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TABLE 1.—CAPITAL EXPENDITURE

(New Works and Repairs required immediately)

Amount	Date	Factor	Present Value	Details
£62,000	Immediately	1	£62,000	XE £36,000 XC £26,000
£72,000	8 Year	0.711	£51,000	XE £54,000 XC £18,000
Total P.V. of Capital Expenditure ---- ---- ----			£113,000	
Less P.V. of Residual Value of Asset Replaced ---- ----			Nil	
Nett P.V. of Capital Expenditure ---- ---- ----			£113,000	

ANNUAL CHARGES

Amount	Commencing	Factor	Present Value	Details
£10,600	Immediately	20	£212,000	7,700 lines of exchange equipment at £1. 33,000 wire miles at 1/9.
£5,300	8 Year	14.2	£74,000	4,500 lines of XE at £1, and 9,000 wire miles at 1/9.
Total P.V. of Annual Charges ---- ---- ---- ----			£286,000	
Total P.V. of All Charges ---- ---- ---- ----			£399,000	

Proposal (2):

Reduce size of areas served by A and B and serve the remainder of the combined areas from Z.

Existing exchange plant, 3,800 lines. Existing underground plant, 20,000 wire miles.

Exchange installation immediately, exchange Z, 2300 lines, cost £32,000.

In 4th year add 1600 lines to B, cost £20,000.

In 7th year add 1200 lines to A, cost £15,000.

In 8th year add 2300 lines to Z, cost £28,000.

Underground cable, scrap 5000 wire miles immediately, residual value £1000.

Instal 20,000 wire miles immediately, cost £40,000.

Instal 6000 wire miles in 8 years, cost £12,000.

Therefore, by comparison, the economical course would be to instal the new exchange at Z.

TABLE 2.—CAPITAL EXPENDITURE

(New Works and Repairs required immediately)

Amount	Date	Factor	Present Value	Details
£72,000	Immediately	1	£72,000	XE £32,000 XC £40,000
£20,000	4th Year	0.864	£17,300	XE
£15,000	7th Year	0.746	£11,200	XE
£40,000	8th Year	0.711	£28,000	XE £28,000 XC £12,000
Total P.V. of Capital Expenditure ---- ---- ----			£129,000	
Less P.V. of Residual Value of Asset Replaced -- ----			£1,000	
Nett P.V. of Capital Expenditure ---- ---- ----			£128,000	

ANNUAL CHARGES

Amount	Commencing	Factor	Present Value	Details
£9,200	Immediately	20	£184,000	6,100 lines of XE at £1, and 35,000 wire miles at 1/9.
£1,600	4th Year	17.3	£27,500	1,600 lines of XE at £1.
£1,200	7th Year	15.0	£18,000	1,200 lines of XE at £1.
£2,800	8th Year	14.2	£40,000	2,300 lines of XE at £1, and 6,000 wire miles at 1/9.
Total P.V. of Annual Charges ---- ---- ---- ----			£269,500	
Total P.V. of All Charges -- ---- ---- ---- ----			£397,500	

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SOME GALVANIC AND RELATED CORROSION PROBLEMS OF A COMMUNICATION NETWORK*

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Introduction: Investigation of the corrosion problems of the Postmaster-General's Department, Australia, over a number of years has involved the examination of many different forms of damage on underground and open wire plant. Although not the most destructive in terms of cost, one of the most widespread sources of damage is that associated with galvanic corrosion. The Postmaster-General's Department, under Commonwealth administration, controls the installation, operation and maintenance of telegraph and telephone facilities throughout Australia and the installation and maintenance of national broadcasting facilities, in addition to the usual postal services. The extent of the plant involved is given by the brief statistics listed in Table 1:—

TABLE 1

Item of Plant	Single Wire or Duct—Mileage	Capital Value £A
Open Wire Lines	849,027	22,552,460
Underground—		
Cable	2,445,466	10,960,000
Conduit	12,973	6,892,653
Broadcasting	—	593,172
Exchange, substation and long-line equipment	—	17,126,096

Although the corrosion problem is principally concerned with underground plant, galvanic corrosion is of considerable importance in the case of certain items of open wire plant, such as iron poles and ground stays (or guys). The main object of this paper will be to present some of the typical galvanic problems which have been encountered on underground and open wire plant over a period of approximately 10 years.

Type of Construction: Open Wire Plant.—The underground portion of open wire plant includes poles and stays. Although the majority of the poles used are local hardwood timber, there are many thousands of miles of iron pole line in areas where termites are a source of danger to wooden poles, or where good pole timber is scarce. In more recent years, and determined by supply and strength considerations, the use of iron poles has been extending to areas where previously only wooden poles have been used. The principal types of iron poles in use are:—

Galvanised and ungalvanised iron pipe poles between $2\frac{1}{2}$ in. and 6 in. in external diameter. These poles may be the same diameter throughout or tapered in sections towards the top of the pole.

Ungalvanised steel rolled sections.

Ungalvanised tramway or railway rails.

The iron poles are fitted below ground level with an ungalvanised iron foot plate to prevent sinking in poor ground and with similar type "heel" and "surface" plates to improve transverse and longitudinal stability. The plates are sometimes tar dipped.

Stays, used to improve the transverse and longitudinal stability of open wire routes, consist of galvanised steel rods $\frac{5}{8}$ in., $\frac{3}{4}$ in., or 1 in. in diameter to the lower end of which is bolted a steel anchoring plate 12 in., 15 in. or 18 in. square. Stays of the screw-in ground anchor type have been used where ground conditions are suitable, but not extensively. On important pole routes stays are installed at least every quarter-mile and on less important routes at slightly longer intervals.

Underground Plant.—The following construction practices are used in the laying of lead-sheathed telephone cable:—

(a) In city and town networks multi-way earthenware conduits either $3\frac{1}{4}$ in. square or 4 in. in internal diameter are used for main cable routes. For branch cable routes involving one or more cables greater in size than approximately 150 pairs, single conduits either earthenware or concrete 4 in. internal diameter are used either singly or in groups up to three in number.

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* Paper presented before the National Bureau of Standards, Washington, D.C., U.S.A., Soil Corrosion Conference, 1943.

This type of construction is used whether the cable is for subscribers, junction or trunk (long distance) service. For distribution cables smaller than 150 pairs in size either black iron (ungalvanised) pipe or zinc galvanised iron pipe is used. The choice of these two types of iron pipe in any particular case has been determined primarily upon the likelihood of external corrosion of the pipe due to the nature of the soil in which the pipe is to be laid. As a result of the galvanic corrosion associated with this form of construction it is being superseded by non-metallic pipe construction or armoured cables.

(b) In rural networks. In the vicinity of townships the construction generally follows that in the larger city networks. For long distribution cables to rural subscribers unarmoured cable is laid direct in the ground. Trunk (or toll) cables in the country areas are normally protected with bitumen impregnated jute and paper and steel tape armouring.

Extent of Damage Occurring: Most of the damage occurs on underground plant and for the four calendar years, 1938 to 1941, the average annual damage arising from all classes of lead-sheathed telephone cable failure throughout Australia was as listed in Table 2:—

TABLE 2

Cause of Failure	Number of Failures		Total cost of Failures	
	Number	%	Cost £A	%
Electrolysis	1,285	28.6	7,357	25.3
Chemical Corrosion ..	94	2.1	862	3.0
Intercrystalline damage	770	17.1	5,012	17.2
Miscellaneous (mainly mechanical damage)	2,346	52.2	15,835	54.5
TOTAL	4,495	100.0	19,066	100.0

Galvanic corrosion is included under Electrolysis and covers the following main sources:—

Metallic Couples—involving connection of the lead-covered cable to copper earthing systems, connections between cable in black iron and in zinc galvanised pipe, etc.

"Long Line" Currents—set up by differing soil conditions, soil resistivity, variation in oxygen concentration, etc.

Local Currents—set up by contact of the cable with cinders or charcoal.

No attempt is made to differentiate under galvanic corrosion the localised attack of the cable sheath which may be due to impurities in the metal or to the 17 possible causes listed by R. B. Mears and R. H. Brown in "Causes of Corrosion Currents, Industrial and Engineering Chemistry," Vol. 33, No. 8, pages 1001-1010. With a considerable proportion of the underground plant located in the larger cities, such as Sydney and Melbourne, where electric tramway and railway systems operate and associated electrical drainage protection has been applied, no clear line of demarcation is obtained in many cases between stray traction current and galvanic current effects. Of the damage listed under Electrolysis, more than 80 per cent. is attributable to galvanic currents and the associated "cathodic" corrosion referred to later in the paper. The proportion of damage due to stray traction currents is decreasing due to the remedial measures adopted.

No similar quantitative figures are available for galvanic corrosion of iron poles and stays. Sufficient evidence, however, has been obtained to indicate the serious corrosion which may occur to poles and stays given the suitable ground conditions. Damage in certain areas was so severe that extensive field and laboratory tests were undertaken to determine causes and remedies. Some of these tests are referred to in detail later.

Galvanic Corrosion: To determine the specific source or sources of galvanic corrosion, the investigator is faced in many cases with a difficult problem. With the factors controlling the production of galvanic currents, so many and varied and not necessarily stable over any lengthy period of time, the treatment of the problem in many cases is of necessity dealt with to a large extent on the basis of effect rather than cause, that is, current and potential distribution on the cable or pipe is of more importance than the precise differences between the various ground conditions through which the cable passes, differential aeration conditions, etc. However, much progress has been and is being made in corelating galvanic current sources with soil conditions in terms of pH value, soil resistivity, soil analyses and electrical cell conductivity tests, and apart from the value of this work in planning new construction, the knowledge of these conditions is of very material assistance in designing protective measures on plant in situ on the basis of observed current and potential conditions on the cable or pipe. It is often argued that because of the variable conditions involved in galvanic corrosion that a quantitative or qualitative estimation of probable conditions is not worth while. It is contended, however, that the estimation of probable maximum current flow to be expected under worst conditions in any particular case is a useful indication of the corrosion hazard and forms a good theoretical background to the practical handling of the case.

In galvanic corrosion the amount of current flowing from the corroding element is a measure of the damage being produced. The current I in a galvanic cell is given by Ohms law $I = E/R$ where E is the driving electromotive force, and depends on the materials of the electrodes of the cell and the electrolyte in which they are immersed. The pH value of the liquid, its total acidity and condition of aeration in addition to the condition of polarisation of the electrodes are important factors in the determination of E at any particular instant. For metallic elements in contact the resistance R of the cell is mainly determined by the resistance to current flow of the surrounding electrolyte. In an electrolyte of infinite extent $R = \rho/4\pi C$ where ρ is the resistance of the medium in ohm/c.c. and C is the mutual geometric capacity of the elements in centimeters and can be calculated in a similar way to the capacity in electrostatic problems. In the case of corroding elements in soil near the ground surface the capacity factor in the formula is reduced, as a large proportion of the current flow lines are limited by the location of the surface. H. B. Dwight, in his paper "Calculation of Resistances to Ground," Electrical Engineering, December, 1936, page 1319, has investigated earth resistances of electrodes and his formulae are useful in the calculation of resistances between parts of pipe lines when galvanic corrosion, due to soil variations, is suspected.

Examples of Galvanic Corrosion on Open Wire Line Plant: Severe corrosion of stay rods often occurs in the low resistance soils which occur in the drier sandy parts of Australia such as the Western plains of New South Wales and the Mallee area of North-western Victoria. These soils, which are generally somewhat alkaline, have resistivities as low as 100 ohms/cc. and often contain up to 1 per cent. of sodium chloride. The amount of soluble salt often varies greatly with depth and the pH value also changes. In winter the surface soil may become slightly acid in reaction due to the leaching of soluble salts and consequently show a low soluble salt content, but at a depth of a few feet the salt content is quite high and the reaction is alkaline. The corrosion of stay rods in these soils is very patchy, some parts of the rods being quite clean whereas other parts are often corroded right through and a dense crust of corrosion products left. These corrosion products are generally very acid in reaction, pH values of 2 being common with much greater concentrations of chlorides in the corrosion products than in the surrounding soil. The uncorroded parts of the rod generally have an alkaline reaction. The concentration of acid ions in the corrosion products is evidently due to ion migration in the galvanic current flowing between corroded and uncorroded parts of the rod. Once established, this type of galvanic corrosion is progressive. The rust tubercles formed inside water supply piping often show this increase of concentration of negative ions and pronounced acidity—See "Corrosion and Discoloration of water supplies of Perth, W.A.," "Chemical Engineering and Mining Review," by H. E. Hill, October 6th, 1930, p. 38.

Another type of stay rod corrosion was found to be due to the use of a tightly fitting black iron base plate on the rod. In investigating the cause of this corrosion a model stay rod made up from a 6 foot length of $\frac{3}{4}$ in. diameter galvanised iron piping was fitted with a 12 in. square black iron base plate but insulated from it with an ebonite bush. A rubber insulated wire was soldered to the base plate and passed up the centre of the pipe. By this means it was possible to measure the galvanic properties of this unit when immersed in a river with water of resistivity 150 ohms/c.c. A potential of 0.56 volts was measured between the black iron base plate and the galvanised iron rod, and a current of 0.16 amperes was found to pass between base plate and rod when connected through a low resistance ammeter, the current passing via the electrolyte from the rod to the base plate. The corrosion hazards of such a unit in a salty soil are thus apparent. Some of the field cases examined have rods corroded through in 12 months. It was found that rods with loosely fitted base plates were less rapidly corroded than those tightly bolted together.

The corrosion of galvanised iron telephone poles of 3 and 4 inches diameter with a cast iron sole or base plate has been very much less than that experienced on the stay rods in similar soil. This is attributed to the smaller concentration of galvanic current on the larger diameter anode, see "Some Factors Involved in Soil Corrosion," E. R. Shepard, "Industrial & Engineering Chemistry," July, 1934, p. 723. To reduce the corrosion problem on stay rods and on poles, experiments are proceeding in the direction of bitumen impregnated wrappings, bitumen dipped coatings, and the use of concrete base plates for stay anchors.

Examples of Galvanic Corrosion on Underground Plant: Two special cases of galvanic corrosion of underground telephone cables are referred to later. Apart from these special cases, the field of galvanic corrosion is covered by the following typical examples:—

(a) Cable laid in black iron and galvanised iron pipe.—It has been the practice to use either black iron or zinc galvanised iron pipe for small sized telephone distribution cables. In a number of cases, both types of pipe exist on successive sections of a cable run (due to the extension of the cable system in two stages, and the necessity in the second stage to use black iron pipe and conserve the use of zinc). This has resulted in many cases of galvanic corrosion. A typical case is illustrated in Fig. 1, which shows the layout of the underground telephone cable and conduit system and the distribution of current flow measured subsequent to the cable failure at Point A, and prior to the installation of an insulating joint at Point B. The soil through which the cable passes is heavy clay with a resistivity between 1,000 ohm/c.c. and 3,000 ohm/c.c. The flow of current is consistent with a zinc anode on the galvanised pipe portion and an iron cathode on the black iron pipe portion, and it will be noticed that the current falls off gradually in each direction. The cable failure occurred on the black iron pipe section.

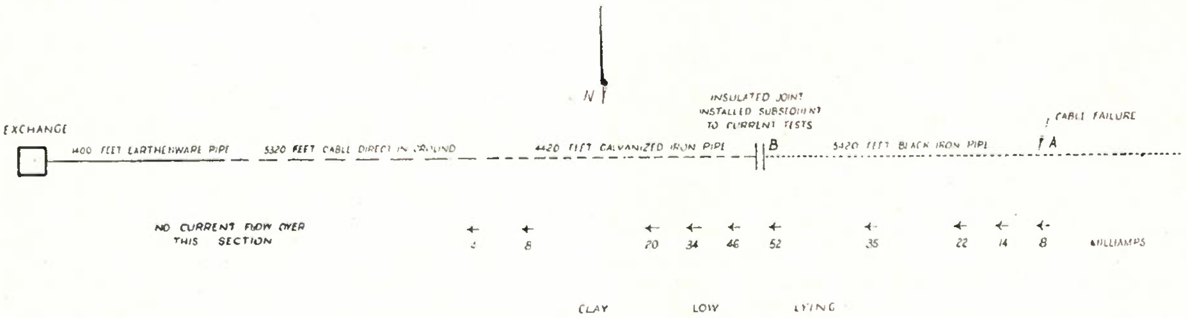


Fig. 1.—Galvanic Corrosion—Case 1.

The corrosion product on the cable sheath consisted of lead monoxide in its typical pale yellow, yellow red, and red varieties, a form of corrosion which has been termed "cathodic" or "alkaline." This type of damage has been extensive in smaller distribution cables laid either in black iron or in galvanised iron pipe, and is referred to later in more detail. To reduce the possibility of further damage an insulating joint was installed at the junction of the two pipe systems at Point B. This reduced the current flow to negligible proportions, and no further failures have occurred.

In another rural area the cable system consisted of a combination of unarmoured cable laid directly in the ground, cable in earthenware ducts, in black iron pipe, and in galvanised iron pipe. The layout of this system, together with relevant current measurements, is shown in Fig. 2. The source of the current flow on the cable is attributed partly to the combination of two types of iron pipe and partly the combination of areas of high, well-drained ground to the north and low, waterlogged ground to the south. The cable at the point of failure had several deep pits containing white corrosion product, chiefly lead carbonate with some chloro-carbonate. Under the microscope the pits showed definite intercrystalline attack. In addition to the pits the sheath also showed areas covered with red lead monoxide and with secondary growths of lead overlaying the layer of oxide. The duct water was slightly opalescent, and carried small amounts of vegetable matter in suspension. The pH value was 6.6, and the resistivity 2,000 ohms/c.c. The chloride content (calculated as sodium chloride) was 180 parts per million. From this evidence the failure was attributed primarily to anodic electrolysis.

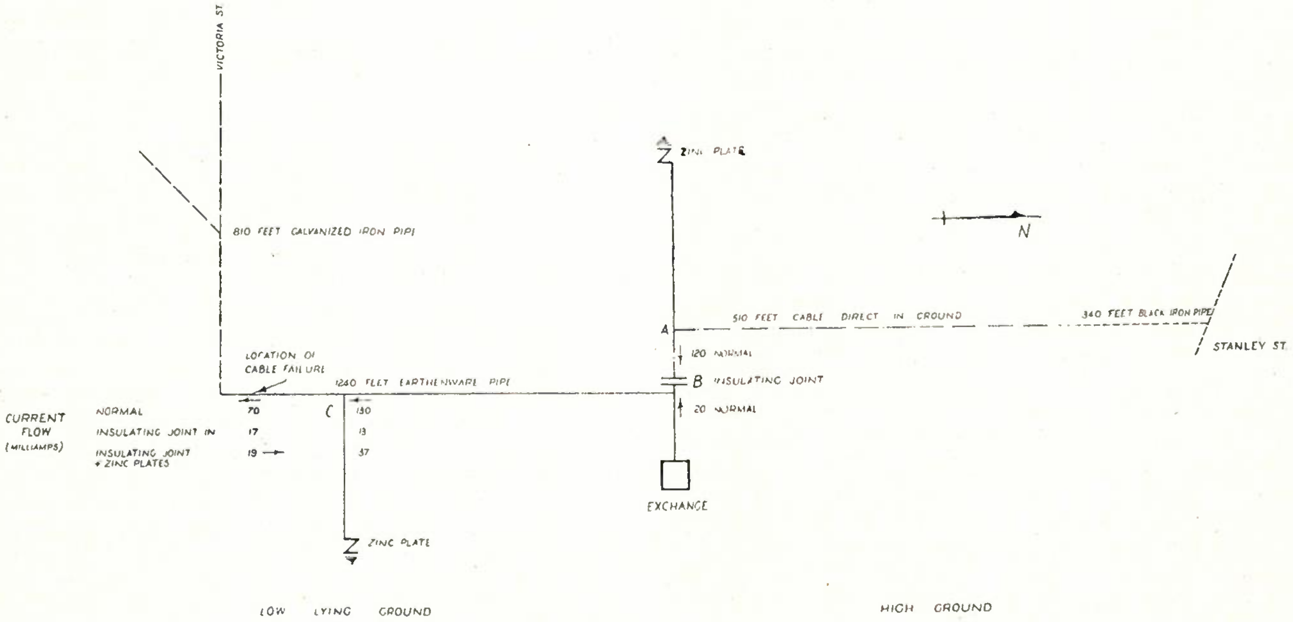


Fig. 2.—Galvanic Corrosion, Case 2.

As a preventive measure an insulating joint was installed at Point B to separate the northern section of the cable system from the southern section, and zinc plates were installed at Points A and C to drain any residual current flow near the insulating joint at A and to limit the current discharge in the area adjacent to where the cable failures occurred.

In examining cases of the foregoing type it is noticed that persistent potentials of the order of 0.5 volts are common in soil between the black iron and galvanised iron. Apparently a condition is established after the destruction of the zinc coating which perpetuates the galvanic current.

(b) Long Line Currents.—Typical of the cases so far investigated is that of the trunk (or toll) cable between Sydney, Newcastle, and Maitland, 116 miles in length. At Sydney and Newcastle the cable passes through areas subject to electric traction influences, and in these areas normal electrical drainage to the traction systems takes care of both stray traction and lone-line currents. Fig. 3 shows the layout of the cable, the type of construction, the general nature of the ground conditions as determined by pH values and soil analyses, the distribution of current and potential to earth on the cable, and the soil resistivity conditions as determined by a field survey using Wenner's method.

Cable potential measurements were made to a lead earth plate installed under the floor or through the side of manholes along the route of the cable. Because of the unknown influence of the electrode on the potential measurement the values obtained are of qualitative value rather than a quantitative guide to corrosion conditions. The main value of the measurements will be to assist in checking the extent of the influence of cathodic protection.

No very close overall co-relation is obtained between the current flow and soil resistivity curves. This is probably due in part to the much closer spacing of soil resistivity readings in comparison with the current tests. The principal objective of the initial survey was to determine the general direction and magnitude of current flow and locate boosted drainage points for cathodic protection therefrom. The most significant observations are firstly, the small current flow in the very high resistivity areas A, B, and C respectively, between Wahroonga and Brooklyn (on the first half of this section traction conditions account for the major portion of the current flow), Brooklyn and Gosford and Wyong and Swansea. In each case these areas are distinguished by dry, well-drained ground conditions. Secondly, the high current flow in the low-resistivity area between Hamilton and Maitland. This section is low lying and has a high moisture content. The steel tape armouring is bonded to the cable sheath at all joints at intervals of approximately 200 yards.

The pH and soil analyses were made on isolated samples taken from particular rather than regular locations, an endeavour being made in each case to choose by observation what appeared to be samples representative of general soil conditions in which the cable was laid. However, as might be expected in the circumstances, there is very little co-relation between the pH values and soil analyses and current distribution.

Remedial measures in the forms of cathodic protection are at present being installed to take care of the long line currents outside the traction areas, and the location of these are also shown in Fig. 3.

(c) Metallic Couples.—At one stage in the installation of rural exchanges it was the practice to use copper earth plates for earthing systems. The "earth" busbar was normally bolted to the main distributing frame with which the underground cables were in contact. In a typical case, the current flow from the exchange to the cable on which the failure occurred was 6 milliamps and the resistance of the copper plate to ground was 17 ohms. The cable was unarmoured, laid direct in the ground, and the failure occurred at a low lying point in the cable run where the current discharge had concentrated. Although the current flow is small in magnitude, the limited area of the cable system over which the discharge occurs under conditions of unarmoured cable laid direct in the ground has resulted in a high percentage of failures from this cause. In the majority of instances the copper plate has been replaced by either a lead earth plate or galvanised iron stakes. In other cases the cable was insulated from contact with the main distributing frame.

(d) Cinders.—In a particular case examined a cable failed adjacent to a railway station. The cable was extensively covered with deep, round pits filled with white corrosion product. Examination of this corrosion product showed mostly basic lead nitrate with some lead chloro-carbonate and lead sulphate. Examination of the soil in which the cable was laid showed that this consisted mainly of slag and cinders similar to that discharged from railway engine fireboxes. It also contained a fair quantity of wood charcoal. The resistivity was 30 ohms/c.c., indicating that most of the material was of a carbonaceous nature. The soil solution had a pH of 6.1, but only a small proportion of soluble salts, among which were traces of nitrates and ammonium salts. A corrosion test was set up, in a sample of the soil, using a strip of lead 4in. by 1½in. by 10 mils thick. Within three weeks penetration of the strip occurred in 30 places, several of the pits exceeding a square millimetre in extent.

Corrosion of Lead-covered Cables in Iron Piping.—An unusual type of corrosion of small lead-covered cables installed in piping has given considerable trouble. In 1941, 1,741 failures of this type occurred, principally on one and two pair cables. The corrosion occurs mainly in black iron piping, but many cases have occurred in galvanised piping. The lead sheathing is in parts completely transformed to the tetragonal or reddish variety of lead monoxide, retaining even the surface extrusion lines originally present on the lead. Apparently the oxygen atoms penetrate the lattice of the lead crystals with no apparent disturbance of the structure. The lead

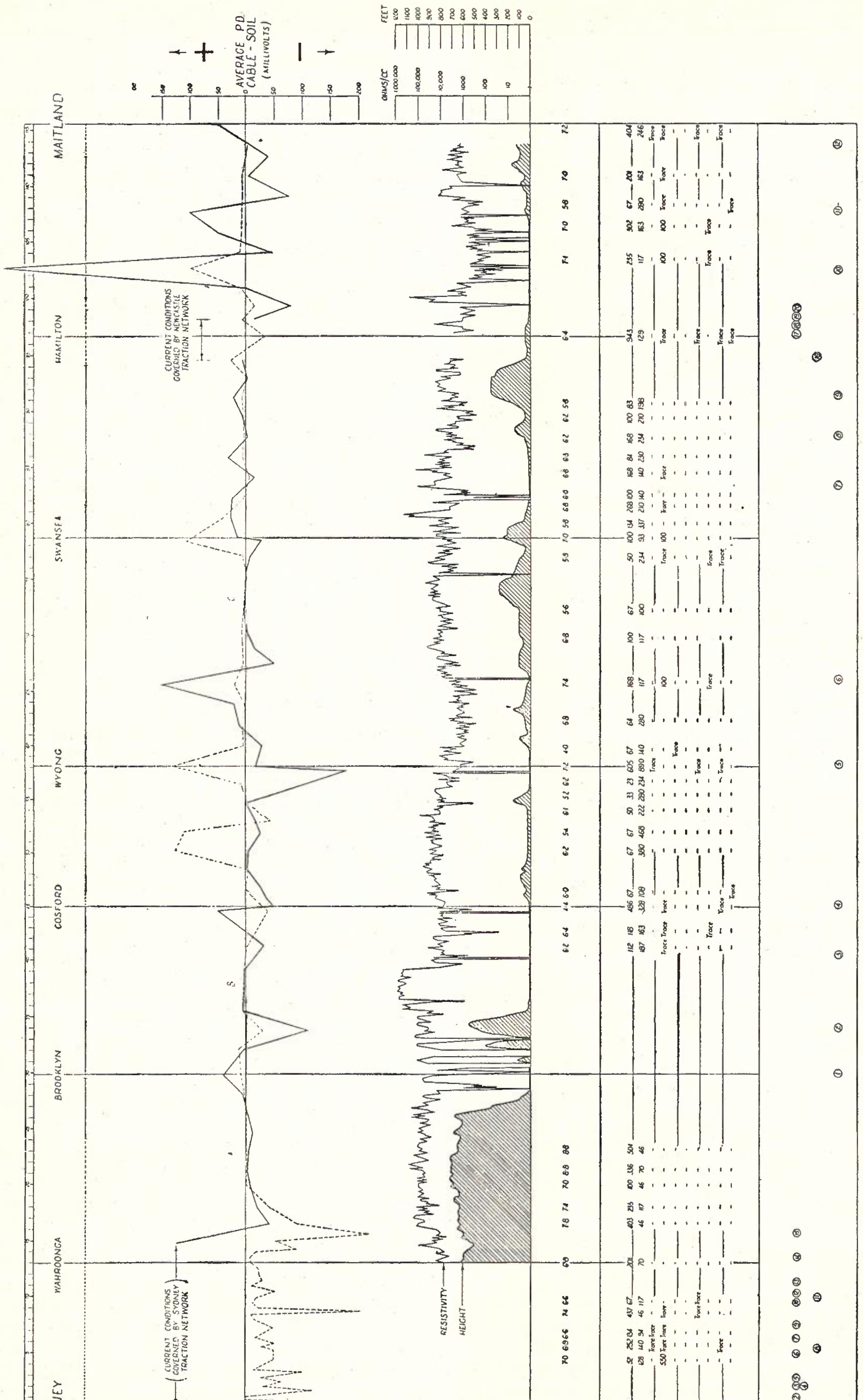


Fig. 3.—Long Line Current Survey, Sydney-Maitland Cable.

monoxide has a density of about 9.5 gms/c.c., which is little less than that of metallic lead, 11.4 gms/c.c. On bending the sheathing the corrosion product cracks away, often showing clean, uncorroded lead underneath. Cases have occurred where one pair lead cables have corroded through in six months in this manner. This corrosion is always associated with alkalinity in the piping, and has usually been referred to as "cathodic" corrosion, as a similar corrosion product is sometimes produced on large cables in cathodic areas associated with the pick-up of current from traction systems. The recent work of Wolf and Bonilla, "Formation of Lead Monoxide as a Cable Corrosion Product," Preprint 79-23 of the Electro-chemical Society, April 21, 1941, however, shows that lead monoxide can be produced by anodic electrolysis under certain conditions.

The accumulation of evidence has led to the conclusion that the bulk of the corrosion in iron piping is of galvanic origin, although the high proportion of such failures which have occurred in cathodic areas of traction systems has undoubtedly materially assisted the corrosion by setting up the alkaline condition in the pipe. The water samples from the areas where the trouble is experienced usually have sodium bicarbonate as the main soluble salt, with concentrations ranging from 200 to 1,000 parts per million, whereas the sodium chloride content is usually round 100 parts per million, or even less. A small quantity of such a water in a black iron pipe containing a lead cable will rapidly become a alkaline due to the formation of insoluble carbonates. The iron will then form a galvanic couple with the lead in contact with it, and the lead will form the anode of the cell. The most favourable condition for corrosion is when the pipe contains only a small amount of water and the lead cable is partly in the air. In such cases the underneath part of the lead may not be corroded at all, but the part near the surface of the liquid is converted to monoxide of lead. In galvanised iron piping the zinc is found to be removed in regular patches, apparently where the lead cable and pools of water have been in contact, the exposed iron being quite bright and unrusted. Cases have also been experienced where black iron piping has been found with a bright metallic surface on the inside after the removal of a lead cable. The complete exclusion of moisture from the pipe is a solution, but is difficult to attain in practice.

Galvanic Corrosion at Radio Stations.—At radio stations, in addition to extensive earth systems of copper, underground lead-covered power and telephone cables are often installed together with buried piping systems for water and fuel oil. As these stations are generally located on sites with low resistivity soil for good radio propagation, the galvanic corrosion hazard is a very real one, and extra precautions have to be taken to combat it, particular care being taken to isolate the different metal systems in the ground from one another. The importance of this fact may be realised from the following cases:—

In a radio-telegraph station a 10-pair lead-covered telephone entrance cable was buried directly in the soil, which had a resistivity of 440 ohms/c.c. The sheathing of the cable was found to be almost completely corroded away 12 months after installation. A steady current of 0.3 amperes was flowing along the cable and escaping to earth. This corrosion was due to the formation of a galvanic cell with the copper earthing system, the lead cable sheathing forming the corroding electrode.

In a radio broadcasting station the lead-covered telephone entrance cable, which was installed in earthenware conduit, was found to be badly corroded where the conduit was subject to occasional submersion over section of 50 yards. Tests showed that a current of 45 milliamps was flowing along the cable from the radio transmitter house. The cable was found to be making good contact with the apparatus racks, which were strapped to the earthing system. On freeing the cable from the frames a potential difference of 0.27 volt was measured, the copper being positive. The soil resistivity in the vicinity of the fault was 575 ohms/c.c. At this station the iron waterpipes, fuel lines, and buried fuel tank were also badly corroded by steady galvanic currents flowing from the radio station, and it was found necessary to install insulating joints in the piping system and place the fuel tanks in open concrete pits. Prevention of further trouble on the telephone cable was obtained by insulating the cable from the main distributing frame with insulating wrapping. In certain cases and as additional precaution against subsequent accidental contact between the cable and copper earthing system in the transmitter house, an insulating joint was installed at the entrance manhole.

Review.—In collecting the foregoing notes into the form of a paper, no special endeavour has been made to form a co-ordinated story of the galvanic corrosion problem, nor to enter into a very detailed description of all the factors associated with each particular case. The aim has been rather to indicate the general field of day-to-day problems and their characteristics. Satisfactory solutions in some cases have not yet been reached. (A technical solution to corrosion damage is often not acceptable on economic grounds.) This applies particularly to the condition set up by telephone cable distribution in black iron and galvanised iron pipe. In the case of the "cathodic" or "alkaline" corrosion none of the palliatives tried, chief of which has been the use of petroleum jelly to fill the pipe and prevent access of moisture to the sheath, have been satisfactory. It is now felt that the solution to this problem is a change in construction practice to jute and bitumen protected cable laid direct in the ground (with or without steel armouring, depending upon the likelihood of mechanical damage) or unarmoured cable laid in small, non-metallic pipe.

Apart from these main changes in construction, consideration is being given to the use of plastic insulations such as Polyvinyl Chloride, for at least one and two pair telephone cable distribution. Cable of this type would normally be drawn into iron pipe for mechanical protection purposes. There seems little doubt that with the rapid developments that are at present taking place in the field of plastics that this medium must play an increasing part in the corrosion field.

EARTH BORER AND POLE LIFTING TRUCK

R. A. A. Foord

With the extensive line constructional works being carried out in Queensland, large economies have been effected by the use of labour saving machines. A truck, which accommodates machinery combining the operation of pole hole excavator, and pole lifter and setter, is being used with advantage. The time required to sink a pole hole and erect the pole occupies, under favourable conditions, about 10 minutes. This is a great improvement on the old method of sinking the hole by hand and erecting the pole by means of jacks.

On one work in this State, it was found possible to erect nearly 100 light steel poles per day, with one boring unit and three men working extended hours. The unit has other obvious uses such as sinking post holes for fences and holes for stumps or piles to support wooden buildings. It has also been used when a length of deep trench is required.

Because of the little extra effort required to sink an extra foot or two the correct height of pole above ground for even grading purposes can be obtained more easily than sawing a length off the pole.

As the truck is equipped with a powerful winch, it can be used for cable hauling or for pulling a plough when excavating a trench in light soil for buried cable.

Operation.—The boring machinery, housing and boom are located at the rear of a heavy duty truck. The borer projects over the back approximately 2 ft. to give ample room for the boring operation. A winch is located at the rear of the driver's cabin. The gearing arrangement in the truck is fairly complicated. The engine, having a nominal rating of approximately 50 H.P., drives through an ordinary gear box, which has 4 forward gears and one reverse gear similar to the gear box fitted to an ordinary truck. This gear box drives a secondary gear box equipped with three gears as follows:—

(1) Transmits power through the differential to the back axle only.

(2) Provides power through a 1 : 2 ratio to both front and back axles.

(3) A gear which disengages the axle drive and changes over to the borer and winch drive. This gear controls an auxiliary gear box which can either transmit power to the winch or borer.

Changeover clutches are embodied in the borer and boom mechanism. These are manually oper-

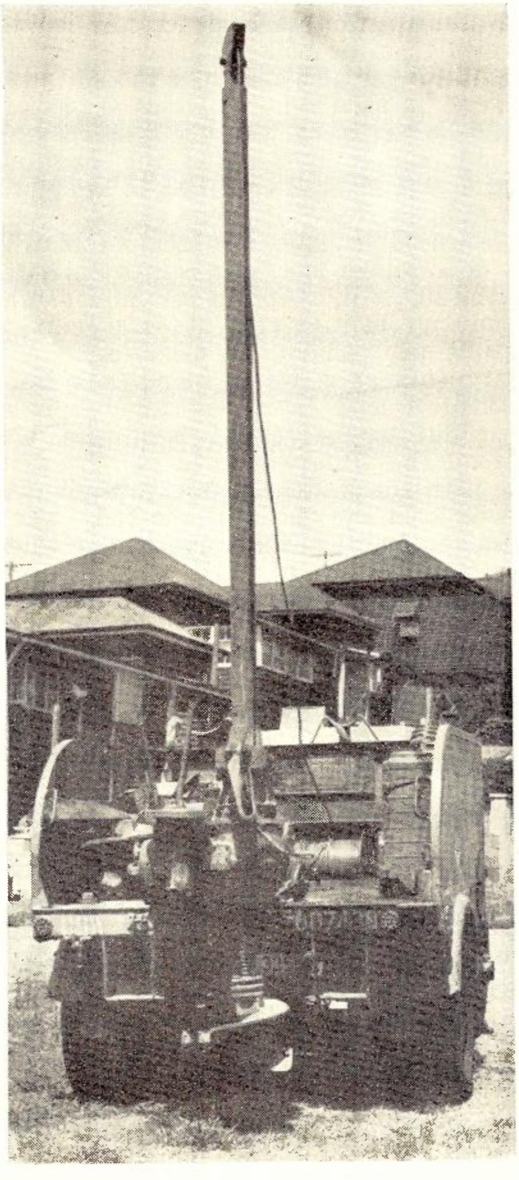


Fig. 1.—End View of Boring Machine with Boom in Vertical Position Ready for Boring.

ated and control the rotation of the borer, the lifting or lowering of the borer and the lifting or lowering of the boom in a longitudinal direction. A hand operated worm gear and quadrant allow of the boom being moved in a lateral direction.

The main, secondary and auxiliary gear boxes are located under the driver's cabin, the gear levers being controlled by the driver. The borer will sink a hole to a depth of 10 ft. A hole of diameter from 12" to 30" can be bored by fitting a suitable sized auger. When using the machine it is found that second or third speed gear is suitable, but if the ground is rocky or clayey the low gear should be used.

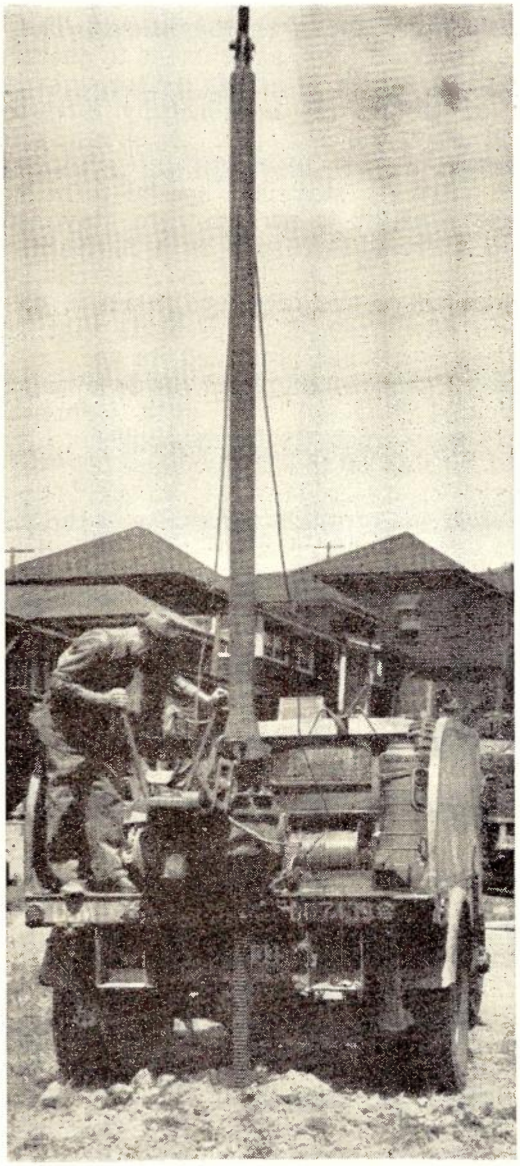


Fig. 2.—Boring in Progress.

Procedure for Boring.—Before the operation is started, a method of signalling is arranged between the operator controlling the boring clutches and the driver. It is essential that the maximum co-operation exist between these two men as much depends on them for the successful operation of the boring machine. The truck is moved into position and the boom of the boring machine is raised into a vertical position. The hand brakes are operated and the rear jack supports are lowered to the ground. This ensures that the load due to the boring is carried by the supports, and not by the truck springs. If the ground is uneven it is usual to place heavy wooden chocks at the front and rear of the rear wheels. This prevents any movement of the truck. By pulling on the clutch levers the borer is made to rotate and feed into the ground. The accelerator is used to give the desired boring and feed speed. The hole is freed of earth by withdrawing the borer at about every 6" of boring.

