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Maintenance of Multi-Channel Carrier Telephone Systems

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F. O. MORRELL, B.Sc., A.M.I.E.E.

A Paper read before the London Centre of the Institution on 5th April, 1948, and at other Centres during the Session.

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SUMMARY.

The effect of faults in multi-channel telephone systems is such that preventive maintenance—routine testing and overhaul—must form a large part of the total maintenance effort. Maintenance organisation is based on a number of independent controls, each of which directs the work done on the section for which it is responsible. Examination of faults discloses weaknesses in existing equipment, and by far the most important of these are unsound connections resulting from "dry" soldered joints, base metal contacts and the presence of dust and dirt. The cost and organisation of maintenance must be considered at every stage in the design, construction and installation of the equipment. Very much higher standards of reliability are considered essential in future systems, and an attempt is made to lay down some general principles of good design from the point of view of maintenance. At the present time there is no ready means of assessing the efficiency of maintenance in a repeater station. The application of statistical quality control is being studied with a view to meeting this need.

1. INTRODUCTION.

It is about ten years since, after some initial experiments between Bristol and Plymouth, it was decided to equip all backbone telephone circuit routes in this country with multichannel carrier systems. Shortly afterwards the first coaxial cable system, between London and Birmingham, was put into service, and in the intervening years growth of both systems has been such that there are now (January, 1948) 521 working 12-circuit groups in service. About one eighth of these are carried wholly in coaxial cable ; a few are working partly in coaxial and partly in quad-type cable, and the remainder, about 400 in number, wholly in quad-type cable. The 1042 carrier terminals are installed in 89 stations. There are also 222 intermediate repeater stations of which 179 are normally unattended. The capital cost of the equipment and buildings was approximately £3.5 million, and it is important to realise that the capitalised cost of maintenance charges over a period of 20 years is rather more than this. Fig. 1 is a map of existing and proposed carrier and coaxial cable systems in Great Britain and Northern Ireland.

The maintenance of this equipment is therefore a task of the first magnitude. Unfortunately the bulk of it was installed during the war, and a maintenance organisation had to be built up not only rapidly but also at a time when it was impossible to give the problem adequate study. Since the war, attention has been concentrated on the singular maintenance problems presented by multichannel systems. Some fairly definite general principles have been worked out, and have been and are the subject of experimental trials. It is intended in this paper to describe some of this work.

It must be confessed, with regret, that it has not been possible to include in the paper anything more than mere reference to some of the most important aspects of multichannel telephone system maintenance, namely, the maintenance of the power equipment and cable network and the training of maintenance staff. On each of these subjects a paper could be read and discussed with advantage.

The paper is devoted to the maintenance of 12-circuit carrier systems operated by the British Post Office on quad-type and coaxial cables. The equipment itself has already been fully described in the Printed Papers and the Journal of this Institution (see Bibliography).

2. PURPOSE AND SCOPE OF MAINTENANCE.

The maintenance engineers' aim is to keep the transmission characteristics of circuits within the limits prescribed for their use, and he does this by ensuring, to the best of his ability, firstly that the circuits do not go beyond these limits and secondly that if they do they are quickly brought back. It follows that his work must be partly preventive and partly corrective.

For each piece of apparatus there is an optimum division of the available effort between preventive and corrective maintenance. Without attempting to say exactly how it should be divided in any particular case, the division must obviously depend very largely on the effect of a fault on the service. In this respect there is a profound difference between faults on audio and carrier systems, for whereas a fault on an audio repeater circuit causes the loss of but one circuit, a multichannel system fault may affect hundreds of circuits. If the average time audio circuits are out of order is, say, 2%, the proportion of circuits out of order at any one time is not likely to exceed 5 or 6% whilst the same average lost time on circuits carried in a coaxial system means that all circuits may be out of order at certain periods. The effect of such a fault is comparable with that of a complete cable breakdown and is far more serious than the loss of a few circuits. Coaxial systems are installed only on busy routes which in the busy hour have little margin against overload ; the loss of circuits may cause a route to go into delay, with the result that the remaining circuits are used less efficiently ; additional operating staff is required in the trunk exchange and the repercussions are felt not only on the route in question but on many other routes as well. It follows therefore that, as compared with audio plant, it is much more important to prevent the occurrence of faults on multichannel plant, and preventive maintenance must constitute the bulk of the maintenance work.

The prescribed standards within which circuits must be maintained are principally standards of overall equivalent, but noise and distortion are also

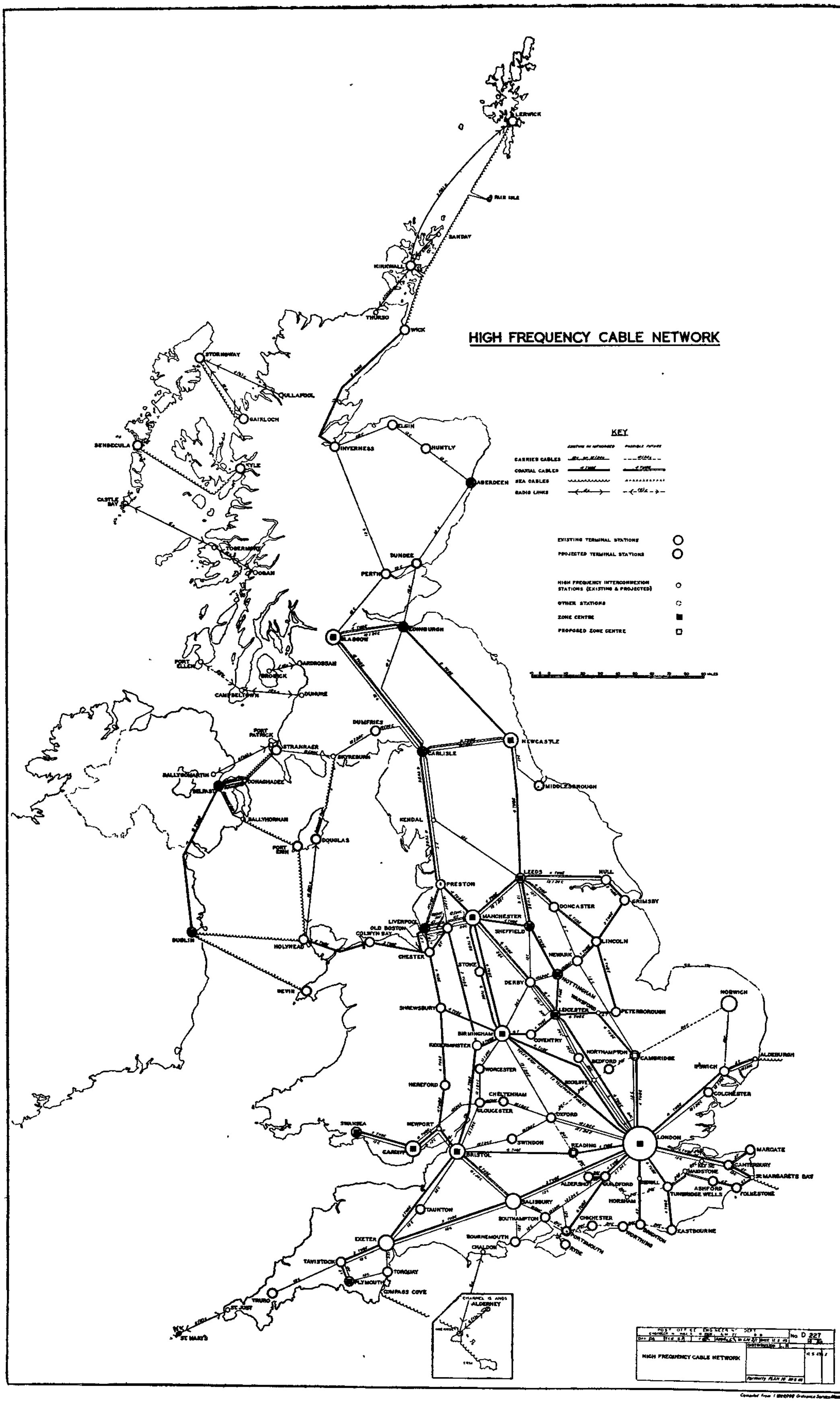

FIG. 1.—MULTI-CHANNEL CARRIER SYSTEMS IN GREAT BRITAIN

important, though less precisely defined. Preventive maintenance, including routine testing, can be expected to anticipate and prevent failure of circuits due to comparatively slow changes in the component parts of the system—e.g., deterioration of valves and possibly other items, and the effect of temperature on cable losses. The latter is very great. The overall equivalents of circuits in a 400-mile twelve-circuit carrier cable vary by about 27db between summer and winter, and by 3db per week when the rate of change of temperature is a maximum. Corresponding variations in a 400-mile coaxial system are 70db and 8db respectively.

Changes of this kind, though considerable, can, however, be dealt with, preferably automatically but, if not, manually. Other changes, erratic in nature, are much more difficult to deal with. When condensers, resistors, joints in the circuit and valves fail they do so more or less instantaneously, causing faults and calling for corrective maintenance. Generally the maintenance officer is powerless to prevent these faults though he can curtail the duration of them; they can be prevented only by good design, construction and installation.

3. MAINTENANCE ORGANISATION.

Before describing the existing organisation it would be as well to say something about the basic requirements of any procedure used for the maintenance of a trunk network, and briefly to trace the development of the organisation to the present day. Essentially, the organisation must allow testing offices, repeater stations and other intermediate points to work together for the expeditious location and clearance of faults and the carrying out of routine testing. This covers the whole field of activities of personnel engaged on the maintenance of the trunk network and includes such items as fault reporting, routine testing, test equipment, accommodation, staffing, etc.

In the early days the trunk network consisted of unrepeatered circuits provided on aerial routes and loaded cables. The organisation set up to maintain such a system was simple, requiring only a satisfactory method of controlling and administering the staff and the nomination of testing offices, test points and the Controlling Testing Office. Such testing equipment as was required was of a type in common use for other classes of Post Office work, and its provision and operation presented no difficulty.

During the next phase, the trunk network expanded rapidly, and the aerial lines and unrepeatered cable circuits gave way to a wholly underground cable system equipped with thermionic valve repeaters working on an audio basis. Initially repeaters were relatively few in number and it was found expedient to adapt the organisation to include these repeater stations. In view of the very special nature of the test equipment required for the maintenance of repeatered circuits the testing office function was split. Fault location, being a matter primarily of transmission measurement, was given to one of the terminal repeater stations and this station was called the Transmission Control; the Controlling Testing Office was retained as the office to which faults were reported by the operating staff and which made preliminary tests to prove the line or exchange portions of the circuit. In many ways the split was unfortunate as it complicated an essentially simple system, but in the circumstances it was perhaps unavoidable, and it has not been found unsatisfactory in practice.

Conditions became very different on the introduction of 12-circuit carrier working. Each of the twelve circuits in a 12-circuit group may have a different Transmission Control, and it is clearly undesirable for each of them to exercise control over the 12-circuit group as a whole; a change in, say, the audio portion of a circuit must not be corrected by an adjustment of the equipment common to 12 circuits as otherwise it may be the cause of faults on each of the eleven other circuits. Hence, the control of a group has been vested in a Group Control working entirely independently of the Transmission Controls. Although a fault detected on one circuit may ultimately be found in a 12-circuit group, it must be corrected without reference to the particular circuit in question.

Similarly, where 12-circuit groups are combined to form a coaxial system, it is necessary to set up a Coaxial Control independent of the Transmission and Group Controls. So far it has not been necessary to set up Supergroup Controls, merely because supergroups have not been separated from their coaxial transmission system, but it is likely that these will be required in the future.

The number of these controls naturally leads at first sight to the conclusion that the organisation is no longer simple or convenient. It is possible that Transmission Controls will become redundant when trunk and other testing offices are equipped with transmission testing apparatus, but even so, we shall still be left with three controlling offices, and possibly a fourth will have to be added in the future.

3.1. Functions and Responsibilities of Controls.

In tracing the development of, and the need for, the various controls, brief reference has been made to their functions and responsibilities. It is proposed now to describe them in greater detail. Later, an example showing how the controls work together to locate and clear a fault will be described.

Controlling Testing Offices. The primary testing office, which is finally responsible for ensuring that the circuit is available for traffic, is called the Controlling Testing Office (C.T.O.); one of the terminal exchanges, or exceptionally a more convenient office on the circuit, is nominated as the C.T.O. when the circuit is set up. The C.T.O. receives reports of faults from the operating staff and arranges for their clearance and the restoration of circuits to service, and is also responsible for arranging for the withdrawal of circuits for routine testing and other engineering operations.

Transmission Controls. One of the terminal repeater stations on each circuit is nominated as the Transmission Control, which is responsible for the direction of all transmission testing and other work required at all repeater stations on the circuit, either as a routine measure or for the clearance of faults reported to it by the C.T.O. The Transmission Control is also responsible for the maintenance of the circuit within the prescribed transmission limits. When circuits have been restored to normal, as a result of work initiated by the Transmission Control, the C.T.O. is advised.

Group Controls and Sub-Controls. A 12-circuit group is said to exist between the channel equipments at the 12-circuit terminal stations no matter how the group is provided, *i.e.*, whether it is routed on coaxial equipment or unloaded carrier-type cable or a combination of both. One of the terminal stations is designated the Group Control, and is responsible for the direction and co-ordination of all testing and other work required on the group as a routine measure or for the clearance of faults, and for maintaining the group within prescribed limits. Because of the large number of intermediate repeater stations on 12-circuit carrier systems, and the length of the 12-circuit groups, it is not practicable to make the Group Control directly responsible for all intermediate repeaters, which in the main are unattended. The cable circuit is therefore divided into convenient sections, and repeater stations on the route are selected to act as Sub-Controls for these sections.

