states are shown thus:

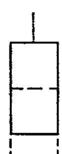
NOTE.
t is the duration of the quasi-stable state.

Normal inputs.



A normal input is drawn to the side of a square. Application of a signal representing 1 brings about the state in which an output representing 1 is produced from that square, irrespective of the previous state.

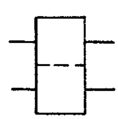
Stepping (clock) input.



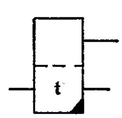
A stepping input is drawn to the end of the element. Each application of a signal representing 1 causes a change from one state to the next in a direction away from the input until the last state is reached.

examples

Bistable element with normal inputs and outputs.



Monostable element.



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SECTION 6

MINISTRY OF DEFENCE SERVICING RECORDS

CHAPTER 2

THE MAINTENANCE DATA COMPUTER SYSTEM

List of Contents

Introduction

1. Unreliability in technical equipments results in a high annual expenditure which limits the operational effectiveness of both the Royal Air Force and the Fleet Air Arm. This situation could become worse as equipments become more complicated and the price of spare parts increases. In order to check rising costs, and to reduce the time for which aircraft and equipment is unserviceable, a maintenance data service is to be introduced. A computer will be used to store and analyse complete and accurate maintenance data for almost all technical equipments used in the Royal Air Force and the Fleet Air Arm.

2. The computer will be installed at a maintenance data centre at RAF Swanton Morley and will become operational during 1970. It will produce outputs to assist executive decisions in the technical field by analysis of previous defect histories. As complete maintenance data will be held in the computer 'store' the system will entirely supersede existing defect reporting and analysis procedures. Since engineering decisions involving the future of the RAF will be made on the information taken from the computer, the importance of CARE and ACCURACY by all concerned in completing the job cards and their associated forms cannot be over-emphasized.

3. For the purpose of computer input, standardization of the forms used to record servicing must be introduced. It would be ideal if the same design of form could be used for all jobs but this solution cannot be achieved. A small family of similar documents have been produced which were designed:

a. To keep the recording load on the technician to a minimum.

b. To prevent wastage of time caused by the technician making copies of documents or by looking up codes for defect analysis reports.

Job Cards

4. The primary input to the computer is from "carbon" copies of a family of job cards which will be the legal and only job cards to be used throughout the Royal Air Force and the Fleet Air Arm. There are three job cards and their MOD Form numbers and titles are:

a. MOD Form 720B—AIRCRAFT JOB CARD—UNSERVICEABILITY LOG.

b. MOD Form 720C—JOB CARD

c. MOD Form 720D—SUPPLEMENTARY JOB CARD.

These job cards are augmented by Additional Item Identification cards and by a continuation sheet for the certificate of work.

MOD Form 720B—Aircraft Job Card—Unserviceability Log

5. The aircraft job card (MOD Form 720B) is a four-leaf document, a pad of which will be used as the Unserviceability Log in the aircraft servicing form (MOD Form 700). It is used for all work carried out on the aircraft and is printed in blue on white.

Note. A four-leaf 'take out' illustration of this form can be found at the end of this chapter. It may be taken out of the book spine to assist study of this chapter (and chapter 3) and should be replaced at the end of this chapter after use.

Page 1—Unserviceability Log

6. A MOD form 720 B is originated by entering the symptoms of a defect, or other work to be done, in the Unserviceability Log. This entry puts the aircraft unserviceable. The entry will normally be made by the aircraft's captain or by the SNCO in charge of aircraft servicing. All the information entered on this log is automatically copied on to the next two pages and partly on to the fourth page. The first page (Unserviceability Log) remains in the Form 700 while the aircraft is unserviceable; the other three pages are removed as one document and form the job card.

7. On completion of the work, the unserviceability is cleared by transferring the 'Details of Action Taken' from the job card (field 34) to the unserviceability log (field 34). This will normally be done by the controlling SNCO or the tradesman's supervisor. Where work is to be deferred, or limitations to the aircraft introduced, this field *must* be signed by an authorized person (AP3158 leaflet C2) who will also have made the appropriate entry in the deferred defects log (or limitations log) of the aircraft servicing form MOD 700.

Page 2—Aircraft Job Card

8. The second page, titled 'Aircraft Job Card' is the Unit's permanent legal record of work carried out and is filed after use in accordance with local instructions. All the information on the second page is automatically copied on to the third page and partly on to the fourth page.

