THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL

VOL. 34 JANUARY, 1942 PART 4

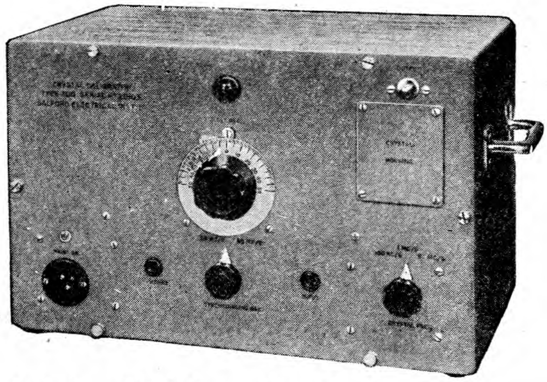
CONTENTS

	PAGE
A REVIEW OF WAR-TIME FUELS FOR ROAD VEHICLES—D. W. Glover, M.Sc., F.I.C., and E. A. Taylor, B.Sc., A.I.C. ..	151
THE GENERATION AND DISTRIBUTION OF A STANDARD 1 kc/s SYNCHRONISING SIGNAL—C. F. Booth, A.M.I.E.E., and G. Gregory	156
CARRIER SYSTEM No. 7. Part II—F. J. D. Taylor, B.Sc.(Eng.) ..	161
NEW TOOLS FOR IDENTIFYING WIRES IN CABLE JOINTS—N. F. Sephton, M.I.E.E., and A. J. Jackman, B.Sc., A.C.G.I. ..	169
A SIMPLE INTRODUCTION TO THE USE OF STATISTICS IN TELECOMMUNICATIONS ENGINEERING—J. F. Doust and H. J. Josephs, F.S.S., A.M.I.E.E. Part IV — Correlation and Regression	173
MODERN MATERIALS IN TELECOMMUNICATIONS—W. G. Radley, Ph.D., M.I.E.E., E. A. Speight, Ph.D., D.I.C., A.R.C.S., C. E. Richards, F.I.C., E. V. Walker, B.Sc., A.R.S.M. Part VIa—Semi-Conductors	179
EQUIPMENT FOR CUTTING STEEL AND WROUGHT IRON PIPES CONTAINING WORKING CABLES—F. E. Plumpton ..	184
IMPEDANCE MATCHING NETWORKS FOR UNLOADED CABLE—D. G. Tucker, B.Sc.(Eng.), A.M.I.E.E.	187
NOTES AND COMMENTS	190
REGIONAL NOTES	191
STAFF CHANGES	193
INDEX TO VOLUME 34	195

Price 1/- net

THE INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

G.E.C. CRYSTAL CALIBRATOR



A new precision instrument for the rapid and accurate checking and adjustment of radio frequency oscillators, receivers, transmitters and similar apparatus.

It is crystal controlled and A.C. mains operated.

Ask for full information from :

SALFORD ELECTRICAL INSTRUMENTS LTD.

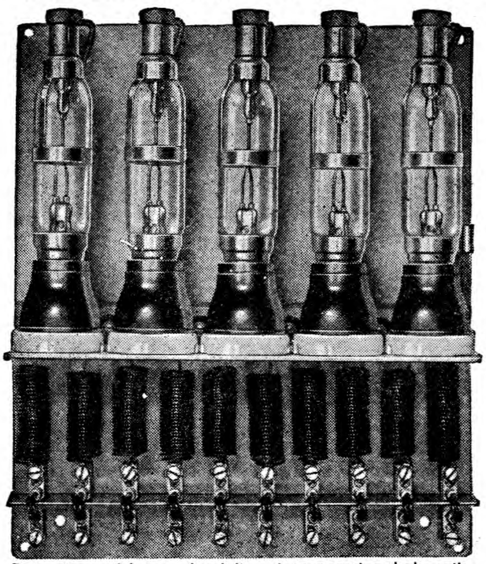
SALFORD. Telephone : Blackfriars 6688 (6 lines). Telegrams and Cables : "SPARKLESS, MANCHESTER"

PROPRIETORS: THE GENERAL ELECTRIC CO., LTD.

EDISWAN

TELEPHONE LINE PROTECTOR PANELS

EDISWAN-SHOTTER-GREETHAM PATENT (British Patent No. 353924)



5-circuit panel for overhead lines incorporating choke coils, spark gaps, etc.

for the protection of telephone systems against surges induced by faults on neighbouring power lines

Of the difficulties attendant upon the employment of overhead systems one of the most serious is to ensure uninterrupted working of the telephone system, by providing adequate protection against induced surges caused by switching or line faults in adjacent power lines or by lightning.

The Ediswan Patent Protectors provide the solution. They are inert at the normal working pressure of the telephone line, they keep the voltage on the line down to a pre-determined figure by providing a path of low resistance to earth whereby the surge is cleared and they again become inert immediately the surge is cleared.

They ensure simultaneous discharge of both lines and are capable of clearing heavy discharges without detriment to the system or the protector.

Ediswan Telephone Line Protectors have now been in use by Supply Companies for many years.

THE EDISON SWAN ELECTRIC CO. LTD., 155 CHARING CROSS ROAD, LONDON, W.C.2

T.E.I.

Carry on with deliveries–

PETROL OR NO PETROL

Banish wartime transport problems once and for all by switching to Electric Vehicles. The fuel they use is unrestricted, their low running cost and reliability have been conclusively proved, and they are very easy to drive. To make sure your battery costs are reduced to a minimum use Exide-Ironclads. They stand the wear and tear of short-distance transport better than any other. They are made *and serviced* by the Chloride Company, the largest battery makers in the British Empire.

USE 'ELECTRICS'

POWERED BY

Exide-Ironclad

BATTERIES

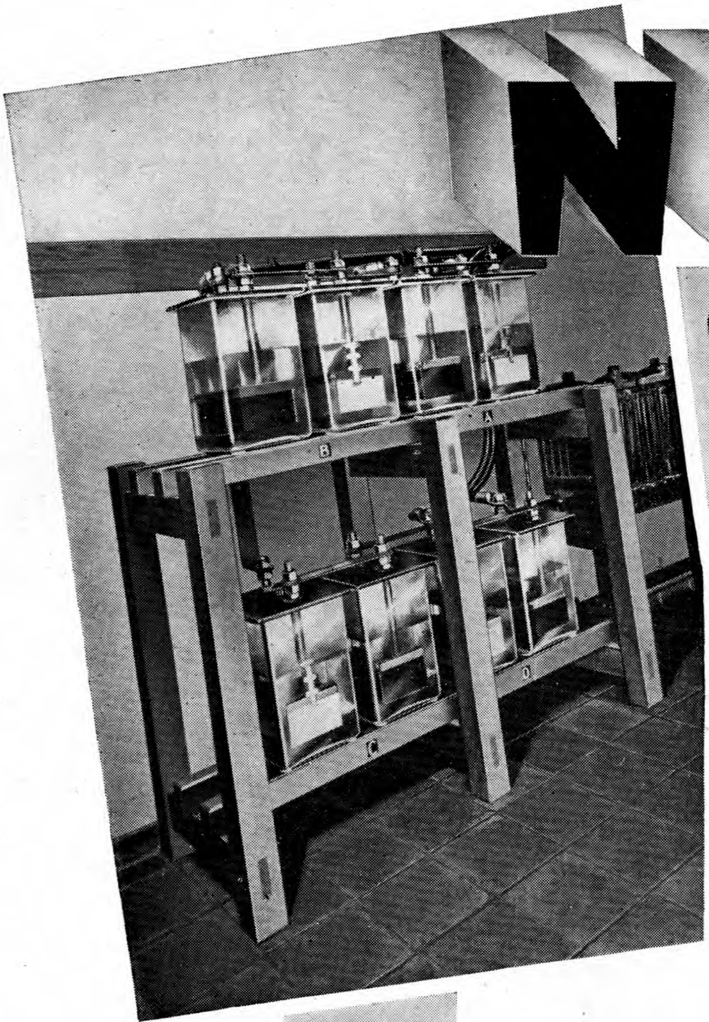
'Still keep going when the rest have stopped'

FUEL FOR 'ELECTRICS' comes from British coal
—saves vital shipping space and foreign exchange

**For further details about electric vehicles and batteries write to :* The Chloride Electrical Storage Co. Ltd., Grosvenor Gardens House, Grosvenor Gardens, London, S.W.1.

Telephone : VICtoria 2299. *Telegrams :* Chloridic, Sowest, London

W.T. 6/40



PRECISION

Notwithstanding the difficulties met with under present conditions, the Telephone Manufacturing Company, Ltd., is maintaining the well-known reliability of its condensers. These are manufactured in a modern condenser plant, and are notable for the following features :—

- Rigid construction.
- Small size and weight.
- Extreme stability.
- Low temperature co-efficient of capacity.
- High insulation resistance.
- Maintenance of initial capacitance values.
- Low power factor.
- Adequate safety factor, and
- Long life.

Only high grade materials are used, which have been proved to be suitable by chemical, physical and electrical tests, and careful supervision is given at all stages of manufacture.

Enquiries are solicited in respect of the following types :—

(a) **Mica Condensers.**

These are manufactured in copper or other metal cans, as required, which are marked with the actual and nominal capacities. They may be supplied and adjusted to within $\frac{1}{2}$ per cent. from the nominal capacity. The temperature co-efficient is not greater than ·0045 per cent. and the power factor at 1,000 cycles/second is not greater than ·001.

(b) **Precision Paper Condensers.**

These are of the oil impregnated, oil filled, clamped paper dielectric type. The capacity is adjusted to within 2 per cent. of the nominal capacity and departures from the actual capacity due to temperature variations from 0 deg. C. to 50 deg. C. are not greater than 2 per cent. These condensers are fitted with terminals constructed from Mica-filled bakelite and having an insulation of not less than 10,000 Megohms at normal temperature and humidity.

Prompt attention given to enquiries and deliveries expedited.

TELEPHONE MANUFACTURING COMPANY LTD.

WEST DULWICH, S.E.21

View of a corner of the Condenser Test Department (gauging thickness of mica.)

THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL

Vol. XXXIV January, 1942 Part IV

A Review of War-Time Fuels for Road Vehicles

D. W. GLOVER, M.Sc., F.I.C., and
E. A. TAYLOR, B.Sc., A.I.C.

U.D.C. 662.7 621.43

The authors review the fuels which are available in this country to replace petrol for road vehicles. Producer gas is the most suitable, and details are given of the method of its production and of its characteristics.

Primary Sources of Energy.

THE only practical source of energy for any heat engine is the combustion of the carbon and hydrogen contained in materials such as oil, coal and wood. In the elementary state these burn according to the following equations[1] :—

C Carbon	$+ \frac{1}{2} O_2$ Oxygen	=	CO $+29\frac{1}{2}$ Cals[2] Carbon Monoxide	...(1)
CO	$+ \frac{1}{2} O_2$	=	$CO_2 + 67\frac{1}{2}$ Cals Carbon Dioxide	....(2)
C	$+ O_2$	=	$CO_2 + 97$ Cals	....(3)
H_2 Hydrogen	$+ \frac{1}{2} O_2$	=	$H_2O + 58$ Cals Steam	....(4)
H_2	$+ \frac{1}{2} O_2$	=	$H_2O + 68\frac{1}{2}$ Cals[3] Water	...(4a)

At the present stage of development there can be no question that liquid fuel is the most satisfactory for internal combustion engines of any type, as it possesses peculiarly the combined merits of cleanliness and ease of handling. It also enjoys the additional advantage that existing engines have been specially developed over a period of many years to obtain the best results from it. The present quest for alternatives is entirely due to emergency conditions.

Oil from Coal.

As coal is our only extensive indigenous source of energy, the technique of its conversion to liquid fuel has been studied and developed with considerable success; the product is highly satisfactory, but the plant required is at present so elaborate and costly as to put any vast scale operations out of the question. Certain grades of creosote oil, a gas works by-product, have, after suitable refining, been successfully blended with petroleum oils for use in compression ignition engines, but the quantity of such materials available as fuel is strictly limited.

Town's Gas.

Coals consist essentially of carbon together with variable proportions of hydrogen, nitrogen, oxygen, sulphur and mineral matter in obscure combination and association with one another.

Bituminous coals are characterised by their ability to give off on heating more volatile matter[4] than the so-called anthracites; this method of decomposition is known as "destructive distillation" and is employed by gas works. At the best, however, no more than 20–25 per cent. of the coal can be so gasified, and the process requires too much apparatus to be carried out on vehicles.

Suitable coals yield 10,000–20,000 cu. ft. of "straight" coal gas per ton, but this is almost invariably modified by "steaming" the retorts, which results in the production of additional hydrogen and carbon monoxide.

The final product, known as "town's gas," usually approximates to the following composition :—

Hydrogen	50 per cent.
Methane	25 per cent.
Carbon Monoxide	15 per cent.
Higher Hydrocarbons	5 per cent.
Carbon Dioxide, Nitrogen, Oxygen	Balance

Town's gas is a satisfactory fuel for internal combustion engines, but it cannot conveniently be liquefied and if used for transport must be carried in a bulky balloon or steel cylinders. Its main properties are compared with those of other fuels in Table I.

[1] The equations are written in terms of "gram molecules." Thus :
C = 12 g. Carbon. CO = 28 g. Carbon Monoxide.
O_2 = 32 g. Oxygen. CO_2 = 44 g. Carbon Dioxide.
H_2 = 2 g. Hydrogen. H_2O = 18 g. Steam or water.

[2] The "Calorie" or "big calorie" is indicated.

[3] When combined together as, for example, in natural fuels, carbon and hydrogen will not necessarily produce the same heats of combustion as indicated above.

[4] The volatile matter consists of: Hydrogen, hydrocarbons, carbon monoxide, water, ammonia, sulphur compounds and complex tarry bodies.

TABLE 1.

APPROXIMATE CHARACTERISTICS OF VARIOUS FUELS

Fuel	Formula or Composition	Calorific value B.Th.U. per lb.	Calorific value B.Th.U. per cu. ft	Volumes of additional air for complete combustion	Calorific value of fuel-air mixture (B.Th.U. per cu. ft.)	Ratio: Volume of Products/ Volume of reactants	Remarks
Carbon (Charcoal)	C	14,600	—	—	—	—	—
Hydrogen ..	H_2	61,000	360	$2\frac{1}{2}$	103	0·85	Very bulky.
Carbon Monoxide.	CO	4,500	370	$2\frac{1}{2}$	106	0·85	See composition of producer gas.
Methane ..	CH_4	23,000	1,100	10	100	1·00	Very bulky.
Ethane	C_2H_6	22,000	2,000	$17\frac{1}{2}$	110	1·03	Can be liquefied under high pressure.
Propane	C_3H_8	21,500	2,800	25	108	1·04	Can be liquefied under pressure.
Butane	C_4H_{10}	21,000	3,600	$32\frac{1}{2}$	108	1·04	Can be liquefied with slight pressure.
Benzene	C_6H_6	18,000	—	—	110	1·01	Can be blended with petrol.
Alcohol	C_2H_5OH	13,000	—	—	105	1·06	Can be blended with petrol.
Petrol	Mixture of many hydrocarbons, especially C_7H_{16} and C_8H_{18}	20,000	—	—	105	1·06	The standard by which other fuels are judged.
Town's gas ..	H_2 40-50% CH_4 20-30% CO 15-20%	17,000	400 —500	5	70-85	0·9	Very bulky.
Producer gas ..	CO 23-30% H_2 4-23% N_2 50-80%	1,000	90 —130	1	45-65	0·9	Can be produced on the vehicle.

This indicates that 1 gal. of petrol is equal in energy to about 300 cu. ft. of town's gas at atmospheric pressure or to $2\frac{1}{2}$ cu. ft. at 120 atmospheres pressure; in the latter case three cylinders about 4 ft. 6 in. long and weighing in all 250–350 lb. are required to store this quantity. These inconveniences impose a severe limitation on its utility, although it has found an appreciable field of service in short distance delivery work.

Producer Gas.

It is possible to convert solid fuels almost completely to an inflammable gas called "producer gas" in a simple apparatus known as a "producer." The process depends upon the fact that when a current of oxygen is passed through a mass of hot carbon the reactions shown by equations (1) and (3) proceed simultaneously.

Production of carbon dioxide results in waste of fuel and a low-power gas. The proportion of monoxide and dioxide in the product depends chiefly on temperature, and the theoretical equilibrium percentages at different temperatures are shown in Table 2, where it is seen that above 1,000°C. the gas is nearly pure carbon monoxide.

In practice the source of oxygen is, of course, air which contains four volumes of nitrogen to one of oxygen; the former takes no part in the reactions and behaves merely as a diluent. The air admitted to the producer is called "primary air." The resulting producer gas, which may be regarded as half-burnt carbon, is later mixed with sufficient secondary air to burn it completely in the engine cylinder, where the remaining combustion energy of the carbon is obtained according to equation (2).

TABLE 2.

PROPORTIONS OF CARBON MONOXIDE AND CARBON DIOXIDE IN EQUILIBRIUM WITH CARBON AT VARIOUS TEMPERATURES

Temp. °C.	Proportion by volume CO	Proportion by volume CO_2
700	60%	40%
800	88%	12%
900	97%	3%
1,000	99%	1%
1,100	99·8%	0·2%
1,200	99·94%	0·06%

It will be seen by comparing equations (1) and (3) that about 30 per cent. of the available heat energy of the carbon is evolved in the producer and for practical purposes wasted, part radiating from the walls and the remainder being carried away by the issuing gas.

If when the producer is working at high temperature steam is introduced into the hot fuel, the following reaction occurs :—

$$H_2O + C = CO + H_2 - 29 \text{ Cals} \ldots\ldots\ldots\ldots (5)$$

The negative sign to the calories shows that the reaction is "endothermic," that is, it involves the abstraction of heat from the surroundings and will, therefore, cool the fire. A suitable proportion of steam added to the primary air will thus prevent overheating with its consequent troubles, in addition to enriching the gas produced. As the steam can be raised by the waste heat of the producer the arrangement is highly efficient. A producer using steam or water-injection is called a wet-blast producer as distinct from the dry-blast type.

One of the main attractions of producer gas as a substitute for liquid fuels at the present time is that it can be applied to existing lorries without excessive alterations to their engines.

Fuels Suitable for Use in Producers.

Although charcoal, the nearest commercial approximation to pure carbon, has much to recommend it as a producer fuel it is not sufficiently plentiful in this country to merit detailed consideration.

Coal, as already shown, contains other constituents besides carbon, and when it is used destructive distillation occurs in the cooler regions of the apparatus as in ordinary gas works practice ; this results in the production of hydrogen and methane by the decomposition of the complex coal substance. On account of the extra calorific value which these confer upon the gas, they are in themselves highly welcome additions to the product, but, unfortunately, bituminous coals, which evolve these gases most readily, also form excessive tar and sulphur dioxide, which, on account of their respective clogging and corrosive effects, must be removed by relatively heavy and elaborate plant. Consequently, although stationary engines can operate on bituminous coal, only certain types of anthracite and coke are suitable for vehicles. The amount of mineral matter present imposes a further restriction on choice, as an excess is liable to cause the formation of masses of clinker which may stifle the fire.

Finally, it is desirable that the fuel shall possess high "reactivity" ; this is a measure of the ease with which it will burn. Reactivity may be increased by certain "activators," but, unfortunately, these give rise to a variety of additional problems which are still under investigation.

Characteristics of Producer Gas.

Since air consists approximately of four volumes of nitrogen to one volume of oxygen the carbon monoxide produced according to equation (1) is accompanied by twice its volume of nitrogen. In practice the composition of producer gas varies with the type of fuel used, and also changes progressively during the burning of a charge owing to the early loss of volatile bodies. Typical analyses are given in Tables 3 and 4, and the calorific value is compared with that of other fuels in Table 1.

TABLE 3.

COMPOSITION OF PRODUCER GAS OBTAINED UNDER FIXED CONDITIONS FROM DIFFERENT MIXTURES OF NEW AND USED ANTHRACITE

Sample	% CO	% H_2	% CO_2	% N_2	Calorific value. (B.Th.U. per cu ft.)
All new coal..	27·2	12·3	2·7	57·8	120
Equal parts of new and used coal ..	28·5	7·6	3·0	60·9	115
All used coal	27·4	4·2	3·4	65·0	100

TABLE 4.

COMPOSITION OF PRODUCER GAS AT DIFFERENT STAGES DURING A RUN

Time from start of run (mins)	% CO	% H_2	% CO_2	% N_2	Calorific value (B.Th.U. per Cu. Ft.)
20	24·8	21·6	2·8	50·8	137
55	27·2	12·3	2·7	57·8	120
95	28·6	9·1	2·3	60·0	116
130	29·0	6·3	2·6	62·1	109

The gas must be mixed in the engine with just the right amount of secondary air to burn it, and the calorific value of the resulting mixture is very significant as it gives a measure of the maximum energy available per cylinder charge. The figures for producer gas-air and several other fuel-air mixtures are given in Table 1.

The calorific value of the fuel-air mixture is the most important factor affecting the power which a given engine will develop with different fuels, although this is also influenced to an important extent by the ratio of the volume of reaction products to the volume of the charge, both calculated at standard temperature and pressure. This ratio for the various fuels is also shown in Table 1, where it is seen that in this respect again producer gas suffers in comparison with petrol. The net result of these and other factors[5] is that in a converted engine producer gas delivers about 60 per cent. of the power available from petrol, but as it is markedly free from knocking tendency this figure may be raised to the neighbourhood of 70 per cent. by increasing the compression ratio.

The Necessity for Filtration of the Gas.

All available producer fuels contain several per cent. of mineral matter or ash. When supplying an engine developing 40 B.H.P. the velocity of gas in the off-take pipe of the producer is 100–200 ft./sec., and it is obvious that a considerable amount of this ash in the

[5] The question is much more complex than these elementary considerations might suggest. A theoretical discussion bearing on this matter, by E. A. C. Chamberlain, appeared in *The Engineer*, October 11th, 1940 ("Conversion of petrol vehicles to operate on town's gas").

form of dust, together with fine unburnt fuel, will be carried forward by such a hurricane. Such an abrasive mixture must be prevented from reaching the engine as otherwise enormous cylinder wear will occur. The filter which is fitted for the purpose, usually at the end of a series of cooling pipes, is, therefore, a vital part of the equipment. Mechanical, electrostatic, centrifugal and water devices have been tried with varying degrees of success, but cylinder wear generally exceeds that produced by petrol.

Arrangement,[6] Operation and Performance of Producer Plant.

Fig. **1** shows diagrammatically a typical practical arrangement of a producer plant. The combustion chamber or hopper is charged with fuel from the top. Primary air enters through the tuyère, which is usually water cooled, and the reaction gases pass through the grate to the coolers. Efficient cooling is highly desirable so that when the gas arrives at the engine it will have the highest possible density and thus permit the maximum weight of charge to be drawn into the cylinders at each stroke. The increase in density also has the advantage of reducing the velocity through the filtering apparatus, after passing through which the gas is led to the induction manifold via the gas control throttle. Secondary air is admitted at an adjustable valve which is located on the engine side of the carburettor. Before the start of a run air-tightness of the system must be proved by blowing low-pressure air into the tuyère and testing for leaks with soap solution.

To light the fire the engine is started on petrol, the controls being so arranged that it takes its air supply through the producer while a torch is applied to the tuyère so that the flame is drawn into the fuel bed until ignition occurs. The controls are then so altered that the petrol supply is gradually cut off as the fire builds up, and at the same time the necessary secondary air is admitted. These operations normally take 3–5 min.; the vehicle can then be driven on gas, though full power will not be developed for a further 15 min. or so.

As indicated previously, producer gas shows little tendency to knock, and as a result the engine will "hang on" to a particular gear at surprisingly low speeds. Halts of more than a few minutes' duration necessitate further petrol assistance to draw the fire up again. This, of course, imposes a serious handicap on short-distance delivery work; but on clear main roads, involving ordinary hills, properly maintained lorries generally give reliable and trouble-free service, running continuously at or near their legal maximum speeds despite their reduced engine power. Owing to their poor acceleration, however, time is always lost in passing through towns and their pay-loads are reduced by the weight of the equipment, which is of the order of ½ ton.

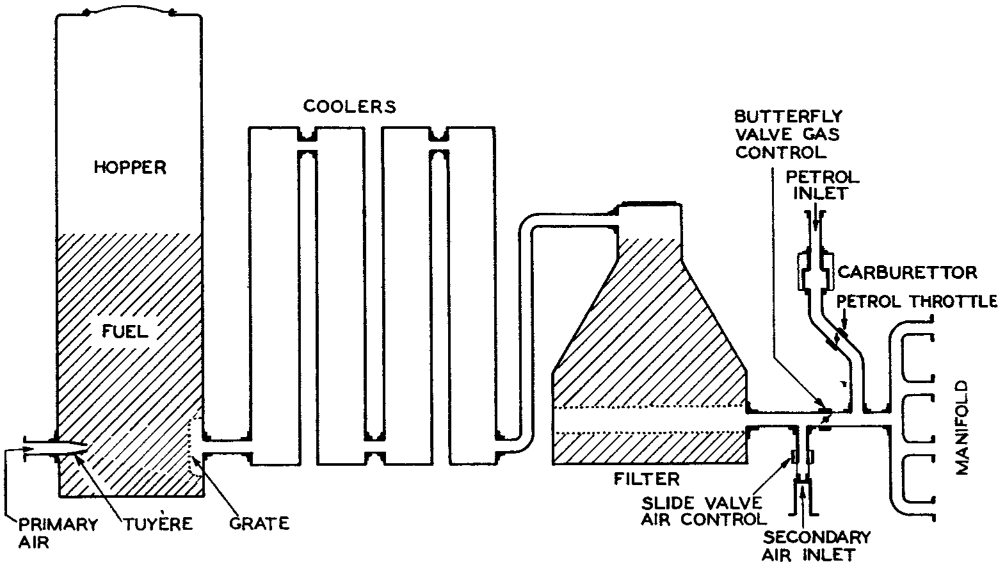


FIG. 1 —PRACTICAL ARRANGEMENT OF PRODUCER GAS PLANT.

A vehicle carrying a pay-load of 3 tons consumes 1–1½ lb. of fuel per mile; in comparison with these figures it is interesting to note that a 400-ton load requires about 60 lb. of coal per mile for its transport by goods train.

Producer gas fuel costs £5–£6 per ton, which is equivalent to ½d.–¾d. per mile for the lorry as against 1⅛d.[7] per mile when using petrol.

Disadvantages of Producer Gas.

Probably the most serious drawback of producer gas plant is its lack of flexibility. From what has already been explained of the chemical reactions involved it is clear that the fire is maintained by the suction of the engine. If the throttle be suddenly opened to accelerate, or to climb a hill, gas production

[6] For a more detailed description of a practical plant see "Report of the Committee on Emergency Conversion of Motor Vehicles and Producer Gas." His Majesty's Stationery Office, 1940.

[7] Calculated on a tax free basis.

can increase only gradually as the fire adjusts itself to the new requirements ; the delay is a function of the reactivity of the fuel and therefore varies considerably. Fuels with high ash content tend to form clinker, which may divert or subdivide the blast so that the fire fails to burn satisfactorily. Occasionally the only remedy for this fault is to empty out and recharge the producer. At the end of a run the fire box contains a minimum of about 130 lb. of unburnt fuel which for economy must be recovered and mixed, after sieving from the ash, with the fresh charge. In addition dry filters require cleaning about every 500 miles. This is a very dirty and unpopular job.

It is probable that most of the difficulties encountered by the operators are due to air leaks in the plant, to detect and prevent which rigid precautions are necessary ; these involve constant vigilance in view of the frequency with which various parts are opened. Leaks[8] in the producer body may cause the fire to spread, and possibly result in the casing being melted. They also reduce the blast through the tuyère. If they occur at other points in the system where the gas is still very hot, premature combustion occurs and the engine receives fuel of reduced calorific value. At the cool end of the system they are not so serious as they may, in part, be compensated for by a closer setting of the secondary air valve.

Future Prospects for Producer Gas.

Despite the defects outlined producer gas affords a fairly simple means of keeping long-distance vehicles mobile during the present crisis, but as has been intimated previously, there is little reason to doubt that petrol or oil, when obtainable, will continue to be preferred for road transport of the type at present used. Economics, however, play an important part in the selection and the producer gas system would be favoured by progress in the following directions :—

1. Improved filtration and possibly chemical purification of the gas so as to reduce cylinder wear to the petrol figure.
2. Reduction of producer equipment maintenance.
3. Supercharging devices.
4. Easier lighting and starting.
5. Adaptation to use a wider range of fuel.

Technically, it appears quite probable that with specially designed vehicles a sufficiently high standard of performance in these respects could be achieved ; but whether incentives for the necessary research and development would exist in time of peace is a political question which it is not proposed to answer.

Even if the use of indigenous fuel became a perpetual necessity, the merits of producer gas would require to be carefully balanced against those of steam, compressed coal gas, and a greatly extended coal-oil conversion programme.

Other Miscellaneous Gaseous Fuels.

Methane (also known as marsh gas or sludge gas) is the main product of anaerobic fermentation of sewage and is, therefore, available in considerable quantities, but suffers, like town's gas, of which it is a component, from the disadvantage of excessive bulkiness. There is, however, some ill-informed talk of its use for transport in the liquid, and, therefore, highly concentrated state, but this is quite impracticable as it cannot be liquefied at temperatures above —95°C. by any pressure, however great. Those who speak of liquid methane in this connection probably mean its near chemical relatives which have higher molecular weights and may be liquefied by moderate pressures at atmospheric temperature. The essential characteristics of these have been included in Table 1, and calor gas (liquefied butane) is a well-known example. Town's gas contains up to 5 per cent. of hydrocarbons such as ethane and ethylene, which would be very useful if they could be segregated, but this would present considerable difficulty and is presumably impracticable.

[8] Since the pressure inside the plant is always below that of the atmosphere a leak means entry of air and not escape of gas.