Sub-Control stations, selected to work under the general direction of the Group Controls, are chosen primarily for their suitability to control work at the intermediate unattended repeater stations. The availability of staff and testing equipment are the chief considerations influencing the choice. It so happens that the majority of these sub-control stations are equipped with terminal carrier equipment and also have audio installations. The duties of these sub-controls include the maintenance of the sections within limits and for arranging co-operation at the unattended stations.

Coaxial Controls. The Coaxial Control station is the terminal station of a coaxial system provided with the alarm extension circuits and other control facilities for supervising the condition of the system. The Coaxial Control is responsible for directing and co-ordinating work on the coaxial system. The other terminal station on the coaxial system is called the Remote Terminal and acts as a sub-control under the direction of the Coaxial Control.

3.2. Fault Location and Clearance.

Further to illustrate the functions of these controls, the location and clearance of a typical fault will be described. The circuit chosen as an example is assumed to be carried in a 12-circuit group between London and Glasgow, coaxial between London and Manchester (Stockport) and in a 12-channel carrier cable for the remainder. All the main controls—Transmission, Group and Coaxial Controls and, assuming the circuit is bothway or outgoing from London, Controlling Testing Office—are in London. Since two coaxial systems are involved, London—Birmingham and Birmingham—Manchester, there is a second Coaxial Control in Birmingham. There are group sub-controls at Birmingham, Stockport, Old Boston, Carlisle and Glasgow. Hackthorpe, where the fault is assumed to be, is the first repeater station south of Carlisle. It is normally unattended. Routing and other details are shown schematically in Fig. **2**.

Assume that the fault has caused a degradation of transmission in the London—Glasgow direction and has been discovered by a traffic operator whilst supervising the setting up or progress of a London—Glasgow trunk call. This operator reports the faulty circuit to the Testing Telephonist(s) who confirms by speech and ringing tests the existence of a fault. The faulty circuit is then reported by means of a fault docket to the Controlling Testing Office, which contacts Glasgow Trunk Test and confirms the

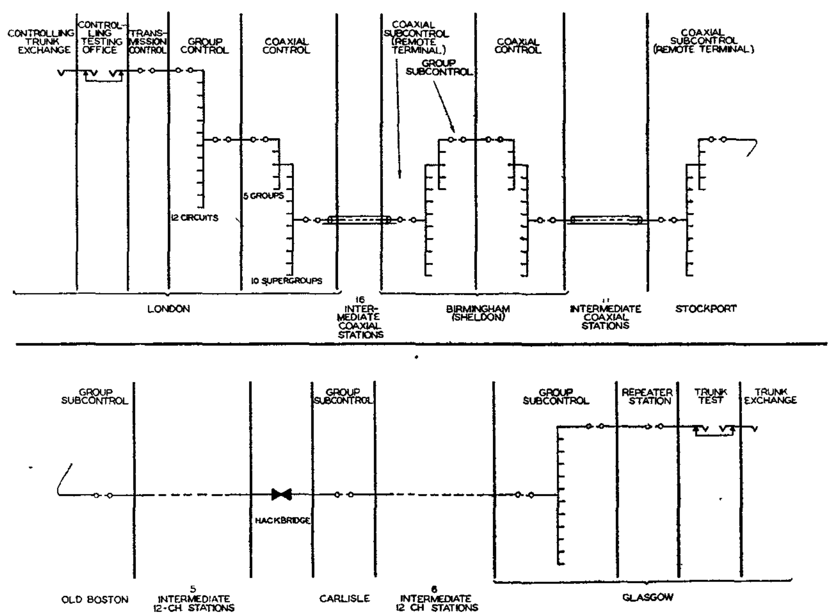

FIG. 2.—MAINTENANCE OF 12-CIRCUIT GROUPS—CONTROLS.

existence of the fault reported. If poor transmission is suspected, the overall gain or loss of the circuit in both directions is measured between the trunk test boards. If the result of the test confirms that the circuit is faulty, the fault is reported by telephone to the Transmission Control and slip numbers are exchanged to register the fault for subsequent identification.

Up to this point it has been assumed that only one channel in the group has been reported faulty even though the fault is in the HF line. This frequently happens, but tests between the Transmission and Group Controls, when these are separated, show whether the fault is confined to the channel or is in the group. If several channels in the group are faulty and are all reported at or near the same time no difficulty arises and the faults are reported on a group basis to the Group Control.

On receipt of the fault report, the Group Control picks up the faulty channel, monitoring it before disconnexion in case a call is in progress. An 800 c/s test-tone at the correct level is then sent into the two-wire end of the circuit and the output level of the H.F. signal checked at the Transmit line amplifier. Having proved his own station equipment to be in order in the transmit direction, he calls Glasgow repeater station on the speaker network and requests co-operation. The Glasgow maintenance officer makes a similar H.F. measurement at the output of the Receive line amplifier. If this measurement is within limits, the fault lies in the Glasgow terminal equipment and appropriate steps are taken to locate and clear the trouble. If the measurement is outside the limits, the fault lies somewhere on the group H.F. link.

The Group Control now proceeds to make measurements of the signal level at various points along the line. These checks are always made at sub-controls, but the actual stations selected depend upon the experience and knowledge of the officer tracing the fault. Generally a check would be made half-way, say, at Manchester, and in this typical case, the measurements would be found to be within limits. The fault has now been located to the northern half of the circuit.

The next check would probably be made at Carlisle, the measurements revealing that the fault lies between Carlisle and Manchester. The next test would be made at the adjacent sub-control, *i.e.*, Old Boston and the measurements at this point would point to the fault being between Old Boston and Carlisle. At this point, the Group Control hands the further location and clearance of the fault to the care of the sub-control station, *i.e.*, Old Boston. If a spare equipped pair exists between Old Boston and Carlisle the faulty group is made good since speedy restoration of service is the first consideration.

The sub-control then checks the levels at various stations in the sub-section, following the same principles as the Group Control. Since several or all of the intermediate repeater stations may be unattended, the sub-control's choice is somewhat limited. In this particular example the sub-control would check at Preston and Kendal/C and would find the level within limits at both stations, which would point to Hackthorpe as being the location of the fault. The next step is to instruct the lineman who is responsible for the maintenance of this station to attend, or to send a maintenance officer to Hackthorpe from the nearest attended station. On arrival, he would be asked to check the level of the test signal and after confirming the discrepancy, the spare amplifier set to the appropriate gain would be patched into circuit. If this did not clear the fault, the spare equaliser would be set up and brought into use.

As soon as the faulty amplifier (or other item) has been located and patched out the intermediate R.S. should advise the sub-control station. An end-to-end test is made over the section to check the overall gain, and if this is satisfactory the Group Control is advised and the group restored to service (on its original routing) if this has not already been done. If, however, the group has been patched out on a spare pair, the group control will already have restored the group of circuits to the Controlling Testing Office on a " temporary OK " basis. Controlling Testing Office verifies that the audio circuits are restored to normal condition and hands them back to the traffic operating staff, who again test the circuits and finally restore them to service.

When the permanent clearance of the fault has been effected, the details are reported to the Group Control, who makes the necessary entry on the Fault Acceptance Record and the Group Fault Card.

No one will dispute the fact that, at present, the location and clearance of a fault of this nature is a long and complicated process. Had the fault been in the coaxial portion of the route, its location might have been even more complicated, as it might have been necessary to bring in the Coaxial Control as well. Not necessarily so, however, because the coaxial system pilot and supervisories might have signalled the existence of the fault automatically to the Coaxial Control. It might then have been cleared by bringing in the spare amplifier at the unattended station, which can be done from the control terminal, and it is probable that it would be cleared before the C.T.O. had received notice of it from the Testing Telephonist. This shows clearly just what is needed to speed-up clearance of faults on multichannel telephone systems —*i.e.*, a liberal provision of group and supergroup pilots with pilot deviation alarms to warn maintenance officers of any excessive departure from the nominal overall value.

3.3. Maintenance Staff.

The London—Glasgow carrier group previously described passes through no less than five Regions and twelve Areas; nevertheless, until 1942 the staffing of the terminal and repeater stations was organised, along with that of most other activities of the Post Office Engineering Department, on the usual Area and Regional bases, the large stations being maintained by whole-time repeater maintenance officers and the small ones as part of a lineman's mixed load. It then became clear that this was not providing the skilled maintenance service the equipment demanded, and it was decided to set up Regional Transmission Groups whose chief function would be to advise Area and repeater station staffs on the maintenance of the multi-channel telephone systems growing continually more numerous and more complex.

This did not suffice, however, for the Regional Transmission Groups operated for the most part at long range, when the details of day-to-day maintenance were necessarily obscured. This is not to say that the scheme was not partially successful; on the contrary, in those Regions where strong Transmission Groups were set up, extremely useful work was done by their visits to repeater stations, investigations into unusual faults, examinations of fault returns and so on, but they were still not close enough to be of much assistance on normal day-to-day problems which have to be solved more or less immediately.

The chief obstacle in the efficient maintenance of the trunk network is the small, normally unattended, station where the number of faults occurring is usually so few that the maintenance officer with a mixed load cannot possibly gain the experience necessary for their speedy clearance. What is wanted is to reproduce, as far as possible, the much more favourable conditions prevailing in large continuously-attended stations. In 1947, therefore, it was decided to appoint in each Area a Transmission Efficiency Officer (T.E.O.), whose first duty is to be the expert to whom the lineman can turn for immediate assistance. In Areas with only a little transmission equipment the T.E.O.'s is not a full-time job, and in such cases it is, or should be, combined with work of a similar nature—repeater station construction, supervision of acceptance testing, etc.

The nature of the work of the Regional Transmission Group and Transmission Efficiency Officers will enable them to acquire a unique and specialist knowledge of the maintenance of carrier and coaxial systems. The benefits of this organisation are twofold: the day-to-day problems in repeater stations can be solved with minimum delay without recourse to Headquarters, and the maintenance duty at Headquarters will be able to concentrate on national policy and procedure (which should result in worthwhile improvements in maintenance organisation and control), testing equipment and the examination of new systems from the maintenance point of view.

3.4. Limits of Fault Location and Clearance in Repeater Stations.

The nature of the carrier and coaxial equipment demands access to test equipment of laboratory type for the location and clearance of certain kinds of fault. It is impracticable to supply such test equipment to all repeater stations with carrier-type plant, particularly as the majority of the stations are normally unattended. It is therefore necessary to specify the limits of fault location and clearance which can be permitted in repeater stations and arrange for faults which cannot be cleared there to be dealt with by a central repair depot.

In practice the limits of fault location depend primarily on the limitations of test equipment and the skill of the maintenance staff, but broadly speaking it is intended that it will not go further than the finding of the panel at fault. Sub-location tests on the panel, and the steps taken to repair the fault, will be left, in the case of twelve-circuit carrier equipment, largely to the discretion of the local supervising officers. With coaxial equipment, the work to be carried out in repeater stations on the amplifier panel will be limited to the rectification of obvious faults, *e.g.*, wiring faults and the replacement of valves, all other work, including changes of components other than valves, being done at the central repair depot.

To cover the intermediate class of fault where the precise location and repair are beyond the scope of the standard repeater station facilities, but where replacement of the equipment is impracticable because of its size and weight, it is intended to provide in each Region a set of special testing apparatus, which will be brought to the station and operated by a member of the Regional Transmission Group or the T.E.O. Experience has shown that the number of faults requiring such special treatment is very small.

3.5. Stores and Spares.

In addition to the standby duplicate equipment provided on carrier generating equipment and coaxial line amplifiers, spare amplifier and equalizer panels are provided for maintenance of Carrier No. 5, 6, and 7 equipment. A small stock of components is kept for replacement purposes for Carrier No. 5 and 6 type terminal equipment and includes odd attenuators, resistors, condensers, frequency changers, filter panels, etc.

In general, reliance has been placed on obtaining any required component from a spare panel and ordering (under the local order procedure) a replacement component from the contractors. This procedure has been proved to be expensive in cost and time, and proposals are afoot to develop a Central Piece Parts Depot for non-standard transmission equipment spares on the lines of the Depot for non-standard automatic exchange piece-parts organised by the Telephone Branch. This depot will hold a complete stock of spare components for all non-standard carrier and coaxial systems and will provide a speedy replacement service for repeater stations. Standard or Rate Book items would, of course, be stocked in the normal manner by the Stores Department.

At present a small stock of consumable items is maintained in each repeater station. This stock includes valves, fuses, fuse wire, dry batteries, resistance lamps, solder, cleaning materials, jumper and other wire. In coaxial stations, spare rectifiers, condensers, attenuators, equaliser networks, and power transformers are held, and arrangements are also in hand for large stocks of spare panels to be held in the Stores Department. Several fully-equipped bays are also held either at coaxial terminal stations, or at the Stores Department, for fire emergency purposes.

4. FAULTS, TEST EQUIPMENT, TESTS, AND TOOLS.

Tests necessary to locate faults on carrier groups have already been described ; this section is therefore devoted to faults, routine tests and overhauls, and the equipment and tools provided to enable this work to be done.

