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THE EARTHING OF TELEPHONE SYSTEMS WITH PARTICULAR REFERENCE TO SOUTH AFRICA

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SUMMARY

Provided the resistivity of the ground in the vicinity of a proposed earth electrode is known down to a depth of about 20 feet, the resistance of the earth connection may be calculated with a fair degree of accuracy.

A comparison of earth plates, grids, rods and horizontal wires reveals the superiority of the latter, particularly in the high-resistivity soils of South Africa.

The impulse characteristics of soil and various electrode systems are considered. It is concluded that the low-frequency resistance is an adequate criterion as far as telephone-system earths are concerned.

A brief survey is made of the ranges of resistivities likely to be encountered in soils and rocks in South Africa. Some practical suggestions are made for obtaining satisfactory earths, and a comparison of the costs of various earthing arrangements is given.

The more important overseas references are given together with several references pertaining to South Africa.

CONTENTS

1. INTRODUCTION

During the past four or five years the Post Office has been conducting investigations into the effects of lightning on telephone and telegraph equipment. Since the resistance of the earth connection plays an important part in the protection of such equipment from damage by lightning it was important to examine the subject in some detail.

The object of this paper is to summarize the factors involved in earth connections for telephone systems, with particular reference to South African conditions.

Considerable effort has been devoted during the past fifteen years to the problems of determining the most economical way of providing an earth connection and forecasting its resistance. In spite of the extensive literature on the subject, most earth connections are based on rule-of-thumb methods, much of the planning being left to the imagination or inclinations of the workmen installing the earth. With a knowledge of the local earth resistivity it is possible to determine the type and size of electrode required to provide in the most economical manner, a connection of any desired resistance.

Although much of what follows is applicable to power-system earthing also, certain distinctions should be made. The main function of a telephone earth is to dissipate lightning currents. Since these currents are due to induced lightning surges or, very occasionally, direct strokes to the line, the current-carrying capacity is not a problem.

The maximum current crest values will rarely exceed 500-800 amperes (for one pair of wires) with a total wave duration of not more than 2 to 5 milliseconds. If 30 or 40 wires are involved, the total current may reach a maximum value of 3,000-4,000 amperes. In the case of power systems, the earth connection has to cope with direct lightning strokes and power fault currents. For the same reason the voltage gradient in the earth system and surrounding earth does not present a problem in telephone earths.

Since this paper deals primarily with earth electrodes for protecting telephone systems against lightning damage, the effects of frequency have not been considered, other than to state the effective impedance to impulse voltages. For earth electrodes of moderate lengths, the inductance plays a very small part even up to very high frequencies. It is, however, important to keep the length of the lead to the earth electrode as short as possible to reduce self inductance.

Due mainly to the low average rainfall and generally shallow soil strata encountered in South Africa, the average resistivity is considerably higher than that for Europe or America. Thus recommended practices for this country will differ in some respects from those for either of the latter two continents.

2. RESISTANCE OF AN EARTH CONNECTION

The resistance of an earth connection is made up of three components:—

(i) The resistance of the electrode itself and the associated leads. This is usually low and may be ignored.

(ii) The contact resistance between the electrode surface and the adjacent soil. This is usually small, but may in some cases increase the effective resistance by some 10 per cent. Under surge conditions this resistance may be reduced by arc-over. In addition the contact resistance is

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bridged by the capacitative admittance between the conductor and earth. It is usual to neglect this factor.

(iii) The resistance of the volume of soil surrounding the electrode. The bulk of the resistance lies in the soil or rock surrounding the electrode. The volume concerned varies with the shape and size of the electrode. For a rod practically all the resistance is contained within a hemisphere having a radius 1.5 times the length of the rod. It is thus obvious that an earth system which causes the current to spread through a large volume of earth will have a resistance lower than one in which the current density is high. Since most earths or rocks are poor conductors it is essential to keep the current density as low as possible. It is the linear extension of the electrode that is of importance, not its shape or even its surface area. Special electrode shapes have little or no virtue.

The resistivity of a soil or rock depends on three main factors:—

(i) The grain size.

(ii) The amount and composition of soluble material. The two main constituents of the earth are silicon oxide and aluminium oxide, which are good insulators, and the conductivity of the earth is due in large measure to the salt embedded between these insulators.

(iii) The percentage of moisture.

The conductance is thus partly an electrolytic process and partly a question of the contact resistance between a large number of small particles. If both the moisture and salt content is high, the electrolytic process will probably predominate, whereas when the soil is dry the grain size (and thus the amount of air space between the grains) will have more effect.

It is obvious that the resistivity of soils and rocks will vary a great deal and this subject is dealt with in some detail in Sections 7 and 8.

3. VARIOUS TYPES OF ELECTRODES IN EARTH OF UNIFORM RESISTIVITY

Provided the earth resistivity is known, and is uniform down to an adequate depth, the resistance of an earth connection can be accurately forecast from formulae first developed by Dwight (2) and others (see Appendix II). Figs. 1 to 4 enable electrode resistances to be forecast when the value of the resistivity is known. Most of the graphs have been drawn on a logarithmic scale since the resulting curve is linear (16). The graphs are drawn for a resistivity of 10,000 ohm-cm or 100 meter-ohms. Since the electrode resistance is always directly proportional to resistivity the electrode resistance for any resistivity ρX can be obtained by multiplying the values of these curves by $\rho X/10{,}000$.

A comparative table of the three types of earth electrodes described is given in Table I. In high-resistivity and hard ground the trench earth appears to be the only practicable means of obtaining a low resistance.

The accuracy of the formulae for plate, rod and trench earths has been verified in numerous cases, including many investigated by the Post Office staff in Johannesburg (20).

3.1 Driven-rod earths

Fig. 1 covers a half-inch rod only. Larger-diameter rods or pipes do give lower resistances but the decrease in resistance is not commensurate with the higher cost and they are harder to drive in. An increase of size from 0.5 to 1.0 inch results in a decrease in resistance of only 9 per cent. Since a resistivity of 10,000 ohm-cm is relatively low and not frequently encountered in South Africa, it is seen that a single rod even 12 ft. long will rarely suffice.

If several rods are used in parallel they must be spaced at least the same distance apart as their own depth. The reduction in resistance of several rods compared to a single rod is given in Fig. 2 (provided they are spaced as stated above).

The advantages of rod earths may be summarized as

(i) they may be economically "salted"

(ii) they require no excavation and are therefore the cheapest as far as labour is concerned

(iii) when several spaced rods are used resistivity of layers considerably below the rod depth is brought into play. This is advantageous since resistivity often decreases with depth

(iv) a long rod may reach layers of low resistivity. It would also be less dependent on seasonal variations.

The disadvantages of rod earths are that in South Africa there are few localities where rods can be driven in deeply enough and where the resistivity is low enough to obtain the required electrode resistance. It is not worth while using more than three or four rods in parallel.

TYPE OF ELECTRODE		1 ELECTRODE			2 ELECTRODES			3 ELECRODES			4 ELECTRODES		
PLATE BURIED VERTICALLY WITH TOP EDGE 3 FT. BELOW SURFACE	SIZE (INS.)	12 X 12	48 X 14 Ø		12 X 12	48 X 14 Ø		12 X 12	48 X 14 Ø		12 X 12	48 X 14 Ø	
	OHMS	76	42		45	23		32	17·5		26	14	
HORIZONTAL WIRE BURIED 24 INS. BELOW THE SURFACE (ARRANGED RADIALLY)	LENGTH (FEET)	30	60	100	30	60	100	30	60	100	30	60	100
	OHMS	16·0	9·3	6·1	9·6	5·5	3·5	7·1	4·0	2·6	6·3	3·5	2·2
DRIVEN RODS ½ INCH DIA.	LENGTH (FEET)	3	6	12	3	6	12	3	6	12	3	6	12
	OHMS	100	60	30	60	36	18	43	25	13	35	21	10·5

Ø LONG EDGE HORIZONTAL

TABLE I
Earth resistance of various electrodes (ρ = 10,000 ohm-cm.)

3.2 Plate and grid earths

The resistance of a plate earth varies approximately in inverse proportion to the square root of the area. There is little advantage (see Fig. 3) in using a plate larger than 3 ft. by 6 ft.

A single 1 ft. by 1 ft. grid as used by the Post Office is quite inadequate (76 ohms for $\rho = 10{,}000$ ohm-cm), except in very low-resistivity soils.

If a plate earth does not give a low enough resistance, it is better to multiple

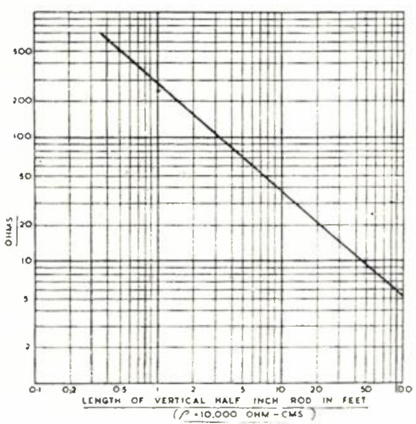


Fig. 1.—Resistance of a rod earth.

the plates than to enlarge the area of the plate. If several plates are used they must be spaced at least 6 ft. apart. The reduction in resistance will be very similar to the curve given for multiple-rod earths (see Fig. 2).

3.3 Buried horizontal wires (or trench earths)

The resistance of such an arrangement is given in Fig. 4. It will be observed that the resistance values are considerably lower than either rod or plate earths.

If there is no variation of resistivity with depth, there is little decrease of resistance when a wire is buried lower than 18 inches. (Going to 36 inches results in only a 5 per cent. reduction of resistance.) However this rarely applies in practice, since the top layers of soil are usually dry (see Section 7.3 for further discussion on this point).

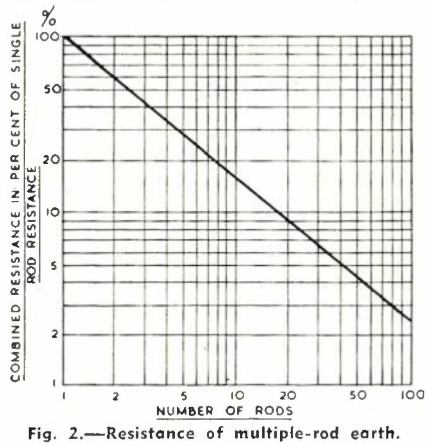


Fig. 2.—Resistance of multiple-rod earth.

There are two reasons why the resistance of a trench earth is lower than that for other types of electrode. Firstly, due to its length it causes the current to spread through a large volume of ground and, secondly, it brings into play the deeper layers of earth which usually have a resistivity lower than the surface layers. The fact that the trench earth may join up with pockets of earth of lower resistivity and thereby reduce its effective resistance is not of great importance.

There is little reduction in resistance when two wires are laid in the same trench, compared to a single wire. Two wires would give a greater degree of immunity against damage. The size of the wire is not important, except that if it is too small, the resistance of the electrode itself becomes important. The wire must also be capable of carrying the lightning current. One or two 150 lb/mile copper wires is a satisfactory arrangement.

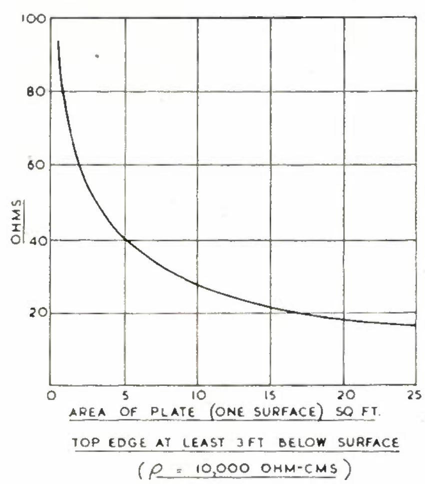


Fig. 3.—Resistance of a plate earth.

It would appear from Fig. 4 that there is nothing to be gained by using several short radial wires compared to the same length of wire laid in one line. The 2-, 3-, 4-, 6- (or more) wire arrangement does, however, have the following advantages:—

(i) For single long wires the resistance of the wire itself may become important (if over 300 yards of single 150-lb/mile copper is used)

(ii) It will often be more practicable to dig several short trenches than a single long one

(iii) As shown in Section 6 the surge impedance of two or more radial wires is lower than for a single long wire.

4. METHOD OF MEASURING RESISTIVITIES AND ELECTRODE RESISTANCES

The methods of making earth-resistivity and electrode-resistance measurements are well known (16,4). The four equally-spaced (Wenner configuration)-electrode method is the one most commonly used for resistivity. For electrode-resistance measurement one current and one potential electrode are combined.

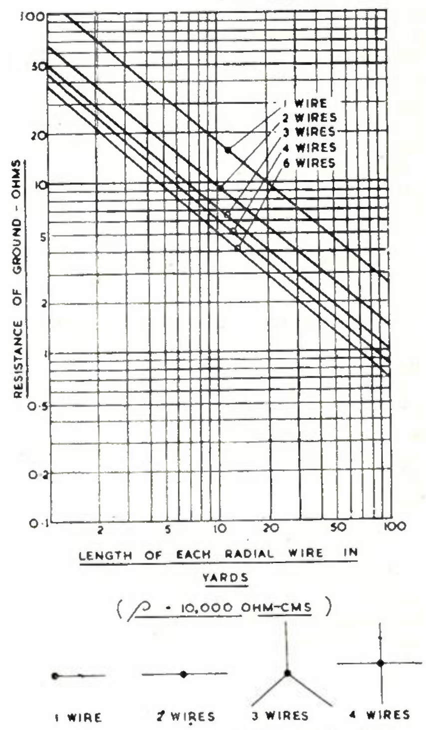


Fig. 4.—Resistance of a horizontal buried wire.

It has been found (16,4,20) that, unless the earth resistivity is low, the conventional earth tester gives too low a reading. This is because of the additional resistance in the potential circuit caused by the high electrode resistance. The "null," or bridge method overcomes this difficulty and gives accurate readings. The "null" method is essential for both resistivity and electrode-resistance tests in many parts of South Africa.

Even with the "null" method (and using standard Post Office sets), the test-electrode resistance must not be too high or the "null" indication will be indefinite. About 2 or 3 feet is required for test electrodes in high-resistivity soil. On the other hand, the depth to which test electrodes are driven must not exceed about one-fifth of the electrode spacing (or the simplified equation $\rho = 2\pi aR$, does not hold—see Appendix I.)

For the Wenner configuration of electrodes, an empirical rule states that the depth of effective measurement of resistivity is equal to the electrode separation a. Thus a change in the slope of a depth probe curve should occur when the electrode separation a equals h, the depth to the contact between the two layers of different resistivity. Thus, when stating resistivity figures for a particular area or point, the electrode spacing must be quoted. Figures such as given in Reference 18 without any qualification in regard to depth, are of little value.

In measuring extensive earth electrodes it is preferable to keep the two auxiliary grounds on opposite sides of the earth to be measured. In the case of a buried wire along a road this is difficult and both auxiliary electrodes would be on one side of the wire. In this case the distance to the remote auxiliary earth should be at least half the length of the buried wire under test.

Measurement of soil resistivity or earth-electrode resistance cannot be made with direct current in view of the electrolytic polarization of the soil which takes place.[4] Alternating current at 50 or 60 c/s is used in Post Office equipment.

When making a depth-resistivity probe, readings should be taken at the electrode spacings of 2, 3, 5, 10, 15 and 20 ft.

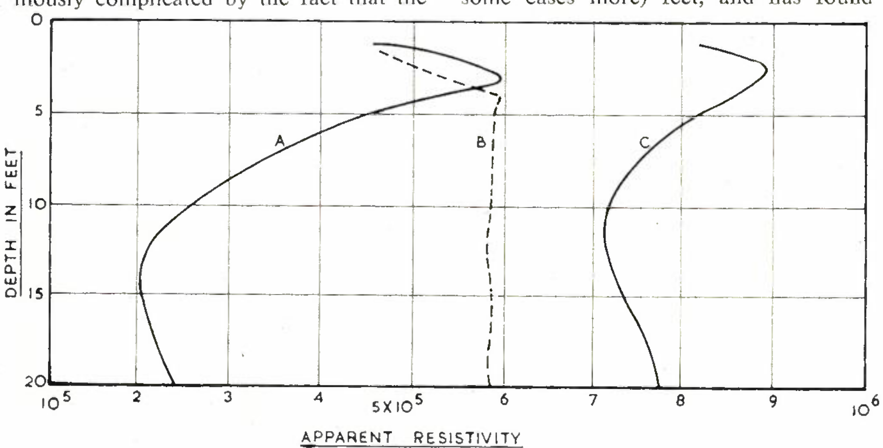
Readings at 1-foot spacing are not necessary since wires should not be laid as close to the surface as this. In any case readings at 1 foot may be considerably in error if the resistivity is very high.

5. EFFECT OF LAYERS OF DIFFERENT RESISTIVITIES

The problem of selecting the most suitable type of earth electrode and the forecasting of its resistance, is enormously complicated by the fact that the resistivity usually varies with the depth. The graphs of Section 3 are based on uniform resistivity only.

The simplest arrangement is a two-layer earth, and curves are available (16) relating apparent resistivity to the resistivities ρ_1 and ρ_2 of a two-layer structure for various thicknesses of the upper layer. The subject is complicated and the use of two-layer graphs in the field is barely practicable. In some cases, several layers are concerned and the two-layer simplification cannot then be applied.

The effect of a lower layer on the resistance of a wire buried near the surface may be seen from the following figures for a wire about 150 yards in length.



CURVE	THEORETICAL VALUE (ρAT 2 FT)	MEASURED
A	160 OHMS	40 OHMS
B	130 "	130 "
C	230 "	195 "

Fig. 5.—Resistance of 100 yard wire buried 2 ft. deep.