TELEPHONE AND TELEGRAPH STATISTICS—SINGLE WIRE MILEAGES AS AT 30TH SEPTEMBER, 1941
THE PROPERTY OF, AND MAINTAINED BY, THE POST OFFICE

REGION	OVERHEAD			UNDERGROUND		
	Trunks and Telegraphs	Junctions	Subscribers *	Trunks and Telegraphs †	Junctions ‡	Subscribers ¶
Home Counties	13,455	41,548	295,699	1,017,998	228,995	1,159,874
South Western	8,760	34,775	221,342	458,891	93,831	614,841
Midland	10,599	26,231	184,550	694,662	247,393	853,354
Welsh & Border Counties ..	9,258	24,456	124,468	352,136	63,659	247,335
North Eastern	13,222	23,297	151,885	599,860	195,185	858,777
North Western	2,235	8,046	106,655	491,497	293,672	1,081,042
Northern Ireland	9,003	7,714	27,154	41,961	14,225	106,412
Scottish	24,489	32,571	166,553	489,520	174,817	660,942
Provinces	91,021	198,638	1,278,306	4,146,525	1,316,777	5,582,577
London	601	1,471	67,348	630,162	1,481,252	3,562,498
United Kingdom	91,622	200,109	1,345,654	4,776,687	2,798,029	9,145,075

* Includes all spare wires. † All wires (including spares) in M.U. Cables. ‡ All wires (including spares) in wholly Junction Cables.
¶ All wires (including spares) in Sub's. and mixed Junction and Sub's. Cables.

The Generation and Distribution of a Standard 1 kc/s Synchronising Signal

C. F. BOOTH, A.M.I.E.E., and
G. GREGORY

U.D.C. 621.396.615

The generation and distribution of a standard 1 kc/s signal used for synchronisation purposes in connection with carrier telephony systems is described. The method of generation by " working " and " standby," temperature and pressure controlled valve maintained tuning fork frequency standards is set out. The precautions taken to ensure an unfailing 1 kc/s supply to the distribution network by the provision of an automatic high speed change-over device, together with three alternative 1 kc/s signal sources derived from the coaxial cable master oscillators are detailed.

Introduction.

IN single sideband suppressed carrier working, employed in the Post Office 12-channel carrier telephone network, it is imperative, if appreciable degradation of the speech circuits is to be avoided, that the corresponding send and receive carriers at the two terminals of a cable shall not differ in frequency by more than a few cycles per second. The permissible difference for music transmission is less than that for speech and voice frequency signalling and telegraphy call for even closer agreement. In addition to the high frequency stability called for at the two ends of a particular cable it is desirable, to facilitate the interconnection of carrier systems throughout the country, that all corresponding carriers shall not differ. Obviously the simplest way to achieve this condition is to lock all the carrier generators to a master frequency so that although they vary in unison with the master, they do not give a difference frequency. In this way the inherent frequency stability of the master need only be of an order to prevent the translated speech bands from wandering outside the pass-bands of the corresponding filters. In view of the desirability of a standard synchronising signal for the carrier system throughout the country the system described in this article, employing a 1 kc/s synchronising signal, has been adopted.

The 1 kc/s signal is derived normally from the Post Office frequency standard, and is transmitted over two independent routes to the London terminal where it is arranged to control the master oscillators associated with the local 12-channel systems. The 60th harmonic of the 1 kc/s signal, 60 kc/s, is transmitted over the cables to the remote terminals for synchronising purposes, and is passed on from these stations so that the whole cable network is controlled from the standard. In addition, 1 kc/s signals are produced at the coaxial cable terminals, London, Birmingham and Manchester (Newcastle will be included in the near future), and these signals are arranged to act as standbys to the standard in this order.

Equipment Associated with Frequency Standard

Tuning Fork Oscillators.

The frequency standard comprises a number of quartz crystal controlled oscillators, 100 and 1,000 kc/s, and two valve-maintained tuning fork oscillators of 1 kc/s. The absolute frequencies of the crystal oscillators are determined to within ± 2 parts in 10^8 and their stabilities during a 24-hour period are of the same order. The corresponding figure for fork A is $\pm 2/10^7$ and for fork B $\pm 1/10^6$. Although the performance of the forks is inferior to that of the crystals, they are at present employed to provide the 1 kc/s synchronising signal. The reason for the decision is that risk of failure of the outgoing signal must be reduced to the absolute minimum, and whereas the 1 kc/s tone is produced directly by the fork oscillators, frequency dividing trains employing several valves are necessary to provide a 1 kc/s signal from the crystals. So, despite the inferior accuracy of the fork oscillators it was considered desirable to use them rather than to risk the very

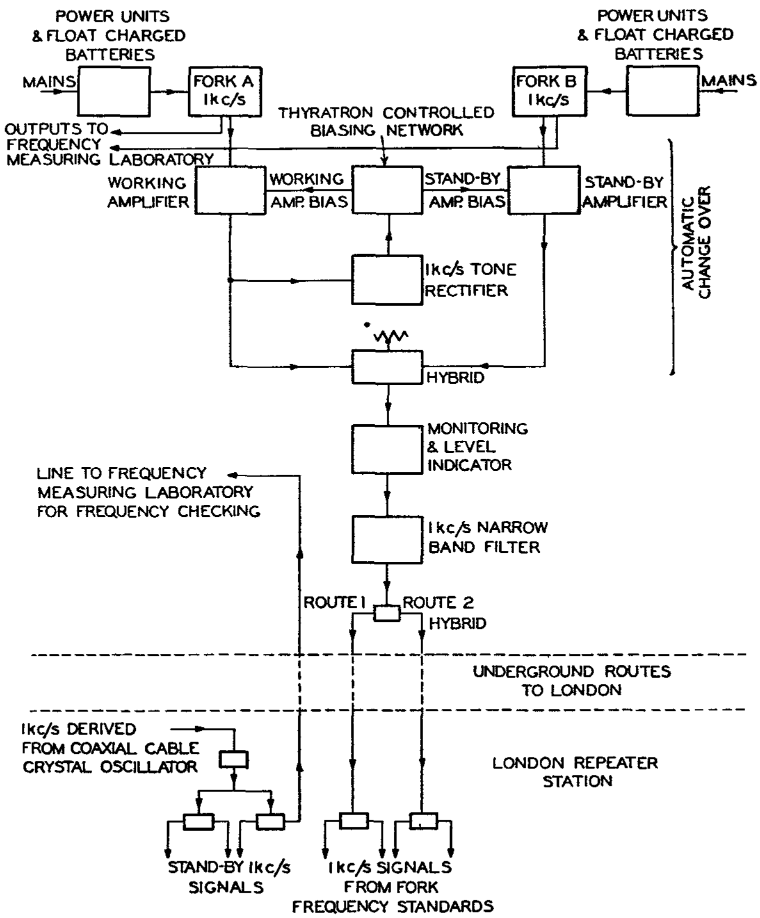


Fig 1.—Distribution of Standard 1 kc/s Synchronising Signal from Fork Frequency Standards

occasional failure of the dividing trains associated with the crystals. Rapid advances have recently been made with frequency dividers, and, with the improved reliability now available, it is hoped to derive the synchronising signal from the crystals in the near future. To reduce further the risk of failure the two forks A and B are employed, the output normally being taken from A via a change-over device which in the event of output failure of A causes B to be automatically switched to line. Alternative underground routes are provided to London, the general schematic being as shown in Fig **1**.

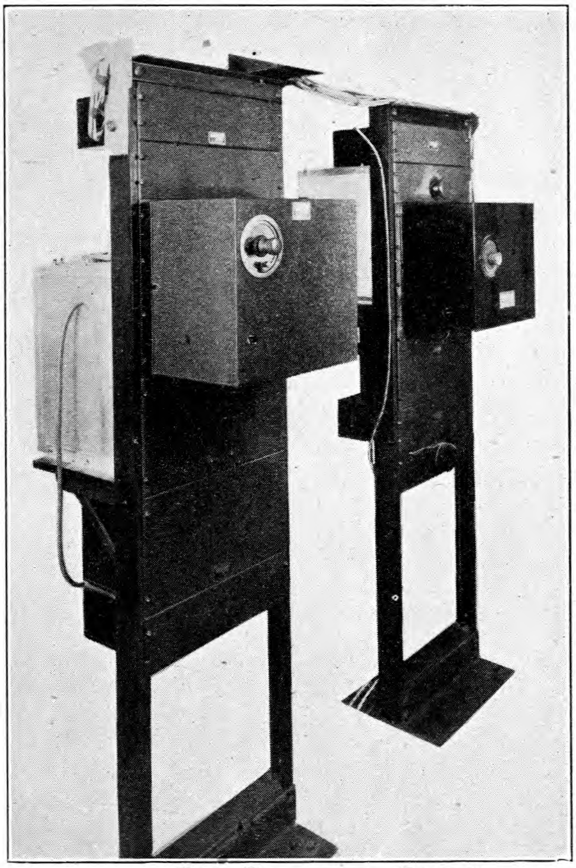
The forks are made of elinvar (frequency-temperature co-efficient less than 10 parts in 10^6 per 1°C), and are mounted in temperature-controlled supplies, temperature, pressure and frequency of oscillation of each fork are monitored on the associated control bay, Fig. **3**, installed in the Frequency Measuring Laboratory, remote from the cellar, and access to the latter is confined to a maintenance visit to the cellar once each day. The temperature control equipment for each fork pot is duplicated, the stand-by circuit being brought into operation on the failure of the working circuit. The absolute frequency of each fork is determined daily and daily records are kept of all factors which might affect frequency stability.

The fork maintaining circuits consist of two-stage drive units plus amplifiers, the latter acting as buffer stages to isolate the loads from the drives and giving levels of + 5 db. ref. 1 mW.

Fork Maintaining and Buffer Circuits.

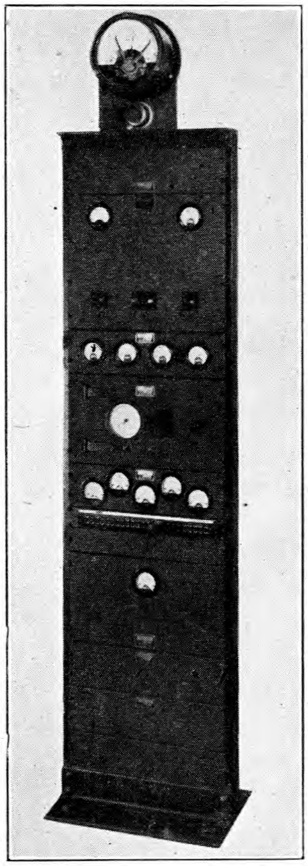
Lagged Chamber containing Fork Pot.

Decoupling and Smoothing Circuits.



Fork B. Fork A.

Fig. **2**.—Frequency Standard Bays.



Distribution.

Temperature Control.

Temperature and Pressure Indicator.

1 kc/s Synchronous Clock.

Supplies Monitoring.

Synchronous Clock Power Amplifier.

Supplies.

Fig. **3**.—Control Bay for Fork A.

pots which are sealed against atmospheric pressure variations (frequency-pressure coefficient $- 2{\cdot}5/10^6/ + 1$ cm Hg), at a pressure of 10cms Hg. These assemblies (Fig. **2**) together with the associated maintaining circuits are installed in an underground temperature-controlled room. The cellar temperature is maintained at 24° ±1°C, and the effective temperature changes of the forks are less than ±0·005°C. The power required for the maintaining circuits is obtained from float charged stabilised batteries of sufficient capacity to maintain the forks in oscillation during A.C. mains failures of up to 48 hours duration. Supplies for the heater circuits are obtained from separate high capacity batteries. The voltage

The fork temperature control systems employ mercury contact thermometers, sensitivity 1 in. per 1°C, valves and mercury relays. The thermometer contacts are fused into the glass stem, one near the bulb and the other in a position to make contact with the mercury column at the control temperature 27·5°C. The heater resistances are wound round the sealed metal pot containing the fork, the thermometer bulb being in intimate association with the heater windings. Thus, as the pot temperature rises to the control value, the circuit between the thermometer contacts is made through the mercury column, the valve grid bias is changed and the heater current is switched off by the mercury relay in the valve anode circuit. Alternatively, as the temperature falls below the control value, the heat is switched on. The heater windings, thermometer, mercury relay and valve are duplicated, and an automatic change-over device is included to enable the " working " system to be supplanted by the " stand-by " system in the event of the failure of the former. The change-over device consists of a thermometer (the control thermometer) having three contacts, one in the bulb and the others at positions corresponding to temperatures $\pm$ 0·25°C from the operating temperature of 27·5°C, and a relay which is arranged to switch on the filament supply to either the " working " or " stand-by " valve. While the control thermometer mercury column is within $\pm$ 0·25°C of 27·5°C, the filament circuit of the "working" valve is made via the relay tongue and the "working" heating system is ready to function, but immediately the control thermometer mercury moves outside this range the relay is operated, the " stand-by " system takes control and a visual warning of the change-over is given. To enable the fork pot temperature and air pressure to be monitored at the associated control bay (Fig. **3**), the pot is fitted with a resistance bridge thermometer and a manometer. The bridge is balanced at the operating temperature 27·5°C, and a calibrated microammeter on the control bay registers the actual pot temperature. The manometer is fitted with contacts, so arranged that slight pressure variations about the normal value, 10 cms. Hg., result in the manometer mercury column level altering the value of the current flowing through a monitoring meter. Tests have shown that as a result of the precautions described the fork temperature and the air pressure within the sealed pot are maintained constant at 27·5°C $\pm$ 0·005°C and 10 cms. $\pm$ 0·05 mm. Hg., corresponding to fork frequency variations of less than ± 3 and ± 1 part in 10^8 respectively. The equipment, which is somewhat complicated, is fitted with test keys whereby the operation of both thermostats and the changeover device can be simulated. The system has been in operation for some six years, and has proved to be very reliable.

The mean frequency of each fork is determined daily in terms of mean solar time. For the purpose, the two fork outputs are arranged to drive two synchronous motor clocks which keep true mean solar time rate when the control frequency is exactly 1 kc/s. The clock rates are compared with rhythmic time signals on a double pen recorder[1], one pen being operated by the Rugby time signal and the other by second impulses from the fork driven clock. The displacement of the " fork " second marks from successive time signals, separated by a 24-hour interval, enables the mean frequency of the fork during the interval to be calculated. The accuracy of the determination is primarily dependent on the accuracy of the 24-hour interval as radiated from Rugby. This is normally good to within $\pm$ 0·02 secs.

[1] *P.O.E.E.J.*, Vol. 33, p. 111.

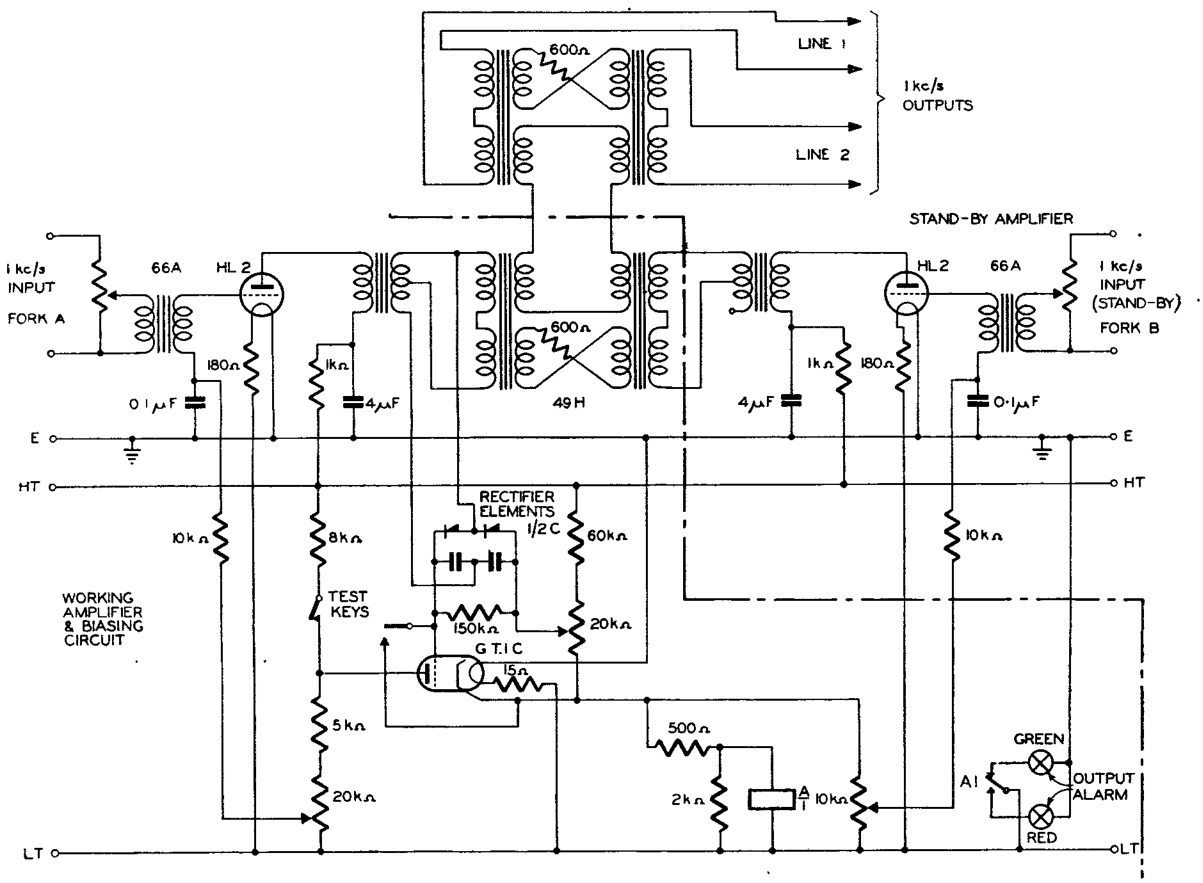


Fig. **4**.—Automatic Change-over Device Circuit.

corresponding to a maximum possible frequency error of $\pm 4{\cdot}6/10^7$ c/s for a 24-hour interval, the error decreasing proportionally as the length of the interval is increased. It must be remembered that time signal determinations give information only of the mean frequency of the fork over the period of comparison, but the "instantaneous frequency" can be readily measured in a few seconds to within $\pm 2/10^8$ by recording the beat frequency between the 1,000th harmonic of the fork and the output of one of the 1,000 kc/s crystal standards whose frequencies are always known to that accuracy. Such "instantaneous frequency" checks of the fork standards form part of the routine work carried out in the associated Frequency Measuring Laboratory.

Change-Over Circuit.

The change-over device employed for the purpose of switching the alternative standard 1 kc/s supply to line, is shown in schematic form in Fig. **1**, and the circuit given in Fig. **4**. It is required to operate at high speed; for this reason electro-mechanical relays are omitted and switching is achieved by electronic means. It comprises working and standby amplifiers fed from forks A and B, the amplifiers being biased by an associated thyratron circuit. Normally the thyratron arc is extinguished, in which condition a resistance network provides an operating grid bias of some −2V for the working amplifier, and a blocking bias of approximately −22V for the standby amplifier. Thus the output fed to line is derived from fork A via the working amplifier, the standby amplifier output being reduced to a level of −60 db. relative to the working output. The arc is prevented from striking by negative grid bias obtained by rectifying a part of the working amplifier 1 kc/s output. If the working amplifier output fails the rectified bias voltage also fails and the thyratron strikes. The ignition of the thyratron reverses the bias conditions, i.e., the working amplifier is blocked, the standby amplifier becomes operative, and the output fed to line is derived from fork B, the change-over being indicated by an alarm lamp. When the fault which caused the working amplifier to fail is cleared, the distribution will not revert to A since it is not possible to extinguish the thyratron by grid control once a D.C. arc is struck. A key is therefore provided to interrupt the thyratron anode circuit so that the normal conditions may be restored. The time required for the change-over to take place depends on the time constant of the 1 kc/s tone rectifier, which has been made as small as practicable, on the ignition delay of the thyratron, and on the delay in the standby amplifier. While no precise measurements have been made to determine the total delay this is known to be very small. With a common input to both amplifiers it was found possible to run a 1 kc/s synchronous clock from the output despite frequent operation of the change-over device. Under this condition, however, no phase difference was introduced to the clock supply. With separate sources of input clock stoppages occurred whenever there was an appreciable phase difference between the two sources at the moment of change-over. The respective input and output levels of both forks are −8 and +10 db. ref. 1 mW, the output level of the transmitted 1 kc/s signal being constantly monitored. Indicating lamps on the change-over panel are illuminated, green when the working amplifier is in operation and red when the circuit changes over to the standby amplifier. The operation of the device is tested twice daily and records are taken of the input and output levels.

Causes of Failure.

The most probable causes of failure of the 1 kc/s signal to line are as follows:—

(*a*) Battery supply failures.
(*b*) Valve failures in the drive and buffer stages of the standards and in the change-over unit.
(*c*) Prolonged A.C. power failures.

The batteries which supply the generating and distribution equipment are maintained in the Frequency Measuring Laboratory battery room, the forks being fed from float charged batteries which safeguard them from A.C. power failures up to 48 hours duration, and the distribution equipment is fed from high capacity batteries alternately charged and discharged. The valves used in the standards drive and buffer circuits have a very long life, and those in the change-over circuit are of a very reliable type. Furthermore, the standby amplifier valve is biased to cut-off. Prolonged A.C. power failures would probably affect associated terminal equipment equally with the generating and distributing apparatus.

Equipment at Coaxial Cable Terminals

The carrier frequencies required for the London-Birmingham-Manchester coaxial cable system[2] are derived at each of the three terminals from a chain of frequency dividing circuits which are rigidly locked to a master oscillator of nominal frequency 400 kc/s, a high-grade crystal oscillator, 400 kc/s, being provided at each terminal. Normally the London oscillator is arranged to control directly the carrier generators at that terminal, and the generators at Birmingham and Manchester by a 400 kc/s synchronising signal transmitted over the cable. Failure of the London oscillator causes Birmingham automatically to take control, and similarly the role of master is taken over by Manchester should both London and Birmingham fail. (A similar system will be installed at Newcastle when the Manchester-Newcastle section of the cable is equipped). A nominal 1 kc/s signal is produced at each terminal from a dividing chain driven either by the local oscillator, or the incoming synchronising pilot, the frequency being exactly one four-hundredth of the control frequency. Thus, under normal conditions, there is available at the terminals a nominal 1 kc/s signal which is one four-hundredth of the London master oscillator frequency, while under fault conditions each 1 kc/s signal might be similarly related to its local master. The crystal oscillator employs a 400 kc/s crystal of low-frequency temperature coefficient. Minimum damping of the crystal is ensured by the use of a nodal plane suspension and by a reduction of the air pressure in

[2] *P.O E.E.J.*, Vol. 30, p. 275.

the holder to less than 5 cm Hg. The effective frequency-temperature coefficient of the mounted crystal over the range 20° to 60°C. is less than $1/10^6/1°C$. The crystal is mounted in a thermostatically-controlled oven designed to reduce ambient temperature variations to less than $\pm$ 0·1°C. The temperature control is achieved with a contact mercury thermometer in association with a valve rectifier and a mercury relay. A second thermometer fitted with contacts at temperatures $\pm$1°C. from the control value of 40°C. is employed to give warnings of oven temperature irregularities. Trimmer capacitors across the crystals provide means of compensating for the second order frequency variations which occur due to ageing of crystal, mounting and circuit components. As a measure of safety two similar crystals are contained within the oven, either of which may be connected to the drive circuit. The load on the drive valve is stabilised by a pentode valve buffer stage. No special precautions are taken to stabilise the supplies which are obtained from the station busbars. The day-to-day stabilities of the master oscillators are better than $\pm$ $1/10^6$.

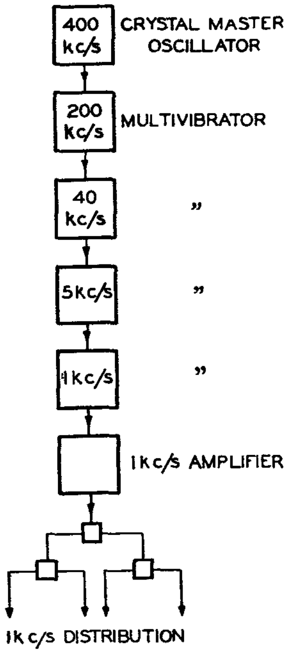


FIG. 5.—FREQUENCY DIVIDING TRAIN FOR GENERATION OF 1 KC/S SIGNAL FROM COAXIAL MASTER OSCILLATOR.

Two multivibrator chains are provided and failure of the working chain causes the standby to be automatically switched into service. The division to 1 kc/s is achieved in four multivibrator stages, 400/200, 200/40, 40/5, 5/1, Fig. 5. Each unit comprises a control signal amplifier, a multivibrator, a wide-band filter and amplifier to cover the required carrier frequency band. In the 5/1 stage the wide-band filter is replaced by a low pass filter and four independent 600 ohm outputs at a level of +8 db. ref. 1 mW. are available.

The frequencies of the 1 kc/s signals at each of the three stations are regularly measured in terms of the frequency standard. This is achieved by causing each of the 400 kc/s master oscillators to provide the control to the London dividing train and by transmitting the nominal 1 kc/s derived signals over a special pair to the Frequency Measuring Laboratory.

The stability, during a period of six months, of the 1 kc/s signal derived from the London coaxial cable master oscillator is illustrated graphically in Fig. 6. During the first three months the working crystal was in operation, after which the spare crystal was brought into use. The average absolute errors of the two frequencies from 1 kc/s were $+ 4/10^6$ (working) and $-2{\cdot}5/10^6$ (spare), and their stabilities over periods of days were within $\pm$ $1/10^6$. As already stated the three coaxial cable master oscillator 1 kc/s signals are used as standbys to the standard 1 kc/s signal. It should be appreciated, however, that the equipment was designed for the coaxial system, and is actually intimately associated with the terminal equipment. It is proposed in the near future to provide three new sets of equipment at the three terminals giving a 1 kc/s signal of much higher absolute accuracy and stability. The production of this apparatus is actually in hand.

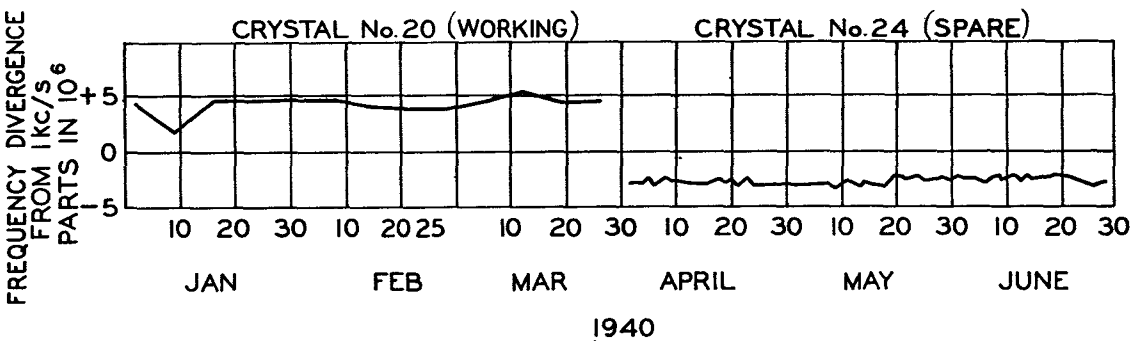


FIG. 6.—COMPARISON OF FREQUENCY OF LONDON COAXIAL CABLE MASTER OSCILLATOR WITH FREQUENCY STANDARD.

Carrier System No. 7

Part II

F. J. D. TAYLOR, B.Sc.(Eng.)

U.D.C. 621.395.443.3

The second and final part of this article describes the principal equipment comprising the new Carrier System No. 7 and gives particulars of the performance of a typical installation.

Introduction.

THE first part of this article dealt with the basic features of this particular type of 12-circuit carrier system; in this part, circuits and equipment details are described at greater length. It will be appreciated that as a great number of different panels are involved it is impracticable to deal with all them in the detail which, perhaps, they deserve. The equipment details mentioned and the measured performance indicated are those of the apparatus as made by one particular manufacturer; another manufacturer is making the equipment to almost identical drawings, but it is unlikely that the performance of the equipment as made by different manufacturers will vary to any considerable extent.

The equipment involved and subsidiary apparatus introduced in conjunction with it falls into the following sections:—

(i) Channel and group modulating equipment.
(ii) Carrier frequency generating and synchronising equipment.
(iii) Distribution frames.
(iv) Line amplifiers and equalisers.
(v) Distant end crosstalk balancing equipment.
(vi) Inverters.
(vii) Inverter carrier frequency generating equipment.
(viii) Testing equipment.

This article is concerned in the main with items (i), (ii), (iii) and (viii), and to a lesser extent with (iv). Though initial installations of the No. 7 equipment will employ line amplifiers of the type used in connection with No. 5 and No. 6 type installations, amplifiers capable of dealing with the 12–108 kc/s range have been introduced and these will be dealt with in a later article. Item (v) has been dealt with elsewhere[1] and items (vi) and (vii) will form the subject of another article. The relative position and interconnection of items (i) to (v) will be apparent from Fig. 3 of the first part of this article.

Channel Equipment.

This may be defined as the apparatus required to assemble 12 speech bands into the frequency range 60–108 kc/s and to effect the reverse process; it is indicated in block schematic form in Fig. **1**, which illustrates that part of the apparatus proper to the modulating and demodulating stages for one speech channel. The carrier frequencies are 64, 68–108 kc/s, and inverted (lower) sidebands are selected.

The input pads preceding the modulator are adjustable in order that the relative test level at the modulator proper may be independent (within the design limits) of the signal level as applied at the input terminals. Both modulator and demodulator networks are of the Cowan type, i.e. alternate half waves of the carrier cause rectifiers to become conducting, thus short-circuiting the line and so "chopping" the applied audio signal at carrier frequency. The potentiometer associated with the modulator network may be adjusted to keep carrier leak to a minimum. A fixed attenuator pad follows the modulator network in order that a sensibly constant impedance may close the band selecting filter on its input side. In addition there are adjustable attenuator pads preceding the filter input, but these are adjusted in the factory and result in a similar relative test level for each channel as measured at the common output point.