4.1. Faults.

The following notes and tables show, for the year 1946, the distribution of reported faults, *i.e.*, faults reported by operating staff traced to carrier groups, including those in coaxial systems.

Notes : (i) For the purpose of this analysis carrier groups have been divided according to length into three categories—100 to 200, 200 to 300 and 300 to 500 miles. In each category the faults are divided into line, common terminal equipment and channel equipment faults.

(ii) The total number of faults per group is roughly proportional to the length of the group. It is reasonable to expect this in line equipment ; it is unexpected in the terminal equipment, and it is difficult to suggest a reason, but as the number of terminal equipment faults is small it may not be significant.

(iii) About 90% of faults occur in line equipment, about 8% of faults occur in common terminal equipment, about 2% of faults occur in channel equipment.

TABLE I.
DISTRIBUTION OF LINE FAULTS.

	Per cent. of total		
	100—200 miles	200—300 miles	300—500 miles
Adjustment	31	25	34
Valves	6	9	5
Components	4	6	5
Wiring	9	9	5
Engineers Working Faults (E.W.F.) and Misc.	14	14	14
Power	8	6	6
Found O.K. (F.O.K.) ...	25	30	28
Cable	3	2	3

TABLE II.
DISTRIBUTION OF COMMON TERMINAL EQUIPMENT FAULTS.

	Per cent. of total		
	100—200 miles	200—300 miles	300—500 miles
Adjustments	5	5	5
Valves	11	12	8
Components	16	19	5
Wiring	17	18	22
E.W.F.	8	7	5
F.O.K.	12	19	21
Miscellaneous, including carrier supply faults and pilot failures ...	31	21	34

TABLE III.
DISTRIBUTION OF CHANNEL EQUIPMENT FAULTS.

	Per cent. of total		
	100—200 miles	200—300 miles	300—500 miles
Adjustment	25	27	38
Valves	9	7	3
Components	12	10	9
Wiring	21	20	13
E.W.F.	6	4	10
F.O.K.	27	32	27

Considering line faults (Table 1) which are the most important factor in the overall fault liability, investigations show that the number of " adjustments " —mostly gain adjustments—is far higher than might reasonably be expected on account of cable temperature, power supplies and deterioration of valves. Only one explanation has been found for these adjustments and that is the prevalence of poor joints in the electrical circuits—U links, valve pins and holders, badly soldered and unsoldered joints, etc. Close examination has revealed an extraordinarily large number of such faults in circuits normally in use ; on a certain somewhat troublesome London—Glasgow group eighty-three were discovered, an average of about 0.5 per panel or item of equipment. The writer is confident that nearly all " Adjustments ", " Wiring " and " F.O.K." faults are due to faults of this nature, and this applies to terminal and channel as well as line equipment. About 65% of faults are traced directly to these three classes, but bad joints are responsible for many faults in other classes also. Some component failures are due to poor internal joints, and whilst most Engineers Working Faults (E.W.F.) are caused by construction parties, some, no doubt, are due to maintenance officers searching for bad joints on other equipment. It can be said without hesitation that if bad joints of all kinds were removed, something like 80% of faults would disappear.

The usual effect of these faults is a change in the overall loss or gain in the circuit. Fig. **3** shows sections of a level recorder chart showing the level of a test-tone received at the end of a group with constant input.

(*a*) Shows the effect of a faulty, *i.e.*, dirty, U link. For the first few hours the overall loss of the circuit was varying slightly, and at about 10 p.m. the contact began to fail more or less completely. It was therefore fairly easy to find and clear. This happens only rarely ; more often than not the contact resistance varies continually, giving rise to R.W.T. and F.O.K. faults.

(*b*) Shows the effect of a Working Party operating close to a poor joint. In this case the contact appears to be satisfactory so long as it is not disturbed.

(*c*) Shows the effect of a routine harmonic margin measurement, for which purpose the amplifier to be tested has to be taken out of circuit. The record shows a few other relatively small interruptions, or changes in gain, of which the origins were not located. The largest is thought to be due to a changeover of carrier generating equipment.

It is easy to see that most of these interruptions or level variations could result in a fault report by the operating staff, and that the clear is quite likely to be F.O.K. or " Adjustment."

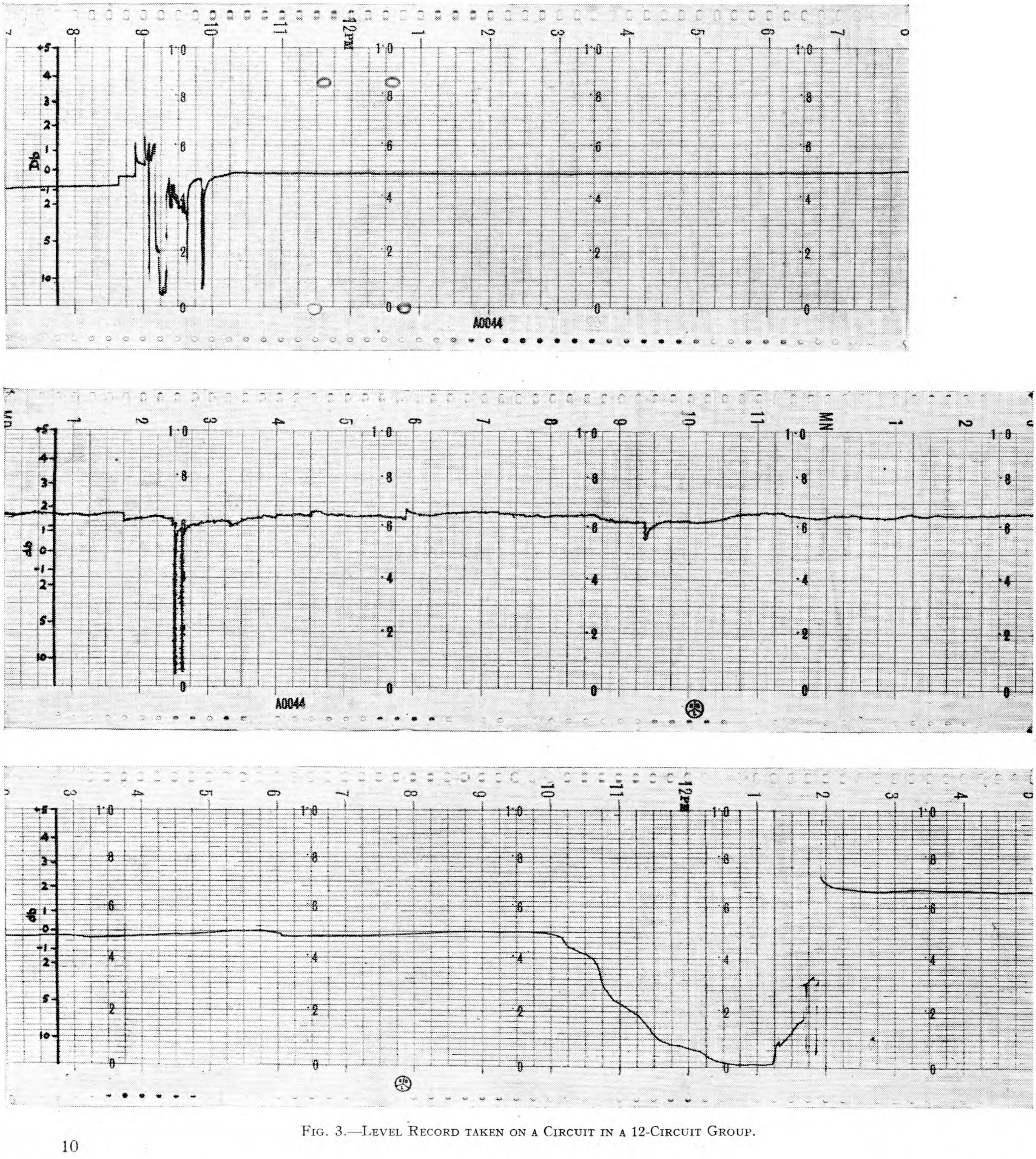

FIG. 3.—LEVEL RECORD TAKEN ON A CIRCUIT IN A 12-CIRCUIT GROUP.

4.2. Test Equipment.

A schedule of transmission test equipment used in the maintenance of carrier systems is given in Appendix I. It will be seen that the number of different types is extremely large and it might be thought more than adequate. Unfortunately, most of these instruments suffer from the defect that measurements can be made only when the group or system has been taken out of traffic, which is not only inconvenient to operating staff and private wire users but also tends to hurry the maintenance officer unduly in the completion of his work. It is then much easier to make an " adjustment " than find out the real cause of the fault. With this difficulty in mind a complete range of rackmounted and portable selective measuring sets has been specified and is now under development.

In general these sets will comprise :—

(*a*) A Send Unit incorporating an oscillator providing very stable frequencies (generally corresponding to virtual channel carrier frequencies, and locked to the carrier supplies) and having a high output impedance to allow a test signal to be injected at any point in a system without affecting the levels of traffic signals already existing at that point.

(*b*) A Receive unit having a high impedance input (to avoid appreciable " tapping " loss) and highly selective to the frequencies generated by the Send Unit.

Just as, for the maintenance of audio circuits, overall loss is measured at an agreed reference frequency (usually 800 c/s), so reference frequencies will be specified for each channel, group and supergroup of an H.F. system. There will thus be a Channel Reference Frequency situated in the audio-frequency band (O-4 kc/s) a Group Reference Frequency in the range 60-108 kc/s, and a Supergroup Reference Frequency specified in the range 312-552 kc/s. For carrier and coaxial line tests it is proposed to employ Line Reference Frequencies, consisting of the pilot frequency or frequencies together with additional frequencies as required.

Further details are given in Table IV below.

Portable versus Rack Mounted test equipment. A considerable proportion of test equipment used for the maintenance of carrier and coaxial equipment is in portable or transportable form. In general, portable equipment has not been looked upon with favour chiefly because of the high breakage liability. Other points against portable equipment are : inaccuracies either due to restrictions in design or resulting from careless handling, inadequate facilities for convenient storage when not in use and encroachment of space in an already restricted gangway. Factors which are in favour of portable equipment are : the economy in test equipment, the absence of test trunks and the advantage of being able to make tests close to the equipment concerned. Economy in bay space is also effected to some extent but this is not always such an economy as would appear—for example, the test

TABLE IV.

Set No.	Purpose for which Set is envisaged.	Brief details of Receive Unit.	Brief details of Send Unit.
1	Maintenance of 12 and 24-circuit terminal equipment using channel reference frequency. Probably located adjacent to G.D.F. with facilities for use at H.F.R.D.F.	Selective to 24 frequencies each corresponding to 2000 c/s on channels of 24-circuit system, i.e., 14, 18—102, 106 kc/s, selectivity 40 db for ± 1800 c/s	Transmits, or injects at high impedance frequencies as specified for Receive Unit
2	Maintenance of 12 and 24-circuit lines only, using group reference frequency, 120–(group reference frequency) and pilot frequency. Probably located adjacent to H.F.R.D.F. with facilities for use at the G.D.F.	Highly selective to two frequencies, viz., 36, and 84 kc/s. Selectivity 40db for 300 c/s	Transmits, or injects at high impedance, frequencies as specified for Receive Unit. High order accuracy required
3	A portable Receive Unit only for use at intermediate stations on 12 and 24-circuit lines	As Set 2	No send Unit
4	Maintenance of coaxial lines only. Probably located adjacent to line equipment at terminal stations	Selective to 9 frequencies occurring between Supergroup bands, i.e., 308, 356—2048, 2296 kc/s. Will also measure H.F. pilots which are outside the frequency band allocated for circuits. Selectivity 40 db for ± 4000 c/s	Transmits, or injects at high impedance same frequencies as specified for Receive Unit
5	A portable Receive unit only ; for use at intermediate stations on coaxial lines	As Set 4	No Send Unit
6	Maintenance of coaxial terminal equipment using supergroup reference frequency and group reference frequency	Highly selective to 15 frequencies, corresponding to 84 kc/s in each group and 432 kc/s in each supergroup, i.e., 84, 180, 336, 384, 432, 480, 528, 684, 932–(248)–2172, 2420 kc/s. Selectivity 40 db for ± 300 c/s	Transmits, or injects at high impedance same frequencies as specified for Receive Unit

trolley requires floor space for parking, and future station layouts will take cognizance of this. Recently, in the design of selective measuring equipment, a suggested method of combining the advantages of portable and rack-mounted equipment is to have the main part of the set rack-mounted but to have portable test heads, facilities being provided at convenient points on the equipment for mounting the test head. This method would appear to strike a good compromise between portable and rack-mounted equipment.

4.3. Routine Tests.

It has already been mentioned that in order to keep the actual number of reported faults to a minimum, preventive maintenance must constitute the bulk of the work done in repeater stations. Whilst this is undoubtedly the case at the present time, it cannot be said that the outcome is satisfactory—in point of fact, far too many faults are reported within a short time of routine test. For example, an adjustment of gain made on routine test is frequently nullified by an adjustment made a few days later as result of a reported fault.

The suggestion is therefore sometimes made that since routine tests apparently do not clear faults, or incipient faults, it would be better to drop the routines and concentrate all the available effort on the rapid clearance of reported faults as they occur. The writer is convinced that this is quite the wrong way to secure adequate service from multichannel equipment, and would go as far as to say that unless faults can be either substantially eliminated or detected and cleared before service is adversely affected, the value and economics of multichannel working are seriously threatened.