If the ground is wet, the earth should be removed at more frequent intervals. The earth is thrown off the borer when it is rotated. If rock is struck in boring, the machine should be stopped and the extent of the resistant substance investigated by means of a bar or shovel.

Erecting the Pole.—The truck is moved approximately two feet so that the borer is clear of the hole. After having released the winch brake, the winch clutch is engaged. This will unreel the winch cable which is taken out to the pole. The cable is attached to pole above the balance point so that the pole is heavy at the butt end. The winch motion is reversed by means of lever, and pole is raised until butt is about 1 foot off the ground. The pole is then lowered gently into the hole. As the boom is not stayed it is necessary that precautions be taken to guard against undue strain. Therefore, if the pole is located at some distance from the hole, the

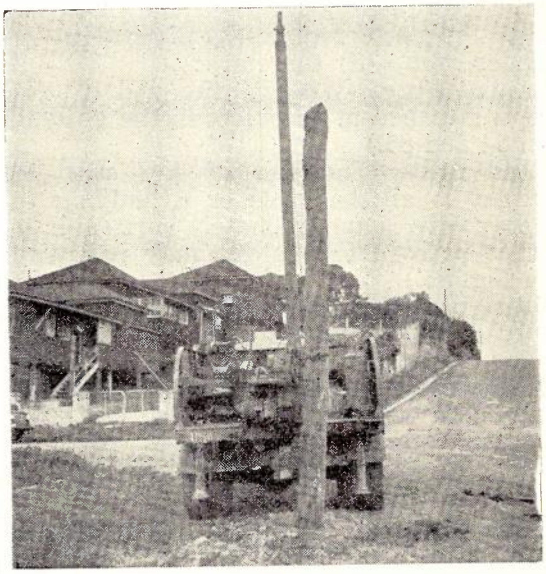


Fig. 3.—Pole Lowered Into Hole Ready for Filling In.

winch cable should be fed through the lower sheave attached to the boring housing, thence top sheave of boom and then through top sheave of boring housing. The sheaves on the boring mechanism are designed so that cable can be removed without disconnecting from the pole. When the pole has been moved over to the hole the cable is freed from the top sheave of the boring housing and lifting proceeds as described previously.

AERIAL LINE CONSTRUCTION

A. S. Bundle

Section 8—Anchoring of Pole Routes (continued)

Staying — Theoretical Aspects

Stays as Pole Supports.—A stay is a form of support so fixed that it is subjected to a tensile stress and couples a loaded structure to some anchorage so that it helps to support the structure under load. The coupling medium is usually wire (stranded, steel), and the objects to which it may be attached are:—

(i) A rod attached to an object buried in the ground.
(ii) Another pole.
(iii) A rock or a building.

Because the stay is in tension the length of wire used is not dependent on the load. Compared with a strut, which depends upon compression to counteract the load on the pole, the stay is usually the most efficient.

Types of Stays.—Stays are classified in two ways:—

(a) According to the form which the stay takes.
(b) According to their purpose or position in the pole route.

Under group (a) there are:—

Ground Stay.—Wherein the end of the stay wire is attached to an object in the ground. (See Figs. 84 and 85.)

Head Stay.—The end of the stay wire is attached to another pole or a building so that the stay wire is approximately horizontal, usually so that persons or vehicles may pass under it. (See Fig. 85.)

Outrigger Stay.—A special form of stay, using a spreader to prevent the wire interfering with traffic in a narrow thoroughfare. (See Fig. 86.)

V. Stays.—A form of double stays, where a single stay wire is not sufficient to take the load, and two stay wires are attached to a single stay rod or stay pole or other anchorage. When two stay wires are necessary because the load is too heavy for a single wire, it is advisable to attach them to different points along the pole to distribute the forces.

Parallel Stays.—Where two or more stay attachments are necessary to obtain greater anchorage than a single anchor will provide, two or more separate stay wires are attached to individual anchors. These stays are kept as parallel as practicable, hence the term.

The ground stay is used where practicable. Headstays or outrigger stays are necessary only if groundstays cannot be conveniently fitted because of intervening objects or necessity to keep clearance for a thoroughfare. The usual form of a headstay is attachment to another pole (stay-pole), which is across a thoroughfare and clear of traffic. It is generally advisable to ground stay the stay-pole to obtain sufficient anchorage.

The outrigger stay is a special form suitable for use when it is necessary to stay across a narrow thoroughfare such as a footpath. It is used more in U.S.A. than in Australia, where, although there are occasions when it could be used to advantage, it is probable that lack of knowledge of it has precluded its use.

Under group (b) there are the following types:

Terminal Stay.—A stay at a terminal pole, used to counteract the forces applied to the pole due to tension of the line wires.

Angle Stay.—A stay at an angle pole to counteract the resultant forces due to the tensions of the line wire at the angle.

Side Stay (otherwise called a Wind Stay or a Lateral Stay) is a stay at right angles to the line of route, and used to counteract any lateral forces, the principal being that of the wind on the wires. An angle stay usually incorporates this function.

Line Stay (otherwise called a Longitudinal Stay or a Marching Stay) is a stay placed along the line of the route either to counteract uneven loading on a pole, such as occurs at the top of a steep grade, or else to prevent the spread of damage which occurs when the wires on a heavy route are snapped, for example, by a falling tree.

Requirements of Stays. — There are two primary requirements of stays:—

1. They must support the pole against collapse under maximum loading. That is to say, the stay wire, stay rod, ground anchorage, and attachments must all be strong enough to withstand maximum loading.

2. Particularly at angles and terminal poles there must be practically no give in any part of the stay. That is, the ground anchorage must be deep enough and of adequate area; it must be carefully installed so as to bear against firm soil; the stay wire must be practically inextensible and securely made-off.

Terminal and angle stays are the most critical, for it is upon the staying at terminal and angle poles that the route depends for its ability to hold the wires properly tensioned. If the stays at these points do not counteract the load properly then the poles will move in the direction of the load and slacken the wires. Such stays must be capable of taking the full load of the wires, having regard for ultimate development, with an adequate factor of safety and without any tendency to "give" or "creep," either with increased load or if the moisture content of the soil varies.

Basis of Staying Calculation.—The general basis for calculating anchorage of a pole route is that the supports shall be stronger than the wires. This is usually achieved by providing stays of sufficient strength to counteract the maximum load which can be applied by the wires, considering the pole only as a column to counteract downward thrust. The initial staying must usually provide for the ultimate development on the route.

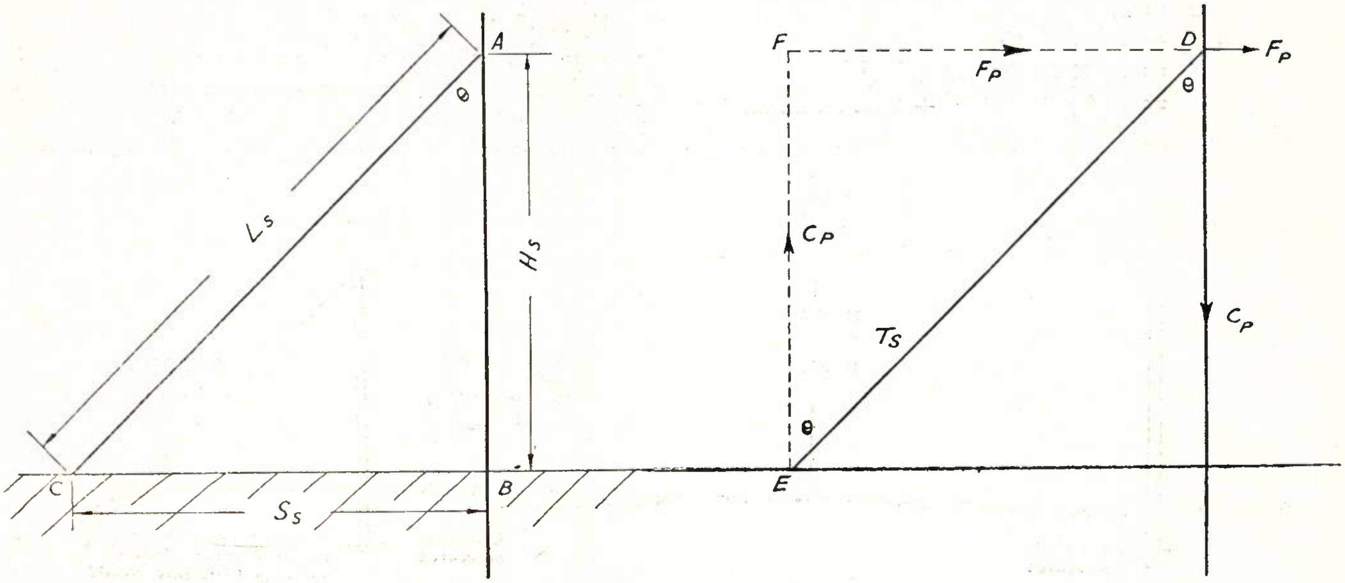


Fig. 84.—Space and Force Diagrams for Ground Stay.

Line wires are usually erected with factors of safety of 2.5 or 3, so that a minimum factor of safety of 3 on the normal line wire tension is advisable for anchoring. An alternative method of dealing with the problem is to work on the breaking loads of the wires. This latter method is the simpler in Australia, where wires are rated by their weight per mile, and, therefore (although indirectly), by their strength, if certain minor differences due to skin effect are neglected. Thus the breaking load of 100lb. H.D.C. wire is 330lb., or 3.3 times its weight per mile, and 200lb. H.D.C. wire has approximately twice this strength (640lb.). It follows, therefore, that the total breaking loads of all wires of one class of material on the route can readily be found by multiplying their total weight per mile by one of the following factors:—

Hard drawn copper, multiply by 3.25.

Cadmium copper, multiply by 5.

Galvanised iron, multiply by 3.

Ground Stays.—These are the commonest form of stays, being cheaper to provide, unless a pole or other suitable anchorage happens to be available in the correct position, which is seldom the case. The forces which apply at a ground-stayed pole are dependent upon the angle the stay makes with the pole. For convenience, both in measuring and calculating, this angle is not measured in degrees but by the ratio between the "height" and the "spread" of the stay.

Referring to Fig. 84, if A.B.C. is a space diagram, in which:—

S_s = Spread of stay
and H_s = Height of stay
and L_s = Length of stay
then $L_s = \sqrt{S_s^2 + H_s^2}$

D.E.F. is a force triangle representing the forces keeping the head of the pole in equilibrium, and the triangles A.B.C. and D.E.F. are therefore equi-angular. Hence:—

$$T_s/F_p = L_s/S_s$$

whence: $T_s = F_p \times L_s/S_s$

$= F_p \sqrt{(S_s^2 + H_s^2)}/S_s$
by substituting for L_s

$= F_p \sqrt{1 + (H_s/S_s)^2}$ ....(26)

When the horizontal force F_p is applied to the head of a ground-stayed pole the resulting force on the stay wire is upward, but there is also a downward or compressive force (C_p) applied to the pole. This force tends to buckle the pole, and also tends to force it deeper into the ground. If the ground is soft or the sectional area of the pole is too small the pole will sink lower, thereby making the effective length of the stay longer and allowing the head of the pole to move over in the direction of the horizontal force F_p. Care is necessary, therefore, that poles to which ground stays are to be fitted shall have ample bearing area to overcome this tendency to sink. If there is any doubt about this bearing it is advisable to fit a base block or plate under the pole butt.

Referring to the equi-angled triangles A.B.C. and D.E.F. in Fig. 84,

$$C_p/F_p = H_s/S_s$$

$$\text{whence: } C_p = F_p \times H_s/S_s \quad \ldots \quad (27)$$

Thus the compressive load on the pole is seen to be inversely proportional to the spread of the stay. This points to the advisability of having the spread of the stay as large as possible. This is also desirable, because the movement of the head of the pole in the direction of the load, due to the pole sinking, is greater with smaller spread. There is, however, a point beyond which the additional length of stay wire required is not justified by the advantages gained, and it can be shown that the ideal ratio between height and spread is one, i.e., the stay should be at 45 degrees to the pole.

It is useful also to note from Fig. 84 that

$$C_p/T_s = H_s/L_s$$

$$\begin{aligned} \text{whence } C_p &= T_s \times H_s/L_s \\ &= T_s \times H_s / \sqrt{S_s^2 + H_s^2} \\ &= T_s/\sqrt{(S_s/H_s)^2 + 1} \quad \ldots \quad (28) \end{aligned}$$

Head Stays (Fig. 85).—With these stays the overhead wire is usually in line with the load, or very nearly so, so that its strength must be equal to or greater than the maximum load which can be applied. If the overhead stay is not reasonably close to being horizontal, then the height and spread should be measured and the load calculated from (26).

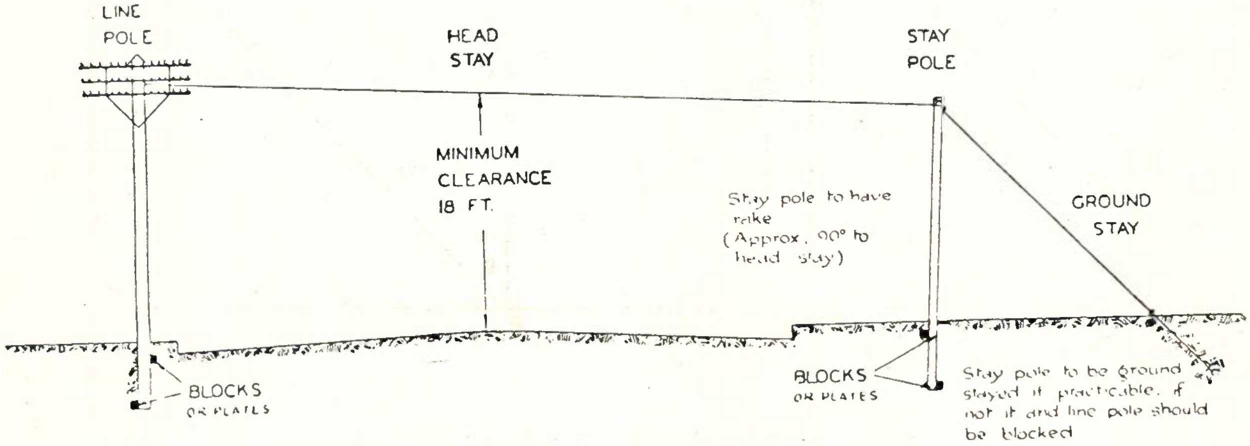


Fig. 85.—Line Pole Fitted with Head Stay.

If the stay is attached to a stay pole, the latter should be fitted with a ground stay capable of counteracting the load. Care should be taken to ensure that the stay pole has ample bearing area against the ground to prevent any tendency to sink under the resultant downward force.

Outrigger Stays.—It is considered that more extensive use might be made of this form of stay for providing additional anchorage in awkward situations. It is important, however, that the various forces involved be properly appreciated so that the installation is correctly carried out.

From the following formula it will be appreciated that:—

(a) The spreader should be as low as possible.

(b) The spreader must be stout enough to prevent buckling under the heavy load applied.

(c) The tension in the upper stay (T_{SU}) is greater than that in the lower stay (T_{SL}).

Fig. 86 shows diagramatically a practical form of outrigger stay. It is advisable that the butt of such a pole be either concreted or fitted with blocks or plates to increase the bearing area against the soil, both to prevent tendency to sink and also to utilise the pole as far as possible in resisting the horizontal load of the wires.

Referring to the diagram, the height of the stay (H_s) in this case is measured to the pivot point, which is a distance below the surface closely approximating two-thirds of the depth of setting. We find, by taking moments about this point, that:—

$$F_p \times H_s = T_{SL} \times S_s$$

$$\text{so that, } T_{SL} = F_p \times H_s/S_s \quad \ldots \quad (29)$$

As the end of the spreader must remain steady the downward force applied by the lower stay ($= T_{SL}$) must be counteracted by an equal and opposite force (F_{SU}) resulting from the tension T_{SU} in the upper stay, i.e.,

$$\begin{aligned} T_{SL} &= T_{SU} \sin \theta \\ &= T_{SU} \times h/\sqrt{h^2 + S_s^2} \\ &= T_{SU}/\sqrt{1 + (S_s/h)^2} \\ \text{and } T_{SU} &= T_{SL}\sqrt{1 + (S_s/h)^2} \quad \ldots \quad (30) \\ &= F_p \times H_s \times \sqrt{1 + (S_s/h)^2}\,/S_s \quad \ldots \quad (31) \end{aligned}$$

From (30) it is clear that T_{SU} is greater than T_{SL} and is greater as h is reduced.

The compressive force in the spreader

$$\begin{aligned} &= C_s = T_{SU} \cos \theta \\ &= T_{SU} \times S_s/\sqrt{S_s^2 + h^2} \\ &= T_{SU}/\sqrt{1 + (h/S_s)^2} \quad \ldots \quad (32) \end{aligned}$$

It will be noted that C_s is also greater as h is reduced.

The stay block or plate should be set below an under-cut made into virgin soil and filled in with concrete which is reinforced above the level of the plate with scrap lengths of G.I. line wire.

Terminal Stays.—These are critical stays, and their strength should be at least sufficient to counteract the total breaking load of the wires to the ultimate capacity of the route. A most important consideration is that they shall prevent the head of the pole moving in the direction of the line wires:—

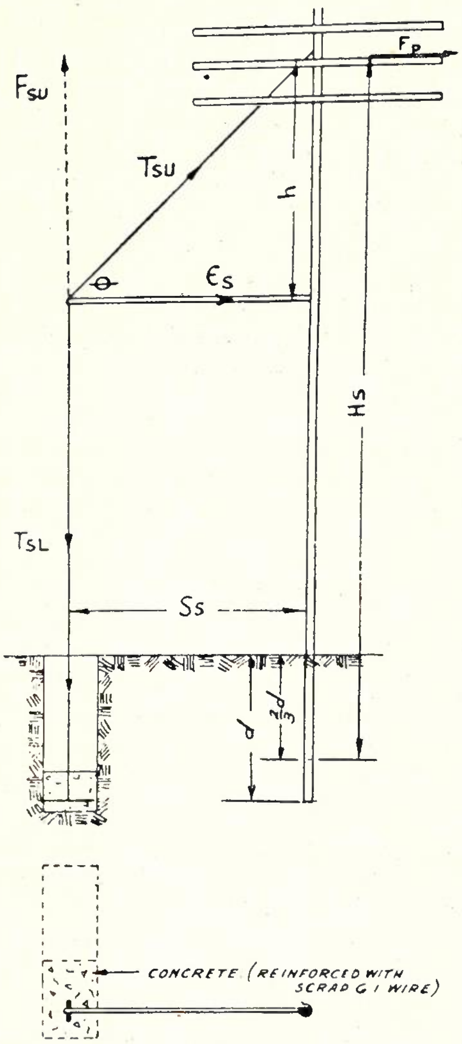


Fig. 86.—Outrigger Stay Diagram.

F_w = total breaking load of wires (= F_p in (26), in this case).
= total weight (per mile) of wire of each class of material multiplied by the appropriate breaking load factor for that material.

Then T_s = total tension in stay =

$$F_w\sqrt{1 + (H_s/S_s)^2} \quad .... \; .... \; .... \; .... \quad (33)$$

The stay should be behind the pole and directly in line with the route. The loads on these stays are often extremely heavy, and if the stay cannot be put directly in the line of the route special action must be taken to counter the resultant side force either by dividing the load equally between two stays placed symmetrically about the correct point or else by providing an additional side stay set at right angles to the line of route.

Angle Stays. — Angle stays are required to counteract the pull of the wires at angles in the pole route. The resultant pull on the pole from the tensions of the line wires acting at an angle is usually along the bisector of the angle as the tensions of the wires are, except in special circumstances, the same on either side of the angle pole. Thus, to counteract the resultant the stay should be placed along the bisector of the angle produced on the other side of the pole, Fig. 87A. If this practice is not carefully followed there will be a resultant force along the line of the wires which will tend to force the pole sidewards and result in uneven tension and strained ties.

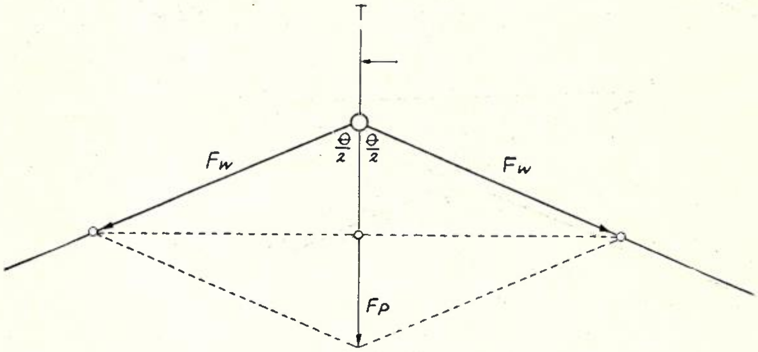


Fig. 87A.—Force Diagram at Angle Pole.

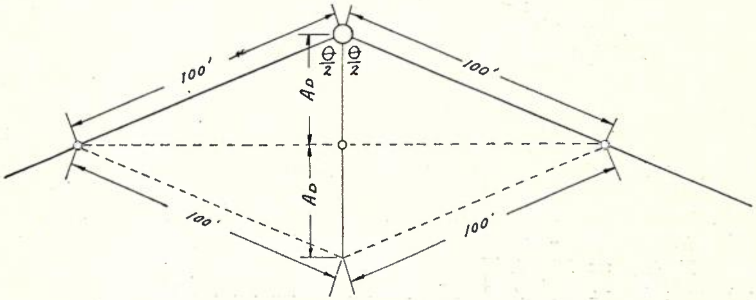


Fig. 87B.—Space Diagram at Angle Pole.

Fig. 87.—Force and Space Diagrams at Angle in Route.

The pull on an angle pole is dependent upon the tension of the wires and the extent of the horizontal angle in the route. For purposes of calculating the required strength of a stay it is advisable to consider the breaking load of the wires as the maximum tension and allow for the resistance of the pole to overturning as an additional margin of safety which makes the supports stronger than the wires.

The measure of the angle may be taken in degrees or in the terms of "angle depth," which is a term applicable to the shortest distance in feet from the angle pole to a line joining two points each of which is in the line of the route, one at either side of the angle pole, and each 100ft. from the angle pole. This is shown as A_D in Fig. 88A. In B and C of this figure are shown alternative methods of making this measurement if there is an obstruction inside the angle preventing the measurement shown in A from being made.

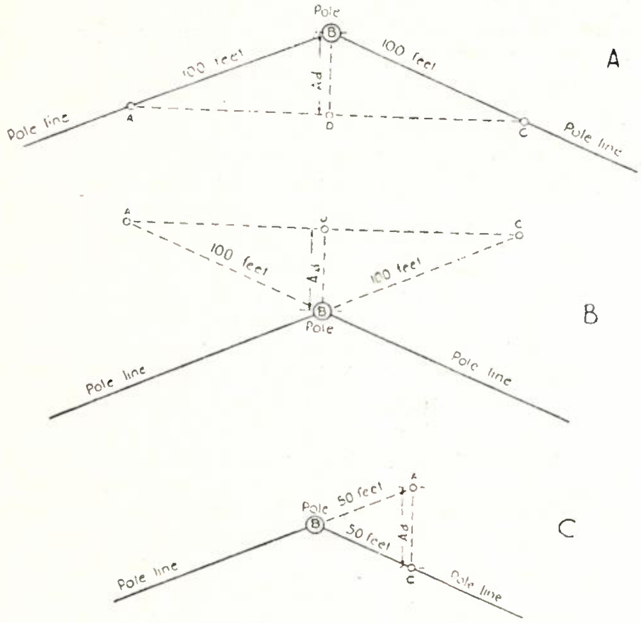


Fig. 88.—Angle Depth and Method of Measuring it.
A—General Method.
B and C—Alternative Methods of Measuring when A is Unsuitable.

Returning again to the force diagram Fig. 87A, and also to the similar space diagram Fig. 87B, we have:—

$$F_p/F_w = 2A_D/100$$

whence: $F_p = F_w \times A_D/50$ .... (34)

So that from (26) and (34) we have, for a ground stay:

$$T_s = F_w \times A_D \times \sqrt{1 + (H_s/S_s)^2}/50 \quad (35)$$

The angle can, of course, be measured in degrees if suitable instruments are available, and mention has been made in an earlier section of this series regarding the advisability of measuring the angles of new routes when they are being set out during the survey.

In addition to the pull of the wires, an angle stay should be capable of acting as a side stay to counteract wind pressure in the wires in nearby spans. If the side-staying is also being calculated allowance can be made to take the full load of a side or wind stay in addition to the pull of the wires. If this information is not available it is advisable for the angle stay to be capable at least of taking the additional load due to wind pressure on the spans of wire adjacent to the angle pole. For simplicity of calculation it is usual to assume that the wind is at right angles to both of these spans. The variation from the true condition resulting from this approximation is not usually very great, and is on the safe side.

Angle Depth Gauge.—To facilitate for linemen the work of measuring an angle in a pole route and of bisecting it, a device has been designed termed an Angle Depth Gauge. The device is strapped to the angle pole (Fig. 89), or, in the case of a new route, is attached to a stake at the angle.

The two arms are attached to a small table, which is held firmly against the pole with the strap or is screwed to the stake. The right-hand arm, which carries the scale, is then sighted by looking from a V backsight on the arm to a foresight at the centre and lined along the route to the left. It is then secured by tightening a knurled nut under the table. The lefthand arm is then sighted similarly, but along the route to the right, and when lined up is secured by tightening a wing nut under the table. Opposite an index mark on the lefthand arm can be read directly the measure of the angle either in degrees or in terms of Angle Depth, whichever is desired.

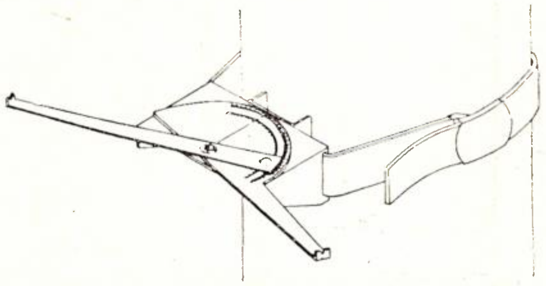


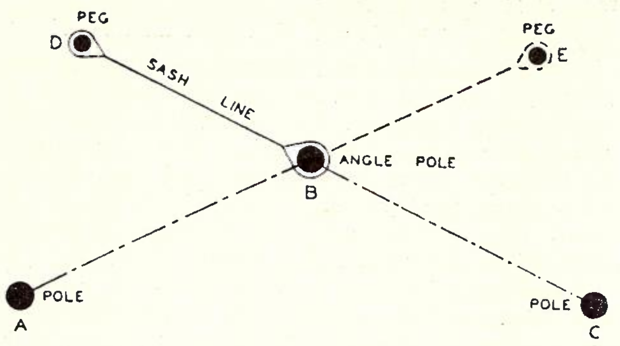
Fig. 89.—Angle Depth Gauge on Angle Pole.

To bisect the angle, the device is set up as described, and the angle measured. The lefthand arm is then released by unscrewing the wing nut and is then moved until the index mark is opposite the **same** figure on an "Angle Halved" scale. It is again clamped, and points along the bisector are marked by the observer lining up a plumb-bob line with the backsight and foresight on the arm.

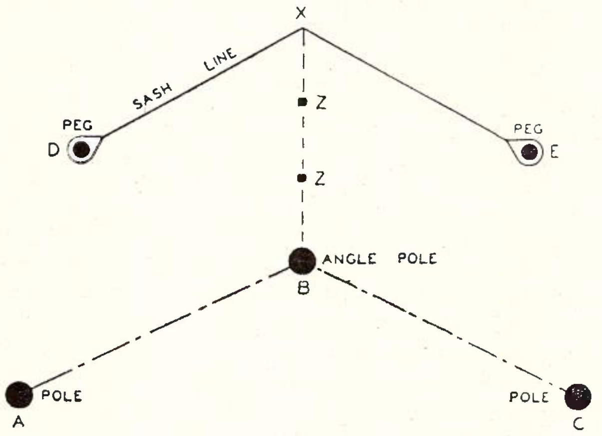
Another method of bisecting the angle is by means of two sash lines of exactly equal length, and about 36ft. One end of each line is finished with a tackle hook and the other is whipped. The lines are used solely for this purpose. The actions necessary to bisect the angle are indicated under the diagrams in Fig. 90.

Side Stays.—Side stays may be installed for several reasons. On all important routes they are installed at regular intervals as a safety measure to ensure that in the event of excessive loading due to unusual storm conditions or rapid decay of poles the extent of the damaged section will be limited—usually the line wires afford considerable assistance to intermediate poles which are not side-stayed. Sometimes owing to unexpected development more wires are installed than the poles in a route were originally designed to carry, and side staying is necessary to meet even normal climatic conditions. With very soft soils or soils which occasionally become very soft it is sometimes necessary to use side stays to augment the strength of the anchorage and prevent the poles canting over in the direction of prevailing winds.

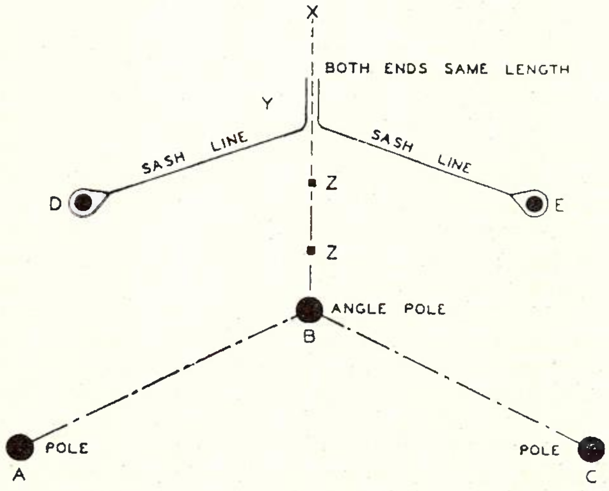
These stays are usually fitted in pairs, one stay



LOOP END OF ONE SASH LINE AROUND BASE OF POLE B
PROCEED TO POINT D IN LINE WITH POLES B AND C AT THE FULL LENGTH OF THE LINE
MARK WITH PEG
IN THE SAME MANNER SET OUT POINT E IN LINE WITH A & B



LOOP END OF ONE LINE AROUND D AND END OF OTHER LINE AROUND E
MOVE TO X FOUND WHERE THE ENDS OF BOTH LINES COME TOGETHER AT THEIR FULL LENGTH
THE LINE B-X IS THE DIRECTION OF THE REQUIRED STAY AND SHOULD BE PEGGED AT ZZ



SHOULD X BE INACCESSIBLE. A SUITABLE POINT Y IN THE LINE X-B MAY BE FOUND BY KEEPING THE LOOSE ENDS OF BOTH LINES THE SAME LENGTH, AND MOVING TOWARDS B.
PLACE TWO PEGS ZZ TO MARK LINE OF STAY AS BEFORE

Fig. 90.—Bisecting an Angle with Sash Cords.

on either side of the pole and at right angles to the line of the route. They may be spaced at half-mile intervals on minor routes, but on all important routes a maximum spacing of a quarter-mile is desirable. On particularly important routes or where the poles are overloaded the spacing may be appreciably closer, the extreme probably being every alternate pole.

Precise calculation requires consideration of the wind pressure on poles and wires and the resisting strength of the poles and their setting in the ground. This is necessary only in exceptional cases, and for general purposes it may be assumed that the poles are sufficiently strong and sufficiently well set in the ground to withstand wind pressure on themselves and the arms and fittings, so that the stays support the wind pressure on the wires only. On this latter basis the wind pressure over a mile of route is assessed and a convenient size of stay wire and stay rod is decided upon to take the full loading (with a factor of safety of 3), with stays spaced at convenient intervals. The spacing will depend upon cost and the importance of the route; light stays at close intervals are preferable, but usually more expensive; longer spacing than quarter-mile should be avoided if possible.

Wind pressure per square ft. of projected area of poles or wires $= KV^2$.

Where $V =$ maximum wind velocity in miles per hour and

$K =$ a constant $= 0.003$ for wires

$= 0.001$ for poles and fittings.

For normal Australian conditions a maximum wind velocity of 70 m.p.h. may be assumed. In localities where severe wind conditions may be expected a maximum velocity of 80 m.p.h. may be allowed for, and for mild areas a maximum of 60 m.p.h. is allowable. At these velocities the wind pressure per sq. ft. of projected area of wire is:—

Severe, i.e., 80 m.p.h. maximum: 19.2lb., say 20lb.

Normal, i.e., 70 m.p.h. maximum: 14.7lb., say 15lb.

Mild, i.e., 60 m.p.h. maximum: 10.8lb., say 11lb.

Line Stays.—Line stays have several purposes:

(a) If the wires in a route are severed (as might occur by a tree falling across the route) the full tension of the wires is applied to the adjacent poles, which are thus liable to collapse either by fracture, bending, or pulling out of the ground. In such circumstances almost the full tension of the wires is applied to the next poles, which, in turn, may collapse, and so on. Line stays, by providing the additional strength necessary to enable the pole to support the load of the wires, limit the spread of such failures. These stays are installed in pairs, one on either side of the pole.

(b) In some localities, either because of the soil becoming very soft or because of soil movement, the whole of the poles cant over along the line of the route, and, because of a certain similarity of appearance to a line of marching men with characteristic lean forward, are said to be "marching." Line stays are used to counteract this tendency when it shows up, and are sometimes referred to as "marching stays."

(c) At some poles there is a sharp change in the vertical grade of the line wires, and in some circumstances may result in unequal tensions of these wires. For example, if the wires are horizontal and then change to a sharp downward grade at a given pole—the initial tensions in the wires on either side of the pole being equal—there will be a resultant force on the pole tending to force the head of the pole in the direction of the horizontal wires. Unless this force is counteracted with a stay or strut the head of the pole will most probably move and result in uneven tensions and strained ties.

As a general rule line stays are spaced at mile intervals on minor routes and half or quarter mile intervals on more important routes, when used to prevent spread of breakdowns or possible marching.

Where these stays are installed for the purpose of limiting the extent of breakdowns the ultimate strength of the stay should be capable of counteracting the **normal tension** of the line wires, the strength of the pole being taken as the safety margin. The strength of the poles along the line of the route must be considered, however, as special pole sections are often weaker in this direction. In the latter case an additional margin of strength may be advisable. On the other hand, if the poles are stout and are of equal strength along or across the route it may be practicable to reduce the strength of the stays somewhat. This practice is not advisable on important routes.

With those types of steel poles where the strength along the route is less than one-quarter of their strength across the route, it is necessary to have closer spacing between line stays to prevent the tendency of the poles to twist in the direction of the weaker axis when a load is applied to the stronger.

Position for Attachment of Stays. — Stays should be attached where practicable at the resultant point of the forces applied by the line wires, allowing, of course, for the ultimate number of wires on the route. Usually this is approximately midway between the top and bottom arms.

Sometimes it will be found that the position of the wires will not provide a convenient clearance to the stay wire (minimum 2in.) if attached exactly to this point, and in such cases it should be placed above the resultant point. Should circumstances make it necessary to attach a stay to the pole appreciably below the resultant point, it will be necessary to allow for extra loading on the stay. This is found by application of the principle of levers. Thus, if

H_R = height of resultant above ground level.
H_S = height of stay above ground level.
F_R = resultant force of wires.
F_S = horizontal force for stay to counteract.

then $F \times H_R = F_s \times H_s$

whence $F_s = F \times H_R/H_s$ .... (36)

If two stay wires are attached to a pole they should preferably be of equal strength, and be attached one on either side of the resultant point such that each will pass through the resultant point of the forces acting on that side of the general resultant point. Similarly, if the stays are of unequal capacity or there are three or more, then the total load must be divided proportionately between the stays according to their capacity, and the stays then attached to the individual resultant points for each of these portions of the total load.

The attachment of the stay close to or at the resultant point (or points, if there are several stay wires) is very important on light poles. Any appreciable departure is liable to deform the pole and increase its liability to buckle as well as making it unsightly. Only on stout poles should any marked departure from the resultant point be allowed, while on light poles every care should be taken to attach the stay very close to the resultant point. When additional arms and wires are added, the resultant point is lowered and the load is increased. Consideration should, therefore, be given to the need to lower the point of attachment of the stay in such cases.

Staying at Sharp Angles.—If the route is to change direction so sharply that the angle subtended is less than 135 degrees it is advisable that the turn be made on at least two poles, partly because of the heavy load on spindles and fittings and pole, and partly to avoid reducing the spacing between the line wires by having the arm at an oblique angle to the route. If it is not practicable for the turn to be made on two consecutive poles at normal spacing an additional pole should be inserted and the turn taken in a short span.

If the route is to turn at right angles, as at a street corner, the load on a single pole is extremely heavy, and, moreover, there are generally limiting positions for line poles and ground stays and stay poles. Usually at street corners two poles are necessary near the points where the building alignments projected would meet the kerbing. There are also electricity supply poles and wires to be considered. It is, therefore, difficult to arrange for stays to be fitted along the bisectors of the angles—usually head stays are necessary and the ground staying of the stay poles is difficult. Consideration has also to be given to the appearance of the construction, which must not be too unsightly; two or more wires crossing roadways other than at right angles to them are usually unpleasing to the eye. Figs. 91 and 92 show two methods which meet most requirements.

In Fig. 91 the wires are terminated on each of the poles, and terminal head stays are fitted across the roadway along the kerb alignment. In the short span connecting the two poles the tension of the wires can be light, and little or no side staying is necessary. While this method provides a very satisfactory anchorage it is expensive, and has the disadvantage that four joints are introduced into each wire.

The alternative method shown in Fig. 92 is not to terminate the wires, although the short span is adopted. Stays are fitted at right angles to the route and a headstay is connected between the two poles forming the short span. It will be noted that the total stress on the side stays is not less than with the terminal stays on the other method, while the positions of the stay poles are not as suitable for ground staying.

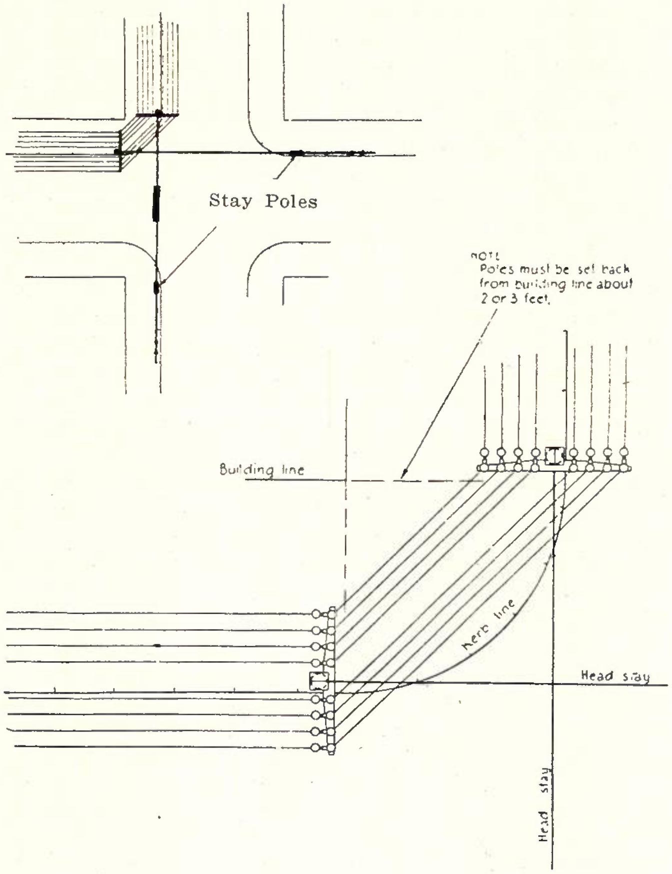


Fig. 91.—Turning Street Corners—Wires Terminated at Poles.

The tensions in the stay wires in the last method are found by resolving the various forces as in the force diagram for pole P in Fig. 92. PA and PB represent the total maximum tensions T (i.e., the total breaking loads) of the line wires. As the wires are not terminated the tensions should be equal, and to maintain the pole in equilibrium with stays these forces are to be counteracted by forces acting along the lines PE and PG. The force T along PA should be counteracted by a force along PF, but since there is no stay in the line of PF it must be counteracted by a force along the line PE consisting of the tension T of the line wires and a force X in the head stay.