It will be observed that voltage limiters of conventional type are not used at the input of the transmitting channel equipment; a special device is rendered unnecessary by the characteristic of the modulator. For a given level of carrier voltage, sideband power and input power have a linear relationship for a wide range of input levels; when,

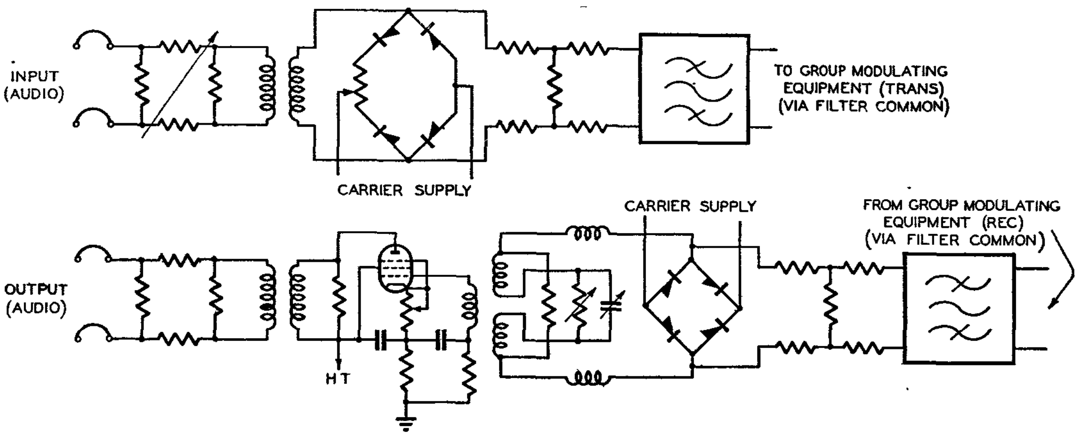


FIG. 1.—CHANNEL EQUIPMENT.

[1] *I.P.O.E.E. Printed Paper*, No. 171.

however, the input level approaches the carrier level linearity is lost and a point is reached where increase of input level does not result in an increase of output level.

It will be observed that the demodulator is similar in form to the modulator, but as it is not necessary to balance the network a potentiometer is not provided. The resistance condenser combination in series with the input transformer of the channel amplifier is provided so that slight irregularities in the gain-frequency response of the equipment may be equalised; the adjustment of these components is effected in the factory.

The channel amplifier has a single gain stage, series negative feed-back being employed. Adjustment of gain is effected by the variable cathode resistor; this is provided in the form of a variable potentiometer which may be adjusted by a control projecting through the dust cover.

All the channel filters are of conventional design and employ crystal resonators as well as condensers and inductors of normal type. Fig. 2 illustrates a typical filter circuit. The crystals forming opposite arms of a lattice are not mechanically separate; one crystal only is used to form each "pair," but the electrodes on the opposite faces are divided to form, in effect, two resonator elements. (*Note.*—The two manufacturers at present making this type of equipment use different crystal "cuts.") The trimming condensers are a small air dielectric type. The inductors employ iron dust cores, molybdenum-nickel-iron being used almost exclusively in the equipments tested, though nickel-iron dusts are used in the equipment of another manufacturer. The individual filters are enclosed in air-tight cans which are sealed after a drying process.

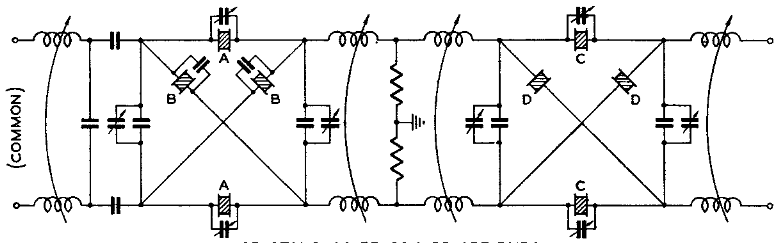


FIG. 2.—CIRCUIT OF TYPICAL CHANNEL FILTER.

The modulator and demodulator networks, channel amplifier and associated filters for one circuit end are mounted upon one panel known as a channel panel. (*See* Fig. 3.)

Associated with the filter common points on both the transmitting and receiving sides compensating filters are provided; these filters are of conventional type and their function is well known.

Group Modulating Equipment.

This comprises on the transmitting side a group modulator and associated low-pass filter, whereas on the receiving side there is a group demodulator, low-pass filter and a group amplifier. The group "modem" (modulator-demodulator unit) is of conventional type, modified (biased rectifiers) double balanced bridges being used. At the input of the demodulator side of the group "modem" there is provided a differential transformer from one winding of which are taken leads which carry a received carrier synchronising signal. The low-pass filters are of coil and condenser type and their construction is normal. The group amplifier has a fixed gain of approximately 42 db. and is a two-stage transformer coupled unit, negative feedback being employed.

Initial installations of the equipment are not provided with group combining filters, but these may be added readily if and when it is desired to work with two 12-circuit groups on one pair in carrier cables. It is not desired to provide these filters when not absolutely necessary as, owing to the narrow separating band, they degrade somewhat the loss-frequency characteristic of the channels immediately adjacent to the 60 kc/s group separating frequency. Initial installations will not be wired to the G.D.F. at the junction of the channel and group modulating equipment. However, the interconnection of the two sections of the apparatus is so arranged that the wiring to the frame can be provided as and when necessary and without causing undue disturbance.

The channel and group modulating equipment for one 12-circuit group occupies two standard baysides 10 ft. 6 in. in height (Fig. 3). The channel panels, compensating networks and miscellaneous panels occupy most of the space on each of the baysides; the remaining space is normally left blank on one of the baysides whereas on the other it is used to accommodate the group modulating equipment. The normally blank space on every twelfth pair of baysides is used to accommodate a carrier distribution panel, this comprising the carrier supply busbars and associated compensating resistors for a group of 12-channel and group modulating equipments.

At a later date a change may be made in the layout of apparatus on the channel bays. Without considerable alteration to component panels it will be possible to mount all of the channel panels on one bayside and to mount the group equipment upon separate bays. This may result in a more economical use of bay space and should decrease the mean length of run to and from the G.D.F. It is contemplated that this change of layout will not be adopted until after the cessation of hostilities. In certain instances, however, group modulating equipment will be mounted on special bays, e.g., at the junction of 12-circuit and coaxial cable installations.

Carrier Frequency Generating Equipment.

Fig. 4 indicates in block schematic form the carrier frequency generating apparatus. The primary frequency of 4 kc/s is generated by an oscillator the frequency of which is controlled either by a local high accuracy source of 1 kc/s tone or by a pilot tone received from line. There is also a standby oscillator which is also frequency controlled. The control panel associated with the two 4 kc/s oscillators is used firstly to observe that there is no asynchronism between the oscillators and secondly to assist in the adjustment for frequency stability against battery potential variations.

Each of the 4 kc/s oscillators feeds tone into a harmonic generator. This consists of a two-stage power amplifier designed to feed a saturated coil circuit of the type described in the first part of this article; odd and even harmonics are generated. The level of harmonic generated is approximately 27 db. above 1 mW. In the "normal" harmonic generator a transformer associated with the output of the amplifier is used to apply a monitoring signal of 4 kc/s to the change-over panel. The function of the change-over panel is to ensure that while the output from the "normal" harmonic generator is at its designed value that from the "stand-by" unit is suppressed, so that one output only is applied to each of the combining differential transformers; if the "normal" 4 kc/s oscillator or harmonic generator fails, the changeover panel "opens up" the stand-by path and suppresses the "normal" path. The change-over process is automatic in the direction "normal" to "stand-by," but manual restoration is necessary.

Briefly, the change-over panel comprises three gas-discharge relay circuits, two of these circuits being in parallel. Under normal conditions, the circuit including the single relay is conducting, and certain of the potentials developed are applied to the anode and screen circuits of the output valves of the stand-by equipment in order that, though the apparatus is "alive" and ready for working, only very low anode and screen currents will be maintained; this arrangement improves the reliability of the stand-by equipment and lengthens the life of the valves concerned. At change-over the relay is extinguished and the anode and screen potentials controlled are restored to normal.

The other relays are paralleled to ensure reliability; they are normally extinguished, and the circuit conditions are such that only one of them will strike at the change-over. On the failure of the 4 kc/s monitoring tone from the "normal" harmonic generator one of the paralleled relays will strike and continue to conduct as long as the stand-by equipment is working. With both of the paralleled valves non-conducting, potentials from the circuits are used

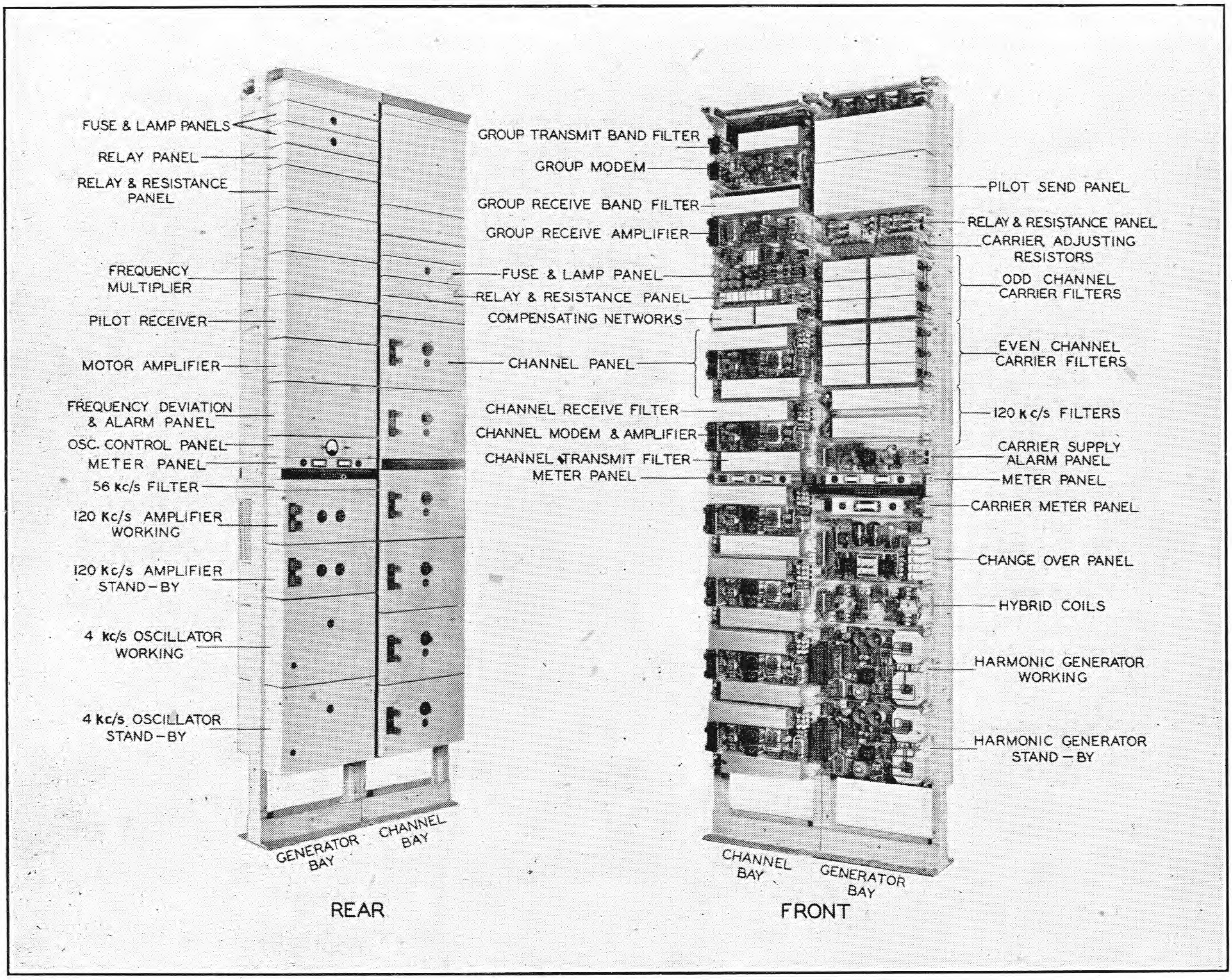


FIG. 3.—CHANNEL AND GENERATOR BAYS.

(*a*) to apply a blocking voltage to the first stage valve of the stand-by harmonic generator and (*b*) apply a working bias to the corresponding valve of the normal harmonic generator. Striking of the valves on failure of the 4 kc/s monitoring signal is effected by the reduction of grid bias supplied normally by the monitoring signal. Facilities are provided so that the operation of the change-over equipment can be tested at any time.

It should be pointed out here that change-over by the one panel can be effected not only by failure of the monitoring 4 kc/s signal from the " normal " harmonic generator but also by the failure of the 120 kc/s supply at the output of the " normal " amplifier supplying that frequency (amplifier N of Fig 4.). The operation of the change-over panel is the same for control by either the 4 or 120 kc/s signals.

It will be observed from Fig. 4 that from each of the harmonic generators there are three outputs, i.e., the odd and even harmonic frequencies of 4 kc/s and also 120 kc/s. From the odd and even supplies the primary carrier frequencies 64, 68—108 kc/s are selected by filters passing only a very narrow band and grouped as shown in the figure.

Separate amplifiers are used in the " normal " and " stand-by " paths of the 120 kc/s supply and the stand-by amplifier is normally back-biased via the change-over panel.

An alarm panel is provided to monitor the output of both the 120 kc/s supply and the " common " of the odd harmonic supply ; failure of either of these supplies brings into operation an urgent alarm as the failure of all of the equipment supplied by the carrier generating equipment is involved.

The filters are of crystal element type and similar in general construction to the channel filters of the channel equipment. The normal level of carrier at the output of the filters is adjusted to be 0·4 V, and the level of 120 kc/s supply is 1·1 V.

The power available from the carrier selecting filters is sufficient for 12 groups of channel equipment ; if 12 groups or less are to be fed from the generating equipment connections such as that indicated as (*a*) in Fig. 4 are made. If, however, 13 to 48 groups are to be supplied a bay of carrier amplifiers is employed, connection then being of the form shown as (*b*) of the figure. In the diagram the connections for the 84 kc/s supply only are shown in full, but similar arrangements exist for each of the other 11 primary carrier frequencies.

Distribution of the carrier is effected via a distribution panel associated with the first of every group of twelve channel equipments, e.g., in a station accommodating 38 channel equipments there would be carrier distribution panels on the 1st, 13th, 25th and 37th units. The design of the distribution panel is such that a constant load is maintained independently of the number of channel equipments being supplied.

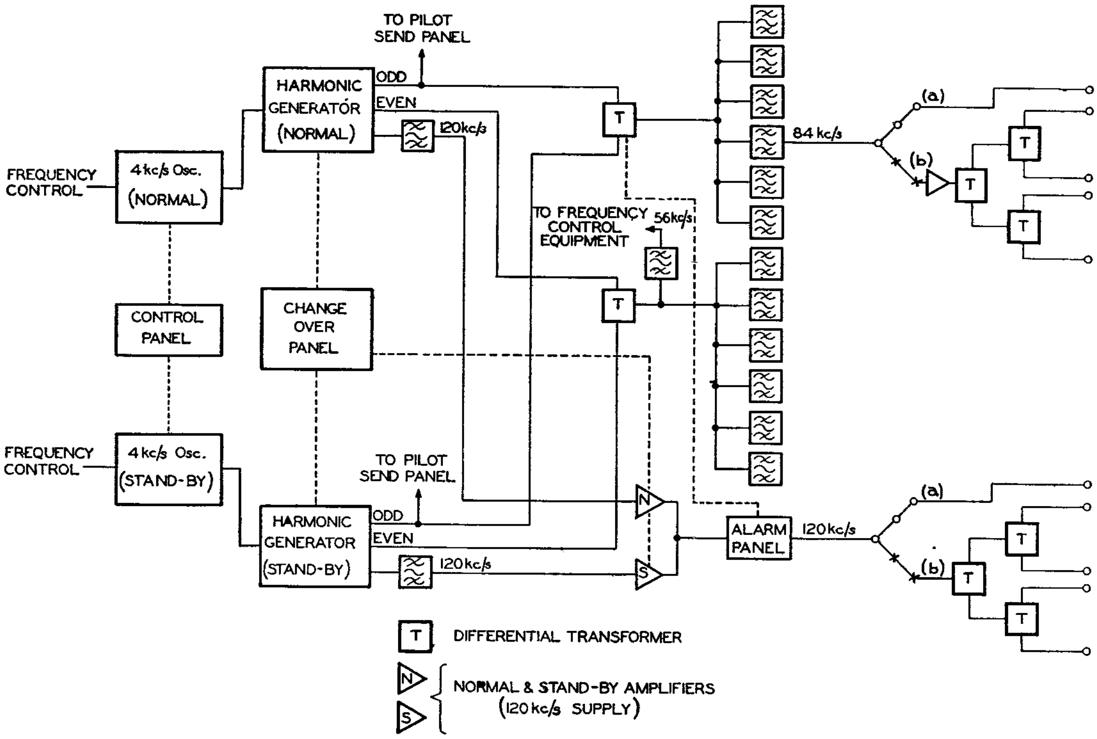


FIG. 4.—SCHEMATIC OF CARRIER FREQUENCY GENERATING EQUIPMENT.

Carrier Frequency Synchronising Equipment.

This is, essentially, associated very closely with the carrier generating apparatus and is illustrated in block schematic form in Fig. **5**. As has been indicated in the first part of this article, the oscillator equipment at one station can control the frequency generated by that at a distant station, and the process is reversible. The controlling frequency transmitted to line has a frequency of 60 kc/s. Where a suitable high accuracy source of 1 kc/s current is available[2] a frequency multiplying device is provided in order that the oscillators may be controlled either locally or by the synchronising signal received from line. As has been mentioned earlier, it is the intention that ultimately the whole of the 12-circuit carrier network will be linked up and controlled at any instant by one high accuracy master oscillator, the linking and control being modified as required under fault conditions.

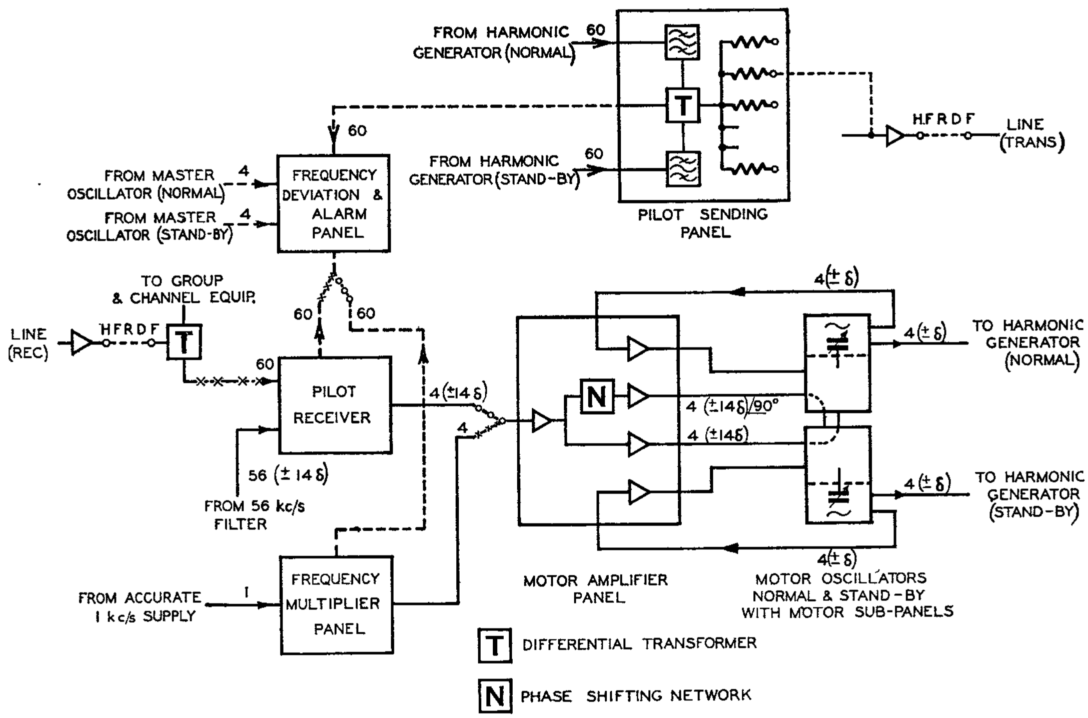


FIG. **5**.—SCHEMATIC OF CARRIER FREQUENCY SYNCHRONISING EQUIPMENT.

To facilitate explanation of the operation of the carrier synchronising apparatus the function of each of the panels indicated in Fig. **5** will first be described. (Figs. **4** and **5** should, of course, be considered in association with each other.)

Frequency Multiplier Panel.—This produces from a high accuracy 1 kc/s source harmonic frequencies of 4 and 60 kc/s, the former being used to control the frequency generated by the 4 kc/s oscillators and the latter to act as a frequency against which the outgoing pilot frequency can be checked.

Pilot Receiver.—This receives the 60 kc/s signal from line and by modulation with the locally generated frequency of nominally 56 kc/s produces the 4 kc/s signal for the control of the 4 kc/s oscillators. A portion of the incoming pilot signal is diverted for comparison with the transmitted pilot signal.

Frequency Deviation and Alarm Panel.—This unit compares the frequency of the following pairs of signals and operates an alarm if there is asynchronism :—

(i) 60 kc/s derived from a local high accuracy 1 kc/s source and that transmitted to line for control purposes.

(ii) 60 kc/s signal received from line and that transmitted to line.

(*Note.*—(i) and (ii) are, of course, alternatives.)

(iii) 4 kc/s generated by the "normal" oscillator and that generated by the "stand-by" unit.

Pilot Sending Panel.—This is a combining unit receiving 60 kc/s currents from the "normal" and "stand-by" harmonic generators and is provided with distribution facilities to the transmitting line amplifiers.

Motor Amplifier Panel.—This unit incorporates all the amplifiers required to amplify the various 4 kc/s (nominal) signals which control the condenser driving motors. The phase shifting network is also included.

Motor Sub-panels.—One of these panels is associated with each of the two controlled oscillators and is mounted directly upon the oscillator proper. It incorporates the rectifier system and the condenser driving motor.

[2] *P.O.E.E.J.*, Vol. 34, p. 156.

The arrangement obtaining where the frequency control is derived from a local 1 kc/s oscillator will now be considered. In this condition 4 kc/s tone is derived from the controlling source and applied to the motor amplifier panel. (*Note.*—In Fig. 5 figures placed immediately adjacent to a line indicate the synchronising signal frequency at that point.) Two of the output frequencies of this panel will be of 4 kc/s in quadrature with respect to one another. If the frequency generated by either the " normal " or " stand-by " oscillator differs from 4 kc/s it will be brought into synchronism with the controlling 4 kc/s tone, the mechanism of the control being as explained in the first part of this article.

When the oscillators are generating the accurate 4th harmonic of the controlling source the pilot sending panel will be delivering the 60th harmonic of the control frequency to line via the input circuits of all transmitting line amplifiers.

If the frequency control is to be derived from a signal received from a distant controlling station, it is first necessary to select the particular incoming signal which shall be used; this is apparent, for at any station there may be receiving line amplifiers associated with many different routes. To enable this selection to be accomplished there are provided for each set of carrier generating equipment two selection " fields," the first on the channel bays (one for each 12 groups) and the second on the carrier generating bays. Preceding the input of each group demodulator there is provided a differential transformer, one output of which is associated with the group demodulator and the other with the first pilot selecting field. On one in each group of 12-channel equipments there is provided a pilot selecting field, and the pilot inputs of the 12 groups are wired to this field, which has only one output; any one of the 12 inputs can be jumpered to this output. The outputs of four sets of 12 groups can be wired directly to a secondary field on the generator bays; hence only one incoming pilot signal derived from 48 groups can be used to control the carrier generating equipment.

Normally, when there are more than one set of carrier generating equipment in a station it is intended that each set shall be controlled (if from a distant station) by one of the groups of channel equipment driven by it. However, should this prove impracticable, arrangements will be made for tie circuits to be available between secondary selection fields.

The incoming controlling signal (60 kc/s) is applied to the pilot receiver in which, by modulation with the locally generated 56 kc/s current, a nominally 4 kc/s current is produced. This is used to control the frequency of the local 4 kc/s generators in the manner already indicated.

Distribution Frames.

In connection with installations of the Nos. 5 and 6 type equipments there have been provided high frequency repeater distribution frames, and these were made of fixed size; experience showed, however, that it was desirable to make such frames in such a manner that they could be extended as necessary, i.e., that they should be built on the lines of the repeater distribution frame as used in repeater stations. It was apparent that neither the H.F.R.D.F. nor the G.D.F. could be made quite as simple in form as the R.D.F. as the technical considerations involved were more complex.

Considerations involved in the design of the flexible frames were as follows :—

G.D.F.—Test signal levels vary from -8 db. to -37 db.[3] Apparatus interconnection to be at a point having a nominal impedance of 75 ohms unbalanced to earth. Signals to be within the frequency range 60 to 108 kc/s.

H.F.R.D.F.—Test signal level to be $+5$ db. in all cases. Apparatus interconnection to be at a point having a nominal impedance of 140 ohms balanced to earth. Signals normally to be within the frequency range 12 to 60 kc/s, this being extended to 108 kc/s in the event of 24-channel working.

It is apparent that for each of the frames the crosstalk requirements are stringent and considerable attention has therefore had to be paid to screening of tags, screening of jumpers and layout of tag blocks and wiring. It is now felt that all of the problems have been solved, and though, at the time of writing, drawings of the frames have not been completed it is anticipated that no difficulties will arise. For the H.F.R.D.F. the tag blocks will be somewhat similar to the conventional item; single screen pair wire will be used for the jumpers. It has been arranged that the frames shall have the same " back to front " dimension as the standard bay; it will therefore be possible to put the frames " en suite " with other apparatus. Blocks on one face of the H.F.R.D.F. will be associated with apparatus passing signal currents into the frame and the other side of the frame with outgoing signal currents.

The G.D.F. has involved the development of a special terminal block of very unconventional design, the size and spacing of tag being greater than normal. A double-screened and braided coaxial cable has been adopted for jumpering, the overall diameter of the cable being about 0·3 in.; the use of this somewhat inflexible wire and the comparative difficulty of making off the screen has involved the production of a special technique for running and terminating the jumpers—special tools being used in the process.

Testing Equipment.

It has been considered desirable to provide testing apparatus at terminal stations to measure :—

(*a*) The audio to audio gain—frequency response of channels as measured end-to-end of complete circuits or " back-to-back " with channel and line amplifier equipment looped.

(*b*) Audio to sideband and sideband to audio gain—frequency response of channels as looped " go " to " return " at the output of the transmitting line amplifier.

(*c*) Gain of channel amplifiers.

(*d*) Gain—frequency response of line amplifiers whether or not associated with attenuation distortion equalisers.

[3] The range of -8 db. to -36 db. quoted in Part I has since been extended.

(*e*) Filter insertion loss at the approximate mid-band frequency of all channel filters.

(*f*) Carrier leak.

(*g*) Harmonic production in line amplifiers.

(*h*) Carrier level at the output of the carrier frequency generators.

For intermediate amplifier stations it is considered to be necessary to measure only :—

(*a*) Output level of line amplifiers.

(*b*) Gain of line amplifiers as measured at a single frequency.

(*c*) Harmonic production of line amplifiers.

When audio frequency transmission equipment is concerned it is standard practice in repeater stations to accommodate all testing equipment at a central point and to make the inputs and outputs of most forms of equipment available at the centralised repeater test rack (R.T.R.). However, in the early days of multi-frequency carrier working it was considered undesirable to run low level high frequency test trunks over considerable distances in repeater stations, and arrangements were therefore made to have the testing apparatus in portable form so that it might be connected to the apparatus under test by short patching leads only. In the earlier installations the individual testsets were made up in the form of transportable boxes, combinations of test units being set up as necessary; this arrangement suffered from obvious disadvantages, and an endeavour was made to mount these boxes upon trolleys. Experience showed, however, that such trolleys were too cumbersome, and it was therefore decided that a special arrangement of trolley mounted test equipment should be designed.

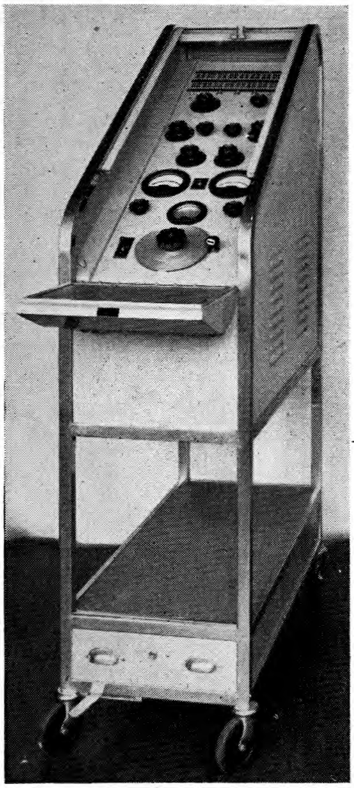


Fig. 6.—Trolley-mounted Test Unit.

The form of trolley mounted test unit now coming into general use is shown in Fig. **6**; the item concerned is of the type designed for use at terminal stations. It consists essentially of the following items of equipment :—

(*a*) Continuously variable audio frequency oscillator covering the frequency range 0 to 4,000 c/s.

(*b*) Carrier frequency oscillator generating **24** fixed frequencies each corresponding to the **1,300 c/s** sideband frequency which would be transmitted to line in a system designed for **24**-channel working.

(*c*) Level measuring set suitable for measuring the level of signals in the frequency range 50 c/s to 120 kc/s.

(*d*) Amplifier distortion measuring set.

(*e*) Jack field.

It will be observed that no valve test sets are provided. Experience with earlier types of carrier equipment has shown that with amplifiers having a large degree of negative feedback tests of the static and dynamic characteristics of the valves employed do not offer a satisfactory indication of the termination of useful life; some schools of thought have it that it is preferable to test a valve as an integral part of the amplifier in which it is employed. As a valve should be rejected only if it causes circuit interference it has been considered necessary only to measure the distortion characteristic (overload point) of amplifiers. The distortion test set consists essentially of a pair of filters, one to select the fundamental frequency to be applied to the amplifier under test and the other to select the third harmonic produced by the amplifier; comparison of fundamental and harmonic can be made with the aid of the level measuring set.

For intermediate stations a somewhat simpler form of trolley will be used, the items of test equipment employed being a level measuring set, single frequency oscillator and amplifier distortion measuring set.

Performance.