9. **Certificate of Work.** The reverse side of page 2 forms the certificate of work used by the tradesmen. The left hand side, titled 'Instructions and Progress' is used by the controlling NCO to detail the order in which the work is to be carried out and to call up any independent/vital checks which may be required. The right hand side, titled 'Work Carried Out' is used by the tradesmen and their supervisors to record full details of all work carried out. Where possible, this part of the form will also quote the appropriate authority for the work method, *eg* 'Damaged port flap removed and replaced with a serviceable item in accordance with AP1234, Vol 1, Chap 10 paras 10 to 28'. If there is not enough room on the sheet, a certificate of work continuation sheet (MOD Form 720H) is raised and the serial number entered on the job card (field 33).

10. On completion of work, the certificate fields on the certificate of work are signed by all tradesmen and trade supervising NCOs. Brief details of the action taken are then entered in the Details of Action Taken field by the controlling NCO.

11. The 'Item identification' fields on the job card are used to identify the 'main equipment', 'assembly' or 'sub-assembly' which contains the defect. These items are identified from the aircraft Vol 3 or the illustrated parts catalogue which gives both description and section/reference number. The defect entered at field 20 *must* be related to the last item identified. If it is not possible to identify the defect it should be entered as 'defective—cause not known'. Above all *do not guess* the defect, the computer is capable of finding the *real cause* from subsequent documentation.

Page 3—Aircraft Job Card—Data Centre Copy

12. The third page is a flimsy copy of the tradesman's job card and is the information for the Maintenance Data Centre. It is automatically filled in at the same time as the job card by a no-carbon copying process. On completion of the job card, the data centre copy is detached for coding and onward transmission to the data centre.

Page 4—Equipment Label (Reverse)

13. This page is a label for use when an item has to be transferred to another line of servicing. If the defect was repaired on the aircraft and a label is not required this page should be destroyed.

14. Where a defective item has been removed from the aircraft and a replacement item fitted, page 4 is used as a transit label on the defective item. The top side, Equipment Label (Reverse), has already been filled in by a no-carbon copying process from the job card. This side gives the originators reference, identity fields and symptoms of the defect for information at the next line of servicing. To attach the label to an item it is folded in half so that this information is on the inside; this gives a two-hole fixing label titled Equipment Label (MOD Form 731B).

15. **MOD Form 731B.** Details of the item identity are entered on the top half of the label which also contains details of action taken in the equipment section (if any). The bottom part of the form contains a safety certificate and a condition certificate signed by an authorized trade specialist officer.

Additional Item Identification Card (MOD Form 720E—Aircraft Job Card)

16. If more than one item was removed from the aircraft in order to rectify the defect, a MOD form 720E must be raised for each additional item removed. It is a two page form and consists of the identity fields from the aircraft job card (the left hand side of the job card); and an equipment label as before. It is essential to the computer that the original reference on this card is *exactly* the same as that on the original job card. Any MOD forms 720E raised on a job are serial numbered and these numbers are entered on the original job card (field 32).

MOD Form 720D—Supplementary Job Card

17. When an item has been transferred to another line of servicing it will arrive with an equipment label (MOD Form 731B) attached. This label is removed, opened up, and the details on the 'reverse' side are copied into the left hand column of the supplementary job card. To enable the computer to cross-refer the defect it is essential that the originators reference is *copied exactly* on to form 720D. Unless an originators reference is available from a previous line of servicing the supplementary job card cannot be used; it is *not* an initial report.

18. The supplementary job card is a three page document printed green and consists of:

a. A supplementary tradesman's job card similar to the aircraft job card.

b. A flimsy copy of this card for the Maintenance Data Centre.

c. An equipment label.

It is used in the same way as the aircraft job card, and if any items are transferred to a further line of servicing the equipment label from the form 720D must be attached as before. A supplementary job card is raised at each line of servicing (including the manufacturers) so that eventually the computer gets complete details of the defect and of all action taken.

19. **Additional Item Identification Card (MOD Form 720G—Supplementary job card).** If more than one item was removed during work carried out on a supplementary job card, an additional item card (form 720G) must be raised for each item (see para 16).

MOD Form 720C—Job Card

20. This job card is used to record details of work done on:

a. Ground installations such as radar stations, flight simulators etc.

b. Class 1 ground equipments such as test equipment and starters.

c. Airborne equipment which was not allocated to an aircraft at the time *eg* spare equipment held in store.

A MOD Form 720C *must not be used* for work on equipment passed on from a previous servicing level.

21. The job card is a three page document, printed in red, similar in format to the last three pages of the aircraft job card (and the supplementary job card). It is used in the same way as the aircraft job card and there is an additional item identification card (MOD Form 720F) for use when more than one item is removed during repairs. Any item which is then sent on to another line of servicing will have the equipment label attached and all subsequent servicing will be carried out on the supplementary job card (MOD Form 720D) as before.