Unfortunately, intermittent faults in the form of poor joints are so prevalent that the real value of routine tests is not obtained, but as will be seen later in this section a great deal of work is being done in an attempt to clear such faults and, assuming this work to be successful, most of the remaining faults will be of the kind which can be detected and cleared by routine test.

It is not proposed to describe here all the routines carried out on circuits and carrier groups but some general information is given and further details will be found in Appendix II.

Routine tests are divided into two categories: (*i*) tests on circuits or groups, *i.e.*, overall tests, and (*ii*) tests on station equipment.

4.3.1. *Overall Routine Tests.*

Audio Circuits. The routine test of the overall loss of all circuits comprises the measurement at 800 c/s of the overall gain or loss of the circuit between the two-wire test points at each terminal. This test is carried out monthly but certain classes of circuits are tested more frequently, and further, are tested at several frequencies.

These special circuits are :—

V.F. telegraph reserves tested fortnightly
Tariff E „ „

Main V.F. telegraph circuits and music circuits are tested only when reported faulty, it being assumed that the special conditions of service constitute a continuous routine check.

If portable apparatus has to be obtained specially for the routine test, the periodicity may be reduced to a quarterly test.

Speech tests are always made in conjunction with the overall measurements.

Carrier Groups. The routine test of a carrier group consists of measuring the overall gain or loss of a selected channel, thus checking the condition of the group terminal and line equipment in one operation. The test is made weekly and comprises an 800 c/s measurement of the overall gain or loss of the channel.

Attention is being paid to the possibility of a routine H.F. measurement by means of a special high level signal applied independently to the line. This would be an interim measure pending the availability of selective measuring sets to check selectively the level of the 60 kc/s synchronising pilot or other signal which could be transmitted on every group in the cable.

Coaxial H.F. Lines. The gain frequency response of the H.F. circuit is measured weekly at a time of light traffic in both directions of transmission. Generally the test is made by injecting the testing signal into the H.F. line so that it is unnecessary to disconnect the H.F. circuit. The test signal is approximately 15 db above the normal signal level. Test frequencies depend upon the type of system and are shown in the following table.

TABLE V.

Repeater spacing miles	Frequency band width of H.F. cct.	Test Frequencies Kc/s.
6	60—2852 Kc/s	60, 100, 200, 800, 1600, 2000, 2400, 2852
12	60—1364 „	60, 100, 200, 400, 600, 900, 1100, 1364
24	60—408 „	60, 100, 200, 300, 350, 408.

The purpose of this test is not only to check the overall gain of the H.F. circuit, but also to determine whether the H.F. equalisation needs to be changed on account of seasonal temperature variations. If the results of the routine test indicate that re-equalisation is required, temperature equalisers are switched in or out of circuit as required, subject to a given schedule held at the Coaxial Control Station.

4.3.2. *Equipment Routines.*

No specific routines are carried out on audio transmission equipment, reliance being placed on the overall tests of circuits to show up incipient faults. Routines are performed on associated equipment, however, *e.g.*, power supply voltages and station alarms which are tested daily.

For carrier systems, a comprehensive series of tests have been drawn up to be carried out daily, weekly, monthly, quarterly, half-yearly and yearly. In addition, at least once a year, or more frequently where circumstances dictate, equipment should be overhauled, the intention being to anticipate faults in known weak parts of the system. Points requiring special attention are: station wiring, U links and sockets, valve pins and sockets, and test cords.

4.3.3. *Control of Routines.*

The method of controlling routines has up to the present been on the lines of that laid down by the Engineer-in-Chief's Office, suitably modified to meet local circumstances.

Briefly, a programme of routine tests on equipment at the repeater station is prepared by the Officer-in-Charge. The tests are set out at the specified periodicities and are arranged to suit staffing conditions. A series of Rota Test Cards (TE 885 suitably modified) are used to lay out the tests and provide for the distribution of the work among the personnel, and also for the supervision of the work by the officer-in-charge. At small stations where the routine tests are few, a schedule of tests placed on the notice board is sufficient, a note of their performance and completion being entered in the station diary.

This method of control has not proved satisfactory, partly because the routine cards did not provide for the entry of routine measurements which would enable the history of items of equipment to be examined. Several alternative schemes have been suggested, and at the present time a full-scale trial of a Routine Control Scheme sponsored by all Branches of the Engineering Department is in progress.

The main features of this control scheme are facilities for :—

1. Bringing to notice the fact that a routine is due.
2. Certification of the performance of the routine.
3. Recording of the results of the routine measurements and/or functional tests.

A watch can therefore be kept on equipment performance with the possibility of taking remedial action at an early stage before the equipment fails in service.

The trial of this scheme embraces all classes of plant, including transmission equipment, and it is expected that routine tests of circuits, groups and systems as well as equipment can be covered under the one system.

4.4. Special Overhauls.

A new system of overhaul is now being introduced with the principal object of detecting, locating and clearing the poor joints referred to earlier in this section.

Low-level Vibration Testing. It has long been known that faults caused by bad contacts can be removed temporarily by the application of a test-tone at normal level—*i.e.*, at zero level with reference to the two-wire part of the circuit. The use of test-tones at levels far below the normal operating levels to investigate obscure faults, and to overhaul all types of equipment for incipient faults, has lately been exploited with marked success

There are in use several variants of this technique, but basically the method is to send a test signal at a level comparable with the noise level of the equipment being tested and to reproduce the resultant output signal by means of a loudspeaker amplifier. This audible signal serves to focus the attention of the maintenance officer, who, while listening intently to the tone, subjects the equipment to mechanical shock by gently moving all wiring, testing each soldered connection and tapping each component and valve with a tool such as a small screwdriver. The object of this combined aural-vibration test is to disturb unsound connexions and give rise to audible effects which denote the presence of these faults. Items such as valveholders, variable potentiometers, keys, switches, jacks and U links are particularly prone to bad connexions, which manifest themselves as crackles or interruptions. Any change in the level of the steady tone must be painstakingly investigated and a satisfactory clear obtained. It has been proved that equipment which has been maintained on a normal fault basis *i.e.*, corrective maintenance, has usually a large number of potential faults of this nature and quite often a number of actual faults which have not been cleared. Once the equipment has been overhauled by low-level vibration testing methods, trouble-free service can be guaranteed for long periods.

A variant of this method, shown in Fig. **4**, is to send a test-tone of suitable level and frequency into the equipment under test and to demodulate the output signal by means of a rectifier and low pass filter. The rectified and filtered output is applied to a

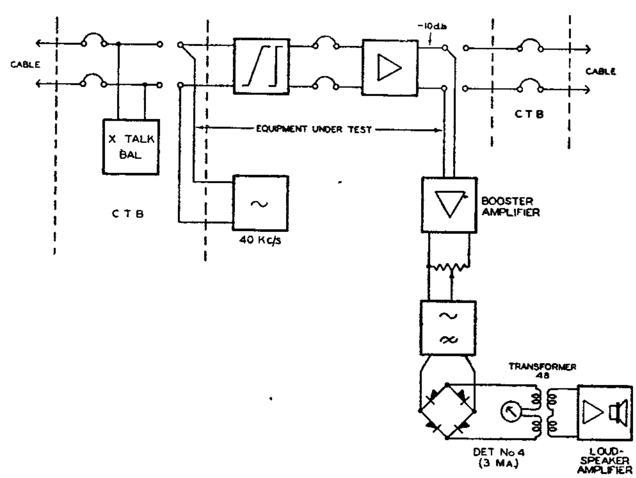

FIG. 4.—OVERHAUL OF 12-CIRCUIT INTERMEDIATE LINE AMPLIFIER.

loudspeaker-amplifier, and if the equipment is free from faults no sound should be heard from the loudspeaker. Disturbance of a bad connexion modulates the test-tone and produces a crackle from the loudspeaker. It is found that this is a more satisfactory manifestation of a fault than the crackle accompanied by a background of tone and circuit noise; it is also more sensitive than the original method and less tiring to the observer.

It is clear from the experience already gained that the success of these methods of fault prevention depends largely upon the employment of careful and conscientious officers, and as the more obvious faults are cleared it becomes increasingly difficult to locate and clear the remaining obscure faults. Such faults which will later give rise to considerable trouble may give only fleeting indications of their presence in the early stages. Keen observation and patient systematic tracing of faults and unusual symptoms are necessary for the success of this overhaul technique.

Loudspeaker-amplifier. A light, portable amplifier and loudspeaker set is an essential part of the apparatus used in low-level testing and other methods of overhauling equipment. It is preferable to headgear receivers for several reasons, among them being the risk of acoustic shock and the discomfort of wearing headphones for long periods.

The requirements of the unit are unusually stringent; it must have high gain and a wide frequency response, and must not introduce perceptible noise when working at maximum gain. It must also cause negligible tapping loss.

As a result of experience with several types of proprietary items, a unit to the following brief specification is now in course of production.

(i) Maximum gain 90 db. with gain control to 45 db.
(ii) Frequency response substantially flat from 200 to 10,000 c/s.
(iii) Input impedance of the order of 2 megohms.
(iv) Loudspeaker, 6½in. dia., wafer type.

Monitoring Equipment. Some time before the war, short investigations were made into faults which occurred on V.F. telegraph and certain long distance circuits with bad fault histories and two new testing instruments were developed for the purpose. One was a recording milliammeter modified by the addition of a simple full-wave rectifier. This instrument was capable of continuously recording transmission levels of a tone—usually 800 c/s—between about –10 db. and +5 db. (ref. 1mW). A typical record from an average 12-channel circuit which has a number of faults is shown in Fig. **3**.

While this instrument was very valuable for assessing the stability and freedom from faults of any circuit put under observation it did not help to locate faults. An improvised tone interruption alarm was therefore tried out. This alarm was designed to operate on any V.F. tone between about –30 db and +20 db. above 0.775 V (zero level in 600 ohms). A reduction in level in excess of 3 db. operated a visual and audible alarm. The experience gained with this improvised tester showed that it was invaluable for the location of intermittent faults, and the design of a self-contained tester was put in hand. The war prevented these two testers being fully developed and exploited, but development was restarted soon afterwards and both items are now in fairly common use. The recording milliammeter is known as the Decibelmeter No. 10 and the tone interrupton alarm as the Tester RP 1620.

The results obtained with this equipment on audio circuits were so promising that it was considered that similar equipment should be made available for 12-circuit groups, not only for the actual location of difficult faults but also as a means whereby continuous observation of 12-circuit groups could be carried out as a routine measure without having to withdraw circuits from service. Here again an improvised item was tried out experimentally. A number of pilot receivers recovered from aerial line carrier equipment were modified so as to operate at 60 kc/s. The modified tester was capable of detecting a variation in level of about 1 or 2 db. over a range extending from +3 to –5 db. relative to one milliwatt in 140 ohms. Audible and visual alarms were provided and also facilities for connecting a recording milliammeter to the d.c. side of the panel so as to get a continuous record of the level at the test point.

Several of these panels were tried out on an experimental basis on a selected route, and the results of these field trials have confirmed that the units would give valuable assistance in faulting and special investigations on carrier groups. On one particular group, which was monitored for a period of four weeks, evidence of the following faults was observed.

(*a*)	Power failures ...	4 faults
(*b*)	Working parties ...	14 ,,
(*c*)	Level variations ...	4 ,,
(*d*)	" U " links ...	1 ,,
	Total...	23 ,,

For each fault it was possible to locate the subsection concerned by means of the indications on the alarm panels fitted along the route and with the exception of (*c*) practically all the interruptions were located to individual stations. Only one fault (a power failure) was reported by the traffic staff during this period, and this fault had been located before the advice of the fault was given to the Group Control Station. An improved type of level monitor alarm panel is now in course of development with a view to quantity production.

4.5. Maintenance Tools and Aids.

Contact with staff in Repeater Stations in the course of field investigations carried out by Lines Branch and through the medium of conferences with Regional staffs has shown that some thought must be given to proper maintenance tools if a reasonably high standard of maintenance is to be obtained.

Soldering. There is little doubt that the most important side of maintenance as far as repeater stations is concerned is the soldering of connexions. The reason for poor soldering is not far to seek; it is due to three causes:—

(i) Unsatisfactory soldering irons,
(ii) Lack of care on the part of maintenance staff and failure to appreciate the simple requirements for good soldering,
(iii) Unsatisfactory solder.

(i) and (ii) are very closely related in that, provided maintenance staff are at all times conscious of the importance of soldering the ordinary gas-heated iron is capable of making excellent soldered joints. Human nature, being what it is, cannot easily be schooled into new standards and while soldering is an art requiring only simple precautions it remains a fact that far too many maintenance officers fail to realise the importance of care in the cleanliness of the work and correct iron temperature. It is admittedly difficult to ensure satisfaction from gas-heated irons for maintenance due to the infrequent nature of the work coupled usually with the natural desire to get the job done quickly, especially if the clearance of a fault depends upon the soldering. This sense of urgency often results in soldering being attempted before the iron has become properly heated and such attempts usually result in a " dry " joint.