Case 1

Dry sandy upper layer 6 feet thick ($\rho = 10^6$ ohm-cm) based on shale and sandstone ($\rho = 10^4$ ohm-cm).

Resistance: 160 ohms.

(If there had been sand only of $\rho = 10^6$ ohm-cm, the resistance would have been 250 ohms.)

Case 2

Fairly moist soil, 15 feet thick with $\rho = 10^4$ ohm-cm, based on granite ($\rho = 10^6$ ohm-cm).

Resistance: 16 ohms.

(If there had been no granite the resistance would have been 2.5 ohms.)

It will be noted from Case 2, that even when the top layer of low-resistivity soil is fairly thick (15 feet) the underlying rock has had an appreciable effect. This is particularly so when an extensive earth is used, such as the 150 yards in these cases.

It is evident that a knowledge of the surface resistivity alone is not sufficient for reliable estimates of the ground resistance. The Post Office staff in Johannesburg has carried out (20) a large number of depth probes to 20 (and in some cases more) feet, and has found that the forecast values for trench and rod earths have generally been accurate.

An example of three depth probes and the resistances of three 100-yard trench earths made by the Post Office in Johannesburg (20) in very high-resistivity soil are shown in Fig. 5. The theoretical values are based on the resistivity of the soil at a depth of 2 feet (the depth at which the wires were laid). It will be observed that for Earth B both calculated and measured values agree exactly, since the resistivity is very uniform. Both A and C gave measured values below the calculated values, particularly Earth A, in view of the decrease of resistivity below 2 feet.

The foregoing examples show that it is not sufficient to consider only the resistivity of the layer in which the wire rests. In the same way back-filling a trench with clay of moist material, when the surrounding soil is dry and sandy, will only increase the effective diameter of the wire and the resistance of the earth wire may remain very high. It is nevertheless desirable to back-fill a trench with the more clayey or moist portion of the material encountered.

6. THE IMPULSE CHARACTERISTICS OF EARTH ELECTRODES

The foregoing treatment is based on measurements made at a frequency of 50 or 60 cycles per second. It is important to know whether the impedance of an earth connection to lightning surges is sufficiently close to the value as measured at these low frequencies.

The impulse characteristics of various types of soil and various shapes of electrodes have been measured by Towne, Eaton (11), Bellaschi (9), Sunde (16) and others. As far as the soil is concerned the low-frequency impedance is always more than the impulse impedance. The electrode impulse impedance will normally be very much higher than its low-frequency or d.c. resistance for a fraction of a microsecond to two or three microseconds, the time depending on the size of the electrode.

6.1 Impulse characteristics of soils

Breakdown or ionization processes occur in soil. The ratio of impulse impedance to low-frequency resistance depends on the type of soil and the voltage gradient. Soils with a fine grain structure give ratios nearer to unity than coarse-grained soils, since the air spaces in fine-grained soils are smaller. Common values of this ratio are 0.5 to 0.9.

Soils behave as non-linear impedances, i.e. as the voltage is increased the impedance decreases. If the voltage gradient exceeds a certain critical value the soil punctures in a fashion similar to an insulating material (11). This critical value varies from about 10 to 30 kilovolts/cm depending on the type of soil and its moisture content.

When the paths of current through soil are parallel the soil behaves like a resistance of constant value up to the point where the soil punctures. The resistance of the soil so tested under impulse is substantially the same as the value measured by the four-electrode low-frequency method. When the current flow-lines through the earth volume are converging the high gradient at points of concentration produce local breakdown of the soil within this region of high gradient. This reduces the impedance during and immediately following the period of the high gradient. The time-lag characteristics of moist soil result in the soil puncture lagging somewhat behind the application of the voltage, with the result that the minimum value of the soil impedance may occur a few microseconds after the crest value of the voltage wave (11).

The foregoing breakdown effects in the soil will not generally be operative until the crest current through the electrode reaches several hundred amperes; the actual figure depends on the electrode size and shape as well as the soil. Thus for telephone earths, where induced surges are normally dealt with, soil breakdown will occur only on the very highest current discharges where the current may reach values of 3,000 to 4,000 amperes.

6.2 Effect of electrode shape and size on its impulse impedance

There are three separate effects to be considered, and these are dealt with in the following three paragraphs.

Firstly, the shape of the electrode influences the gradient in the soil. Electrode arrangements which result in high gradients within the soil will show a greater percentage reduction in impedance than will arrangements in which, with the same voltage applied, the gradient within the soil will be low. In general the higher the voltage applied, the lower will be the impedance of the earth connection. In addition to the breakdown effect within the soil volume, the impedance of an earth connection may be reduced during an impulse due to the formation of streamers radiating horizontally along the surface of the ground.

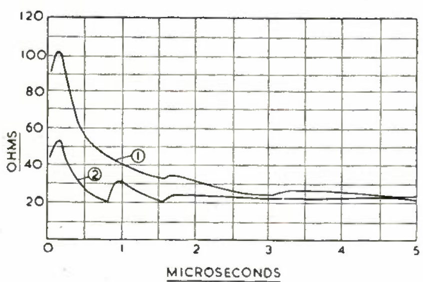


Fig. 6.—Impedance of wire 100 yd. buried 1 ft. in soil of resistivity 10^5 ohm-cm. and dielectric constant = 10.
(1) Current entering endpoint.
(2) Current entering midpoint.

Secondly, the low-frequency resistance of earths depends to some extent on contact resistance between the conductor and earth, which for high-frequency and surge currents is bridged by a fairly high capacitative admittance (16) (see Section 2). The impulse impedance of the arrangement would then be somewhat lower than that obtained by the direct or low-frequency-current measurement.

A third effect (which tends to increase the impedance of an earth connection instead of decreasing it as in the previous two effects) is the surge impedance of the electrode itself. This effect is important in the case of long buried wires only. Initially, such a wire offers an impedance of about 100 ohms (see Fig. 6) which rapidly reduces to the d.c. resistance value. The time required for the change is determined by the time required for two or three reflections of the wave from the end of the conductor (16). The velocity of propagation is a little more than one-third the velocity of light, hence the period required for a reduction to the d.c. resistance is about one microsecond for 100 feet of wire. Thus it is better to have two conductors of 150 feet and make the earth connection at the centre (Curve 2 in Fig. 6), than to have one conductor of 300 feet. It is better still to have four conductors of 75 feet than one of 300 feet. This applies only as far as the impulse impedance is concerned. The d.c. resistance, from Fig. 4, shows that four 75-ft. conductors will give 2.9 ohms as against 2.6 ohms for 300 feet.

This effect is not apparent in rod and plate electrodes since the transition time to d.c. resistance is practically zero. In this respect these two types of electrode are at an advantage over the buried wire, but it must be borne in mind that it is still necessary to achieve a low d.c. resistance.

6.3 The practical importance of considing the impulse impedance of telephone-system earths

Except for the brief period at the commencement of a surge (Section 6.2), the various factors associated with impulse impedances all tend to reduce the impedance of a ground below the d.c. or low-frequency resistance. Thus the low-frequency measurement is a reliable criterion since the impulse value (except for a microsecond or two) is always less than this.

In the case of earths for telephone systems, in distinction to those for power systems, we find that—

(i) since direct strokes are not normally encountered, the currents involved are relatively low and therefore the soil gradients will tend to be low

(ii) the wavefronts of the induced surges, particularly if they have been propagated for any distance along the route, are relatively long, i.e. anything from 2 or 3 to 30 or 50 microseconds, the shorter wavefronts being less common

(iii) the maximum length of trench earth involved would not exceed about 200 yards (or 200 yards for each wire of a radial earth).

The above three factors will reduce the importance of the various effects associated with the impulse characteristics of an earth connection, and it is therefore recommended that only the low-frequency resistance value be used as a criterion, and that wires longer than 200 yards should not be used.

TABLE II

Rainfall	Region	Class	Name	Colour	Texture	Average depth ft.	Resistivity in ohm-centimetres: Little moisture *	50 per cent. water†	Variation with depth
Summer rainfall area	Arid and semi-arid	A	Desert	Light brown to yellow	Coarse Sand	3	—	300-5 000	Moderate decrease
		B	Solonetzic	Grey	Fine sand and clay	4	—	600–6 000	Considerable decrease
		C	Kalahari sand	Red-brown	Coarse to fine sand	40–200	10^4–10^5	2 000–8 000	Moderate decrease
		D	Kalahari sand on lime	Red-brown	Coarse to fine sand	3– 15	2×10^3–10^5	2 000–8 000	Moderate decrease
		E	Subtropical black clay	Black-brown	Fine (clay)	3	—	1 000–4 000	Generally increases
		F	Brown forest (Lowveld)	Red-brown	Fine sand and clay	2	—	3 000–8 000	Small decrease
	Sub-humid and humid regions	G	Waterberg and Zoutpansberg	Light brown	—	2– 8	10^5-5×10^5	—	—
		H	Lydenburg, Pretoria Quartzite	Dark brown	Sandy	3	—	10 000–60 000	—
		I	Drakensberg clay and basalt	Black clay	Fine (clay)	2– 5	—	2 000– 3 000	Little change
		J	High veld prairie	Grey	Fine sand	3– 4	10^3–3×10^4	1 000– 8 000	Considerable decrease
		K	East Province semi-coastal	Grey	Fine sand	2	—	4 000–16 000	Small decrease
		L	Natal coastal (sugar belt)	Dark grey	Coarse to fine sand	3	—	2 000– 8 000	Considerable decrease
		M	Laterite and lateritic red	Red-brown	Fine (clay)	3–20	4×10^4-2×10^6	5 000–60 000	Increases
		N	Lateritic yellow	Yellow-brown	Fine (clay)	6–20	4×10^4-2×10^6	10 000–60 000	Increases
		O	Ferruginous lateritic	Grey	Coarse (sandy)	4– 6	3×10^3–10^6	4 000–16 000	Moderate decrease
		P	Ferruginous lateritic	Brown-red	Coarse (sandy)	4– 6	10^3–2×10^5	1 500–15 000	Increases
		Q	Eastern litoral	Light brown	—	10–70	—	—	—
		R	Aeolian (N.W. O.F.S.)	Grey-brown	Coarse to fine sand	6– 8	—	6 000–16 000	Moderate decrease
Winter rainfall	S.W. and S. Cape Province	S	Sandy soil and T.M.S.	Grey-dark brown	Fine sand to silt	3– 8	5×10^2–5×10^4	4 000– 8 000	Little change
		T	Gravelly sandy clay loam on clay	Grey-brown	Gravel to sand	2	2×10^2–3×10^4	3 000– 6 000	Considerable decrease
		U	Sandy loam on lime and clay	Red-brown	Sandy loam	7	5×10^3–2×10^5	—	—
		V	As U but red-brown	Red-brown	Sandy loam	4– 5	5×10^3–2×10^5	—	—
		W	Coastal aeolian sand on lime and sandy soil	White or red	Sand	Deep	5×10^3–10^5	—	—
		X	Shifting sand	Yellow-white	Sand	Deep	—	—	—

* After Dr. J. F. Enslin   † After Dr. C. R. van der Merwe

7. THE RESISTIVITY OF SOUTH AFRICAN SOILS

Most of the information contained in this section has been obtained from Dr. C. R. van der Merwe, who is the South African authority on soil types, and from his book (6) on this subject.

Although a considerable amount of information on soil resistivities is available, samples of the same type of soil show large variations in resistivity. Furthermore, the resistivity is so greatly affected by the moisture content that it is impossible to forecast the resistivity for a particular area from a soil map. It is, however, possible to draw some useful conclusions from the information available.

7.1 The effect of moisture

The moisture content of South African soils varies from 1 to 30 per cent. with occasional values in excess of this (6). Due to dry climate much of the soil for the greater part of the year has a very low moisture content. Sandy soils can absorb more water than clayey soils, but they retain very much less water.

Generally, the resistivity of a soil decreases a great deal with an increase in moisture above about 5 per cent., but there is little decrease in resistivity above 30 per cent. moisture (10).

Thus, in addition to the inherently lower resistivity of clayey soils (due to their finer structure), such soils are likely to contain more moisture than sandy soils, and should thus be selected in preference to the latter. The neighbourhood of trees should be avoided as these reduce moisture percentages very considerably.

7.2 The effect of temperature

Soil resistivity increases with a decrease in temperature (10) but the effect is not very important until freezing point is reached. Since lightning storms and frozen ground will never occur simultaneously, this effect is not of any practical importance in South Africa.

7.3 South African soils

Table II and the accompanying soil map, Fig. 7, give some idea of the various types of soil, their average depth and probable values of resistivity. The resistivity values of moist earth (50-per cent. water) are not to be taken as representative of the values of the soil in situ. They do give, however, an indication of the percentage of soluble material present. Due to the higher specific water retention of clay soils, their resistivities will tend to be nearer the values given in Table II under the heading 50 per cent. moisture.

The resistivities of a particular soil type may vary as much as ten times. The red and yellow lateritic earths found in the Eastern Transvaal and Natal (types M and N) have a very low salt content and thus have a high resistivity. The salt has been leached out by the heavy rainfall (see Fig. 9). These soils are normally deep (up to 20 feet) and generally contain a fairly high percentage of moisture. The addition of salts to these soils would be beneficial, but the high rate of leaching would require the frequent (probable yearly) replenishment of salt.

The desert soils (A) and the Kalahari sands (C and D) have a high salt content and would therefore give a low-resistance earth connection when wet. These soils are, however, normally very dry and sandy, particularly the top 2 or 3 feet.

The clay soils (B, E and I) have generally a low resistivity, but are shallow.

Most of the soils have several distinctive layers, or horizons, as they are called. The resistivity of these layers may vary considerably, not only due to the fact that the lower horizons are generally more moist (although the reverse may be true for a period after heavy rains), but because the soluble material tends to percolate to the lower layers. Thus the lower layers usually have a lower resistivity, although this effect may be offset by the increase in grain size that usually occurs in the lower layers.

Generally speaking, the top 18 inches of soil should be avoided (because of

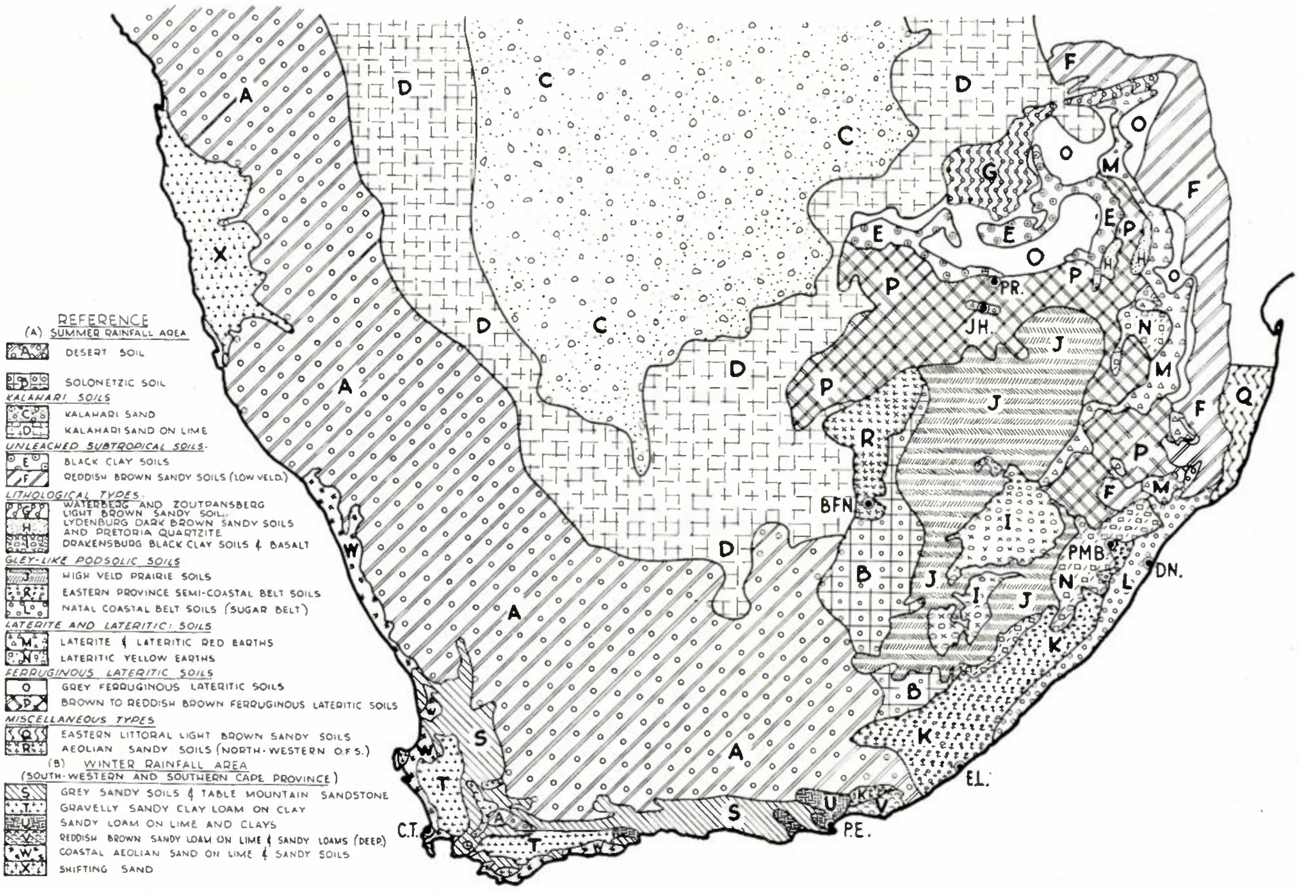


Fig. 7.—Simplified soil map of South Africa.
(Compiled from the original by Dr. C. R. v. d. Merwe)

lack of moisture in the dry season) and trench earths should be laid at not less than 24 inches. Shallow trench earths are also more liable to be damaged.