The following details of performance are those of a typical terminal equipment, and tests on other installations indicate that the figures are representative. The tests were made on a single terminal equipment, the "go" and "return" circuits being looped by an artificial line having zero distortion and by an amplifier of the type used in association with 12-circuit apparatus of this type. Each of the 12 unidirectional channels so set up were adjusted to have a gain of 8 db. as measured at 800 c/s, i.e. the circuit conditions were those applicable to a zero loss 2-wire to 2-wire circuit. The curves shown in respect of audio to sideband response and audio to audio response are envelopes, all of the 12 channels of the group having a performance lying between the envelope lines.

Fig **7** indicates the audio to sideband response

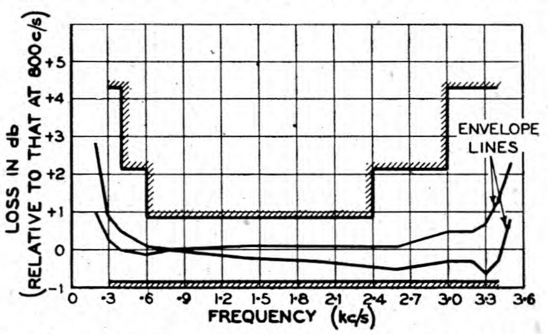


Fig. 7.—Audio/Sideband Response Characteristics.

characteristic for the group of channels, the audio signal being applied at the modulator input terminals and the corresponding carrier power being measured at the output of the transmitting line amplifier. The relevant specification limits are also indicated in the figure.

Fig 8 corresponds to Fig. 7 but is for the audio to

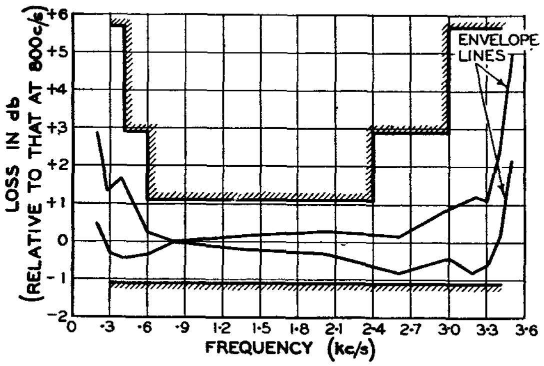


FIG. 8.—AUDIO/AUDIO RESPONSE CHARACTERISTICS.

audio channel response measurements being made at the modulator input terminals and at the output of the channel amplifier. For both of Figs. **7** and **8** the response characteristic is shown in terms of losses and gains relative to the loss at 800 c/s. Here again the specification limits are shown.

(These characteristics are, of course, dependent upon the setting of the low frequency equaliser in the channel amplifier circuit; in this particular test all of the channels were slightly over equalised at the low frequency end.)

A typical channel limiting characteristic is shown in Fig. **9**. The test conditions were as indicated above and Fig. **9** is drawn to show the relationship between level at the input terminals and level at the output of the transmitting line amplifier. The tests were carried out using a test signal of 800 c/s. The measured output levels were corrected for a previously measured value of carrier leak.

Measurements of noise existing at the output of the channel amplifiers in the absence of artificial interference indicated that, as measured at a point of + 4 db. relative test level, the weighted psophometric potential difference did not exceed 0·5 mV. With disturbance of the type detailed in the first part of this article the total noise on any channel did not exceed 1 mV, and on the majority of channels was less than 0·5 mV.

The total carrier leak as measured at the output of the transmitting line amplifier was found to be lower than 17 db. below relative test level at that point.

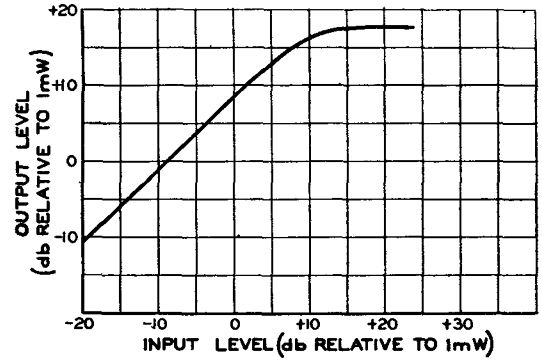


FIG. 9.—TYPICAL CHANNEL LIMITING CHARACTERISTIC.

Measurements of impedance at the 4-wire test points and at the input and output of the group modulating equipment showed return losses in excess of 20 db. with respect to the nominal impedances at these points.

Conclusion.

An endeavour has been made to sketch briefly the major features of the latest type of 12-circuit carrier equipment which is now being brought into general use; it is recognised that the description is incomplete —it could not be otherwise in view of the limited space available—but it is hoped that some indication has been given of the trend of present development in this sphere. Development has aimed at a universal 12-channel group end suitable for association with equipment for pair or coaxial cables and with ultra-short wave radio links; in addition complete flexibility of interconnection has been sought, together with means for ensuring absence of carrier asynchronism, however complex the line network connecting the terminals of a 12-circuit carrier group.

Acknowledgments are due to Messrs. S. T. & C., Ltd., for the supply of photographs used in this article.

New Tools for Identifying Wires in Cable Joints

U.D.C. 621.315.23 : 621.317.7   621.315.687.1

N. F. SEPHTON, M.I.E.E., and
A. J. JACKMAN, B.Sc., A.C.G.I.

Two new tools are described which facilitate the rapid identification of a cable pair at an opened cable joint. A voice frequency E.M.F. is applied to the pair concerned and the test made using a probe, which is inserted into the wires, connected to a head set. One of the methods depends on the electromagnetic and the other on the electrostatic effect of the current in the required pair.

Introduction.

IT is frequently necessary to find a specified pair of wires at a cable joint for purposes of intercepting or diverting the circuit. Standard methods all involve pricking through the insulation of wires with a sharp-pointed probe until the wire sought gives an audible or visual indication in the detecting apparatus. These methods must, of necessity, be very slow, particularly when the cable is large, say, 800 to 1,400 pairs, and a certain amount of damage to the paper insulation of the joint is unavoidable. A considerable amount of work of this nature has been caused by war-time needs and has led to the investigation of new methods of tracing wires. Two methods will be described, both of which avoid testing a considerable number of wires individually, and are, therefore, much quicker than older methods, and which also avoid damage to the paper insulation. The first method makes use of the magnetic field surrounding a wire carrying alternating current, and the second method makes use of the electric field around the wire. The tool used in the first method has been, conveniently, named the Swiffer, the name embodying the initials of its designers, Messrs. Sephton and Whittaker, and suggesting swifter work than hitherto possible. The tool used in the second method has been called the Capacitance Probe ; its P.O. description will be Tester S.A. 9003. Both methods make use of the Tester No. 92 as a portable buzzer (of predominant frequency 400–500 c/s) because this instrument is available in quantity and will meet main requirements.

General Description of the " Swiffer."

The swiffer is in principle similar to the clip-on ammeter often used to measure current in A.C. bus-bars and transmission lines. It embodies a winding of a suitable number of turns of insulated wire carried on an iron core, an extension of which can be closed around a bunch of cable conductors. If alternating current is flowing in one or more wires—the return circuit for the current being outside the iron core—an alternating magnetic flux will be set up in the core and will result in an E.M.F. in the winding on it. The energised conductor acts as the primary of a transformer and the winding on the iron core forms the secondary. For use with a frequency within the normal audible range the core must be laminated and, for use without an amplifier, of one of the alloys of high initial permeability, e.g. mumetal or permalloy, etc. Considerable experimental work was involved in preparing suitably shaped stampings of different alloys and in heat-treating them to remove the effects of cutting, etc. Swiffers of different designs were made as experience in their use was acquired, including models with a trigger action for snapping the laminated core tightly around the cable conductors. Finally, however, a tong-shaped spring open model was produced as shown in Fig. **1**. This design

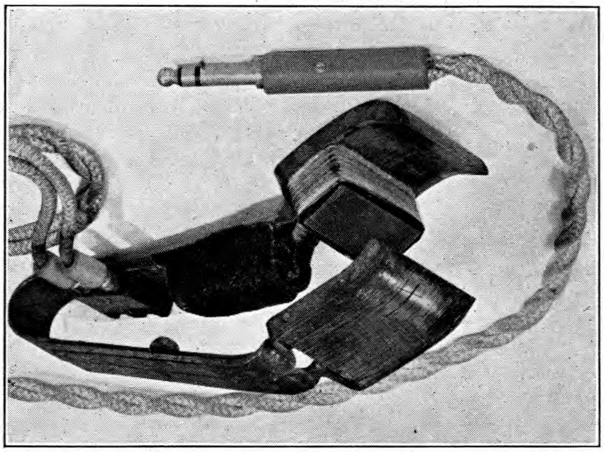


FIG. **1**.—THE " SWIFFER."

satisfied the requirements of the tool and was at the same time simple and relatively easy to construct. Care is needed in the construction to make sure that the air gap will be closed on both the pole faces, and a condenser mounted on the handle helps to this end by preventing too great pressure acting on the tongs and causing the forward gap to remain open.[1] The best winding for the coil was chosen by experiment and depends on the iron circuit and also on whether the instrument is used with an amplifier or a pair of phones direct. Several swiffer models are fitted with coils to match Phones 8A, the most suitable phones readily available.

Method of Use of the Swiffer.

The buzzer unit of Tester No. 92, which is used as a tone generator only, is connected between the bunched wires of a pair or quad and earth at the exchange, repeater station, or other place where the identity of the circuit is known. At the point where the pairs have to be identified the swiffer, connected either directly or through an amplifier to a pair of phones, is used by the jointer. The tool, with its jaws open, is placed alongside the cable joint (the lead sleeve having been removed) and, if the buzzer has been

[1]The condenser is not essential but its inclusion was found to improve the sensitivity of the device.

correctly connected, a faint sound is heard in the phones. The tool is now passed slowly around the periphery of the joint until the buzz received is at its loudest. A bunch of pairs is passed into the jaws of the tool and these are closed. If the wanted pair is in this bunch the received signal increases to a loud note, but if the wanted pair is not included it decreases and may be quite inaudible. A few trials will discover a bunch of conductors containing the required pair and further subdivision of the bunch will soon reveal it. The preliminary search facility is of very great value since it enables the jointer to assure himself that conditions at the sending end have been set up properly.

The swiffer is actuated (electrically) by the magnetic field set up by the current from the buzzer, and since normally the far end of the wanted pair must be regarded as inaccessible and unidentified, the current can only flow by way of the capacitance between the bunched pair and earth beyond the point of search. The swiffer can be used to find wires at a cable end only if the ends of all the wires are first bunched together by bare wire and then earthed ; and at any intermediate joint the loudness of the signal will be influenced by the length of cable between the joint and the end remote from the source of alternating current. If this length is sufficient, say, more than half a mile, the swiffer can be used without an amplifier, but the preliminary search tone is very faint. Using an amplifier the swiffer can be used with only a short length of cable, say, 30 yds. beyond the point of search.

The amplifier used in the trials was a simple one-stage unit using a pentode valve and an output transformer. The valve is operated from dry batteries both for L.T. and H.T. The large and robust box shown not only houses the amplifier and its batteries but also provides space for the swiffer and its lead and the phones so that the test set is complete. The amplifier needs no adjustable controls and the filament current is automatically switched off when the lid of the box is closed. In the model used extensively at Nottingham the valve was a Mazda Pen 220 pentode (V.T. 136) with an output transformer 67A ; two dry cells were used to give 2 V supply to the filament and two 40 V dry batteries to give 80 V to the anode. The circuit was very similar to that shown in Fig. 2 which could be used as an alternative and will be suitable for either the swiffer or the probe.

General Description of the Capacitance Probe (*Tester S.A.* 9003).

The cable conductors attached to the Tester No. 92, used only as a tone source, will have not only a magnetic field around them but also an electric field due to the potential of the wires to earth, and moreover, this electric field will persist all along the length of the conductors, down to the (open-circuited) end, whereas the magnetic field decreases to zero. The probe tester is simply a device for detecting a conductor by reason of its electric field. The probe itself consists of a small metal strip held in an insulated support, and communicating through an insulated lead, with the detector. When it is close to the energised conductors the strip picks up the potential due to the electric field, and thus operates the detector.

The device is found to work quite well with the Tester No. 92 connected between the two wires of the wanted pair and not connected to earth. This is an advantage because there is less risk of interference with other circuits than when one side of the buzzer is earthed. The two wires of the pair, having equal capacitances to earth, will take up equal voltages to earth and will set up an electric field at all neighbouring points except those in the plane which perpendicularly bisects the line joining the conductors. By making the probe about 1 in. long and $\frac{1}{8}$ in. wide it has been found that no errors result from the existence of this locality of zero field, since, in searching for the pair the probe is never wholly in this zero plane for any noticeable interval.

It is possible to get an audible signal by connecting the probe to the primary winding of a high impedance step-down transformer and connecting the secondary winding to a high impedance pair of phones. The transformer, in these models, was included in the handle. The apparatus was thus reduced to the minimum possible size and was very robust, but the received signal was faint, and listening for it imposed a strain on the operator, and in this form the tool would hardly be acceptable without increasing the voltage of the source of alternating current, which is undesirable. A much more efficient arrangement is obtained by connecting the probe to the grid of a valve, to the anode of which the phones are connected either directly or through a matching transformer. This arrangement provides a good impedance match between the probe and the phones, and in addition gives some useful amplification. Two models were built with valves included in the handle and batteries only in a box, this being the most efficient electrical system possible, but for greater robustness, and to make use of valves more readily obtainable in war-time, it is preferred to put the amplifier in a box with its batteries.

Almost any valve of low power consumption would do, and the most readily available is V.T. 188, a screened pentode. The circuit diagram of the amplifier is given in Fig. 2, and it will be seen that it is operated from a single dry battery for the filament and two 40 V blocks (batteries No. 2) for the H.T. The valve is, therefore, underrun because it is designed for 2 V L.T. and 150 V H.T., and its life should be reasonably long.

The transformer 67A is a Rate Book item and has

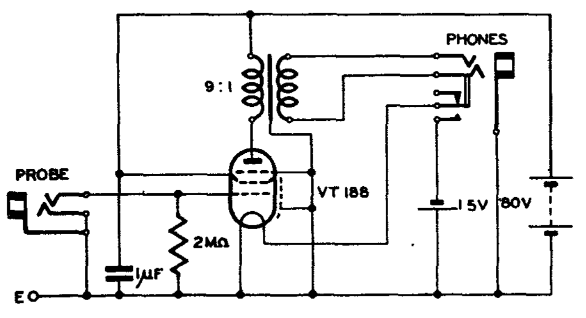


FIG. 2.—CIRCUIT DIAGRAM OF AMPLIFIER FOR TESTER S A. 9003

been adopted for greatest convenience. The amplifier in an experimental set is shown in Fig. **3**.

The box has been made big enough to carry all the components and in future models the amplifier will be made to give still easier access. No switches or controls are necessary, the battery circuits being closed when the probe and telephone jacks are plugged in.

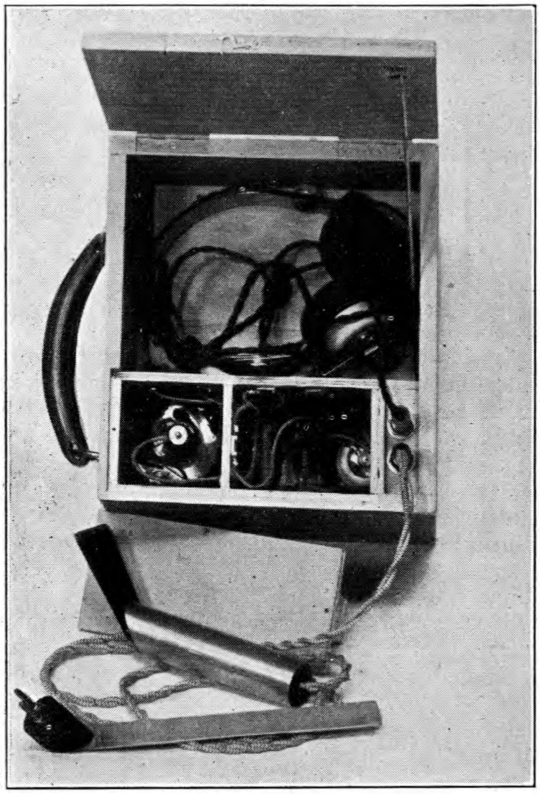


FIG. **3**.—AMPLIFIER USED IN EXPERIMENTAL SET, AND CAPACITANCE PROBES.

A cable in the exchange distribution network will have many wires in it at a negative potential to earth, due to connection to the exchange battery. These wires will be surrounded by a negative electric field, which will act on the probe when it is near enough and might be expected to shut down the amplifier. The grid leak is sufficient, however, to prevent this effect. The short probe shown in the handle in the illustration is screened except at the tip, so that it will only give maximum pick-up when the tip is directly adjacent to the wanted pair of wires. The illustration shows also a long unscreened probe which can be plugged into the handle. This tool is of value in searching for a pair in a large joint. The long probe can be slid at random into the large bundle of conductors, and will indicate that part of the joint in which the wanted pair will be found. Alternatively, the search might be made systematically, because if the "ballooned" joint is divided into halves the probe will indicate which half contains the required pair, and this half can then be subdivided until only a small number of pairs remains for individual testing. If the joint is tight the final search is best done with the short shielded probe, but if the joint is loose the operator will probably finish the job with the long probe. One model has a switch which can make the same tool function either as a long unshielded probe or as a short shielded probe, and experiments have been carried out at Nottingham using a single probe fitted with a sliding screen.

Method of Use of the Probe.

The method to be adopted for tracing a cable pair should need little further description. As stated, the Tester No. 92 is connected across the ends of the pair which is required to be indentified at a distant joint. At this point the test set earth terminal is connected to the cable sheath and the probe and phones plugged in. The probe should be held so that its end is roughly parallel to the conductors. Passing the probe all round the joint, keeping its end parallel to the conductors, will indicate an area in which the note received is loudest, and further search in successively smaller bundles of pairs will soon indicate the pair required. Alternatively, in dealing with a very loose array of wires, for example, a pieced-out multiple joint, the conductors may be divided into two or three bunches initially and the probe placed against each bunch in turn. The bunch which gives the loudest tone is subdivided until the pair is found. It is unnecessary, and, in fact, undesirable to make contact with the bared conductor at any stage of the test. In production models the probes will be covered with thin insulating material in order to avoid accidental contact with bare wires or with the cable sheath. A and B wires can be identified, if necessary, by applying the buzzer between wire and earth for a few seconds, when the pair has been found.

Comparison of the Two Tools.

The swiffer has been in extensive use in the Nottingham Area for about two years and has also been used elsewhere, and has been greatly appreciated. The probe has not yet had extensive field trials, but comparative field trials of the probe and the swiffer have been carried out at Nottingham. These trials confirmed that both tools can be used to find wires in a few minutes, even in the largest array of a multiple joint, but that the probe has the following advantages over the swiffer :—

(*a*) Since the Tester No. 92 can be connected across a pair in a balanced manner instead of having to have one terminal earthed, the risk of interference with working circuits is reduced.

(*b*) It is much more suitable for use at a cable end since it does not require all the wires to be in contact and earthed at this point.

(*c*) It is easier to produce.

In view of these advantages it was decided to introduce the probe device extensively without delay.

Future Development.

A major consideration throughout has been the necessity for using components of a standard type, or items which are easily obtainable in quantity, and therefore Rate Book items have been used wherever possible. Tester No. 92 is used as the source of the signal because it already exists for the purpose. Evidence as to whether it will cause serious interference with working circuits is not complete. Few complaints have been received in Nottingham, even though the tester was used with one terminal earthed, but it is claimed elsewhere that it does cause some interference. There is ample sensitivity in the amplifier and it will probably be possible to shunt down the output of the tester if it is found to cause interference, but with the balanced tone no interference is anticipated.

For present needs the Tester No. 92 appears adequate, although many better tone generators can be suggested.

It is probable that some of these may be investigated after the war, and at that time the very obvious and convenient arrangement of switching the jointer's telephone to work with the headphones or with a small loudspeaker may merit consideration.

Cast Joints in Duct Lines

Shortly before the war trials were made of a new method of casting joints in earthenware and asbestos cement duct lines. It has not been possible to complete the experimental work under current conditions, but a brief description of the method will give some idea of its possibilities.

While the trench excavation for, say, a line of self-aligning earthenware ducts is in progress, the pipe layer and his assistant place around the inner edge of the socket of each duct a small ring of clay or putty to prevent the bitumen, when poured, from escaping from the joint into the barrel of the duct. They also place a papier mâché collar about 4 in. long over the socket end of each pipe to hold the liquid bitumen around the joint until it sets.

The collar, where it fits round the socket, is slightly corrugated to allow the air to escape as the bitumen is poured in, and a pouring aperture (uncut) is provided in the collar at the socket end. The end of the collar remote from the socket has a cylindrical hole through which the spigot end of the succeeding pipe passes.

As soon as the trench is ready the pipe layer places the first pipe in position with the socket end towards him, keeping the filling hole in the papier mâché collar on top, and inserts the spigot end of the next pipe into the collar on the pipe already laid, the second pipe being turned slightly with a screw action to facilitate entry into the collar. When through, the pipe should be pushed straight home, keeping the filling hole on top.

The uncut filling aperture on each collar is opened by pushing the thumb through and pulling off the small piece of papier mâché. Each successive joint is then filled with a bitumen compound which is allowed to set for about 15 mins. before the trench filling commences or a pressure test applied. In practice it is found that although the collar can be completely filled at one operation, slight shrinkage of the bitumen takes place during casting, necessitating the topping up of each joint, while the first filling is still in a fairly liquid state.

When applying the process to asbestos-cement ducts the hot compound is prevented from running into the bores by using a papier mâché washer under the collar of the same material, the washer being fitted with flanges to cover the butt joint of the ducts both inside and outside. Such joints, after cooling for 1½ hrs., were found capable of standing 60 to 80 lb./sq. in. when cut out and tested under water pressure.

Although tests made up to the outbreak of war were limited to single-way duct joints, some progress had been made with papier mâché collars for multiway ducts. So far as earthenware ducts of standard P.O. type are concerned the casting of the joints *in situ* would enable the present Stanford lining to be dispensed with, so cheapening the cost of manufacture and eliminating the wastage caused by damage to these linings in transit. With asbestos-cement ducts economic advantage is also expected to be obtained. It is important to note that the poured bitumen joint can be made in all weathers, and that trench filling can proceed within 15 mins. of the filling of the joint.

J.J.E.

A Simple Introduction to the Use of Statistics in Telecommunications Engineering

J. F. DOUST and
H. J. JOSEPHS, F.S.S., A.M.I.E.E.

U.D.C. 519.2 : 621.39

Part IV.—Correlation and Regression

This article discusses in a simple manner the analysis of bivariate distributions and shows how to test the significance of correlation coefficients obtained from small samples.

Introduction.

THE first three articles of this series have dealt with the frequency distribution of a single variable and have shown how closely the properties of a parent population can be estimated by taking samples of various sizes. This final article deals with problems involving two related variables which are both subject to chance variations. These bivariate distributions, as they are called, are subject to sampling variations, and tests of stability and significance must be applied before the relation between the variables can be estimated. The sampling fluctuations may be such that it is not possible to decide by mere inspection whether the variables are related or not. It is then necessary to calculate the coefficient of correlation between the variables and test it for significance. Simple methods of carrying out these tests are illustrated by examples.

Logarithmic-Probability Paper.

In applying arithmetic-probability paper to certain sets of observations it may be found that the points do not fall upon straight lines, but in smooth curves ; consequently the simple properties of the straight line normal probability law do not apply. Attempts were made, therefore, to modify the paper by changing the linear or arithmetic scale in such a way that these special cases would plot as straight lines.

In statistical theory the logarithmic transformation is of unique importance : it is shown in Appendix 1 that even if the variate x does not follow the bell-shaped normal law but is extremely skew, its logarithms will be found to follow an approximate normal law. Thus the scheme which proved most successful was to use a logarithmic scale in place of the arithmetic one. Graph paper having a logarithmic scale of ordinates and a probability scale of abscissæ is known as logarithmic-probability paper. It is found that points which fall in curves on arithmetic-probability paper will generally fall in approximate straight lines when plotted on logarithmic-probability paper.

The method of plotting data on logarithmic-probability paper is the same as that used for plotting on arithmetic-probability paper and is described in the first article[1] of this series. It has been shown that the slope of a straight line on arithmetic-probability paper is determined by the spread or dispersion of the data ; the slope of a straight line on logarithmic-probability paper, however, is determined not only by the dispersion of the data but also by its skewness and lack of symmetry relative to the bell-shaped normal probability curve.

[1] *P.O.E.E.J.*, Vol. 34, p. 36.

Bivariate Distributions.

In many practical applications of logarithmic-probability paper two distinct variables, each of which is subject to sampling fluctuations, are concerned.

It is shown in Appendix 2 that by fitting a simple algebraic equation to a straight line on logarithmic-probability paper one variable, measured on the probability scale, can be expressed in terms of the other variable, measured on the logarithmic scale. This general expression, which is given by equation (A) in Appendix 2, has several shortcomings from an engineer's point of view. It is a relatively simple matter to fit straight lines to observations plotted on logarithmic-probability paper, but this gives no direct information about the stability of the relationship between the variables or the magnitude of the sampling fluctuations, and has no practical value until the stability of the relationship between the two variables has been established. If, however, it can be shown by probability tests that the variables are correlated and that the plotted data are statistically stable, then the slope of the straight lines on logarithmic-probability paper can be used to form a valuable statistical index for the forecasting of future trends.

The Coefficient of Correlation.

There are many instances in which an increase in one variable is accompanied by an increase in another. In other words, large values of one variable tend to be associated with large values of a second, whereas small values of the first tend to be associated with small values of the second, without the existence of a strict mathematical relationship between the two. The variables are then said to be correlated. Of course an increase in one variable may be accompanied by a decrease in the other, that is, large values of each variable may tend to be associated with small values of the other. This situation is called inverse or negative correlation.

The meaning of the above statements may be easily illustrated. Suppose the height x and weight y of a random sample of N people are measured. Now suppose the tallest person is also the heaviest, the second tallest the second heaviest, and so on ; there would be complete positive correlation between the variables x and y. If, on the other hand, the sample was so peculiar that the tallest person was also the lightest, the second tallest the second lightest, and so on, then there would be complete negative correlation between the variables x and y.

The most widely used measure of correlation for N pairs of values of the variables x and y is called the coefficient of correlation r and is defined by the equation

$$r = \Sigma \frac{(x-\bar{x})(y-\bar{y})}{N \sigma_x \sigma_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

In this equation $\bar{x}$ and $\bar{y}$ are the means of the variables and σ_x and σ_y represent their standard deviations. Since the various values of the variables will always be considered in pairs, an x and a y, there will always be the same number N of x's and y's.

If there is complete positive correlation between x and y, the coefficient of correlation r has unity value; if there is complete negative correlation it has the value of -1. Complete correlation is, however, very rare; most practical cases give incomplete correlation with value of r between $+1$ and -1. If there is no correlation at all between the variables, r is zero.

For dealing with small samples equation (1) may be transformed into the form

$$r = \frac{\frac{\Sigma (xy)}{N} - (\bar{x}\bar{y})}{\sigma_x \sigma_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

which is a more convenient form for dealing with small samples.

Test for Significance of Correlation Coefficient.

The value of a correlation coefficient will very rarely be found to be unity or zero. It is therefore necessary to apply a test to decide whether the correlation coefficient differs significantly from zero or, in other words, whether correlation actually exists. It must always be remembered that correlation coefficients, like other statistics, are subject to fluctuations of sampling. It will be recalled that in the second article of this series,[2] it was shown that since the frequency distribution of a statistic follows a normal law, the determination of its standard deviation (or "standard error" as it is called when referring to a statistic) makes it possible to form an estimate of the confidence that can be placed in the observed value. It can be shown[3] that, when N is large, i.e., if $N>50$, σ (r), the standard error of r, takes the form

$$\sigma (r) = \frac{1-r^2}{\sqrt{N}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

If $r > 2\,\sigma (r)$ the correlation coefficient is regarded as differing significantly from zero.

If, however, N is less than 50, equation (3) should not be used to calculate σ (r); the significance of a correlation coefficient could then be assessed by the t method described in the second article. This method involves the calculation of t, where

$$t = r\frac{\sqrt{N-2}}{\sqrt{1-r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The simplest way is to use Table 1, which has been prepared[4] to enable the significance of correlation coefficients obtained from small samples to be determined by mere inspection.

TABLE 1.

N	r	N	r
3	0·997	16	0·497
4	0·950	17	0·482
5	0·878	18	0·468
6	0·811	19	0·456
7	0·755	20	0·444
8	0·707	21	0·433
9	0·666	22	0·423
10	0·632	27	0·381
11	0·602	32	0·349
12	0·576	37	0·325
13	0·553	42	0·304
14	0·532	47	0·288
15	0·514	52	0·273

Table 1 is used by noting that if a calculated value of r is as big or bigger than the value given in the table for the appropriate value of N, then the correlation differs significantly from zero; in other words, it indicates a real degree of correlation between the two variables.

Testing the Significance of Correlated Data.

As an example of the application of equation (2) to a small sample, consider the test results shown in Table 2.

TABLE 2

Breaking Load of Telegraph Paper

No. of Test Specimen ..	1	2	3	4	5	6	7	8	9	10
Breaking Load 50 per cent. R.H. ..	16·5	10·5	15·1	11·1	13·2	11·8	10·8	14·9	11·5	12·9
Breaking Load 70 per cent. R.H. ..	9·0	14·0	13·8	10·5	12·1	11·5	9·7	12·7	10·9	11·8

These figures refer to the breaking loads in lbs. of 10 long strips of parchmentised Wheatstone telegraph paper cut from the same roll. Two breaking loads were obtained from each specimen. In the first test a specimen was broken in a test atmosphere of 50 per cent. relative humidity (R.H.) and the remainder of the specimen was broken in a test atmosphere of 70 per cent. R.H. Can it be inferred from these results that the breaking strength of Wheatstone telegraph paper is correlated with humidity?