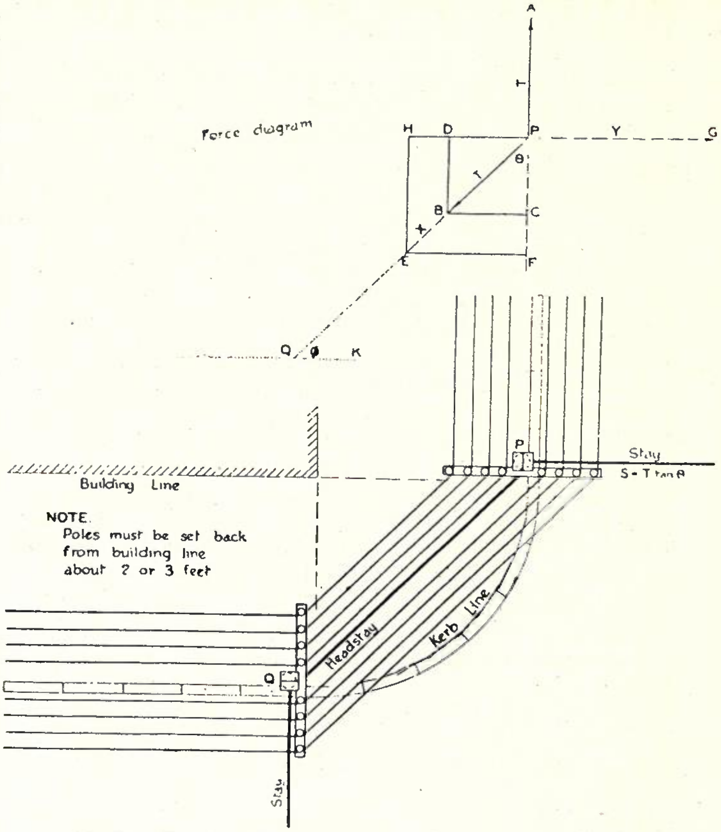


Fig. 92.—Turning Street Corners, Alternative Method.

That is: T + X resolved along PF must be equal and opposite to T along PA,

$$\text{thus: } (T + X) \cos \theta = T$$
$$\text{whence: } X \cos \theta = T - T \cos \theta$$
$$\text{and } X = T (\operatorname{Sec} \theta - 1) \quad \ldots\ldots \quad (37)$$

There is a similar and opposite force on this stay due to the loading.

The force Y in the stay along PG has to counteract the resolved parts of the forces T and X along PH.

$$\begin{aligned} \text{That is: } Y &= (T + X) \operatorname{Sin} \theta \\ \text{and from (37) } &= T \sin \theta + T (\operatorname{Sec} \theta - 1) \operatorname{Sin} \theta \\ &= T (\operatorname{Sin} \theta + \operatorname{Sin} \theta \operatorname{Sec} \theta - \operatorname{Sin} \theta) \\ &= T \tan \theta \quad \ldots\ldots \quad (38) \end{aligned}$$

Similar conditions apply, of course, at pole Q.

In the general case when the wires are at right angles as at most street corners: $\theta = 45°$ and Sec $\theta = 1.414$.

$$\begin{aligned} \text{Whence X the tension in the hand stay } &= T (1.414 - 1) \\ &= 0.414 \times T. \end{aligned}$$

Since the tangent of 45 degrees is 1, the tension Y in the stay in the direction of PG is equal to T, the maximum tension in the line wires.

(To be Continued.)

FAULTS IN AUTOMATIC EXCHANGES

H. L. Cook

The detection and localisation of faults in telephone switching equipment is a subject which is full of interest and intrigue for all who come in contact with apparatus of this type. Investigation of a fault condition in a circuit, which, according to superficial indication, should function correctly, but fails to do so when put to the test, calls for a review of the symptoms, the testing out of the different sections of the equipment and circuits, and the recognition of some symptom which perhaps leads to an ultimate solution of a fault, all combine to appeal to the imagination and give real satisfaction to the fault-man when ultimately a successful conclusion is reached and the faulty condition rectified. In order to bring a discussion of this subject within reasonable limits, attention has been confined to working circuits in automatic exchanges, and, even at that, it is obvious the subject is beyond the possibility of proper treatment in the space available in a technical publication which endeavours to cover such a field as the "Telecommunication Journal." Moreover, the comparatively recent introduction of 2,000 type equipment, with its high-speed testing over larger trunking group, has in no small measure increased the scope, calling for a wider knowledge and much more subtle handling than was necessary in the early days of telephony, with circuits such as those of simple magneto working.

The application of advanced technical knowledge and the possession of skill in handling testing apparatus in order to solve difficult fault problems which at times develop in automatic exchange equipment is a real test on the fault-man's ability to use all his faculties, even employing his sense of smell in the detection of an occasional hot coil.

An important factor when considering fault clearance generally is the time element, i.e., the duration of the fault. In exchange work this factor is often vital, as a major item of equipment, when defective, may represent the dislocation of service to a large group of lines, or perhaps all services may be suspended by the failure of common equipment. It is essential, therefore, that the methods adopted to deal with exchange faults provide for an expeditious system of testing and location. It must be admitted that experience may very largely modify a dogmatic step by step scheme of fault finding, and that a man with long practice in this class of work may obtain good results by taking short cuts based on familiarity with the circuits and equipment. At the same time it is considered that too much reliance can be placed on "hit and miss" principles of testing, and the best results are obtained by the fault-man who knows just when to abandon quick "stab" tests and to take up more scientific methods.

Without doubt, the greatest percentage of automatic exchange faults are found in the electrical circuits of the apparatus; therefore circuit faults must receive major consideration in this article, and may be attacked in three stages. The first, which we may call a functional analysis, is applied section by section to a circuit so that ultimately the fault is defined to one particular function or subsidiary circuit.

The term circuit is quite often applied to a complex set of individual electrical connections combined with mechanical movements, and the successful functioning of this combination is dependent on the proper operation of each of the elements in a pre-arranged orderly sequence. A faulty operation may be due to the failure of a minor intermediate section of the circuit, the detection of which may involve the consideration of the whole, from the initial step to the ultimate faulty effect, each stage must be carefully analysed to prove that its particular function is being successfully accomplished. This process is then a functional analysis, and represents the elimination of all but the one faulty circuit element from further consideration.

The next step in the diagnosis of the defective circuit is the reduction of the faulty effect to one of certain recognised electrical conditions. Speaking broadly, faults which affect working electrical circuits may be classified under two headings:—(a) disconnection or open circuits; (b) foreign contact, the latter including such terms as "loop," "short circuit," "cross," or "earth," and the contact may be of any resistance between the extremely low value of direct metallic contact and the correspondingly high figures of insulation weakness. Furthermore, any conductor carrying a direct current must possess, when tested at any point, a definite potential having a polarity and a magnitude dependent on its circuit connection and resistance. A test is, therefore, applied to determine the class of fault existing in the circuit, also to determine what variations from normal exist both in respect to polarity and potential, i.e., whether earth or battery is connected, and whether negative or positive, also the resistance value should be determined.

From this defining test the faulty electrical condition would be revealed. Finally, it may be necessary to locate the actual point of fault by a localisation test; quite often the faulty conductor will have connection at a number of springs or terminals, etc., and from these the defective section must be selected by point-to-point tests.

The three stages of systematic testing may then be summarised:—(1) Functional analysis; (2) defining test; (3) localisation test. It should be understood that all three tests are not necessary in every instance; at times tests may be combined with advantage, and that one test may confirm a suspected indication of another.

To demonstrate the existence of these stages let us briefly apply the system as outlined to one or two familiar cases. A 2,000-type 200-outlet group selector is reported to be cut in on a busy trunk. The first step is to busy the switch at the test jack to prevent its release until a record has been made of the level and trunk affected, as a good fault-man takes nothing for granted. The second switch concerned should also be detected and busied, and the conditions noted also. If the switches are "cut in" on different trunks then it is possible that the trouble is due to "crossed trunks." Assuming that both switches are "cut in" on the same trunk, then the line of reasoning, on a functional basis, is that one of the switches failed to test the "busy private" condition during its automatic rotary movement. This brings under suspicion such elements as wipers, bank contacts, wiper cords, interrupter springs, the testing relay, and associated spring sets, etc., and care should be taken while testing not to disturb more than necessary any portion of the apparatus, as the trouble might clear only to reappear at a later date. A careful inspection indicates that both switches appear to be in good condition, wipers making good contact, etc. A test, with a test lamp, proves the presence of a low-resistance earth on the private bank contact (normal condition on a busy trunk). Further testing shows that on one of the selectors a good earth is present at the wiper tag, but further testing at the wiper cord terminal shows that the resistance of the earth is considerably higher, proving that the wiper cord is faulty or that the soldered connections are high resistance.

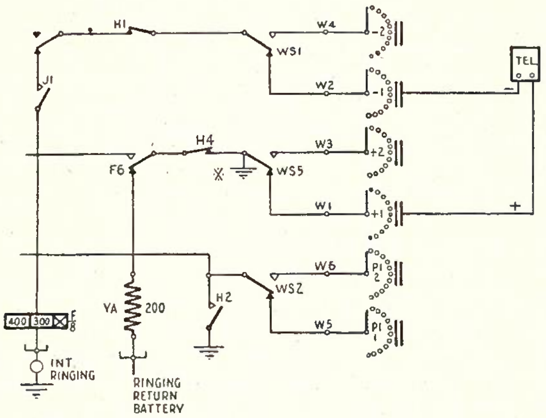


Fig. 1.—Showing Earth Fault at W.S.5.

Immediate action should be taken to clear the fault condition with the least amount of inconvenience to any subscribers who may be concerned.

Again, a final selector is reported as "ring and no voice." A functional check on the switch discloses that the "ring trip" "F" relay fails to operate when the called party answers. An electrical test proves that the positive wiper circuit is earthed at W.S.5, and as the ring supply is from an earthed generator (see Fig. 1) the ring "trip relay" is "shunted."

The functional analysis of a circuit calls for a thorough knowledge of the normal circuit conditions, and also familiarity with sequential operation of the relays concerned. When necessary, relays are manually operated or prevented from operation or retarded in operation or release, so that the progress of operation may be traced, also certain sections of a circuit are at times temporarily isolated at convenient points in order to prove the efficiency of other sections. The imagination, ingenuity, and deductive powers of the fault-man are in greatest demand during the functional analysis.

The defining test requires testing equipment to determine the polarity and resistance value of any section of a circuit, and the type of test equipment will depend on the degree of accuracy demanded. The test lamp is suitable in the majority of cases, but at times the use of a milliammeter is advisable. This latter instrument is, however, always liable to damage by an accidental or unexpected short circuit which increases the current value beyond safe limits. A voltmeter is safer in this respect, and provided its resistance value is suitable may be used to great advantage, resistance being measured by the "drop of potential" method. Breakdown tests for insulation weakness may be carried out with an instrument of the Megger type.

The fault-man's greatest aid is probably the test lamp, and it may be used for continuity testing and to determine polarity, as exchange battery terminations are easily distinguishable, whether they be negative battery and positive earth or vice versa, as in the case of metering battery.

As a means of measuring resistance the value of the current flowing when it is connected in circuit is indicated by the brilliancy of its filament glow and the value of the resistance under test is then estimated by the testing officer from his experience or by comparison with a similar test of a known normal circuit condition. This is rendered easy, in most cases, by the multiplicity of similar circuits and terminations. If the circuit resistance under test is of such a high value that the test lamp filament does not glow, it is sometimes possible to obtain an indication of the resistance by testing the suspected conductor in parallel with an adjacent good conductor and a comparison of the glow thus obtained with that through two good conductors similarly tested in parallel.

For example, the limit of resistance through which a glow may be distinguished is approximately 1,300 ohms when using a 50 volt switchboard lamp in conjunction with 50 volt battery supply, and the resistance of normal private wire condition of a bimotional primary line finder is 1,925 ohms. (See Fig. 2.)

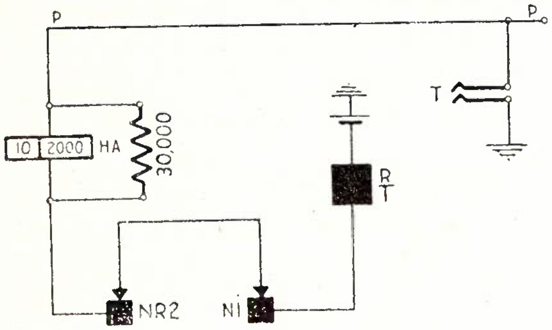


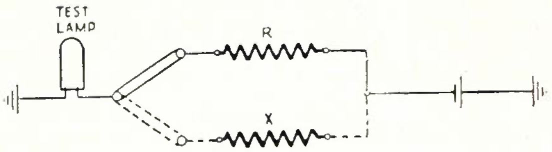
Fig. 2.—Private Wire Condition, Primary Line Finder.

The resistance of this circuit is too high to be indicated if the test lamp is connected to positive battery. If, however, two normal "Finder" circuits are connected in parallel the combined resistance is 962 ohms, approximately, and this value is within the range of the test lamp. Since a variation of one of the parallel resistances will vary the combined resistance value, a faulty circuit may be detected in this manner, and it is possible to detect an open circuit in the 30,000 ohm non-inductive resistance by using one of the good circuits alternately with a suspected one.

More accurate measurements of resistance value may be carried out, using a test lamp, by comparison testing, using a 50-volt battery supply and a resistance box of known values in conjunction with an unknown resistance. (See Fig. 3.) Alternate bridging of the known and unknown resistances with the test lamp, varying the former until equal brilliancy is obtained across each, the resistance values then being the same, the unknown resistance is equal to that of the reading on the resistance box. This test, although limited in practice, may be used to compare the resistance values of balanced relay windings, such as battery feed relays of selectors and repeaters, and may be practically applied as follows:—

A 200/200 ohms "A" relay of a group selector may be "short circuited" at the test jack of the switch; connect one terminal of the test lamp at this junction and connect the other terminal alternately to negative and positive battery and compare the intensity of glow; a difference of approximately 20 ohms in resistance values may be readily detected by this method. The use of a metallic filament type lamp with a nominal voltage range of 36 to 48 volts will permit the measurement of resistances from 20 ohms to 1,000 ohms, within 10 per cent.

Method 1



Method 2

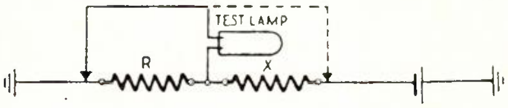


Fig. 3.—Comparison of Resistances, Using Test Lamp.
Note.—With both methods equal brilliancy of the glow of the test lamp when connected alternately to the resistances as shown denotes similar resistance values. Method 2 is more accurate.

The reliability of testing by the above methods is dependent on experience and skill displayed by the testing officer together with his foresight by keeping on hand one or two spare lamps as replacements, which possess similar characteristics to that used in the test lamp. Testing with an instrument of the Detector No. 2 or No. 4 types will give excellent results where accurate measurements are required or until the tester feels confident of good results when using the test lamp.

In localisation testing for "open circuit" conditions the test lamp is, within its limits, again brought into use, and by point to point testing at each connection "open circuit" conditions may be localised to within one or two directly connected points. In the application of testing by this method consideration must be given to high resistance values which might be associated with any portion of the equipment under test.

Again, the test lamp may be used for the identification purposes when it is desired to check the continuity and condition of apparently spare or unconnected local wiring. Two test lamps may be used; one terminal of each should be connected to positive and negative battery respectively, and the remaining terminals connected to the ends of wiring under test. Continuity (within the limits of the test lamps) is a half brilliancy glow on each lamp due to the series connection via the wire under test, while any variation from this condition would indicate the presence of positive or negative battery.

Drop of Potential Testing.—Contact faults often affect wiring of the multiple type, and as minimum disturbance of this wiring and its termination is essential a special test known as the "drop of potential" test is generally applied. The test depends on the principle that as any conductor possesses resistance, a potential drop must exist across any two points of a conductor carrying current. Both the resistance of the conductor used for wiring and the current which can conveniently be used for testing are comparatively small in value, therefore the potential drop (by

Ohm's law, E = I × R) is correspondingly small, and the apparatus used to detect this potential drop must be exceedingly sensitive. Such sensitivity exists in the telephone receiver, and this instrument is used in either of two types or sets (see Fig. 4).

One set comprises a pair of 60 ohms receivers (of the regular wireless pattern) connected in series with the secondary winding of a magneto type (1.50 ohms primary, 75 ohms secondary) induction coil, the primary of the latter being terminated by means of two low resistance flexible conductors to testing pointers. The induction coil is mounted in a case suitable for carrying in the pocket, or it may be mounted on a breastplate and carried in the manner of a telephonist's transmitter. The second form is a much simpler set, consisting of a pair of similar headband receivers, but the latter are rewound to a resistance of 1 ohm each and directly terminated in the same fashion with flexible conductors and pointer. The first type is made up of standard apparatus, but the necessity for carrying the induction coil is a disadvantage compared with the freedom of movement provided by the second simpler set, which, however, requires specially wound receiver coils. Both sets possess about the same degree of sensitivity. A disadvantage to which each is subject is the liability of the receiver to become depolarised if a high-value current passes through the set, as may sometimes happen when battery leads are accidentally bridged. In the case of the induction coil set, it is the high-value increased current in the secondary circuit occurring at the break of the abnormal circuit, which causes the demagnetising action, e.g., when a fuse is operated by the short circuit due to the low resistance of the primary winding.

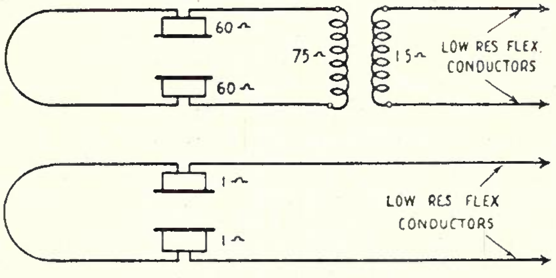


Fig. 4.—Types of Drop of Potential Test Sets.

Experiments have been made with this type of set to ascertain if a low-capacity condenser connected in series with the secondary winding and receiver would restrict this induced current surge so as to prevent the demagnetising effect without materially affecting the efficiency of the set. A 0.02 μF condenser has given satisfactory results when used in this manner, the receiver and induction coil having the values previously mentioned. The sensitivity is such that a faint click can be heard in the receivers when the test is applied across one inch of ordinary switchboard wire (0.0015 ohms) carrying a current of 100 milliamps. In applying the test (see Fig. 5) the test lamp is again brought into use; its purpose is twofold: to provide current of a reasonable value along the conductor or conductors through the fault, and to maintain a signal while the fault exists. The conductor in the fault circuit is then tested by bridging sections of its length at convenient tapping points. While any portion of the section of conductor bridged by the set is carrying current a click, or rather a characteristic scraping noise, is heard as the test pointers are tapped on and off, and when no current is flowing in the portion bridged, i.e., when the fault is passed, no such signal is heard. As contact faults occur principally at connecting points, the exact location of such a fault can be found by these means. An interrupted current is sometimes used in the fault circuit to produce a tone in the receivers when the test is applied. An interesting variation has been used to locate an insulation breakdown between positive and negative conductors in a selector bank multiple, occurring when dialling voltages were impressed. Impulses were applied continuously to the associated selector circuit by means of the impulse or vary machine, and the test then made from bank to bank as usual. The dialling voltages produced during the break periods of the machine impulses caused the puncturing of insulation at the point of fault, and the pulses of current which in consequence passed along the fault circuit served for the location test.

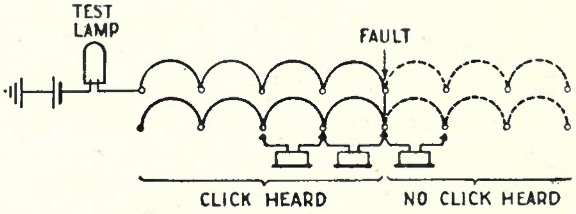


Fig. 5.—Application of Drop of Potential Test to Multiple Wiring.

Note.—Fault Circuit shown in full lines.

Faults due to defective mechanism sometimes occur, but the cause is generally of an obvious nature. When this is not so, an examination of the adjustment of a switch will usually disclose the trouble. Friction of moving parts, faulty engagement of pawls, detents, ratchets, or similar actions and incorrect tension of springs sum up the major causes of mechanical failure. On rare occasions irregularities of operation are discovered to be of magnetic origin. Generally, a fault is treated on the assumption that it is due to an electrical defect, and when the affected electrical circuit is tested and then proved beyond doubt, suspicion falls on the magnetic function. Apart from the inspection and measurement to the ordinary standards of adjustment for relays and magnets there is little scope for testing of the usual type when dealing with magnetic irregularities. Substitution of the doubtful component by one of similar type and of known efficiency is the practical method of proving failure by magnetic circuit deficiency.

Faults which develop in automatic exchange equipment so as to affect transmission of speech are, with few exceptions, due to faults in electrical circuits, and as such are mostly accompanied by operating failures or irregularities. The detection and clearance of the electrical circuit fault will, therefore, usually also restore normal transmission efficiency.

An interesting fault condition, detected by keen hearing, was a multi-metering condition set up in a 2,000-type Line Finder exchange during testing operations prior to "cut over." An officer working near a register rack noticed that occasionally registers operated at regular intervals for short periods, and decided that as the exchange was not handling traffic at the time the condition should be investigated. Further observations indicated that the trouble was in evidence when routining operations were performed on primary line finders, and so long as the finders were searching for "mark conditions" certain registers operated every time a switch passed a contact in the finder bank multiple, associated with one of the operating registers. Tests with a test lamp indicated that registers were operated by a negative battery pulse in lieu of positive battery, and further observations disclosed that the finders did not stop on the "M" bank contacts associated with the registers. Normal testing under routine conditions failed to disclose the fault condition. Further tests were performed by operating a single finder and causing it to stop on a contact where metering was taking place. It was noticed that when the switch "tested in" with the rotary interrupter in the operated position that the register operated.

The test lamp was again brought into use, and point-to-point testing proved that L22 common (to 20 circuits per level on the front marking bank) was "crossed" with L23 contact (M1 lead) at the back of the spring set on the L relay, thus providing a circuit from negative battery at the rotary magnet of the Finder, N springs operated, rotary interrupter operated, via allotter arc 3 through control set and allotter arc 6, auxiliary wiper 1 to L22 common through the fault to M1 lead, 500 ohms of register, M bank, 10 ohm winding of switching relay, and earth connection through rectifiers at RS1 in control set (See Fig. 6.) Further testing proved that the same conditions existed on the relays associated with other registers, and the faulty conditions were removed. Fault conditions of this type may be readily detected under maintenance conditions by operating the "K" relays associated with the level under test by the routine test key, thereby operating the SF relay in the control set from earth at K1 through the register via "cross" L23 to L22, vertical marking bank, and allotter arc 6. Finders will, under this condition, stand outside the level and fail to cut in.

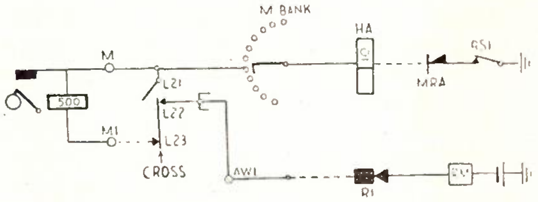


Fig. 6.—Fault Condition on Marking Leads.

In the operating of a bimotional selector of the pre 2,000 type, the proper entry of the wipers into the bank on the initial step of the rotary action is determined (1st) by the elevation of the shaft of the switch to the correct level by the vertical magnet's operation, and (2nd) by this level being maintained by the control of the stationary detent which, when correctly adjusted, permits practically no variation from this correct "cut-in" position. This arrangement is designed to ensure that the wipers are so aligned with relation to the bank that proper engagement on the correct level is certain. Nevertheless, switches are discovered from time to time with wipers jammed between levels, although the adjustment when checked is found to be correct. The reason for this irregular action has caused considerable discussion, and I venture to suggest the following theory. The shaft of this type of switch is lifted in its vertical motion in a series of steps by the magnet-operated pawl and ratchet mechanism. At the end of each step the shaft is suddenly checked by the locking of the pawl between the shaft teeth and the pawl stop.

It can be easily proved that the wipers are deflected from normal by inertia at each of these sudden checks, being lifted slightly at the end of each step, and in consequence, probably vibrate for some little time above and below the correct bank entry position. If the rotary motion should follow the vertical action closely it is conceivable that the wipers, still vibrating, are out of position when stepped into the bank, and thus enter above or below the correct level, where they become jammed by the lack of clearance between adjacent levels. The time which elapses after the vertical action and before the rotary motion commences is controlled by the release lag of the slow relay "C," which is in series with the vertical magnet, and remains operated during the vertical magnet's stepping and for a slight pause after this stepping by the action of the copper slug. This relay is normally designed to release with a certain delay so that the selection by rotary action and the engagement of the trunk to the next rank of switches may be safely accomplished in the time pause between trains of impulses. Therefore, if this theory is correct, this delay may, by adjustment or other circumstances, be reduced to too fine a margin. It also may be noted that the release lag of "C" relay will be controlled by the ratio of impulse received by it from the line impulsing "A" relay, and if the line impulsing conditions are such that impulses of short duration are delivered to the "C" relay, this relay may be insufficiently energised to provide a lag which would ensure a safe entry or "cut in."

The line of reasoning outlined about would, therefore, lead to the conclusion that the origin of the mysterious faulty wiper engagement may be insufficient lag of the "C" relay, which could be brought about by maladjustment or by the fact that the switch had been operated by impulsing of too short a make ratio, i.e., by light impulses. A combination of these two factors would, of course, increase the possibility of the development of the fault.

In conclusion I would like to express my thanks to Mr. C. L. Hosking for his kind assistance and co-operation.

THE APPLICATION OF V.F. AMPLIFIERS TO P.A.B.X. EXCHANGE LINES

R. W. Turnbull, A.S.T.C.

This article describes generally the application of V.F. amplifiers to a group of automatic exchange lines serving a 500 line P.A.B.X. Situated some 17 miles from the nearest metropolitan exchange and having extension lines varying in length to a maximum of 3 miles the P.A.B.X. is, in effect, a satellite exchange with automatic access to the Sydney metropolitan exchanges.

Under normal conditions, for calls between the P.A.B.X. and the metropolitan network, the exchange lines would be required to work at zero transmission equivalent to provide the extension services with a standard overall grade of transmission. The use of 4 wire amplified circuits was planned for this reason and two 24 pair 40 lb. cables, as part of a future trunk cable, were laid. However, the appropriation of cable circuits for other services resulted in the minimum exchange line requirements on a 2 wire basis, being available for the P.A.B.X. when installed.

Although the use of V.F. repeaters in 2 wire trunk line circuits is general, the application of similar equipment to automatic exchange lines presents the difficulty of maintaining an adequate degree of balance between the lines and hybrid nets, particularly during automatic switch operation; any marked unbalance causing oscillation in the amplifiers. Added to this, is the factor of varying line impedances due to the automatic selection of different classes of junctions between the branch and main exchanges.

Following tests by equipment and transmission engineers, a circuit has been developed which gives satisfactory results at the expense of approximately 6 db in transmission equivalent. This is shown in schematic form in Figure 1. The design of the balance networks and the automatic control of a stabilising network (Net 3) to provide the requisite balance under the various operating conditions are the principal features. The gain in the amplifiers is approximately 12 db.

For traffic reasons the 17 exchange lines are equipped for two-way working. Access to the P.A.B.X. is obtained during the day from a selector level, via ringing repeaters. Most of the lines are night switched and are available by dialling the final selector numbers allotted. Both the ringing repeaters and final selectors are wired to standard ringing circuits, earthed ringing current being transmitted on the negative exchange line. Reference to Figure 1 will indicate the method of passing the ringing and dialling circuits round the amplifiers.

Incoming to the P.A.B.X., the exchange line relay set differentiates between incoming and outgoing calls and provides the necessary guard feature to prevent access from the "O" level of the selectors if the line is in use from the manual cabinet. The incoming ring is tripped by the momentary application of negative battery to the negative line. This method was adopted because of the high loop resistance of the exchange line (approx. 1000 ohms). Separate groups of jacks are provided for incoming and outgoing appearances of the lines on the manual cabinet.

Outgoing from the P.A.B.X., the exchange lines are available from the "O" level of the selectors and from the manual cabinet and are connected to uniselectors in the branch exexchange. Loop dialling is employed as shown. The relay sets in the exchange guard the lines against calls from the selector level or the final selectors during the progress of outgoing calls from the P.A.B.X. and the balance network is controlled from the private wires of the switches. Once a junction circuit to the main exchange is connected this provides a suitable balance and the net is disconnected automatically.

For outgoing calls from the P.A.B.X., also, it was necessary to modify the P.A.B.X. repeater circuit to give a fleeting short circuit on reversal for reliable operation of the metering circuits in the branch exchange.

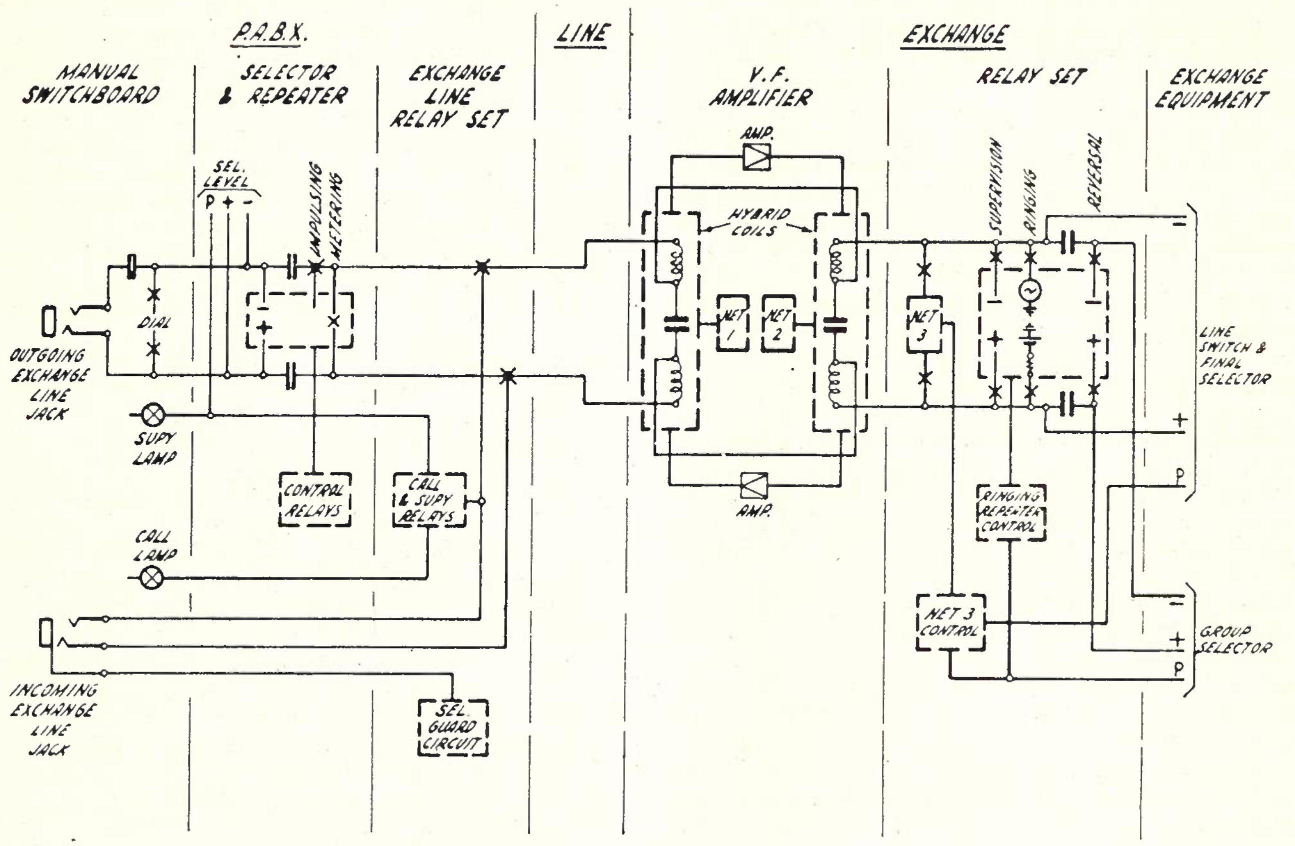


Fig. 1.

Because the exchange lines are available from three different sources, viz., the manual cabinet, the "O" level outlets from the group selectors in the P.A.B.X. and the selector level in the branch exchange, the order of selection in each case is arranged to be different so that the searching time in each group is reduced.

Standard cord circuit supervision is provided from the ringing repeater on calls incoming to the P.A.B.X. and from the repeater in the P.A.B.X. on outgoing calls. To ensure adequate guarding of the lines the circuit provides for last party release. This is essential to avoid such conditions as the seizing of an outgoing line during the clearing of an incoming call.

Because of the transmission loss the lines are not regarded as providing a standard grade of service, but the methods indicated above enabled the traffic requirements to be met months before the capacity of the line plant could be increased to permit 4 wire operation.

SELENIUM METAL RECTIFIERS

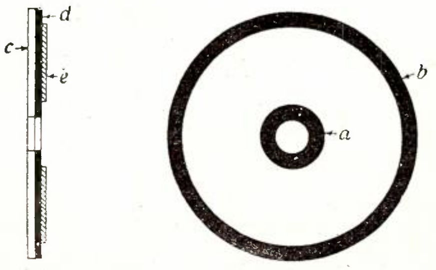
R. F. Haren, A.S.T.C. (Elec. Eng.), Standard Telephones and Cables Pty. Ltd., Sydney

The development of the phenomenon of asymmetric electrical conduction from a scientific novelty to an apparatus of widespread engineering application may be divided into three stages; crystal detection, electrolytic rectification, and modern "metal" rectification.

When a voltage is applied to a conductor comprising a single substance, the resultant current flow is independent of the polarity of the voltage. In certain physical or chemical combinations the current varies according to the direction in which it is passing and the combinations possessing these characteristics are said to exhibit "asymmetric conduction" which can be simply defined as the property of passing current more freely in one direction than in the opposite direction. The direction in which the current is passed more freely is usually called the "forward" or "conducting" direction, and the other the "reverse" or "non-conducting" direction.

Although a recent addition to the manufacturing field in Australia, Selenium rectifiers were first introduced on a commercial scale in Germany 17 years ago, and have been widely used on the Continent, British Isles and America since that date.

The Selenium rectifier consists essentially of a base plate or disc of nickel plated steel, on one face of which a thin layer of Selenium is applied in such a manner as to form an intimate contact with the disc. When first applied to the disc, the Selenium has an almost black mirror-like surface, but this is subsequently changed by a series of carefully controlled heat processes into a grey crystalline form. The disc is then put into a mask and the Selenium surface is sprayed, with the exception of narrow rings at the centre and the periphery, with a low melting-point alloy for the purpose of forming a counter-electrode. A cross-sectional construction diagram of a Selenium disc is shown in Fig. 1a. Since the layers of Selenium and sprayed metal are very thin they are represented to an exaggerated scale. In Fig. 1b it will be noticed that there is a central hole to enable the discs to be threaded on an insulated spindle, and the rings "a" and "b" of uncoated Selenium are also shown.



(a) (b)

Fig. 1.—Selenium Rectifier Disc. (a) Cross-Section. (b) Plan.

Originally electrical contact was made to the counter electrode by a spring contact, with the amount of pressure exerted by this spring contact plate determined by the thickness of an insulating washer placed between the contact plate and the disc. This method of assembly was reasonably satisfactory except that it did not lend itself to moisture proofing. The method is therefore obsolete and an improved construction has been introduced. This improved construction, which is incorporated in Australian manufactured discs, is obtained by spraying an insulating varnish over the top of the Selenium layer at the centre of the disc before the counter-electrode alloy is sprayed on. The Selenium is now insulated from the counter-electrode over the area where pressure will be applied when the rectifier is assembled. Electrical connection can be made by means of a special metal contact washer. On the back of each disc electrical connection is made by means of a metal washer, and desirable spacing between discs is achieved by means of metal spacing washers. The whole of the components for a rectifier assembly are assembled in special jigs to ensure correct pressure and avoid damage to the rectifying elements. This latter construction, known as "centre contact" allows the maximum cooling for the discs which can also be completely dipped in insulating varnish for moisture-proofing.

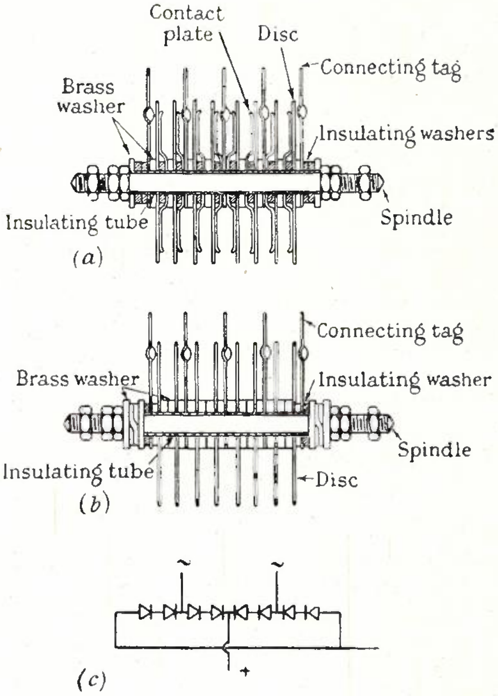


Fig. 2.—Selenium Rectifier Units in Section.

When the mechanical construction of a rectifier is complete the asymmetric properties are not sufficient for the disc to be put into service, and it must therefore be subjected to an electrical "forming process." A rectified A.C. voltage is applied to the disc in the reverse direction and after a period of time the reverse resistance increases to a value satisfactory for commercial use. The forward resistance, however, is practically unaffected by this forming process.

The rectification properties of the Selenium rectifier are not clearly understood by physicists, but a theory has been advanced that a "barrier layer," of a complex chemical compound, is formed between the Selenium layer and the counter-electrode during the process of electrical forming. The nickel-plated steel disc provides a conducting support for the Selenium layer, the semi-conductor, and the counter-electrode of sprayed metal, the good conductor.

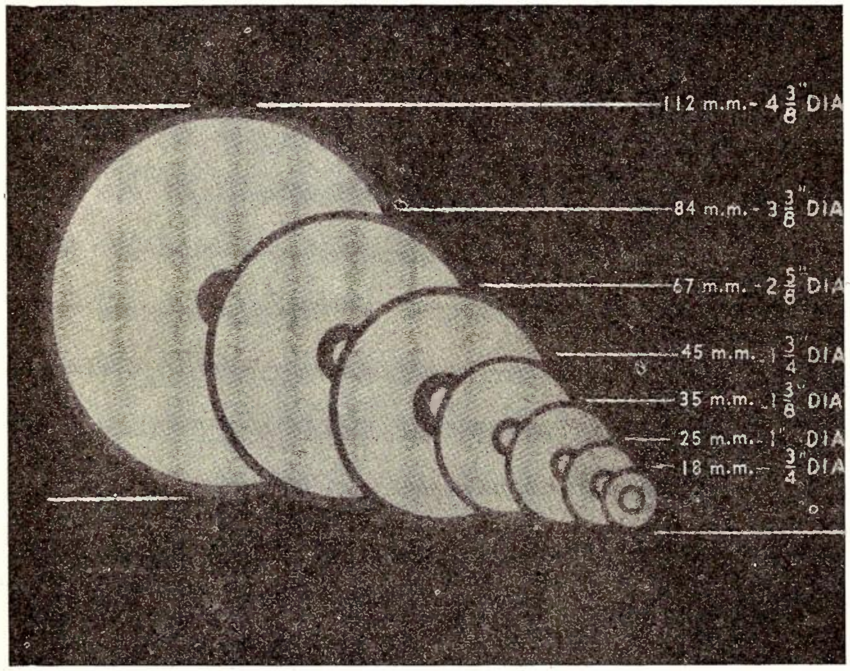


Fig. 3.—Seven Basic Sizes of Selenium Rectifier Plates.

The Selenium discs are at present manufactured in seven different sizes of discs ranging from 18 m.m. to 112 m.m. in diameter. They are subjected to a voltage breakdown test after "forming." A D.C. pressure considerably greater than normal working pressure is applied in the reverse direction. Each disc is then graded for reverse and forward resistance between narrow limits and in the completed rectifier assembly only discs of similar reverse resistance are connected in series and those of similar forward resistance are connected in parallel. Disregarding the effect of unbalance in phase voltages and temperature a rectifier assembled on this basis has the inherent property of complete balance.

Each disc forms a complete rectifying element or cell, the current flowing from the counter-electrode to the steel disc and vice-versa through the Selenium layer in a direction normal to the plane of the disc. On applying a steady potential, however, it will be found that a much larger current will flow from the back of the disc to the counter-electrode than in the opposite direction.