In some cases a layer of clay may exist at about 2 to 3 feet below the surface and trench earths should be laid in this in preference to sandy or pebbly ground.

7.4 Choice of rod or trench earth

Although it is impossible to formulate precise rules in regard to the choice of rod or trench earths, or their number or size, without a depth/resistivity survey of the exact locality of the proposed earth, some general guidance can be given.

Due to the shallowness and hardness of most South African soils, there are few areas where even six-foot rods can be driven in. The trench earth is generally the only one which will give a reasonably low resistance.

Where the soil is sandy and reasonably deep, the top layer tends to be dry, and here it is preferable, and probably easier, to drive in one or more rods. There is often a considerable amount of water in the lower horizons. Rod earths may be advantageously used in the following soils:—

(i) Kalahari sand (C and D)
(ii) Red and yellow lateritic earths (if salted) (M and N)
(iii) The coastal aeolian sands (W)

Rod earths for the lateritic earths also recommend themselves in view of the possibility of adding salt to these leached soils, although salting is not favoured since it is not permanently effective.

It is unfortunate that the worst lightning areas of the Union (see Fig. 9) also include the most difficult soils for earthing purposes, viz. groups M, N, O and P. i.e. the lateritic and ferruginous lateritic earths.

8. THE RESISTIVITY OF ROCK FORMATIONS IN SOUTH AFRICA

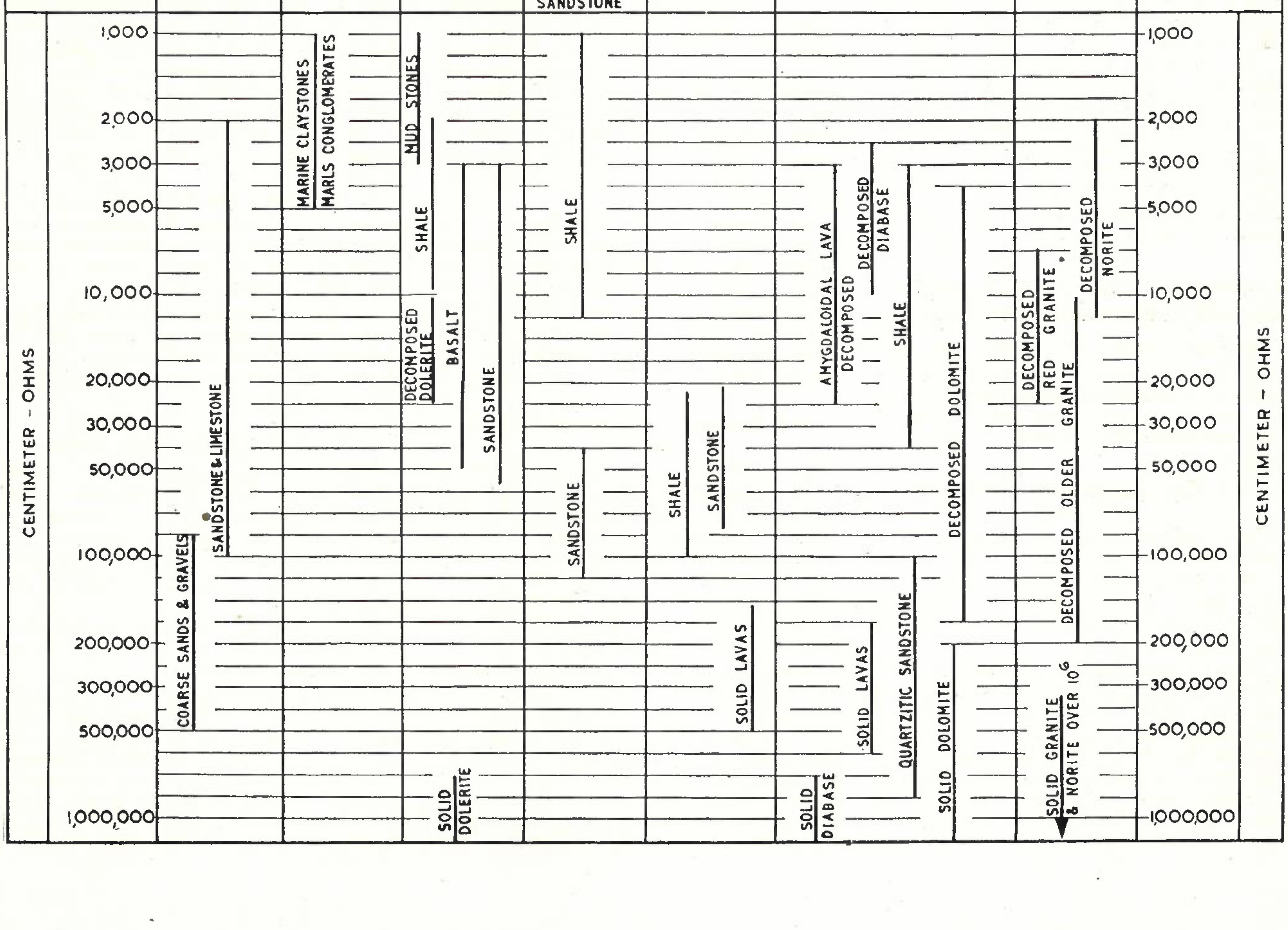
Except when the soil depth exceeds 10 to 15 feet, the resistivity of the underlying parent rock plays a considerable part in the resistance of an earth connection. This is particularly so when trench and multiple-rod earths are used. Since the average depth of South African soils is about 3 to 6 feet, the underlying rock is of importance.

Some approximate values of resistivities, based on information furnished by Dr. J. F. Enslin of the Department of Geological Survey are given in Table III. It must be stressed that these values are representative only and that very wide variations of resistivity may occur in the same type of rock, particularly if various degrees of weathering are present.

The Department of Geological Survey conducts earth resistivity surveys to depths of 200 to 300 feet on a very large scale for the purpose of mineral prospecting and water boring. Dr. Enslin was of the opinion that, while a resistivity map of the Union for formations below 20 or 30 feet was a practicable proposition, the great local variations encountered as well as the effects of seasonal variations, precluded the preparation of such a map for the top 20 or 30 feet. Thus the type and size

TABLE III

PERIODS	RECENT TERTIARY	CRETACEOUS	TRIASSIC TO CARBONIFEROUS	LOWER-CARBON DEVONIAN	CAMBRIAN	PRE-CAMBRIAN		
SYSTEMS	SUPERFICIAL DEPOSITS	CRETACEOUS	KAROO	CAPE	WATERBERG-MATSAP	TRANSVAAL-NAMA VENTERSDORP AND WITWATERSRAND SYSTEMS		
SERIES	KALAHARI BEDS BREDASDORP-ALEXANDRIA BEDS	UITENHAGE ZULULAND NEEDS CAMP	BEAUFORT ECCA DWYKA BASIC LAVAS	WITTEBERG BOKKEVELD TABLE-MOUNTAIN SANDSTONE		ROOIBERG PRETORIA DOLOMITE BLACK REEF	ACID IGNEOUS ROCKS	



of the electrode could be determined only after a depth/resistivity survey in situ had been made.

It has been found (1,16) that the resistivities of rocks tend to increase with their geological age. Table III has been arranged in accordance with the various geological ages, the more recent ages being on the left. Since some geological maps are in terms of the various systems and series, these have been given as well as the actual types of rock. Table III indicates the wide range of variation in resistivity in the same type of rock if weathering has occurred. Although solid granite has a very high resistivity, decomposed granite may be as low as 10,000 to 50,000 ohm-cm. The depth of weathering of rock varies from zero depth to depths of the order of 100 feet.

It will be observed from Fig. 8 that most of the Transvaal is based on granite, dolomite or quartzitic sandstone, all of which have a resistivity over 10^5 ohm-cm. As indicated in Section 7.4 the soil strata in this area (soils M, N. O and P) also have a high resistivity. Hence it is very probable that more difficulties will be experienced with earths in the Transvaal than in any other province. There are, however, limited areas of the Transvaal where rock resistivities are particularly low. The rock types in South West Africa are very similar to the Transvaal, but here the soil covering is sandy and shallow (soil A). Most of the rest of the Union is based on sandstone and shale, the resistivity of which does not often exceed 10^5 ohm-cm.

The apparent resistivity may be considerably altered by the lateral effects of dykes or where the various rocks are not layered, e.g. a depth probe in soil covering say sandstone (30,000 ohm-cm) may give very much lower apparent resistivities due to an adjacent dyke of decomposed dolerite which may have a resistivity as low as 5,000 ohm-cm.

9. CONCLUSIONS AND SUMMARY OF RECOMMENDED PROCEDURE

The calculations of Appendix III indicate that the resistance of earth connections at a telephone subscriber's protector should be not more than 10 ohms and not more than 3 ohms at all other points.

9.1 Cost comparison of various electrodes

The following are the current Post Office costs of earth electrodes:—

Steel pipe, ¾ inch diameter, 6 ft. long: 21s. Plate, copper, 48 by 14 inches: 22s 6d. Grid, copper, 12 by 12 inches: 1s. 10d.

Fig. 10 indicates the total cost of providing a 10-ohm earth (including excavation costs) for various resistivities and using various electrodes. It will be noticed that, not only is the trench earth the only practicable means of achieving a 10-ohm earth beyond $\rho = 5{,}700$ ohm-cm, but it is the cheapest earth down to $\rho = 1{,}000$ ohm-cm.

Apart from a limited number of localities where there are objections to a trench earth (e.g., where reinstatement costs are high or where the top 4 or 5 feet of soil is dry and sandy) there appears to be no justification for using rods. Plates and small grids are never as effective as a trench earth.

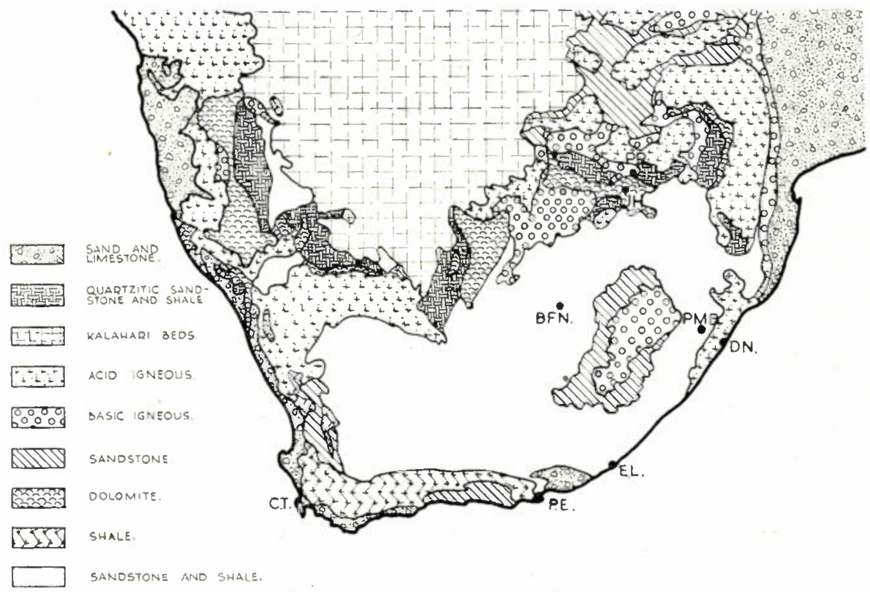


Fig. 8.—Simplified geological map of South Africa.
(Original by Dr. A. L. du Toit.)

Fig. 10 indicates the number of rods, plates or grids required in parallel to meet the 10-ohm limit. The curves for these three types of electrode may not be extended beyond the points shown in the figure, unless more than three electrodes are used, and this is not recommended since the decrease in resistance would not be commensurate with the increase in cost.

The curves in Fig. 10 assume uniform resistivity. If the depth probe indicates that the top three or four feet has a particularly high resistivity and that a layer of very much lower resistivity lies below, the two or three 6-ft. rods may give a better earth than the buried wire.

9.2 Exchange and carrier-station earths

Resistivity measurements to a depth of 20 feet should be taken before all new exchange or carrier-station earths are made. By referring to Figs. 10 (and 4 if necessary) the type and size of earth may be determined. When the resistivity varies with the depth, the calculation of the resistance is more difficult and requires some experience.

Since rod and plate earths are useful only for resistivities up to about 5,000 ohm-cm, their use should be restricted to those coastal areas of the Cape Province, where soil and rock resistivities are generally lower than the rest of the Union. There are considerable areas in the coastal belts based on quartzite, and, unless the soil is deep and moist, high values of apparent surface resistivity may be encountered. In the Transvaal, Natal, the Orange Free State and the dry areas of the Cape Province, trench earths should be used exclusively.

9.3 Earths for cable-distribution points

Measurements made on the Witwatersrand (20) show that the resistance to earth of the sheath of an armoured cable is often considerably less than the earth laid at the distribution point. Since the sheath is directly connected to the cantop frame it would thus carry most of the current. This current often discharges to earth at a buried joint sometimes causing damage. (All buried joints should be taped.)

In the case of a distribution point a trench should be dug for the cable itself and two 150-lb/mile copper wires should be buried in the same trench for the required distance.

As for exchange earths, a resistivity/depth survey should be made and the resistance of the earth (before connection to the cantop) should be measured and recorded.

9.4 Subscriber's-station earths

Where a connection to the public water system can be made, this should be used as an earth. The resistance of the connection should be checked.

Where no water mains are available the following procedure should be followed:—

9.4.1 Transvaal, Natal and O.F.S. Provinces and the dry areas of the Cape Province

Lay 20 yards of 150-lb/mile copper 24 inches deep and measure the resistance. If above 10 ohms lay a further one, two or three lengths of 20 yards (in different directions) until 10 ohms is reached. If the resistance is still above 10 ohms, either extend the wires, or select another site within 100 yards and try a similar arrangement there, connecting the second earth back to the first.

9.4.2 The low-resistivity areas of the Cape Province

In order to absorb present stocks of 12 by 12 inches earth grids these may be used in the lower-resistivity areas as follows:—

Three grid earths should be laid (vertically with top edge 3 ft. below the surface and 6 ft. apart). If the resistance is still above 10 ohms, a trench earth should be made until the resistance is reduced below this value.

9.5 Additional protectors

Where difficulty is experienced in obtaining the low values of resistance specified above, a second protector may be fitted along a subscriber's line, not more than one-quarter of a mile from the end of the line, provided the earth resistance of this protector is not more than 10 ohms.

The same procedure may be adopted for cable-distribution points but only as a last resort.

9.6 Salting of electrodes

Since the effect of salting is not permanent it should be resorted to only at exchanges, where a yearly renewal can be laid down as a routine. Only rods and plates can be effectively salted. The red and yellow lateritic earths will show the greatest benefit from salt treatment. Salt should not be added to the desert soils.

9.7 Long rods

Although long earth rods are normally impracticable in South Africa, the Johannesburg Post Office staff has suggested (20) that drilling through preliminary rock barriers to clayey soil below (such as found in several parts of the Rand) may be economic and effective. Tests made prove this point, but the cost of such drilling is not known. The method would require skilled supervision. Rods 12 or more feet in length would be required.

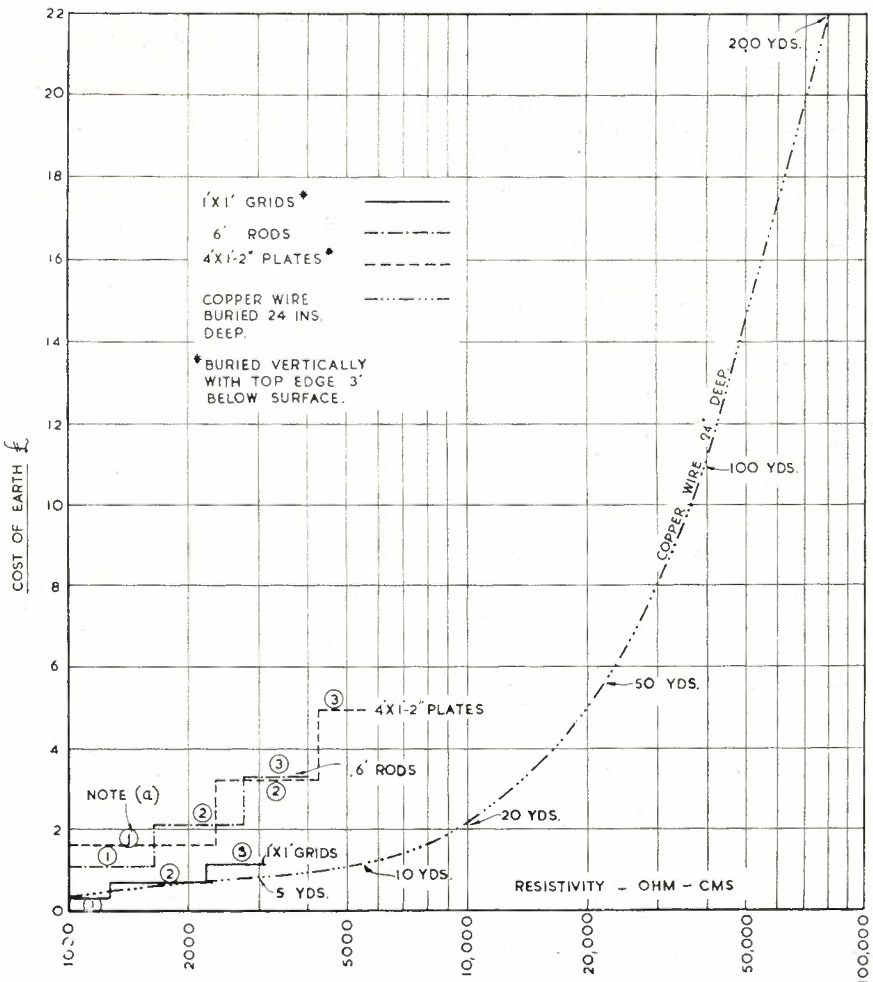


Fig. 10.—Cost of 10-ohm earth.