To answer this question the coefficient of correlation r must be calculated and then its significance tested. From the viewpoint of equation (2) it can be seen that $N=10$ and that the x values are given by the figures in the first row and the corresponding y values are given in the second row. By straightforward arithmetic it is found that

$$\Sigma x = 128{\cdot}3 \quad \therefore \quad \bar{x} = 12{\cdot}83$$
$$\Sigma y = 116{\cdot}0 \quad \therefore \quad \bar{y} = 11{\cdot}60$$
$$\Sigma (xy) = 1487, \quad \bar{x}\bar{y} = 148{\cdot}8.$$

Also,

[2] *P.O.E.E.J.*, Vol. 34, p. 79.

[3] R. A. Fisher. *Statistical Methods for Research Workers.* Oliver and Boyd. 1936.

[4] *Statistical Tables for Biological, Agricultural and Medical Research.* Fisher and Yates. Oliver and Boyd. 1938.

$$\sigma_x = 1{\cdot}960 \quad \text{and} \quad \sigma_y = 1{\cdot}555$$

Thus

$$r = \frac{148{\cdot}7 - 148{\cdot}8}{1{\cdot}960 \times 1{\cdot}555} = -0{\cdot}033$$

In the example considered the significance of r can be determined easily by reference to Table 1. Entering the table at N=10 it can be seen that r must be at least equal to 0·632 before it can be regarded as significantly different from zero. Since r is only 0·033 it can be seen that the sample is far too small to enable the correlation between the strength and humidity to be stated. The figures recorded in Table 2 may be mere sampling fluctuations and indicate no real trend at all. To get a significant value of r it will be necessary to continue the testing of specimens until Table 2 or equation (3) can be used to demonstrate that r is now greater than twice its standard error.

Suppose now that in the testing of the Wheatstone telegraph paper 100 specimens had been broken and that the coefficient of correlation was found to be −0·33. In order to test the significance of this correlation put N=100 and r= −0·33 in equation (3) and calculate $\sigma(r)$. Thus

$$\sigma(r) = \frac{1-0{\cdot}1089}{10} = 0{\cdot}0891$$

Since 0·33 is more than three times its standard error 0·089, it follows that r is significant, and consequently there exists a real correlation between strength and humidity in the population tested.

Regression Lines.

At this stage it may be helpful to consider for a moment the way bivariate distributions arise in communications engineering. Suppose that 50 loading coils are measured for permeability x, and eddy current loss y. These measurements provide 50 paired numbers (x_n, y_n) which may be plotted as points in a plane. The resulting collection of points is called a " scatter " or " dot " diagram, an example of which is shown in Fig. 1.

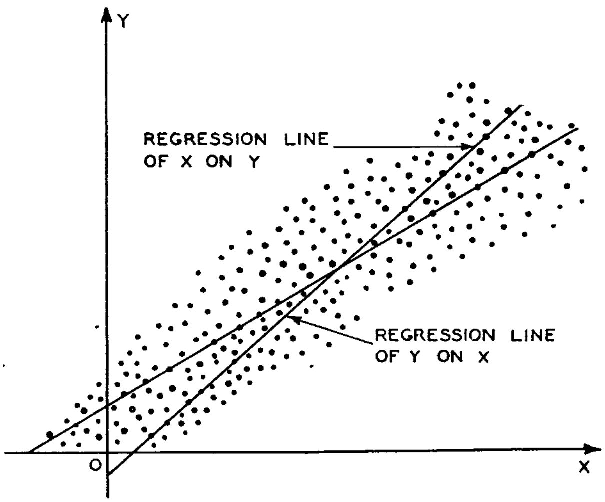


FIG. 1.—EXAMPLE OF A " SCATTER " OR " DOT " DIAGRAM.

There is often a tendency for values of x to conform in some way to the corresponding values of y; any such tendency towards a functional relationship, although obscured by random fluctuations, will manifest itself in the scatter diagram by the greater density of dots along a certain line. This line is not sharply defined, but its estimation is important to engineers, for it is a smudged image of a line which may be fine and clear cut in the parent population of which the observations are only a random sample. This latent curve or mathematical relationship y=F(x) is called a " regression," the regression of y on x; likewise, the inverse form x=F(y) is called the regression of x on y.

Owing to errors of random sampling, the observed regression lines which arise are usually irregular, but it is usually possible to " fit " straight lines to them and to show mathematically that the observed regression lines do not depart significantly from the fitted regression lines. It can be shown that these straight lines can be represented by the simple equations

$$(y-\bar{y}) = r\frac{\sigma_y}{\sigma_x}(x-\bar{x}) \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$(x-\bar{x}) = r\frac{\sigma_x}{\sigma_y}(y-\bar{y}) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where the letters have the same meaning as before. Equation (5) is the regression straight line of y on x and equation (6) is the regression straight line of x on y. As before, r is the coefficient of correlation between the variables x and y.

If r=1, the two regression equations are identical, and the regression straight lines coincide. If r=0, the two lines are horizontal and vertical respectively and cross at right-angles. The lines cross for any intermediate value of r, so that the larger the value of r, the smaller is the acute angle between them. The two lines always cross at the point $\bar{x}$, $\bar{y}$ on the graph, i.e., the point indicating where the means of x and y lie. The angles these lines make to the horizontal and vertical axes respectively are measured by the expressions

$$r\frac{\sigma_y}{\sigma_x} \text{ and } r\frac{\sigma_x}{\sigma_y}$$

and these are called the coefficients of regression.

These equations can be used in practice to express one variable in terms of the other. The variables considered may be, for example, the power factor of electrolytic condensers and temperature, or the mutual conductance and anode current under given conditions in thermionic valves, or any other pair of correlated variables which arise in telecommunications engineering. In all these examples it is necessary to calculate the means $\bar{x}$ and $\bar{y}$ and their standard deviations σ_x and σ_y. Then the coefficient of correlation r can be calculated, and if this differs significantly from zero, equations (5) and (6) can be used. As an example, suppose that in an electrical investigation a large number of paired values of two variables x and y were measured and it was found that

$$\bar{x} = -0{\cdot}21, \quad \bar{y} = 0{\cdot}81,$$
$$\sigma_x = 1{\cdot}818, \quad \sigma_y = 2{\cdot}181,$$

and r=0·666 was found to be more than twice its standard error (i.e. significantly different from zero), then, substituting these values in equations (5) and (6), there results,

$$y - 0{\cdot}81 = 0{\cdot}7990\,(x + 0{\cdot}21)$$

and

$$x + 0{\cdot}21 = 0{\cdot}5551\,(y - 0{\cdot}81)$$

which can be put into the form

$$y = 0{\cdot}7990x + 0{\cdot}9778$$

and

$$x = 0{\cdot}5551y - 0{\cdot}6596.$$

This simple example shows that it is only a matter of straightforward arithmetic to estimate one variable in terms of the other and to plot the regression lines across the scatter diagram.

A Force-Displacement Characteristic.

As an example of the application of these principles consider the problem of the determination of the force-displacement characteristic of carbon granules. A knowledge of this characteristic is of importance since the most fundamental step towards the understanding of the physics of microphones is the solution of the problem of the "loose contact" when in its sensitive or microphonic state. Measurements have been made of the force-displacement characteristic of carbon granules pressed against a polished carbon plate: Table 3 contains five determinations of force (in dynes) and displacement (in $\text{cm} \times 10^{-7}$) made by F. S. Goucher.[5]

TABLE 3

Force (Dynes) F	0·6	2·0	3·0	6·8	9·8
Displacement ($\text{cm} \times 10^{-7}$) D	9	14·5	19·5	26·8	32·1

It is shown in Appendix 2 that if these data are plotted on logarithmic-probability paper a straight line is obtained. It is also shown that it is a simple matter to fit an algebraic equation to this straight line from which the complete force-displacement characteristic may be plotted. It has been pointed out, however, that this expression (which is given by equation (B) in Appendix 2) is merely a graduation formula and has no practical value unless the stability of the relationship between the two variables, force F and displacement D, has been established. To test this stability it is necessary to calculate the coefficient of correlation r between the force and displacement and then test its significance. From the viewpoint of equation (2) it can be seen that N is only 5 and that the x values are given by the force figures and the corresponding y values by the displacement figures. By simple arithmetic it is found that

$$\Sigma x = 22{\cdot}2 \qquad \therefore\ \bar{x} = 4{\cdot}44$$

$$\Sigma y = 101{\cdot}9 \qquad \therefore\ \bar{y} = 20{\cdot}38$$

$$\Sigma(xy) = 589{\cdot}72, \quad \text{and } \bar{x}\bar{y} = 90{\cdot}487$$

Also

$$\sigma_x = 3{\cdot}378 \quad \text{and} \quad \sigma_y = 8{\cdot}287$$

Thus

$$r = \frac{117{\cdot}94 - 90{\cdot}487}{3{\cdot}378 \times 8{\cdot}287} = 0{\cdot}9807$$

[5] *B.S.T.J.*, Vol. 13, pp. 163-194.

The significance of r can be determined easily by reference to Table 1. Entering the table at N=5 it can be seen that r must be at least equal to 0·878 before it can be regarded as significantly different from zero. Since r is greater than 0·878 it follows that the sample, although small, is stable; and that the two regression lines calculated from equations (5) and (6) will almost coincide in the scatter diagram. This shows that equation (B) in Appendix 2 is now more than a mere graduation formula and may be used to calculate the force-displacement characteristic outside the range of the original measurements given in Table 3.

The χ^2 Test.

In addition to the methods already described for determining the probabilities associated with bivariate distributions, other powerful methods, dependent upon a statistic known as χ^2 (pronounced Ki squared), may be used. The mathematical distribution of this statistic has been worked out by statisticians and they have prepared tables[6] showing the probabilities that different values of χ^2 will be exceeded in random sampling. Use may be made of the χ^2 tables for the determination of the probabilities associated with many different types of problem. It should be noted that the calculation of χ^2 is essentially the same for each type.

If the entire range of a variable is divided into r classes and f_o is the observed frequency in a particular class, and f_e the frequency which would be expected to fall in that class on some hypothesis, then χ^2 may be found by dividing the square of the difference between f_o and f_e by f_e and summing these quotients for all of the r classes into which the variable has been divided. Thus, in symbols,

$$\chi^2 = \Sigma\,\frac{(f_o - f_e)^2}{f_e} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

When χ^2 has been calculated, consultation of tables will indicate the probability P of the calculated value being exceeded as a result of random sampling. If this probability is less than 0·05 (i.e. 19 : 1) then χ^2 may be regarded as showing that the observed data depart significantly from the hypothesis which is being examined. Table 4 is an extract of a χ^2 table for P=0·05.

TABLE 4

n	χ^2	n	χ^2	n	χ^2
1	3·841	11	19·675	21	32·671
2	5·991	12	21·026	22	33·924
3	7·815	13	22·362	23	35·172
4	9·488	14	23·685	24	36·415
5	11·070	15	24·996	25	37·652
6	12·592	16	26·296	26	38·885
7	14·067	17	27·587	27	40·113
8	15·507	18	28·869	28	41·337
9	16·919	19	30·144	29	42·557
10	18·307	20	31·410	30	43·773

[6] *Tables for Statisticians*, Part 1. Karl Pearson, 1930.

Before use can be made of the χ^2 tables, however, it is necessary to know n, the number of degrees of freedom involved in the calculation of χ^2. The conception of "degrees of freedom" may appear strange to a beginner in statistical theory; perhaps the idea can be made clear by the following example. Suppose that £1,000 is to be shared amongst 100 men in some manner. It is possible to share out the money in any arbitrary way to 99 of the men, but it is absolutely necessary to give the hundredth man what is left over. A statistician would say that there are "ninety-nine degrees of freedom" involved in the splitting of the £1,000. Suppose that another condition is imposed, namely, that £100 must be shared amongst the oldest five men and £900 amongst the rest. There are now only 98 degrees of freedom for doing this, since the last man in each group would have to have what was left over, since it is not possible to vary his share.

In many engineering applications of the χ^2 test the number of degrees of freedom is the number of classes into which an observed distribution has been divided, less the number of parameters in which a hypothetical distribution has been forced to agree with the observed distribution. As an example it will be recalled that in the third article[7] of this series an analysis was made of the occurrence of faults on a particular type of relay contact used in automatic exchanges. It was shown that the observed number of contact faults followed a Poisson probability law. Table 5 contains data obtained from another type of relay contact operating under slightly different conditions. Is it safe to assume that the observed number of contact faults in Table 5 will again follow a Poisson law? In other words, it is required to examine the hypothesis that the observed frequency distribution of faults form a Poisson series.

To determine the hypothetical or expected frequencies f_E on the assumption that the distribution of faults forms a Poisson series, calculate the mean m and make the number N agree with that observed. The mean is 3·892; and since N, the total number of observations, is 398, it is, as was shown in the preceding article, a simple matter to calculate the Poisson frequencies recorded in the third row of Table 5. Before χ^2 can be calculated it will be necessary to divide the range of the variable into groups. Inspection of Table 5 shows that 10 groups can be conveniently taken as 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and over; the last six frequencies being combined into one group because it is an empirical rule that a class having a theoretical frequency less than 5 should never be used. The theoretical frequency for the last group is 7·28, this being the sum of the six frequencies classed together. The calculation of χ^2 from equation (7) involves only straightforward arithmetic; details of the arithmetic are shown in Table 5. The sum of the fifth row is 38·50, which is the value of χ^2. To get the required probability Table 4 must be entered; but before this is done it must be carefully noted that although 10 groups have been used to calculate χ^2, the number of degrees of freedom n is only 8, since both N and m were fixed in the formation of the Poisson series. From Table 4 it is found that for eight degrees of freedom χ^2 is 15·507. The calculated value is much greater than this; hence the theoretical Poisson series is a bad fit to the observed fault distribution. From more detailed tables[6] it is found that for this value of χ^2, the probability P is less than 0·001; consequently it may be concluded that the observed fault distribution certainly does not follow a Poisson law.

If P is between 0·1 and 0·9 there is no reason to suspect the hypothesis tested. If it is below 0·02 it is strongly indicated that the hypothesis fails to account for the whole of the facts. There will be a very small chance of error if values of P lower than 0·05 be taken to indicate a real discrepancy. There is, however, a large chance of error if very large values of P ($P>0·95$) are obtained. This rather surprising result arises because a large value of P normally corresponds to a small value of χ^2, that is to say, a very close agreement between theory and fact. Now such agreements are rare; almost as rare as great divergences; very close agreement between theory and fact is too good to be true.

The χ^2 test can also be applied to problems in telecommunication engineering in which the available data is qualitative or quantitative only in the sense that the number of cases falling into different classes is known. The analysis of these cases, however, is beyond the scope of these articles.

TABLE 5

Number of Contact Faults per Exchange per week ..	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Observed frequency f_0 ..	14	37	76	70	64	53	31	19	14	9	5	5	1	0	0
Hypothetical frequency (calculated) f_E	8·12	31·61	61·51	79·80	77·64	60·43	39·20	21·80	10·60	4·59	1·78	0·63	0·20	0·06	0·02
$f_0 - f_E$ ..	5·88	5·39	14·49	− 9·80	−13·64	− 7·43	− 8·20	− 2·80	3·40	12·72					
$(f_0 - f_E)^2/f_E$ ..	4·26	0·92	3·41	1·20	2·40	0·91	1·72	0·36	1·09	22·23					

[7] *P.O.E E.J.*, Vol. 34, p. 139.

Conclusion.

The above brief description of methods of dealing with bivariate distributions completes a simple survey of statistical methods of dealing with some engineering problems. The shortcomings of such a treatment are obvious, but the object of these articles has been merely to interest those who have hitherto regarded statistical studies as falling solely within the province of the mathematician, and to show that such studies can often be made with profit by the engineer.

Although only the simplest methods have been discussed, a number of extremely useful mathematical tools have been demonstrated. These tools are all in regular use at the P.O. Research Station, often by those who would not have the time or opportunity to search them out for themselves in mathematical papers and treatises and adapt them for their own purposes. It is hoped that it will be possible later to give some account of new methods as they are developed and applied to particular problems.

Appendix 1.

The Logarithmic Transformation.

If the frequency curve of a certain variable be F(x), what will be the frequency curve of a certain function of x, say f(x)?

In this discussion F(x) is the normal probability expression $(\sigma\sqrt{2\pi})^{-1} \exp(-x^2/2\sigma^2)$ discussed in the first two articles of this series. It follows that F(x) dx is the probability that x falls in the interval between $x-\frac{1}{2}dx$ and $x+\frac{1}{2}dx$. The probability that a new variable z after the transformation $z=f(x)$ or $\phi(z)=x$, falls in the interval $z-\frac{1}{2}dz$ and $z+\frac{1}{2}dz$ is therefore $F[\phi(z)]\ \phi^1(z)\ dz=F(x)\ dx$, which gives in symbolic form the equation of the transformed frequency curve. In this article f(x) is log X and the required expression for the logarithmic skew distribution is therefore

$$(\sigma X\sqrt{2\pi})^{-1} \exp\left\{-\frac{(\log X)^2}{2\sigma^2}\right\}.$$

In the normal probability expression the standard deviation σ (which may be regarded as a measure of dispersion of the observations) is defined as the square root of the mean of the squares of the deviations of the separate observations from their average. If a straight line is obtained when the observations are plotted on arithmetic-probability paper, the value of σ is given approximately by the difference between the values of x at the 84th percentile and the median, whereas if a straight line is obtained (from a skew distribution) on logarithmic-probability paper, σ is the difference between the corresponding logarithms.

A mode is that value of a variable which is of the most frequent occurrence. To determine the modal value of the logarithmic distribution the first derivative of the expression must be equated to zero and there results $X=\exp(-\sigma^2)$, which defines the peak of the frequency curve or the mode of the variable.

Appendix 2.

The Straight Line on Logarithmic-Probability Paper.

To obtain an expression for a straight line on logarithmic-probability paper begin with the linear equation

$$y = mx + c$$

where x is now log X and m and c are constants which must satisfy boundary conditions imposed by the probability scale P. Since the origin has been fixed at 1/2 on the probability scale P, it follows that y can be replaced by the function $\text{erf}^{-1}2\ (\frac{1}{2}-P)$, which is the equivalent area under the normal probability curve, which it will be recalled,[8] was used to construct the probability scale. Thus the linear equation may be written,

$$\text{erf}^{-1}2\ (\tfrac{1}{2}-P) = m \log X + C$$

$$\therefore\ 1-2P = \text{erf}\,(m \log X + C)$$

$$\therefore\ P = \tfrac{1}{2}[1 - \text{erf}\,(m \log X + C)] \ldots (A)$$

$$\text{Now } C = y \text{ when } x = 0$$

$$\text{thus } C = \text{erf}^{-1}(1-2P) \log X = 0$$

$$\text{When } P = \tfrac{1}{2}$$

$$\text{then } m = -\,C/[\log X]_{P=0\cdot5}$$

As an example of the use of this equation consider the five determinations of force and displacement given in Table 3. The only way to get a straight line from these data is to plot them on logarithmic-probability paper. The force is plotted on the logarithmic axis as (dynes/10) and the displacement is plotted on the probability percentage axis. It is necessary to determine the values of c and m to fit equation (A). Let F denote the force and D the displacement, then log X or log F is zero when F=1; continuing the straight line to cut the displacement axis at F=1 and the force axis at P=0·5, there results P=0·027 and F=450.

Thus

$$c = \text{erf}^{-1}(1 - 0{\cdot}054) = 1{\cdot}36$$

and

$$m = -\frac{1{\cdot}36}{\log 450} = -0{\cdot}5126$$

Thus equation (A) can be written in the form,

$$D = \tfrac{1}{2}[1 - \text{erf}\,(1{\cdot}36 - 0{\cdot}5126 \log F)] \quad \ldots (B)$$

from which the force-displacement characteristic can readily be calculated.

[8] *P.O.E.E.J.*, Vol. 34, p. 36.

Modern Materials in Telecommunications

U.D.C. 537.311.3

W. G. RADLEY, Ph.D., M.I.E.E. C. E. RICHARDS, F.I.C.
E. A. SPEIGHT, Ph. D., D.I.C., A.R.C.S. E. V. WALKER, B.Sc., A.R.S.M.

Part VIa.—Semi-Conductors

This article describes some of the chief properties and useful practical applications of semi-conducting materials. A short account of the theory of semi-conduction is given. The use of semi-conductors in metal rectifiers and some forms of photo-electric cells will be covered in the next article.

Introduction.

IT is probable that most people, if asked to name a typical conductor of electricity, would reply "copper," and few would name any non-metallic substance. This probably arises from the widely held interpretation of the word "conductor" as a "wire" along which a current can flow. A little thought will reveal the narrowness of this view and will recall many examples of electrical equipment which functions by, or involves, the passage of currents through non-metallic media. It is the purpose of this article to discuss the properties of some of these other types of conductor and to indicate a few ways in which they are playing an increasingly important part in electrical industry. Unfortunately, limitations of space prevent a comprehensive survey, and many interesting types, such as liquid and gaseous conductors, have had to be omitted entirely.

SEMI-CONDUCTORS.

Classification of Solid Conductors.

In the infancy of electrical science only two electrically different types of substance were recognised—conductors and insulators. Following the discovery of current electricity, methods of measurement improved rapidly and it was found that many substances had conductivities far too low to justify their being called conductors yet far too large to admit them to the class of insulators. For want of a better term they were called semi-conductors. Nowadays, modern physical science frowns on the indiscriminate use of the term semi-conductor and recognises at least two fundamentally different types of substance which are neither good conductors nor good insulators.

First there are the so-called ionic (or electrolytic) conductors, such as the metal halides, in which the current is carried by the movement of ions, i.e. electrically charged atoms. Secondly, there are those substances of intermediate conductivity in which the mechanism of the current flow appears to be purely electronic; these are the true semi-conductors, and it is with these that the present article is chiefly concerned. It is important to realise, however, that semi-conductors are not just poor electronic conductors of the same type as the metals and that the magnitudes of their conductivities depend on very different factors. To illustrate this point some of the more important properties of semi-conductors will now be described.

General Properties of Semi-Conductors.

There are two principal qualitative differences between metals and semi-conductors. At constant temperature the resistance of a metallic conductor is constant (curve A, Fig. 1) and the current flowing is strictly proportional to the applied potential difference (curve B, Fig. 1). So closely is this law followed that

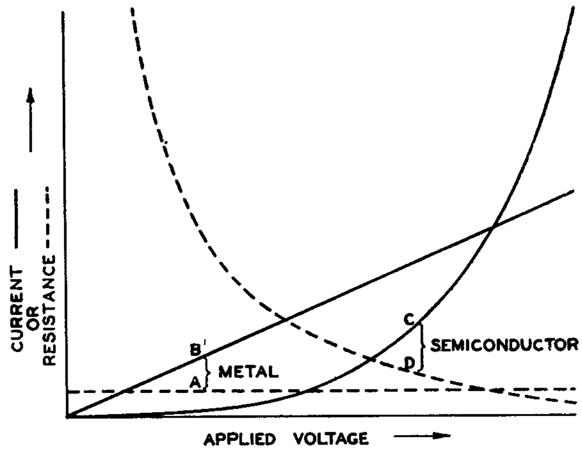


FIG. 1.—CURRENT AND RESISTANCE VS. VOLTAGE CHARACTERISTICS OF METALS AND SEMI-CONDUCTORS.

it forms the basis of the most precise methods of electrical measurement.

In semi-conductors, on the other hand, the current is not always proportional to the voltage, i.e., the resistance is not constant. As the applied voltage is steadily raised the current increases more and more rapidly (curve C, Fig. 1) and the resistance falls (curve D, Fig. 1). This property has been put to many technical uses in recent years and, as will be seen

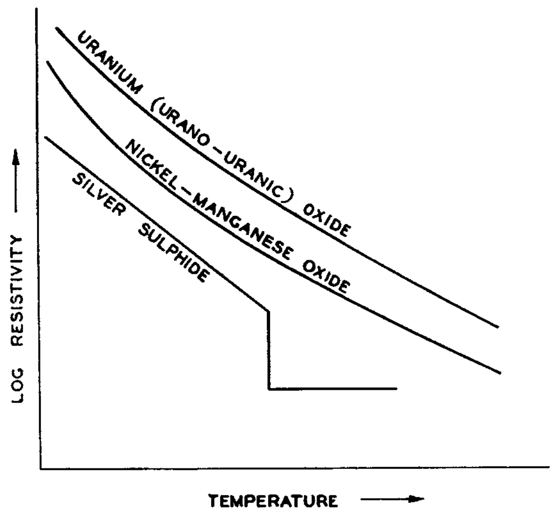


FIG. 2.—RESISTIVITY-TEMPERATURE CHARACTERISTICS OF SILVER SULPHIDE, URANIUM OXIDE AND NICKEL-MANGANESE OXIDE.

later, several commercial embodiments of this type of semi-conductor are now available to the engineer.

Semi-conductors differ sharply from metals also in the effect of temperature. At ordinary temperatures the resistivity of the common metals approximates closely to a linear function of temperature and may be expressed in the form $R_t = R_o (1 + \alpha t)$. For all pure metals the temperature coefficient, α, is positive and is usually about 0·004. The behaviour of semi-conductors can only rarely be expressed in this simple way and, moreover, a most significant fact is that the resistivity falls as the temperature is raised. This is illustrated in Fig. **2**, which is based on the data of G. L. Pearson, Bell Telephone Laboratories. The example of silver sulphide, which, incidentally, was first investigated by Faraday, is particularly interesting. Over the temperature range −100 to +179°C a 50°C rise in temperature reduces the resistivity by a factor of 10. At 179°C a change in crystal structure occurs which explains the sharp discontinuity in the curve. Interesting technical uses are now being found for this type of semi-conductor in which the temperature effect is large.

Voltage-Dependent Resistors.

"Thyrite," "Atmite," "Metrosil" and the "Varistors" of the Bell Telephone Company are the names of some typical commercial devices which exploit the voltage dependence of the resistivity of some semi-conductors. The basic material used in their manufacture is silicon carbide (carborundum) either alone or mixed with powdered graphite or a finely divided metal such as tungsten or molybdenum, and a binding material such as alumina or clay is frequently added. The intimate mixture of the constituents is pressed into the shape required (usually a rod or disc) and fired in a kiln at a high temperature. Contact with the opposite faces of a disc or the ends of a rod is obtained by metallic electrodes such as copper or zinc applied by spraying.

Except at very low current densities the current, I, flowing in such components is related to the applied voltage, V, by the following expressions :

$$V = K\,I^{\beta} \text{ or } I = \left(\frac{V}{K}\right)^{\frac{1}{\beta}}$$

The effective resistance, R, is given by the expression :

$$R = \frac{K}{I^{1-\beta}} = K\,I^{\beta-1}$$

where K is termed the constant of the unit and β the index or exponent. The latter is a characteristic of the material, but K, assuming a given material, is a function of the size and shape of the specimen, being, actually, the resistance of the specimen when carrying a current of 1 ampère. For discs of the same material but of different areas (A) and thicknesses (d), the values of K are related by the expression :

$$\frac{K_1}{K_2} = \left(\frac{A_2}{A_1}\right)^{\beta} \times \frac{d_1}{d_2}$$

The index β usually lies between 0·2 and 0·5 and is substantially independent of temperature up to about 120°C. Above this temperature β increases somewhat. K decreases with rise in temperature and, up to about 100°C, has a temperature coefficient of the order of 0·001 per degree C. By varying the composition of the material, discs of a given size and shape can be produced having widely different values of K. For example, for discs 1 in. diameter and $\frac{1}{8}$ in. thick K may be anything from 100 to 800. The fact that β is considerably less than unity is, of course, the most interesting property of this type of non-linear resistor and the feature on which most of its applications are based. Many of the modern improvements in manufacturing technique have therefore been directed towards making β as small as possible. The recent attainment of the value 0·2 means that, for this particular material, the expressions relating I, R and V can be written in the form $I \propto V^5$ and $R \propto 1/V^4$. The extent to which the potentialities implied by these high indices for V can be utilised naturally depends on the rapidity of response of the material, i.e., on whether or not there is any appreciable time lag between the instant of variation of V and the moment when I and R attain their new stable values. This has been investigated in many ways by means involving measurements with very high-frequency alternating currents or with impulses of only a few microseconds duration. These experiments have revealed a very valuable property—the changes of resistance and current appear to be absolutely instantaneous and the behaviour of the unit is at all times purely resistive (unless the frequency is so high that the capacitance between the electrodes has an appreciable effect).

Turning to the applications of voltage-dependent, non-linear resistors, the first important use was the protection of power lines against the effects of near-by lightning discharges. The resistor is connected between the line and earth and its characteristics are such that, at the normal system voltage, the current leakage to earth is negligible. When a lightning discharge occurs, if there were no protective device a dangerously high voltage might be induced in the line. With the non-linear resistor connected, however, the resistance of the shunt path falls rapidly as the voltage tends to rise, and the extent of the rise is thereby greatly reduced. Providing the resistor is correctly designed and does not overheat sufficiently, as a result of the momentary heavy current flow, to sustain permanent damage, it will function repeatedly without attention, returning to its normal, high-resistance condition at the end of each discharge. Particularly in America this type of protective device has found many applications. In the field of light current engineering a similar use is the protection of delicate apparatus against damage due to the accidental application of excess voltage. Used in shunt with a current consuming device, the combination being fed through a suitable ordinary series resistor, a useful degree of stabilisation against fluctuations in the voltage of the power supply can be obtained. In such a circuit, if the load is an ordinary measuring instrument, the range of voltages which can be measured is considerably increased, though, of course, at the cost of a non-linear scale. There are many possible uses for a meter of this type.

To the communications engineer the most obvious application of non-linear resistors is probably in quenching the spark which occurs when the current in an inductive circuit, e.g., a relay coil or switch magnet, is interrupted. Such sparks, if not quenched, lead to rapid deterioration of the contact surfaces and consequent increased fault liability. To avoid these bad effects it is usual to shunt the contacts with a combination of a resistor and a condenser in series which is effective in suppressing the spark. Recent work has shown that, in many circuits, a non-linear resistor alone is capable of performing the same function successfully and without apparent deterioration. In such instances an important advantage is the smaller space occupied by a non-linear resistor as compared with that taken by the standard quench. There is one aspect of the action of a non-linear resistor which may be of considerable importance in some specialised circuits. This is the fact that whereas, with the standard quench, the decay of the current in the circuit may be oscillatory, with the non-linear resistor it is not.