Characteristic Curve for Forward and Reverse Currents and Voltages.—The standard characteristic curve for the relation between the currents and voltages in the forward and reverse direction for a single Selenium disc based on an effective surface disc area of one sq. cm. is shown in Fig. 4. The curve passes through zero level with the current value increasing rapidly at a forward potential of approximately 0.3 volt and finally becoming almost linear. Since the reverse currents are so much smaller than the forward currents, it is only possible, by altering the scale of current for the former, to make a comparison. The maximum working voltage usually applied in the reverse direction is 18 volts (r.m.s.) per disc. The normal current loading for continuous working in the forward direction for naturally cooled discs is approximately 50 m.a. per sq. cm. which corresponds to a potential drop of about 1 volt. Considering a reverse current of 1 m.a. for a potential of 18 volts (Fig. 4) and a forward current of 50 m.a. for a voltage drop of one volt, an effective ratio of forward to reverse current at full reverse potential and full load current, a ratio of 50:1 is obtained.

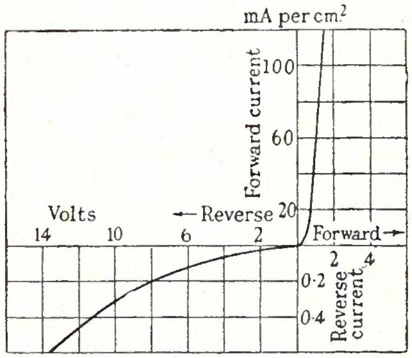


Fig. 4.—Forward and Reverse D.C. Characteristic.

Resistance Characteristic.—It is interesting to plot a curve to compare the characteristic curve of Fig. 4 with a curve of forward and reverse resistance plotted against forward and reverse voltage as shown in Fig. 5. The ordinates are drawn on a logarithmic scale.

The resistance of the disc has a maximum value at approximate zero voltage and as the voltage is increased in the reverse direction the resistance decreases slowly within the normal working voltage range. When the voltage is increased in the forward direction, the resistance at first falls very rapidly and then more slowly.

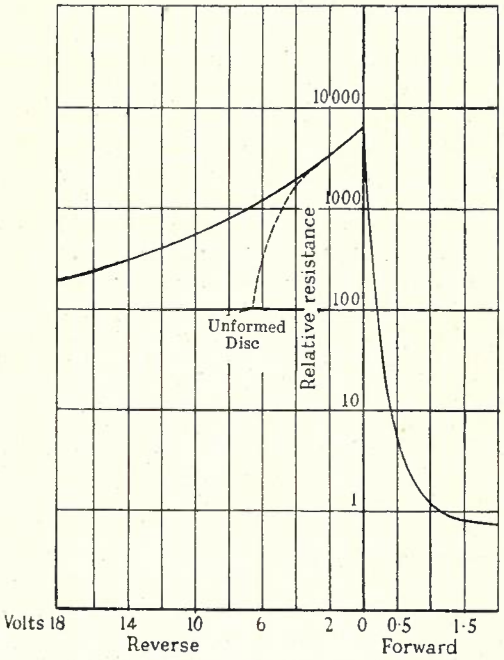


Fig. 5.—Resistance Characteristic.

We can thus consider that the resistance of the rectifier in either forward or reverse direction is dependent on the applied voltage, i.e., the rectifier does not obey Ohms Law. The fact that the rectifier does not obey Ohms Law inasmuch that the resistance varies with the current gives rise to many peculiarities in operation.

Efficiency.—Due to variation in resistance with current, losses in the forward direction do not increase directly in proportion to the square of the current as they would if the disc behaved like a true resistance. The losses are of course equal to I^2r, but since r is decreasing, the rate of increase of the product also diminishes. Since the reverse losses are almost constant for a given value of the applied voltage, the efficiency remains high over a wide range, and is approximately constant from about 15% to 150% of full load.

Efficiency Curve.—In measuring the efficiency of a rectifier it is usual to use moving coil instruments which read the average value of the current and voltage, with a wattmeter in the A.C. supply. This method of measuring efficiency is called the volt-ampere efficiency. The results of this method of measurement depend on the form factors of the output voltage and current and these factors vary considerably for different loads and rectifier circuit arrangements. The curves of Fig. 6 show typical volt-ampere efficiencies for various arrangements of rectifier and load.

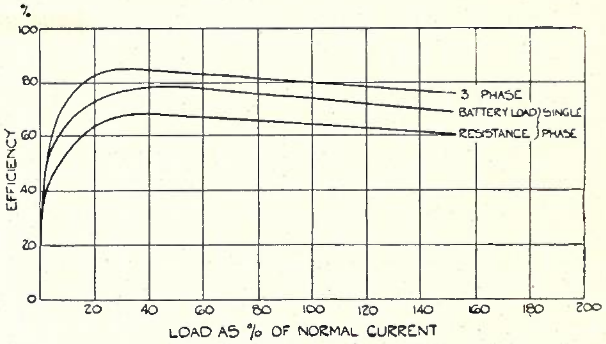


Fig. 6.—Efficiency of Selenium Rectifier Operating at Full-Load Voltage.

The watt efficiency, as obtained with a wattmeter in the A.C. input and D.C. output circuits, is about 85% for a maximum current density of 50 m.a. per sq. cm. for all sizes of discs and types of load.

The output power from a rectifier is the product of the current and voltage and the forward loss depends only on the current. It follows, therefore, that the efficiency of the rectifier will increase with the voltage applied. The comparatively high voltage at which the rectifier can be operated is therefore a distinct advantage.

Temperature Co-Efficient of the Rectifier Resistance.—In the forward direction, the Selenium rectifier has a negative co-efficient so that as the rectifier warms up its resistance is reduced. Fig. 7 shows the curves for current densities of 50 m.a. and 5 m.a. per sq. cm. of active surface in relation to voltage drop for a range —30 deg. C. to +75 deg. C. Since the rectifier resistance is usually only a small fraction of the total resistance of the whole circuit (approximately 10 per cent.) the effect of the change of temperature on the output of the rectifier is quite unimportant. Furthermore, the negative temperature co-efficient of the rectifier resistance is largely balanced by the positive temperature coefficient of the transformer, chokes and other copper conductors when used in the circuit.

In the reverse direction the variation of resistance with temperature is very small for values of temperature between the normal working range from 20° to 75° C. This variation is again affected by the reverse voltage on the disc. With low temperatures from 0° to —30° C. the resistance is decreased and similarly above the value of 85° C. If the temperature of the rectifier approaches 100° C. the reverse current increases very rapidly and causes the sprayed metal counter-electrode to melt and destroy the rectifier.

We may then consider that at very low temperatures the forward resistance is increased and the reverse resistance decreased, but satisfactory rectification can still be obtained. As both of these effects tend to cause heating of the rectifier a rapid approach to normal working condition is obtained.

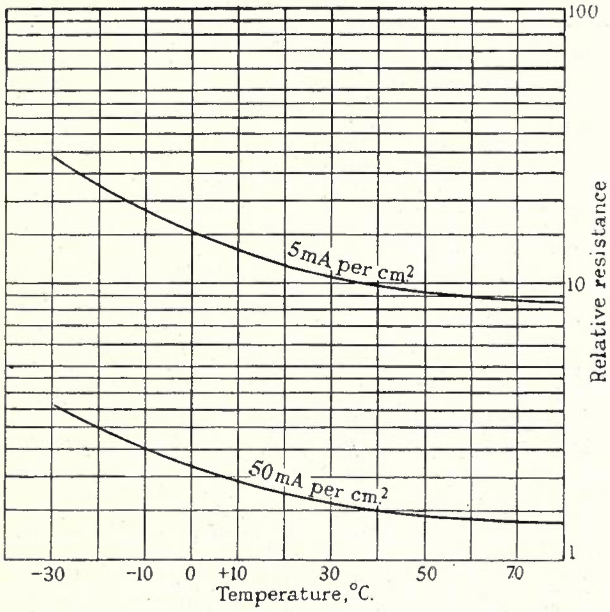


Fig. 7.—Variation of Forward Resistance with Temperature.

TABLE 1

SELENIUM RECTIFIER RATINGS

Disc Dia. m.m.	BLOCKING RECTIFIER Max. D.C. Volts per Disc	BLOCKING RECTIFIER Max. Fwd. Current Amps.	Max. A.C. Volts per Disc R.M.S.	FULL LOAD CURRENT (AMPS.) SINGLE PHASE HALF-WAVE Res. Load	HALF-WAVE Batt. Load	BRIDGE Res. Load	BRIDGE Batt. Load	PUSH-PULL Res. Load	PUSH-PULL Batt. Load	THREE PHASE Half-Wave (Resistance or Battery Load)	Bridge	Push-Pull
18	15	.06	18	.04	.032	.075	.06	.075	.06	.1	.11	.13
25	15	.12	18	.075	.06	.15	.12	.15	.12	.2	.22	.27
35	15	.23	18	.15	.12	.3	.24	.3	.24	.4	.45	.55
45	15	.47	18	.3	.24	.6	.48	.6	.48	.8	.9	1.1
45C	15	—	18	.6	.48	1.2	.96	1.2	.96	1.6	1.8	2.2
67	15	.9	18	.6	.48	1.2	.96	1.2	.96	1.6	1.8	2.2
67C	15	—	18	1.2	.96	2.4	1.9	2.4	1.9	3.2	3.6	4.4
84	12	1.88	16	1.2	.96	2.4	1.9	2.4	1.9	3.2	3.6	4.5
84C	12	—	16	2.4	1.9	4.8	3.8	4.8	3.8	6.4	7.2	9.0
112	12	3.12	14	2.0	1.6	4.0	3.2	4.0	3.2	5.3	6.0	7.5
112C	12	—	14	4.0	3.2	8.0	6.4	8.0	6.4	10.6	12.0	15.0

In general it may be stated that the Selenium rectifier will operate satisfactorily in a range of ambient temperature from —30° to +55° C., and it is therefore suitable for use in aeroplane and exposed situations where wide variations may be experienced.

Temperature Rise.—Limitation of the current loading on the rectifier disc is imposed by the temperature rise of the element, due to its internal losses. The normal working temperature of the Selenium rectifier is about 65° C., although a temperature of 85° C. can be withstood with safety for some hours. This margin is allowed to take care of abnormal temperature conditions, mains voltage fluctuations and increase in resistance of discs due to ageing. Rectifiers intended for use in Australia are rated to operate with an ambient temperature not exceeding 40° C., and a temperature rise not exceeding 35° C. For temperatures exceeding 40° C. the current rating of the disc must be reduced to limit the temperature rise. However, in the case of tropical conditions, where the equipment is to operate continuously in ambient temperatures up to 55° C. the relatively high working temperature of the Selenium rectifier is a great advantage since there is still a reasonable difference of 20° C. available for cooling. The current ratings shown in Table 1 are based on 40° C. (104° F.) with maximum spacing between discs. In the case where smaller spacing between discs is required, due to special mounting, the values shown are decreased.

Maximum Voltage and Current Loadings Based on 40° C.—In ambient temperatures exceeding 40° C. (104° F.) the power rating of the rectifier must be reduced as indicated in Table 2, in order to maintain the final disc temperature below 75° C., the safe maximum. It will be noted that, by decreasing the voltage rating, a small increase in current rating is allowable.

The percentage currents and voltages from Table 2 are based on current and voltage ratings of an uncooled disc at 40° C.

TABLE 2

Air Temperature °C	Air Temperature °F	Current Rating % of Normal	Voltage Rating % of Normal
45°	113°	79	100
50°	122°	54	100
50°	122°	79	80
55°	131°	54	80
60°	140°	33	80
60°	140°	54	60

Working Voltage.—The voltage which may be applied to a Selenium rectifier disc is limited by the strength of the dielectric and the heating produced by the reverse current characteristic. Although the breakdown test on rectifier discs is of a voltage more than double working voltage, any increase in the working voltage is not recommended, due to the non-linear increase in reverse current.

Intermittent Service.—In the case of intermittent service the only limit to the amount of current which can be carried by a disc is controlled by the rate at which the heat can be conducted away from the surface of the disc. Depending upon the duty cycle of operation the current density in air can be increased with safety up to about 10 times the normal value, and in oil this value can be increased still further.

Regulation.—The voltage regulation of the Selenium rectifier is particularly good, due to its low forward resistance. For a single phase bridge rectifier with a resistance load, the mean D.C. voltage at full load and no load are respectively about 77% and 90% of the R.M.S. input voltage. The regulation from no load to full load is, therefore, of the order of 15%. With an inductive load the regulation depends on the ratio of inductance to resistance, but is usually higher than for a resistance load. When closer regulation is required compounding devices can be used which enable the output voltage to be maintained at a nearly constant value over a wide range of load.

Power Factor.—The Selenium rectifier has substantially unity power factor.

Ageing.—During the electrical "forming" process in the manufacture of the disc the forward resistance of the rectifier is increased to a small degree, whilst the reverse resistance is greatly increased. A possible explanation is that the thickness of the barrier layer is increased. In service this phenomenon known as "ageing" is experienced, inasmuch that there is a gradual increase in forward resistance with a resultant increase in reverse resistance. The rate of ageing is determined by the normal temperature at which the rectifier is operating. It is accelerated in the case of high temperature operating, but in the case of normal working temperature (65° C.) a stable condition is reached in about 10,000 hours of continuous operation. For working temperatures lower than normal, ageing takes place after continuous operation for about 40,000 hours.

This increase in resistance can be compensated by an increase in the applied voltage, and the amount depends upon the ratio of the resistance of the rectifier to that of the whole circuit. There is, of course, a slight falling off in efficiency from this cause, but this is partly compensated by the reduction in the reverse current which takes place at the same time.

Cooling.—In the table of disc current loading, the discs are rated for current density at a given ambient temperature, but the disc loading is actually only determined by the temperature rise. By using artificial cooling the current rating can be greatly increased, and owing to the shape of the voltage/current characteristic, as explained under efficiency, only a slight reduction in efficiency is obtained.

The methods used for the better radiation of the heat produced by the increased current loading on discs are as follows:—

1. The addition of cooling fins.
2. Ventilation by the chimney draft principle.
3. Forced draught cooling.
4. Oil cooling.

With the first method each rectifier is provided with an additional fin of considerable area so as to increase the available cooling surface. The addition of these fins to the disc increases the current rating to approximately double, with a consequent saving in cost and space.

The rectifier assemblies with and without cooling fins are mostly cooled by convection. For uniform heating, in the case of a rectifier assembly made up in a number of stacks, the whole of the stacks should be mounted on the one horizontal plane. It is obvious, however, that in the case of large assemblies the floor area would be excessive and so result in a cumbersome equipment. From an economical consideration, it is desirable that the maximum current density per disc should be obtained consistently with a safe working temperature and a reasonable margin for ageing. Considerable experimental work has been carried out, and the results have indicated that a high narrow housing, with unperforated panels, results in a lower final temperature on the rectifier discs. The panels of the cabinet are arranged so that they do not reach the angle iron at the base of the cabinet, but an air duct is allowed on the four sides of the cabinet equal in area to approximately the outlet at the top of the cabinet. This method of construction gives an enhanced chimney effect, so that in the case of a rectifier with three layers of rectifier stacks mounted vertically, the final temperature is approximately 10° C. lower than in the case of the same rectifier stacks mounted horizontally in a much larger housing. The degree of temperature difference between the top and bottom layer of stacks is not sufficient to cause any undue unbalance, whereas the lower operating temperature of the rectifier is a decided advantage.

In the case of forced-draught cooling, a fan can be utilized and so resulting in an increase of 2.5 to 3 times the normal uncooled disc rating. The use of fans, however, detracts from the static nature of Selenium rectifiers, but in certain equipments, such as sealed equipments for tropical conditions, fans are incorporated. They, however, suffer from the disadvantage that the failure of the fan could result in the destruction of the rectifier unless special protective devices are included.

The Selenium rectifier operates just as well when immersed in transformer oil. Selenium rectifiers for use in such diverse applications as electro-plating, electro-static dust precipitation and railway signalling, are oil immersed for protection against the deleterious effects of chemical vapours, insulation for D.C. voltages to 80,000 volts and for protective housing in exposed conditions.

Oil immersed Selenium rectifiers due to the thermal storage of the oil can carry, without damage, heavy overloads of short duration which would result in the destruction of the air-cooled type. For continuous service under oil Selenium rectifier discs carry at least 2.5 times the normal current of an uncooled disc.

The usual standard type of oil-immersed Selenium rectifier for electro-plating has an output of 12 volts at 1000 amps. Although the average overall efficiency of such a unit is approximately 72.5% from one-fifth to full load, the losses to dissipate, necessitate a tank of fairly large surface area, so that it is generally more economical to standardise on 1000 amp. units and parallel for larger output currents.

A typical Selenium rectifier is the standard 65-volt 30-ampere battery charger designed to provide a noiseless D.C. output for the purpose of float and boost charging the 48-volt battery as used in telephone exchanges.

The rectifier is designed for operation from a 50-cycle, 3-phase mains' supply of 350 to 450 volts. The filtered output is capable of charging a battery of 24 lead acid cells between the limits of 2.0 and 2.65 volts per cell at a maximum charge rate of 30 amperes, in addition to a trickle charge of approximately 1 ampere at 48 volts.

The transformer is a 3-phase, core type and double wound with the primary connected in star and the secondary in delta. The primary is overwound and by altering the star point, by means of an "on load" 3-phase tap changer of the bye-pass resistor type, the voltage turns ratio is altered so that variations in the secondary voltage can be obtained.

The rectifier is of the Selenium dry metal type and is connected as a 3-phase, full-wave bridge. The coding is as follows: PB112-5-3C. The rectifier is capable of a continuous output of 65 volts at 30 amperes in ambient temperatures not exceeding 110° Fah.

A feature of the 3-phase bridge rectifier is the low ripple percentage in the D.C. output voltage. With the introduction of a smoothing choke the actual ripple component in the filtered output is less than the equivalent of 2 millivolts of psophometric voltage measured across 0.1 ohm non-inductive resistance connected in series in the load circuit.

The overall efficiency of the rectifier unit at the maximum rated output is approximately 72%. The power factor is approximately .95.

The cubicle to house the components is of welded angle iron and sheet steel construction and is designed on the chimney draught system to give adequate natural convection cooling to the rectifying elements. The heavy components, that is, the transformer and choke, are located at the bottom of the cubicle. The rectifier is made up of six stacks, arranged in half wave and constituting each, one arm of the 3-phase bridge. The six stacks are arranged in the cubicle in two tiers, with four stacks arranged on the one horizontal plane and two stacks mounted underneath. This arrangement prevents any undue temperature unbalance in the rectifier discs by reducing the effect of preheated air to a minimum.

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2. "Metal Rectifiers," by A. L. Williams and L. E. Thompson, Journal I.E.E., Vol. 88, Part I., No. 10, October, 1941.

THE POSTAL ELECTRICAL SOCIETY OF VICTORIA

MEETINGS HELD DURING 1943

Owing to the war situation the usual lecture programme of the Society was suspended for the year. However, in addition to the Annual Meeting held on 14th December, 1942, when Mr. S. H. Witt gave a lecture on "Some Developments in Materials Used in Telecommunication Equipment," which was later published in Vol. 4, No. 4, of the Journal, two other special meetings were arranged.

At the special meeting held on 5th May, Mr. C. J. Prosser gave a lecture on "Aircraft Recognition," which was illustrated by slides and films. At the second special meeting held on 8th September, Mr. C. L. Hosking gave a lecture on "The Melbourne Trunk Switchboard," which included demonstrations with some items of equipment.

All these meetings were well attended and created considerable interest.

AUTOMATIC ROUTINERS IN TYPE 2000 EXCHANGES

T. T. Lowe

Résumé of Earlier Sections: In previous issues of the Journal (Volume 4, Nos. 2, 3 and 4) earlier sections of this article which describes Automatic Routiners in Type 2000 Exchanges have appeared. In these issues routine testing and manual routine test sets were first briefly referred to. The considerations which justify the provision of automatic routiners were then discussed, followed by notes on the design and development of routiners. The automatic routine testing equipment which is installed at Rockdale Exchange, Sydney, was then described briefly followed by a detailed description of the operation of the Final Selector Routiner when testing P.B.X. Final Selectors.

In Figs. 1-29 the operation of the Access Control Equipment and Associated Alarms was described. In Figs. 30-75 the operation of the routiner when testing 200 outlet, 2-10 line P.B.X., final selectors is described. A complete list of Tests performed by the Routiner on Final Selectors was included on pages 226 and 227 of Volume 4, No. 4, tests 1-10, Figs. 30-45 being included in that issue. Tests 11-26, Figs. 46-61 are included in this issue. The article will conclude in the next issue with Tests 27-40, Figs. 62-75.

Test Switch Position 9—Private Guard Fail—Test Switch Steps to Position 10 (Fig. 46).—If ground is disconnected from the private during impulsing, relay PE will release (see Fig. 44) and the "Private Guard Fail" lamp will light from ground via TX 8-9 operated, AT8 wiper and bank, PD 21-22 normal, PE 27-28 normal, Lamp LPA1, Relay GF1000 to battery. GF 21-22 operates and closes a locking circuit for relay GF. If Relay PE releases, the test switch drive magnet stepping circuit is opened at PE 21-22.

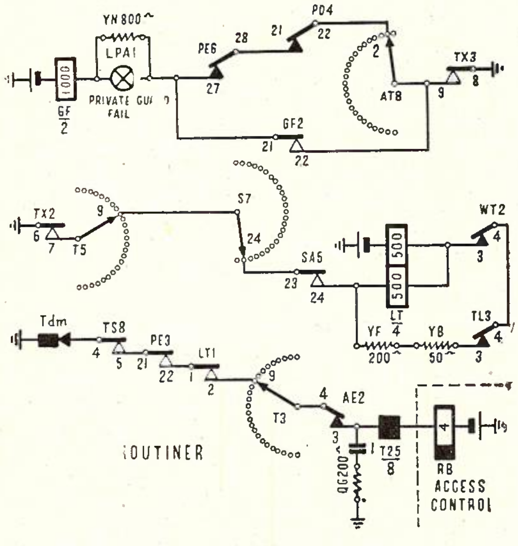

Fig. 46.

When the sending switch reaches position 24, LT operates from ground via TX 6-7 operated, T5 wiper and bank, S7 wiper and bank, SA 23-24 operated, YF 200, YB 50, TL 3-4 normal, WT 3-4 normal, relay LT 500 to battery. If relay PE does not release the test switch drive magnet operates from ground via Tdm, TS 4-5 operated, PE 21-22 operated, LT 1-2 operated, T3 bank and wiper, AE 3-4 normal, test switch drive magnet to battery. In operating, the test switch drive magnet opens its own circuit at Tdm and in releasing steps test switch to position 10.

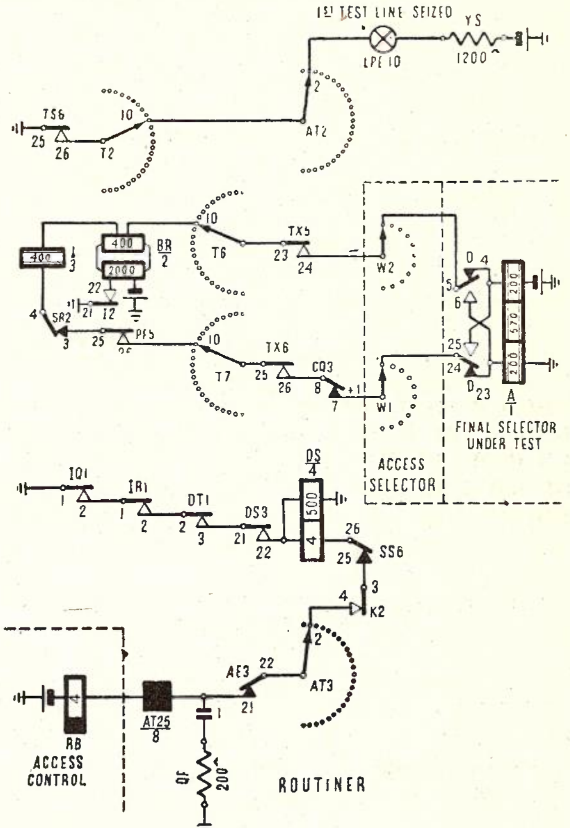

Fig. 47.

Test Switch Position 10—Auxiliary Test Switch Position 2—First Test Line Seized (Fig. 47).—When the test switch steps to position 10, the "Impulsing Short Line" lamp LPE9 goes out and the "First Test Line Seized" lamp, LPE10 lights from ground via TS25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPE10, YS 1200 to battery. Relay I is operated in series with the final selector relay "A," from battery via relay "A" 200, D 4-5 normal, access switch W2 bank and wiper, negative lead, TX 23-24 operated, T6 bank and wiper, relay BR 400, relay I 400, SR 4-3 normal, PE 25-26 operated, T7 bank and wiper, TX 25-26 operated, CQ 7-8 normal, positive 1 lead, access switch wiper and bank W1, D 23-24 normal, final selector relay A200 to ground. I 21-22 operated closes circuit for relay BR 2000 but being a shunt field relay, BR will not operate at this stage. Relays LT, SA, SS, PH and RG release (see Figs. 43, 44 and 46) and the sending switch rotates home. When relay SS releases relay DS operates and the AT switch steps to position 3 after a delayed step as described previously, from ground via IQ 1-2 operated.

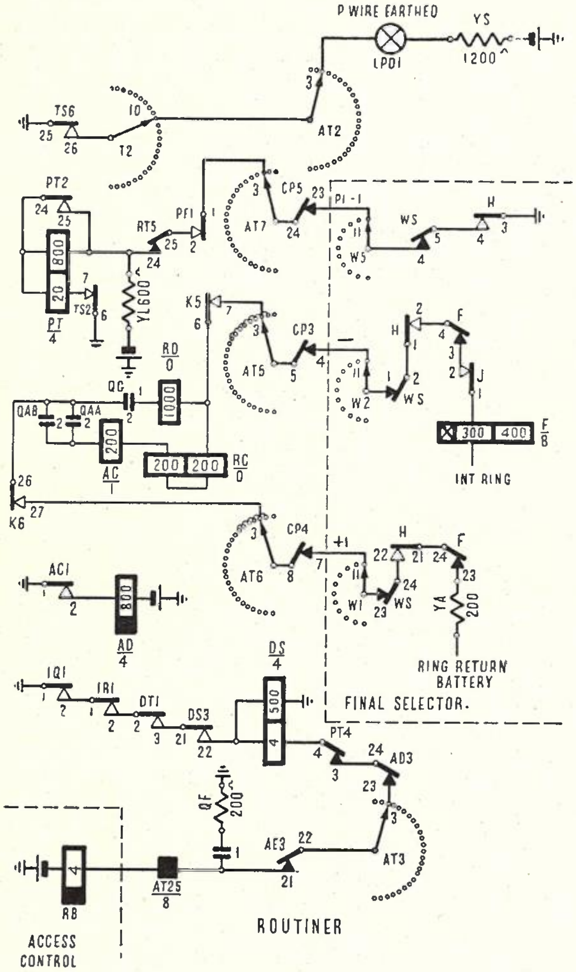

Fig. 48.

Test Switch Position 10—Auxiliary Test Switch Position 3—P1-1 Wire Earthed (Fig. 48).—With the test switch on position 10, when the auxiliary test switch steps to position 3 the "1st Test Line Seized" lamp LPE 10 goes out, and the "P Wire Earthed" lamp LPD1 lights from ground via TS 25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD1, YS 1200 to battery. Relay PT, operated, is connected to the 1st test line P1-1 lead, from ground via TS 6-7 operated, relay PT20, PT 24-25 operated, RT 24-25 normal, PF 1-2 operated, AT7 bank and wiper, CP 23-24 normal, P1-1 lead, selector P1-1 bank W5, WS 4-5 normal H 3-4 operated, to ground. The full earth potential on P1-1 lead shunts relay PT which releases and the AT magnet is energised from ground via IQ 1-2 operated, IR 1-2 operated, DT 2-3 operated, DS 21-22 operated, relay DS4, PT 3-4 normal AD 23-24 normal, AT 3 bank and wiper, AE 21-22 normal, AT magnet to battery. After a delayed step when its circuit is broken at IQ 1-2, AT magnet releases and in doing so steps AT switch to position 4. During this test ringing current has been sent from the final selector from interrupted ring, relay F300, J 1-2 operated, F 3-4 normal, H1-2 operated, WS 1-2 normal, final selector bank W2, CP4-5 normal AT5 wiper and bank K 6-7 operated, RC 200 + 200, relay AC 200, QAA QAB in parallel with RD 1000 and QC, via K26-27 operated, AT6 bank and wiper, CP 7-8 normal, selector bank W1, WS 23-24 normal, H 21-22 operated, F 23-24 normal, YA200 to ring return battery. Relay AC operates with each ringing pulse and AC1-2 operated, closes circuit for relay AD which operates, but releases again during the long silent period of the ring when its circuit is broken by the release of relay A.C.

Test Switch, Position 10 — Auxiliary Test Switch, Positions 4, 5 and 6—Ring (Fig. 49).—With the test switch on position 10, when the auxiliary test switch steps to position 4 the "P Wire Earthed" lamp LPD 1 goes out and the "Ring" lamp, LPD2 lights from ground via TS 25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD2, YS 1200 to battery. The operation and release of relay AD due to ringing (see Fig. 48) causes AD 1-2 to close and then open the circuit for the auxiliary test switch drive magnet from ground via key KRT1-2 normal, AD1-2 operated, AT3 bank and wiper, AE21-22 normal, AT drive magnet to battery. As AT magnet releases it steps AT switch from position 4 to positions 5, 6 and 7. If it is desired to check the receipt of ringing tone from the final selector, the "Ring Tone" Key, KRT, is thrown disconnecting the AT switch stepping circuit. If a buttinski is plugged in the routiner test jack the ringing tone can now be observed.

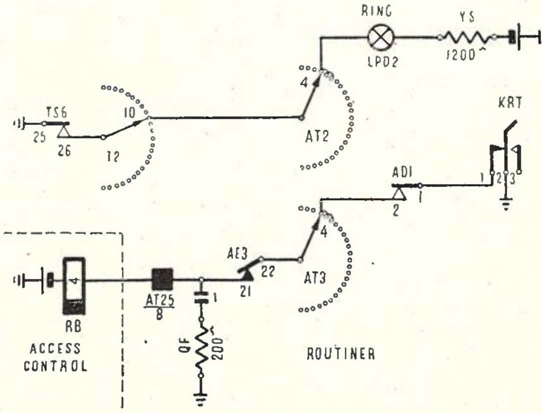

Fig. 49.

Test Switch, Position 10 — Auxiliary Test Switch, Position 7—Ring Trip (Fig. 50).—With the test switch on position 10 and the auxiliary test switch on position 7 the "Ring" lamp, LPD2 goes out and the "Ring Trip" lamp LPD3 lights from ground via TS 25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD3, YS1200 to battery. A loop is placed across the test line from int. ring via relay F 300, J 1-2 operated, F3-4 normal, H1-2 operated, WS 1-2 normal, wiper and bank WT, — 1 lead, CP4-5 normal, AT5 wiper and bank, K6-7 operated, RC 200 + 200, YQ800, AT 6 bank and wiper, CP 7-8 normal, + 1 lead, W1 bank and wiper, WS 23-24 normal, H21-22 operated, F23-24 normal, YA200 to ring return battery. Relay F in the selector operates, tripping the ring and closing the circuit for relay D to operate via F 1-2 operated, F4-5 operated, F26-27 operated, F24-25 operated. D 5-6 operated and D24-25 operated reverse the lines and relay BR operates from ground via relay A 200, D 5-6 operated, TX 23-24 operated, T6 wiper and bank, relay BR400, relay I400, SR 3-4 normal, D 24-25 operated, relay A200 to battery. This should take place during the release time of relay BS which was operated from the ringing pulse by AD21-22 operated. The auxiliary test switch drive magnet is energised from ground via ATdm, TX 4-5 operated, BS 21-22 operated, BR 1-2 operated, AT3 bank and wiper, AE 21-22 normal, AT drive magnet to battery. AT drive magnet in operating opens its own circuit at ATdm and in releasing steps AT switch to position 8.

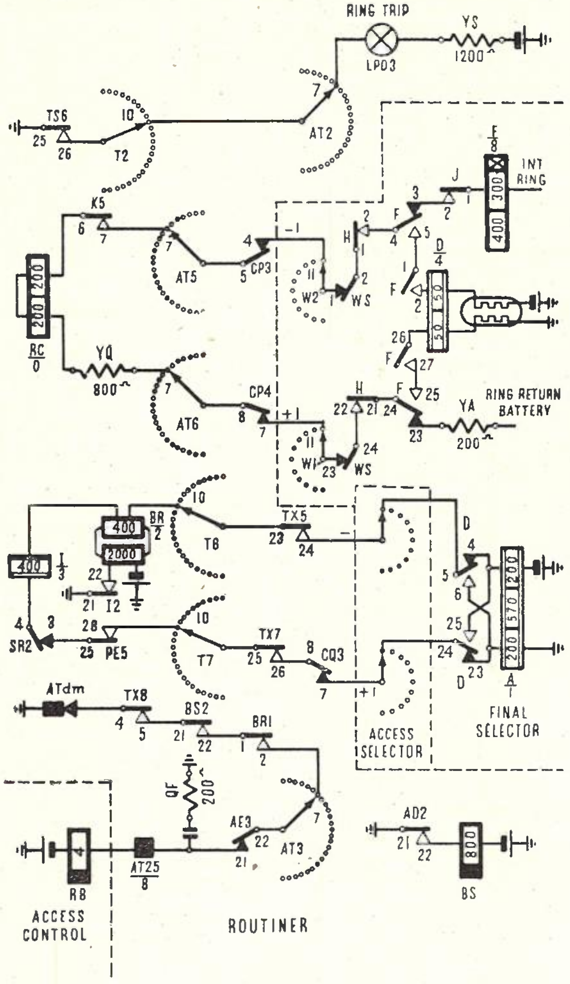

Fig. 50.

Test Switch, Position 10 — Auxiliary Test Switch, Position 8—Metering (Fig. 51).—With the test switch on position 10, when the auxiliary test switch steps to position 8, the "Ring Trip" lamp LPD3 goes out and the "Metering" lamp LPD4 lights from ground via TS25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD4, relay PP 1200 to battery. Relay PP operates. PP1-2 operated disconnects the "Incorrect Metering" lamp circuit. Positive battery is applied to the final selector "P" lead via E 21-22 operated, J 4-5 operated, B 3-4 operated, "P" lead, key KBF 1-2 normal, TX 27-28 operated, MRA, relay PM 2000 to ground and relay PM operates during the metering pulse. PM 1-2 operates relay PN 800. When the meter pulse is disconnected, relay PM releases and breaks the circuit to relay PN which releases slowly. The AT drive magnet is energised during the slow release of relay PN from ground via PM 3-4 normal, PN 1-2 operated, AT3 bank and wiper, AE 21-22 normal, auxiliary test drive magnet to battery. When its circuit is broken at PN 1-2 normal, the AT drive magnet releases and in doing so steps AT switch to position 9.

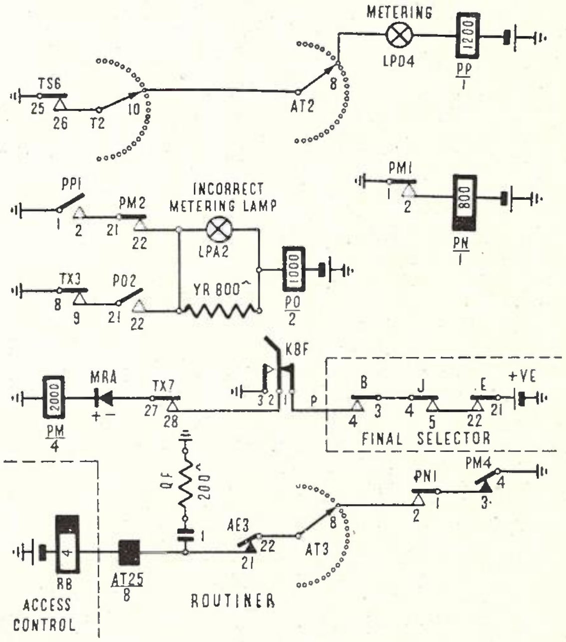

Fig. 51.

Test Switch, Position 10 — Auxiliary Test Switch, Position 9—Outgoing Negative Line. 1st Choice (Fig. 52).—With the test switch on position 10, when the auxiliary test switch steps to position 9 the "Metering" lamp LPD4 goes out and the "Outgoing Negative Line (1st Choice)" lamp LPD5 lights from ground via TS 25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD5, YS1200 to battery. Ground via TX 6-7 operated, AT 4 wiper and bank is connected through relay LT 500/500 to battery. The —1 test line is connected across one 500 ohm winding of relay LT from battery via barretter lamp, relay D 50, F1-2 operated, F4-5 operated, H 1-2 operated, WS 1-2 normal, W2 wiper and bank, —1 lead, C.P. 4-5 normal and AT5 wiper and bank. Across the other 500 ohm winding of relay LT YB50 and YF200 are connected through WT 3-4 and TL 3-4. If the potential tested on the negative lead is correct, relay LT being differentially wound, will not operate. The AT drive magnet will be energised from ground via IQ 1-2 operated, IR1-2 operated, DT 2-3 operated, DS21-22 operated, relay DS4, LT 23-24 normal, BR 21-22 operated, AT3 bank and wiper, AE 21-22 normal, AT drive magnet to battery and after a delayed step when its circuit is broken at IQ1-2 the AT drive magnet releases and steps the AT switch to position 10.

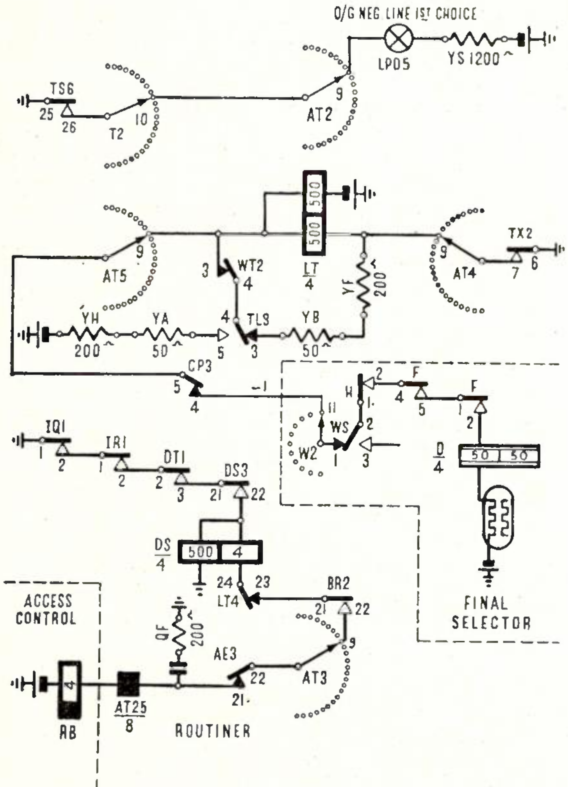

Fig. 52.

Test Switch, Position 10 — Auxiliary Test Switch, Position 10—Outgoing Positive Line (1st Choice) (Fig. 53).—With the test switch on position 10, when the auxiliary test switch steps to position 10 the "Outgoing Negative Line (1st Choice)" lamp goes out and the "Outgoing Positive Line (1st Choice)" lamp lights from ground via TS25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD6, YS 1200 to battery. Contacts TL 4-5 change the potential across one 500 ohm winding of relay LT from ground as in Fig. 52 to battery, via relay YH 200, relay YA 50, TL 4-5 operated, WT 3-4 normal to relay LT. The positive test line is connected also to relay LT from ground via barretter, relay D50, F26-27 operated, F24-25 operated, H21-22 operated, WS 23-24 normal, final selector wiper and bank W1, +1 lead, CP7-8 normal, AT6 wiper and bank, TL 1-2 operated to relay LT. If the potential tested on the + lead is correct, relay LT will not operate and after a delayed step the AT switch will step to position 11 in the same manner as described in Fig. 52.

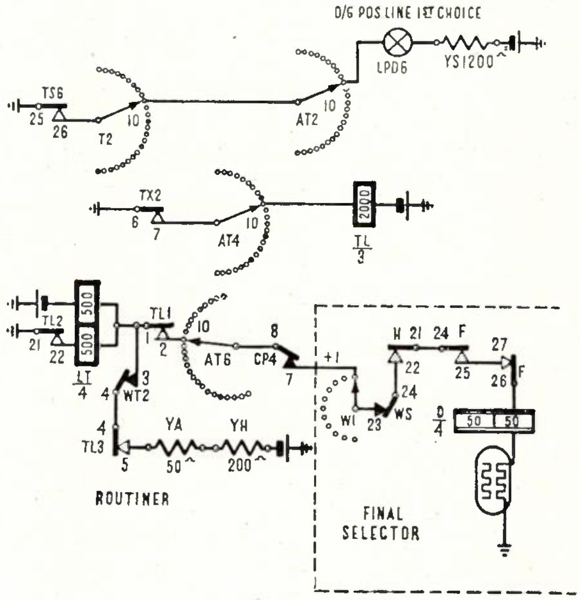

Fig. 53.