It is important therefore that the special requirements of maintenance in regard to soldering irons should be recognised and met if at all possible. The barest essential requirement is rapid heating to an adequate temperature without burning of the " face ", and is most easily met by an electric soldering iron. Ordinary forms of mains operated irons are not suitable because of the necessity for the bit to be earthed, but a 22V 70W iron is now being introduced generally. This iron attains soldering temperature in about three minutes, and although somewhat light, it can be used for all normal soldering required in repeater station maintenance or construction. Two other types of iron shown in Fig. **5**, are to be given a trial

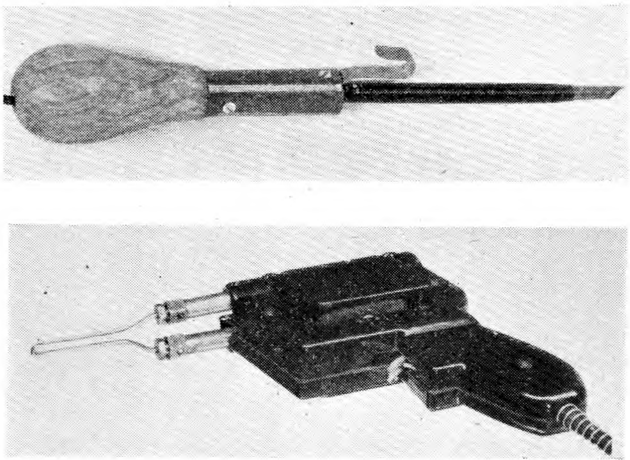

FIG. 5.—EXPERIMENTAL SOLDERING IRONS FOR MAINTENANCE WORK.

as soon as supplies are available. One is a very light iron, roughly the same size and shape as an 8in. cabinet screwdriver and taking 30W. This iron heats up in about one minute and is particularly useful for connexions which are normally difficult to reach with the orthodox iron. The other is an A.C. mains-type iron shaped like a pistol in which the " chamber " is a step-down transformer. The bit consists of a loop of thick copper wire connected to the secondary winding. The open circuit secondary voltage is about 0.3V, the power consumption about 100W, and the bit attains soldering temperature in less than 10 seconds. A switch is provided in the form of a trigger so that the iron consumes power only so long as the switch is held operated.

None of the soldering irons so far tried is ideal from the maintenance officer's point of view. In an attempt to provide the perfect iron for maintenance, a broad specification has been drawn up in co-operation with various Branches of the E-in-C.O., and R. Branch has been requested to examine the requirements with a view to producing a practical design.

The main requirements are :—

(1) The soldering iron should be as light as possible.
(2) The bit should be easily replaceable and of such a shape that soldering operations can be carried out in a cramped position.
(3) The efficiency of the iron should not be impaired by the formation of scale between the body of the iron and the bit.
(4) The face of the bit should be approximately 3/16in. square.
(5) The bit should not be earthed.
(6) The iron should be thermostatically controlled and have a temperature indicating device.
(7) The iron should reach working heat within 30 seconds.
(8) The iron should be capable of continuous soldering on a row of tags of the type used on Strips, Connexion, No. 22A.
(9) The iron should be suitable for use on 200—250 volts, 46—50 volts and 20—24 volts.
(10) A portable cradle with a universal clip should be provided with the iron.

The remaining difficulty in soldering which must not be overlooked is the actual grade of solder. As is generally known the supply of tin has been difficult for some time, but it is now improving, and a supply of 60 : 40 (tin to lead) solder is becoming available. Ultimately, all supplies of cored solder used in the Department will be of this grade, but for the time being its use on maintenance work is restricted to 12-circuit carrier and coaxial equipment.

Cleaning Tools for U Links and Sockets.. The actual number of faults due to test links and sockets was thought to be relatively small, but experience in overhauling equipment has shown that dirty links and sockets form an appreciable percentage of the total faults. Some thought has therefore been given to methods of cleaning. As far as the socket is concerned, the simplest method of cleaning is by means of a special wire brush (Fig. **6**) rotated in the socket by means of a hand drill. This has given good results in the field though the improvement may not last very long, particularly in industrial areas. This is, of course, a defect inherent in the use of base metal contacts. Tests have shown that the amount of wear on the walls of the socket is very small and provided the cleaning is not overdone it is considered that no difficulties should arise due to wear.

Inspection Lamps. Adequate lighting of equipment is essential during overhaul or when looking for intermittent faults caused, for example, by poor soldering or " contacts ". The ordinary rack lighting although provided on a most generous scale is totally unsuited for panel illumination. Repeater station staff have therefore been supplied with head-lamps but these are not entirely suitable as they are uncomfortable to wear over long periods, tend to restrict free movement and frequently obstruct the operator. Various suggestions relating to lamps which can be clipped on to the iron framework or to cover guides have been made, but the best suggestion so far is an " Anglepoise " lamp of standard pattern modified to provide additional extension. It is mounted on a cast steel, or iron, stand with rubber swivel wheels and the lamp is capable of being placed in any desired position from about 18in. off the floor level up to 7ft. Apart from the topmost panel of a 10ft. 6in. rack all other panels can be adequately illuminated. It is likely that this type of lamp will be supplied for repeater stations and in consequence the standards for rack lighting can be reduced to those necessary for normal illumination purposes.

Hand Lamps. Although most components of any panel can be examined with the aid of an ordinary lamp with a suitable holder or stand, certain components can only be examined with the aid of a small torch. For these cases a small inspection lamp using a focusing bulb and fitted with a detachable dentists' mirror has been suggested. That shown in Fig. **6** has proved extremely useful and a similar item is being designed for general use.

Prods. The instrument shown in Fig. **6** was designed for prodding and poking at soldered joints to see whether they are sound. A field trial of this tool is in progress.

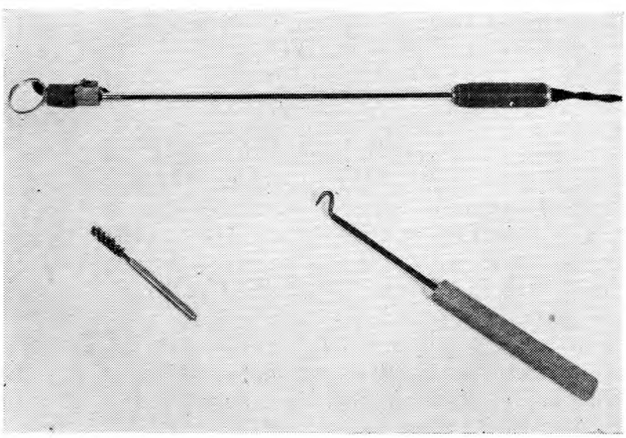

FIG. 6.—SOCKET CLEARING BRUSH, INSPECTION LAMP AND PROD.

5. DESIGN OF EQUIPMENT FOR MAINTENANCE.

Designers of transmission equipment, extolling the virtues of their latest masterpiece, almost invariably state that the desirability of easy maintenance was kept constantly in mind throughout their work. This assertion is usually made, apparently as an afterthought, towards the end of a list of attributes nearly always starting with a statement that the equipment in question is simple and cheap. It is astonishing that simplicity and cheapness are held in such high regard. Apparatus with a world-wide reputation for high quality—Rolls-Royce, a Spitfire or the " Queen Elizabeth "—is seldom simple and never cheap ; on the contrary it is nearly always very complicated and very expensive, but its performance is brilliant and its reliability even more outstanding, and these are the things which really matter.

Designers as a rule take more pride in, say, reducing the number of valves in a piece of equipment and thereby saving a small amount of space, than in reducing maintenance costs by an equivalent amount. Other designers say that their equipment is " simple and reliable " as though the latter followed automatically from the former. No greater mistake could be made. Faults on simple equipment are perhaps more easily located than those on complicated equipment, but when a fault occurs the claim of reliability is shown to be false. Faults should not occur on multichannel telephone equipment. The writer suggests that the assertion that subsequent maintenance is well considered in the design of new equipment is little more than lip service.

It must be admitted that the designer is not wholly to blame for this state of affairs. The maintenance engineer is rarely consulted in the early stages of a design, but even if he were, he would find it difficult to point out definite and specific lines on which the design must proceed if its maintenance is to be a practicable proposition. The designer is circumscribed by the limitations of the materials at his disposal, and the demands of the production engineer, and the inarticulate maintenance engineer is all but forgotten. The maintenance engineer is inarticulate because the rate of development of transmission equipment is so great that before he can collect his data, the type of equipment he is using is obsolescent, and the designer is thinking years ahead of something entirely fresh.

It must be emphasized that reliability and easy maintenance must figure high on the list of desirable attributes of a new piece of equipment. It has already been stated that the cost of maintenance is roughly the same as the cost of the equipment itself so that it should be given at least as much attention. In addition, the cost of a fault in poor service, loss of revenue and inconvenience to operating staff, though difficult to calculate, is nevertheless very great.

As Dr. R. A. Brockbank and Mr. C. F. Floyd have said in their paper " Wideband Transmission over Coaxial Cables " : " Reliability is not obtained as the result of attention to any one detail as, for example, the testing of components or the training of maintenance staff, the soldering of joints or rigorous inspection, but is only achieved by painstaking, non-spectacular progress in improving all the influencing factors." An attempt will therefore be made to point out some of the more important influencing design factors, to which, it is considered, insufficient attention has been given. This is by no means easy ; it would be much easier to point out some of the numerous bad features of existing equipment. The following are some general principles of good design, from the point of view of the maintenance engineer.

5.1. Every unnecessary joint in the electrical circuit, whether soldered, brazed, welded or made in any other way, must be avoided. This frequently conflicts with the desires of the production engineer. Examples of unnecessary joints are :—

(*a*) The ordinary level-type U link, shown in Fig. **7**, has four joints within itself, *i.e.*, not including the contacts with the sockets. Each of these joints has become loose at one time or another and if at all possible they must be eliminated. A U link, recently developed and shown in the same Figure, appears to have possibilities in this direction ; all four joints have been eliminated.

(*b*) A certain valveholder, shown in Fig. **8**, and unfortunately used in transmission equipment, has two joints between the socket and tag. These are entirely unnecessary, as shown by the many examples in which the socket and tag are in one piece.

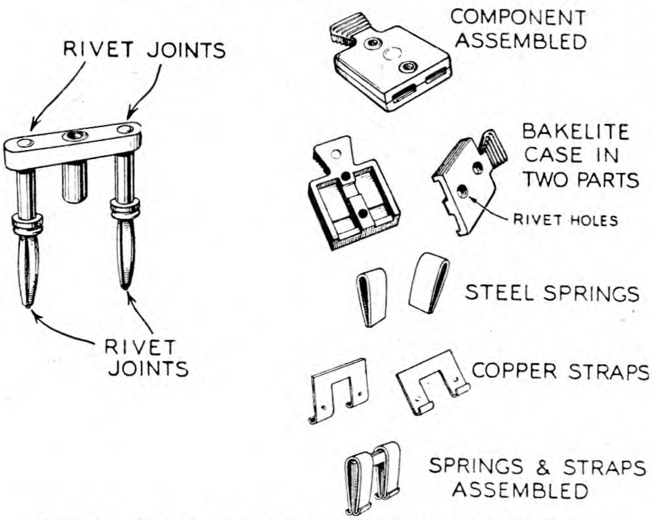

FIG. 7.—EXAMPLES OF UNNECESSARY JOINTS IN U-LINKS.

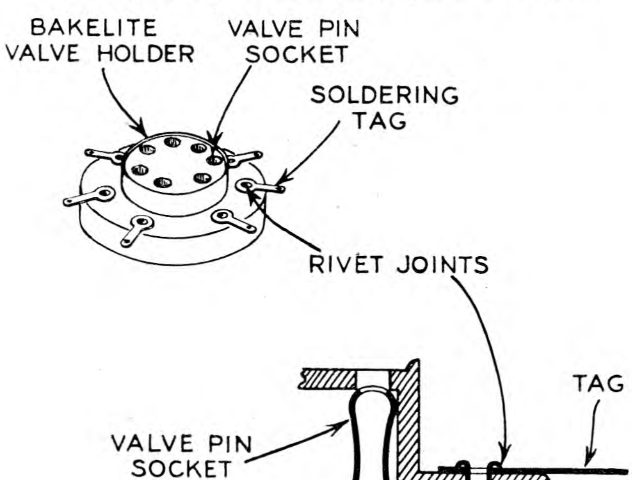

FIG. 8.—VALVE HOLDER NO. 18, SHOWING UNNECESSARY RIVETED JOINTS.

A close examination of existing transmission equipment will usually disclose several joints which were better eliminated.

5.2. Contacts should always be of precious metal. There is no doubt that contacts are responsible for many of the R.W.T., F.O.K. and other faults of like nature, and improvement of contacts is a matter of great urgency. There is considerable difference of opinion as to whether contacts should be of precious metal at low pressure or of base metal at high pressure. Whatever may be the outcome of this controversy, it will be many years before the case is proved one way or the other, but in the meantime it is certain that the combination of both precious metal and high pressure would be superior to either, and this course should be followed. It is sometimes argued that soft precious metal would quickly wear through, and the presence of two dissimilar metals may make the case even worse. The solution is to use a hard precious metal, *e.g.*, rhodium, or if this is impracticable, to make the coating so thick that it is unlikely to wear through during the anticipated life of the equipment.

It goes without saying that contacts of this kind should be avoided if possible in favour of soldered joints, and riveted joints should be completely barred. There is a lot to be said for soldered-in valves, and in the opinion of the writer this will become the standard practice in multichannel telephone equipment.

Contact faults are frequent on continuously variable potentiometers ; the stud type, or, in certain cases, those with a soldered connexion at the tapping point, are much preferred.

5.3. Components must never be overcrowded or otherwise made inaccessible. The designer's anxiety to squeeze his components into a small space frequently results in components being overcrowded and sometimes completely inaccessible to the maintenance officer unless he dismantles part of the equipment.