Notes:

1. As the whole of the data computer system depends on the *accurate* completion of the input documents described in this chapter; some of the more important parts of the forms and their method of completion will be described in the next chapter.
2. Full information on the maintenance data computer system will be provided in AP3408 "The Maintenance Data Computer System".

CHAPTER 3

ASPECTS OF COMPLETING COMPUTER INPUT DOCUMENTS

List of Contents

Introduction

1. To enable the maintenance data computer to file information in the proper place in its store, the information supplied to the computer must be in standardized form. This means that rigid definitions have to be applied to words such as 'system' which were formerly used in a rather loose way. The methods of writing down numbers, such as the date and section and reference numbers, must also be controlled so that the computer is able to use them as an 'index' to its store.

2. This chapter explains how to fill in the more important fields of the Ministry of Defence job cards. It also explains the meaning of various signatures on the cards and the responsibilities of the person making such signatures. Where any part of this chapter contradicts Defence Council Instructions or official publications such as AP3158, those publications are to be taken as the mandatory method.

Note: The four leaf 'take-out' illustration of MOD Form 720B at the beginning of this chapter may be taken out of the book spine to assist study. It should be replaced between chapters 2 and 3 after use.

Originator's Reference

3. The originator's reference is a name and number which the computer uses to identify a defect in its 'files'. This number is *unique* and brings together all the data from different lines of servicing to produce the *complete* engineering story of the defect. Because of this role it is essential that the reference is accurately compiled and that it is *carefully transferred* when raising additional item cards or supplementary job cards. All boxes in the number frame must be filled in, using zero where necessary.

e.g.

Card No	Aircraft No	Day	Month	Yr
0 8	X T 8 9 9	0 7	0 6	9

= Card 8 raised on the 7th of June 1969 for aircraft XT899

The words entered in the fields for operational effect and mission are also subject to definition, but as these fields are normally filled in by the pilot or the controlling NCO they are not defined in this Chapter.

AL 11, JUL, 1970

Item Identification (Fields 8-17)

4. The aim of these fields is to *positively identify* the item which contains the defect. All fields are not printed on all the forms because aircraft and installations are usually repaired by changing an assembly or sub-assembly. The identity fields are normally completed by the tradesman or the trade NCO.

5. **Fields 8 and 9.** These fields are only printed on the aircraft job card (MOD Form 720B) and are used to identify the system and sub-system of the aircraft within which the defect lies. For coding purposes the aircraft has been divided into seventy five systems, each of which contains several sub-systems. A full list of these systems and sub-systems, together with their definitions and code numbers, will be found in AP3408. Examples of two such systems are given below:

	Sys	Sub Sys
Communications	06	
General		00
HF		10
VHF		20
UHF		30
Passenger Address		40
Interphone		50
Audio Integrating		60
Static Discharging		70
Voice Recorders		80

	Sys	Sub Sys
Tail Plane	35	
General		00
Horizontal Stabilizer		10
Elevator		20
Vertical Stabilizer		30
Rudder		40
Attach. Fittings		50

6. **Field 10.** This field, titled 'Installation' only appears on the Job Card (MOD Form 720C). It is only intended to be completed when working on radar stations, flight simulators and surface to air missile systems. The entry uses the common name of the installation *eg* Type 85 Radar.

7. **Field 11.** This field, titled 'Main Equipment' is printed on all three job cards. A main equipment is defined as a group of interconnected assemblies. It usually has a code name or number and in the case of radio equipments the entry would be the ARI or GRI number. On the aircraft job cards (MOD Form 720B) field 11 is limited to four applications; aero-engines, ejection seats, air radio installations and weapon systems.

8. **Field 14.** This field, titled 'Assembly' is also printed on all three job cards. An assembly is defined as an entity in itself comprising two or more sub-assemblies. It is identified by a single description and part number and usually has a Section/Reference number. Typical items are instruments, radio black boxes and generators. Assemblies are listed in the aircraft AP Vol 3 and the description and section/reference shown there should be entered in field 14 (see para 13 for method of entering reference number).

9. **Field 15.** This field, titled 'Sub-assembly' is on all three job cards. A sub-assembly is defined as an entity in itself comprising two or more components. It is identified by a single description and section/reference number which should be entered in field 15. A typical sub-assembly in the radio trade would be an IF unit which forms part of a transmitter-receiver (the 'Assembly').

10. **Field 16.** This field, titled "Component" is printed on the job card (MOD Form 720C) and on the supplementary job card (MOD Form 720D). A component is defined as an entity in itself which requires connection to a sub-assembly before it can perform its work. It is identified by a single description and section/reference number. Items such as relays and switches come under this definition.