Test Switch, Position 10 — Auxiliary Test Switch, Position 11—P2-1 Wiper (Fig. 54).—With the test switch on position 10, when the auxiliary test switch steps to position 11 the "Outgoing Positive Line (1st Choice)" lamp goes out and the "P2 Wiper" lamp LPD7 lights in series with relay WT from ground via TS 25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD7, relay WT 1200 to battery. Relay WT operates. WT 1-2 connects ground to relay LT 500 + 500. WT 3-4 disconnects the short circuit potential from relay LT (Figs. 52 and 53). The "P2-1" lead is connected to relay LT from WS 7-8, final selector bank and wiper W7, "P2-1" lead, CP 26-27 normal, TT 4-5 operated, WT 22-23 operated to relay LT. The "P2-1" lead should be free of earth or battery and relay LT being differentially connected should not operate. After a delayed step AT switch should step to position 12 in the same manner as described in Fig. 52.

Test Switch, Position 10 — Auxiliary Test Switch, Position 12—Last Party Hold—Loop Removed from Final Selector "A" Relay (Fig. 55).

—With the test switch on position 10 and the auxiliary test switch on position 12, the "P2 Wiper" lamp LPD7 goes out, relay WT releases and the "Last Party Hold" lamp LPD8 lights from ground via TS 25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD8, YS 1200 to battery. Relay SR operates from ground via TX 6-7 operated, AT4 wiper and bank, PE 23-24 operated, relay SR 800 to battery. SR 3-4 operated, breaks the loop circuit to the final selector which is from battery via relay A 200, D 24-25 operated, access selector wiper and bank W1, CQ 7-8 normal, TX 25-26 operated, T7 wiper and bank, PE 25-26 operated, SR 3-4 normal, I 400, BR 500, T6 bank and wiper, TX 23-24 operated, access selector wiper and bank W2, D 5-6 operated, A 200 to ground. When the loop circuit is broken, relays BR and I release. Ground via SR1-2 operated maintains relay PF operated.

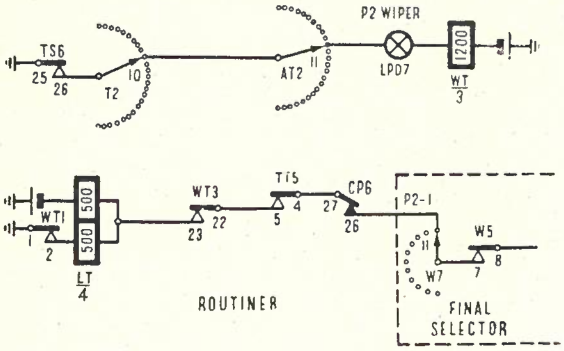

Fig. 54.

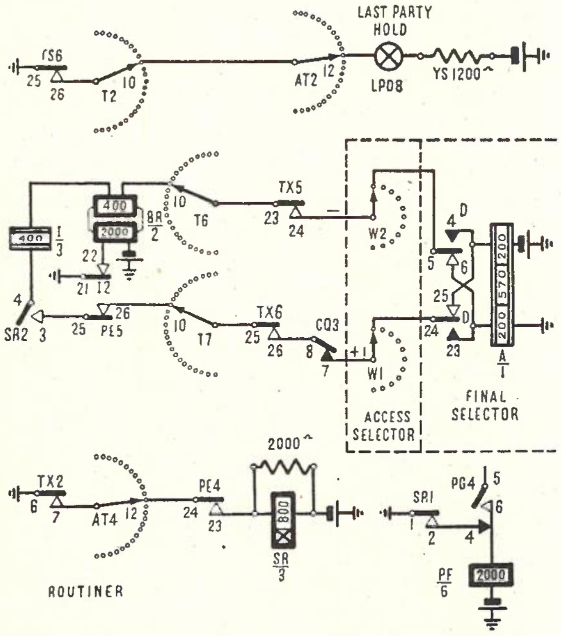

Fig. 55.

Test Switch, Position 10 — Auxiliary Test Switch, Position 12—Last Party Hold (Fig. 56).—Relay PE is held operated to ground on the "P" lead from J 3-4 normal, B3-4 operated, "P" lead, key KBF 1-2 normal, TX27-28 operated, PE 6-7 operated, relay PE 2000 to battery. When the calling loop to the final selector is broken (Fig. 55) the final selector "A" relay releases followed by relay "B." B3-4 normal disconnects ground from the "P" lead and relay PE releases. Final selector relay "C" releases and C6-7 normal, reconnects ground via N7-8 operated to the "P" lead after the private unguard period. Relay PE releasing disconnects the circuit to relay SR (Fig. 55). When relay SR releases, relays PG and PF release and if the private is still earthed, relay PT is shunted from ground via C6-7 normal, N7-8 operated, "P" lead, key KBF 1-2 normal, TX27-28 operated, PE 5-6 normal, PM3-4 normal, PF5-6 normal RT24-25 normal, PT24-25 operated, relay PT20, TS 6-7 operated to ground. Relay PT releases. A loop is maintained on the test line from battery via barretter, relay D50, F1-2 operated, F4-5 operated, H1-2 operated, WS1-2 normal, selector wiper and bank W2, negative lead, CP4-5 normal, AT5 wiper and bank, K6-7 operated, RC 200/200, YG800, AT6 bank and wiper, CP7-8 normal positive 1 lead, final selector bank and wiper W1, WS 23-24 normal, H21-22 operated, F24-25 operated, F26-27 operated, relay D50 via barretter to ground. This is to prevent the release of the final selector and

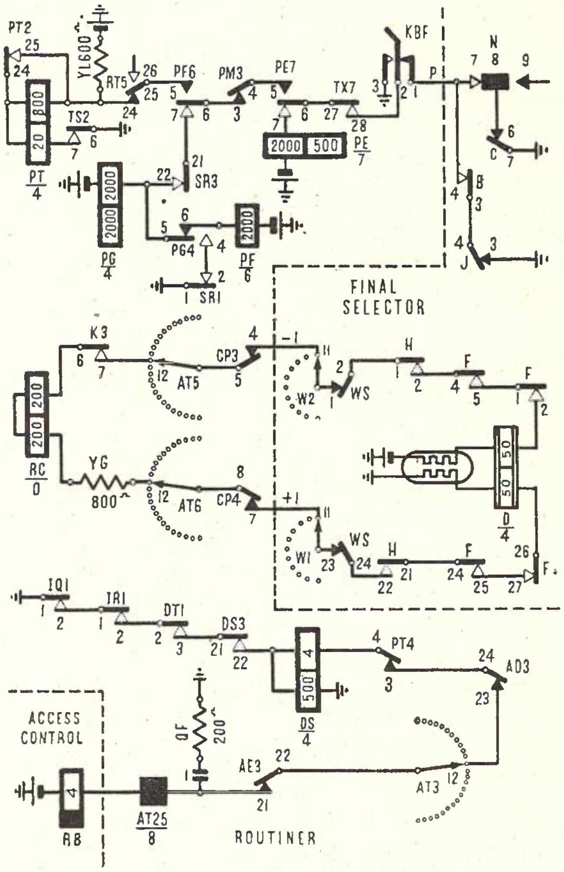

Fig. 56.

maintain the ground on the "P" lead after the unguarded interval. The auxiliary test switch drive magnet is energised from ground via IQ1-2 operated, IR1-2 operated, DT 2-3 operated, DS21-22 operated, relay DS4, PT 3-4 normal, AD 23-24 normal, AT3 bank and wiper, AE 21-22 normal, AT drive magnet to battery and after a delayed step when its circuit is broken at IQ 1-2 the AT drive magnet releases and steps the AT switch to position 13.

Test Switch, Position 10 — Auxiliary Test Switch Position 13—Release (Fig. 57).—With the test switch on position 10 and auxiliary test switch on position 13, the release lamp LPD9 lights from ground via T25-26 operated, T2 wiper and bank, AT2 wiper and bank, lamp LPD9, YS1200 to battery. Relay AD operates from ground via TX8-9 operated, AT8 wiper and bank, relay AD800 to battery. AT wipers 5 and 6 disconnect the test line loop (Fig. 56) and the final selector releases. Ground is removed from "P" lead when the final selector releases and relay PT operates from ground via TS 6-7 operated, relay PT 20/800, YL600 to battery. PT 4-5 operated closes circuit for auxiliary test drive magnet from ground via IQ1-2 operated, IR1-2 operated, DT2-3 operated, DS21-22 operated, relay DS4, PT4-5 operated, AT3 bank and wiper, AE21-22 normal, AT magnet to battery. AT drive magnet operates and when its circuit is broken at IQ1-2 normal, AT drive magnet releases and steps AT switch to position 14. The circuit to relay AD is broken at AT8 bank and AD releases. AD3-4 closes circuit for test switch drive magnet from ground via TX6-7 operated, AT4 wiper and bank, AD3-4 operated, T3 bank and wiper, AE3-4 normal, T magnet to battery. AD relay is slow to release and remains operated long enough to operate the drive magnet and step the test switch to position 11.

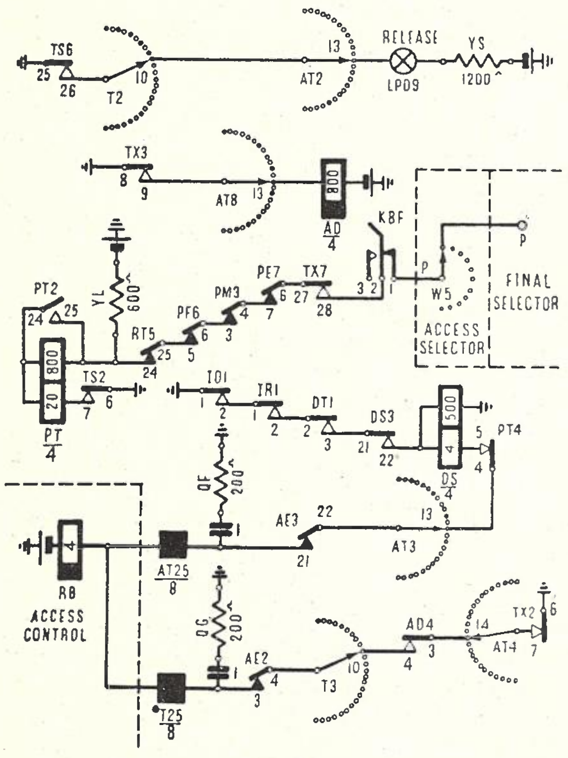

Fig. 57.

Test Switch, Position 11 — Auxiliary Test Switch, Position 14—Test Line Private Earthed. Impulsing Short Line (Fig. 58).—When the test switch steps to position 11 the "Impulsing Short Line" lamp, LPD10 lights from ground via TS25-26 operated, T2 wiper and bank, lamp LPD10, YT1200 to battery. Relay SS operates from ground via TX6-7 operated, T5 wiper and bank, S7 wiper and bank, relay SS2000 to battery. SS relay locks via SS21-22 operated. The selector is impulsed under short line conditions as described in Figs. 43 to 45. With the auxiliary test switch on position 14, relay K is disconnected from the test line private, P1-1 lead, and ground from contacts TS6-7 is extended through relay PT 20 via PT24-25 operated, RT24-25 normal, PF1-2 operated, AT7 bank and wiper, CP23-24 normal, to P1-1 lead. At the completion of impulsing, relay LT operates (Fig. 46) and test switch drive magnet operates from ground via TDM, TS4-5 operated, PE21-22 operated, LT1-2 operated, T3 wiper and bank, AE3-4 normal, test switch drive magnet to battery. T magnet operating breaks its own circuit at Tdm and in releasing steps test switch to position 12.

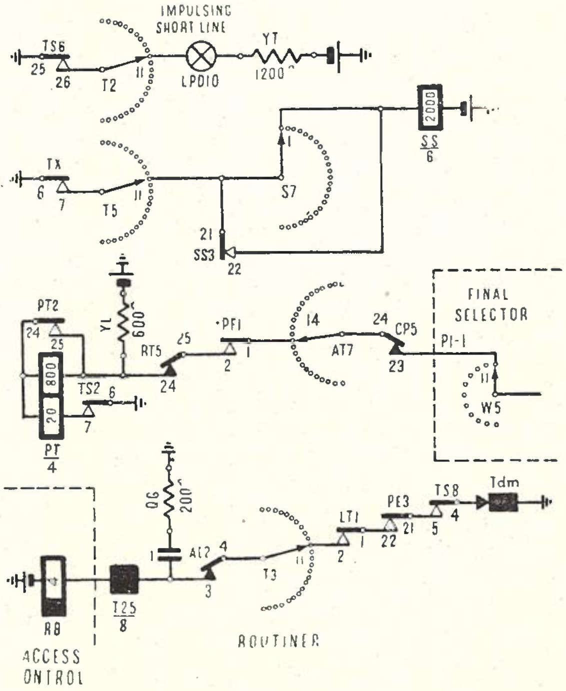

Fig. 58.

Test Switch, Positions 12-13-14—Auxiliary Test Switch, Position 14. Busy and Private Guard Fail (Fig. 59).—When the test switch steps to position 12 the "Busy" lamp LPC1 lights from ground via TS25-26 operated, T2 wiper and bank, lamp LPC1, YT 1200 to battery. Ground on the P1-1 test lead prevents H relay in the final selector from operating and allows final selector G relay to operate. When G relay in final selector operates, busy tone is fed via — lead, TX 23-24 operated, T6 wiper and bank, transformer TRA, T7 wiper and bank, TX25-26 operated, CQ 7-8 normal to +1 lead. On receipt of busy tone, relay AR operates and AR 1-2 short circuits relay TU which is normally held operated from ground on the S.R. lead. During the silent period of the busy tone, relay AR releases and allows relay TU to operate. When AR1-2 shunts relay TU relay TU releases. BS relay operates from ground via TS8-9 operated, T8 wiper and bank, TU1-2 normal, relay BS800 to battery. BS1-2 operated prepares a circuit for test switch drive magnet. During the silent period of the busy tone relay AR releases and removes the shunt from TU which re-operates. TU21-22 closes a circuit for T magnet from ground via KBT1-2 normal, TU21-22 operated, BS1-2 operated, T3 bank and wiper, AE3-4 normal, T magnet to battery. T magnet operates. When relay TU operates it breaks the circuit to BS which releases slowly and breaks T magnet circuit at BS1-2. T releases and steps T switch to position 13. This sequence of operations continues until test switch steps to position 15. When test switch steps to position 13 a private guard fail test is applied and if the private is unguarded relay PE will release (Fig. 44) and close a circuit to GF relay from ground via TX 6-7 operated, T5 wiper and bank, PE27-28 normal, "Private Guard Fail" lamp relay GF1000 to battery. Relay GF will lock from ground via TX8-9 operated, GF21-22 operated, "Private Guard Fail" lamp, relay GF1000 to battery. By operating the Busy tone key, KBT, ground is removed from the T magnet circuit and stepping is prevented. If a buttinski is inserted in the routiner test jack, the busy tone may be observed.

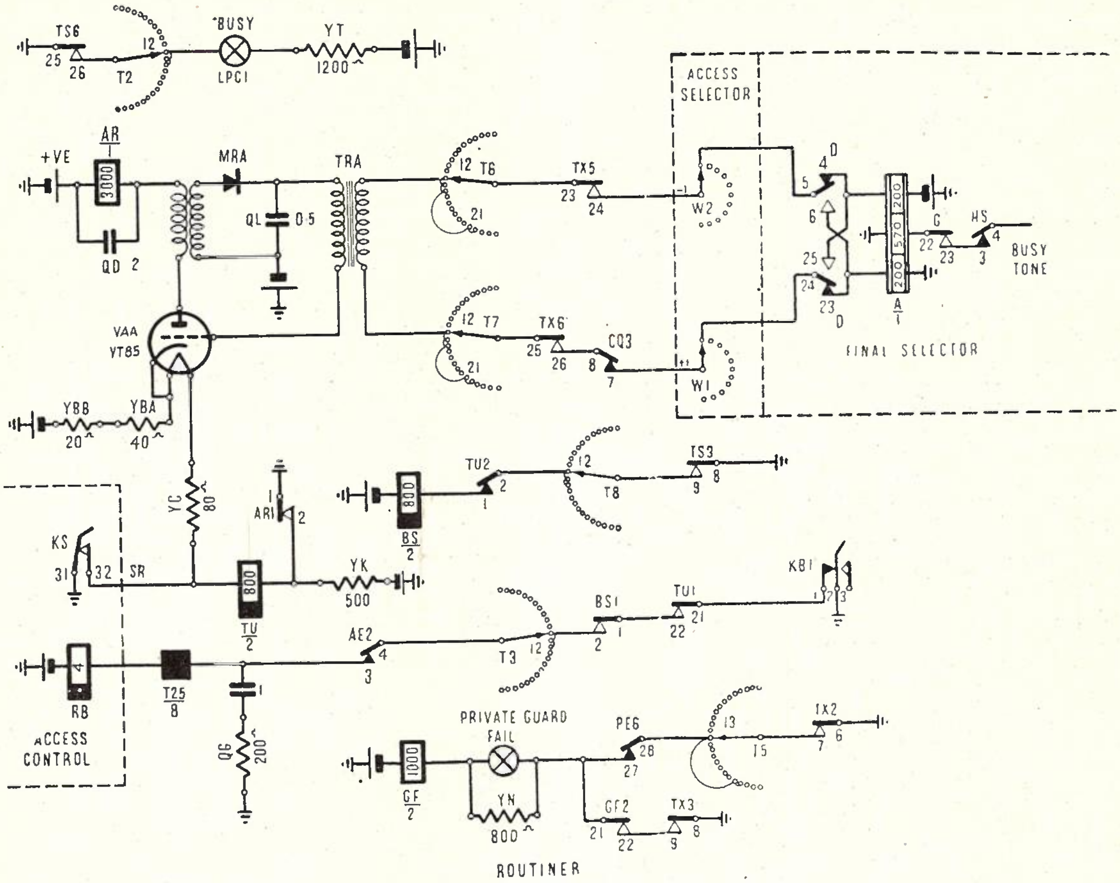

Fig. 59.

Test Switch Position 15 — Auxiliary Test Switch, Position 14—Wipers Disconnected (Fig. 60).—When the test switch steps to position 15 the "Wipers Disc" lamp lights from ground via TS25-26 operated, T2 wiper and bank, lamp LPC2, YT1200 to battery. During the busy test there should be no battery or ground on —1, +1 or P1-1 test leads from the final selector and relay WD should not operate. Relay PT should operate owing to the absence of earth on the P1-1 lead, from battery via YL600 to relay PT800 + 20, TS6-7 operated to ground. This test shows that all wipers are clear during the busy test. PT1-2 operated closes circuit for test switch drive magnet from ground via IQ1-2 operated, IR1-2 operated, DT2-3 operated, DS21-22 operated, relay DS4, PT1-2 operated, WD1-2 normal, T3 bank and wiper, AE3-4 normal, T magnet to battery. T magnet operates and when its circuit is broken at IQ1-2 normal it releases and steps test switch to position 16.

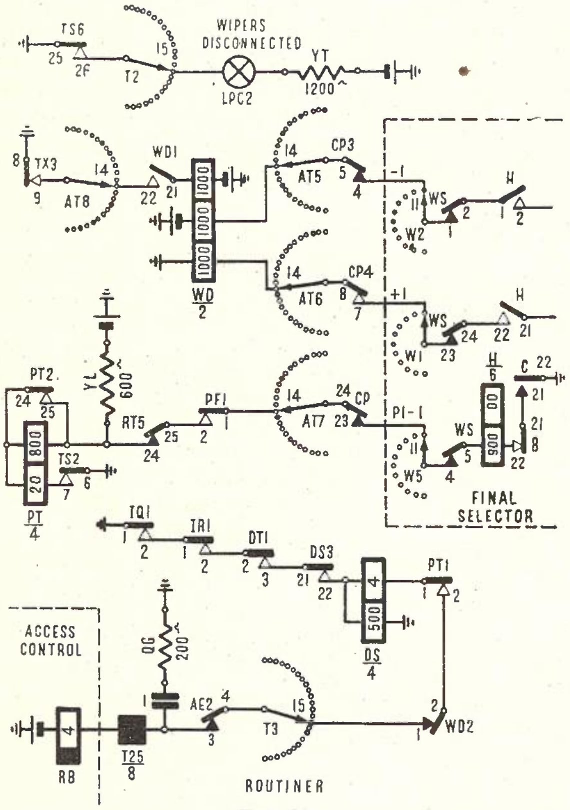

Fig. 60.

Test Switch, Position 16 — Release — (Fig. 61).—When the test switch steps to position 16 the "Release" lamp LPC3 lights from ground via TS25-26 operated, T2 wiper and bank, lamp LPC3, YT1200 to battery. Relay PE is held operated by ground on the "P" lead via KBF1-2 normal TX27-28 operated, PE6-7 operated, relay PE2000 to battery. Relay SR operates from ground via TX 6-7 operated, T5 wiper and bank, PE 23-24 operated, relay SR 800 to battery. SR 3-4 operated breaks calling loop and circuit of relays BR and I which release followed by relay PE which releases when ground is taken off "P" lead during the private unguard period. Final Selector releases. When ground is restored to the "P" lead during the release of the selector, relay PG operates from ground on the "P" lead via KBF 1-2 normal, TX27-28 operated, PE5-6 normal, PM3-4 normal, PF6-7 operated, SR21-22 operated, relay PG200 to battery. Relay PG locks from ground via SR1-2 operated, PG21-22 operated, during the slow release of relay SR. PG5-6 closes circuit for relay PF2000 which operates to ground on the "P" lead. When the selector has restored to normal, ground is removed from the "P" lead and relay PF releases. The test switch drive magnet is energised from ground via TDM, TS4-5 operated, PG 2-3 operated, PF23-24 normal, T3 wiper and bank, AE3-4 normal, "T" magnet to battery. "T" magnet operates and opens its own circuit at TDM and in releasing steps the "T" switch to position 17. If the selector fails to restore to normal before SR has released, relays PF and PG will release and open the driving circuit of the "T" switch.

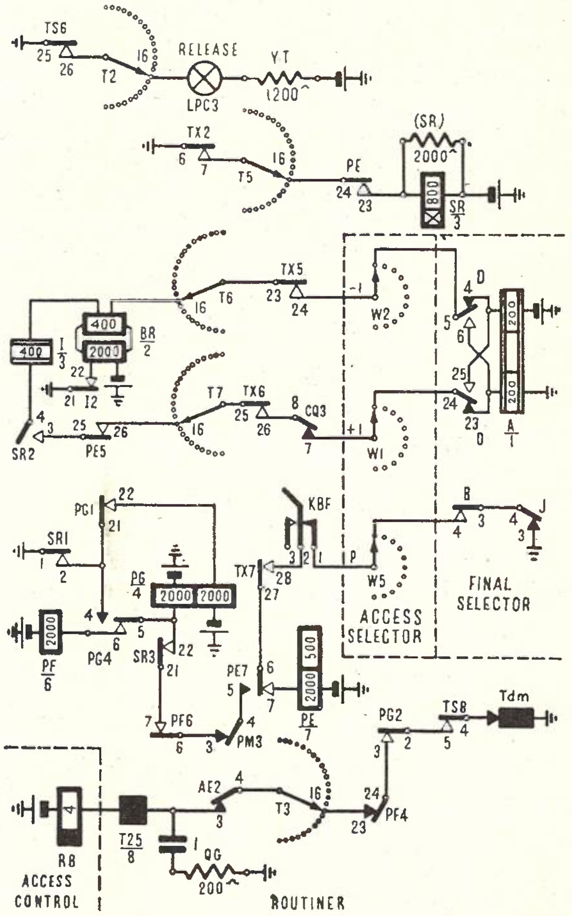

Fig. 61.

NOISE IN AUDIO-FREQUENCY AMPLIFIERS

F. O. Viol

The general improvement of the equipment used in the National Broadcasting Service during the last few years is due to improved components and the use of special circuits, including negative feedback. To ensure the highest practicable grade for the broadcasting system, the electrical standards applied to the equipment used need constant revision to take into account the results of laboratory testing and the experience gained when new equipment is installed.

Electrical standards associated with frequency response and harmonic distortion have remained fairly constant, but the question of noise has not been regarded as satisfactory, and the problems dealing with its elimination have received considerable attention. In this paper it is proposed to deal with some of the aspects of noise in audio frequency amplifiers.

In any audio-frequency system the limit of amplification for a specific power output is not determined by the total gain of the amplifiers in the system but by the lowest signal level in the whole system. When judging the merit of a system to determine its value for broadcasting purposes the margin between the signal and the noise is an important consideration. In the ideal system the noise should not be heard, but this is not always possible in practice. Good design, however, can approach the ideal for low level amplifiers, and give a satisfactory level for high level amplifiers. Level in these cases refers to the input signal and not to the output, for it will be shown later that the ratio of signal to noise is determined by the level of the signal at the input terminals of the amplifier.

Before a system can be designed and the requirements specified it is necessary to determine the points at which the signal is at a low level, and with a knowledge of the cause and level of the noise proceed to calculate the signal to noise ratio. It will be realised that noise is assumed to exist, although in a well-designed system it should not be evident.

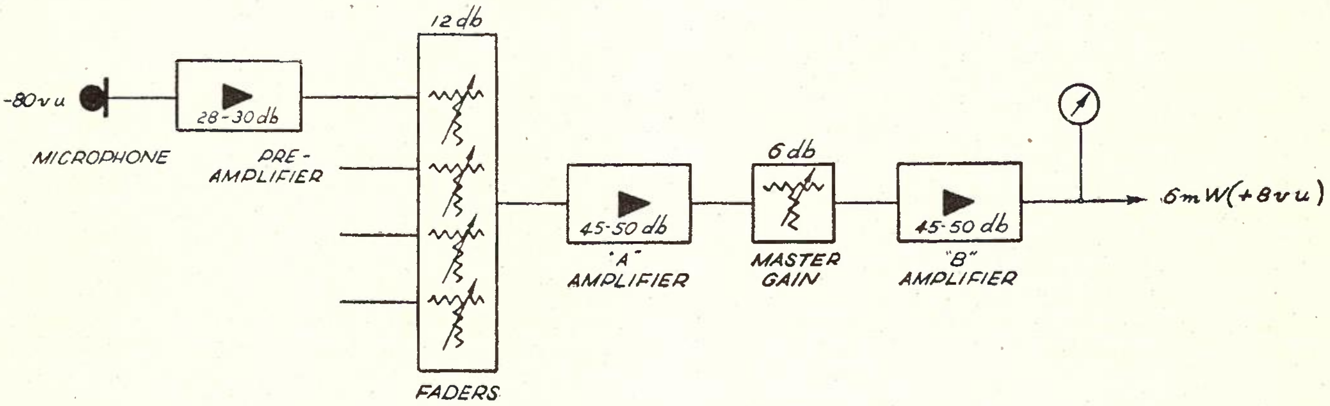

Fig. 1.—High Level Mixing.

Although it is usual to use the volume unit (vu) in relation to programme levels, use is made of it in this paper to differentiate between signal to noise ratio, which must be defined in decibels (db) and noise in relation to a specific level. It can be assumed for purposes of illustration that all noise levels mentioned have been determined by means of a circuit using a vu meter. It is preferable for certain types of noise to use a specific meter and, now that a meter having defined dynamic and electrical characteristics is available, the vu meter is a suitable type for this purpose.

The vu meter is calibrated with 1 milliwatt of sine wave power in 600 ohms, across which the meter is bridged. As will be shown later, the first step in noise measurement is to send a calibrating tone through the amplifier under test, hence this tone will also calibrate the meter in vu. Therefore, the use of this meter for noise measurement is satisfactory, and noise can be defined in terms of the volume unit.

A typical layout of a portion of a system is shown in Fig. 1, and from this the low-level signal points will be determined.

For design purposes the level of a microphone is taken to be —80 vu. This is the lowest level of the originated signal, and is the first point to be considered. The gain of a pre-amplifier is 30 db, and the insertion loss of a four-channel fader circuit is 12 db, so that cases will occur when the signal at the input to the "A" amplifier will fall to an equally low level due to the operation of the faders. The insertion loss of the master gain control at the position of minimum attenuation is 6 db, and it has an overall loss just before cut-off of 45 db; however, this loss will not be used, as a 6 mW (plus 8 vu) output is required from the "B" amplifier. The signal at the input of the "B" amplifier, therefore, will not be less than —42 vu. From this it will be seen that the signal is at a very low level at the inputs of the pre- and "A" amplifiers. The examination need not be carried further, as the system is designed to have a programme level of plus 8vu from there onwards. Losses will occur in the lines to the transmitter and over repeater sections on interstate programme lines, but at no point will it fall to a level as low as —80 vu. This means that the signal to noise ratio of the whole system is determined in the first two amplifiers of the system, and no matter how large the ratio in all other amplifiers, unless a satisfactory ratio is achieved in the pre- and "A" amplifier, the system as a whole will not be satisfactory.

As it is usual to operate broadcasting amplifiers from A.C., the A.C. conditions will be examined. There are three main components in the noise from an amplifier:—

A.—Hum at the A.C. supply frequency.

B.—Hum at twice the A.C. supply frequency due to the action of the rectifier tube in the power converter. Other harmonics are present, but the levels are low compared to the second.

C.—Random noise distributed throughout the audio frequency band.

Of these, only the last should be heard, as it is possible in the design to eliminate A and B. This applies only to an amplifier with a band width of 10 kC/s or greater, but for band widths of less than 10 kC/s, the A.C. on the filament of the tube will be the limiting factor, as will be shown later.

The various types and sources of noise in an amplifier are as follow:—

a. Random noise due to the resistance apparent or otherwise at the grid of the first tube.
b. The effect of external electro-magnetic fields on the audio frequency transformers.
c. Random noise of the internal impedances of the tube.
d. Noise due to the A.C. operation of the filament of the tube.
e. Microphonic noise of the tube.
f. Flicker effect, low insulation and noisy resistors.

Of the above, the last four sources can be avoided by the use of special types of tubes, but mention will be made here of the cause of the noise.

Random Noise in a Resistance. — In a resistance, the heat motion of the electrons produces a random voltage fluctuation at the terminals. The noise is independent of the material of which the resistor is made, and is distributed uniformly over all frequency intervals. It is directly proportional to the absolute temperature. The mean square thermal noise voltage (V^2) at the terminals of a resistor is given by the expression:—

$$V^2 = 4kT \int_0^\infty R \, df,$$

where k is the Boltzmann gas constant and is equal to 1.37×10^{-23} watt-second per degree

T is the absolute temperature, degrees Kelvin.

R is the resistance in ohms at the frequency f.

When a resistor is considered for a definite band-width f and the voltage outside the band is zero and R is constant over the frequency band and is at a normal temperature of 300° Kelvin (27°C.), the mean square voltage at the terminals of the resistor is:

$$1.64 \times 10^{-20} R f.$$

This is the voltage that would be produced by a generator supplying to the resistance R the power $1.64f \times 10^{-20}$ watts. The power W is independent of R and is equal to —128 vu, for $f = 10{,}000$ c/s.

In the case of an audio frequency amplifier for broadcasting purposes the frequency response is 30 to 10,000 c/s, plus or minus 1 db, so that f is not 10,000 c/s, but some figure greater than this. It will be apparent that the amplifier will not cut-off sharply at 10 kC, but will have appreciable gain at higher frequencies. If, for point of demonstration, the response is sensibly flat to 20 kC, the power W will be —125 vu. This is an important point, and the effect has to be kept in mind when dealing with amplifiers. Where an amplifier is designed for a special purpose and a large signal to noise ratio is required, then the band width f should be reduced to a minimum, as each time f is reduced by half the value W is increased by —3 vu.

Therefore the noise due to the resistance at the grid of the first tube of a broadcast amplifier generates a noise of a random nature of a power —128 vu for a 10 kC band width, and in the practical case it is nearer —125 vu.

Electro-magnetic Fields.—A pre-amplifier usually has one tube, a triode, and the "A" amplifier two tubes, a pentode as a voltage amplifier and a triode as the output tube. This means that the signal is low in the input transformer and appreciably higher in the output transformer. The electro-magnetic fields from external sources induce voltages in the windings of the transformers, and these voltages appear at the output terminals of the amplifier as a noise voltage. As stated above, the signal is low in the input transformer, therefore steps have to be taken to minimise the effect of electro-magnetic fields on this unit.

There are two methods used to achieve a satisfactory condition; one is to use a special transformer, while in the second case the equipment creating the field is mounted away from the pre- and "A" amplifiers. In the second case it is usual to mount the power converter at the top of a rack followed by the "C," then the "B," then the "A" amplifier, followed by the jack field, and finally the pre-amplifiers. While this arrangement has advantages it is not always practicable, as cases arise where it is not possible to mount equipment in this manner, and, further, with this arrangement the electro-magnetic fields still produce a large noise voltage in a standard type of transformer.

An input transformer especially developed for use in low level amplifiers has two features. Firstly, the windings are of the astatic type; that is, the windings are so arranged that the lines of force from an external field producing a voltage in one winding balance out the voltage produced in an identical winding on another part of the core. Secondly, the windings have metallic shields of high permeability metal up to four in number. It may be interesting to mention that the improvement in shielding of a multi-shielded transformer astatically wound is at least 35 db when compared with a transformer astatically wound, but with a diecast case.

Random Noise Due to Tubes.—The emission of electrons from the cathode of a tube is subject to random fluctuation known as "shot noise" or "shot effect."

In the case of the A.C. operated amplifier the "shot effect" is not important, as the noise produced is of an extremely low level. For the type 6C6 tube information has been published to show that the noise from this cause for a 10 kC channel is approximately —140 vu. The noise is usually given in terms of the value of a resistance which, if connected to the grid of the tube, would produce the same level of noise at the tube output. The tube for this purpose is considered to be noiseless. For the 6C6 the equivalent grid resistor is 6,200 ohms. It will be seen that "shot noise" in the case of an amplifier for broadcasting purposes can be ignored, since the noise from the normal grid resistor discussed earlier is of a much higher level. This can be considered in another way. Usually the value of the resistance at the grid of the tube in a pre-amplifier or "A" amplifier is from 60,000 to 100,000 ohms, whereas the "shot noise" from the type 6C6 tube is only equivalent to 6.200 ohms.

Noise Due to A.C. Operated Filaments.—For the application of A.C. to the filament of a tube it is usual to use tubes of the cathode type designed for the purpose. Published information shows that the noise due to A.C. operation is in the order of —130 vu. This figure closely approaches the value of —128 vu calculated for a resistor over a band width not greater than 10 kC. Although not directly applicable to broadcasting, the noise due to A.C. operation will limit the signal to noise ratio for a band width of 5 kC or less. In other words, the A.C. filament is the controlling factor for narrow bands, while for bands 10 kC or wider the resistance at the grid of the first tube is the limiting factor.

Microphonic Noise.—Microphonic noise in tubes is due to mechanical vibration of the tube's elements, and for this reason an indirectly heated tube is preferred for low level work. This has been recognised by manufacturers, who have produced special tubes for this reason. The 1603 is the only type made in Australia at present. It is of heavy construction internally, and the elements are more robust than the average tube. The characteristics are the same as for the type 6C6, and it is not difficult to select 6C6 tubes with a low microphonic output as replacements for the type 1603 tubes.

The vibration of the elements of tubes is caused by acoustic noise acting directly on the glass envelope or the mechanical transfer of vibration from the chassis through the pins to the elements. This latter cause has been found to be the most serious, and it is usual to mount the tube socket on rubber. A simple but effective mounting is to use four rubber grommets, two in the chassis and two in the metal flange of the socket, so that the mounting bolts are isolated with rubber, and the socket is then clear of the amplifier chassis. It is usual also to use light flexible wire to make the socket connections.

When type 1603 tubes are mounted in this manner the microphonic noise is at a level below the noise due to the A.C. on the filament or the noise of resistor at the grid of the first tube.

Flicker Effect, Low Insulation, and Noisy Resistors.—The grouping of these effects has been intentional, as the latter two causes are faulty conditions, and the first not usual with tubes designed for low level work.

Flicker effect is due to changes in emission which occur over small areas of the cathode, and should not be confused with "shot effect." The noise is negligible, but is of a higher value than "shot effect." Cases occur where a tube develops a high level flicker due to a faulty condition, and has to be removed from service. Low insulation of the tube elements will also cause an increase in noise, and will require the removal of a tube from service.

Noisy resistors, although relatively uncommon, still appear occasionally. The most critical points are at the grid of the first tube and in the plate circuit.

Summarising the above, for a 10 kC channel the limits of amplification are controlled by the A.C. operation of tubes and the resistance at the grid of the first tube. An improvement of 3 db can be achieved in the signal to noise ratio by dispensing with the resistance terminating the input transformer. Fig. 2 shows the normal arrangement, the special circuit, and the equivalent circuits.

In Fig. 2 (b) R_1 equals R_2 provided the transformer is correctly terminated, while in Fig. 2 (d) R_2 is not used. It can be shown that if R_2 is very large compared with R_1 an improvement of 3 db in the signal to noise ratio is obtained. The operation of an input transformer without a terminating resistance has been general in pre-amplifiers for a number of years. It has the additional advantage that an increase in overall gain of as much as 6 db can be obtained.

This arrangement, however, requires the use of a transformer of special design to ensure a satisfactory frequency response from 30 to 10,000 c/s.

When judging the merits of an amplifier it is usual to consider the noise in relation to the signal output, hence the term "signal to noise ratio." While this is satisfactory for most purposes, it does not give the level of the noise in terms of an absolute value.

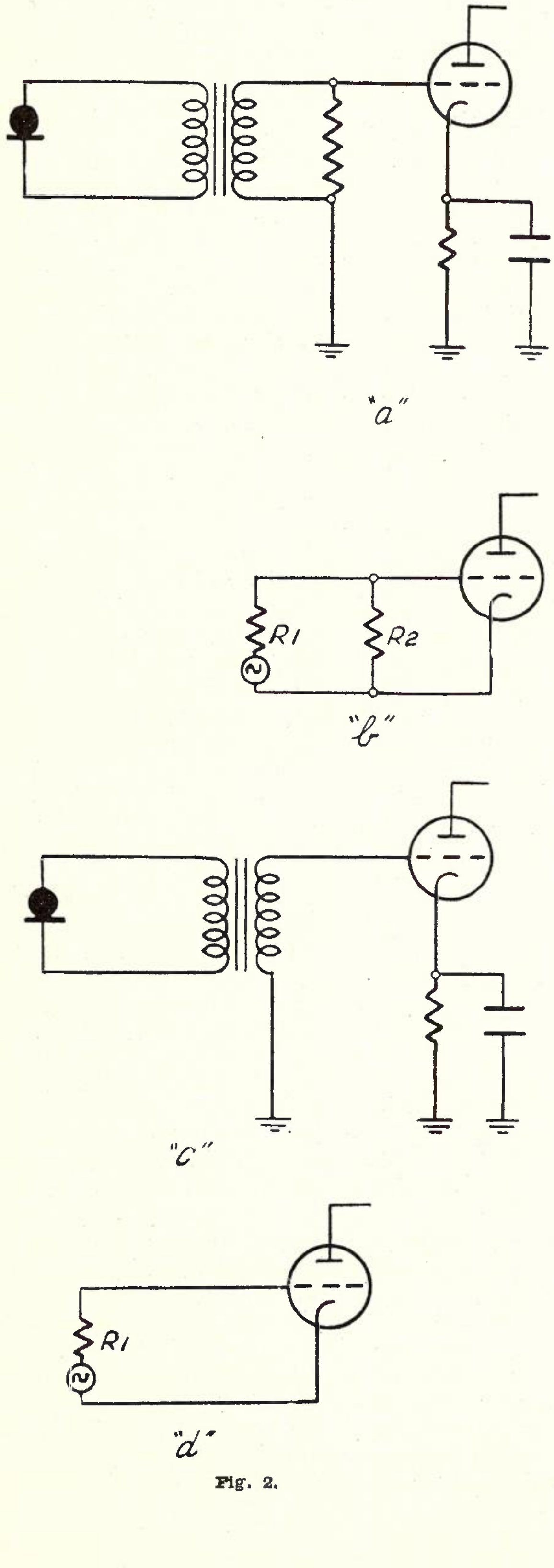

Fig. 2.