Further interesting possibilities arise for the use of these devices in alternating current circuits. Since there is no time-lag in the response, the resistance of the unit will change from instant to instant as the potential difference across it varies. In other words, the current wave form differs considerably from the voltage wave form and the current flowing contains strong odd harmonics of the fundamental frequency, particularly the third. This fact immediately suggests a use for non-linear resistors in frequency multiplying circuits.

For some applications a negative temperature coefficient is a disadvantage. Care is therefore taken in manufacture to keep the coefficient as small as possible consistent with a suitably low value of β. Also the circuit should be so designed that the heat dissipated in the heavily loaded condition does not result in excessive temperature rise.

Thermal Non-Linear Resistors.

The conditions governing the manufacture and use of thermal non-linear resistors are exactly opposite to those of the voltage-dependent type. The value of β is relatively unimportant and, in fact, is preferably nearly unity, but the negative temperature "coefficient" should be large. Various oxides and sulphides have been found to possess the desired properties. Those whose characteristics were shown in Fig. **2** are employed in some of the "Thermistors" of the Bell Telephone Company, and uranous oxide (UO_2) is used in the "Urdox" thermal resistor.

The manufacturing process is comparatively simple and, in principle, involves merely compressing the powdered material into the desired physical form, baking afterwards if necessary. Electrodes are applied by metal spraying, etc. Nearly all materials showing a sufficiently large change of resistivity with temperature can be used for the manufacture of thermal resistors for use in A.C. circuits, but some, e.g., Ag_2S and U_3O_8, are unsuitable for use in D.C. circuits owing to polarisation effects which greatly increase the apparent resistivity at all temperatures.

At ordinary temperatures the resistance of a thermal resistor is high and the current passed at a given voltage is correspondingly small. The power dissipated tends to heat the resistor and its resistivity falls. The current therefore increases with time in a cumulative manner, if the applied voltage is maintained, until the component is destroyed. It is therefore always necessary to incorporate a suitable protective resistance in the circuit to limit the final current. If a constant voltage (V) is applied to a circuit consisting of an ohmic resistor (R) and a thermal resistor in series the current varies with time after the manner shown in Fig. **3**.

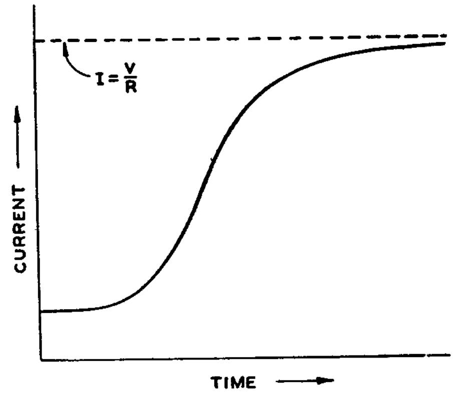


Fig. **3**.—Current-Time Characteristic of a Thermal Resistor.

By a suitable choice of values the time of transition from the low current condition to the high current condition can be varied from several seconds down to a few milliseconds. Useful applications here are the employment of ordinary relays as slow-acting switches which, moreover, are immune from operation by quite large voltage surges if these are of short duration.

If the current passed through, and, consequently, the power dissipated in a thermal resistor are small, the temperature of the resistor will not differ appreciably from its surroundings. Under these conditions any change in ambient temperature will alter the resistance and the device can, therefore, be used as a resistance thermometer, the sensitivity of which may be ten or more times that of the well-known platinum resistance thermometer.

If the current passed is sufficient appreciably to alter the resistance of the resistor and the latter is allowed to attain thermal equilibrium at any given value of current, the resistance will be found to vary with the power dissipated in the manner shown in Fig. **4(a)**. The corresponding voltage-current curve

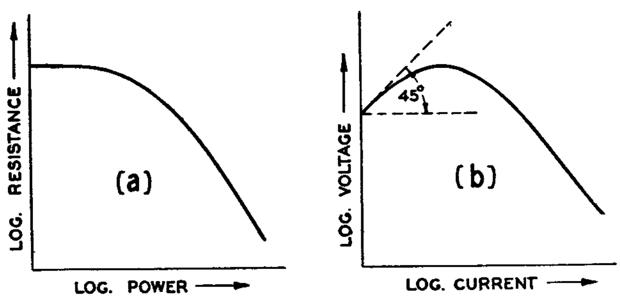


Fig. **4**.—Resistance-Power and Voltage-Current Characteristics of a Thermal Resistor.

is shown in Fig. 4(**b**), and it will be seen that, at low currents, the current is proportional to the voltage and the resistance is constant. Departures from these conditions are apparent at the higher current loadings and ultimately the resistance becomes negative. A thermal resistor working in the latter region in conjunction with a suitable ohmic resistor can be used as a voltage stabiliser.

A further interesting series of applications for the thermal resistor arises from the fact that its temperature, and therefore its resistance, can be changed by altering the current flowing in a heating coil surrounding the resistor. Since thermal resistors can be used satisfactorily at high radio frequencies this provides a useful method of controlling a high-frequency current from a distant point to which high-frequency leads could not be run. The range of control is wide, and thermal resistors are made in which the resistance can be changed by a factor of 10^5 for a power dissipation of only 20 mW in the heating coil.

Theory of Semi-Conductors.

Although the technical use of semi-conductors is of comparatively recent development the study of the fundamental nature of these substances has attracted the attention of very many scientists. As a result, despite the complexity of the subject, the theory of semi-conductors is now very nearly as complete as the electron theory of metals, and there is sound reason to believe that future progress is unlikely to result in any substantial change in the fundamental conceptions. The modern theory of semi-conductors is based on the same fundamental assumptions as in the free-electron theory of metals. These, as discussed in Part V of this series, lead to the conclusion that the valency (outer) electrons of the atoms in a metallic crystal are not bound to their parent atoms in the solid state. Though not more than two electrons have exactly the same energy at any instant there is a band or zone of closely grouped energy levels in which all the valency or "free" electrons are to be found. This band, in metals, also includes a relatively large number of energy levels which, at any instant, are not occupied by electrons. When an electric field is applied to a metal it will always be possible for most of the free electrons to move to a higher energy level in the band by absorbing energy from the field. Such electrons will move along the direction of the field and, in so doing, constitute a current flow. The inner or bound electrons, on the other hand, occupy and, in fact, fill completely all the energy levels in a number of similar bands of lower mean energy. An applied field cannot therefore accelerate any of these bound electrons within its own band. Since there are, between consecutive bands, gaps of forbidden energies to which the electrons cannot attain, bound electrons play no part in the conduction process. The relative widths of the bands and gaps depend on the number of atoms in the crystal and, in the limiting case of a single free atom, the bands are reduced to widely separated, single discrete energy levels.

In an insulator, on the other hand, the energy situation at very low temperatures can be represented diagrammatically as in Fig. 5(**a**). The lower energy bands, of which two are shown in the diagram, are full as before, but the next higher band is empty. No acceleration of any electron is possible and normally no current can flow on the application of an electric field. When the substance is heated, however, a few electrons acquire sufficient thermal energy to enable them to jump over the gap into the previously empty conduction band where they can then take part in electrical conduction. The narrower the gap of forbidden energies the smaller is the amount of thermal energy an electron must acquire in order to make the jump, and hence the more rapid is the increase of conductivity with temperature. This accounts for some of the properties of semi-conductors, though it is not normally the main or sole cause of the conduction.

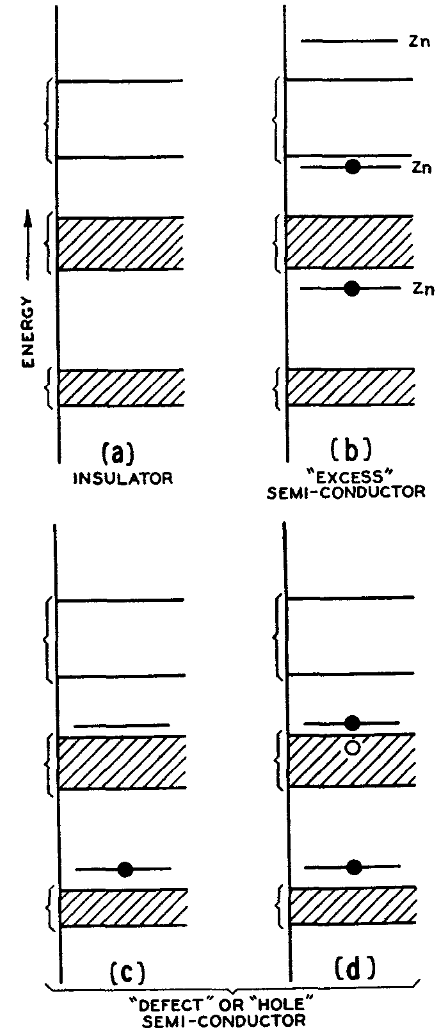


Fig. 5.—Energy Levels in Insulators and Semi-conductors.

So far the discussion has been confined to perfectly pure homogeneous substances, and there is little doubt that, at normal or low temperatures, all such substances would be either conductors or insulators. In a true conductor, the effect of purifying a slightly impure material is always to increase the conductivity. Semi-conductors, however, are always slightly impure, though the impurity may be hard to detect by chemical means,and the conductivity is reduced by the removal of impurities. The way in which impurity atoms cause conductivity is, therefore, of prime importance and will now be described.

It is necessary to consider two kinds of impurity atoms. There are electropositive atoms, such as those of the metals, and electronegative atoms, such as those of the non-metals, oxygen and sulphur. These give rise respectively to two different types of semi-conductor. An example of the first type which has been very extensively investigated is zinc oxide which has been strongly heated and allowed to cool. After this treatment it is found to have acquired both a slight brownish colour and an appreciable electrical conductivity. Both of these properties are believed to result from a slight loss of oxygen in consequence of which a (relatively) very small number of free zinc atoms is present. Since the number is small, mutual interaction between the zinc atoms is negligible and their electron energies are discrete levels such as the lines marked Zn in Fig. **5**(**b**). Suppose that, as shown, one of the electrons from a zinc atom occupies one such level lying just below the lowest unoccupied zinc oxide band. By the absorption of quite a small amount of thermal energy this electron can jump to a level in the hitherto empty band. From there it can be electrically excited to a still higher level in just the same way as the valency electrons in a metal and weak electrical conduction occurs. Since this and any other electrons which carry the current come from the atoms (the zinc atoms) which are present in excess of the exact proportions required by the chemical formula, zinc oxide is termed an "excess" semi-conductor. Other typical excess semi-conductors are the sulphides of copper, tin and silver.

The second type of semi-conductor is one in which an unoccupied energy level corresponding to an impurity atom lies just above the highest full band of the parent substance as in Fig. **5**(**c**). It is possible, then, for an electron in the full band to be thermally excited to this impurity level, leaving behind a vacancy or "hole" (Fig. **5** (**d**)). This particular electron cannot further be electrically excited. Both theory and experiment, however, show that the hole has all the properties of an electron except that it is equivalent to a positive charge. It can, therefore, move through the space lattice and give rise to electrical conduction in exactly the same way as the valency electrons in a metal, though, of course, its movement is in the opposite sense with respect to the electric field. Substances in which this phenomenon occurs are known as "defect" or "hole" semi-conductors and include materials such as cuprous oxide and the oxides of manganese, cobalt and nickel. In these the necessary unoccupied energy level is supplied by a slight excess of oxygen atoms.

Where the impurity consists of atoms foreign to the main bulk of the material several possibilities may arise. If the amount of impurity is very small, conduction of either the excess or the hole types may occur, or even of both types simultaneously. If the percentage of impurity is large the energy levels of its electrons may be bands rather than discrete levels. In some circumstances these impurity bands may be wide enough to span the gap of forbidden energies and constitute a bridge whereby electrons can pass from a full band in the main material to a hitherto unoccupied band. Conduction will then occur. Owing largely to the complexity of this type of substance the experimental difficulties are considerable, and comparatively little work has so far been done in this field.

This outline of the theory has, of necessity, dealt mainly with highly idealised examples. In any practical piece of semi-conducting material there will be a very large number of individual crystals, each with its own degree of impurity and even with different types of impurity. It is not surprising, therefore, that although the theory does, from a qualitative standpoint, account satisfactorily for the actual behaviour of semi-conductors, much more work will be necessary before a complete quantitative explanation can be given.

Equipment for Cutting Steel and Wrought Iron Pipes Containing Working Cables

F. E. PLUMPTON

U.D.C. 621.93 : 621.315.23

The use of a power-driven abrasive disc to cut open steel and wrought iron pipes is described. A screw feed is provided on a special machine carrier to enable the disc to be lowered gradually as its diameter is reduced due to wear. Only one longitudinal cut is made after which the pipe is prised open by screw claws.

Introduction.

RECENT damage to the Department's plant in congested areas has caused greater attention to be given to the methods of obtaining access to cables contained in steel or wrought iron pipes. This question had arisen in peace time when the usual method of cutting the pipe round the circumference and of splitting it longitudinally with a hammer and cold chisel was found to be too slow and costly. The rate of cutting was slow and two longitudinal cuts were necessary to enable the pipe to be removed from the cable in two halves. Attempts by a contractor to speed up the process by the use of power-driven apparatus met with some success. The method employed was to utilise an electrically-driven circular saw marketed under the proprietary name of "Skilsaw," the saw blade being replaced by a thin abrasive disc of suitable grade. The method was described and illustrated in the POST OFFICE ELECTRICAL ENGINEERS' JOURNAL for April, 1937. The discs are very brittle and break if they are "jabbed" into the work, or are subjected to side thrusts. In spite of the employment of a skilled operator many comparatively expensive abrasive discs were broken long before the end of their useful lives, and time was wasted in changing the discs, the cost of the work being increased accordingly. Although the method was much superior to the hammer and chisel method previously in use it was felt that considerable improvement in carrying and directing the cutting disc could be made. Various solutions of these difficulties were tried, and a set of experimental equipment was made up locally. This equipment forms the subject of this article.

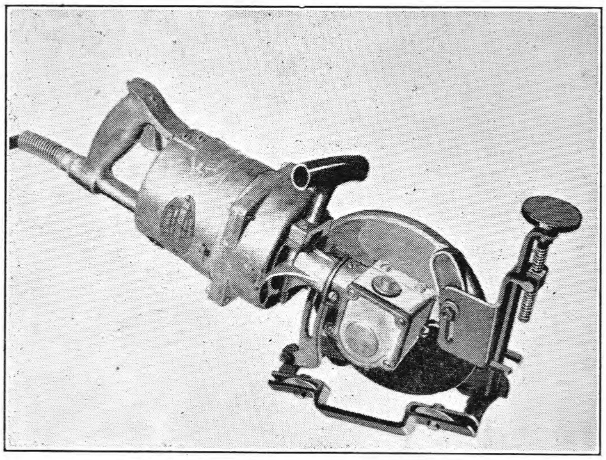


FIG. 1.—"SKILSAW" AND WHEELED CARRIER.

Method of Operation.

The basis of the equipment now in use is a Model E "Skilsaw." This is supplied primarily as an 8 in. circular saw for cutting building timbers, and accessories are available to enable it to be adapted for

FIG. 2.—"SKILSAW" CUTTING STEEL PIPE.

various other operations. It is powered by a universal electric motor available for various voltages absorbing 1,250 watts on full load, and has a blade speed of about 3,400 revolutions per minute on no load. Its weight is 19 lb. The abrasive discs are 8 in. in diameter, 1/16 or 3/32 in. in thickness, and are of carborundum or other abrasive material bonded in bakelite. The normal soleplate of the "Skilsaw" is replaced by a wheeled carrier (Fig. 1), designed to run along the outside of the pipe to be cut. Adjustments are provided to allow for wear of the abrasive disc and to control the depth of the cut.

The section of pipe to be removed is first cut off by ordinary pipe cutters. If a section of a pipe passing through an excavation is to be removed a cut is made at each end of the section, and wooden wedges are inserted to lift the unwanted section of pipe away from the sheathing of the cable; if the pipe to be cut is of steel the tarred hessian wrapping is removed, and the outside of the pipe thoroughly cleaned.

The " Skilsaw " is bolted to the slotted bracket at the front of the frame, and the hand wheel on the screw feed is turned until the bracket has been raised to its upper limit. During this operation the machine is allowed to move freely in the rear slotted arm. The carrier is then placed on the pipe and the " Skilsaw " is lowered at the rear slotted arm until the disc just touches the pipe. In this position the adjustment is locked by tightening the appropriate nut on the " Skilsaw." The front wheels of the carrier are rested on the pipe and, with the abrasive disc running, the machine is moved along until the disc is brought into contact with the end of the pipe and the cutting of the slot is commenced. As the work proceeds the machine is moved along until all four wheels of the carrier bear on the pipe. If care is taken during the foregoing operations no real difficulty is experienced. Care must also be taken to ensure that the slot is cut straight and that the disc cuts right through the thickness of the metal of the pipe. The carrier is moved slowly along the pipe (Fig. **2**) as the slot is cut. The diameter of the abrasive disc is reduced as the work proceeds, and the correct depth of cut is maintained by further adjustment of the hand wheel, as the cut is being made.

When the whole of the hand adjustment has been taken up it is necessary to stop the machine and to turn the hand wheel in the reverse direction, so that the front bracket is again at its upper limit; the abrasive disc can then be brought to bear on the work again by readjustment of the rear fixing. By this method a slot is cut along the section of pipe to be removed. As the slot nears the end of the pipe the front wheels run off the pipe, but the weight of the machine is easily carried on the rear wheels for the remaining few inches of cut.

The abrasive discs wear rapidly during the splitting operation, and it is better to remove the pipe from the cable by forcing the slot open than to make a second cut diametrically opposite to the first to enable the pipe to be removed in two halves. By avoiding a second cut the number of discs worn out is halved, and wear and tear on the machine used for driving the discs is also halved. This course has to be adopted when the pipe has been flattened and it is not possible to revolve the pipe on the cable to make a second cut.

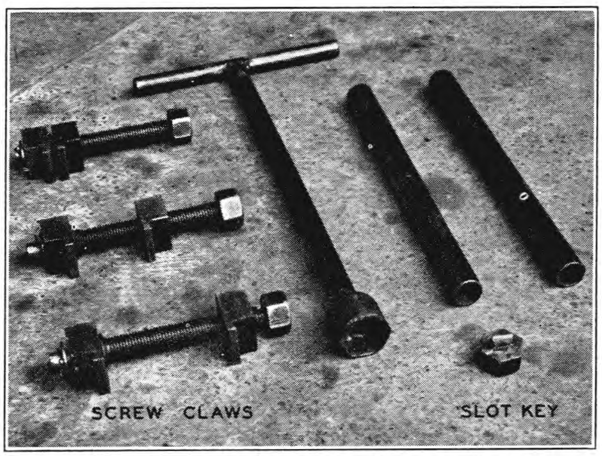


Fig. **3**.—Screw Claws, Slot Key and Spanner.

To open the slot cut by the " Skilsaw " two tools have been devised, namely, the slot-widening tool and the pipe-opening claw. The slot-widening tool consists of a hardened steel tongue (Fig. **3**) rounded on three sides to avoid damage to the cable inside the pipe and attached to a hexagonal head used for turning. The sides of the tongue are slightly recessed to prevent it from jumping out of the slot while it is being turned. The pipe-opening claws consist of two case-hardened steel claws, one of which is moved by a screw thread when the hexagon head is turned. An ordinary T-handled box spanner fits the slot key, and the screw claws. Lengths of tube fit over the handle to increase leverage if this is necessary. This is considered preferable to having a long handle on the box spanner as in restricted situations it may not be possible to turn a large handle whereas a short one can usually be turned half a revolution at a time by removing the extension tubes from each half of the handle in turn.

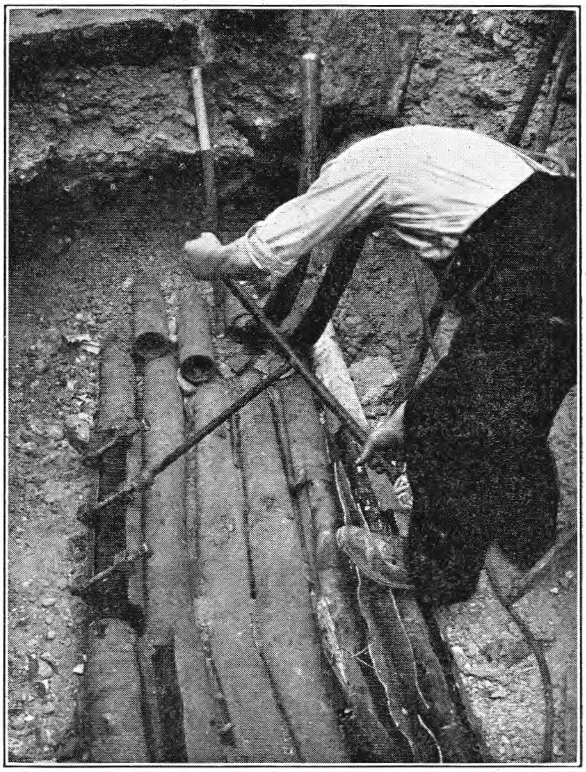


Fig. **4**.—Use of the Screw Claws.

The cutting of the slot having been completed, the slot-widening key is inserted and turned through a right-angle. This springs the slot open so that a screw claw in its fully closed condition can be inserted. This is repeated along the pipe, and additional screw claws are inserted at intervals of 12 to 18 inches. The box spanner is then fitted to each screw claw in turn (Fig. **4**) and the slot is forced open until it is wide enough to pass the cable(s) contained in the pipe. It is necessary to exceed this distance by about half an inch, as it has been found that the pipe closes about half an inch when the screw claws are removed. The screw claws are released by unscrewing and the pipe is then removed from the cable.

Typical Applications.

When a manhole wall through which steel pipes enter is to be set back it is necessary to remove the lengths of pipe that would otherwise project into the manhole. Empty pipes are easily cut with the ordinary wheeled pipe cutters, but where cables are contained in the pipes it is necessary to split the pipes longitudinally to enable the surplus lengths to be removed. The alternative is the renewal of the length of cable.

The equipment has been used also to facilitate removal of a section of a nest of pipes embedded in a concrete road where the pipes are set too close together to enable a wheeled pipe cutter to be fitted round the pipe. The concrete was first cut away from the section of pipe to be removed. Two cuts about 9 in. apart were then made with the "Skilsaw," as far as possible round the pipe, at each end of the unwanted section. Each pair of cuts was joined by a longitudinal cut, and the pipe split open for about 9 in., using the screw claws. This enabled a diamond-pointed chisel to be used on the inside of the pipe at each end of the unwanted section, which was then easily removed.

On another occasion a cable contained in a steel pipe had been damaged by a pneumatic road drill which penetrated through both the pipe and the cable. The concrete foundation of the road was cut away for about 5 ft. on each side of the damage. Transverse cuts were made with the "Skilsaw" about half-way round the pipe at each end of the section, and a longitudinal cut was made along the length. The section was opened with the screw claws and the necessary repairs to the cable effected. The jagged edges of the hole where the drill had penetrated the pipe were cut away with a cold chisel, and the holes plugged by pouring in molten lead. The sharp edges of the cuts made by the "Skilsaw" were rounded off with suitable files, and the pipe was hammered back into shape to contain the cable. The cuts were suitably protected with sheet lead and embedded in the concrete foundation of the road.

On a recent work where the steel pipes had been disturbed it was found to be possible to revolve them on the cables by means of a large chain wrench. Advantage was taken of this factor to use the "Skilsaw" for making the circumferential cut. Thsi was done in a series of short cuts revolving the pipe with the chain wrench as each cut was completed. Worn-down discs unsuitable for making a longitudinal cut were used up by this method, which was found to be considerably quicker than the use of pipe cutters.

The uses suggested above are by no means exhaustive, and no doubt other applications of the equipment will suggest themselves from time to time.

Observations.

The method indicated is capable of application to any size of pipe, the limiting factors being the strength of the screw claws and the capacity of the carrier. It is difficult to give any accurate figures for the time occupied by these various operations owing to difference in conditions under which they are performed. The following figures taken from an actual job may, however, be of interest.

Size of pipe: $3\frac{1}{4}$ in.
Length of cut: 36 in.
Time to make slot with "Skilsaw": 25 minutes.
Time to open slot with slot-widening tool, and insert pipe-opening claws: 5 minutes.
Time to open slot to full extent: 20 minutes.

It is realised that a suitable electricity supply may not always be available at or near the scene of operations, but this difficulty could be overcome by the provision of a small petrol engine generating set to supply the necessary power where these conditions arise. On the other hand, steel pipes are used mainly in congested areas, and an electricity supply is usually available at or near the scene of operations. Consideration has also been given to the use of compressed air as a motive power, and enquiries have been made with a view to finding a suitable machine. A machine of the same type as the "Skilsaw" but with an air motor in place of the electric motor would meet the requirements, but so far no such tool has been discovered.

Various grades of high speed steel are now available, and the possibility of using a circular saw blade of this material in place of the abrasive disc could perhaps be explored with advantage. Difficulties would probably arise in connection with its lubrication as there would be risk of increased damage to the cable by the presence of the lubricant if the cable sheathing were not intact.

In some situations the T-handled box spanner could, with advantage, be replaced by an ordinary lever ratchet spanner, working direct on the hexagonal head of the screw claws.

Impedance Matching Networks for Unloaded Cable

D. G. TUCKER, B.Sc.(Eng.), A.M.I.E.E.

U.D.C. 621.391.312

A simple design method is developed in this article for impedance matching networks used for duplex telephone circuits on unloaded cables. Two typical examples are worked out and discussed.

Introduction.

CERTAIN carrier systems set up nowadays on routes involving submarine cable are arranged in a manner such that the voice and one or two of the lower carrier circuits work on a duplex basis. The carrier system involved in the duplex working is generally Carrier System No. 4,[1] though other systems may occupy the higher frequency bands. The number of circuits that can be worked duplex depends on the attenuation length of the cable. Sometimes only the voice circuit can be so worked, but on one or two cables the voice and three carrier circuits have been operated duplex. The determining factor is the balance return loss (or singing point) that can be obtained between the line and the impedance matching network. To ensure adequate stability of the circuits, the return loss should exceed the line attenuation at all frequencies at which duplex operation is required. It is thus clearly not necessary for the return loss required at high frequencies to be maintained down to the low frequencies. It is sufficient if the curve of return loss against frequency be maintained parallel to the curve of cable attenuation, the difference between them being determined by the degree of circuit stability required.

If the line consists solely of one cable link (or is arranged so that duplex operation takes place only over the one link), and if the cable is in good repair and has a smooth impedance/frequency characteristic, then a return loss of at least 40 db. at the upper frequencies can generally be maintained, even allowing for a certain lack of matching between the filters in the line and balance circuits. If the line consists of a more complex circuit, comprising different types of cable or open line,. then it will be very difficult to obtain any adequate return loss by a simple balance network; it is generally necessary in such circumstances to provide 4-terminal networks to simulate the transmission characteristics of the shorter sections of line where these are nearer the terminal concerned and are not so short as to be negligible, and then a normal 2-terminal network to simulate the impedance of the more distant

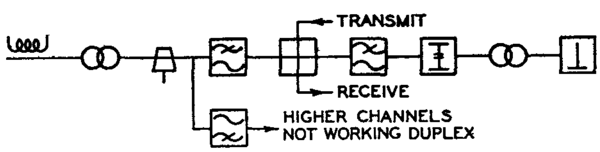


FIG. 1.—COMPLEX CIRCUIT OF CABLE AND OPEN LINE.

and longer cable. Fig. 1 shows such an arrangement. From this it will be clear that the network simulating the open line is a 4-terminal network which gives phase and attenuation characteristics similar to those of the open line, whereas the final 2-terminal network has an impedance characteristic similar to that of the submarine cable, but resembles the cable in no other way. The use of the filters for separating the duplex and uni-directional channels is obvious and well known.

It is apparent that the design of the impedance matching network must be carried out with some precision. The networks used for this purpose consist, for the unloaded cables under consideration, of resistances and capacitances only, and four useful configurations are shown in Fig. **2**(*a*), (*b*), (*c*) and (*d*), type (*c*) being a development of (*a*).

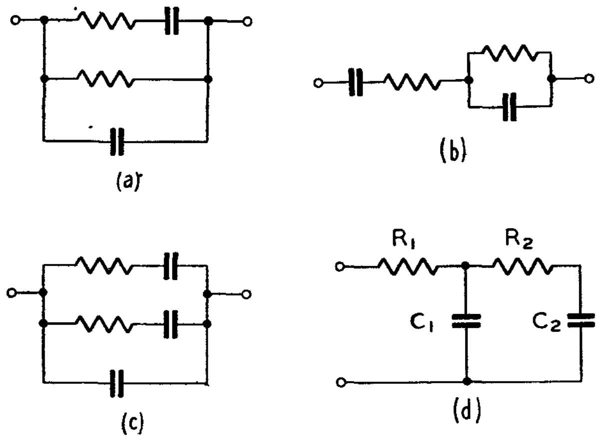


FIG. 2.—IMPEDANCE MATCHING NETWORKS.

Of these, (*a*) and (*b*) are well known, and their design has been described fully elsewhere.[2] However, (*d*) is the most satisfactory type to use in practice, and lends itself to more precise design over a wide frequency range. It is this type that is to be described in this article.[3]

It can be readily shown that the impedance of this network is given by the expression—

$$\left[R_1 + \frac{C_2^2 R_2}{(C_1 + C_2)^2 + \omega^2 C_1^2 C_2^2 R_2^2}\right] - j\left[\frac{(C_1 + C_2) + \omega^2 C_1 C_2^2 R_2^2}{\omega\{(C_1 + C_2)^2 + \omega^2 C_1^2 C_2^2 R_2^2\}}\right] \quad \ldots\ldots..(1)$$

Derivation of Method of Design.

Let R—jX be the impedance of the cable or line to be matched. In unloaded cable, the reactance is always negative; consequently the expression above

[1] *P.O.E.E.J.*, Vol. 29, pp. 226 and 294.

[2] P.O. Engineering Instructions, Transmission, Telephones, R1107 and 1108.