Fig. **9** shows a supervisory panel used in coaxial terminal stations ; 3,000 type relays are fitted behind lamp jacks, so that it is impossible to inspect and

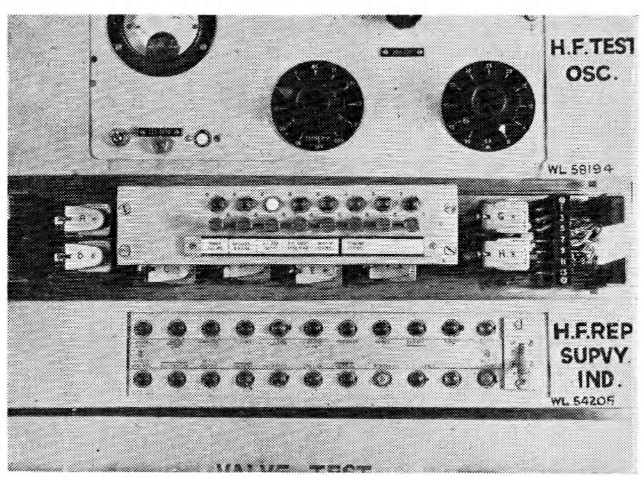

FIG. 9.—SUPERVISORY LAMP PANEL—UNIT BAY 1B EQUIPMENT.

adjust the relay springsets. Figs. **10** and **11** show two different designs of one piece of equipment, one on a $12\frac{1}{4}$in. panel, the other on an $8\frac{3}{4}$in. panel. The difference in the accessibility of components, particularly valveholders, is striking. Valveholders are usually confined between tall components and have to be removed for inspection, cleaning and adjustment.

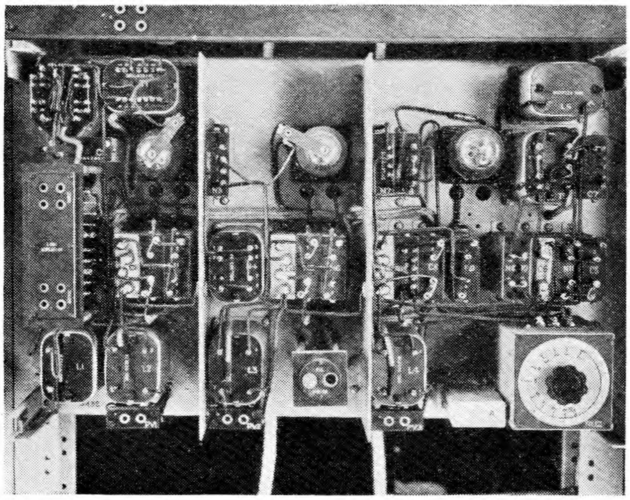

FIG. **10**.—12-CHANNEL LINE AMPLIFIER ON $12\frac{1}{4}$ INCH PANEL.

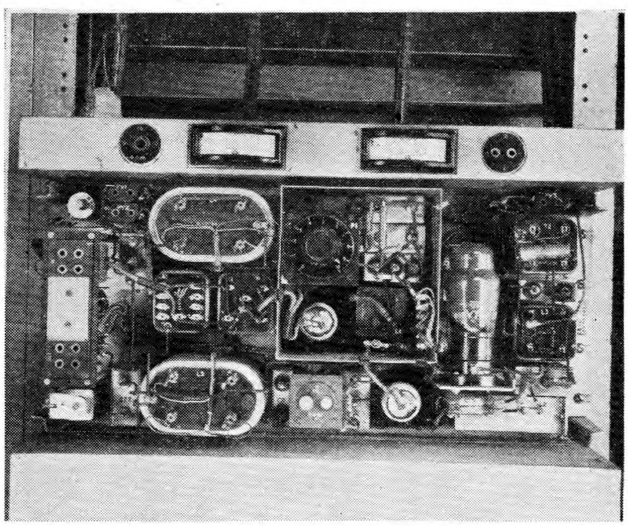

FIG. **11**.—12-CHANNEL LINE AMPLIFIER ON $8\frac{3}{4}$ INCH PANEL.

The valve and valveholder shown in Fig. **12** are incomparably better in this respect than the standard types in use in our Repeater Stations.

Space saving, so popular with designers, is a comparatively worthless objective. It is seldom realized how cheap space really is. The cost of Faraday Building—probably the most costly space housing transmission equipment in this country—is about 8% of that of the equipment it contains. On the average, the cost of accommodation is only about 5% of the cost of the equipment on circuits for which it is provided. The maintenance engineer is therefore rarely impressed by claims to have reduced the space occupied by a unit, realizing that while it will make a negligible difference to the cost of providing service, his task will almost certainly be made more difficult. These remarks apply not only to components on a panel but

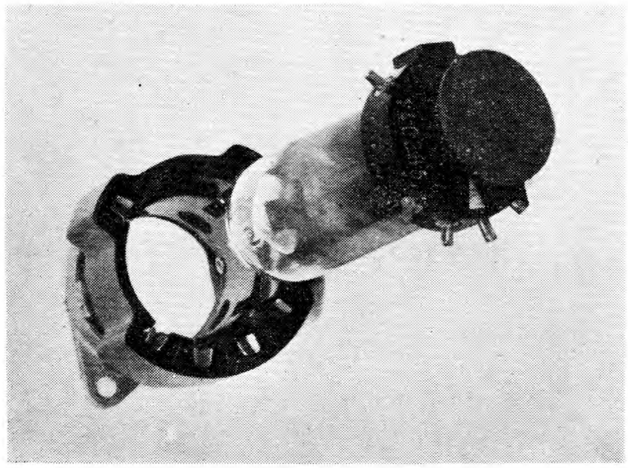

FIG. **12**.—INVERTED TYPE VALVE AND VALVE-HOLDER.

also to the equipment in the repeater station, where a little more free space would improve working conditions and efficiency out of all proportion to its cost.

It is, of course, readily admitted that in some parts of the country at the present time space is simply not available at any cost, and purely as a temporary measure the maintenance officer is prepared to tolerate a certain amount of space-saving. One way of saving space is to use miniature components, but the space between them should not be miniaturized; unfortunately, perhaps, the maintenance officer himself cannot be miniaturized though something might be done with his tools.

This question is affected to a large extent by the maintenance organization employed, in particular, whether faults on a panel are expected to be cleared without taking it from the rack or whether it is withdrawn from service and repaired elsewhere. This point is referred to in Section 3.4.

5.4. Equipment should be designed so that it is possible to keep it reasonably clean. Nearly all transmission gear is open to the atmosphere with its dust and corrosive action, but so far as could be noticed, no attempt is made to design it in such a way that it can easily be cleaned. On the contrary, it is so full of nooks and crannies to collect dust and dirt that it is impossible to make a thorough examination without the risk of causing more faults than one expects to clear. The ordinary vacuum cleaner is practically useless on transmission equipment; a powerful airblast is considerably better, but some means of collecting the dislodged dust is required, and so far is not available.

" U " links and sockets are particularly difficult to clean, and it would be well worthwhile to consider the abandonment of the circular in favour of the flat pin type. In the meantime various little cleaning tools, brushes, etc., are being developed and will be supplied to maintenance officers as soon as possible. Valvepins and sockets are equally unsatisfactory from this point of view.

5.5. Adequate testing facilities should be provided. Designers should decide on what testing facilities are to be provided, with a full knowledge of the maintenance organization employed and the conditions under which tests will have to be made. As a rule the facilities given are adequate so far as the provision of test points is concerned, but too often it is impossible to make a test without taking the system out of service, a condition which is most inconvenient to operating staff and users of private wires.

5.6. It is considered that multi-channel equipment should be under constant supervision throughout its working life, but this need not be done manually. A pilot in each group, or at least each super-group, with pilot deviation alarms to warn the maintenance engineer of any abnormal departure from standard, would save its cost in a very short time.

5.7. Automatic circuit routiners measuring the audio-to-audio transmission equivalent of circuits would be extremely useful, and may well be essential under automatic trunk switching conditions.

5.8. Faults classified as Engineer's Working Faults are excessive. The susceptibility of multichannel systems to this type of fault should be borne in mind in the design of the equipment. It may be that the standard type of open rack construction is unsuitable, and sealed units will be necessary to eliminate these faults. Potentiometers and such like should not be too easily capable of adjustment, or they may be altered inadvertently. Usually, screw-driver adjustment is preferable to a projecting knob. Similarly " U " links should be locked in position so that some effort on the part of the maintenance officer is necessary before they can be removed.

5.9. The fault liability of power supply equipment in coaxial systems is very high on account of the unreliability of country supply mains and imperfections of standby emergency sets. Consideration should therefore be given to a system not requiring intermediate power feeding stations, all power being supplied from terminal stations in large towns where more reliable power mains can be expected. Ideally, all stations on a route, say 100 miles in length, could be fed at will from either terminal so that adequate alternative power supply is available.

5.10. The fault liability of circuits in multichannel systems is higher than in completely audio plant, and with a given standard of electrical and mechanical design and construction this is only to be expected. A much higher standard of reliability is required in future systems, and to obtain a reasonable overall fault liability, equipment in the wide-band path must be substantially perfect.

A fully-equipped 100-mile coaxial system would probably have sixteen intermediate amplifier stations. If an overall fault rate of two faults per annum is aimed at, a figure comparable with that of audio circuits, one fault is the most that can be allowed to the intermediate amplifier stations, including its power supply, from which it follows that the average fault liability per station must be no more than one fault in sixteen years.

Judging from what is expected of submerged repeaters it should not be impossible to attain this standard, and it would probably be economical, for such equipment would require little or no maintenance apart from changing valves at intervals of, say, not less than three years. The cost of maintaining an intermediate amplifier station is several times that of the equipment itself, on the basis of " present value of annual charges ", so that if necessary, there is, for all practical purposes, no limit to what can economically be spent in order to improve the reliability of the equipment.

6. RECORDS AND RETURNS.

It is essential that an adequate system of records be kept in repeater stations in order that normal everyday work is carried out in an orderly and efficient manner. Records can provide a ready source of information and make it unnecessary for staff to memorize complicated (or alternatively, unimportant) details of work. Over a period, a record can provide valuable information regarding the running of the repeater station, behaviour of circuits and equipment, and other such details. Records are also required for day-to-day accounting of stores, stock items, etc.

A most important adjunct to records and returns is an adequate system of inspection and analysis. This is, unfortunately, lacking at the present time, and yet some such system is absolutely necessary if supervising officers are to exercise control over their stations. Further, the one existing group fault return is insufficient to show precisely the strong and weak points in not only the equipment but also in the maintenance organisation. It is proposed, therefore, to modify this return with two purposes in mind.

(i) To provide as much information as possible concerning the origin, effect of and attention given to the fault.

(ii) To emphasize the seriousness of H.F. system faults and enable supervising officers to satisfy themselves that faults are adequately dealt with.

Another missing return is an adequate measure of the service given by circuits in multichannel systems. At present the operating staff keeps records of circuit lost time due to faults and other engineering work, and there is also a fault return prepared by the Controlling Testing Office showing, among other things, the average number of faults per annum for each type of circuit (A171). These are moderately useful for audio, but quite unsuitable for carrier circuits, for in the latter case the most important factor is the number of circuits simultaneously faulty—due to a line fault for example—and a return to bring this out is badly needed.

Fig. **13** shows an experimental return made out by the Group Control and intended to show the condition of all groups in a coaxial system throughout the normal working week. This and other returns are being studied by a Working Party of Engineering and Operating Staff.

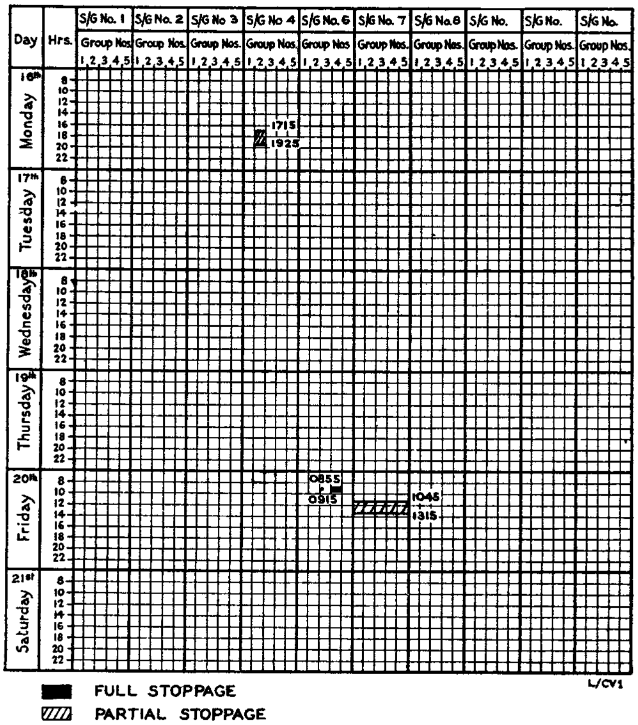

FIG. 13.—COAXIAL SYSTEM FAULT RECORD.

7. FUTURE DEVELOPMENTS.

Apart from developments in design which, it is hoped, will ease the maintenance officer's task, there are likely to be considerable changes in maintenance methods themselves.