If all the noise at the output terminals of an amplifier be considered to be due to a generator at the grid of the first tube, then a satisfactory method of comparing the merit of amplifiers has been obtained. Now as shown earlier, the noise from external fields influencing the output transformer and the noise due to the resistance at the grid of the first tube are the two sources which determine the limits of amplification for an amplifier with a nominal band width of 10 kC. It should be noted that in the case of pre-amplifiers, the resistance at the grid of the first tube is the resistance of the load as seen from the secondary side, and as shown in Fig. 2 (d), the transformer and load can be replaced by an equivalent resistance. Actually, the use of improved multi-shielded transformers has resulted in the resistor being the limiting factor.

Assuming that all noise is generated at the grid of the first tube, and given the gain, the signal level and the signal to noise ratio, the noise can be translated into an "equivalent noise input." Fig. 3 has been drawn to give the case of the pre-amplifier.

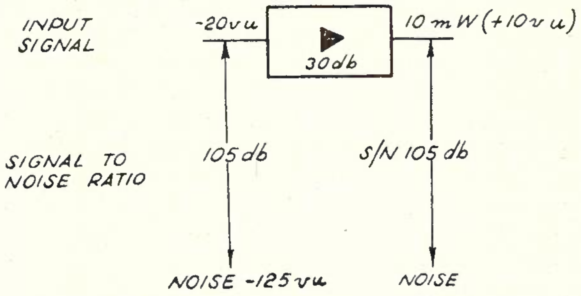

Fig. 3.—Pre-Amplifier Analysis.

In this case a pre-amplifier with a power capability of 10 milliwatts and a gain of 30 db has a signal to noise ratio of 105 db, hence the equivalent noise input is —125 vu. This is near the figure that has been obtained on rack mounted equipment, as tests have given figures varying from —122 to —126 vu. At first sight this signal to noise ratio may appear to contradict an earlier statement that the "noise in the first two amplifiers determines the ratio for the system." It must not be overlooked that, for design purposes, the signal level of a microphone is taken to be —80 vu. Applying this value to Fig. 3 a signal to noise ratio of only 40 db will be obtained. The advantage of this method of noise calculation can be seen immediately as the equivalent noise input was obtained from the signal to noise ratio and the input signal level. Vice versa, given the equivalent noise input and the input signal level the signal to noise ratio can be determined.

This method of calculation is of particular value when the merit of amplifiers with different gains and different power outputs has to be examined. The case of the pre-amplifier above is an excellent example, and to attempt to compare this with, say, an amplifier with an output of 20 watts, at first sight appears to be difficult. However, given the gain, the signal to noise ratio and the output signal level at which the test was made, and transferring the results to the input, enables the equivalent noise input to be determined. The case of a high level amplifier, i.e., high level input, is not quite the same, particularly if the gain is relatively low. A "C" amplifier has a power capability of 3 watts, and a gain of 27 db. It normally works from programme level, plus 8 vu. Using the noise figures of —125 vu, the signal to noise ratio is then 133 db, a figure far above normal requirements. In fact, a figure of 65 db unweighted, is quite satisfactory.

There is an important point often overlooked which will be discussed here. This deals with the use of amplifiers not designed for the work in hand. The case often arises where an amplifier is required as a substitute, and provided the gain is satisfactory and the power capability large enough, then the substitute is used. If, for instance, the "C" amplifier is used in a circuit where an output of 6 mW and not 3 watts, is required, the signal to noise is reduced by 27 db, and going to the extreme, if a 20 watt amplifier is used, the signal to noise ratio is reduced by 35 db. Assuming the ratio is 65 db at maximum output, then at an output of 6 mW, the signal to noise ratio will be only 30 db.

While the method of calculation dealt with so far is satisfactory for most purposes, it will be necessary to consider the case of low level mixing as used in certain types of outside broadcast amplifiers.

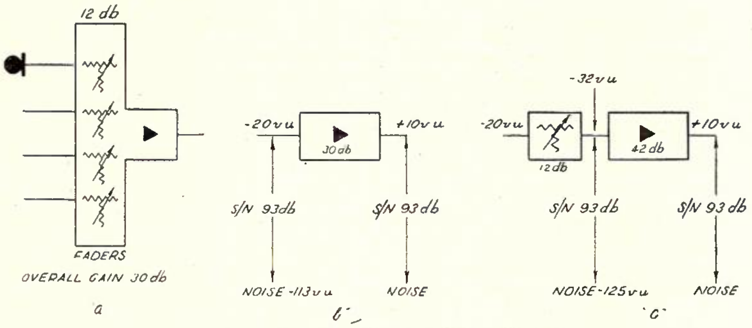

Fig. 4.—Low Level Mixing.

Fig. 4 shows the general arrangement. In this case the faders are before the first tube, and it is usual to measure the gain and signal to noise ratio from the microphone input connections. It follows then, that the signal at the input of the first tube is reduced by insertion loss of a fader system which is 12 db for a normal series parallel connection. The equivalent block circuit is shown, and for purposes of illustration, the pre-amplifier is used. Although the overall gain is still 30 db, the signal to noise ratio is only 93 db and the equivalent noise input appears to be —112 vu. To analyse this condition fully it is necessary to separate the faders from the amplifier, and consider the condition at the grid of the first tube as shown in Fig. 4C. The equivalent noise input is correct and the signal to noise ratio is reduced by the insertion loss of the fader circuit.

Whenever a fader circuit or other signal reducing device is used before the first tube, then the signal to noise ratio is reduced by a value equal to the insertion loss of the device. This is the reason why low level mixing is not as satisfactory as high level mixing, which is the term used when pre-amplifiers are used before faders. Although 12 db has been given as the insertion loss of a four-channel mixer, this figure can be reduced by omitting the terminating resistance of the input transformer.

Noise Measurement.—The noise measurement of audio frequency amplifiers is made to determine the margin by which the noise is below the output signal, hence the term signal to noise ratio. This is the ratio that determines the deterioration of a signal by the noise from all sources in the amplifier. In the method most widely used, and the basis of a number of testing instruments developed for this purpose, an oscillator, the amplifier under test, two variable attenuators, a measuring amplifier, and a suitable meter such as a vu meter are arranged as shown in Fig. 5.

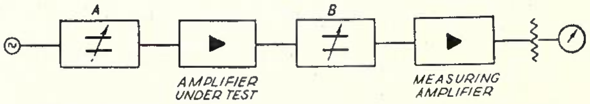

Fig. 5.—Noise Measurement.

A 1000 c/s tone is supplied to the amplifier under test, and the input level adjusted until the amplifier delivers the rated output. Without further adjustment of the input a variable attenuator adjusted to have a loss at least equal to the specified signal to noise ratio is connected to the amplifier output. The measuring amplifier is then adjusted until a suitable meter reading is obtained. The tone is then removed from the input of the amplifier under test, and a terminating resistance is substituted. Then attenuator "B" is adjusted until the meter reads the same as before. The difference between the two settings of attenuator "B" will be the signal to noise ratio in db.

The method described above is the unweighted signal to noise ratio, and does not take into account the fact that the ear does not, except at high levels, hear all frequencies with equal intensity. For a 10kC channel the ear discriminates against low frequencies, and to a lesser degree against the high frequencies.

For broadcasting purposes use is made of a weighting network to determine the level of the noise in so far as the ear would hear it. This network, with a frequency response as shown in Fig. 6, is inserted between attenuator "B" and the measuring amplifier, and the method of measurement is the same as described early. Measurements made by this method are known as weighted measurements.

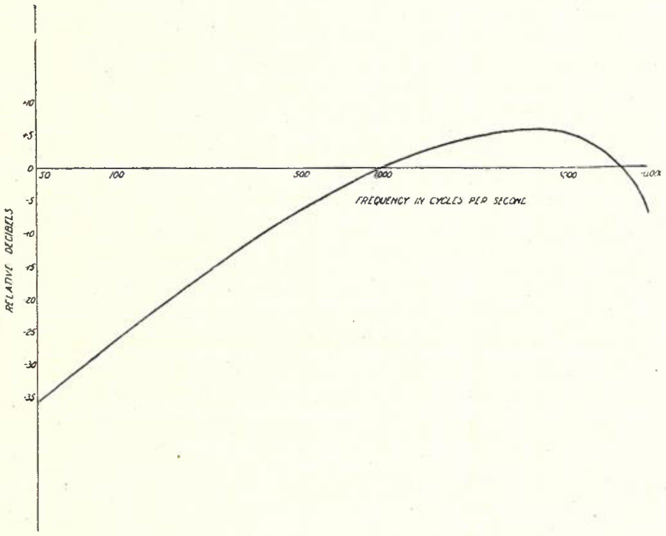

Fig. 6.—Frequency Response of Weighting Network (Broadcast Type).

An examination of Fig. 6 will show that the network discriminates against 50 c/s by 36 db and 100 c/s by 26 db. It follows then that if an amplifier is measured by the weighting method a large component of 50 or 100 c/s can be present in the total noise and ultimately appear at the loud-speaker at the end of the amplifier chain. It has been shown by Beers, Belar and others that these low frequencies can cause cross-modulation and frequency modulation products in the acoustic output of the loud-speaker. For this reason weighted noise measurements should not be considered alone, but always in conjunction with the unweighted measurement.

The analysis of noise made earlier has shown that the pre- and "A" amplifiers determine the signal to noise ratio for the whole system provided the amplifiers in the rest of the system are well designed. For this reason it is departmental practice to specify unweighted noise limits for the pre-amplifier and "A" amplifier.

While this method of noise measurement is satisfactory for the majority of cases, a modification is needed when pre-amplifiers are tested. The pre-amplifier as specified has a gain of 28 to 30 db, a power capability of 10 milliwatts and an unweighted signal to noise ratio of 95 db. An examination of Fig. 5 will show that the signal at the input of the measuring amplifier will be at least —85 vu, and depending on the impedance matching conditions, may fall to values as low as —115 vu. Low levels of this nature introduce difficulties, particularly if longitudinal currents are to be avoided. In fact, experience has shown that, if possible, levels lower than —70 vu should be avoided if reliable measurements are to be obtained.

To overcome the difficulty outlined, the usual method of noise measurement has been modified as shown in Fig. 7:

The basic difference is that the pre-amplifier is connected in tandem with an "A" amplifier and the noise measurement made over the two amplifiers. This method is usually readily arranged as pre-amplifiers are mounted with an

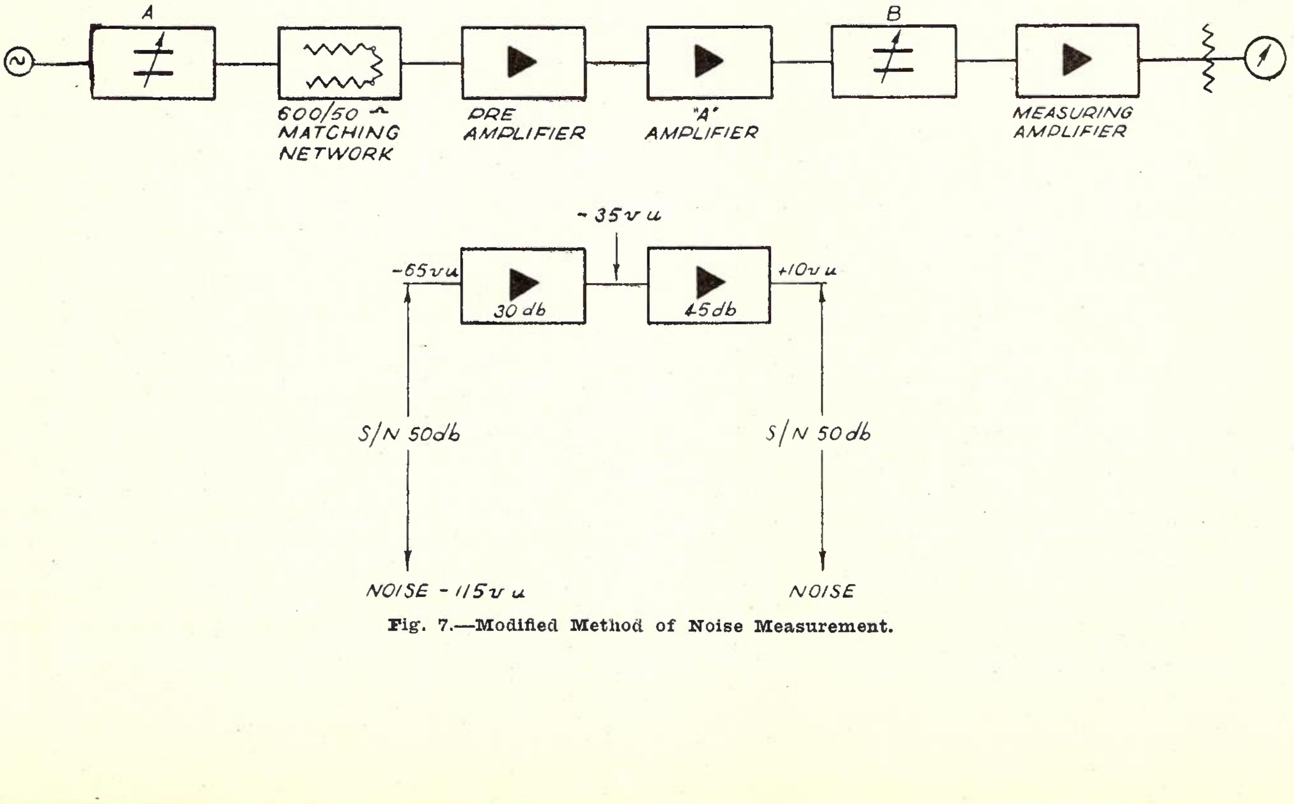

Fig. 7.—Modified Method of Noise Measurement.

"A" amplifier on racks, and suitable jacking facilities are available.

Before the overall test can be made, it is necessary that the "A" amplifier be tested alone to ensure that the signal to noise ratio of at least 70 db is achieved. Then the overall test can be made and the values given in Fig. 7 show that the noise due to the overall measurement is greater by at least 30 db, a margin that will not materially affect the final results obtained. The result can be corrected by the use of the following expression:

$$N = \sqrt{n_1^2 + n_2^2}$$

When N = total noise.
n_1 = noise of "A" amplifier alone.
n_2 = noise of amplifiers in tandem.

In the above case, normal measuring tolerances exceed the error introduced by this method of measurement. This method of measurement is based on practical application and the figure of —115 vu for the equivalent noise input is the tentative value in use at present for specification purposes. A reasonable tolerance was considered necessary until experience had been gained with equipment manufactured to new specifications. The noise figures now being obtained indicate that a figure of —120 vu may be used in the near future; however, under wartime conditions this will depend on the availability of suitable materials, particularly for transformer shields.

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TRANSMISSION MEASUREMENTS TO 150 KILOCYCLES PER SECOND

J. D. Uffindell

PART 2—TESTING

Testing Procedure for Open Wire Lines.—Concerning transmission test procedure in general, it may be stated that with increase in frequency the greater becomes the effect of coupling between the high and low level circuits of any test set-up. At high frequencies, therefore, the imposition of safeguards against this effect is of prime importance, and in this connection there are certain fundamentals which should be adhered to.

Efficient earthing of all equipment used is necessary. All connecting leads should be as short as possible, and consist of screened pairs; rubber-covered flexible twin microphone cable is satisfactory for the purpose. Attention should be paid to lay-out—sending and receiving equipment should not be crowded together. Oscillators and detector-amplifiers should not be used from a common battery supply unless tests have indicated the efficiency of the decoupling method used. Before commencing measurements, tests should be made to ensure that no coupling exists between signal source and measuring equipment that is sufficient to affect the accuracy of expected results. Checks should also be made for longitudinal effects. This is generally indicated by a change of reading if the leads to the detector-amplifier are reversed.

Test leads from measuring equipment to the circuit under test, if of appreciable length, should have approximately the same impedance characteristics as the circuit to be tested. For 9 inch spaced open wire circuits the use of single O.D.T. wires spaced 9 inches apart with wooden slats is satisfactory.

Where interference is of a relatively steady nature the effect on accuracy of measurements can be gauged and correction applied, if necessary, from reference to Table 1. Comparative readings are required at the receiving end with the test power both on and off.

TABLE 1

Difference between Readings Test current on and off	Correction Subtract from reading with test current on
20 db	0.1 db
10 db	0.5 db
3 db	3.0 db

Impedance Measurement. — For measurement of impedance, either the W.E. or S.T.C. 5A bridge may be used with the 17B oscillator as a frequency source and balance indication provided by a W.E. 2A amplifier-detector or an S.T.C. 3A, where a tuned input is desirable (as is usually the case for open wire measurement). In cases where measurement is not affected by interference the 2A gives greater ease of operation by reason of its large meter scale and the automatic restriction of the needle swing at the upper end of its movement.

The connections of the test set-up are as indicated in Fig. 16. Consideration must be given to the test lead from the bridge to the open wire. Balancing of the test lead with a lumped capacitance across the opposite side of the bridge does not take into effect the impedance of the lead as a transmission line, and is inadvisable. In the case of the W.E. bridge an equal length of lead, identical with the test lead, can be connected between the "known" side of the bridge and the R and C standards. This method satisfactorily eliminates lead error, but complicates procedure, since the change of sign in the reactive component cannot be taken care of by changing over the "Capacitance Standard" key in the usual manner. The method found most satisfactory is to use a test lead of the same electrical characteristics as the circuit under test, and to regard it simply as an extension of that circuit. Two single O.D.T. wires spaced to 9 inches apart with wooden slats at suitable intervals have been found satisfactory. A similar lead should be used at the far end, unless the terminating network or shorting switch is placed right at the open wire.

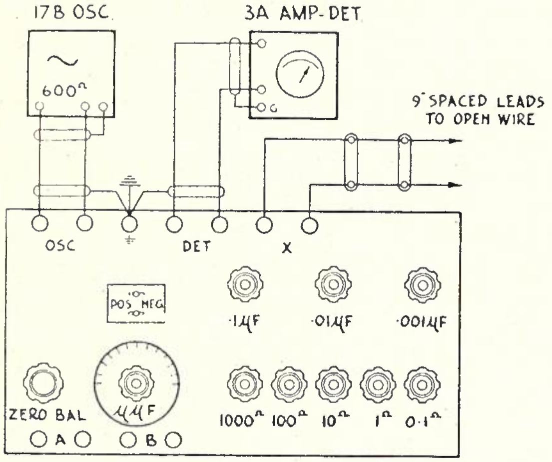


Fig. 16.—Impedance Measurement, Schematic Circuit.

As a check for satisfactory operation of the measuring apparatus the leads to the amplifier-detector should be reversed after making a reading at the highest frequency concerned — no appreciable change in balance should occur.

Impedance Z is calculated from parallel equivalent values of R and C in accordance with the following:—

$$Z = \frac{R}{\sqrt{1 + R^2 \omega^2 C^2}} \pm \tan^{-1} R\omega C.$$

Method Using S.T.C. 5A Bridge.—Zero balancing of the capacity standards is a preliminary to measurement. With both X and RES keys set to zero, as in Fig. 1 of Fig. 10, the capacity standards all set to zero, and with the oscillator output set to a suitable frequency and level, the ZERO BAL. condenser is adjusted for balance as indicated by a minimum reading of the amplifier-detector meter. This balance should hold sufficiently well with frequency over the measuring range.

To measure, the oscillator is set to the required frequency, the amplifier-detector tuned (if necessary), and both keys operated to NEG or POS, depending upon whether the impedance is expected to exhibit a negative or a positive angle. The resistance and capacity standards are then adjusted for balance, as indicated by the amplifier-detector. The impedance is calculated from the equivalent R and C values so obtained in accordance with the formula above.

Method Using W.E. 5A Bridge. — (Refer to Fig. 11.) Before zero balancing is commenced the test lead must be removed from the X_1-X_2 terminals. The capacity standards are then set to zero, the UNBAL-BAL. key to BAL. and the CAP. STD. keys to S_1-S_2 (as for measurement of negative angle), all other keys remain vertical. The ZERO BAL. condenser is then adjusted for balance as above. Where positive angle measurements are met with, then zero balance will need to be re-checked with the CAP. STD. key operated to X_1-X_2.

To measure, the test lead is connected to the X_1-X_2 terminals, the RES. STD. key operated to S_1-S_2, the UNBAL-BAL. key to BAL. and the CAP. STD. key to S_1-S_2 or X_1-X_2, depending upon the expected sign of the reactive component. The resistance and capacity standards are then adjusted for balance as above and the R and C values noted.

Crosstalk Measurement. — The 51A Crosstalk Set, if used at frequencies much above 50 KC/sec., is subject to increasing error, and can be regarded as unsuitable. Since no self-contained set is available for use in 600 ohm circuits, it becomes necessary to arrange a comparison circuit from individual components.

General Method.—The requirements are:—A 17B oscillator, Muirhead attenuator, Muirhead key, and a 2A or 3A amplifier-detector, arranged as indicated in Fig. 17. It will be seen that for "near end" measurements the oscillator is connected across the "disturbing" line, and the comparison attenuator in parallel, the assumption being that current from the oscillator will divide equally over the two paths. For normal 9 inch spaced open wire lines the impedance at the higher frequencies varies little from 630 ohms, and inappreciable error has been indicated by comparison between measurements made with the parallel connection and with the oscillator connected in turn to the "disturbed" line and attenuator, as the key is changed from the "line" to "meter" positions respetcively.

For the "meter" position of the key, the "disturbed" line is shown terminated in 600 ohms; discretion can be used as to the necessity for this. In the "line" position there is no provision for terminating the "disturbed" line behind the attenuator, but the attenuator will normally be set at a loss value more than adequate to take care of this.

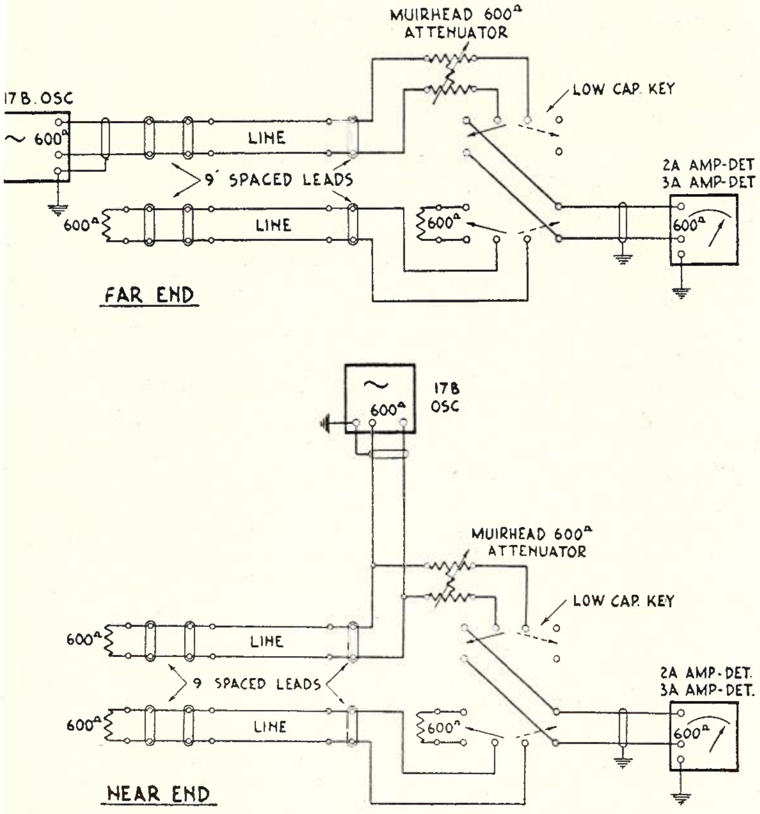


Fig. 17.—Crosstalk Measurements and Schematic Circuit.

The tuning of the amplifier-detector is preferably accomplished with the key in the "meter" position to obviate the possibility of tuning to an interference frequency instead of the oscillator frequency. It might be noted here that a meter as compared to headphones does not give discrimination between a wanted signal frequency and a near-by interfering signal of comparable strength. On that account, selectivity of a higher order is required for a meter type instrument than would be necessary in the case of a heterodyne type of amplifier-detector using headphones.

With the 2A amplifier-detector the 600 ohm tappings on the input transformer should be used, and, if necessary, attention given to building out the input impedance in the manner indicated in the description of this instrument. Nine inch spaced test leads should be used at the measuring end and at the terminating end, unless the terminations are placed right at the open wires.

The arrangement for "far end" measurement differs from the near end only in the disposition of the oscillator. Measurement is accomplished as follows:—By operation of the key to the "line" position the amplifier-detector is connected directly to the "disturbed" line, and a suitable deflection of the meter obtained by adjustment of the gain control. The key is then operated to the "meter" position, connecting the amplifier-detector to the disturbing signal source through the variable attenuator, which is adjusted to give the same reading as previously obtained. The attenuator reading will then indicate the crosstalk attenuation between the two circuits.

Two sets of "far end" measurements should be made, the second following reversal of the two circuits in respect of the "disturbing" and "disturbed" function. This reversal should not normally be necessary for near end measurements.

Measurement of Crosstalk Peaks and Troughs.—Where interference conditions are such as to allow the use of the untuned 2A amplifier-detector or the 3A in its untuned condition very useful variations in the above technique are possible. For "far end" crosstalk the measurements of most consequence are in general those indicating the peaks in the crosstalk curve, as indicated by the lowest values of crosstalk attenuation. "Near end" measurements are valuable mainly from considerations of transposition design, the figures of most consequence in this case being for the peaks and the troughs of the curve. These figures for both "far" and "near end" conditions are obtainable in the following manner, making use of the test set-up of Fig. 17. A measurement is made at 150 KC/sec. in the normal manner. The comparison key is then left in the "line" position, connecting the amplifier-detector to the "disturbed" line. The oscillator frequency is then slowly reduced, and the movement of the meter needle observed, operating the variable attenuator, if necessary, to keep the needle on scale. The peaks and troughs of crosstalk will be indicated by the extremes of upward and downward movements of the needle respectively. Measurements are made at these points, and at intermediate points if it should be required to fill out the curves.

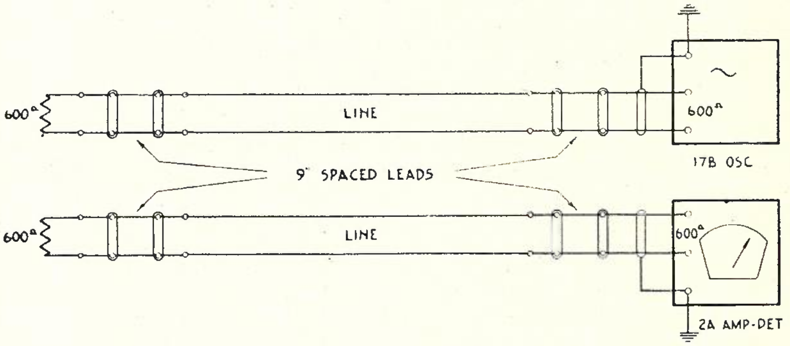


Fig. 18.—Measurement of Peaks and Troughs of "Near-End" Crosstalk.

Fig. 18 illustrates a rapid method, applicable to "near end" conditions only, whereby crosstalk values at the peaks and troughs and at any intermediate points may be obtained. It is made possible by the exceptionally flat Output-frequency and Gain-frequency characteristics of the 17B oscillator and 2A amplifier-detector.

A preliminary calibration is achieved by feeding the maximum output of the 17B oscillator to the input of the 2A through a variable attenuator which is adjusted to give a zero reading on the 2A scale. The attenuator reading thus obtained is the calibration figure required by the method. This figure will be in the vicinity of 83 db, and if it is obtained at a frequency round 50 KC/sec. it will be found that the total variation with frequency between 3-150 KC/sec. will not exceed some 0.5 db.

To carry out measurements, the oscillator is connected directly to the "disturbing" line and the 2A to the "disturbed" line through the variable attenuator. The oscillator is then run slowly through the frequency range from 150 KC/sec. downwards, the attenuator being adjusted at the same time to maintain a zero reading of the meter. The attenuator readings can be taken at the peaks and troughs as indicated by the extremes of meter movement and/or at desired frequencies. The crosstalk value for any particular frequency is given by the subtraction of the attenuator reading for that frequency from the original calibration reading. Since the meter reads to —4.0 below the zero point of calibration it is possible to measure crosstalk of the order of 87 db.

Crosstalk measurements obtained by untuned amplifier-detector methods provide a maximum of useful information without the necessity for a long series of measurements at closely spaced frequencies. However, there are limitations to their use, due to the effects of interference, and discretion is necessary on the part of the operator. The accuracy of any measurement is appreciably affected if the level of interference is less than 8 db below that of the crosstalk signal for the particular frequency concerned. Where this condition is not met the measurement must be made with the amplifier-detector (where the 3A is used) in the tuned condition. In the case of the 2A, which is not tunable, the measurement can only be indicated as being greater than the ascertained maximum value that can be measured with accuracy.

The use of this method on the existing "J" route necessitates the "J" system being cut off from its circuit (this has been found possible to date by patching essential channels). Measurements to 30 KC over such a route have been satisfactorily made by measuring through the low pass filter of a programme carrier group interposed between the "disturbed" line and the measuring equipment.

Insertion Loss Measurements. — The 30A Transmission Measuring Set has been developed for gain loss measurements to 150 KC/sec., and where two of these are available the addition of a 17B oscillator completes the essential requirements for what may be regarded as the basic form of measurement. Variations from this may be necessary due to 30A sets being unavailable or to meet special conditions. The use of "J" type thermocouples is quite satisfactory, and will be described first as giving the most straight-forward illustration of the manner in which the flat output frequency characteristic of the 17B oscillator may be further used to advantage, in this case enabling the insertion loss curve for the line to be continuously followed for the detection of absorption peaks.

Use of Thermocouples and Vacuum Tube Voltmeters.—The arrangement is illustrated in Fig. 19. The requirements consist of a 17B oscillator, two Muirhead attenuators, two 600 ohm "J" type thermocouples with associated Rawson microammeters (or suitable V.T. voltmeters), and a Muirhead change-over key.

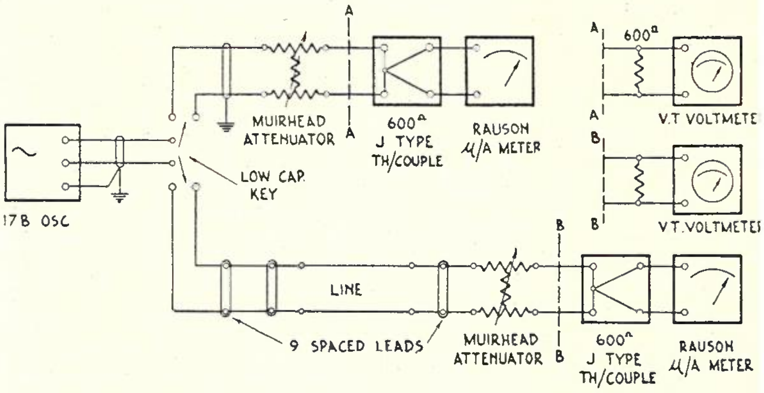


Fig. 19.—Measurement of Insertion Loss, Using Thermocouple or Vacuum Tube Volt Meters.

Calibrate the two thermocouples in respect to meter deflections for the same heater current; this reading for the respective meters is taken to indicate reference power. Check that the readings remain satisfactorily in step over the frequency range of the measurements.

At the sending end a loss, A, somewhat greater than the anticipated maximum loss to be measured, is introduced into the attenuator, and the oscillator output is adjusted for reference deflection of the thermocouple meter at, say, 50 KC/sec. The oscillator frequency is then set to 150 KC/sec., and the key operated to send the test current to line, this current representing a power A db above reference power.

At the receiving end the attenuator is adjusted for reference deflection of the thermocouple meter. The line loss is given by the difference between the reading of sending and receiving attenuators. The oscillator frequency is then slowly reduced and the receiving attenuator adjusted to maintain the reference deflection of the meter. Deviations from a mean curve will be indicated by maximum and minimum swings of the receiving meter; attenuator readings can be taken at these points and at such frequencies as may be required to satisfactorily fill in the curve.

The use of vacuum tube voltmeters involves no change from this procedure except that the meters should be correctly terminated in 600 ohms. An exceptional case where such meters were used to advantage is worthy of note. As a check on the suitability of a certain transposition design, insertion loss measurements were required over an eight mile "E" section to indicate the incidence and magnitude of absorption peaks. The maximum expected loss being little in excess of 0.5 db, with variations about a mean curve correspondingly small, it was obvious that meters having very close scale agreement for the whole frequency range would be required. It was to this end that the Weston 669 vacuum tube voltmeters mentioned earlier were modified, and their use made possible a continuous insertion loss curve of satisfactory accuracy.

Use of 30A Transmission Measuring Set.—The method of measurement is identical with that outlined above. For the purpose in view, the 30A sets can be regarded simply as embodying, in conveniently jacked form, the individual components used at the "sending" and "receiving" ends of the test set-up shown in Fig. 19. Reference can be made to Fig. 12 for details of the 30A set.

These sets have been designed for use in 135 ohm circuits; consequently matching is necessary in the case of 600 ohm circuits. The procedure is as follows:—Calibrate both 30A sets. At the "sending" end the line is patched to the "loss in" jacks through one of the 600 ohm: 135 ohm matching transformers provided.

The key is operated to "adjust" and the attenuator set to a loss equal to the desired sending level above 1 mW. The oscillator output control, in conjunction with the test potentiometer, is adjusted for a zero (1 mW.) reading on the 30A meter. The key is operated to "compare," sending the test power to line.

At the "receiving" end the line is patched through a 600 ohm: 135 ohm matching transformer to the "attenuator in" jacks, with the attenuator set to maximum loss. With the key in the "adjust" position the attenuator is adjusted for a zero reading of the meter.

The difference in reading between the sending and receiving attenuators, plus or minus the meter reading at the "receiving" end, is the measure of the line loss plus that of the matching transformers. To obtain the net line loss the two transformer losses should be subtracted in accordance with their loss frequency characteristic shown in Fig. 13.

For maximum accuracy the "receiving" end meter should be kept within plus or minus 1 db of zero, so that the maximum loss measurable by this method is equal to the maximum sending level above 1 mW available at the "sending" end. This is about 30 db for the 17B oscillator. For the measurement of loss greater than this, or where for any reason the input power to the line under test is limited, the 2A amplifier-detector can be substituted for the 30A meter at the "receiving" end.

Use of 30A Sets with 2A Amplifier-detector.—The usual calibration of the 2A for scale accuracy is carried out, and also calibration for the gain sensitivity in terms of the input level below 1 mW required for a zero scale reading. The 2A (135 ohm input) is then patched to the "test key out" jacks, and measurement proceeded with exactly as above.

The line loss in this case is given by the difference between the reading of the sending attenuator plus the gain sensitivity figure of the 2A and the reading of the receiving attenuator plus or minus the reading of the 2A meter with respect to zero. Correction for the transformer losses is necessary.

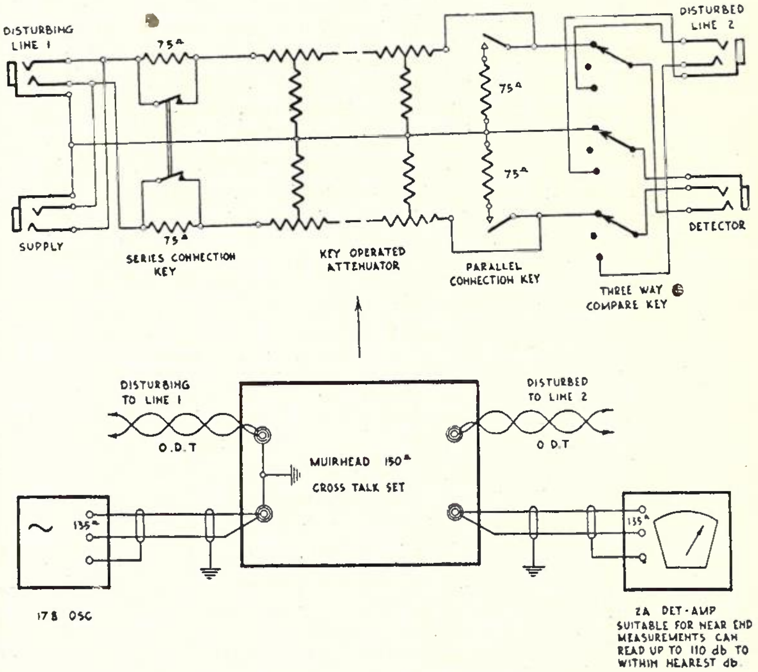


Fig. 20.—Crosstalk in Cables.

Testing Procedure for Cables

The general remarks concerning test procedure, as set out for open wire lines, apply equally to cables except in the matter of test leads for which twisted O.D.T. is suitable. Oscillator and amplifier-detector impedances will usually be set to 135 ohms. So far as measuring technique is concerned, the methods outlined above are satisfactory for cable measurements normally undertaken. However, variations having particular application to cables and to meet specific cases are set out below.

Crosstalk.—There is little difference from the general procedure described, except that there is available a self-contained Muirhead Crosstalk Set with an image impedance of 150 ohms combining the functions of the key and attenuator of Fig. 17. The schematic circuit of the set as shown in Fig. 20 is seen to be identical with the made-up circuit of Fig. 17, except for the provision of two keys, a "Parallel Connection" key providing a termination for the "disturbing" line, if required, and a "Series Connection" key not normally used. Connection is provided to the cable pairs and to oscillator and amplifier-detector by jacks and tip-ring-sleeve plugs having the respective sleeves connected to the shielding of the leads. Oscillator and amplifier-detector impedances are set to 135 ohms. Twisted O.D.T. test leads are suitable, but should be kept short.

Impedance Measurements on Spare Sections of Mainland-Tasmania Telephone Cable.—The impedance set-up of Fig. 21 was used for checking to 60KC/sec. the characteristic impedance of short spare sections of Bass Strait submarine telephone cable (of the unbalanced concentric type). Since three of the telephone channels carried by the cable work on a two-wire basis, smoothness of the impedance frequency characteristic is essential to stable operation of the equipment at the high gains required. On this account more than ordinary accuracy was required of the measurements for satisfactory comparison against the specified values of impedance and the small allowable deviations from a mean curve.

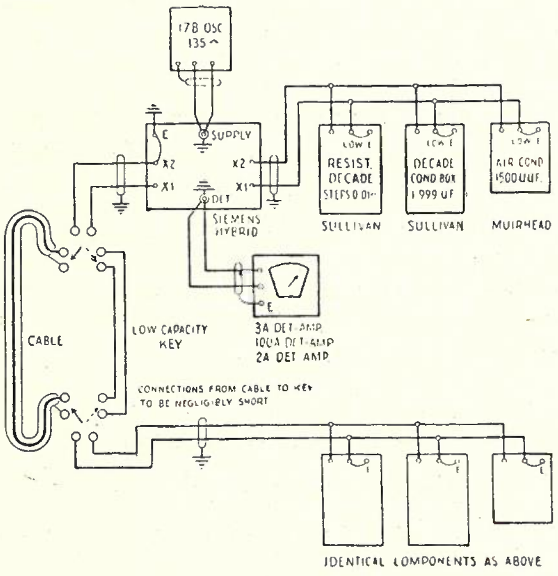


Fig. 21.—Impedance Measurement (Unbalanced) on Short Spare Sections of the Bass Strait Cable.

The lengths of the sections to be measured were in some cases little in excess of 100 yards, and the "open and closed" method, using a 5A bridge, was found to be impracticable. The equivalent R and C values at some frequencies were far in excess of the values provided by the bridge, and where measurements could be made it was not possible to closely reproduce results, this latter apparently being due to the steepness of the "open" and "closed" curves requiring greater stability than the apparatus provided. Further, excessive variation in reading occurred with turnover of oscillator and amplifier-detector leads.

The method finally adopted required the apparatus shown in Fig. 21, and hinged about the use of the double-screened and highly balanced Siemens hybrid coil, with external standards in place of a conventional impedance bridge. Both the terminating network and the bridge standards are identical components, having a high degree of accuracy. This is essential to provide the close scale agreement upon which the technique is based. The method depends upon the fact that if a finite line be terminated at the far end in its characteristic impedance for any particular frequency, then the measured impedance of the line will also be the characteristic impedance for that frequency.

Since the cable is of the concentric unbalanced type, the test set-up must be connected as an unbalanced circuit with the X2 terminals of the hybrid coil (unbalanced type) connected to ground. Both the "detector" and "supply" windings are internally grounded on one side.

Care must be taken to ensure that the "low" side of all R and C components and the sheath of the cable are connected to the relevant X2 terminals of the hybrid coil. The interposition of the shorting key across the two ends of the cable is to enable checks to be made as to the agreement between the scales of the two sets of components.