Notes: (a) Figures indicate number of grids, rods, or plates in parallel (6 ft. apart).
(b) If 5-ohm earth required, multiply resistivity figures by 5/10 and so on.
(c) Resistivity assumed to be uniform.

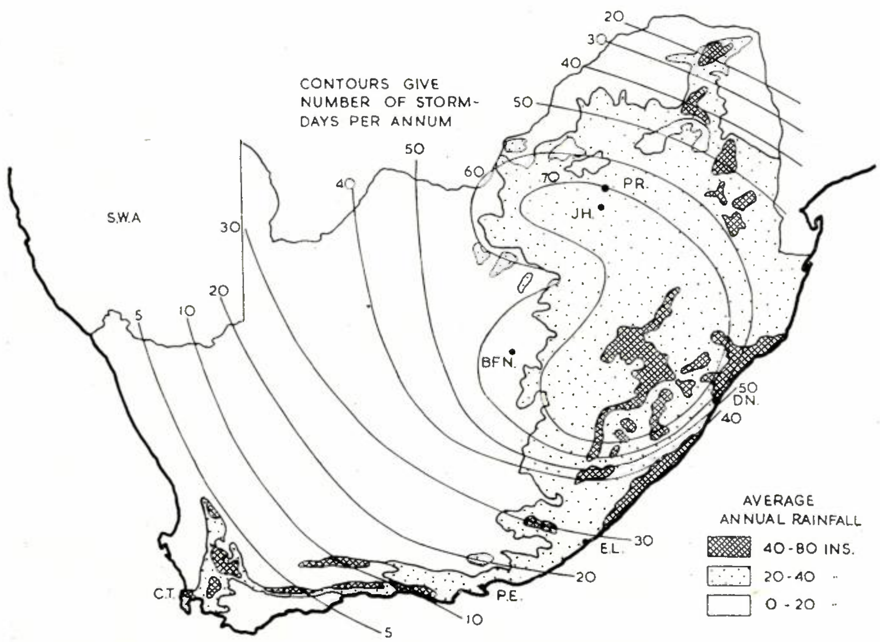


Fig. 9.—Distribution of thunderstorms in South Africa.

10. ACKNOWLEDGMENTS

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APPENDIX I
THE CALCULATION OF EARTH RESISTIVITY

Assume that two point electrodes touch the surface of the earth and let a current I enter the ground at one electrode, the second electrode being sufficiently remote so that its presence may be neglected. The current is then radial about the electrode. The area of a hemispherical surface with centre at the electrode and radius S is $2\pi S^2$, and the radial current density in the ground at the distance S is

$$C = \frac{I}{2\pi S^2}$$

If ρ is the earth resistivity the radial electric intensity in the ground at a distance is

$$E_s = \frac{I\rho}{2\pi S^2}$$

The potential at the distance S is the integral of electric force between S and an infinitely remote point

$$P = \int_S^\infty E_s dS = \frac{I\rho}{2\pi S}$$

The ratio of potential to current is

$$R = \frac{\rho}{2\pi S}$$

If current enters Electrode 1 and leaves at Electrode 2, the mutual resistance with a third point, Electrode 3, is the difference between R_{13} and R_{23}.

$$R_{13} - R_{23} = \frac{\rho}{2\pi}\left[\frac{1}{S_{13}} - \frac{1}{S_{23}}\right]$$

Where S_{13} in the distance between Points 1 and 3, and S_{23} the distance between Points 2 and 3.

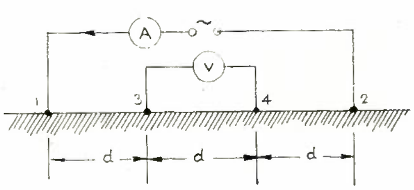

Fig. 11—Four-electrode method of earth-resistivity measurement.

Measured mutual resistance $\frac{V}{A} = R$.

Apparent earth resistivity $\rho = 2\pi dR$.

If there are four electrodes (which is the usual arrangement (see Fig. 11) for measuring earth resistivity, since current is passed between 1 and 2 and the voltage is measured between 3 and 4) the mutual resistance between 1 and 2 and on the other hand 3 and 4 is

$$R_{13} - R_{23} - R_{14} + R_{24} = \frac{\rho}{2\pi}\left(\frac{1}{S_{13}} - \frac{1}{S_{23}} - \frac{1}{S_{14}} + \frac{1}{S_{24}}\right)$$

If the four electrodes are equally spaced at distance d apart in a straight line, the mutual resistance is

$$R = \frac{\rho}{2\pi}\left(\frac{2}{d} - \frac{1}{d}\right) = \frac{\rho}{2\pi d}$$

or

$\rho = 2\pi d$ R ohm-cm, if d is in centimetres.

APPENDIX II
THE CALCULATION OF THE EARTH RESISTANCE OF A BURIED ELECTRODE

A current flowing from a buried electrode to earth produces a series of equipotential lines or shells. They are in fact equipotential hemispheres whose axes pass vertically through the electrode. At a great distance away there would be a zero potential hemisphere and the resistance to earth of the electrode may be defined as the ratio—

$$R = \frac{\text{Voltage between electrode and zero potential area}}{\text{Current between electrode and zero potential area}}$$

Most of the formulae for earth-electrode resistance have been calculated from a consideration of the electrostatic capacity of similar electrodes and their images situated in free space. The method of changing a formula for capacitance into one for resistance to earth may be found by considering the case of two parallel plates whose distance apart is small and the effect of whose edges may be neglected.

If each of the plates has an area of A square centimetres and if the charge densities are + q and − q on each of the plates respectively, the number of flux lines is $4\pi qA$. The voltage gradient is $4\pi q$ volts/centimetre between the plates. If the distance between the plates is d, the potential difference V between the plates is $4\pi qd$. Thus

$$\frac{1}{c} = \frac{V}{qA} = \frac{4\pi d}{A} \quad \ldots\ldots\ldots\ldots 1$$

For the current between the same plates when they are embedded in earth of resistivity ρ abohms per cubic centimetre, the resistance between the plates in abohms is

$$R = \frac{A}{\rho d} \quad \ldots\ldots\ldots\ldots 2$$

Thus in this case

$$R = \frac{\rho}{4\pi C} \text{ ohms,} \quad \ldots\ldots\ldots\ldots 3$$

where C is in statfarads and ρ is in ohm-cm.

The equation 3 merely shows the relation between the units and has no connection with the geometry of the flow of dielectric flux and current. Equation 3 applies to any conductor or combination of conductors. If C includes the capacitance of the images of a conductor or conductors, the resistance to earth is

$$R = \frac{\rho}{2\pi C} \quad \ldots\ldots\ldots\ldots 4$$

The following Table IV of approximate formulae is given by H. B. Dwight (2). In each case

Radius of electrode = a cm

Length of electrode = L cm

Depth of buried electrode = $\frac{S}{2}$ cm

Width of rectangular plate = W cm

The formulae give ρ in ohm-cm.

APPENDIX III
VOLTAGES DEVELOPED ACROSS THE TERMINAL EQUIPMENT OF A TELEPHONE LINE

The limit to the maximum resistance of an earth connection is set by the maximum permissible voltage across the

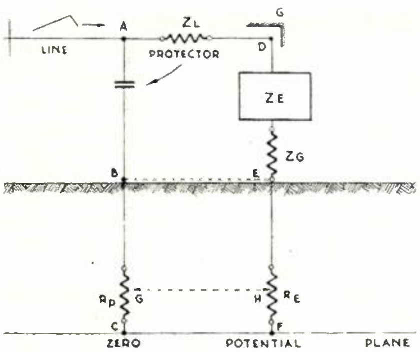

Fig. 12.—Schematic of equivalent impedances to earth at the end of a telephone line (one wire only shown).

terminal equipment. A general schematic representation of the impedances involved in given in Fig. 12. Only the voltages to ground are considered, since any other voltages are normally small in comparison.

$R\rho$ is the resistance of the protector earth connection and across which a high voltage may be developed. In the case of a single pair of telephone wires the highest current that may be expected through the protector earth electrode (due to both wires) is about 500 to 800 amperes. A large route may carry 30 or 40 wires and in this case the total electrode current may reach 3,000-4,000 amperes.

Z_L represents the impedance between the protector and the terminal equipment whose impedance is Z_E. The former impedance is generally small and may usually be neglected. Z_G is the impedance between the terminal equipment and the ground surface in its immediate vicinity. R_E is the resistance of the earth system associated with the equipment.

There are three different terminal conditions to be considered:—

(i) Where Z_E is a telephone at a subscriber's premises

In this case no earth connection is provided at the telephone itself. The telephone is either mounted on a wall or stands on a table or similar item of furniture. The value of Z_G is then normally very high and the effect of a high voltage developed across AC is to raise the potential of the whole telephone above earth. There is therefore little possibility of damage to the telephone.

There are, however, two further aspects to be considered. Firstly, the proximity of the leads to earthed objects, such as an earthed iron roof, steel window frame, etc. (shown as G in the sketch), may cause a spark discharge with possible damage to insulation and the risk of fire. Secondly, a person using a defective telephone may come into contact with part of the circuit and receive a shock. The magnitude of the shock will depend on

(a) The voltage across AC
(b) the proximity of points E and B (if the telephone is near the protector the earth at E is raised in potential and the voltage DE is thus less than the full voltage AC)
(c) the resistance between E and the zero potential plane
(d) the well known factors such as resistance of the persons's skin, footwear and flooring material.

It is unlikely that all of these factors would be such that the full voltage AC is applied across the person's skin surfaces. Although a considerable amount of information on the effects of continuous currents on humans and animals is available, there is little definite information on the effects of short impulses of the order of two or three milliseconds or less. It does appear certain, however, from the limited tests which have been made, as well as from general experience that impulses of considerable voltages have no harmful effect.

It is suggested that a resistance limit of 10 ohms be prescribed for the protector earth electrode at a telephone subscriber. This will result in a maxi-

TABLE IV

Type of electrode		Resistance (Ohms)
Vertical rod		$\frac{\rho}{2\pi L}\left\{\log_e \frac{4L}{a} - 1\right\}$
Buried horizontal wire		$\frac{\rho}{2\pi L}\left\{\log_e \frac{2L}{a} + \text{Log}_e \frac{2L}{S} - 2 + \frac{S}{2L} - \frac{S^2}{4L^2} + \frac{S^4}{32L^4}\right\}$
Right-angle turn of wire. Length of arm L ...		$\frac{\rho}{4\pi L}\left\{\log_e \frac{2L}{a} + \log_e \frac{2L}{S} - 0{\cdot}2373 + 0{\cdot}2146\frac{S}{L} + 0{\cdot}1035\frac{S^2}{L^2} - 0{\cdot}0424\frac{S^4}{L^4} \ldots\right\}$
Three-point star. Length of arm L		$\frac{\rho}{6\pi L}\left\{\log_e \frac{2L}{a} + \log_e \frac{2L}{S} + 1{\cdot}071 - 0{\cdot}209\frac{S}{L} + 0{\cdot}238\frac{S^2}{L^2} - 0{\cdot}054\frac{S^4}{L^4} \ldots\ldots\right\}$
Four-point star. Length of arm L		$\frac{\rho}{8\pi L}\left\{\log_e \frac{2L}{a} + \log_e \frac{2L}{S} + 2{\cdot}912 - 1{\cdot}071\frac{S}{L} + 0{\cdot}645\frac{S^2}{L^2} - 0{\cdot}145\frac{S^4}{L^4}\ldots\ldots\ldots\right\}$
Vertical round plate		$\frac{\rho}{8a} + \frac{\rho}{4\pi S}\left\{1 + \frac{7}{24}\cdot\frac{a^2}{S^2} + \frac{99}{320}\cdot\frac{a^4}{S^4}\ldots\ldots\ldots\right\}$
Rectangular plate	← L → W	$\frac{\rho}{2\pi}\left\{\frac{3{\cdot}1\,(1 + 0{\cdot}037\,5/W) - 1}{(WL)} + \frac{1}{2S}\right\}$

mum impulse voltage of 5 to 8 kilovolts across DE, which is considered to be a safe value, in so far as danger to life or risk of fire is concerned. There is no possibility of damage to the telephone unless this stands on a well-earthed metal structure, e.g. a refrigerator. It is, however, possible for damage to the telephone to occur due to high voltages between the two wires of the telephone pair, but this is not due to earth resistances, and its consideration lies outside of the scope of this paper.

(ii) Exchange or trunk equipment

Where the open-wire route terminates at a point close to the equipment, i.e. where little or no cable is involved, conditions are more severe for two reasons. Firstly, several pairs are involved and the total current through R_E is higher than for a single pair. Secondly, it is usual, and in many cases essential, to have an earth connection applied to the framework or casing or other parts of the equipment. Thus Z_G is zero. If a common earth electrode is used (i.e. if B and E are connected) the whole of the equipment including all earthed parts is raised in potential above the zero-potential plane. In this case there is little possibility of damage to the equipment although there is some danger to life as discussed under (i) above. If a separate earth system, situated outside of the potential field of the protector earth electrode, is used, the voltage across the equipment will be determined by

$$IR_p \cdot \frac{Z_E}{Z_E + R_E}$$

where I is the lightning current. It is thus essential to ensure that $R\rho$ is at least as low as R_E. Normally Z_E will be very much higher than R_E and thus the voltage will tend towards I $R\rho$.

If the two earth electrodes are near each other, their potential fields will exist in the same volume of earth and portions of both $R\rho$ and R_E are, in effect, eliminated as illustrated by the line GH. Thus the voltage across DE would be reduced.

For exchange and trunk-equipment earths, the resistance should be made as low as possible, and in any case should not exceed 3 ohms. It is preferable to common the protector and equipment earths.

(iii) Cable-distribution points.

In this case, Z_E represents an underground cable. Z_G is the resistance between the cable sheath and the surrounding earth, and will in most cases be very low. The cable sheath (and steel pipe if one exists) comprises an effective earth and therefore R_E is very small. In this case practically the whole of the voltage I $R\rho$ appears between the cable conductor and the sheath.

However, in this case a considerable portion, if not the major portion, of the current will pass along the cable sheath. This will tend to reduce the voltage I $R\rho$ but if the sheath current is high damage to the sheath itself may occur.

It is barely practicable to isolate the protector earth electrode from the cable sheath and thus to reduce the current in the sheath. The value of such action is doubtful since the voltage between the conductors and the sheath would be increased, although the sheath current would decrease.

It is recommended that the resistance of the protector earth be made less than 3 ohms, and that it be measured separately before connecting it to the cable cantop.

REPEATER SPACINGS FOR 12-CHANNEL OPEN-WIRE CARRIER SYSTEMS

P. J. KILLEY.

Introduction

The 12-channel open-wire carrier system has found a very large application in Australia, where the long distances make open-wire trunk routes indispensable. Although there are now several long trunk cables (50 to 100 miles) and many more are proposed on the heavier traffic routes, for many years the open-wire routes will continue to span the longer distances and their circuit capacity must be continually increased. A 12-channel system now being installed between Kalgoorlie and Pt. Augusta will complete a chain of 12-channel systems extending from Perth, in Western Australia, to Townsville, in Queensland, a distance of 4,300 miles. The total channel mileage of these systems in service at June, 1953, exceeded 110,000 miles.

Most of the routes were designed originally for voice-frequency operation and were retransposed later for 3-channel carrier systems with repeater stations spaced usually at intervals of 150-200 miles. Conversion to 12-channel operation using frequencies to 143 kc/s means more stringent transmission requirements in order to retain the desired performance for crosstalk and noise at the higher frequencies.

Volume 7, No. 2 of this Journal contains an article by W. H. Walker which surveys the changes in transposition practices which are necessary to meet the 12-channel crosstalk requirements. This article deals mainly with the other aspect of line noise and its effect on repeater section design.

Circuit Noise

Noise in carrier telephone circuits may be introduced into the circuits by the equipment itself or be picked up in the transmission lines, and may be due to a variety of causes such as the following:—

Equipment Noises:

(a) resistance noise;
(b) valve noise;
(c) intermodulation noise; and
(d) power supply noise.

Line Noises:—

(a) atmospheric static noise;
(b) induction from man-made sources, for example, power lines, power line carrier systems, and radio transmitters; and
(c) unintelligible crosstalk from other systems.

In designing a telephone trunk network which will give satisfactory performance, consideration must be given to each of the several sources of noise to ensure that the total noise will not exceed certain limits on even the longest trunk connections. However, in open-wire carrier systems noise originating in the wires is over-riding, assuming that well designed carrier systems are used and that normal precautions are taken to prevent undue noise conditions in office equipment and power supplies. This is in contrast to cable-carrier systems using special carrier cables in which the noise is so low that the controlling noise factor becomes the equipment noises listed previously.

Fig. 1 shows two adjacent sections of open-wire line, one between A and B, and another between B and C, of equal length and each having an attenuation of 20 db. If it is assumed that each is exposed to atmospheric noise picked up uniformly throughout its length, then the noise Nb received at B from the line A-B will be equal to the noise Nc received at C from the line B-C. If, now the two lines are joined together at B, the noise Nb will be transmitted to C but will be attenuated 20 db in the line B-C. 20 db equals a power ratio of 100 to 1, hence the noise power at C will be increased to a value of $Nc + \frac{Nc}{100}$ the addition being made on a power basis as the line noise is random in nature. This represents an increase in noise of only 0.04 db which can be neglected. Consequently, for practical lengths of repeater sections static noise can be considered as independent of the length of the section, and it can be expected that for a given type of line construction there will be an average value of open-wire line noise which controls the general design of repeater sections. The desired signal is, of course, attenuated in accordance with the line attenuation, and consequently the signal to noise ratio relating to uniform atmospheric interference and to only one repeater section, is governed by the following factors:—

(a) the transmission level of the signal;
(b) the line attenuation which is usually directly proportional to its length; and
(c) the magnitude of the noise which, as indicated above, is for practical purposes independent of the length of the line.