[3] A completely different attack on the problem of design of this type of network has been published in an article by Chardon in Annales des Postes, March, 1938. The method described there has, however, the disadvantage that lower return losses are obtained at higher frequencies than at lower frequencies and this condition is generally unacceptable.

has been written with a minus sign so that, for convenience, X may be taken as positive.

Consider equation (1) above :—

At higher frequencies, say 15 kc/s, the second term in the resistance expression is almost negligible compared with R_1, generally being of the order of 1 per cent. of R_1. At this frequency, too, the resistance component of the cable impedance is approaching a fairly constant value, R_H, say (suffix $_H$ indicating high frequency).

Thus, $R_1 = R_H$ ....(2)

At low frequencies, say 200-300 c/s, since C_1 and C_2 are generally of the order of 1 μF and R_2 is between 10 and 1,000 ohms—

$(C_1 + C_2)^2$ is of the order 4×10^{-12}

and $\omega^2 C_1^2 C_2^2 R_2^2$ is of the order $10^6 \times 10^{-24} \times 10^2$ to $10^6 \times 10^{-24} \times 10^6$, i.e. 10^{-16} to 10^{-12}.

It will thus be justifiable to neglect the second term at low frequencies. In the same way, $\omega^2 C_1 C_2^2 R_2^2$ may be neglected compared with $C_1 + C_2$.

So at low frequencies, say ω_L,

$$R_L - jX_L = \left[R_H + \frac{C_2^2 R_2}{(C_1 + C_2)^2} \right] - j \left[\frac{1}{\omega_L (C_1 + C_2)} \right]$$

$$\therefore\ R_L - R_H = \frac{C_2^2 R_2}{(C_1 + C_2)^2} \quad \ldots\ldots\ldots\ldots\ldots (3a)$$

$$\text{and } X_L = \frac{1}{\omega_L (C_1 + C_2)} \quad \ldots\ldots\ldots\ldots\ldots (3b)$$

$$\text{So that } C_2^2 R_2 = \frac{R_L - R_H}{\omega_L^2 X_L^2} \quad \ldots\ldots\ldots\ldots\ldots (3c)$$

To determine R_2, C_1 and C_2 one more equation is needed. At a medium frequency (ω_M), R_M is greater than X_M, and therefore has a greater effect in determining the balance. From equation (1)—

$$R_M - R_H = \frac{C_2^2 R_2}{(C_1 + C_2)^2 + \omega_M^2 C_1^2 C_2^2 R_2^2}$$

Substitute from 3(c)

$$= \frac{\dfrac{R_L - R_H}{\omega_L^2 X_L^2}}{(C_1 + C_2)^2 + \omega_M^2 C_1^2 R_2 \left(\dfrac{R_L - R_H}{\omega_L^2 X_L^2} \right)}$$

$$= \frac{R_L - R_H}{1 + \omega_M^2 C_1^2 R_2 (R_L - R_H)} \text{ using (3b)}$$

Solving for $C_1^2 R_2$

$$C_1^2 R_2 = \frac{R_L - R_M}{\omega_M^2 (R_M - R_H)(R_L - R_H)} \quad \ldots\ldots (4)$$

Dividing (4) by 3(c) and taking the square root—

$$\frac{C_1}{C_2} = \frac{\omega_L X_L}{\omega_M (R_L - R_H)} \sqrt{\frac{R_L - R_M}{R\ \ - R_H}}$$

From (3b)

$$C_1 + C_2 = \frac{1}{\omega_L X_L}$$

$$\text{so } C_2 = \frac{\omega_M (R_L - R_H)}{\omega_L X_L \left[\omega_M (R_L - R_H) + \omega_L X_L \sqrt{\dfrac{R_L - R_M}{R_M - R_H}} \right]} \quad \ldots (5a)$$

From (3c)

$$R_2 = \frac{R_L - R_H}{\omega_L^2 X_L^2 C_2^2} \quad \ldots\ldots\ldots\ldots\ldots (5b)$$

And from (3b)

$$C_1 = \frac{1}{\omega_L X_L} - C_2 \quad \ldots\ldots\ldots\ldots\ldots (5c)$$

Thus the network can be designed in terms of—

$R_H = R$ at high frequencies, say 10–15 kc/s.
$R_M = R$ at medium frequencies, say 3 kc/s.
$R_L - jX_L$ = impedance at low frequencies, say 200 c/s.

Realisable values of the components will be obtained if $R_L > R_M > R_H$ and if $-X_L$ is negative.

Design in Practice.

In practice it will be found that a network, designed as described above, will give quite a good return loss over any frequency range likely to be required. However, improvement can be effected (*a*) by measuring on a bridge (R—jX) for the network and making small adjustments so that a better match is obtained over the frequency range or (*b*) by connecting the network to the balance side of a hybrid transformer, and making transmission measurements from 4-wire to 4-wire terminals, across the hybrid, connecting to the line terminals a resistor and condenser in parallel, set to the bridge readings of the cable impedance for each particular frequency. Small adjustments can then be made in the balance so as to give as high a loss as possible at all frequencies at which balance has to be maintained; or (*c*) if no measuring facilities are available during design, small adjustments of R_1 and R_2 should be made available by tappings on the made-up balance networks. Then when the circuits are lined up, adjustments can be made *in situ* to give the best stability margin to the speech circuits.

It will be found that, if necessary, a higher return loss can be obtained over a wide frequency band if another RC section is added to the network, as shown in Fig. 3.

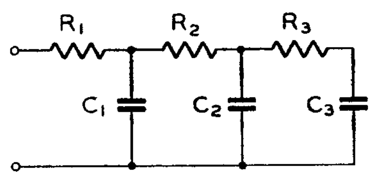


FIG. 3.—NETWORK OF FIG. 2(*d*) WITH ADDITIONAL RC SECTION.

R_3 and C_3 are best determined by practical tests, but they will be of the same order as the other components. Experience has shown that C_1, C_2 and C_3 are generally very nearly equal.

It is of interest to note that in information already published,[4] describing the equipment for the Australia-Tasmania cable, it is seen that a 6-element network as described above is used to maintain a return loss greater than 50 db. from about 1 to 13 kc/s; and the return loss does not fall below 39 db. up to 45 kc/s. In attempting to maintain such high return

[4] *Electrical Communication*, Vol. 15, 1936-37, p. 303.

losses, one meets the problem of variation of cable impedance with temperature. This amounts to 0·02 per cent. per degree Fahrenheit for the resistance component, the effect on the reactance being negligible. The temperature variations on the sea-bed are generally quite small, but to maintain a high degree of balance, it is necessary to provide small adjustments on R_1 which can be set up from time to time to follow seasonal variations.

Example 1.

Coaxial Paragutta Submarine Cable.

This type of cable is now quite extensively used. Cables made at different times have slightly different impedance characteristics, but that shown in Fig. **4** may be regarded as typical.

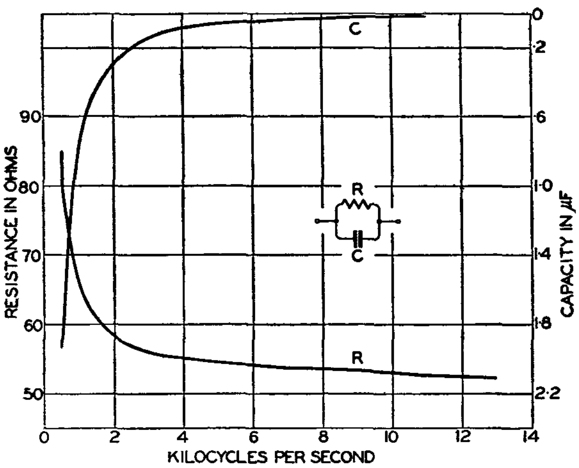


FIG. **4**.—TYPICAL IMPEDANCE CHARACTERISTIC OF COAXIAL PARAGUTTA SUBMARINE CABLE (GIVEN AS BRIDGE READINGS).

Suppose the balance is required from about 300 c/s to 12·5 kc/s ; this allows a 1+3 channel duplex system to be operated. Using the symbols given above, take

$R_H = 52$ ohms.

At 3 kc/s, $\omega_M = 18{\cdot}85 \times 10^3$, $R_M = 55$ ohms.

At 500 c/s, $\omega_L = 3{\cdot}142 \times 10^3$, $R_L = 67$, $X_L = 35$ ohms.

So that from (5) $\underline{C_2 = 5{\cdot}1\mu F,\ R_2 = 47{\cdot}5,}$

$\underline{C_1 = 4{\cdot}0\mu F}$

and from (2) $\underline{R_1 = 52 \text{ ohms.}}$

A network with these values would generally be satisfactory, but by making adjustments *in situ*, it was found that with $R_1 = 52{\cdot}3$ and $R_2 = 40$ ohms, values as given in line 2 of Table 1 were obtained. A further improvement was obtained by adding another resistance and condenser as shown in Fig. **3**. With $R_1=51{\cdot}6$, $R_2=15$, $R_3=80$ ohms, $C_1=3{\cdot}6$, $C_2=3{\cdot}6$ and $C_3=4{\cdot}5$ μF, values were obtained as shown in line 3 of Table 1. For comparison, the best results obtained with a network as shown in Fig. **2**(*c*) are given in line **4** ; inferior results were obtained with the networks of Figs. **2**(*a*) and **2**(*b*).

TABLE 1.

	Frequency kc/s	·3	·5	1	2	4	6	8	10	12
Return loss (db.)	4-element network	19	24	27	27	30	35	39	50	52
	6-element network	28	38	35	36	41	45	45	53	52
	Network as Fig. 2c	22	24	26	30	34	36	38	39	40

Example 2.

107/150 *lb. Submarine Telegraph Cable.*

Suppose a voice channel with a frequency range 300–2,700 c/s is required on a submarine cable of this type. The impedance characteristic of this cable is shown in Fig. **5**.

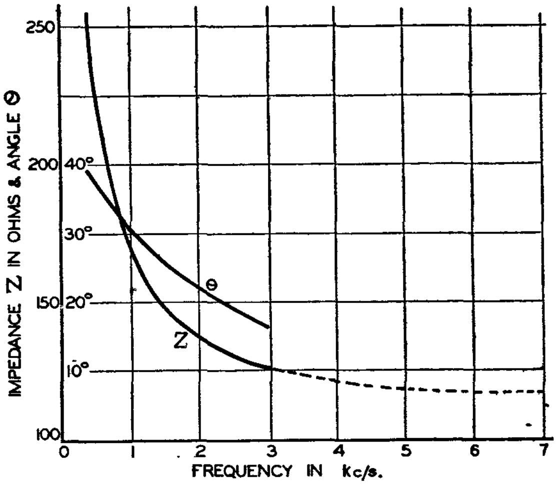


FIG. **5**.—IMPEDANCE OF 107/150 LB. SUBMARINE CABLE.

By extrapolation (as shown) or by actual measurement, $R_H =$ about 117 ohms. At 2 kc/s,

$\omega_M = 12{\cdot}56 \times 10^3$, $R_M = Z_M \cos \theta_M = 127$ ohms.

At 400 c/s, $\omega_L = 2{\cdot}512 \times 10^3$, $R_L = 198$ ohms,

$X_L = Z_L \sin \theta_L = 160$ ohms.

Thus from (5) and (2) $\underline{C_2 = 1{\cdot}21\ \mu F,\ R_2 = 342 \text{ ohms}}$

$\underline{C_1 = 1{\cdot}28\ \mu F,\ R_1 = 117 \text{ ohms}}$

A network constructed with these components was found to give return losses as shown in Line 2 of Table 2.

By adjustment, slight improvement was obtained, as shown in Line 3 of Table 2, with values exactly as above except $R_2=300$ ohms.

TABLE 2.

Frequency kc/s		·3	·8	1·2	1·6	2·0	3·0
Return Loss (db.)	Network as calculated	33	28	31	35	44	45
	As modified	30	32	35	38	44	45

In both examples it will be noticed that the highest values of return loss are obtained at the highest frequencies. This is necessary, since the cable attenuation increases with frequency.

Notes and Comments

Roll of Honour

The Board of Editors deeply regrets to have to record the deaths of the following members of the Engineering Department .—

While serving with the Armed Forces, including Home Guard

Belfast Telephone Area ..	Long, A.	Unestablished Skilled Workman	Signalman, Royal Corps of Signals
Brighton Telephone Area ..	Keywood, C. J. ..	Unestablished Skilled Workman	Driver, Royal Army Service Corps
Glasgow Telephone Area ..	Drummond, A. ..	Unestablished Skilled Workman	Signalman, Royal Corps of Signals
London Telecommunications Region	Swallow, W. A. ..	Unestablished Skilled Workman	Lance-Corporal, Grenadier Guards
London Telecommunications Region	Wallace, R. ..	Labourer..	Corporal, Royal Corps of Signals
Nottingham Telephone Area	Winstanley, D. ..	Unestablished Skilled Workman	Sergeant, Royal Air Force
Oxford Telephone Area ..	Weeks, W. E. R...	Unestablished Skilled Workman	Able Seaman, Royal Navy
Shrewsbury Telephone Area	Gwilliam, R. G. ..	Unestablished Skilled Workman	Driver, Royal Army Service Corps
Shrewsbury Telephone Area	Wright, A. D. ..	Unestablished Skilled Workman	Sergeant Pilot, Royal Air Force
Stoke-on-Trent Telephone Area	Jones, W. J. ..	Labourer..	Private, North Staffordshire Regiment

Recent Awards

The Board of Editors has learnt with great pleasure of the honours recently conferred on the following members of the Engineering Department :—

While serving with the Armed Forces including Home Guard

Edinburgh Telephone Area	Alexander, A.	Skilled Workman, Class I	Sergeant, Royal Corps of Signals	Military Medal
Leicester Telephone Area	Lawrence, B.	Unestablished Skilled Workman	Corporal, Royal Corps of Signals	Military Medal

While serving with the Civil Defence Forces or on Post Office Duty

Canterbury Telephone Area	Bax, C.	Unestablished Skilled Workman	British Empire Medal
Canterbury Telephone Area	Goodwin, W. O. L.	Inspector	British Empire Medal
Canterbury Telephone Area	Shepherd, A. J. ..	Skilled Workman, Class II ..	British Empire Medal
Plymouth Telephone Area..	Antliff, J. E. E. ..	Skilled Workman, Class I ..	British Empire Medal
Plymouth Telephone Area..	Brown, W. E. ..	Inspector	British Empire Medal
Plymouth Telephone Area..	Stokes, E. P. ..	Skilled Workman, Class I ..	British Empire Medal
Brighton Telephone Area ..	Dilloway, A. C. ..	Unestablished Skilled Workman	Commended by H.M. the King
Brighton Telephone Area ..	Peacock, D. C. ..	Skilled Workman, Class II ..	Commended by H.M. the King
Brighton Telephone Area ..	Pike, E.	Skilled Workman, Class I ..	Commended by H.M. the King
Canterbury Telephone Area	Powell, W. C. ..	Skilled Workman, Class II ..	Commended by H.M. the King
Liverpool Telephone Area..	Blackburn, E. ..	Assistant Engineer	Commended by H.M. the King
Liverpool Telephone Area..	Waring, H. G. ..	Skilled Workman, Class I ..	Commended by H.M. the King
Liverpool Telephone Area..	Wright, F. C. ..	Inspector	Commended by H.M. the King
Plymouth Telephone Area..	Coombe, A. ..	Skilled Workman, Class II ..	Commended by H.M. the King

Reduction in Size

A severe cut in the amount of paper allowed to this Journal will affect the size of the next (April) and subsequent issues. In total a reduction of about 50 per cent. has to be achieved and it is proposed to make the following cuts :—

Advertisements, reduce by		67	per cent.
Supplement,	,,	50	,,
Text,	,,	33	,,

The severe cut in the amount of advertising matter will seriously affect the advertisement revenue, but as this will be offset to some extent by the reduction in printing costs due to the reduced size, it will still be possible to sell the Journal for 1s.

As regards the Supplement, the reduction will be effected by publishing 6 answers from each paper instead of the whole number set. It is hoped to be able to cover all papers in this manner and by choosing the more difficult questions in each paper it is thought that the value of the Supplement as an aid to study will be only slightly impaired.

Regional Notes

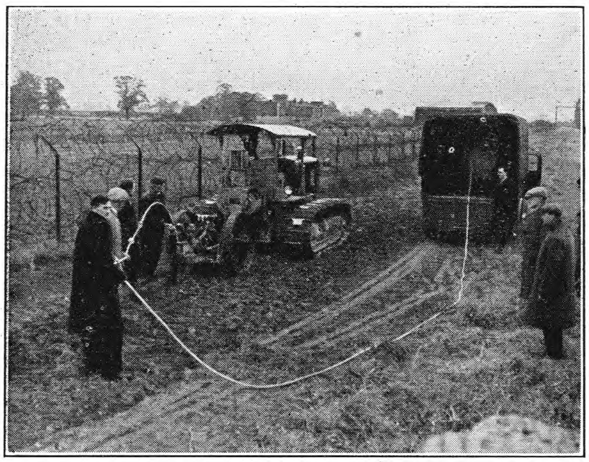
London Telecommunications Region

MOLEDRAINER—MODIFIED USE IN L.T.R. NORTH AREA

By the use of a modified form of agricultural moledrainer, 4,000 yd. of 20/20 P.C.Q.L. cable was laid direct in the ground over a period of three days at a labour expenditure of 200 manhours.

The work was carried out early in October under dry weather conditions and generally the soil was of a loamy clay character, fairly free from flints. The alterations to the standard moledrainer consisted of substituting the cylindrical mole for a flat mole to reduce the earth displacement at the bottom of the slot and an expander attachment at the rear of the coulter so that a 2-in. cable feed pipe following the expander would pass through the cut before it was closed by the loose top soil. The cable feed pipe entered the ground with a bend of 24 in diameter.

The tractive power was supplied by a D.6 Caterpillar Tractor to which the moledrainer was coupled direct. The whole of the cable laying operations, which included approximately 50 yd. of hand digging, were carried out by nine Post Office men and a driver supplied by the owner of the tractor.



For the laying operation the cable drum was set up in a low-speed lorry and the cable end passed through the cable feed pipe with the free end of the cable held by one man. The tractor and moledrainer with a lorry a few yards in advance proceeded along the route which had been previously pegged out.

After the first 10 yd. of operation, the soil resistance was found to be sufficient to hold the cable, which was liberally supplied with petroleum jelly at the input of the feed pipe. The cable was laid at an average depth of 12 in. and the lengths varied according to the specified jointing points. One continuous length of 1,000 yd. was laid.

The cost of the hire of the moledrainer was £1 per day, and it is estimated that tractor hire charges would be £5 per day including the driver. The Post Office gratefully acknowledged the assistance given by the Hertfordshire County Council Agricultural Institute and the loan of the tractor together with driver without charge by Messrs. J. Olding & Co.

S. D.

Welsh and Border Counties Region

SUB-AQUEOUS CABLE LAYING

Two 1,000 yd. sub-aqueous cable links have recently been laid in this Region by direct labour. The cables are laid in each case to span estuaries which lay across the route of a defence cable.

Case I.

At low water this estuary was clear of water with the exception of three channels carrying water from the hills. At the place chosen for the crossing, the bed when exposed consisted of firm sand. Because of these conditions, the cable was placed in position by man-power. The first channel was spanned by a temporary bridge, the second, being only 2–3 ft. in depth at the crossing, was forded. The third had only to be crossed with the shore end of the cable, and this was hauled into position by a line stretched across the channel.

The cable was P.C.Q.T. made and armoured in 250 yd. lengths. The cable was transported from the factory to the site, a distance of 100 miles by road, in a single journey. Each drum of 250 yd. of cable weighed 3 tons.

The cable was removed from the drums with the aid of cable rollers and a lorry. The four lengths were laid out side by side along the road leading from the landing point. On the day chosen for the laying the estuary cleared of water at 11.00 hours. Placing of the cable in position was done by 400 military personnel, 100 to each 250 yd. length of cable. Each party picked up the cable allotted to it and proceeded to the appropriate position in the estuary. The cable was carried on the men's shoulders, each man bearing a dead weight of about 40 lb. All the cable was in position by 12.45 hours.

Stages whose platforms were clear of high water were erected in the estuary prior to the placing of the cable in position. On these stages the joints and parts of the splices were made. The cable was lowered off the stages after overall tests and the splices completed on the sand. The stages were then removed. Observations show the cable to be burying itself with the action of the tides.

Case II.

P.C.Q.T. cable made and armoured in 250 yd. lengths was transported by road from the factory to the site in a single journey. Each drum of 250 yd. of cable weighed 3½ tons.

The cable was laid in two lengths—one of 250 yd. and the other of 750 yd. Both lengths were floated into position. Flotation was provided by 10 gal. oil drums spaced at 9 ft. intervals along the cable. The 250 yd. length was dropped over the side of a jetty with the oil drums attached and was then towed into position by two motor-boats, one at each end. The boats were powered by 25 H.P. petrol engines.

The three 250 yd. lengths making up the second cable were fleated out on the foreshore and jointed and spliced before launching. This cable was floated into position by hauling on the leading end with a 4 in. line attached to a farm tractor on the opposite shore. The oil drums, 244 in number, were removed from the cable from two boats, each with a cable sheave attached to its bow through which the cable was made to pass. The joint between the 750 yd. length and the 250 yd. length was on a promontory clear of water at all except the highest of tides.

S. J. M.

South-Western Region

A SOLID WAX JOINT FOR INTERRUPTION CABLE

Interruption cable (Cable I.R. aerial) is not usually left in service for a prolonged period, but in one case where circuits to an R.A.F. station were provided initially by this means, the underground cabling scheme was so long maturing, due to changes in the Air Ministry's requirements plus war-time delay in carrying out the work, that the interruption cable remained in service for an abnormally long time.

Difficulty was experienced due to failure of the joints which had been taped in accordance with E.I. Lines Overhead F 3501. After six months' service the tape had perished sufficiently to allow the ingress of moisture, which had crept along the cable. The cables were cut back and jointed by the standard method, but failed again within 3 months.

After cutting away the affected portion, a solid wax joint was made as follows :—

The cable was set up as for an ordinary joint in a paper core cable. The tapes were removed from each conductor for approximately 2 ins. and the rubber removed about 1 in. Paper sleeves were used on each conductor and a twisted and soldered joint was made. The jointed wires were tied to prevent the paper sleeves from slipping. On completion of this jointing a split lead sleeve was placed around the jointed wires, since working circuits were involved. The outside rubber sheath projected approximately 2 ins. inside the end of the sleeve. The ends of the sleeve were then dressed down tightly on to the rubber sheath and the seam closed. Three holes were then made in the top of the sleeve, two at approximately 3 ins. from each end, and one about ½ in. in diameter in the centre. Molten paraffin wax was then poured into the sleeve through the centre hole until the wax reached the two end holes. These were sealed and more wax was poured in until the sleeve was filled and the centre hole was then sealed. It is probably not necessary to seal these holes, but this was done by plugging the holes with lamp cotton and then sealing with solder.

The insulation resistance was tested the following day and showed infinity. The joint was in service for over 12 months in very exposed conditions and when examined recently the insulation resistance was still infinity and no trouble has been experienced with the joint at any time since it was formed.

On recovery of the cable the joint was opened and as far as could be seen the rubber insulation had not been affected in any way by the hot wax.

Midland Region

A P.I. AT ADDIS ABABA

B. H. Berresford, formerly a P.I. stationed at Birmingham, now with the Royal Corps of Signals, was made responsible for the automatic exchange at Addis Ababa when the British Forces occupied the town. He writes in a letter :—

"When I first arrived here I was placed in sole command of the telephone system — an automatic one, in fact a Bell rotary 1,500 line effort. Not much compared with Birmingham Central, I admit, but a big enough task when everything is written in Italian and one has only two ex-P.O. linemen as assistants. However, by sheer luck and with the aid of my putrid French, I managed to get the thing organised, and in due course connected up about 120 military subscribers.

I instituted advice notes, a directory enquiry, and directory issue department, fault control centre and all modern inconveniences ; the only thing I did not have, I'm sorry to say, was an estimate group." C. T. L.

North-Eastern Region.

PROVISION OF UNDERGROUND PLANT BY USE OF MECHANICAL AIDS

Shortage of labour coupled with an abnormally heavy works programme has necessitated the exploration of methods by which underground plant could be provided at a considerably accelerated rate of progress.

The Allen Parsons Bucket Excavator, referred to in the Home Counties Region notes of the October issue, has been in use in this Region and has given excellent service on roads where wide grass margins exist, but for works on enclosed sites a considerably greater rate of progress can be achieved by other means.

Experiments were carried out using the Calliper plough, which consists of a caterpillar tractor driven by 110 h.p. Diesel engines to which one of two attachments can be made, i.e. the plough or the rooter. The latter is in the form of cutting tool some 18 in. in depth and length and 4 in. wide, and breaks up the subsoil by a run up and down tracks to be excavated. The plough then proceeds over the tracks making a trench approximately 2 ft. 6 in. wide and 2 ft. 4 in. deep in V formation, the displaced earth being piled up at the sides of the trench. Allowing for stoppages, 1,000 yd. per hour is easily excavated. Some "bottoming up" and "levelling" is necessary, and this is done by hand.

The main difficulty is to provide sufficient labour for duct laying to keep up with the length of trench excavated by the plough. It has been found that the best results are obtained by ploughing in advance, then moving the machine to the next site, and later returning to Site 1 for filling in which is carried out by an angle or bull dozer attached to the tractor pushing the earth back into the trench after the duct has been laid.

Approximately 90,000 yd. of duct has been laid by the aforementioned means and the average output of completed work, including ductwork, has been 1,000 yd. per day.

With a view to obviating the difficulty of providing labour for duct laying further investigation has been made into the possibility of adapting the rooter to the purpose of laying the cable direct, and very promising results have been obtained.

It has been explained previously that the rooter is a cutting tool 18 in. deep, 18 in. long, and 4 in. wide, mounted on a strong chassis. The adaptation for cable laying consists of the mounting of a securely bolted platform at the rear of the machine to carry cable jacks which are also firmly bolted to the platform. A funnel through which the cable is fed from the drum to the rooter was made and fixed to the rooter. The funnel also acts as a container for petroleum jelly.

Two sheaves were fitted to the rooter itself to maintain the proper curvature of the cable entering the ground. In the bottom rear of the rooter, a 4 in. cylinder was fitted which, in effect, produced a mole drainer which had the necessary power to deal with subsoil in which an ordinary mole drainer would be ineffective.

In the trial under review a 20pr./20 P.C.Q.L. cable was laid in a 260 yd. section, the subsoil being 14 in. sand and 4 in. soft sandstone, and the actual operation of excavating and laying the cable at a depth of 18 in. took 15 minutes. Six Post Office men and two machine operators were employed on the job. Later the cable was tested for insulation, contacts and conductivity. All these tests were satisfactory and a pressure of 22 lb. per sq. in. was maintained for 24 hours. The cable was dug out in a few places but no sheath damage was observed.

Further tests are in progress, all of which promise satisfactory results. It is considered that a speed of 880 yd. per hour on straight runs can be considered a conservative estimate. A.J.H.

Staff Changes

Promotions

From Exec. Engr. to Asst. Staff Engr.

Name	Region	Date
Marr, H. R.	L.T.R. to E.-in-C.O.	15.11.41
Booth, C. F.	E.-in-C.O.	15.11.41

From Asst. Engr. to Exec. Engr.

Name	Region	Date
Wallworth, A. R.	E.-in-C.O.	29.8.41
Cameron, C. J.	Test Section (B'ham) to E.-in-C.O.	27.9.41
Worthington, C. E.	N. Ire. Reg.	7 11.41

From Chief Insp. to Asst. Engr.

Name	Region	Date
Birnie, R. C.	Scot. Reg. to E.-in-C.O.	24.8.41
Goman, L. V.	E.-in-C.O. to H.C. Reg.	8.9.41
Frost, J.	N.W.R.	8.9.41
Holliday, R. F.	L.T.R. to E.-in-C.O.	8.9.41
Chamberlain, A. E.	E.-in-C.O. to Rugby R/S	1.10.41
Redington, F. D.	E.-in-C.O.	16.10.41
Chubb, E.	E.-in-C.O. to Scot. Reg.	23.10.41
Spooner, J. W.	N.E. Reg.	7.11.41
Mann, R. G.	E.-in-C.O.	13.11.41

From Chief Insp. to Chief Insp. with Allowance

Name	Region	Date
Shipperbottam, F.	N.W. Reg.	2.9.41

From Insp. to Chief Insp.

Name	Region	Date
Norfolk, E. W.	E.-in-C.O.	1.10.41
Clarke, W. J. F.	S.W. Reg. to E.-in-C.O.	1.10.41
Campbell, A. D.	E.-in-C.O.	1.10.41
Plant, F.	N.W. Reg.	2.3.41
McWalter, W. V.	Scot. Reg. to E.-in-C.O.	13.7.41
Cheetham, H.	N.W. Reg.	18.5.41
Dickenson, C. R.	S.W. Reg.	3.11.40
Conn, C. A.	E.-in-C.O. (Seconded to Contracts Dept.)	1.10.41
Thorley, C. B.	Mid. Reg.	20.10.40
Stainer, W. H.	H.C. Reg.	7.9.41
Atkin, E. W.	H.C. Reg.	2.11.41
Willis, S. T.	E.-in-C.O.	19.1.41
Helm, S.	E.-in-C.O.	26.10.41
Counsell, A. J. T.	E.-in-C.O. to L.T.R.	8.9.41
Tyler, H. H.	H.C. Reg.	15.10.40
Crump, S. G.	H.C. Reg.	18.8.41
Belk, A.	N.E. Reg.	To be fixed later
Richardson, D. B.	H.C. Reg.	7.9.41
Fryatt, M. E.	H.C. Reg.	9.11.41
McKendrick, W.	Scot. Reg.	21.9.41
Tuck, R. O.	Mid. Reg. to N.W. Reg.	To be fixed later
Gray, W.	E.-in-C.O.	26.10.41
Brown, E. H. K.	E.-in-C.O.	16.10.41
Rogers, F.	S.W. Reg.	2.8.41
Bickerton, J.	N.W. Reg.	To be fixed later
Gibson, J.	Scot. Reg.	29.10.41

From S.W.I. to Insp.