The method of measurement is as follows:—

The "standard" and "terminating" components are initially given identical settings, based upon an assumption as to the cable impedance. The two sets of components are then successively adjusted **"in step"** until optimum balance is obtained. The **"in step"** must be emphasized; the two resistance components must be adjusted together, both maintaining identical values. The same applies to the capacity components. To facilitate this process it is desirable that the layout is such as to place the related components close together. This applies particularly to the air condensers, which are more difficult to keep in step than the decades. Any attempt to reach a balance by varying components individually leads to an increasing departure from the necessary agreement between the two sets of values upon which the method is based. The equivalent R and C values for the characteristic impedance at the particular frequency concerned are given by the common R and C values of the two sets of components after successive **"in step"** adjustments, alternating between resistance and capacity, have achieved the lowest possible reading of the amplifier-detector and evidence of clean-cut balance conditions.

Insertion Loss Over Cable Pairs.—The measuring technique need depart in no way from that used for open wire measurement. However, there is one method of particular application to cable measurements, combining accuracy and convenience.

By looping two cable pairs at the far end a simple substitution method can be adopted, the test set-up and procedure being exactly as for measurement of near end crosstalk (see Fig. 20). The insertion loss for each cable pair is one-half of the measured value. Accuracy of measurement is dependent upon the relative magnitude of "near end" crosstalk between the pairs concerned; this should be checked, and if not greater in value by 20 db than the measured insertion loss for any particular frequency, then correction should be applied as set out in the general remarks relating to test procedure, or a different method of measurement adopted. The existence of crosstalk interference sufficient to affect the accuracy of measurement may also be checked by reversing the connection to the crosstalk set of one or other of the two-looped cable pairs. Interference will be indicated by a change in the measured value.

Admittance Unbalance Measurement. — Measurements of this nature are a comparatively new development following on the introduction into Australia of carrier type trunk cables. The basis of measurement is provided by the Siemens Admittance Unbalance Set, concerning which details have been given. Associated equipment consists of the 0-150 KC/sec. oscillator and B3 type amplifier-detector by the same makers. However, the 17B oscillator could be used, also the 3A amplifier-detector could be used with suitable modification to the input impedance. The 2A detector-amplifier lacks sensitivity adequate to the fine balance conditions obtained.

The set-up for measurement is shown in Fig. 22. For simplicity, only single "disturbing" and "disturbed" pairs are shown. The oscillator output is set to 150 ohms (135 ohms for the 17B), and the far end of the "disturbed" line, the "disturbing" line at the measuring end, and the amplifier-detector terminated in either the average characteristic impedance of the cable or some suitable network. The B3 amplifier-detector incorporates a high input impedance so that any suitable termination can be applied.

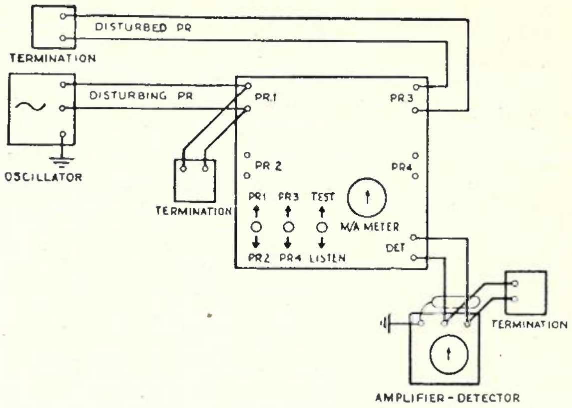


Fig. 22.—Measurement of Admittance Unbalance.

Test leads should be short, carefully balanced, and adequately spaced. Before connection to the cable pairs the two measuring dials are set to zero and the two zero adjustments provided are set to achieve initial balance of the set plus leads.

The cable pairs are next connected and the capacity and leakance dials adjusted in succession to achieve balance conditions as indicated by the amplifier-detector. The magnitude and sign of the dial readings are noted. A second measurement is made with the "disturbing" and "disturbed" pairs interchanged. The sign of these readings is, of course, dependent upon consistency in the tip and ring connection of the cable pairs, and care is necessary in this respect.

Conclusion.—It will be appreciated that the foregoing does not cover in complete detail the new field of transmission testing opened up by the extension of the carrier frequency band to 150 KC/sec., but it is hoped that sufficient has been included of the methods used and the experience gained for the paper to be of general interest.

INFORMATION SECTION

A SCALE RULE FOR SETTING OUT 2000 TYPE AUTOMATIC EXCHANGE EQUIPMENT

A scale rule designed as an aid to the drawing of the floor layout of 2000 type automatic exchange equipment has been in use for some years in Sydney, and has proved of considerable value to engineers and draftsmen engaged in this work. The rule was first designed by Mr. F. P. Blakey, formerly a Divisional Engineer in the Postmaster-General's Department.

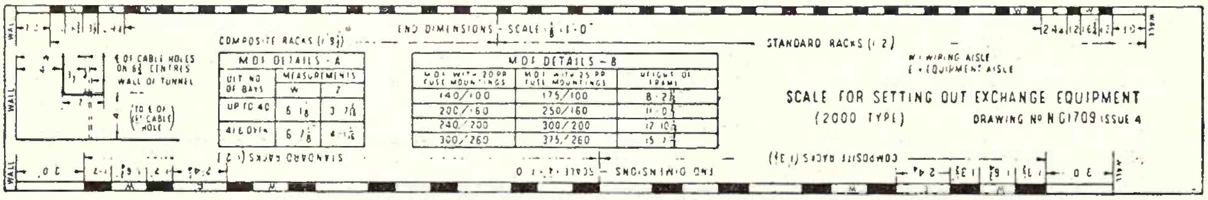
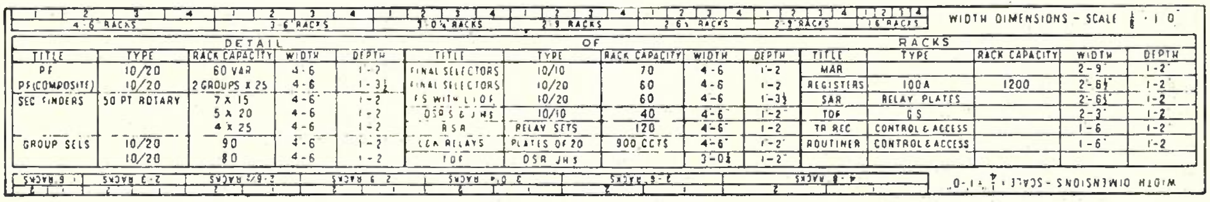


Fig. 1.

The scale and its reverse are shown in Fig. 1 and 2 respectively. In Fig. 1 the opposite edges of the scale are marked to show the relative spacings of suites of 2000 type racks to scales of ⅛in. and ¼in. to the foot. The former scale, ⅛in. to the foot, is generally used in drawings associated with proposals in connection with telephone exchange buildings, and the latter for setting out equipment in switchrooms when cable runways and other details are added. It will be noticed that on each edge of the rule the scale is divided into two sections. This permits the correct dimensions to be used when locating suites of racks having depths of 1ft. 2in. and 1ft. 3½in., the latter referring to racks of the composite line-finder type. The rack aisle dimensions are constant, these being 1ft. 6¾in. for wiring aisles and 2ft. 4¼in. in equipment aisles. A table is included showing the dimensions of main distributing frames of various capacities and details for the location of the M.D.F. in a building.



DETAIL					OF					RACKS				
TITLE	TYPE	RACK CAPACITY	WIDTH	DEPTH	TITLE	TYPE	RACK CAPACITY	WIDTH	DEPTH	TITLE	TYPE	RACK CAPACITY	WIDTH	DEPTH
PF	10/20	60 VAR	4-6	1-2	FINAL SELECTORS	10/10	70	4-6	1-2	MAR			2-9	1-2
PF(COMPOSITE)	10/20	2 GROUPS X 25	4-6	1-3½	FINAL SELECTORS	10/20	60	4-6	1-2	REGISTERS	100A	1200	2-6½	1-2
SEC FINDERS	50 PT ROTARY	7 X 15	4-6	1-2	F S WITH L.T.O.F.	10/20	60	4-6	1-3½	SAR	RELAY PLATES		2-6½	1-2
		5 X 20	4-6	1-2	OSR'S & JHS	10/10	40	4-6	1-2	TDF	GS		2-3	1-2
		4 X 25	4-6	1-2	RSR	RELAY SETS	120	4-6	1-2	TR REC	CONTROL & ACCESS		1-6	1-2
GROUP SELS	10/20	90	4-6	1-2	CCA RELAYS	PLATES OF 20	900 CCTS	4-6	1-2	ROUTINER	CONTROL & ACCESS		1-6	1-2
	10/20	80	4-6	1-2	TDF	OSR JHS		3-0½	1-2					

Fig. 2.

The reverse side of the rule is shown in Fig. 2. In this case the width dimensions of racks of various types are shown to the ⅛in. and ¼in. scales as before. The dimensions and capacities of racks in common use are also tabulated as a guide to the number of racks required to accommodate estimated switch quantities.

—R.W.T.

USE OF DETECTOR NO. 4 FOR MEASURING A.C. CURRENTS AND VOLTAGES

A useful adjunct to the Detector No. 4 permitting it to be used for A.C. measurements (V.F. and Power) has been developed, a small supply having been obtained recently. The stock title of the article is "Rectifier Attachment, Detector No. 4" (serial 139/6E), and as its name implies comprises a rectifier (Westinghouse metal oxide type) with certain multipliers to provide the following current and voltage ranges:—

(1) 15 M.As. A.C.
(2) 150 V. A.C.
(3) 100 V. A.C.

The voltage multipliers are based on 66.7 ohms per volt. The measurements must all be made with the compound switch of the detector in either the 5 V. or 50 V. position.

The advantages of the moving-coil type of instrument for D.C. measurements are well known, in that they have high sensitivity, good damping, long scale arcs, low power consumption, short-time period, and high torque-weight ratio. By the addition of a suitable rectifier an instrument of this class can be adapted as a means of readily measuring alternating quantities, and, for this purpose, a special bridge-connected instrument-type rectifier, giving full-wave rectification of the alternating current, is employed. Rectifier instruments are very suitable for the measurement of alternating currents and voltages where only a limited amount of energy may be taken from the circuit. They are particularly applicable to audio frequency circuits, as in radio broadcast systems.

Detector No. 4, being a moving coil type of instrument, is unsuitable for A.C. measurements without a rectifier, but when any such instrument is associated with a rectifier the graduations on the scale for D.C. measurements will not be suitable for A.C. without using a conversion factor. Detector No. 4 measures the average value of the unidirectional pulses (half cycles), but as the intensity of an alternating current is always quoted in terms of its R.M.S. (root mean square) or virtual value, the correct proportioning of the resistances in the attachment is necessary. Even when this has been done the instrument will, in general, be accurate only when the A.C. being measured is of sine wave form, because the ratio of the R.M.S. value to the average value of an A.C. (called the form factor, which is 1.11 for a sine wave) varies according to the form of the wave. The average value of an alternating sine wave current equals

.637 maximum value attained. The virtual, or R.M.S., value of such a current equals .707 maximum value attained.

Therefore, Form factor = 0.707/0.637
= 1.11 for a sine Wave.

In the communications field it is found that audio frequency envelopes have essentially a random distribution of harmonics whereby the actual error introduced by deviation from true sine waves is relatively small, and rectifier instruments are very satisfactory for the measurement of voice currents.

The attachment is very compact, being of the same width and height as the detector, but only 1in. thick, a pair of leads being brought out to a connecting clip marked + and — for attachment to terminals 2 and 4 respectively of the detector. On the top of the attachment are four terminals marked "A.C. Common," "15 Milliamps," "150V," and "300V," to which the A.C. is connected, depending on the range required. A schematic circuit of the attachment is shown in Fig. 1, and another drawing of the circuit, with the addition of the meter, is shown in Fig. 2.

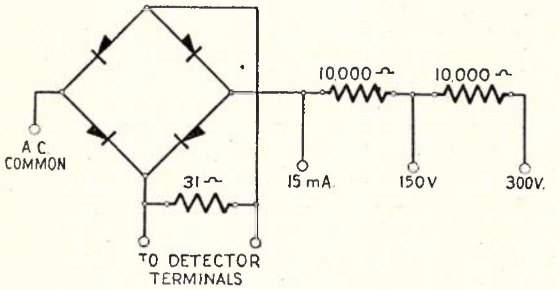


Fig. 1.—Schematic Circuit of Rectifier Attachment.

It will be seen that the Detector No. 4 (terminals 2 and 4) is bridged across a shunt resistance through which unidirectional half cycles of full wave rectified A.C. are passed. This shunt resistance is of such dimensions that when 15 M.As. alternating current flow through the rectifier, the intensity of rectified pulses flowing through the moving coil of the detector is such as to cause full scale deflection. The scale is graduated "0" to "50." Therefore, when measuring small A.C. currents multiply the scale reading by 3 and divide by 10 to give the value in milliamps.

For A.C. current measurement, connect to A.C. common and 15 mA terminals. For A.C. voltage measurements, connect to A.C. common and 150 V. or 300 V. terminals. To determine the voltage, multiply the meter reading by 3 when the 150 V. terminal is used, and multiply by 6 when the 300 V. terminal is used.

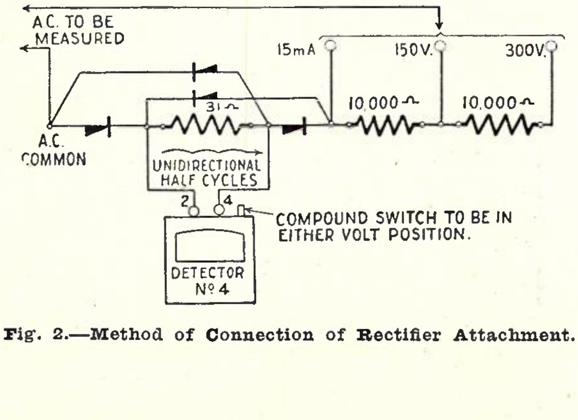
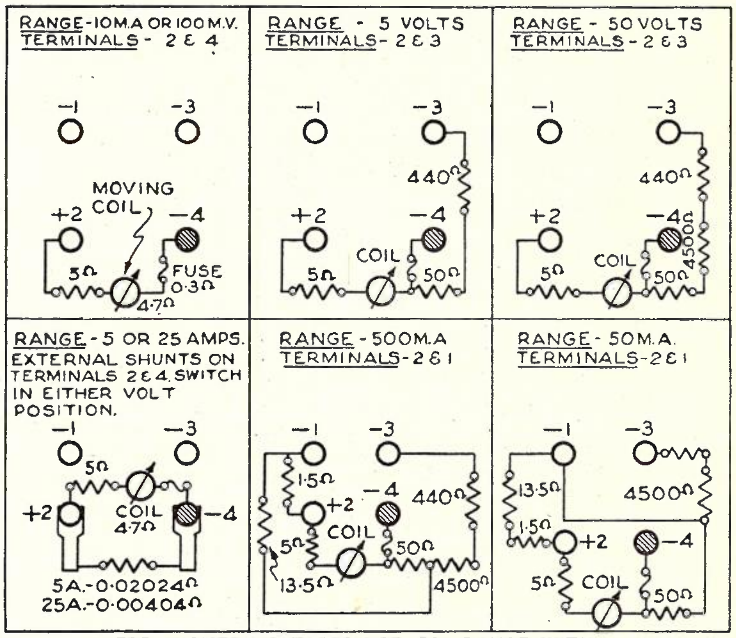


Fig. 2.—Method of Connection of Rectifier Attachment.

This shunt resistance also performs another very useful function, as it protects the rectifier elements against damage if the clip under the detector terminals 2 and 4 should become loose or if the fuse in the moving coil circuit of the instrument should operate and give open circuit. If this should arise and no shunt resistance were included in the attachment, the whole of the A.C. voltage would be impressed across one bank of rectifiers, which would be destroyed.

The attachment may be used for measurements of V.F. current and for measurements of A.C. voltage, including those of A.C. 50 cycle mains up to 300 V. and of ringing machines. Some Detectors No. 4 with a very high Torque—weight ratio may exhibit a vibration on 16-2/3 cycles ringing current, but the movement of the needle will be small, and a reasonably accurate reading can be obtained. It is more robust than the "Thermo-coupled moving coil combination" for V.F. measurements, but its use for V.F. measurements is limited because it has only one current range, 0-15 M.As., and it does not possess a low voltage scale. Potential transformers are generally used in association with rectifier instruments for the measurement of low voltages, the voltage to be measured being stepped up to a high value. This is necessary because the forward resistance of the rectifier becomes an appreciable fraction of the whole resistance of the meter, and thus because the resistance of the meter varies with the current passing through it, the scale shape becomes distorted. It, therefore, follows that if an attempt be made to use a shunt on the A.C. side of the rectifier for increasing the current range, the defects of bad scale shape will also be introduced, as such a shunted meter forms in effect a rectifier voltmeter of very low range connected across the shunt.



FOR HIGHER VOLTAGES USE 50v. RANGE WITH EXTERNAL MULTIPLIER.

Fig. 3.—Detector No. 4, Schematic Circuits.

The rectifier attachment must not be used for D.C. measurements, as the detector would then read approximately 11 per cent. high because the resistance across which the detector is connected is proportioned to cause the instrument to indicate 1.11 times the average value of the current flowing in the rectifiers.

Certain factors, such as the temperature coefficient and the variable resistance of the rectifier elements, depending on the value of current flowing, as well as the wave form, affect the accuracy of a rectifier instrument. Unlike most other indicating instruments, the impedance of a rectifier instrument is not constant over its whole range, but varies with the value of the current passing. For instance, at the lower end of the range, the resistance has a maximum, and at the upper end a minimum value. This variation of resistance introduces a wave-form error, which may be appreciable if the resistance of the external circuit is low in relation to that of the instrument. The impedance of the instrument includes a capacitance component, but this is only important at very high frequencies, and can be neglected for power and audio frequency measurements. Generally, for practical field use, such as analysis of circuit conditions, an accuracy of 2 per cent. is sufficient, and this instrument usually will be suitable for tests by maintenance staff within the ranges shown above. A schematic diagram of the internal connections of the Detector No. 4 for the various scales is shown in Fig. 3 for general information.

—C.J.A.

THE STANDARD TOLL TEST BOARD—OPEN LOCATION TEST

The method used in the standard Toll Test Board for locating "opens" on lines consists of an alternating current bridge arrangement whereby a measurement is made of the capacity between the wire under test and ground and then compared with the capacity of a standard condenser, which forms part of the testing equipment. The arrangement can be used also for ascertaining the capacity of condensers. The following notes on the actual application of the test apply to Toll Test Boards in Queensland and may be of general interest.

General.—In this test the "Bad" and "Good" wires must be identical in all respects. The ideal pair for such a test is a correctly transposed metallic circuit pair, as the capacity to surrounding circuits and earth is identical for each wire. When testing for an open where the "bad" wire is earthed at the test station side of the break, but is showing clear from the distant station, it is sometimes possible to read back to the fault via the good wire by first taking a reading on the good wire to the distant end and then looping the good wire to the bad wire at the distant end and taking a second reading. Where the open circuit is in a morse wire and the "good" wire to be used is another morse wire, there will be a greater margin of error than when testing balanced trunk lines, as although the morse wires may be identical so far as conductor resistance and insulation are concerned, their capacity to surrounding circuits may be entirely different. It is found that tests with these lines give a reasonable degree of accuracy. With the well-balanced trunk lines as erected on all standard construction, clear breaks can be located with practically the same degree of accuracy and ease as earths or contacts are located when using the Varley loop test.

Method of Operation:—

Keys Operated.—"Open location," "Murray," and "Bridge," or 6 V. or 150 V., whichever provided.

Ratio Dial.—Set at M.1000.

The operation of the "open location" key causes 20-cycle alternating current to be supplied to the bridge in lieu of the 24 V. direct current used for Murray and other D.C. tests. The operation of the key also connects the T point of the bridge through condenser 1μF and the "r" resistance in the bridge to ground. With the above conditions set up, the method of testing is as follows:—

Assume the fault to be a clear break (i.e., no earth or leakage showing) in one wire of a metallic circuit trunk:—

(1) After it has been determined which wire is broken the distant end of the circuit is left in an open circuit condition.

(2) The good wire is then earthed at the testing station.

(3) The faulty wire is connected to the RING side of the bridge.

(4) The resistance in the "R" (right hand) arm of the bridge is varied until an approximate balance is obtained, then the "phase shift" key is operated and the resistance in the "r" (left hand) arm varied until an approximate balance is again obtained. The "phase shift" key is released and a balance obtained with the "R" arm, then again with the "r" arm. After several attempts a balance will be obtained which will not be affected by the operation of the "phase shift" key. If a balance cannot be obtained it may be possible to obtain results by the reverse operation of the "phase shift" key, i.e., commence with the key operated to adjust "R" and release the key to adjust "r". On long circuits or circuits where there is interference from adjoining morse circuits it may only be possible to obtain a balance up to the 0.01 ohm shunt of the bridge. This will be sufficiently accurate for the purpose of the test. The resistance in the "R" arm when a balance unaffected by "phase shift" key operation is obtained is called "R," and is the value required for the purpose of the test.

(5) The connections are then reversed so that the faulty wire is earthed and the good wire connected to the bridge, and the test repeated. The result this time is called "R1."

(6) Since the reading of the "R" arm is proportional to the length of the wire being measured, the ratio of R for the bad wire to R1 for the good wire, multiplied by the length of the good wire, gives the distance to the fault.

Expressed as a formula: $X = (R \times D)/R1$.

where X = distance between testing station and fault,
D = length of good wire,
R = reading of R on faulty wire,
R1 = reading of R on good wire.

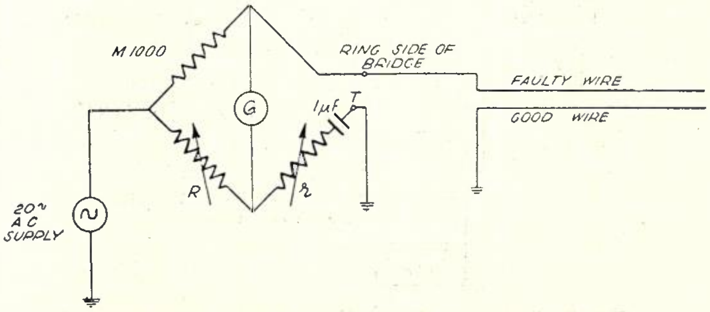


Fig. 1.—Open Circuit Location Test.

Fig. 1 illustrates in schematic form the conditions for test. A satisfactory balance cannot be obtained where any leakage is showing. The formula as given is only applicable where construction is similar throughout the total distance, D.

If the circuit consists of cable for a certain distance and aerial construction for the remainder of the route it will be necessary to assess capacity values for the cable and deduct same from the R and R1 readings obtained in the test. The formula as given will then apply, D and X being calculated from the cable head.

As the capacity of a trunk cable is practically constant it is possible to have values of the capacity in terms of R readings obtained by means of the above test by earthing one wire of a pair and testing on the other wire, and these readings can be recorded ready for use when faults occur. It may be found that there is a slight variation in the readings obtained from various pairs in the cable, but for practical purposes an average of these will suffice.

Example.—An example of test for open location of fault on circuit which consists partly of cable and partly of aerial construction:—

Reading on bad wire R .... = 200
Reading on good wire R1 .... = 600
Length of good wire (from cable head) = 50 miles
Value of R for cable as obtained from records .... = 100
R from cable head then equals 200-100 = 100
R1 from cable head then equals 600-100 = 500
Applying the formula $X = RD/R1$
$X = (100 \times 50)/500$
$X = 10$ miles.

If the above fault had been tested for without allowing for the comparatively high cable capacity the result would not have been a correct location for the fault, as the values of R and R1 taken right from the test board are not in direct proportion to the distance D.

Where there are intermediate testing points in a circuit it is often possible to reduce the margin of error by using the test point as an imaginary cable head and obtaining the value of R to that point. All that is necessary then is to deduct the R value to that point from the R and R1 readings and calculate the distance to the fault from the intermediate test point—I.T.

THE SUBCYCLE RINGER

The "Subcycle" ringer is basically a static converter designed for the derivation of 16-2/3 cycle ringing current at 75/90 volts from a 50-cycle power supply. The ringer is automatic in its operation, having no moving parts except a starting relay. It is, therefore, very suitable for use at country centres or for small exchanges not continuously staffed. The equipment does not produce tones other than ringing tone, and is, therefore, not used where the full range of standard tones are required.

Fig. 1 shows a schematic circuit of the ringer, the essential parts of which are the transformer (T), condenser (C), and inductance (L1). The relay (R) is incorporated in the circuit for starting the oscillatory circuit, while inductance (L2) is included to produce sufficient harmonics to give a satisfactory audible ringing tone. The transformer, condenser, and inductance L1 together form a resonant circuit, the natural frequency of which is 16-2/3 C.P.S. This circuit is linked via the transformer to the 50 C.P.S. supply circuit, from which it receives the energy required to maintain the 16-2/3 cycle oscillations and to supply the ringing current. The inductance L1 is designed to saturate with the current produced by a 50-cycle mains voltage of approximately 210 volts.

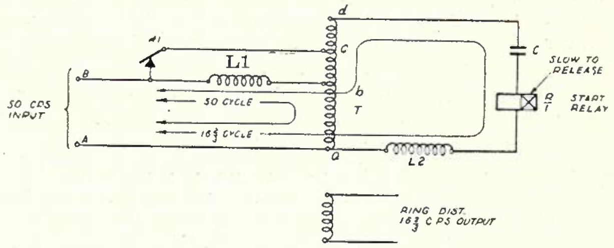


Fig. 1.—Subcycle Ringer Circuit Arrangement.

Fig. 2 shows graphically a complete cycle of 16-2/3 C.P.S. ringing current with the corresponding curve of 3 cycles of 50 C.P.S. The diagram also shows the time period involved, i.e., 60 milliseconds. From a study of the curves it will be apparent that during the positive half cycle of 16-2/3 C.P.S., two positive and one negative half cycle of 50 C.P.S. occur, while during the negative half cycle there are two negative and one positive half cycles of 50 C.P.S. Also that during each half cycle of 16-2/3 C.P.S. there are two assisting and one opposing half cycle of 50 C.P.S. The circuit design is such that the two opposing half cycles of the input frequency are suppressed, and the four assisting half cycles maintain the 16-2/3 oscillating current in the resonant portion of the circuit. From Fig. 2 it will be seen that the suppressed periods are those which occur from 10 to 20 and from 40 to 50 milliseconds.

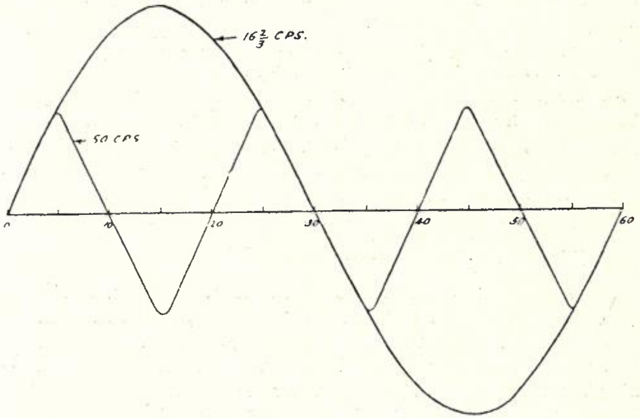


Fig. 2.—Subcycle Ringer Frequency Curves.

When the ringer is in operation, the path of the input 50-cycle current is through winding a-b of the transformer and L1, while the 16-2/3 cycle current flows in the resonant portion of the circuit comprising the condenser (C), transformer, and L1. The relay R and L2 also form part of this circuit, but do not affect the circuit operation. It will be appreciated that as L1 forms a common part of both the input and resonant circuits the 50 and 16-2/3 currents will at times assist and at others oppose each other. As previously stated, L1 is designed to saturate when the currents assist, its impedance being thereby reduced, permitting a greater input to the transformer. Conversely, when the currents are in opposition, L1's impedance is high and the input is correspondingly reduced. The periods of high input will be 0 to 10, 20 to 40, and 50 to 60 milliseconds, vide Fig. 2.

The function of the relay R is to set up the initial oscillating current in the resonant circuit. This is achieved in the following manner. The transformer T acts as an auto transformer, stepping up the voltage across the a and d terminals to about 400 V. Under these conditions the condenser C charges, via L2, and the relay R, which operates, its operating time being approximately equal to the time occupied in charging the condenser. The contacts of R open and the condenser discharges via the transformer and L1. The relay remains held by the 16-2/3 cycle oscillating current unless the ringer is overloaded, whereupon A releases and C again charges reoperating R and restarting the resonant circuit. Continual overloading such as by a short circuit on the output causes the fuse in the input circuit to operate.

A number of units of the type described are in operation in the Commonwealth, mainly at magneto exchanges in country areas, where they form a very satisfactory alternative to pole changers. They are compact and can readily be mounted on a wall or other convenient position. They are particularly suitable for ringing over trunk line channels, where it is necessary to maintain the ringing frequency within close limits in order to operate relays designed to operate at that frequency only.—W.B.W.

NOTES ON TRANSMISSION LINE THEORY—DEFINITIONS

In problems associated with telephone transmission theory various terms and concepts are encountered whose exact meanings and derivations are not thoroughly understood. The following definitions, while not pretending to be exhaustive, include many of those encountered in practice.

A **quadripole**, or 4-pole, is an electrical network which has four terminals, i.e., two input terminals and two output terminals. It is sometimes called a four-terminal network, and examples are attenuators, equalisers, amplifiers, filters, open-wire lines, cables, &c. The input terminals are usually connected to a generator, and the output terminals to a load.

A **passive** network is one containing no source of energy, while an **active** network is one containing one or more sources of energy.

A **Linear** network is one in which all of the electrical elements, such as resistance, inductance, and capacitance are constant with current or voltage. This means that the impedance of any part of the network remains constant whatever the current or voltage, although the impedance will, in general, vary with frequency. A **non-linear** network is one in which the electrical elements vary with current or voltage. For example, a pure resistance is a linear element, while the plate resistance of a vacuum tube is non-linear.

A **symmetrical** quadripole is one which is longitudinally symmetrical, i.e., symmetrical with respect to either end. The test for symmetry is to interchange the input and output terminals without any change in transmission characteristics. A **non-symmetrical** quadripole is the reverse.

A **balanced** quadripole is one which is laterally symmetrical, i.e., symmetrical with respect to either side or symmetrical with respect to a line joining the electrical centre points of the input and output terminals. An **unbalanced** quadripole is one in which this is not so, and a special case of this latter is when one side contains no electrical elements, i.e., one of the input terminals is connected directly to one of the output terminals. In this case, the network contains only three distinct terminals, and is called a **three-pole.**

A **recurrent** network is one which contains several identical sections in tandem or cascade. The sections need not be symmetrical quadripoles.

A **uniform** line may be regarded as a recurrent network in which the successive sections are infinitesimally small and identical.

A **smooth** line consists of an infinite number of infinitesimally small (but not necessarily identical) quadripoles in tandem. If these elemental quadripoles are identical, then the line is uniform; if they continually increase (or decrease) in size, then the line is **tapered.**

A **composite** line is one consisting of several different lines in tandem. Thus the composite line may consist of a length of cable followed by a length of open-wire line, and then another length of cable.

An **infinite** line is one which is uniform and of infinite length. Such a line cannot be constructed, and appears to be academic rather than practical, but a knowledge of its impedance and propagation characteristics is essential when considering finite lines.

The **driving point,** or **input,** impedance of a network, or line, at any frequency is the complex ratio of the voltage to the current at the input terminals when the output terminals are loaded in any specified manner.

The **characteristic** impedance (Zo or Zk) of a uniform line is, basically, the input impedance to such a line if its length is infinite. It is obvious that the termination is arbitrary, as the output terminals are infinitely distant from the input terminals. An infinite line is equivalent to a finite line terminated in an infinite line or in its equivalent, i.e., in Zo, and this gives rise to the second definition, which states that the characteristic impedance of a uniform line is that terminating impedance which makes the input impedance and the terminating impedance equal to each other. This second definition also applies to the characteristic impedance of a symmetrical quadripole.

Propagation Factor. If the voltages (or currents) at two points along an infinite line are $V1 \underline{/\phi 1}$ and $V2 \underline{/\phi 2}$, then their complex ratio $V1/V2 \underline{/\phi 1 - \phi 2}$ is the propagation factor. The ratio V1/V2 is the **attenuation factor** and the angle ($\phi 1 - \phi 2$) is the **phase shift.** These latter are usually given per unit length (i.e., per mile) from which the attenuation factor and phase shift for any length can be obtained. Thus if K_1 and B_1 are the attenuation factor and phase shift per mile then the corresponding values for x miles would be $K_x = K_1^x$ and $B_x = x.B_1$. As it is more convenient to find x times a quantity than the xth power of a quantity, the obvious thing is to use and think in turns of $\log K_1$ rather than K_1 itself, because if $K_x = K_1^x$ then $\log K_x = x \log K_1$. For this reason the **attenuation constant** is made proportional to the log of the attenuation factor. Two systems are in use and if A_1 is the attenuation constant, then

$$\begin{aligned} A_1 &= \log_e K_1 \text{ (nepers)} \\ &= 20 \log_{10} K_1 \text{ (decibels).} \end{aligned}$$

Open-circuit Impedance.—This is the input impedance to a quadripole whose output terminals are open-circuited.

Short-circuit Impedance.—This is the input impedance to a quadripole whose output terminals are short-circuited.

Bisected Network.—In the case of a symmetrical quadripole or uniform line, it is assumed that the network can be cut in halves by means of a line half way between the input and output terminals. The open and short circuit impedances of a bisected network are also used.

The **Image Impedances** of a quadripole are those which simultaneously terminate each end of the quadripole such that at each pair of terminals the impedances both ways are the same. Thus, if Z_1 and Z_2 are the image impedances, then when end No. 2 is terminated in Z_2 the input impedance at end No. 1 will be Z_1, and vice versa. If the network is symmetrical, then the two image impedances are equal to each other, and are identified with the characteristic impedance.—E.H.P.

DAMAGE TO CABLE SHEATH CAUSED BY A GRUB

An interesting case of damage to a cable has recently been experienced at Metung, in Victoria. The cable was buried solid, and on excavating the fault a large caterpillar was found beside the cable. On the underside of the cable was a hole about ¾in. long by ½in. wide without any appreciable corrosion products.

The caterpillar was identified as the larvæ of Pielus (hyalineata), commonly known as a "Root Borer."

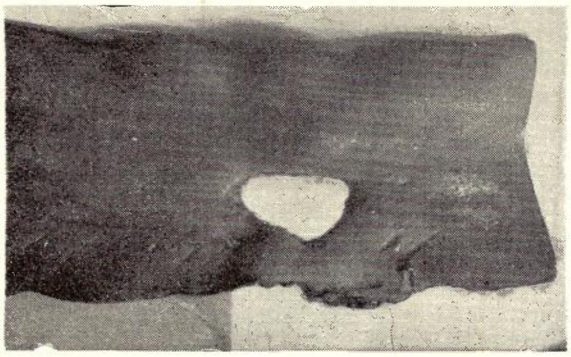


Fig. 1.—Photograph Showing the Damage Done to the Cable Sheath. Natural Size.

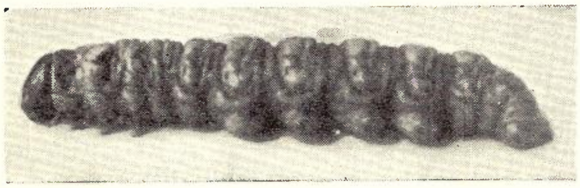


Fig. 2.—Photograph of the Grub Pielus (Hyalineata). Natural Size.

This one of the species commonly known as "Fungus caterpillars," which are subject to attack by the fungus "Cordyceps," which covers the body of the caterpillar as a furry coating, and ultimately causes its death.

The larval stage is passed underground, and it lives on the roots of trees, grass, and shrubs, being equipped with a powerful pair of mandibles. An attempt was made to photograph these, but not with great success, as the caterpillar was a most intractable photographic subject. Fig. 3 shows the serrations on the lead sheath, and it can be seen how well they match the shape of the caterpillar's mandibles.

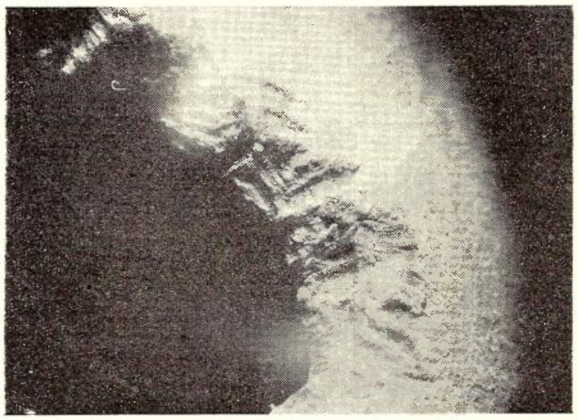


Fig. 3.—Photograph Showing Strong Grooving from Mandibles of the Grub Round the Edge of the Hole, × 8 Diams.

Fig. 4.—Photograph of Head of the Grub Showing the Mandibles of the Grub. Compare with Grooves Shown in the Previous Photograph, × 8 Diams.

When about to pupate the caterpillar burrows to the surface and then closes the mouth of the burrow with a felted mass of silk. It then retires about 10in. down the burrow to pupate. After metamorphosis, the pupæ moves up to the mouth of the burrow and projects itself about 2in. into the open before the moth emerges. These pupæ cases are often seen protruding from the ground as the moth has left them. The moth itself has a wing span of 3 to 4 inches.

The caterpillar was received just at the time when it was ready to pupate, and was apparently burrowing to the surface when it encountered the cable, and it went on burrowing blindly into the cable sheath, since its powerful mandibles would not experience any great difficulty with the lead sheath. However, contact with the live conductors in the cable deterred it from further burrowing, at which time it was unearthed. The failure is thus a matter of pure chance in that the caterpillar should have encountered the cable on its way to the surface.—S.D.C.

ANSWERS TO EXAMINATION PAPERS

The answers to examination papers are not claimed to be thoroughly exhaustive and complete. They are, however, accurate so far as they go and as such might be given by any student capable of securing high marks.

EXAMINATION No. 2425—MECHANIC, GRADE 2

K. B. Smith, B.Sc.

(Continued)

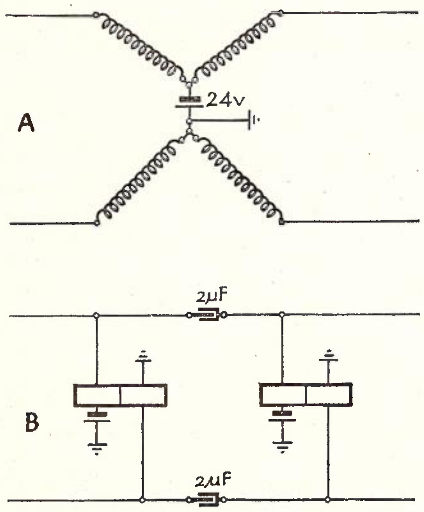
Q. 5.—(a) Describe briefly and furnish diagrams of two common methods of feeding current to subscribers' transmitters for C.B. and Automatic exchanges.

(b) What would be the effect of a resistance of 10 ohms in the main discharge busbars of a C.B. exchange?

A.—(a) The sketches A and B, Fig. 1, show two methods of supplying current to subscribers' transmitters for C.B. exchanges. They are known as the repeating coil and condenser impedance methods respectively.

In the repeating coil method the coil has four equal windings connected as indicated. A steady voltage is applied to each subscriber's transmitter through the windings of the repeating coil. The speech currents are superimposed on the constant D.C. current flowing and are induced from one side of the repeating coil to the other.

The second method known as the condenser impedance method has a $2\mu F$ condenser connected in each leg of the circuit. The impedance coils are connected across the circuit on each side of the condensers as shown. The steady D.C. voltage is fed to the subscriber's transmitter in exactly the same manner as in the previous method. There is no inductive coupling between the coils on each side in this case and the A.C. speech currents are transferred from one side of the connecting circuit to the other through the $2\mu F$ condensers, which, while offering a high resistance to the flow of D.C., offer a relatively low impedance to the voice currents. The impedance coils prevent the battery from shunting the speech currents.



Q. 5, Fig. 1.

(b) The resistance of a C.B. secondary battery and busbars may be considered to be zero. In these circumstances any number of parallel circuits can be connected across the battery without varying the current in the individual circuits. However, if a 10 ohm resistance is inserted in the battery feed, the current in the individual circuits would be reduced as more parallel circuits were connected across the battery.