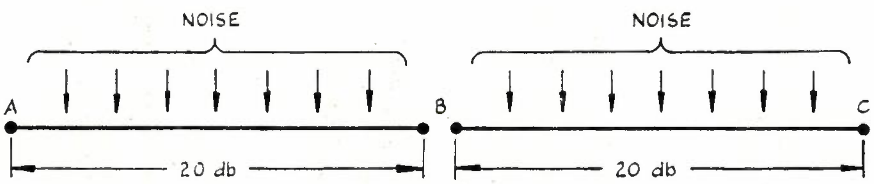

FIG. 1

Thus, in Fig. 2, if a signal is transmitted from A at a level of +17 dbm and is received at B over a line which has 20db attenuation and –80 dbm noise level, this signal to noise ratio at B is 77 db.

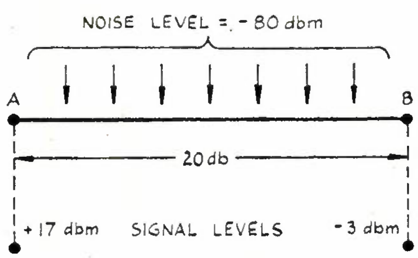

FIG. 2

Localised noises due to man-made sources are encountered in particular cases, but these require corrective action or special treatment of a repeater section. These general considerations do not apply to such cases.

Multiple Repeater Sections

It was shown in the previous paragraph that the noise received on one repeater section is, for practical purposes, independent of the length of the section. However, it is not independent of the length of the circuit because noise in successive repeater sections is additive owing to the gain of the repeaters. Referring again to the two sections of line (A-B and B-C) but connecting them together via a repeater at B, as in Fig. 3, the noise of –80 dbm which is received at B from the section A-B is amplified and passed on to the section B-C at –60 dbm. It reaches C as a level of –80 dbm, which is equal to the noise received at C from its own section B-C. Thus the noise power is doubled (an increase of 3db). The signal to noise ratio is correspondingly reduced by 3 db to 74 db compared with 77 db in the case of one repeater section (Fig. 2). Assuming equal repeater sections and the same line noise on all sections, the noise power is directly proportional to the number of sections. Twenty repeater sections would reduce the signal to noise ratio by $10 \log_{10} 20 = 13$ db. This effect is most important when considering standards of 12 channel operation for the long distances encountered in Australia. It is well known that the attenuation of one repeater section can be increased by 10 or even 15 db above the normal limit without any readily apparent ill effect on the system. However, a succession of such sections or tandem connection of systems which include odd long sections gives definite deterioration of performance.

Factors Affecting Repeater Spacings

It is important from the viewpoint of economics to know the maximum attenuation which should be permitted in repeater sections for a given standard of performance. From the previous discussion it follows that the allowable attenuation per section can be determined if the following information is available:—

(1) the desired standard of performance regarding noise, including the distance over which the performance is to be achieved;
(2) the transmission level to line of the desired signal;
(3) the attenuation of the lines and the variations due to the different weather conditions;
(4) the average number of repeater sections required to span the distance specified in (1); and
(5) the level of noise in the open wires at the highest frequency to be transmitted and the nature of the noise.

Standard of Performance

In connection with the noise standard, the design in Australia is based upon an objective of noise performance of not worse than –51 dbm (weighted) at a receiving point of zero relative level for 99% of time, on a system operating over 1000 miles of route. Because noise power is proportional to the number of repeater sections, and consequently to the distance, the noise objective N in relation to distance can be expressed as $N = -(51 + 10 \log_{10} 1000/L)$ dbm, where L = length in miles.

Hence the following noise figures are obtained—

4,000 miles	–45 dbm
2,000 miles	–48 dbm
1,000 miles	–51 dbm
500 miles	–54 dbm
250 miles	–57 dbm
125 miles	–60 dbm

For systems less than 125 miles in length, noise produced by the equipment tends to become controlling, hence the noise objective remains as – 60 dbm or better for these distances.

It might be argued that a certain value of noise is tolerable to a telephone user and, therefore, this value of noise should apply to all carrier systems, whether they be long or short, due allowance being made if desired for the average number of links involved in a telephone connection. However, a uniform noise standard of this type would have the following disadvantages:—

(a) Different performance would apply to connections between the same two points, depending upon whether a direct circuit is used or whether two or more circuits are connected in tandem.
(b) It would permit long repeater sections for short systems and would require very much shorter sections on long systems. A design on this basis would be impracticable, or at least very costly on main routes where it is desired to use common repeater stations to serve all systems on the route.
(c) A standard which is a reasonable compromise with costs for a circuit of over 1,000 miles in length is not necessarily satisfactory to a telephone user for his more frequent shorter distance calls. Tele-

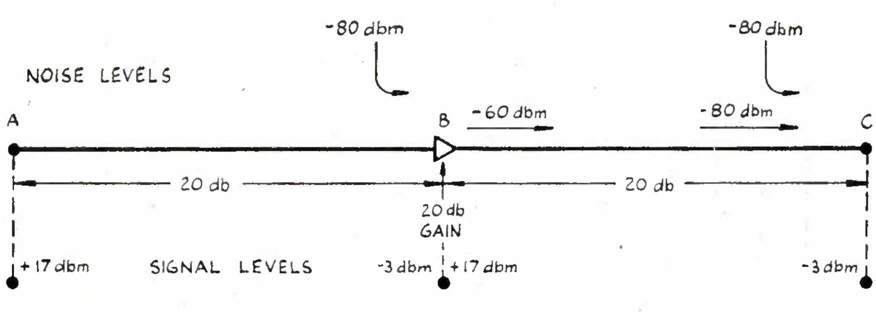

FIG. 3

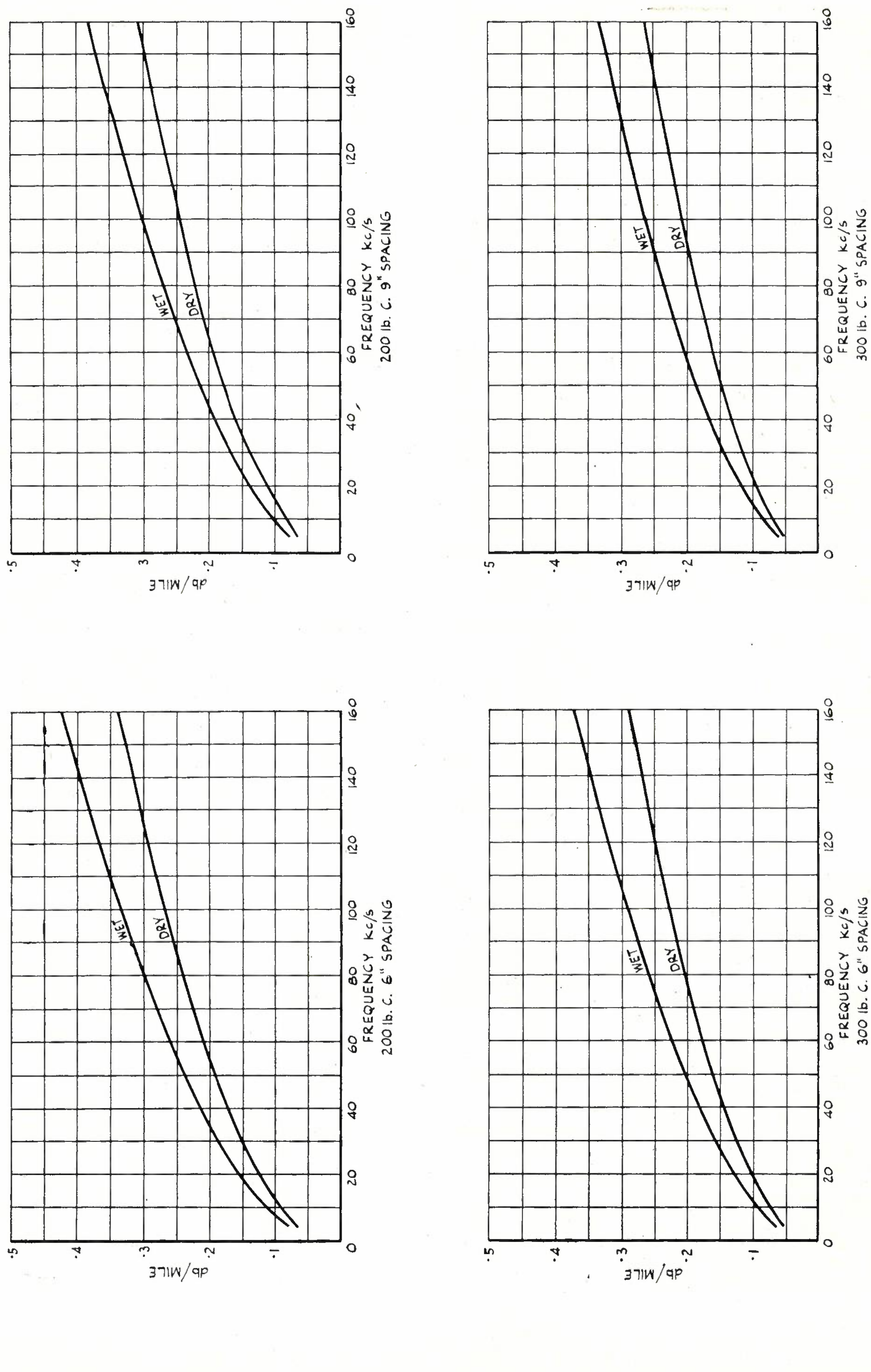

Fig. 4.—Attenuation curves for open wire lines.

phone users nowadays expect to conduct their normal telephone conversations without raising their voices. However, they will still unconsciously raise their speech volume for a very long distance call, even when the circuit is very good. Some advantage can be taken of this for exceptionally long calls over thousands of miles.

Transmission Level: The level available from repeater stations is fixed by economics of equipment design and has been standardised at +17 dbm. When applying this transmission level to the determination of attenuation allowances for the open wires it is only necessary to take into account loss of level delivered to the wires owing to entrance cables, and this is discussed in a later paragraph.

Attenuation of the Lines: Accurate information regarding attenuation to 150 kc/s of the different gauges of wire and for the different wire spacings, is available for both wet and dry weather conditions. Weather conditions in Australia are most favourable to high frequency open-wire circuits because icing of the wires is not encountered except in isolated cases. Icing can cause very high increases in attenuation of more than double the dry weather figure, and in some countries the ability of the repeaters to handle this high attenuation without contributing excessive noise to the circuits is a controlling factor in section allowances rather than normal line noise conditions.

Fig. 4 shows attenuation curves of lines most commonly used for 12-channel systems.

Number of Repeater Sections: The number of repeaters for which allowance should be made naturally depends upon the attenuation (or distance) allowance per repeater section. Although it is most important to allow for the multiple sections as discussed previously, the exact number is not critical when several sections are involved because the allowance in db is proportional to the logarithm of the number of sections. Thus the allowance for 10 sections = $10 \log_{10} 10 = 10$ db, and for 20 sections = $10 \log_{10} 20 = 13$ db. Therefore, an estimation of the average number is sufficiently accurate and fourteen per 1,000 miles has been used in noise considerations discussed in the following paragraphs.

Level of Noise: The remaining factor to be defined in considering section design is the noise in the open wires, which is the variable and more difficult factor. It has been listed earlier under three headings—

(a) atmospheric static,
(b) induction from man-made sources, and
(c) unintelligible crosstalk from other carrier systems.

(a) and (b) must be separated from (c) and from intelligible crosstalk to consider their effect on the allowable length of repeater sections. This separation is necessary because, as discussed earlier, noise which enters the line uniformly throughout its length has a value which is, for practical purposes, independent of the length, hence the signal to noise ratio becomes progressively worse as the desired signal is attenuated. On the other hand, as the attenuation of a repeater section increases the desired signal and the far end crosstalk are both attenuated, and any interference resulting from this crosstalk remains substantially constant. Therefore, although it may be desirable to make an allowance for noise due to unintelligible crosstalk, this noise is not influenced by the attenuation of the individual repeater sections. The method of allowing for this noise is to determine the noise power value of unintelligible crosstalk which will be permitted and deduct this power from the total noise allowance before computing the allowable section attenuation as determined from the magnitude of atmospheric line noise.

Experience gained from years of operation of 3-channel carrier systems can be applied to the layout of 12-channel systems, provided the following factors are known and due allowance is made:—

(a) the reduction in attenuation which is necessary owing to the increased number of repeater sections, and
(b) the relationship between line noise at 140 kc/s and at 30 kc/s.

A series of noise measurements was carried out on selected wires in different parts of the Commonwealth to obtain information on (b), to measure the absolute values of noise in the range 40 to 150 kc/s, and to determine whether there were significant changes of noise between wet and dry conditions. From the previous discussion it follows that noise measurements which are taken for the purpose of section attenuation design should be free from crosstalk or noise due to unintelligible crosstalk. This limits the choice of wires to those which are suitably transposed but are on routes on which there are no working 12-channel systems.

Noise was measured on a noise measuring set which limited the frequency bandwidth of the measurement to 6 kc/s but allowed selection of the 6 kc/s band at any point within the frequency range to 150 kc/s. A 6 kc/s bandwidth was used for convenience in equipment, and

Line Number	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Base Noise—							
(a) Mean value (as measured)	–99 dbm	–92 dbm	–78 dbm	–84.5 dbm	–86.5 dbm	–80 dbm	–94 dbm
(b) Value not exceeded by 99% of readings	–85 dbm	–84 dbm	–69 dbm	–74 dbm	–78 dbm	–68 dbm	–82 dbm
(c) Value of (b) after correction for bandwidth and weighting	–91 dbm	–90 dbm	–75 dbm	–80 dbm	–84 dbm	–74 dbm	–88 dbm
(d) Allowable attenuation of line to give –51 dbm of noise at a point of zero relative level assuming the following:— 1. Only one repeater section. 2. Sending level = +17 dbm	57 db	56 db	41 db	46 db	50 db	40 db	54 db
(e) Allowable attenuation per section assuming 14 similar repeater sections = (d) – 12 db	45 db	44 db	29 db	34 db	38 db	28 db	42 db
Peak Noise—							
(a) Mean value (as measured)	–92 dbm	–77 dbm	–61 dbm	–80 dbm	–84 dbm	–76.5 dbm	–91 dbm
(b) Value not exceeded by 99% of readings	–79 dbm	–69 dbm	–50 dbm	–67 dbm	–77 dbm	–66 dbm	–80 dbm
(c) Allowable attenuation per section to give –51 dbm of noise at a point of zero relative level. No allowance made for bandwidth or weighting	45 db	35 db	16 db	33 db	43 db	32 db	46 db

Table 1.

the results were subsequently corrected to the equivalent of a telephone channel bandwidth of 3,200 c/s. Observations were taken at hourly intervals over periods which varied on the different lines from one week to six months. The total number of noise readings recorded was approximately 15,000.

At each observation of the meter two values of noise were recorded. One was that of noise which had a reasonably constant value, and is referred to as "base" noise. The other was of peak values rising above the base noise at random intervals and is referred to as "peak" noise.

The peak noise is several db above the base noise, but it not necessarily the controlling noise when multiple repeater sections are taken into consideration. Base noise which is constant is additive in successive repeater sections, but peak noise which occurs at irregular intervals in the different repeater sections can be assumed to be non-additive. Table 1 shows the results of the measurements and the conversion of the measurements into repeater section allowances. Line No. 6 was not properly transposed for 12-channel working, and the noise on No. 3 was mostly due to coupling with power distribution circuits. The results obtained on the other lines (Nos. 1, 2, 4, 5 and 7) are believed to be representative of normal average conditions.

The figures shown in Table 1 for the allowable attenuation per section, as determined by the results on each of the lines, assume that no other noise will be present on the line under working conditions.

The measurements were analysed to determine any relationship of noise versus frequency and weather conditions. Line No. 1 showed a decrease in noise with increase in frequency of 7db between 40 and 150 kc/s, but on all other lines the noise value was independent of frequency. The analysis regarding weather conditions showed only a small decrease in noise (approximately 1 db) under wet weather conditions (excluding effects of thunder storms).

Noise in trunk entrance cables should be negligible compared with the noise on the open wires, hence the most important aspect is the lowest level of the signal on the open wires and attenuation allowances are specified on this basis. It is, therefore, more important on long repeater sections to avoid loss of level in long trunk entrance cables at the high frequency sending end than at the receiving end.

Repeater Section Limits

Standard allowances for repeater sections have been determined from consideration of the above measurements, and from experience with systems already in service. The most important requirement of these standards is that the attenuation between the output of a terminal or repeater station and the furthest point of open wire in the section should not exceed 32 db for 9 inch wire spacing, or 36db for 6 inch wire spacing. Wet weather figures are used for the attenuation of the lines. These allowances permit sections of 90 miles for 200 lb., and 102 miles for 300 lb., lines in cases where the attenuation of the entrance cables is negligible.

It is considered that in most areas of the Commonwealth the use of wet weather attenuation figures is most necessary to ensure a reasonable prospect of achieving the noise performance objective for 99% of time. There are, however, a few areas of very low rainfall, such as Port Augusta to Kalgoorlie, where it is reasonable to depart from this standard and design on dry weather figures, particularly because areas of this type are usually sparsely populated and provision of repeater stations is very expensive.

The higher allowance of 36 db for 6 inch wire spacing is possible owing to the lower noise resulting from the closer spacing and the more intense transposing. However, when considering distance, the higher attenuation of the 6 inch line compensates for the extra allowance. Noise measurements have not been taken on this class of line except for some over a short period on a section of line in a very isolated locality. These gave very low noise values. It is thought that the allowance of 4 db more than for a 9 inch line is probably conservative, although there is not sufficient data available at present to confirm this view.