Name	Region	Date
Pay, L.	Test Section (B'ham) to E.-in-C.O.	6.7.41
Roach, J. D.	W. & B.C. Reg. to E.-in-C.O.	6.7.41
Boast, T. W.	N.E. Reg. to E.-in-C.O	7.7.41
Walker, W.	E.-in-C.O.	1.8.41
Page, A. A.	E.-in-C.O.	17.8.41
Stollard, A. C.	E.-in-C.O.	17.8.41
Wilmott, W. H.	E.-in-C.O.	20.8.41

From S.W.I to Insp.—continued

Name	Region	Date
Pitt, R. F.	E.-in-C.O.	31.8.41
Braine, F. A.	E.-in-C.O.	17.8.41
Bennett, J. B.	E.-in-C.O.	1.6.41
Carter, W. A.	E.-in-C.O.	17.8.41
Goddard, W. H.	E.-in-C.O.	31.8.41
Stanton, C. G.	E.-in-C.O.	1.6.41
Shinn, E.	E.-in-C.O.	1.6.41
Dowling, A. G.	E.-in-C.O.	13.7.41
Edwards, A. W. G.	E.-in-C.O.	25.3.41
Campbell, G. R.	Scot. Reg. to E.-in-C.O.	20.7.41
Holt, J. B.	W. & B.C. Reg. to E.-in-C.O.	13.7.41
Flaxman, R. M.	Mid. Reg. to E.-in-C.O.	20.7.41
Whitby, R. A.	Mid. Reg. to E.-in-C.O.	3.8.41
Lewis, R. E.	W. & B.C. Reg. to E.-in-C.O.	13.7.41
Stephens, C. T.	W. & B.C. Reg. to E.-in-C.O.	20.7.41
Weston, F. T.	W. & B.C. Reg. to E.-in-C.O.	13.7.41
Ewen, A. B.	E.-in-C.O.	23.8.41
Genna, W. N.	E.-in-C.O.	23.8.41
Martin, A. J.	H.C. Reg. to E.-in-C.O.	3.8.41
Powell, A. R.	N.W. Reg. to E.-in-C.O.	22.6.41
Gairns, A.	E.-in-C.O.	15.9.41
Mayne, W. J.	L.T.R. to E.-in-C.O.	17.8.41
Bignell, C. C.	L.T.R. to E.-in-C.O.	9.8.41
Menday, F. G.	L.T.R. to E.-in-C.O.	21.9.41
Andrews, H. H.	E.-in-C.O.	5.10.41
Proud, R. D.	E.-in-C.O.	24.8.41
Barker, D. A. G.	E.-in-C.O.	5.10.41
Barker, R. C.	E.-in-C.O.	5.10.41
Walker, S. H.	E.-in-C.O.	5.10.41
Craggs, J. F.	E.-in-C.O.	13.7.41
Pugh, S. M.	E.-in-C.O.	5.10.41
Butterworth, B. B.	E.-in-C.O.	24.8.41
Calkin, S. W.	E.-in-C.O.	5.10.41
Thomas, G. W.	E.-in-C.O.	5.10.41
Tissington, R. S.	E.-in-C.O.	13.7.41
Carden, R. W. G.	E.-in-C.O.	5.10.41
Sheppard, S. H.	E.-in-C.O.	19.5.41
North, J. W.	E.-in-C.O.	24.7.41
Moyler, H.	E.-in-C.O.	24.7.41
Slight, C. G. H.	E.-in-C.O.	10.10.41
Gunn, D. H.	E.-in-C.O.	6.5.41
Stewart, H. C.	Test Sect. (B'ham) to Test Sect. (Ldn.)	4.10.41
Howard, F.	E.-in-C.O.	5.11.41
Lewis, R. A.	E.-in-C.O.	5.11.41
Francis, L. G. M.	E.-in-C.O.	5.11.41
Enwright, J. A.	E.-in-C.O.	5.11.41
Clarkson, J. W.	Scot. Reg. to E.-in-C.O.	12.10.41
Housham, F. A.	L.T.R. to E.-in-C.O.	6.10.41

From Insp. to Asst. Traffic Supt.

Name	Region	Date
Stevens, C. A.	E.-in-C.O. to Norwich Area	2.9.41

From U.S.W. to Asst. Phys.

Name	Region	Date
Roberts, T. E.	Test Section (B'ham) to Test Section (Ldn.)	26.9.41

Transfers

Asst. Engineer.

Name	Region	Date
Holliday, R. F.	E.-in-C.O. to L.T.R.	10.11.41

Inspector.

Name	Region	Date
Middleton, K. M.	St. Erth R./S. to St. Albans R./S.	20.10.41

Inspector—continued

Name	Region	Date
Coombes, R. H.	E.-in-C.O. to S.W. Reg.	13.10.41
Foskett, G. E.	E.-in-C.O. to Scot. Reg.	17.10.41
Stanley, J. W.	E.-in-C.O. to W. & B.C. Reg.	6.11.41
Hughes, J. W.	E.-in-C.O. to. L.T.R.	1.5.41

Retirements

Name	Region	Date	Name	Region	Date
Asst. Staff Engr.			*Chief Insp.—continued*		
Kingston, J. R.	E.-in-C.O.	1.11.41	Impey, A. B.	N.W. Reg.	31.10.41
M.T.O. Cl. III.			*Inspector.*		
Bunt, F. H. J.	E.-in-C.O.	31.5.41	Keyworth, F.	E.-in-C.O.	30.9.41
Chief Insp.			*Repeater Officer Cl. I.*		
Mackay, J. W.	N.W. Reg.	1.9.41	Stewart, J. F.	W. & B.C. Reg.	1.9.41
Rathbone, W. F.	Mid. Reg.	14.7.41	*Acting Chief Officer.*		
Humphrey, E. E.	E.-in-C.O.	26.9.41	Elston, F. A.	H.M.T.S. (resigned)	31.8.41
Jeffries, S. L.	L.T.R.	9.10.41			

Deaths

Name	Region	Date	Name	Region	Date
Asst. Engr.			*Insp.*		
Burnett, H. J.	L.T.R.	5.10.41	Rice, H. J.	E.-in-C.O.	4.10.41
Chief Insp.			*Acting Insp. (Unest).*		
Hutchinson, C. H.	L.T.R.	1.11.41	Williams, E. R.	E.-in-C.O.	19.8.41

CLERICAL GRADES

Promotions

Name	Region	Date	Name	Region	Date
From E. O. to S.O.			*From C.O. to E.O.—continued*		
Johnson, P. B. (Notionally *in absentia*)	E.-in-C.O.	12.11.41	West, A. M. (Notionally *in absentia*)	E.-in-C.O.	31.10.41
Bourne, H. T. B.	E.-in-C.O.	12.11.41	Evans, Miss C. M.	E.-in-C.O.	31.10.41
From C.O. to E.O.			Richard, Miss I. E.	E.-in.C.O.	31.10.41
Sellars, G.	N.E. Reg. to E.-in-C.O.	19.10.41	Pearn, Miss M. A.	E.-in-C.O.	18.11.41
			Fyffe, Miss H. G. (Notionally *in absentia*)	E.-in-C.O.	18.11.41

Retirements

Name	Region	Date	Name	Region	Date
Buzzing, W. F.	Staff Officer E.-in-C.O.	11.11.41			

Note.—All promotions during the war are on an " Acting " basis.

The Board of Editors is not responsible for the statements made or the opinions expressed in any of the articles in this Journal, unless such statement is made specifically by the Board.

Communications

All Communications should be addressed to the Managing Editor, *P.O.E.E. Journal*, Engineer-in-Chief's Office, Alder House, Aldersgate Street, London, E.C.1. Telephone : HEAdquarters 1234. Remittances should be made payable to " *The P.O.E.E. Journal* " and should be crossed " & Co."

Binding Cases

Cases for binding are available, and may be obtained from the Local Agents for 1s. 9d. Subscribers can have their copies of Volumes bound, at a cost of 3s., by sending the complete set of parts to the Local Agents or to the *P.O.E.E. Journal*, Engineer-in-Chief's Office, Alder House, Aldersgate Street, London, E.C.1. Orders for binding for Vols. 1-19 should indicate whether the original binding case with black lettering, or the later pattern with gold, is required. Cases with gold lettering are the only type stocked from Vol. 20 onwards.

Back Numbers

The price of the Journal, which is published quarterly, is 1s. (1s. 3d. post free) per copy, or 5s. per annum post free. Back numbers can be supplied, subject to availability of stocks, at 1s. each (1s. 3d. post free). Orders for back numbers may be sent to the Local Agents or to the Publishers.

Advertisements

All communications relating to space reservations should be addressed to the Advertisement Editor, *P.O.E.E. Journal*, Alder House, Aldersgate Street, London, E.C.1. Communications regarding advertisement copy, proofs, etc., should be addressed to the Publishers, Messrs. Birch & Whittington (Prop. Dorling & Co. [Epsom], Ltd.), 49 Upper High Street, Epsom, Surrey.

Post Office Electrical Engineers' Journal

Volume XXXIV, April 1941—January 1942

INDEX

PAGE NO.

A

Addey, F. Long Distance Position Finding by D.F. .. 94
Alkaline type C.E.M.F. Cells 9
Amplifier No. 32 and Associated Equipment, The New 60
Application of 12-Circuit Carrier Telephony to Existing Cables, The 12
Attenuation and Impedance of Single Coaxial Cables, The 66

B

Bickley, H. D. A Note on Amplitude, Phase and Frequency Modulation 42
Booth, C. F., and G. Gregory. The Generation and Distribution of a Standard 1 kc/s Synchronising Signal 156
Brockbank, R. A. The Attenuation and Impedance of Single Coaxial Cables 66

C

Carrier System No. 7—
Part I 101
Part II 161
Carrier Telephony, The Application of 12-Circuit to Existing Cables 12
Carter, R. O., and D. L. Richards. Principles of Design of Smoothing Chokes 118
Casterton, E. J. The Post Office and Public Address .. 26
Catt, L. H. Alkaline type C.E.M.F. Cells 9
Cells, Alkaline type C.E.M.F. 9
C.E.M.F. Cells, Alkaline type 9
Chandler, W. W., and B. M. Hadfield. An Impulse Generator 31
Chokes, Principles of Design of Smoothing 118
Coaxial Cables, The Attenuation and Impedance of Single 66
Coote, F. Glasgow Director System 51
Cyclometer, The Phase 115
12-Circuit Carrier Telephony, The Application of, to Existing Cables 12

D

D.F., Long Distance Position Finding by 94
Director System, Glasgow 51
Doust, J. F., and H. J. Josephs. A Simple Introduction to the use of Statistics in Telecommunications Engineering 36, 79, 139, 173

E

Economic Design of Manholes, The—
Part I. —Estimation of Loads 1
Part II. —Reinforced Concrete Theory 85
Part III.—Design of a Typical Manhole 133
Equipment for Cutting Steel and Wrought Iron Pipes containing Working Cables 184

F

Fuels for Road Vehicles, A Review of War-Time .. 151

PAGE NO.

G

Generation and Distribution of a Standard 1 kc/s Synchronising Signal, The 156
Glasgow Director System 51
Glover, D. W., and E. A. Taylor. A Review of War-Time Fuels for Road Vehicles 151
Gregory, G., and C. F. Booth. The Generation and Distribution of a Standard 1 kc/s Synchronising Signal 156

H

Hadfield, B. M., and W. W. Chandler. An Impulse Generator 31
Harding, J. P. The Economic Design of Manholes 1, 85, 133

I

Impedance Matching Networks for Unloaded Cable .. 187
Impedance of Single Coaxial Cables, The Attenuation and 66
Impulse Generator, An 31
Institution of Post Office Electrical Engineers, The 47, 148

J

Jackman, A. J., and N. F. Sephton. New Tools for Identifying Wires in Cable Joints 169
Jackman, A. J., and R. A. Seymour. The Application of 12-Circuit Carrier Telephony to Existing Cables 12
Josephs, H. J., and J. F. Doust. A simple Introduction to the use of Statistics in Telecommunications Engineering 36, 79, 139, 173

K

Kilvington, T. E., and H. T. Mitchell. The Phase Cyclometer 115

L

Leigh, H. The Production of the *Post Office Electrical Engineers' Journal* 126
Local Centre Notes 98
Long Distance Position Finding by D. F. 94

M

Manholes, The Economic Design of 1, 85, 133
Materials in Telecommunications, Modern .. 19, 72, 179
Mitchell, H. T., and T. Kilvington. The Phase Cyclometer 115
Modern Materials in Telecommunications—
Part IV.—Magnetic Materials 19
Part V.—Metallic Conductors 72
Part VIa.—Semi-Conductors 179
Modulation, A Note on Amplitude, Phase and Frequency 42

N

	PAGE NO.
Networks for Unloaded Cable, Impedance Matching..	187
New Amplifier No. 32 and Associated Equipment, The	60
New Tools for Identifying Wires in Cable Joints ..	169
Note on Amplitude, Phase and Frequency Modulation, A	42
Notes and Comments	46, 96, 145, 190
Notes, Local Centre	98
Notes, Regional	48, 98, 147, 191

P

Phase Cyclometer, The	115
Phillips, R. S. Services in a Modern P.O. Building ..	109
Plumpton, F. E. Equipment for Cutting Steel and Wrought Iron Pipes Containing Cables	184
Position Finding by D.F., Long Distance	94
Post Office and Public Address, The	26
Post Office Electrical Engineers, The Institution of	47, 148
Post Office Electrical Engineers' Journal, The Production of the	126
Principles of Design of Smoothing Chokes	118
Production of the *Post Office Electrical Engineers' Journal*, The	126
Public Address, The Post Office and	26

R

Radley, W. G., C. E. Richards, E. A. Speight and E. V. Walker. Modern Materials in Telecommunications	19, 72, 179
Regional Notes	48, 98, 147, 191
Review of War-Time Fuels for Road Vehicles, A ..	151
Richards, C. E., W. G. Radley, E. A. Speight and E. V. Walker. Modern Materials in Telecommunications	19, 72, 179
Richards, D. L., and R. O. Carter. Principles of Design of Smoothing Chokes	118

S

Sephton, N. F., and A. J. Jackman. New Tools for Identifying Wires in Cable Joints.	169
Services in a Modern P.O. Building	109
Seymour, R. A., and A. J. Jackman. The Application of 12-Circuit Carrier Telephony to Existing Cables	12
Simple Introduction to the use of Statistics in Telecommunications Engineering, A—	
Part I.—The Normal Probability Law	36
Part II.—Analysis of Small Samples	79
Part III.—The Poisson Probability Law ..	139
Part IV.—Correlation and Regression	173
Smoothing Chokes, Principles of Design of	118
Speight, E. A., W. G. Radley, C. E. Richards and E. V. Walker. Modern Materials in Telecommunications	19, 72, 179
Staff Changes	49, 99, 149, 193
Statistics in Telecommunications Engineering, A Simple Introduction to the Use of ..	36, 79, 139, 173
Steel and Wrought Iron Pipes Containing Cables, Equipment for Cutting	184
Synchronising Signal, The Generation and Distribution of a Standard 1 kc/s	156

T

Taylor, E. A., and D. W. Glover. A Review of War-Time Fuels for Road Vehicles	151
Taylor, F. J. D. Carrier System No. 7	101, 161
Tucker, D. G. Impedance Matching Networks for Unloaded Cable	187

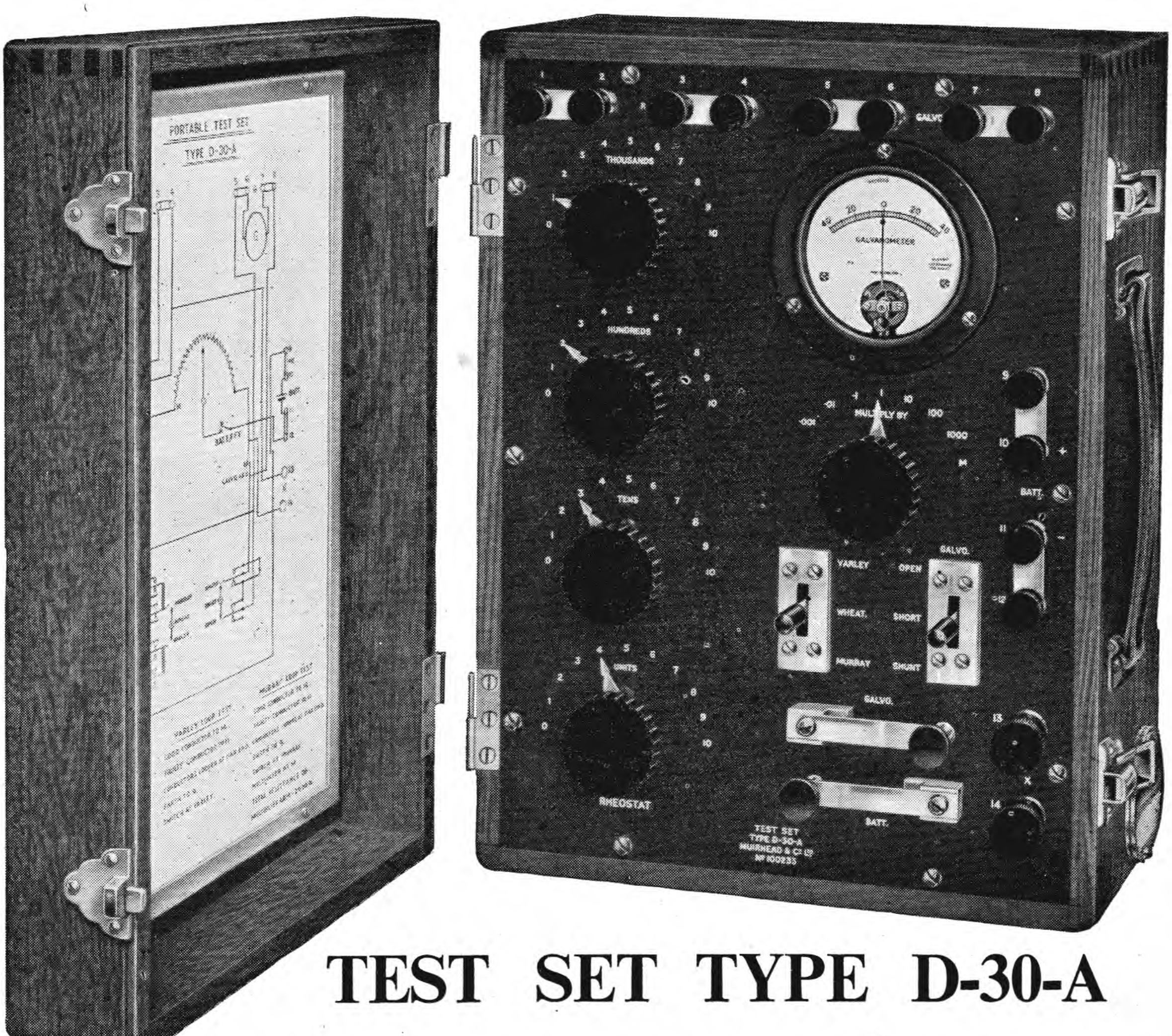
U

Unloaded Cable, Impedance Matching Networks for..	187

W

Walker, E. V., W. G. Radley, C. E. Richards and E. A. Speight. Modern Materials in Telecommunications	19, 72, 179
Williams, H. The new Amplifier No. 32 and Associated Equipment	60
Wires in Cable Joints, New Tools for Identifying ..	169

NOTE.—The fact that goods made of raw material in short supply owing to war conditions are advertised in this Journal should not be taken as an indication that they are necessarily available for export.



TEST SET TYPE D-30-A

RANGE - - ·001 ohm to 11·11 megohms

DIMENSIONS - - - 12½″ x 9½″ x 6″

WEIGHT - - - - - - 12 lbs.

A descriptive bulletin will be supplied on request.

A portable test set for general resistance measurements and for fault location on lines and cables—May be used for A.C. tests with suitable power source and detector—Resistance decades and galvanometer can be used externally.

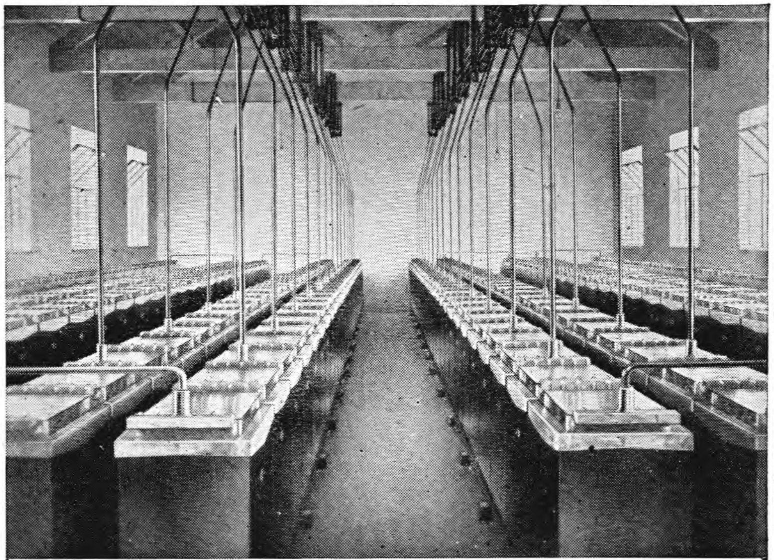
MUIRHEAD

MUIRHEAD AND COMPANY LIMITED, ELMERS END, BECKENHAM, KENT. TELEPHONE : BECKENHAM 0041-0042

FOR OVER 60 YEARS DESIGNERS AND MAKERS OF PRECISION INSTRUMENTS

C.R.C.29

ALTON Batteries of Merit



ALTON Battery of 264 DLWII *Type Cells at a Corporation Electricity Works*

CONSTANCY . . .

Consider it a great task
to be always the same man.
Seneca.

When the Alton organization was founded it was outside any Association. It has always remained outside . . . . The Company had as its aim the production of the very best it could make—Alton Batteries of Merit—to be sold at the lowest prices consistent with profitable trading. It has never wavered from this aim. Always it has sought strength in a consistent and simple policy. And strong it has become.

THE ALTON BATTERY Co. LTD.
ALTON · HANTS
★
ALTON & FULLER
BATTERIES
Telephone: ALTON 2267 & 2268
Telegrams: "BATTERY, ALTON"

High Quality mouldings

Ebonestos have produced many of the finest mouldings manufactured in compositions, Bakelite, Urea, Diakon, and other synthetic resins. For the past 42 years, our reputation for finish and accuracy has been second to none.
Let us know your moulding requirements, and we shall be pleased to send one of our technical experts to discuss the matter with you, or, if you prefer it, meet you at our factory.

Moulders to the General Post Office, Admiralty, Air Ministry and other Government Departments.

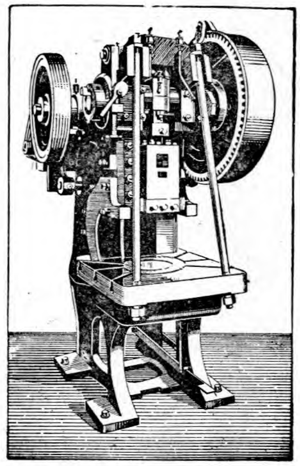
EBONESTOS
INDUSTRIES LIMITED
EXCELSIOR WORKS, ROLLINS STREET, LONDON, S.E.15 *Telephone: New Cross 1913 (6 lines)*

NO WAITING FOR CEMENT TO DRY

if you use

RAWLBOLTS

the speediest method of machine fixing yet devised

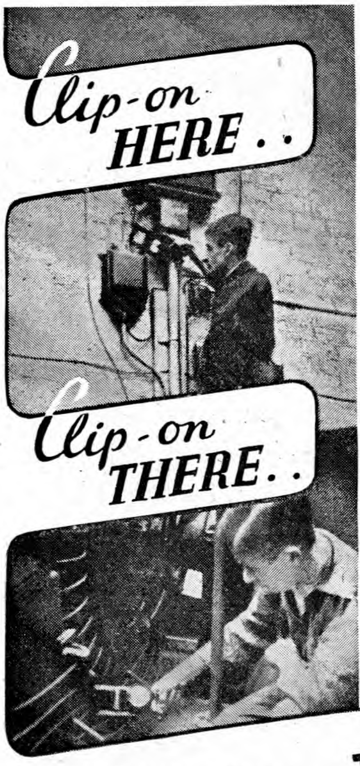


More and more firms are using Rawlbolts for really heavy fixing work. Rawlbolts require no grouting and only a small hole is needed to accommodate them. They can be fixed immediately as there is no waiting for cement to dry. Not only is the Rawlbolt speedy, and therefore very economical, but it is absolutely reliable, too. The two types of Rawlbolts solve every fixing problem with bolts, while the fact that they are available with pipe clips, round and square hooks and eye bolts still further increases their scope and utility. Rawlbolts are sold in stock sizes from ¼" to ¾" diameter.

RAWLBOLTS

Fully illustrated descriptive literature will be supplied on request to:—
THE RAWLPLUG CO. LTD., CROMWELL ROAD, LONDON, S.W.7

B255



Clip-on almost EVERYWHERE

The range of the instrument is changed by a half turn of the switch.

Ranges Available

0 — 10 —	50	amp.
0 — 20 —	100	,,
0 — 50 —	250	,,
0 — 100 —	500	,,
0 — 200 —	1000	,,

FOR CHECKING CURRENT IN BUSBARS, FUSES & CABLES
UP TO 2⅛" DIAMETER

FERRANTI
DUAL RANGE Clip-on AMMETER

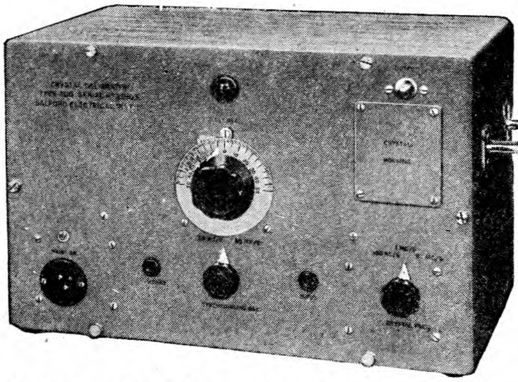
FERRANTI LTD., HOLLINWOOD, LANCS.
London Office: Bush House, Aldwych, W.C.2.

FI 44a

INDEX TO ADVERTISERS

Alton Battery Co., Ltd., The xii
Automatic Coil Winder & Electrical Equipment Co., Ltd. iii
Automatic Telephone & Electric Co., Ltd. xiii
Caplin Engineering Co., Ltd. viii
Chloride Electrical Storage Co., Ltd., The iv
Creed & Co., Ltd. xix
Ebonestos Industries, Ltd. xiv
Edison Swan Electric Co., Ltd., The ii
Elliott Bros. (London), Ltd. xxi
Ericsson Telephones, Ltd. .. .. xvi & xvii
Ferranti, Ltd. xiv
General Electric Co., Ltd., The ii
Hall Telephone Accessories (1928), Ltd. xv
Institution of Post Office Electrical Engineers, The .. xx
Londex, Ltd. xv
Muirhead & Co., Ltd. xi
Multicore Solders, Ltd. xiv
Nife Batteries, Ltd. ix
Pirelli-General Cable Works, Ltd. xxii
Rawlplug Co., Ltd., The xiv
Siemens Brothers & Co., Ltd. .. .. .. vi & vii
Smith, Frederick & Co. xxi
Sullivan, H. W., Ltd. v
Telephone Manufacturing Company, Ltd. x
Turner, Ernest xviii
United Insulator Co., Ltd. v
Westinghouse Brake & Signal Co., Ltd. xv

G.E.C. CRYSTAL CALIBRATOR



A new precision instrument for the rapid and accurate checking and adjustment of radio frequency oscillators, receivers, transmitters and similar apparatus.

It is crystal controlled and A.C. mains operated.

Ask for full information from :

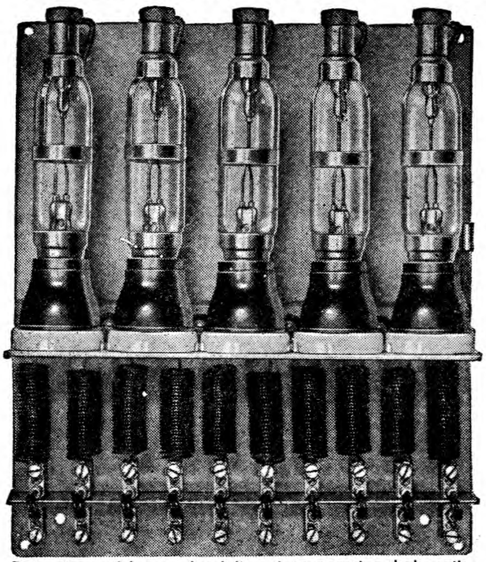
SALFORD ELECTRICAL INSTRUMENTS LTD.

SALFORD. Telephone : Blackfriars 6688 (6 lines). Telegrams and Cables : " SPARKLESS, MANCHESTER "

PROPRIETORS: THE GENERAL ELECTRIC CO., LTD.

EDISWAN

TELEPHONE LINE PROTECTOR PANELS



5-circuit panel for overhead lines incorporating choke coils, spark gaps, etc.

EDISWAN-SHOTTER-GREETHAM PATENT (British Patent No. 353924)

for the protection of telephone systems against surges induced by faults on neighbouring power lines

Of the difficulties attendant upon the employment of overhead systems one of the most serious is to ensure uninterrupted working of the telephone system, by providing adequate protection against induced surges caused by switching or line faults in adjacent power lines or by lightning.

The Ediswan Patent Protectors provide the solution. They are inert at the normal working pressure of the telephone line, they keep the voltage on the line down to a pre-determined figure by providing a path of low resistance to earth whereby the surge is cleared and they again become inert immediately the surge is cleared.

They ensure simultaneous discharge of both lines and are capable of clearing heavy discharges without detriment to the system or the protector.

Ediswan Telephone Line Protectors have now been in use by Supply Companies for many years.

THE EDISON SWAN ELECTRIC CO. LTD., 155 CHARING CROSS ROAD, LONDON, W.C.2

T.E.L.

Printed by SANDERS PHILLIPS & CO., LTD., The Baynard Press, Chryssell Road, London, S.W.9, and Published by BIRCH & WHITTINGTON (*Prop. Dorling & Co. [Epsom], Ltd.*), Epsom, Surrey.