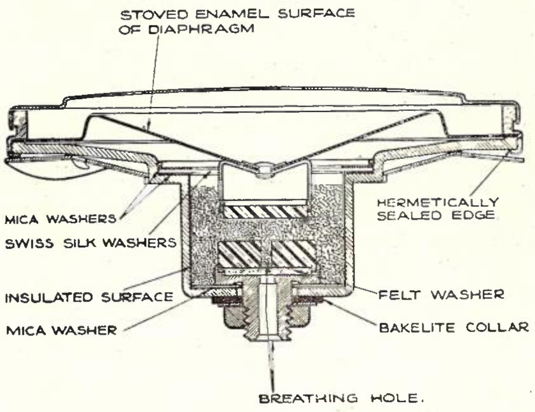
The following example shows this:—

Let the battery voltage $= E = 22$ volts.
The subscriber's loop resistance $= R = 88$ ohms.
Then for each subscriber having a loop resistance $= R$ connected to the battery the current in the loop $= I = E/R = 22/88 = 0.25$ amps.

If a 10 ohm resistance is inserted in series with the battery, for 1 subscriber's loop connected $I = E/(10 + R) = 22/98 = 0.22$ amps. For 10 subscribers' loops connected, $I = E/(10 + R/10) \times 1/10 = 22/(10 + 88/10) \times 1/10 = 22/188 = 0.11$ amps. approx., so that the current is reduced as the number of subs. lines connected to the battery is increased.

Q. 6.—Draw a sketch and explain the principle of operation of a modern inset type of telephone transmitter.

A.—Fig. 1 shows a sectional view of a carbon granule type inset transmitter. It has a conical diaphragm of light metal which has a hollow cylinder of similar material fixed to its apex. The cylinder has an end plate of polished carbon which projects into the granule chamber through silk and mica washers. The other electrode is fixed to the outer case but insulated from it, the walls of the granule chamber are insulated with enamel as otherwise they would shunt the electrodes.



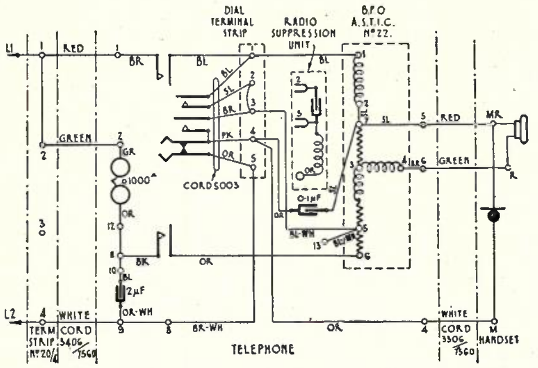
Q. 6, Fig. 1.

The electrical resistance between two electrodes is governed by the contact between the carbon granules which separate them. When the granules are compressed, the contact resistance between them is reduced, thus lowering the resistance between the electrodes. When the pressure is reduced, the resistance rises.

The moving parts are very light and they vibrate in sympathy with sound waves which strike the diaphragm. The change of pressure applied to the carbon granules causes a change in resistance at the terminals of the transmitter. If a battery is connected in series with the transmitter the direct current is varied in sympathy with the sound acting on the diaphragm giving rise to an A.C. component which contains all the frequency and amplitude characteristics of the original sound waves.

Q. 7.—Draw a schematic circuit of a handset telephone. Briefly describe the method of operation.

A.—Fig. 1 shows the circuit of a 332 automatic telephone. When C.B. working is required the dial is omitted and terminals 4 and 5 on the dial cord terminal strip are strapped. The operation of the circuit is briefly as follows:—



Q. 7, Fig. 1.

Incoming Calls:—Ringing current flows from L1 through the magneto bell 2μF condenser to L2.

Transmission:—The battery is fed to the transmitter from the battery feeding bridge in the exchange final selector or equivalent. The circuit is from L1, through the cradle switch contacts, induction coil windings 1-2, transmitter, dial impulse springs, to L2. Portion of the A.C. current flows from the transmitter through the induction coil winding 7-3, 3-5, 5-6, cradle switch contacts 2μF condenser, dial impulse springs and back to the transmitter. The remainder flows from the transmitter through the induction coil windings 1-2, cradle switch contacts to L1 and from L2 back through the dial impulse springs to the transmitter. The induction coil windings 1-2 and 3-5, act as an auto transformer with 3-5 as the primary and 1-2 and 3-5 as the secondary. These match the transmitter to the line and give a greater transference of power to the line than would otherwise be the case.

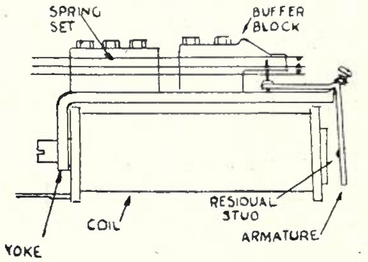
Reception:—In the receiving circuit a major part of the voice frequency passes from L1 to cradle switch contacts, induction coil winding 1-2, transmitter, dial impulse springs to L2. The circuit, induction coil windings 7-3, 3-5, 5-6, cradle switch contacts, 2μF condenser, dial impulse springs has a higher impedance than the transmitter and therefore little current flows over this part. Current is induced in the induction coil winding 3-4 due to current in the winding 1-2 and 3-5. This causes current to flow through the receiver circuit composed of induction coil winding 7-3, 3-4 and receiver.

Side Tone Control:—The current induced in induction coil winding 3-4 from the transmitter by the opposing effects of windings 1-2 and 3-5 is balanced out by the current flowing in the resistance 3-7 which is introduced in the circuit for this purpose. The current in 3-7 is always in opposition to the net current in 3-4 originating from the transmitter.

Q. 8.—With the aid of a sketch describe the construction of a 3,000 type relay. Explain the reason for any special features in the construction.

A.—The main features of the standard 3,000 type relay are shown in Fig. 1.

The coil of enamelled copper wire is wound on a soft iron core which is secured by a nut, to the yoke. The end of the yoke is formed into a knife edge, against which the armature is held by a retaining screw and spring. The armature is prevented from touching the core, when operated, by the use of a brass residual stud or screw. If a fixed residual air gap is required a brass stud is riveted to the armature, but if an adjustable gap is necessary a brass screw is threaded through the centre of the armature and locked in position with a nut. The contact springs are separated from one another by insulating material and are clamped between plates as complete units, one of which can be secured to the yoke on either side of the buffer block. The buffer block is made of white insulating material and projections on the fixed contact springs rest upon shoulders in this block.



Q. 8, Fig. 1.

There are several special features in the construction of the standard relay:—

(i) Each spring is slotted from the front end for a short distance along its length and a contact is riveted to each tongue. The twin contacts reduce the liability to contact faults, and the degree of independent flexibility resulting from the slotting ensures even distribution of pressure between the two contacts of each spring.

(ii) The use of the central block for controlling the positioning of the fixed springs facilitates adjustment of the spring sets, by providing a firm support against which the springs can be tensioned. It ensures that adequate contact pressure is obtained, by arranging for the tension spring to be just lifted from the block by the moving spring. The light color of the block provides a good background against which all springs can be viewed.

(iii) The poleface is of larger cross section than the core, resulting in an improved magnetic circuit and consequent magnetic efficiency.

(iv) The provision of the armature retaining spring and screw enables the relay to be mounted on its side while still retaining the correct knife edge contact between yoke and armature.

(v) The coil, core and the spring sets are detachable as separate units from the yoke, and it is an easy matter to replace these items.

(vi) The knife edge on the yoke, and the corresponding recess in the armature are ground to correct shape, and provide an efficient magnetic joint, having the minimum resistance to armature movement.

Q. 9.—In the subscriber's premises, what test would you make to ensure the satisfactory working order of a cord type C.B.P.B.X.?

A.—To ensure a satisfactory working of a cord type C.B.P.B.X. the power lead voltage should be checked at the P.B.X. busbars when the switchboard is under load to ensure that the voltage drop is not excessive.

Exchange Line Indicators:—Each drop indicator should be tested from the test desk by ringing on the exchange line concerned; the night alarm circuit should be checked for each test. The resistance of the hold coil associated with each exchange line circuit should be checked from the test desk.

Extension Line Indicators:—At the extension line terminal strip at the rear of the switchboard a 500 ohm test pencil should be connected to the A. and B. terminals of each extension line in turn. Each eyeball indicator should operate completely and restore promptly when released. The night alarm circuit should be checked with each test.

The following tests should be applied to each cord circuit:—

(i) Both supervisory indicators should operate completely when the answering plug is raised from the plug seat switch.

(ii) Insert the answering plug in test jack A. The answering supervisory relay should operate and the answering supervisory indicator should restore.

(iii) Operate the testing key to position 1 and operate the ringback key; a ring should be heard on the test bell. Withdraw the plug and restore the test key.

(iv) Repeat the above tests with the calling plug. In this case the calling supervisory relay and indicator will operate and restore respectively and with the test key in position 1, the ring should be heard on the test bell when the ringing key is operated.

(v) Check operation of night alarm buzzer with each clearing indicator.

(vi) Insert the answering plug in test jack "B." Relay AX operates, answering supervisory indicator should restore. B.C.O. relay operates and removes battery from the cord circuit under test (if cord circuits are not equipped with AX relays the answering supervisory indicator will not restore).

(vii) When the calling plug is inserted in test jack "A," both supervisory relays should operate in series and the calling supervisory indicator and the AX relay should restore. This proves the continuity of the A and B sides of the circuit.

(viii) Operate the speaking key. Hold the answering plug and shake the cord. Fractured cord conductor strands will be indicated by a scraping noise heard in the telephonist's receiver.

(ix) Check telephonist's circuit for side tone. Withdraw the calling plug, both supervisory indicators should operate.

(x) Operate the test key to position 2, when ringing tone should be heard in the telephonist's receiver. This proves the transmission condensers in the cord circuit. Restore the answering plug. Insert the calling plug in test jack "B" and answering plug in test jack "A" and repeat test (viii).

Telephonists' Telephones:—Each telephonist's set should be checked with a volume indicator or by means of the transmission efficiency test circuit if the former is not available. Each should be tested to detect electrical contact and low insulation resistance between the metal frame work of the set and the electrical circuits. A megger, if available, should be used for the purpose. Where a megger is not available, a ringing machine or hand generator associated with the switchboard should be used, contact being indicated by the operation of the ringing vibrator or the pull on the hand generator.

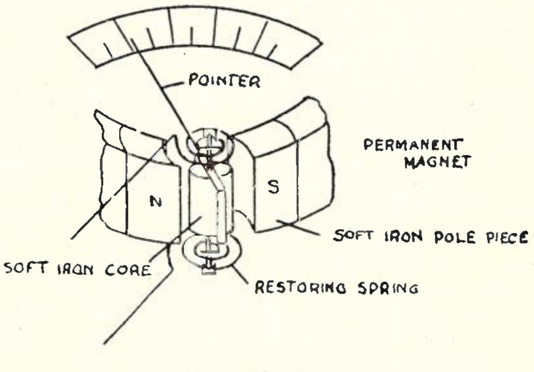
Q. 10.—(a) List the components required for an intercommunication service to provide for 2 exchange lines, 6 internal and 1 external extension lines.

(b) Exchange calls are secret, whereas extension to extension calls are not. Describe briefly the difference in circuit conditions for the two classes of call.

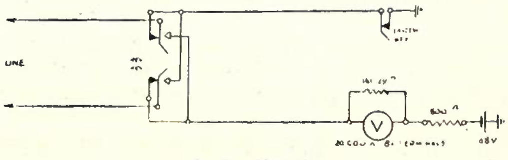
A.—(a) The components required are:—Intercommunication telephones No. 2 (with terminal boxes)—6; Unit, Transfer No. 3A—1; Telephone 332AT (for external extension)—1; Protectors H. C. & F. 2/2—4.

(b) For extension to extension call, the operation of an extension key on a telephone connects the calling extension to the A and B wires in the multiple corresponding to the called extension. As this pair is multipled to all extensions no secrecy is provided, as by pressing the appropriate key any extension can connect across the pair. For an exchange call, the depression of an exchange line key on a telephone connects a relay AA in the telephone to the "D" wire, which will be earthed at the transfer unit if the exchange line is not engaged. The AA relay operates to this earth and connects the extension telephone circuit to the exchange line. The AA relay also earths the "C" wire to operate a control relay in the transfer unit. The springset associated in this relay removes the earth from the "D" wire. The connection to the extension telephone to the exchange pair is dependent upon the operation of the AA relay, which in effect first tests whether the line is busy. Exchange calls are secret, as, if another extension depresses the key of an engaged exchange line, relay AA will not operate due to the removal of earth from the "D" wire, but the caller's buzzer will operate. When an extension is engaged on an exchange call, the circuit for connection to other extensions is disconnected by the exchange key springset, and thereby prevents other extensions from listening on the exchange call.

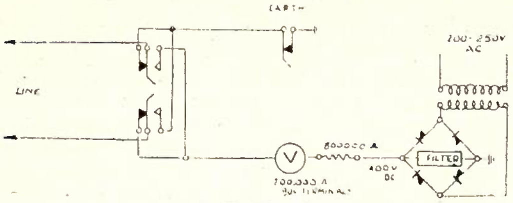
NOTE.—In Vol 4, No. 4, pages 250 and 251, the figures referred to in Questions 1 and 2 were inadvertently omitted. These figures are shown hereunder:—



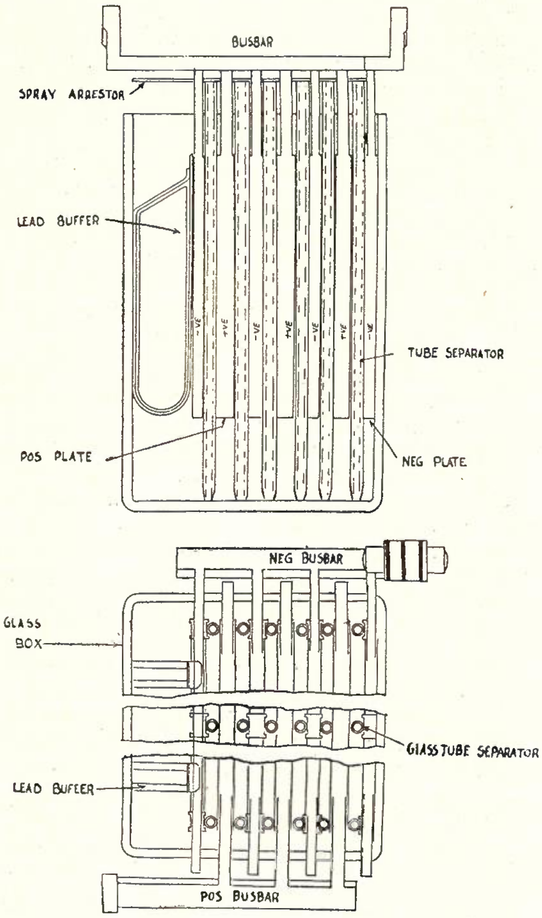
Q. 1, Fig. 1.



Q. 1, Fig. 2.



Q. 1, Fig. 3.



Q. 2, Fig. 1.

EXAMINATION NO. 2381—SUPERVISOR, TELEGRAPHS

(Continued from Page 183)

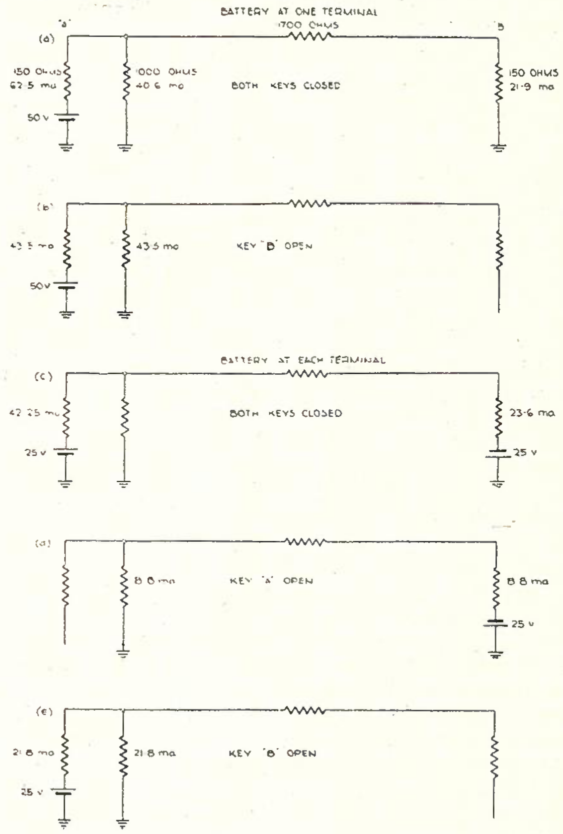
R. G. Mills.

Q. 1.—Discuss the advantages of providing a main battery at each terminal of a simplex telegraph channel as compared with those associated with a single battery at one end only, particularly in respect of heavy leakage conditions occurring on one section of the channel located in close proximity to one terminal. Assume certain voltages, conductor, and insulation resistance values, and amplify your answer arithmetically.

A.—The resistance, and therefore the length, of a simplex telegraph channel is the factor that determines the location of a battery at each terminal. This permits the limitation of the potentials to safe values, minimises leakage, and provides battery for the operation of the circuit on each side of any fault. Short telegraph lines can be operated with a suitable main battery at one terminal.

Assume that the line to be considered has a resistance of 1,700 ohms, and is equipped with one 150 ohm relay at each terminal, with a battery of 50 volts as the source of current. The leakage path is of 1,000 ohms resistance, and is placed against station A (Fig. 1). With the 50 volts at station A, the working margin at A is 62.5—43.5 = 19 mAs on a very high adjustment, while that at B is 21.9—0 = 21.9 mAs. The adjustment of the relay at A is difficult, and at B easy.

If the battery is divided into two sections and 25 volts placed at each terminal, the working margins are:—A, 42.25 — 21.8 = 20.45 mAs, and at B, 23.6 — 8.8 = 14.8 mAs. Therefore, the adjustment of the relay at A is slightly easier, but at station B the adjustment of the relay would be considerably more difficult, as the working margin is 7.1 mAs less. Fig. 1 shows the current values in the different conditions.



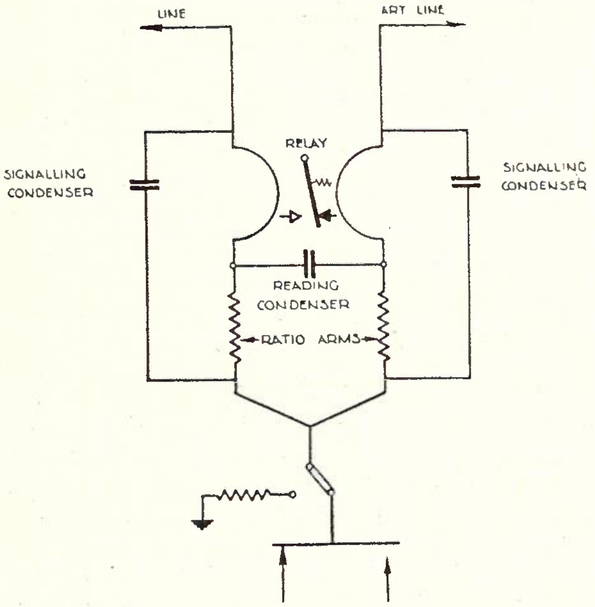
Q. 1, Fig. 1.

Q.—2.—Discuss fully the advantages associated with the application of reading and signalling condensers to high-speed differential duplex operation.

A.—The signalling and reading condensers are arranged on a differential duplex set as shown in Fig. 1. The signalling condensers act as a temporary short circuit to the ratio arms and relay coils, so that when a potential is applied to the line there is a momentary surge of current, which charges the line and starts the operation at the distant end. If such condensers were not provided the line current would rise very slowly, due to the inductance of the home relay coils and line capacity, and some time would elapse before the line was completely charged and the current reached sufficient value to operate the receiving instrument.

The signalling condensers are charged to the potential across the ratio arms and relay coils. When the direction of the current in the line is reversed the condensers discharge, and momentarily act as a source of potential in series with the reversing battery. This enables a quick discharge and recharge of the line capacity to take place, and so increases the speed of working. The use of shunted condensers, therefore, permits the benefits of a higher E.M.F. without disadvantages such as sparking, extra battery resistance, and cost.

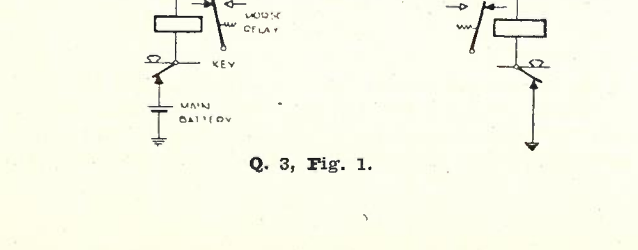
The signalling condensers adversely affect the incoming signal, the first portion of which is lost by their short-circuiting effect. To offset this disadvantage a shunted condenser, called a reading condenser, is placed across the relay as shown in Fig. 1.



Q. 2, Fig. 1.

Q.—3.—Simultaneous telephonic and telegraphic transmission is obtainable over a pair of telephone wires. Explain how a Cailho telegraph channel is derived. Illustrate your answer with diagrams, and designate each piece of apparatus used.

A.—The principle of the Cailho circuit is shown in Fig. 1. The telephone currents pass through the transformers and traverse the metallic loop. The centre points of the line windings of the transformers are connected to earth through the telegraph equipment. The telegraph currents pass through both lines in parallel, and use the earth as a return path. The telegraph currents enter the transformers in such a manner that the two halves of the line windings develop equal but opposite magnetic fields, which cancel, and consequently there is no transfer of energy between the two windings of each transformer. The telegraph currents, therefore, do not affect the telephone system.



Q. 3, Fig. 1.

The Cailho method of simultaneous telephony and telegraphy is dependent upon equal telegraph currents in each conductor, and it is therefore essential that the wires be exactly alike in regard to conductor and insulation resistance, and capacity. Similarly, the windings of the transformers must be exactly balanced. The object of the dual arrangements of the channel is to save line plant. The telephone system is slightly less efficient than in the case of an exclusive telephone circuit, while the telegraph channel is suitable for manual or machine operation. The telegraph channel has approximately half the resistance but double the leakage of an exclusive wire.

EXAMINATION NO. 2377—ENGINEER TELEGRAPH EQUIPMENT

A. R. Glendinning.

Q.—1.—Prepare a list of the apparatus you would require to equip a simplex telegraph circuit leading out from a C.T. office and serving 10 country offices, assuming the following:—

(1) The offices are 50 miles apart, the total length of circuit being 500 miles.

(ii) The line consists of a single 100lb. p.m. H.D.C. wire.

(iii) The maximum permissible line current is 18 m.A.

(iv) The maximum permissible line voltage is 50 volts.

(v) The minimum line I.R. may be assumed at 7,500 ohms, the leakage being distributed uniformly. You may regard the leakage path in any one section as a simple resistance.

A.—Under the given conditions the highest permissible voltage, 50 volts, should be used. This will necessitate the provision of a 50 volt battery at both ends of the circuit. A check of the current is necessary, and can be made by taking half the line, i.e., from maximum to zero voltage, and, using the constitutional method of assuming the leakage path as a parallel circuit, a sufficiently close approximation may be obtained.

Conductor resistance from line jacks at C.T.O. to midway office equals 2,200 ohms. Resistance of morse relays equals 750 ohms. I.R. half line equals 15,000 ohms.

From these values, the apparent resistance from the line jacks = 2,465 ohms. Voltage to provide maximum current of 18 m.A. through this resistance = $2,465 \times 18 \times 10^{-3} = 44.42$ volts.

The drop to the line jacks must be therefore 5.6 volts, and the resistance to give this drop is 311 ohms on the battery side of line jacks. This resistance is provided by the morse relay and the battery resistor. As the morse relay resistance is fixed, a battery resistor of not less than 160 ohms will be needed. The nearest standard vitreous resistances are 150 and 200 ohms, and the 200 ohms is selected.

At the C.T.O. it is assumed that the 50 volt and the 24 volt local battery leads are available at the table, so the equipment required here will be:—

- 1 200 ohm vitreous resistance and socket.
- 1 supervisory lamp, 48 volt, complete with socket and standard.
- 1 S.P. 5 amp tumbler switch.
- 1 milliammeter, 50-0-50.
- 1 morse relay, 150 ohm.
- 1 morse sounder, 900 ohm.
- 1 resonator and cord.
- 1 key morse C.C., with jack.
- 1 form holder, large.

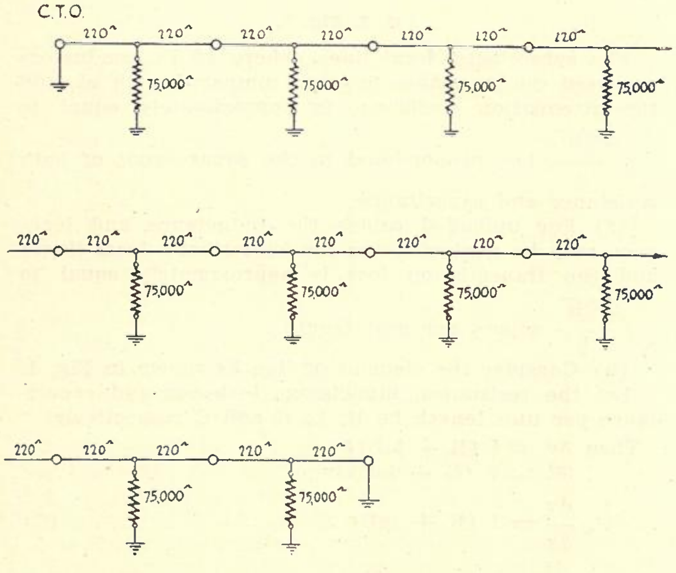
Equipment at each country station:—

- 1 Section switch.
- 1 morse relay, 150 ohm.
- 1 morse sounder, 20 ohm, with cord and resonator.
- 1 key morse, C.C., with jack.
- 2 Leclanche cells, No. 3.
- 1 battery box.
- 1 form holder, large.

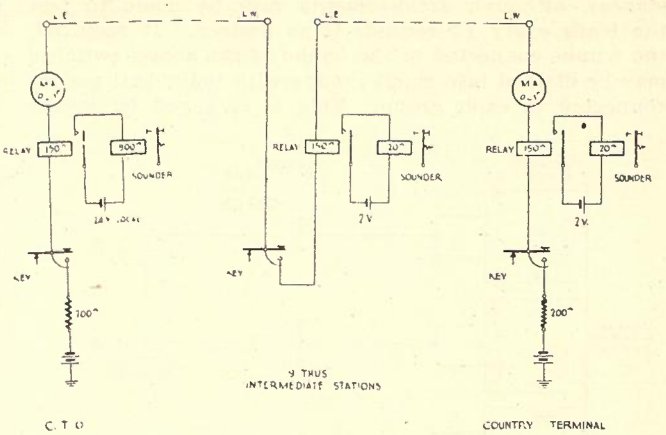
At the country terminal, if no existing power supply is available, power supply would be arranged from the following equipment, depending on circumstances and facilities for maintenance. If A.C. power available from mains, 1 metal rectifier, panel mounted, with smoothing equipment to give 50 volts, with main switch, fuses, D.C. switch, and protective resistor would be suitable. If A.C. not available, two petrol engine driven dynamos with associated fuses, resistances, and switch gear to give required voltage could be provided, or 50 No. 3 Leclanche cells as the alternative. In the last case the vitreous battery resistance value would be reduced by 100 ohms.

Q. 2.—For the circuit described in Question 1 prepare a schematic diagram from end to end showing apparatus and the line resistance values. Do not attempt to describe the functions of the apparatus.

A.—See Figs. 1 and 2 showing line and apparatus resistances.



Q. 2, Fig. 1.



Q. 2, Fig. 2.

(To be Continued.)

EXAMINATION NO. 2377—ENGINEER TELEPHONE EQUIPMENT

E. J. Bulte, B.Sc.

Q. 1 (a).—Describe the main features of any system with which you are acquainted for recording automatically the traffic in an automatic exchange. State how the recorder is connected to the exchange apparatus, what information it records, and how you would calculate traffic units from the data obtained.

(b).—Traffic records taken in an automatic exchange show that selectors in a full-availability group of five were engaged simultaneously during the busy hour as follows:—

5 selectors engaged for 6 minutes.
4 selectors engaged for 18.5 minutes.
3 selectors engaged for 14 minutes.
2 selectors engaged for 12.5 minutes.
1 selector engaged for 9 minutes.

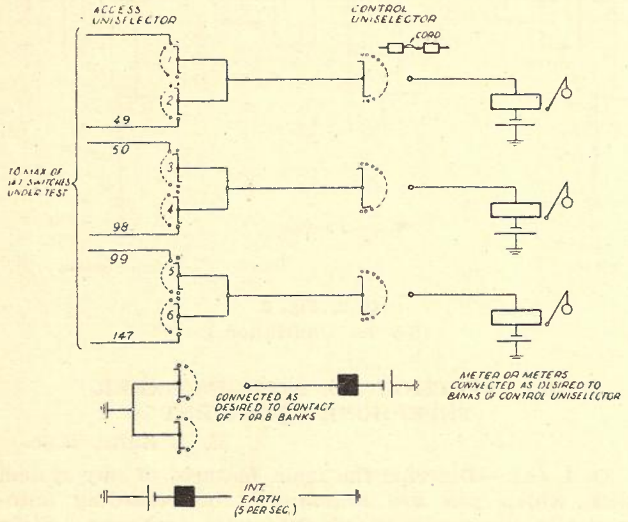
Assuming pure chance traffic, and taking the average duration of a call as 2.5 minutes, calculate for the busy hour:

(i) the number of traffic units;
(ii) the number of calls connected;
(iii) the number of calls lost;
(iv) the grade of service.

A.—(a).—In an automatic exchange the amount of traffic carried by any particular group of switches or trunks may be measured by observing the number in use simultaneously during a period. This is done automatically by an automatic traffic recorder, the elements of which are shown in Fig. 1, the main features of the system being as follow:—

A lead from the private wire is brought from each piece of apparatus on which it is required to take records. This lead becomes earthed whenever the associated apparatus is busy. The recorder tests these leads at required intervals, and a register is operated for every one found earthed. The leads are wired out via a jumpering field to the banks of eight level uniselectors, called access switches, the latter being connected to the registers via a five-level uniselector called a control switch.

When the recorder is started, pulses at the rate of five per second are fed to the access switches, which rotate and test the leads abovementioned. This cycle is repeated over 30 seconds under ordinary circumstances, although arrangements may be made to test the leads every 12 seconds if so desired. If required, the trunks connected to the banks of the access switches may be divided into small groups with individual meters connected to each group. This is arranged by means of suitable strappings on the 7th and 8th banks of the access switches in conjunction with connection of the appropriate meters to the control switches by means of the double-ended single-way cords provided. By this means the traffic on small portions of a grading group may be individually recorded. The apparatus is provided with an alarm system to indicate a failure of the access or control uniselectors to step correctly and a safeguard against false records is therefore given.



Q. 1, Fig. 1.

If the total number of engaged tests during the period of test is divided by the number of tests made during a period, the result will give the traffic in traffic units carried by the group on which records are being taken. For example, if the total number of engaged tests were 240 for a period equal to the average holding time and the number of tests were 12, then 20 T.U. was carried by the group under test.

(b).—If A is traffic units, C = number of calls in the busy hour and T = average time taken for a call, then A = CT.

(i) Number of traffic units
= number of switches occupied by duration of occupancy
= 1 × 9/60 + 2 × 12.5/60 + 3 × 14/60 + 4 × 18.5/60 + 5 × 6/60 = 2.997 T.U.

(ii) Number of calls connected
= A/T
= 2.997/2.5 × 60
= approximately 72 calls.

(iii) Number of calls lost.—During 0.1 of the busy hour, all five selectors are engaged, therefore, any calls originating during this period will be lost, i.e., average number of calls lost = 72 × 0.1 = approximately 7 calls lost.

(iv) Grade of service.—The ratio of number of calls lost to the number offered during the busy hour = 7/(72 + 7) = approximately .09.

(To be continued.)

EXAMINATION NO. 2377.—ENGINEER—TRANSMISSION

J. E. Freeman, B.Sc., A.M.I.R.E.(Am.)

Q. 1.—(a) What are the electrical properties known as the "primary constants" of a telephone line? Discuss the relative importance and effect of these properties on transmission loss at speech frequencies over (1) an open wire line, (2) an unloaded cable.

(b) Show how the attenuation loss per unit length of a circuit may be calculated from the values of the primary constants.

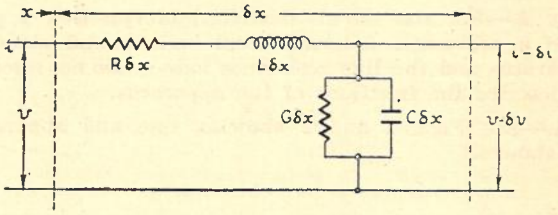
A.—(a) The primary constants of a telephone line are the Resistance per unit length (R), the Inductance per unit length (L), the Leakance per unit length (G), and the Capacitance per unit length (C).

The attenuation loss per unit length of the circuit is given by the formula:

$$\sqrt{\tfrac{1}{2}\left[\sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)}+(GR-\omega^2LC)\right]}$$

Unless the relationship R/L = G/C holds; the attenuation will increase with increase of frequency.

(1) For an open wire line, changes in weather conditions normally produce large variations in the leakance of the line. It is difficult to allow for these variations, but fine weather conditions can be calculated and then a percentage added (approximately 25%) to the attenuation to provide for wet weather. In fine weather, the leakance may be neglected and the following formulæ apply: — If 200 lb. or heavier conductors are used, the resistance is small compared with ωL and the attenuation coefficient $\propto$ is approximately equal to $\frac{R}{2}\sqrt{\frac{C}{L}}$. The attenuation is, therefore, proportional to the resistance, and the square root of the capacitance and is inversely proportional to the square root of the inductance.



Q. 1, Fig. 1.

For subscribers' local lines, where 40 lb. conductors are used the resistance is large compared with ωL and the attenuation coefficient is approximately equal to $\sqrt{\frac{\omega CR}{2}}$, i.e., proportional to the square root of both resistance and capacitance.

(2) For unloaded cables the inductance and leakance may be neglected (as for subscriber's local lines) and the transmission loss is approximately equal to $\sqrt{\frac{\omega CR}{2}}$ nepers per unit length.

(b) Consider the element of line δx shown in Fig. 1. Let the resistance, inductance, leakance and capacitance per unit length be R, L, G and C respectively.

Then $\delta v = i\,(R + j\omega L)\,\delta x$
$\delta i = v\,(G + j\omega C)\,\delta x$

$$\therefore \frac{dv}{dx} = i\,(R + j\omega L) \qquad (1)$$

$$\text{and } \frac{di}{dx} = v\,(G + j\omega C) \qquad (2)$$

Differentiate (2) with respect to x and substitute (1)

$$\therefore \frac{d^2i}{dx^2} = i\,(R + j\omega L)\,(G + j\omega C) = P^2 i \quad \text{.... ....}\ (3)$$

This equation has a general solution of the form

$$i = Ae^{Px} + Be^{-Px}$$

However,

$$\text{when } x = 0,\ i = i_o \quad \therefore A + B = i_o$$
$$\text{when } x = \infty,\ i = 0 \quad \therefore A = 0$$
$$\text{and } B = i_o$$
$$\therefore i = i_o e^{-Px} \quad \text{.... ....}\ (4)$$

P is known as the Propagation Constant and its real portion ($\propto$) is the Attenuation Constant of the Line,

i.e., $\propto + j\beta = P = \sqrt{(R + j\omega L)\,(G + j\omega C)}$

Squaring

$$\propto^2 - \beta^2 + 2j\propto\beta = RG - \omega^2 LC + j\omega\,(LG + RC).$$

Equating real and imaginary parts

$$\propto^2 - \beta^2 = RG - \omega^2 LC \quad \text{.... ....}\ (5)$$
$$2\propto\beta = \omega\,(LG + RC)$$

But since $(\propto^2 - \beta^2)^2 = (\propto^2 + \beta^2)^2 - (2\propto\beta)^2$

$$\therefore \propto^2 + \beta^2 = \sqrt{(R^2 + \omega^2 L^2)\,(G^2 + \omega^2 C^2)} \quad \text{.... ....}\ (6)$$

Adding equations (5) and (6)

$$\propto^2 = \tfrac{1}{2}\,[\sqrt{(R^2 + \omega^2 L^2)\,(G^2 + \omega^2 C^2)} + (RG - \omega^2 LC)]$$
$$\therefore \propto = \sqrt{\tfrac{1}{2}\,[\sqrt{(R^2 + \omega^2 L^2)\,(G^2 + \omega^2 C^2)} + (RG - \omega^2 LC)]}$$

EXAMINATION NO. 2377.—ENGINEER—LINE CONSTRUCTION

J. R. Newland

Q. 5.—It is proposed to establish a new exchange in a metropolitan area in which a number of exchanges exist.

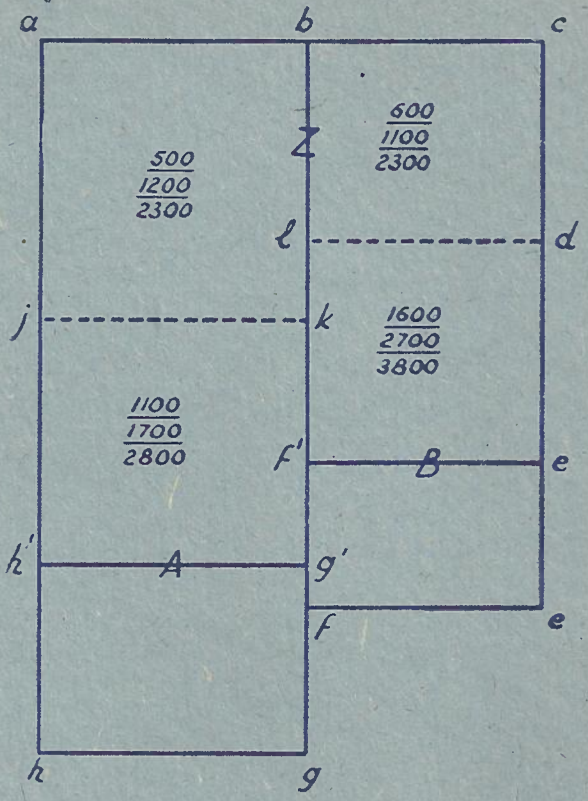
What steps would you take from a "Lines" point of view to ascertain the most suitable location of the exchange, and to what special features and economic considerations would you give preference, stating your reasons therefor? Illustrate your answer by stating a suppositious case.

A.—It is necessary to make an economic comparison between building up existing plant, including conduit and cable routes, exchange equipment, and the associated building, and the saving which would be accomplished by reducing line plant requirements, consequent on the decision to establish a new switching centre. The need for a new exchange is usually first apparent by the difficulty experienced in providing services to an area along a particularly heavy conduit route from one or more adjoining exchanges.

The first requirement is to procure an up-to-date study of the area showing present, 8, 15 and 20 years development, not only of the probable new exchange area, but of the other existing exchange areas affected. From this, the definite area to be served is arrived at after taking into account the ultimate capacity of existing conduit routes and physiographical barriers.

When the new exchange area has been delineated, the theoretical copper centre is obtained by dividing up a plan of the area into equal squares of approximately the size of the average street block and totalling the development figures for each block. The totals for each square are then added both vertically and horizontally, and the position found where the number of lines north and south, and east and west are equal. This theoretical centre may not be suitable perhaps because of high land values, distance from existing main conduit routes to be retained, or unsuitability of the land due to difficulty of access, liability to flooding, building restrictions, etc.

The exact site is therefore chosen after preparing a financial comparison of new line work required, both immediate and future, price of land, and cost of special work needed before building is commenced.



Q. 5, Fig. 1.

Two exchanges A and B serve areas a b g h and b c e f, the underground cable and the exchange equipment in both areas are nearing saturation. The alternatives would be:—

(i) To extend the underground cable and exchange equipment in the two areas and continue to serve from exchanges A and B respectively.

(ii) To subdivide areas a b g h and b c e f by the broken lines j k and l d, as shown, and to continue to serve the smaller areas j k g h and l d e f from the original exchanges, and to serve the remainder of the combined areas (a c d l k j) from one exchange Z.

The costs associated with the areas below the lines h'g' f'e' are common to both proposals and are not included in the comparison. The present, 8 and 20 year development figures for the areas concerned are shown in the sketch.

The method of arriving at the comparative costs of each proposal is as follows:—

Proposal (1):

Retain and expand exchanges A and B and increase internal and external plant. Existing exchange plant, 3,800 lines; existing underground plant, 20,000 wire miles.

Exchange installation immediately, 2,900 lines, cost £36,000.

Exchange installation in 8 years, 4,500 lines, cost £54,000.

U.G. cable installed immediately, 13,000 wire miles, cost £26,000.

U.G. cable installed in 8 years, 9,000 wire miles, cost £18,000.

[Continued on Cover ii.

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