When selective measuring sets, group and super-group pilots and pilot deviation alarms become available much of the work in repeater stations will change. There should be fewer faults to be cleared urgently; routine tests as now made will largely disappear and in their place long-period level records will be taken on charts and studied for incipient faults. Supervising officers will then be able to obtain a much better idea of the condition of their circuits than they can at present, and for this reason alone the general standard of service should improve immensely.

An engineer confronted by a problem in design, production or maintenance, instinctively looks for his measuring tools and methods—his yardstick. In this respect the maintenance engineer is not well served; it is not easy to measure maintenance efficiency. A measure in terms of reported faults per circuit per annum has been used for many years, but that is a very poor one and except on a national basis the figure is subject to such wild fluctuations that the most one can look for is a yearly average with some indication of trends over a period of years. What is wanted is a measurement which a supervising officer can apply daily, or at least weekly. The application of statistical quality control may help to meet this need, and investigations are in progress with the object of discovering how statistics can best be used. Many possibilities can be envisaged.

It seems likely that in any given station the number of circuits found to be faulty on routine test would follow well defined statistical laws. Control charts, on the lines of production control charts, could be drawn up, and any significant departure from standard would be immediately apparent. A.1053 procedure (special investigation of recurring, frequent and long duration faults) could also be controlled in a similar manner, the problem being to determine the probability of a circuit, or piece of equipment, being found faulty, two, three or more times in a given period. Having obtained this information, it could be said with confidence that if a certain piece of apparatus were faulty more than a certain number of times in one week, or month, a special overhaul would be desirable, for in all probability the real cause of the fault has not yet been discovered.

The overall gain of a 12-channel group set up between Salisbury and Swansea, about 150 miles, was measured three times daily for about four months, in the GO and RETURN directions and round the loop. The data from each of the three measurements were examined and found to have normal distribution with standard deviations of 0.86, 1.84 and 2.77 db. These variations, which are considerably more than the probable errors in testing equipment, might be expected to be due to cable temperature, power supply and valve deterioration, but principally the first two, in which case there should be fairly close correlation between variations on the GO and RETURN. The data actually failed to disclose any correlation whatsoever, the coefficient being substantially zero. Examination of the GO and loop measurements, however, showed significant correlation. This, in the writer's opinion, indicates an unsatisfactory condition, and though it has not yet been proved, the circuit is probably full of dry joints and needs thorough overhaul.

Close control of maintenance must, however, be difficult on account of the random nature of most of the faults on carrier equipment. Poor contacts and dry joints must first be cleared away, and for the time being this must be the first consideration of maintenance officers, designers and manufacturers.

To sum up, maintenance can and should become much more scientific than it is now, and this will require three new conditions: (*a*) means of measuring the efficiency of maintenance in terms of service given and its cost, (*b*) utmost co-operation between designers of equipment and the maintenance staffs and (*c*) design and construction of the highest possible standard. Given these, an efficient trunk network based on multichannel carrier systems is assured.

8. ACKNOWLEDGMENTS.

When the word " Writer " has been used in this paper, " editor " would probably have been a better one, for it is very much the work of a group—the maintenance group of LM Branch. He therefore wishes to thank all the members of that group, in particular Messrs. Pyrah, Wilcher, German and Brown, for the information and help they have given him in its compilation.

9. BIBLIOGRAPHY.

A. H. Mumford, B.Sc. (Eng.),A.M.I.E.E.
The London—Birmingham Coaxial Cable System. I.P.O.E.E. Journal, Vol. 30, pp. 206, 270. Vol. 31, pp. 51, 132.

F. J. D. Taylor, B.Sc. (Eng.).
Carrier System No. 7. I.P.O.E.E. Journal Vol. 34, pp. 101, 161.
Group Inverter Equipment, I.P.O.E.E. Journal, Vol. 35, p. 130.

R. A. Brockbank, Ph.D., B.Sc., A.M.I.E.E., and C. F. Floyd, M.A., A.M.I.E.E.
The Unit Bay 1B Coaxial Cable Transmission System. I.P.O.E.E. Journal, Vol. 38, pp. 43, 82. Vol. 39, pp. 14, 64.

G. J. S. Little, B.Sc., A.M.I.E.E.
Twelve-Circuit Carrier Telephone Systems. I.P.O.E.E. Printed Paper No. 167.

E. M. Richards, A.C.G.I., B.Sc. (Eng.), M.I.E.E. and F. J. D. Taylor, B.Sc. (Eng.).
Multi-Circuit Carrier Telephony I.P.O.E.E. Printed Paper No. 171.

R. A. Brockbank, Ph.D., B.Sc., A.M.I.E.E. and C. F. Floyd, M.A., A.M.I.E.E.
Wideband Transmission over Coaxial Cables, I.P.O.E.E. Printed Paper No. 180.

10. DISCUSSION.

Points raised most frequently in the discussion were:

Soldered Joints. It was generally agreed that badly soldered joints were not only the cause of most faults but were responsible also for a good deal of ineffective maintenance time. Alternative methods of making permanent connexions, such as welding, were suggested, but in the opinion of the author there is little likelihood of their showing a substantial improvement. Soldering is a simple, straightforward operation ; the difficulty lies in the very large number of such connexions in the average circuit in the H.F. network. Hence a very high standard is required. It was pointed out that one faulty joint in a thousand or even ten thousand is not good enough ; perfection must be aimed at and one bad joint in one hundred thousand is no better than is really required.

The use of enamelled wire was suggested as being one of the worst causes of dry joints, and it was thought that the use of P.V.C. insulated wire, which does not require enamelling, is likely to lead to substantial improvement.

One or two speakers reported that their examinations of equipment in the field did not confirm the existence of large numbers of dry joints as reported in the paper, and it was frequently stated that such conditions did not occur in automatic telephone exchanges. Whilst this may be true in a few cases, it is known that the number of dry joints detected depends very largely on the skill of the testing officer and the sensitivity of the fault detector used. Repeat tests in selected stations with more sensitive equipment, *e.g.*, that described in Section 4.4 of the paper invariably show up more dry joints than found previously. It is believed that in automatic exchanges the presence of d.c. in most connexions masks the existence of most of the dry joints. Wetting is a well-known and effective method of improving electrical connexions and might with advantage be used more often. There is a danger, however, of introducing noise into the circuit, and where wetting is most effective, *i.e.*, in low-level circuits, noise is most objectionable. The avoidance of all unnecessary joints in the design and first-class workmanship are preferred methods of eliminating bad connexions.

Design. The section of the paper, "Design of Equipment for Maintenance," was discussed by many speakers, disagreement sometimes being expressed with the statement that hitherto maintenance had not received a fair share of attention at the design stage. It was, however, agreed that more co-operation between designers and maintenance engineers was required and in particular that maintenance conditions and procedure must be known and fully understood by designers. Design principles recommended, additional to those given in the paper, were : (*a*) Hermetic sealing of components to avoid the effect of dust, (*b*) Provision for maintenance testing on a functional basis, (*c*) Fault location only as far as the panel at fault and (*d*) jacked-in equipment capable of being easily replaced by spares in the event of a fault and serviced away from the racks.

The implication that considerations of space were of minor importance was criticized, examples of acute shortages of space being freely quoted. It must, of course, be admitted that space saving can be invaluable at the present time, but it is a purely temporary phase, and economic studies show without any doubt whatsoever that in meeting a given performance specification the designer's effort should go firstly into reducing maintenance charges, secondly to reducing capital cost and thirdly, a long way behind, into saving space. At the present time, as in the past, far too much effort is expended on the least important of these three things.

General. The complexity of the maintenance procedure set up to maintain circuits in the H.F. network was commented upon unfavourably by some. No acceptable suggestions enabling it to be simplified were forthcoming, however, apart from general agreement that the work of Transmission Controls could, as stated in the paper, be taken over by Controlling Testing Office. This is a change which will be introduced experimentally as soon as is practicable. The most promising lines of approach to simpler maintenance are the extension of pilots and the development of more suitable test gear. Unfortunately test gear nearly always lags behind the equipment; frequently the design of maintenance test gear commences only after the equipment is installed and put into service, further evidence of the lack of attention given to maintenance in the early stages of equipment design. The cure is obvious.

The desirability of spare equipment on a large scale, *e.g.*, spare fully-equipped tubes on coaxial routes, was stressed. This is largely a question of economics. From the point of view of the maintenance officer ample spare equipment is very desirable and can reduce lost circuit time to a small value. On the other hand it is expensive and except for a few special cases, *e.g.*, carrier generating equipment, it is probably better employed providing a speedier service. The loss of a coaxial route due to a fault is, however, a serious matter and must be provided for. Alternative routes, probably four or five alternatives on the biggest routes, which have little overload capacity, is a likely solution to the problem.

A means of assessing maintenance efficiency is something which all supervising and controlling officers urgently require. The difficulties in the way of devising a satisfactory scheme are formidable. Though the total number of circuit faults now occurring is high, the number actually proved to any one station is quite small. For example, it is stated in the paper that a reasonable fault rate in a two-tube coaxial dependent station would be one fault in 16 years. It is clearly impossible to give a week-by-week or even year-by-year assessment of the standard of maintenance in such a station unless it is very low indeed. More could, however, be done in the big stations, particularly as regards the circuits and groups they control, and work on the lines indicated in the paper is in progress.

TABLE I.—Test Equipment Used for the Maintenance of Carrier Systems. (See Para. 4.2).

Type	Range	Output		Rack (R) or Portable (P) and Weight (Wt)	Power Supplies	T.M.S.	Notes
		Power Ref lmW	Impedance Ohms				
S.T. & C. 74210	35 c/s to 60 Kc/s	+17 db in 1 db steps	600 (B)	(P) Wt. 2 cwt.	2A at 21V. 60 mA at 130V.	—	Used on S.T. & C. Carr. No. 5 using AMP 74129 O/P 1 Watt
S.T. & C. 74601	60 Kc/s to 2.0 Mc/s in 8 steps	0 to –50 db	75 (UB)	(P) in 3 Units. Wt. 20lb each	H.T. & L.T. from Power Unit. 200—250V. A.C.	See Table II	Superseded by 74602. A.C. should be stabilised where possible
S.T. & C. 74602	60 Kc/s to 2.0 Mc/s in 8 steps	0 to –50 db	75 (UB)	(P) in 3 Units. Wt. 20lb each	H.T. & L.T. from Power Unit. 200—250V. A.C.	See Table II	Supersedes 74601. A.C. should be stabilised where possible
S.T. & C. Transmission Test Trolley	14.7 Kc/s to 106.7 Kc/s in 24 steps and 30 c/s to 10 Kc/s	0 to –55 db	600 (B & UB) 140 („) 75 („)	(P) Wt. 400lb	2.7A at 21V. 80 mA at 130V.	See Table II	Supplied to Terminal Stations. Carrier No. 7 routes
G.E.C. Carrier Frequency	3 Kc/s to 60 Kc/s	0 to +20 db	140 (B)	Part trolley equipment Wt. 76lb	1.4 A at 21V. 77 mA at 130V.	—	Used on G.E.C. Carr. No.6. Internal 30db Pad. to reduce O/P if required
Tester WL 56265	60 Kc/s to 2.8 Mc/s in 7 steps or external oscillator	0 to –50 db	75 (UB)	(P) Wt. 25lb	5A at 4V A.C./D.C. 50 mA at 250V. (Coax. bay)	See Table II	Frequencies depend upon number of supergroups. Power obtained from coax. bay or power unit. Superseded by Tester W6
Tester W1	60 Kc/s to 2.85 Mc/s in 10 steps or external oscillator	0 to –50 db	75 (UB)	(R)	5A at 4V. A.C./D.C. 50 mA at 250V. (Coax. bay)	See Table II	Used on coaxial systems
Tester W6 (New type)				(P)			Portable type of tester W1 to replace tester WL 56265, but not yet in production
W4/111	60 Kc/s to 50 Mc/s	2V. in 600Ω max.	For use with Send Unit	(R) or (P) Wt. 20lb	200—250V. A.C. 50 c/s 50 watts	—	Sending network required to stabilise O/P impedance when used for transmission work
W4/114 WX4	50 Kc/s to 5.0 Mc/s	+2 to –30 db	75 (UB)	(R) or (P) Wt. 35lb	4A at 4V. A.C./D.C. 45 mA at 250V. (Coax. Bay 1B)	—	Used on coaxial systems in conjunction with testers WL 56265 or W6. Uses portable power supply of tester WL56265
Halsey Sullivan Heterodyne	0 to 176 Kc/s	Max. +29db	600 } (UB) 75 }	(R)	2.5A at 24V. 160 mA at 130V.	—	Interpolation dial covers 6 Kc/s. Frequency check possible
W44/100 Beat Frequency	100 Kc/s to 5.0 Mc/s	+19 to 23 db	75 (UB)	(R)	10A at 4V. A.C. 140 mA at 250V. from A.C. Power Unit 200—250V.	—	Logarithmic scale. 60 Kc/s incremental control. 150 Kc/s quartz crystal frequency check

O/P—Output.

B—Balanced. UB—Unbalanced.