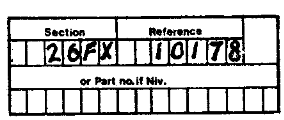
11. **Field 17.** This field, titled "part" is printed only on the supplementary job card (MOD Form 720D). A part can be defined as the lowest identifiable level in an assembly. It is identified by a single description and may have a section/reference number. Typical items within this definition are nuts, bolts, resistors and capacitors.

12. **Supplementary job card (MOD Form 720D) identity fields.** Fields 14 to 17 are printed on the supplementary job card. When an item arrives from another line of servicing it will be classified as an assembly, sub-assembly or component on the Equipment Label (reverse) attached to it. This information should be copied from the label into the appropriate field on the supplementary job card. It is probable that in some cases it will not be necessary to complete all four fields, the defective item being positively identified by some of them. Cases may occasionally arise when the full range from assembly must be utilised in order to identify down to a 'part'. In such cases fields 14 to 17 should be used to the best advantage, irrespective of how the item is classified on the label.

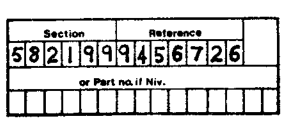
Section/Reference Numbers

13. There are four common methods of entering Section/Reference numbers and part numbers as shown below:

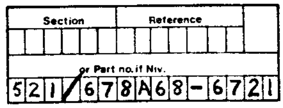
a. The normal RAF classification *eg* Aileron 26FX/10178 should be entered as:



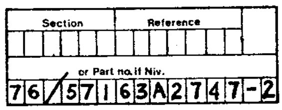
b. When recording NATO reference numbers the punctuation should be omitted *eg* Transmitter/Receiver 5821/99/945/6726 should be entered as:



c. If the item is NIV (not in AP1086—Vocabulary of RAF Equipment) the part number should be entered. Where punctuation is used it should be entered *eg* Control Pedestal 521/678A68-6721 should be entered as:



d. If a part number, with or without punctuation, has more than 15 characters; its right hand 15 characters should be entered *eg* Aileron A976/57163A2747-2.



Note: When entering an oblique stroke ensure that it passes *right through* the box to prevent it being mis-read for a 'one'.

Defect Field

14. The defect recorded at field 20 *must be related to the last item identified* in the item identification fields. For example if the last item recorded is a sub-assembly then the defect must definitely be in that sub-assembly. If you do not positively know the defect is in the sub-assembly say so. Above all *do not guess*, enter 'defective—cause not known'. This field also contains field 21 which is used to distinguish random defects from those caused by either misuse or mishandling. The following definitions apply:

a. Misuse. This is when a defect has occurred through accidental operation of the item outside its design limitations.

b. Mishandling. This is when damage is caused to an item by mishandling *eg* dropping it or allowing it to get wet or dirty during servicing.

c. Neither. This box is used for defects which occur naturally *ie* at random or with no apparent outside cause.

The appropriate box in field 21 is ticked by the NCO i/c servicing or the trade NCO.

Trade Fields

15. Fields 29 and 30 are filled in by the tradesmen and trade NCOs to enable the signatures and initials on the certificate of work page to be easily identified. These signatures or initials are entered on completion of work and constitute certificates for the purposes of the Air Force Acts (see chapter 1 para 4). The signature of the NCO i/c trade in fields 43d and 30 is made as a counter-signature by an NCO as authorized in AP3158 Vol 2 Leaflet C10. Exceptionally the counter-signature may be given by a junior technician provided that he has been authorized by the OCEW as a competent person to carry this responsibility.

16. **Field 31.** This field is used to record the manhour totals of the various trades. These are entered by the trade NCOs or the NCO i/c servicing. The totals are the actual times taken to do the job and include:

a. NCO supervision manhours.

b. Time spent by NCO briefing tradesmen.

c. Manhours spent in diagnosing the fault.

d. Assistance given by tradesmen not signing the job card.

e. Manhours spent reading essential APs and other instructions.

f. Manhours spent collecting tools, equipment and spares.

17. **Fields 34 and 35.** These fields are completed by a person authorized to give a co-ordinating signature *ie* the NCO in charge of the flight or section (or his deputy) or an aircraft servicing chief appointed for the type of aircraft. The information entered is also copied on to fields 34 and 35 of the unserviceability log (MOD Form 720B page 1) which was retained in the aircraft servicing form. The co-ordinating signature certifies:

a. All work required to clear the unserviceability has been completed.

b. The work of each tradesman has been adequately supervised, inspected or tested.

c. That independent/vital checks have been completed when called for in AP3158.

d. That other documents in the MOD Form 700 have been updated where applicable *eg* the Deferred Defects Log and the Servicing and Component Replacement Control documents.

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