The application of noise considerations to the transmission design of repeater sections applies on existing 12-channel routes as well as on the layout of repeaters and entrance arrangements for new routes or routes which are being converted to 12-channel working. From time to time physical problems on existing routes lead to consideration of replacement of portions of the open-wire by cable, either as extensions of the existing entrance cables or as intermediate section cables. In all of these cases the transmission conditions require careful consideration to ensure continuity of a high standard of performance. It is important in these cases to take into account the fact that noise on open wires is a variable factor and any standards can be based only upon average conditions. For this reason it is always an advantage to avoid low signal levels on open wires whenever this is possible, and is consistent with reasonable economics.

NEW METHODS OF LOCATION OF LEAKS IN GAS-FILLED CABLES

P. R. BRETT, B.Sc., A.Inst.P.

Introduction

The normal methods of localizing the position of leaks in gas filled cables, utilizing measured pressure gradients along the cable and measurement of the direction of gas flow, usually are effective only in determining the faulty length of cable between adjacent manholes or jointing pits. Pinpointing the position of the leak between the manholes depends on trial and error and for a buried cable it may, in the worst cases, involve the excavation of almost the whole length of cable. When excavated, the cable sheath is examined by immersion in a trough of water or by soaping with a soap and water solution. Where the cables are in ducts it is difficult to pinpoint the position of the leak and the normal method of repair is to piece in either an interruption cable along the surface or a new cable in a spare duct and draw the faulty cable out. If an interruption cable has been employed, the faulty cable could be repaired and drawn back but generally a new cable is drawn in and rejointed.

It is obvious that both for buried cables and cables in ducts, the location and repair of leaks is time consuming and expensive and any method which can be employed to enable leaks to be accurately pinpointed so that they can be repaired with a minimum of excavation will result in substantial economies.

During the past eighteen months the Research Laboratories, in association with the Victorian and New South Wales Engineering Branches, have been working on two methods of leak location. The first of these involves the use of the radio active gas, radon, as a tracer and is particularly suited to the location of leaks in buried cables. The second method involves partially filling the cables with a halogen gas such as Freon 12 (dichlorodifluoromethane) and searching for the point where it escapes from the cable using a sensitive electronic halide detector. This second method is best suited to location of leaks in ducts, manholes and jointing pits and tunnels.

The two new methods will be treated in turn.

Location of Leaks Using Radon Gas

Principle of Method: A source of radio active gas is injected into the leaking cable and, being a gas, it is carried along with the air stream towards the leak. If a suitable injection technique is employed the radio active gas remains localized in the air stream and the gamma ray activity from its decomposition products can be detected on the surface of the soil for cable depths up to about three feet. The progress of the plug of radon along the cable can be followed on the surface of the ground and the point where it leaks into the surrounding soil can be detected using a suitable detector.

Some years ago it was suggested that radon could be used as a tracer gas to locate leaks in cables in ducts. The proposal was considered by the Research Laboratories but it was felt that, with the techniques and equipment available at that time, it would not be a satisfactory method. (1).

The extensive development of portable radio activity detectors for prospecting and other purposes during and since the war has reawakened interest in the idea of using a radio active tracer gas for locating leaks in cables. The Danish Telephone Administration presented a document to the C.C.I.F. Conference at Florence in 1951 (2) describing a method of locating leaks in coaxial cable using radon gas. Subsequent references have been made in other literature to this method and also to a method used in France utilizing radio-active methyl bromide (3 and 4). In view of the reported success of the method overseas, it was decided to re-examine the possibility of its application to Australian conditions.

The requirements of a suitable radio active tracer for use in this work are:

(i) That it have a half life of several days to enable it to retain sufficient strength to be detectable on reaching a leak even after a week or ten days in the cable.

(ii) That its half life be such that it will decay to a safe level to enable repairs to be made to a cable without undue delays.

(iii) That it be readily available in Australia.

The only radio active gas at present available fitting these requirements is radon gas, which has been used for medical work for many years and which can be forwarded at short notice from the Commonwealth X-Ray and Radium Laboratory in Melbourne to all parts of Australia.

Physical Data Concerning Radon: The radio active gas radon is the first decomposition product of radium and has a half life of 3.825 days. It is widely used throughout Australia for medical purposes and to a lesser extent for industrial radiography, and is produced by radium laboratories situated in the capital cities.

To simplify the production of the radon, it is collected from radium chloride or radium bromide in aqueous solution. The bombardment of the water produces electrolytic gas which amounts to some 50 cubic centimetres per day per gram of radium as against approximately 0.1 cubic millimetres of radon. In addition, small amounts of ozone, helium and chlorine or bromine are also produced. These must be separated from the radon and elaborate plants are required to enable this purification to be carried out.

In the Commonwealth X-Ray and Radium Laboratory in Melbourne it is the general practice to carry out a radon purification each morning and the radon so produced is available to satisfy the medical and industrial demands. Extra requirements, such as the supply of a radon source for leak location work, are met by carrying out a purification in the afternoon. The supply of sources for this work is limited and any programme of work requiring a number of sources must be carefully planned to ensure the most effective use of the number of sources available.

The portion of the radium radio active series which is of interest in cable location work is set out in Table 1.

Table 1

Element	Emission Rays	Half value period
Radium	α β & Υ	1690 years
Radon	α	3.825 days
Radium A	α	3 minutes
Radium B	β & Υ	26.8 minutes
Radium C	β & Υ	19.5 minutes
Radium C′	α	10^{-6} seconds
Radium D	β & Υ	16.5 years

The α and β rays given off by radio-active materials have very little penetration and the radon technique for leak location in cables depends solely on the Υ radiation given off from the decomposition products Radium B and Radium C. The most penetrating Υ radiation is that given off by Radium C which is equivalent to about 2000 K.V. X-rays. The Υ radiation from Radium B is almost completely absorbed by one inch thickness of lead whereas about 25 per cent. of the Υ radiation from Radium C is transmitted.

If a source of radon is separated from its decomposition products, it will have no gamma ray activity. However, with the spontaneous decay of the radon which takes place a radio active deposit of radium A, B and C is formed. This deposit increases in size until the rate of formation of deposit is equal to the rate of decay of its constituents. The elements radium B and radium C give off gamma rays and the maximum of gamma ray activity is reached in about four hours, after which it decays exponentially at the same rate as the radon itself. As a rough guide, the activity of a radon source in equilibrium with its decomposition decreases by a factor of 1.2 per day. The following figures give some idea of the way in which a radon source decays:—

No. of days	Percentage of activity remaining
0	100
2	69.6
4	48.4
6	33.7
10	16.3
20	2.6
30	0.4

Preliminary Experiments with Known Cable Leaks. A large proportion of the major trunk cable in use in Australia is 24 pair 40 lb. conductor star quad carrier type cable, and consequently it was decided to carry out some preliminary experiments using a 200 yard length of this cable laid out on the ground with a controlled leak in it. Discussions were held with officers of the Commonwealth X-ray and Radium Laboratory, who stated that they would be able to make radon sources of about 20 millicuries available for the tests, and they also agreed to co-operate in the tests by providing trained personnel to handle the radon.

The detector used in these tests and in all subsequent tests, was a portable geiger counter fitted with headphones and a rate meter with rate ranges from 250 counts per minute full scale up to 10,000 counts per minute full scale. The accuracy of the scales is not known, but this is not important as long as the various ranges are approximately transferable. The unit in question is the Portable Rate Meter Type PRM 200, manufactured in Melbourne by Austronic Engineering Laboratories.

The first tests were carried out using a leak of several cubic inches per minute, and the method adopted to inject the radon was to break the radon capsule in the air stream from the air cylinder which was feeding the leak. It was found that the rate of air flow was so small that the radon did not get carried into the cable as a plug, but rather became trapped about the point of injection and in the injection apparatus, and very little radon entered the cable at all. A further attempt was made in which valves in the cable were opened to give a good stream of air to blow the radon into the cable and were closed as soon as the geiger counter indicated that radon in quantity was in the cable. It was found, however, that this method resulted in the radon being spread over a large length of cable, about 100 feet, during the injection process and this rendered it difficult to study the progress of the radon in the cable, and also introduced the possibility of the radon being carried right past the leak. In addition, of course, it completely destroyed any steady flow condition which might have been established in the cable. The artificial leak in the cable was buried in a trench about 20 yards long and about 2 feet deep, and this test did show that the radon could be located at a leak and suggested that if a reliable injection technique could be developed, the method would be suitable for locating cable leaks.

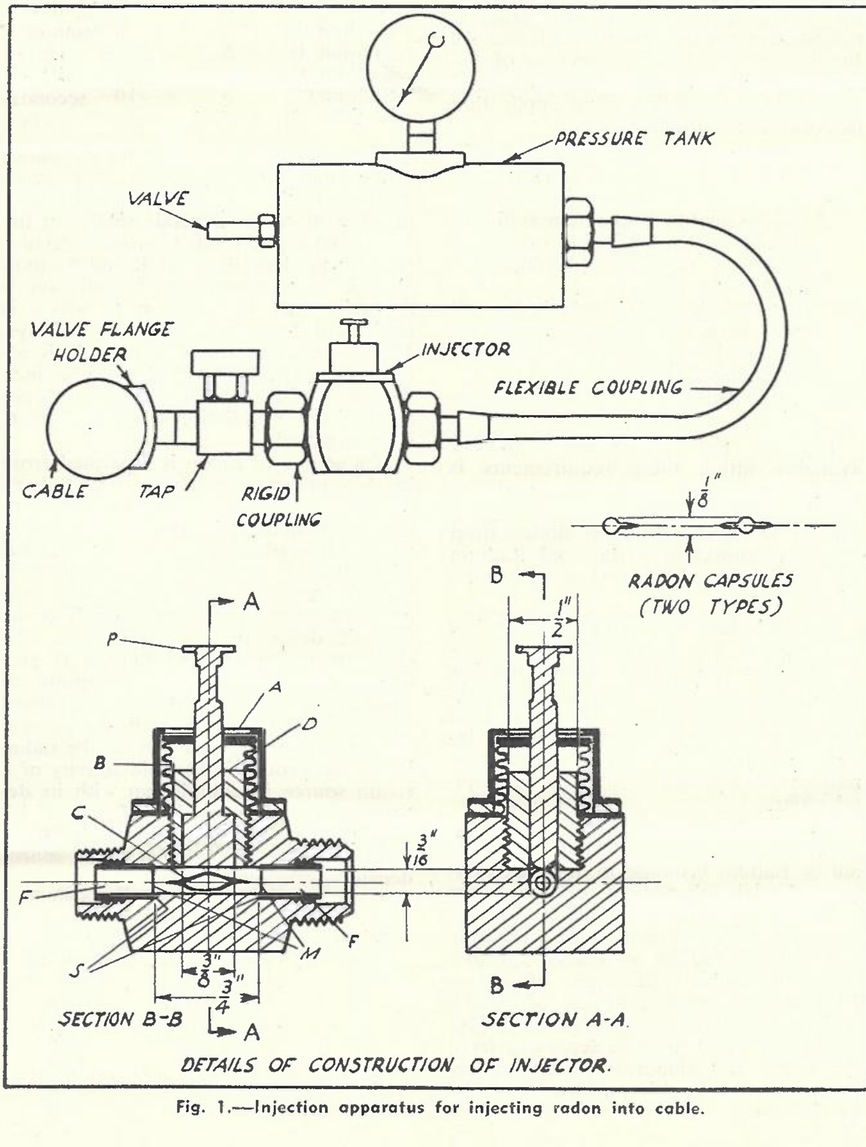

Fig. 1.—Injection apparatus for injecting radon into cable.

Apparatus for Injecting Radon. The preliminary tests showed that it was essential to have some form of apparatus which would positively inject the radon into the cable, but at the same time would cause as little disturbance as possible to the air flow conditions therein. It was felt that the simplest way to do this was to break the capsule of radon in a small enclosed space and then blow the radon into the cable with a blast of air from a small pressure tank. The pressure tank was sufficiently small to be able to discharge its contents into the cable without causing any serious disturbance to the conditions in the cable.

The apparatus designed for the purpose is illustrated in Fig. 1, and its method of use is as follows. As soon as the faulty cable section has been identified a small hole is made in the cable sheath at one end of the faulty length and a tap attached. This can conveniently be done by fitting the tap with a thread which will screw into a valve flange which will be available if the point chosen is a test point. If no test point is available, a suitable flange can be easily attached to the cable. The tap is left closed and steady gas flow conditions are established in the cable by connecting cylinders on either side of the faulty section so that air flows past the tap towards the leak. After an interval of about 24 hours, the radon is blown into the cable through this tap. The radon source, which is contained in a small glass capsule illustrated in Fig. 1, is placed in the central chamber C in the injector proper. To do this the filter plug F is unscrewed and the phial is dropped into the cavity. The plug is then screwed into position until it bears against the shoulder S at the end of the cavity. The plug F is tubular, with a fine wire mesh M on the lower end. This mesh serves to prevent the radon phial being dislodged from the cavity, and also prevents fragments of the broken phial being blown into the tap, where they could interfere with its action. A similar plug at the other end of the cavity prevents particles of glass getting through into the pressure tank.

When the phial is in position the injector is screwed on to the tap by means of a gas-tight coupling, and the small pressure tank of about 10 cubic inches capacity is connected to the injector, preferably by a flexible coupling, such as a length of pressure tubing. The use of a flexible coupling is desirable to ensure ease of manipulation. Air is then blown into the pressure tank from a compressed-air cylinder or a pump until the pressure reaches about 15 p.s.i. above the pressure in the cable, and the whole assembly is tested for leaks, using a soap solution. When any leaks have been eliminated, the radon capsule is crushed by depressing the plunger P on the flexible bellows B until the phial is felt to break. The tap T is then opened, and the air in the pressure tank blows into the cable sweeping the radon with it. The tap is then closed, the injection apparatus removed from the cable, and the glass fragments taken out and disposed of in a safe manner. It will be appreciated that these glass fragments and the injection equipment will retain quite strong radio activity for some days, and they should be removed from the test location so that they do not cause spurious indications to be obtained on the detector. A separation of about 50 yards has been found to be adequate for this purpose.

The bellows, B, is prevented from blowing out under the influence of the air pressure by the cover A, which limits its upward movement. The plunger P is prevented from striking the bottom of the chamber C and being damaged by the stop D. This stop D performs the additional purpose of reducing the air space in the bellows, thus reducing the possibility of radon being drawn up into the bellows and trapped, due to the pumping action as the plunger is released after the radon phial is broken. This equipment has been used for about 40 injections up to date, and in all cases has resulted in the radon successfully entering the cable without being dispersed more than about two feet on either side of the manhole.

Figs. 2 and 3 illustrate the injection equipment in use on an investigation on the Melbourne-Ballarat trunk cable.

Experiments with Controlled Leak Using Injection Apparatus. The cable was the same as was used in the earlier tests. The leak rate was adjusted to be one cubic inch per minute at atmospheric pressure, the leak being situated in the centre of the 20 yard length buried to a depth of two feet. The leak was 145 yards from the injection point. In addition, a length of 10 yards was buried to a depth of one foot at a distance of about 115 yards from the injection point. This second length of buried cable was the site of a previous leak and is without significance in this test, but is mentioned as it explains some of the irregularities in the results obtained.

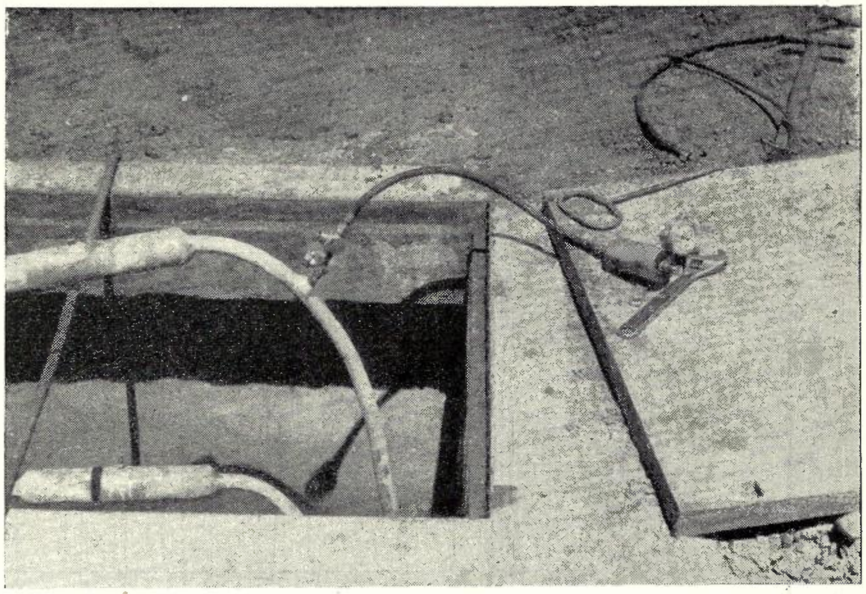

Fig. 3.—Injector and associated equipment in place on cable.