TABLE II.—TRANSMISSION MEASURING SETS AND LEVEL MEASURING SETS

Type	Frequency Range	Level Range	Impedance Ohms	Rack (R) or Portable (P) and Weight (Wt)	Power Supplies	Oscillator	Notes
S.T. & C. 74100	8 Kc/s to 60 Kc/s	–10 to +24 db	600, 140 } (B)	(P) Wt. 21lb.	0.32A at 24V. 10 mA at 130V.	Fixed 40 Kc/s	Used on Carrier System No. 5. Direct reading on 600Ω only
S.T. & C. 74100 (Modified)	8 Kc/s to 60 Kc/s	–10 to +29 db	140 (B)	(P) Wt. T.M.S. 21lb. Wt. S.U. 5lb.	0.324A at 24V. 10 mA at 130V.	40 Kc/s at 0 db or –40 db	Used on Carrier System No. 5 and in conjunction with Send Unit S.T. & C. 74103A. For 600Ω (UB) circuits
S.T. & C. Transmission Test Trolley	30 c/s to 160 Kc/s	–35 to +30 db	600, 140, 75 } (B)	(P) Wt. 400lb.	2.7A at 21V. 80 mA at 130V.	See Table I	Supplied to terminal stations. Carrier System No. 7
S.T. & C. 74117A	1 Kc/s to 150 Kc/s	–20 to +25 db	600, 140 } (B) Suitable for use on (UB)	(P) Wt. 20lb.	0.45A at 24V. 20 mA at 130V.	40 Kc/s at 0 db or –40 db 140Ω or 600Ω	Used on 12 or 24 cct. systems
S.T. & C. 74601 (Coax. Meas. Set)	60 Kc/s to 2.5 Mc/s	–55 to +5 db with pad unit Thro' levels –21 to +39 Term levels –30 to +30	75 (UB) with pad unit 75, 600 } (U.B)	(P) 3 units. Wt. 20lb. each	H.T. & L.T. from Power Unit. 200—250V. A.C. 50 c/s 60 watts	50 Kc/s calibrate Also see Table I	Obsolescent. Superseded by 74602. A.C. should be stabilised where possible
S.T. & C. 74602	60 Kc/s to 3.0 Mc/s	–55 to +25 db	75 (UB)	(P) 3 units. Wt. 20lb. each	H.T. & L.T. from Power Unit. 200—250V. A.C.	See Table I	Supersedes 74601 A.C. stabilised where possible
Tester WL 56265	60 Kc/s to 3.0 Mc/s	–21 to +30 db	75 (UB)	(P) Wt. 25lb.	5A at 4V. A.C./D.C. 50 mA at 250V. (Coax. Bay)	See Table I	Power obtained from Coax. Bay or Power Unit. Contains filters for through level measurements of pilots. Superseded by Tester W6
Tester W1	60 Kc/s to 3.0 Mc/s	–21 to +30 db	75 (UB)	(R)	5A at 4V. A.C./D.C. 50 mA at 250V.	See Table I	Used on coaxial systems
Tester W6				(P)			Portable type of tester W1 to replace tester WL 56265 but not yet in production
Test Panel W4/108	12 Kc/s to 5.0 Mc/s *60 Kc/s to 3.0 Mc/s	Insertion loss meas. up to 60 db. Also up to 80 db for frequencies*	75 (UB)	(R)	4A at 4V. A.C./D.C. 45 mA at 250V. Preferably stabilised	—	Usually associated with Halsey Sullivan or W44/400 oscillator and send unit W42/1
Tester WL 30487	150 Kc/s to 25 Mc/s	Total insertion loss 70 db		(P) Wt. 80lb.	Heaters 2V. D.C., H.T. 180 V. Bias 18V.	—	Superheterodyne radio receiver. I.F. 450 Kc/s. Not a selective measuring instrument
R. Branch Selective Measuring Equipment	(a) Non-selective 200 c s to 1.0 Mc/s. (b) Selective in range 12—800 Kc/s	–30 to +30 db	50, 75, 140, 200, 600 } (B) or (UB)	(R) or (P) Wt. (R) 48lb. Wt. (P) 1 cwt with case	10.5A at 4V. A.C./D.C. 4.2A at 12V. A.C./D.C. 2.1A at 24V. A.C./D.C. 65 mA at 130V.	—	Used on first three S/G's of coaxial systems and submarine cable routes

TABLE II.—TRANSMISSION MEASURING SETS AND LEVEL MEASURING SETS—*continued*.

Type	Frequency Range	Level Range	Impedance ohms	Rack (R) or Portable (P) and Weight (Wt)	Power Supplies	Oscillator	Notes
Wide Band Level Meas. Set. R. Branch Model "C"	200 c/s to 1.0 Mc/s. *300 c/s to 150 Kc/s	–25 to +30 db	I/P 2000 (UB) 50, 75, 140, 200, 600 (B) or (UB) with reduced frequency range*	(R) or (P) Wt. 16lb.	42 mA at 130V. and 4, 12, 17.5, 21 or 24 volts A.C./D.C.	—	Used on submarine cable carrier systems
Moullin Valve Voltmeter Model "A"	Audio to 5.0 Mc/s	0 to 0.5V. RMS. Also calibrated –4.3 to +5.0 db	Open (I/P capacity 5—7 *p*F)	(P) Wt. 5lb.	6V. Battery only	—	Adaptor W5. Extends range up to +12 or +20 db
S.T. & C. 74105B Decibel-meter (No. 6)	50 c/s to 60 Kc/s	–10 to +20 db	600 (B)	(P) Wt. 2lb.	—	—	
G.E.C. Decibel-meter	300 c/s to 60 Kc/s	–10 to +20 db (2 scales for 140 and 600)	140, 600 (B) or high impedance	(P)	—	—	

I/P—Input. O/P—Output.
(B)—Balanced. (UB)—Unbalanced.

TABLE III.—Miscellaneous Measuring Equipment.

Type	Frequency Range	Measurement Range	Impedance ohms	Power Supplies	Rack (R) or Portable (P) and Weight (Wt)	Notes
S.T. & C. 74120A. Distortion Measuring Set	2 fixed frequencies 15.16 Kc/s & 45.5 Kc/s	Amplifier O/P +20 to + 33 db 3rd harmonic content from −17 to −50 db	Send Circuit (UB) Receive Circuit (B)	1A at 20 to 26V. 16 mA at 130V.	(P) Wt. 34lb.	Measures 3rd harmonic content at O/P of line amplifiers. Carrier System No. 5
S.T. & C. 74110 Valve Test Set	—	0 to 4.2 mA/V. (2 ranges) 0 to 50 mA (3 ranges)	—	H.T. 130V. L.T. 21V.	(P) Wt. 34lb.	" A " set covers 12 channel systems. " C " set covers 3 channel overhead systems
G.E.C. Generator Supply Tester	4 filters select: 22 Kc/s, 66 Kc/s, odd harmonic 27 db pad 20 Kc/s, 68 Kc/s even harmonic	Even harmonics suppressed by 27 db	—	1A at 21V. 3 mA at 130V.	(P) Wt. 48lb.	Carrier System No. 6. Carrier generating equipment used with 40 db amplifier and decibelmeter
G.E.C. 40 db Test Amplifier	3 Kc/s to 60 Kc/s	Fixed gain 40 db ±0.5 +26 db. Ref. 1 mW in 140Ω	I/P 600, 140 (B) O/P 140	1.4A at 21V. 73mA at 130V.	(P) Wt. 26lb.	Carrier System No. 6. Harmonic content is better than 55 db below signal level. Used in conjunction with harmonic generator tester
G.E.C. Harmonic Generator Tester	Measures 2nd or 3rd harmonic of 20 Kc/s I/P signal		Amp. in 600 (UB) Amp. out 140 (UB)	—	(P) Wt. 40lb.	Requires 40 db amplifier 20 Kc/s fixed oscillator, and decibelmeter
G.E.C. Valve Testing Panel Type 1 (7 valves) Type 2 (9 valves)		Valve used in amplifier circuit and gain measured		H.T. 130V. L.T. 24V. G.B. 40V.	(P)	Carrier System No. 6. External oscillator. 800 c/s at 1 mW required to operate tester
S.T. & C. 74101 Attenuator Model " A "	Up to 50 Kc/s	Insertion loss up to 75 db in 0.5 db steps	I/P, O/P 600 (UB)		(P) Wt. 17lb.	Constant impedance (UB). T-type attenuator. Power should not exceed +34 db. Errors 0.02 to 0.2 db
S.T. & C. 74101A, 74101B, 74101C Switch Box			600 or 138 600 or 50 600 or 125		(P) Wt. 6½lb.	Used for comparison measurements. 3 Models available with impedances as shown
Send Element W 42/1	0 to 5 Mc/s	−63 to +12 db	O/P 75 (UB)		(R)	Normal range +10 to −60 db covered in 5 db steps. The scale is calibrated at +7 and +12 db to increase the range
H.F. Attenuator Unit W42/1 (*a*) (*b*)	0 to 5 Mc/s	Insertion Loss. 80 db in 1 db steps 61.5 db in 0.5 db steps	I/P, O/P 75 (UB)		(P) Wt. 3lb.	Maximum I/P power 100 mW

I/P—Input. O/P—Output.

(B)—Balanced. (UB)—Unbalanced.

SCHEDULE OF ROUTINE TESTS ON CARRIER EQUIPMENT.

(See Para. 4.3).

1. Carrier Generating and Synchronizing Equipment.

No. 5 System.

Check operation of "pilot fail" alarms, pilot receivers and pilot converters ...	weekly
Check frequency of 4 kc/s master oscillator	weekly
Check output level of 4 kc/s master oscillator	monthly
Check output level(s) of multi-frequency oscillators	monthly
Check levels of 60 kc/s synchronizing pilot and output of pilot receiver (pre-motor control)	monthly
Check stability of master oscillators ...	quarterly

No. 6 System.

Check frequency and output of 1 kc/s driven oscillator	daily
Check output levels of all filter amplifiers	weekly
Check output levels of 6 kc/s amplifiers	weekly
Check output levels of constant volume amplifier	weekly
Check output levels of pilot receivers ...	weekly
Check output levels and even harmonic suppression of frequency doubler and harmonic generator	monthly
Check outputs of buffer amplifier and pilot transmitter	monthly
Check of master oscillator frequency ...	yearly

No. 7 System.

Check output level of master oscillator ...	monthly
Check output level of harmonic generators	monthly
Check and adjust switching panel ...	monthly
Check level of group and channel carrier supplies	monthly
Check gain of channel carrier supply amplifiers (where fitted)	monthly
Check operation and adjustment of motor amplifier panel	monthly
Check operation of "sync" fail alarm ...	monthly
Check levels of receive and transmitted 60 kc/s pilots	monthly
Check stability and frequency control of master oscillators	quarterly
Check operation and adjustment of frequency deviation alarm panel ...	quarterly

No. 7 Type Coaxial in Group and Supergroup Equipment.

No. 7 Type Group and Supergroup Carrier Generating Equipment.

Check operation of group and supergroup changeover panels	monthly
Check levels of group and supergroup carrier supplies	monthly
Check gain/frequency response of all amplifiers on group and supergroup carrier generating equipment	6 monthly

Group Inverter Equipment

Check operation of changeover panels ...	monthly
Check the levels of carrier supplies at distribution panels	monthly
Check operation of carrier-supplies failure alarms	monthly

2. Terminal Equipment.

No. 5 System.

Check and adjust channel carrier leak ...	yearly

No. 6 System.

Check and adjust carrier leak ... ... (Several adjustments of carrier leak are required since the No. 6 System employs a double modulation circuit for each channel.)	yearly

No. 7 System.

Check and adjust carrier leak (group and channels)	yearly
Check gain/frequency response of group amplifiers	monthly

No. 7 (Coaxial).

Check gain/frequency response supergroup amplifiers	6 monthly

3. Line Equipment.

No. 5 System.

Check voltages of grid bias batteries ...	weekly
Check harmonic content of line amplifiers	monthly

No. 6 System.

Check voltages of common 40V. g.b. supply (where fitted)	weekly
Check harmonic content of line amplifiers	monthly

No. 7 System.

Check harmonic content of line amplifiers	monthly

Coaxial System Unit Bay 1B.

Check pilot levels at pilot stabilizers ...	weekly
Check gain/frequency response of H.F. line	weekly
Check operation of A.G.C.	weekly
Check operation of H.F. repeater changeover circuits	weekly
Check local manual changeover of H.F. repeaters	yearly
Replace all valves in H.F. line repeaters ...	yearly

Inverter Equipment.

Assuming that inverters can be regarded as part of the line equipment, the routine test(s) are:

Check harmonic content of inverter line amplifier	monthly
Check level of inverter carrier leak ...	yearly

4. Valve Tests.

No. 5 System.

Filament and anode currents of valves in line amplifiers, channel amplifiers, carrier generating and synchronizing equipment measured ... ... monthly

No. 6 System.

Filament and anode currents of valves in line amplifiers and carrier generating equipment measured ... ... weekly

No. 7 System.

Filament and anode currents of valves in channel, group and line amplifiers measured ... ... weekly

Filament and anode currents of valves in carrier generating and synchronizing equipment measured ... ... monthly

Coaxial System Unit Bay 1B.

Filament and anode currents of valves in group and supergroup translating and associated carrier generating equipment monthly

Replace all H.F. line amplifier valves ... yearly

Test of Gm of valves in supervisory equipment ... ... yearly

Inverter Equipment.

Filament and anode currents of valves in inverter amplifiers measured ... ... weekly

Filament and anode currents of valves in inverter carrier generating equipment measured ... ... monthly

5. Station Tests.

Daily

(i) Check plate, filament and g.b. *voltages* at the powerboard and apparatus racks.

(ii) Check frequency and voltage of 500/20 ringing generators.

(iii) Check operation of all emergency and fault alarms.

Weekly.

(iv) Check operation of power plant emergency changeover equipment.

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