The progress of the radon along the cable was monitored each day until the leak was reached, and the results obtained are illustrated graphically in Fig. 4. It will be seen from the graph that the radon travels along the cable in a well defined plug, the peak of activity being determinable to an accuracy of about ± three feet. The rate of progress is not strictly constant, but remains sufficiently steady to enable the approximate location of the plug at any time to be predicted. It will be noticed also that the maximum activity at the leak, about 24 hours after the arrival of the radon, is less than the peak intensity measured when the plug is within the sheath. It must be remembered, however, that the peak intensities in the cable recorded in the graph were measured with the cable on top of the ground, whereas at the leak the cable is buried two feet deep. It is estimated from observations made during this test that two feet of soil reduce the count obtained to about one-twentieth. This reduction is due, of course, to two factors—the absorption of the soil and the effect due to the greater separation of the detector from the cable. It was found that the location of the leak could be picked up using the headphones with the counter carried at a slow walking pace along the cable track. It could also be detected up to three feet on either side of the track using the headphones, or up to five feet on either side if a detailed survey was made, using the counting rate meter. The actual position of the fault could be pin-pointed to within six inches. It was found to be possible to distinguish between radiation coming from radon in the cable and radiation from radon trapped in the soil by taking soil samples from above the cable and testing these away from the cable. A soil sample taken from above the leak gave a count of 500 counts per minute, whereas samples taken from a yard back along the cable gave a count of about 80,

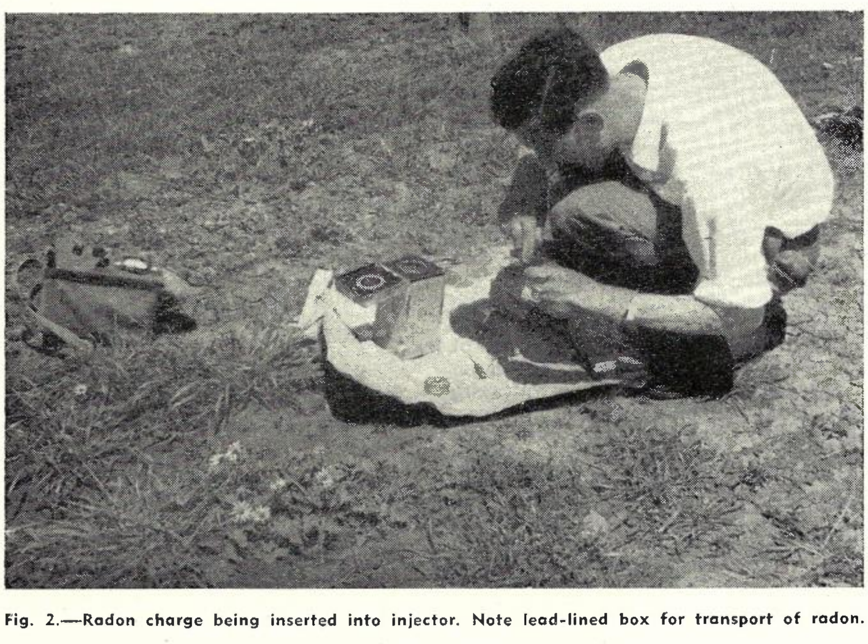

Fig. 2.—Radon charge being inserted into injector. Note lead-lined box for transport of radon.

that is, background count only. In view of the success of these tests it was concluded that the technique was sufficiently promising to justify more extensive field trials under actual working conditions.

Field Trials in New South Wales and Victoria. At the time of these tests the Department was installing a gas pressure alarm system on the Sydney to Orange trunk cable, which consists of two main 24 pair 40 lb. carrier cables and associated voice frequency cables for short distance intermediate circuits. For 35 miles at the Sydney end, and at towns en route, the cables are unarmoured, and drawn into ducts, elsewhere armoured cables are laid directly in the ground. Part of the system was already in operation, but beyond Katoomba a number of the initial leaks had yet to be located. It was felt that tests carried out on this project would serve the purposes of testing the technique, familiarising the New South Wales staff with the technique and, if successful, of locating a number of troublesome leaks. Consequently, arrangements were made with the New South Wales Engineering Branch to co-operate in the tests, and with the Commonwealth X-ray and Radium Laboratory to provide the necessary radon sources. Three series of tests have been carried out on this cable system. The first of these was in January, 1953, and was of the nature of an exploratory series to determine the best technique to be used in the field. It resulted in two leaks being located out of a total of four attempted. The first of these was a large leak near Orange, and a description is given to illustrate the type of behaviour to be expected with large leaks.

A charge of about 18 millicuries of radon was injected in length 308, about three miles from Orange, as pressure measurements had indicated a very large leak in the vicinity. Measurements made immediately after the injection showed that the radon was moving rapidly, and when the cable route was checked about two hours later, the fault was located about 150 yards from the injection point. Detailed measurements made along the cable track near the fault are illustrated in Fig. 5 and illustrate the precision with which the peak intensity was determined. The cable was two feet deep at this place.

With the detector held three feet high and carried at a brisk walk, the fault could be detected with the earphones up to four feet on either side of the cable track. Measurements along the cable track after the radon had passed indicated a slight activity left in the cable. A count of about 100 per minute was received on the surface of the ground compared with a background count of 65-75 counts per minute. Six days later the site of the leak was tested, and all traces of activity had disappeared. The cable was then dug up and the fault, which consisted of two nail holes, was discovered exactly at the point located in the radon test.

The conclusions drawn from the first series of tests were that the radon technique can be used to locate leaks in buried cables with a high degree of precision, provided the following conditions are fulfilled. The general location of the leak is known with sufficient accuracy to permit the radon to be injected close enough to the leak for it to travel to the leak and escape into the soil whilst still

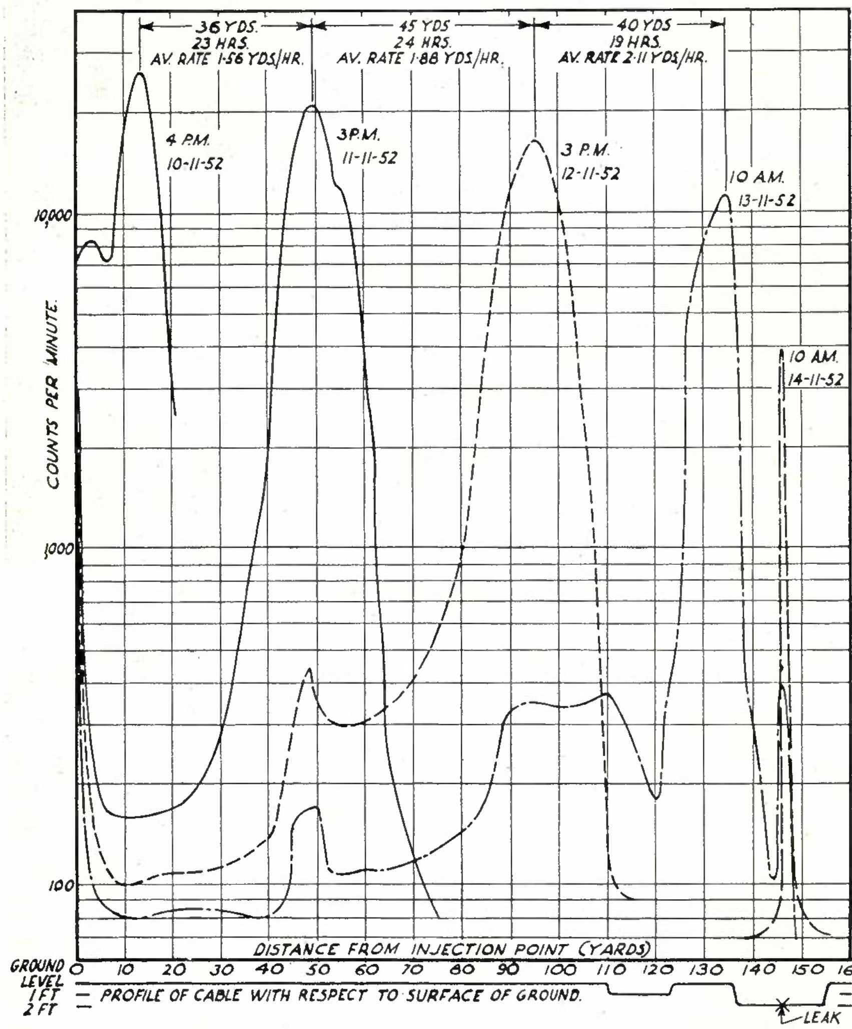

Fig. 4.—Graphs showing progress of radon along cable towards a controlled leak of 1 cubic inch per minute.

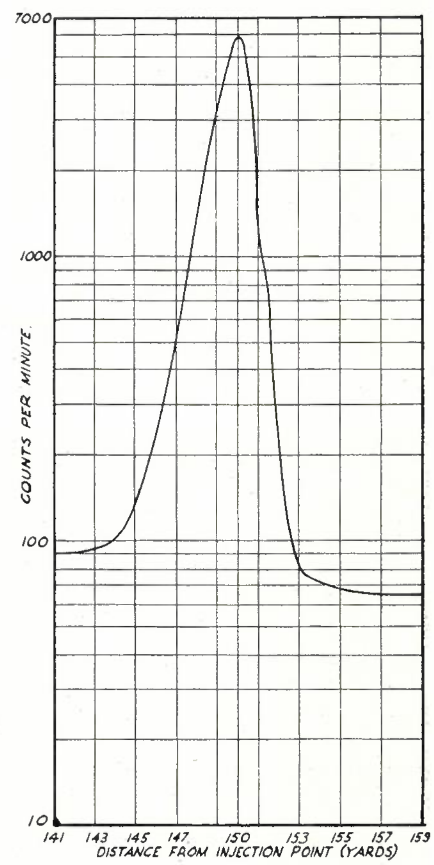

Fig. 5.—Count obtained at leak located in length 308 of Bathurst-Orange carrier cable. Notes:—

1. Background count approximately 65 counts per minute.
2. Cable buried to depth of 2 feet.
3. Fault detectable up to 3 feet on either side of cable track.

retaining sufficient activity to be detectable. Experience has shown that radon charges in cables are still readily detectable after a week. The rate of movement, and hence the precision required in the initial location depends on the size of the leak. With large leaks the radon will move rapidly and it is sufficient to know the leak location to within a mile or even more. However, with very small leaks the rate of movement is of the order of one foot per hour, and a preliminary location to within 50-100 yards is desirable.

It is desirable, but not essential, that steady conditions be established in the cable by connecting cylinders fitted with accurate pressure regulators on either side of the suspected section. If this is not possible it is necessary to ensure that there is a stream of air moving towards the leak at the point of the injection. It is possible with a leak near a gas tight seal that there will be very little air flow in the direction from the the seal towards the leak, and radon injected in this section will remain stationary. Great caution should be exercised in altering the pressure in the cable after injection of radon as a change in conditions could result in the radon being carried beyond the leak and transient alterations in the direction of movement of the plug.

It is desirable to check the position of the radon plug each day as, in this way, much tedious searching can be avoided; it is possible to predict its probable whereabouts from a knowledge of its previous movement. Accurate knowledge of the cable route is desirable so that the search can be made immediately over the cable. For this purpose a cable tracer such as that described in (5) has been used and has given good results. Where there is any doubt as to whether an indication obtained on the counter is due to the radon plug within the cable or due to radon which has leaked into the soil, the matter can be resolved by taking a soil sample from the suspected spot and testing it for activity. If the soil sample shows activity it indicates that the radon has leaked into the soil and that the leak is near the suspected spot.

It was observed in these tests that if the counter is held up in the air, the region over which the radon source in the ground can be detected is considerably increased. The reason for this has been discussed in the literature (6) and is due to the fact that with the detector held in the air some distance from the cable track there is less soil between the radiating source and the detector than if the detector is placed on the ground the same distance from the source. Raising the detector in the air reduces the radiation intensity by an amount determined by the inverse square law (assuming a point source of radiation) but this is more than offset by the reduction in soil absorption. In practice the detector was held at a height of about three feet, as this was a convenient carrying position.

Following the first series of tests, two further series have been made in New South Wales, and a number of isolated faults have been located in Victoria. In all a total of nineteen leaks were investigated in New South Wales and eleven were located. Of those not located the initial locations of three were well outside the desired limits, being from 600 yards up to a mile from the leak. It is almost certain that these three leaks would have been located if the initial location had been to within a cable length. Four leaks have been investigated in Melbourne, and they have all been located although one leak required two attempts, the failure of the first attempt being due to rain, which put the geiger counter out of action at the critical time.

From the experience gained in these field trials it is concluded that the radon technique, when applied by an experienced person, will be successful in locating leaks in buried cables where the position of the fault is known to within 200 yards. The number of times initial locations on faults were in error by distances of several cable lengths stresses the importance of great care in the gas flow measurements which are used to locate the faulty length. The successful use of the present types of gas flow detector requires considerable experience and care, and faulty readings are always possible with inexperienced personnel.

With large leaks the radon charges can be followed and leaks located at much greater distances than 200 yards from the injection points, but with small leaks there is a danger that the activity will have decayed to too low a level to be detectable before the leak is reached. When the initial faulty cable length location is correct most leaks will be detected in less than a week, but where the injection point is remote from the fault charges have been followed for periods up to two weeks. The rate of movement of the radon varies from a few feet per hour for leaks of the order of 0.3 p.s.i. per week from a gas pressure section five miles in length to 50 yards per hour or more for large leaks, such as a split sheath or a nail hole. Average size leaks of the order of 0.5-1 p.s.i. per week give rates of movement of several yards per hour.

Experience has shown that it is possible to investigate four or five leaks at the one time, provided they are not distributed over a distance of more than about 40 miles. Most leaks are located in three or four days, although very small leaks may take up to a fortnight. The actual radon injection can be completed within about half an hour, and the only further work required is daily visits to the test site to check the position of the radon. This does not take more than half an hour for each test site.

When the radon charges in deeply buried cables are being followed it has been found advantageous to dig holes down to the cable at various points along its length. Sufficient residual activity remains in the cable for some days after the radon has passed if the detector is held on the cable, and in some circumstances much tedious searching for the radon charge is avoided.

Health Hazards. The radiations given off by radon and its decay products have an effect on the health of persons subjected to them, and the handling of radio-active materials is a hazardous operation and should be carried out only by trained personnel and subject to adequate controls. In order to obtain some idea of the radiation exposure to be expected in using radon technique, test films were carried by the personnel doing the tests. In the first series of tests the author carried the test film on his body for the duration of the tests and subsequently the film was assessed by the Commonwealth X-ray and Radium Laboratory. The radiation received by the author amounted to 60 per cent. of the maximum permissible tolerance dose for continuous exposure.

In the second series of tests, films were carried on the body and on the hand of the person performing the work, and the exposure received amounted to about 20 per cent. of the maximum permissible dose for both hand and whole body exposure. Some tests have been made to determine the length of time that the soil around a leak remains dangerously contaminated. These have shown that with large leaks all traces of activity disappear in three or four days. This is, no doubt, due to the escaping air from the leak carrying the radon into the atmosphere with it. It is essential that no leak located by the radon technique be excavated for repair less than a week after the radon reached the leak or until it has been checked with a suitable detector and found to be safe.

In view of the dangers involved in the use of radon the Commonwealth X-ray and Radium Laboratory has been consulted regarding safe practices to be used in the technique. An assessment of the hazards has been made, and safety precautions recommended by that organisation have been adopted by the Department. If these precautions are faithfully observed, and no accident occurs, the radon technique is perfectly safe. However, there is always some danger of accidents which could result in the radon charge being released, say, in the confined space of a manhole, and it has been decided that the technique will only be applied by a trained professional officer who has a thorough understanding of the nature of radon and who will be able to cope with any emergencies which may arise. Trained staff are to be made available as required by the Research Laboratories for work in the various States.

Location of Leaks Using Freon Gas.

Introduction. Where cables are buried in ducts the radon technique is not effective because, when the radon charge leaks into the duct it does not remain localised, but will diffuse along the duct and the uncertainty of any location obtained in this way would be such that it would be unwise to attempt to break the duct open to repair the fault. In the absence of any method of accurately pinpointing cable leaks in ducts, it is necessary to replace the faulty length of cable. This is a costly and time consuming procedure, especially where no spare ducts are available, and any method of pinpointing leaks with sufficient accuracy to enable ducts to be broken open and the cable sheath repaired would result in substantial savings.

Attempts have been made to pinpoint leaks using accurate pressure gradient measurements. However, with the most accurate equipment available, and using all reasonable precautions to avoid disturbing the conditions in the cable, there is always some uncertainty regarding the exact position of the leak. During 1952 a small leak occurred in a length of the Footscray-Newport Junction cable forming part of the Melbourne network, and the replacement of the faulty length would have involved a double cut over under particularly difficult circumstances. Four accurate pressure gradient curves were obtained by the Victorian Engineering Branch staff over a period of several days, but when these curves were plotted there was still an uncertainty of about 40 feet in the exact position of the leak (see Fig. 6), and this made an attempt to repair the leak by breaking open the duct inadvisable. The expenditure in repairing this leak by conventional methods would have been several hundred pounds, and this case illustrates the desirability of devising some means of accurately pinpointing leaks in ducts.

During recent years refrigerator manufacturers have been troubled by very small leaks of the refrigerating gas Freon 12 (dichlorodifluoromethane) from refrigerator units and sensitive and rapid methods of detecting such leaks have been developed. It was thought that similar equipment could be used for detecting leaks in cables, and the Research Laboratories were asked to devise a satisfactory technique.

Instruments for Detecting Freon. The first unit developed for detecting Freon leaks was the halide flame detector. This device depends for its operation on the fact that an amyl alcohol flame turns a vivid green in the presence of halide gases, that is, in the presence of those gases whose molecules contain the atoms chlorine, iodine, bromine, or fluorine. Freon 12 is such a gas. The halide flame detector is quite sensitive, but is rather erratic, and it is difficult to get reliable results unless great care is taken. It has been largely replaced by a more sensitive and reliable electronic halide detector.

It was felt that this latter instrument offered the greatest possibilities of success, and arrangements were made to obtain one for experimental purposes. The unit obtained is manufactured by the British Thomson Houston Co., and costs approximately £270. It is claimed that it is sufficiently sensitive to detect a leak at the rate of 1/50 oz. of Freon 12 per year from a refrigerator. The operation depends on the increase in the rate of positive ion formation at a heated platinum surface when the halide content of the surrounding air increases. In the B.T.H. equipment the detector is in a probe unit and consists of two concentric platinum cylinders in a hard glass envelope. The inner element, which is the anode, is heated to 700° C. Air is drawn through the space between the two cylinders and the circuits are arranged so that an increase in the positive ion formation gives rise to an audible signal.

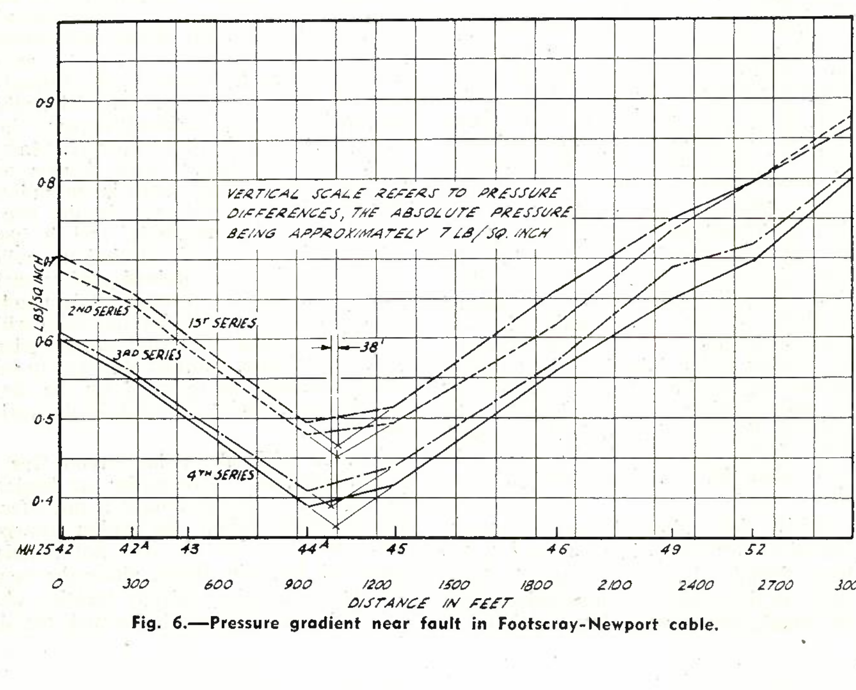

Fig. 6.—Pressure gradient near fault in Footscray-Newport cable.

There was no doubt that if Freon was put into the cable and leaked into the duct the B.T.H. detector could be used to detect the Freon. It remained merely to devise a method of applying the idea.

Leak Location—General. Freon detectors of the type discussed have been used by the Bell Telephone System for detecting leaks in aerial cable. In the unit

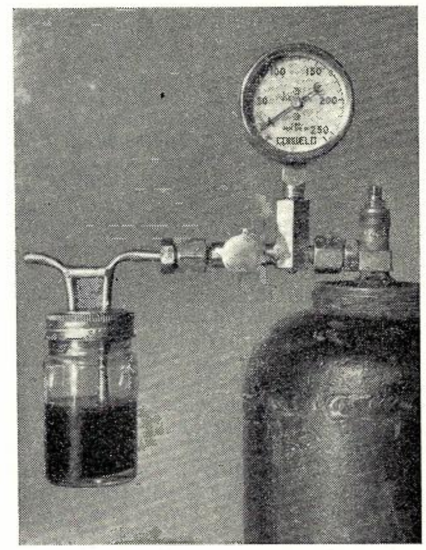
Fig. 7.—Freon cylinder showing pressure gauge, control taps and improvised transformer oil bubbler.

which is described in (7) the detector is mounted in a hollow enclosure which is drawn along the cable, the cable having been previously filled with Freon gas. It is claimed that the device is sufficiently sensitive to detect a leak of 20 cubic inches per day when being drawn along the cable at a rate of 120 feet per minute.

Freon gas is readily available in Australia, the price being about 15/- per lb. It is purchased in cylinders under pressure, and may be introduced into the cables through the conventional fittings. Because of the extreme sensitivity of the detector, it is unnecessary that the cable be completely filled with Freon, but a dilute mixture may be used. The method adopted has been to connect air and Freon cylinders in parallel and control the rate Freon enters the cable by passing it through a transformer oil bubbler, see Fig. 7. The Freon is introduced on one side and a valve is opened on the other side of the leak. The remote valve is left open until the detector indicates that Freon is emerging. The valve can then be closed and the Freon-air mixture will fill the cable on either side of the leak, and the gas escaping from the leak will contain Freon. The cylinders are left connected to replace the gas lost from the leak.

Location of Leaks in Ducts.—To do this is is necessary to sample the air in the duct. A stream of air is blown along the duct so that Freon escaping from the leak is carried along instead of spreading on either side of the leak. Sampling is done by forcing a thin metal tube (about ⅛″ inside diameter) along the duct and withdrawing samples, using some form of pump—a car pump with the washer reversed has been found effective. The air sample withdrawn is tested with the Freon detector and in this way the point where the Freon-air mixture is leaving the cable has been detected to within a few inches.

In some cases, especially with very large cables, it is difficult to insert the tube for the full length of the duct. However, by testing from both ends of the duct, and in bad cases, by excavating to the duct midway between the manholes, breaking open the duct and testing in both directions from this point, it has been possible to explore the full length of the duct in all cases encountered up to date. It is necessary, of course, to guard against the sampling tube becoming blocked by mud or cable pulling compound when it is pushed into the duct. This can be done by blowing the tube clear with an air cylinder before taking a sample.

The technique described above, with minor variations, has been used extensively during the past few months in Victoria, and also in several instances in New South Wales, and numbers of leaks in ducts have been pinpointed with sufficient accuracy to enable them to be repaired by breaking open the ducts. In New South Wales some success has also been achieved using this technique, but with the flame detector as an indicator instead of the B.T.H. detector.

Figs. 8 and 9 illustrate the equipment being used in the investigation of a cable fault in Spencer Street, Melbourne. The power supply shown is a 230 volt A.C. rotary converter operating from a 12 volt battery, but in later tests it has been found more convenient to use a small 300 watt 230 volt A.C. portable petrol electric generator. The particular one which has been used was obtained from Army Disposals in 1948, and was manufactured by the Jacobsen Manufacturing Co. in U.S.A. for the U.S. Army.

Leaks in Jointing Pits and Manholes. Another application of the Freon detector which will result in substantial savings is in checking joints and sleeves in new installations for leaks. Experience has shown that in new installations a large proportion of the leaks are found in the manholes and jointing pits. The normal procedure is to examine laboriously cables in all manholes and pits by soaping. However, by filling the cable with Freon it is possible to tell immediately which pit contains faults merely by inserting the detector into the pit for a few seconds. With normal jointing pits it is not necessary even to lift the lid, as the probe can be inserted through the keyhole. This method has been used on some sections of the Melbourne-Ballarat cable and has given excellent results.

Leaks in Cable Tunnels. Another application of the method has been in cable tunnels where the search for leaks by conventional methods is tedious and difficult. The detector can be used to pick up leaks without disturbing the cables in the racks, as is necessary with the soaping method. One disadvantage is the extreme sensitivity of the unit. Sometimes small leaks at the injection point result in the atmosphere in the tunnel being contaminated and prevent locations being carried out. However, with adequate care, combined with forced ventilation in the tunnel, it has been possible to avoid this trouble in the limited number of leaks investigated.

Leaks in Buried Cables. It was hoped that the Freon technique could be used to locate leaks in buried cables. As stated previously, the radon technique can be used for this work, but has the disadvantage that skilled professional labour is essential because of the health hazard involved. With Freon there is no serious hazard and the technique, if successful, could be applied by suitably trained field staff. A number of experiments have been made to see if a suitable technique could be developed.

The method adopted has been to fill the suspected cable length with Freon-air mixture and then leave the cable for several days. The Freon-air mixture leaking from the cable will saturate the surrounding soil. In order to test the soil iron-bar holes were made every few yards along the cable track and the air in these holes was tested with the probe. Several tests have been carried out using moderate and large cable leaks which had previously been located using the radon technique. Having a prior knowledge of the position of the leak, it has usually been possible to locate the comparatively large leaks tested. The degree of precision in the location is much less than with the radon technique. In one case tested near Bathurst, on the Sydney-Orange cable, a moderate sized leak was tested after Freon had been connected to the cable for about 24 hours. Freon was detectable at the leak over an area about three feet in diameter. On the following day, using holes driven to a depth of 12-18 inches, the Freon could be detected over a distance of 10-12 yards along the cable track.

Other tests have been made on known leaks and the results obtained indicate that the degree of compaction of the soil surrounding and above the cables has an influence on the results. With well compacted soil it is possible that the gas escaping from the leak might travel along the cable for some distance before penetrating through to the surface. It is apparent also, that cracks and fissures in the soil could give rise to errors of some feet in leak locations. With uncompacted soil the Freon will diffuse freely through the soil and an indication may be obtained over a distance of 10-12 yards. The detector is not capable of discriminating between different concentrations of Freon, and consequently an uncertainty of some yards is unavoidable.

It will be appreciated that all tests described have been on known leaks. In the case of an unknown leak it would be necessary to drive holes and test every few yards until the leak is located. This could be for a distance of 200 yards or more. This procedure would be tedious and the location of the leak would depend on the Freon coming to the surface somewhere along the cable track. It is easy to imagine conditions where the Freon comes to the surface some yards from the cable track, say due to a fissure in the soil, and the most exhaustive testing along the cable track would fail to reveal its presence. In the only test made to date with an unknown leak

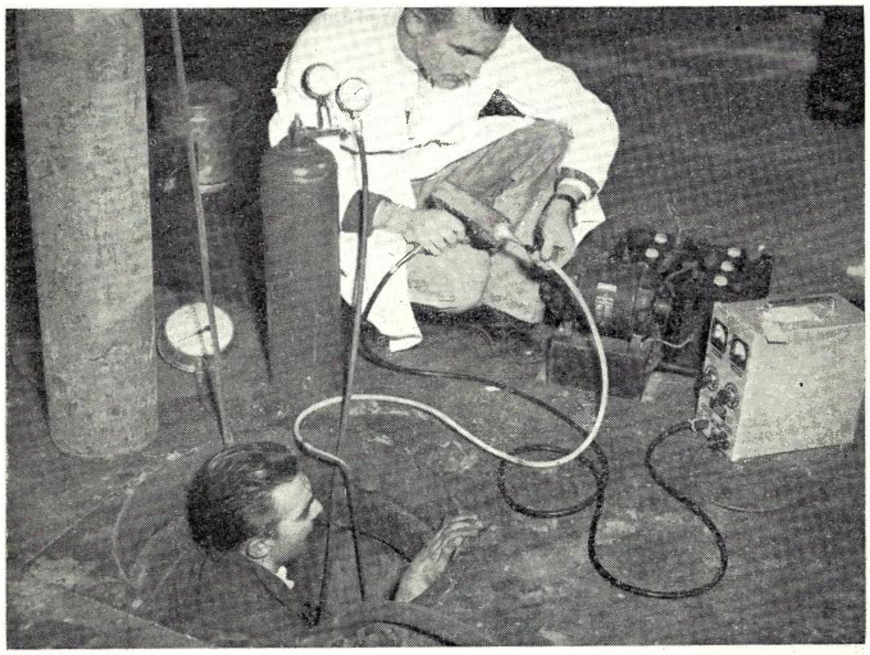

Fig. 8.—General view of B.T.H. detector in use at a cable fault.

the Freon technique failed to locate the leak.

Another disadvantage of the Freon technique for this work is that, even with the most painstaking measurements, the initial leak location may be in error, the leak being in an adjoining length to that suspected. A radon charge acts as a gas flow indicator, so that subsequent searching can be carried out in the right direction. However, with Freon no such indication is possible and the location of leaks would require that the faulty section be known without doubt.

Precautions. The halogen gas Freon 12 used in this technique will break down at high temperature giving hydrofluoric and hydrochloric acid as decomposition products. This will happen at the temperatures used to repair cable sheaths, and the released acid products would cause trouble inside the cable. For this reason, faults can only be repaired after all Freon has been driven from the cable and no heat should be applied to the cable at any time whilst it contains Freon (7). The only other precaution required arises from the use of oil bubblers as flow meters in the Freon supply line. Care must be exercised to ensure that oil from the bubbler is not blown into the controlling pressure regulators as this can cause trouble.

Conclusions.

Recent work carried out by the Research Laboratories in co-operation with the Victorian and New South Wales Engineering Branches has led to the development of new and precise methods of locating leaks in pressure filled cables. Leaks in buried cables can be located using radon as a tracer gas, provided that the radon can be injected into the cable sufficiently close to the leak to enable it to travel to the leak before decaying to an undetectable level. For small leaks the position must be known to within one cable length, but with large leaks the precision required is less and radon charges may travel 600 yards or more and still be detected at the leak.

The Freon technique offers a method of pinpointing leaks in cables in ducts, provided that a sampling tube can be inserted into the duct. It is also useful for locating leaks in jointing pits, manholes and in cables in tunnels. In some circumstances it can be used to locate leaks in buried cables, but there is more uncertainty than with the radon technique, and the latter is to be preferred for this application.

The economic utilisation of these new techniques may require some modification of existing procedures. It has been the experience of Cable Protection staff in various States that when new gas pressure systems are being installed, the majority of the leaks are found in manholes and jointing pits. It follows then, that when searching for leaks in a gas pressure section during installation these are the first points to be checked. The Freon technique lends itself to this application, and all pits and manholes can be checked rapidly with one filling of Freon. When all these points have been checked and any leaks marked, the Freon is flushed from the cable. The leaks can then be repaired. Any remaining leaks will be in the sections of the cable between manholes or pits. Work should then be concentrated on localising these faults to within a cable length, and subsequent action will then be governed by the circumstances. Where faults are in lengths of cable in ducts the Freon technique can be used to give an accurate location; however, if the faults are in buried sections of cable it might be desirable to defer further action until several similar faults are available, and a visit by an officer from the Research Section to apply the radon technique would be worthwhile.

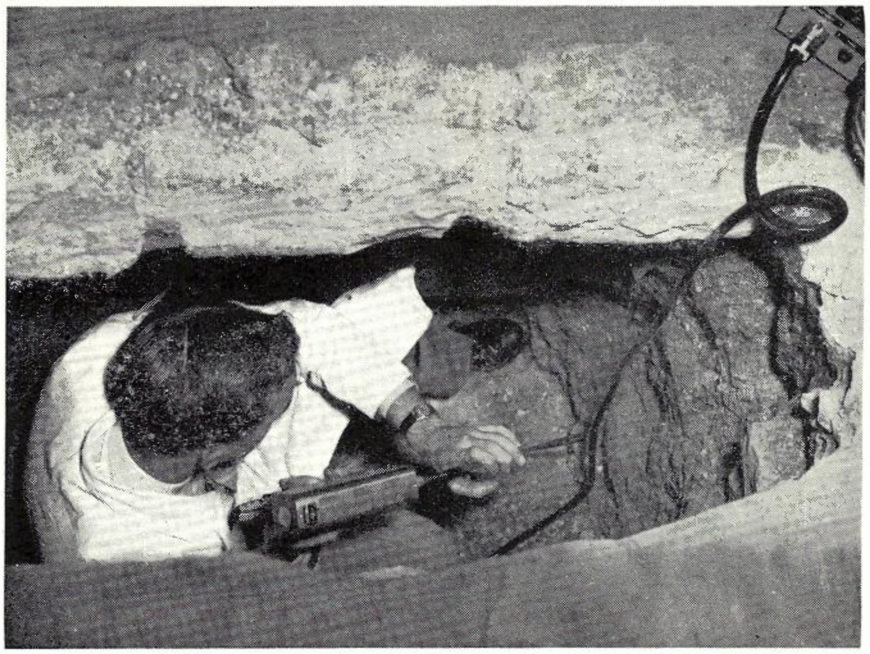

Fig. 9.—B.T.H. detector being used at a small inspection opening in an excavated duct.

Acknowledgments.

It is desired to acknowledge the assistance of the Director and staff of the Commonwealth X-ray and Radium Laboratory, whose co-operation, both in the early experimental work and later in supplying radon sources, made the work on the radon technique possible.

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CIRCUIT OPERATIONAL DIAGRAMS

J. L. HARWOOD.

Introduction.

The preparation of circuit descriptions in a concise and readable form has constituted a problem for many years. Several types of circuit descriptions are used nowadays with varying degrees of intelligibility and suitability for different individuals. The main types of circuit description are the "contact to contact" type and the "narrative" type. The former is extremely laborious to compile and to follow, but has the advantage of being precise. The latter, while being easy to prepare and read, requires a higher degree of initiative on the part of the reader to comprehend the circuit fully. To overcome these difficulties, many different types of diagrams have been developed from time to time with the object of presenting circuit operations in a clear and compact form.

Operational Diagrams.

Methods of presenting the operation of circuits in a pictorial manner include the following two main types:—

(1) Time Chart Method. This method is used to depict the operation of each relay or circuit element by means of a horizontal line preceded and succeeded by some indication of the actual operating and release times. The relationship of the operation of each relay along a time scale is thus clearly shown. This method is of great value to the circuit designer and assists greatly in circuit analysis and the location of obscure faults brought about by timing irregularities.

(2) Graphical Method. This method is similar to the Time Chart method mentioned above, but the time scale is variable to accommodate the longer periods of time during which little circuit activity occurs. The relationship of the operation of each relay with respect to other relays of the circuit is also shown. Generally this method, with suitable symbols added for guidance, is the most flexible for design, analysis and subsequent reading of the circuit.

Circuit operational diagrams of the second type are now being introduced for use in the Australian Post Office, and are similar to those used by several European administrations. The diagrams may be presented on either a vertical or horizontal scale, and the arrangement to be adopted uses a vertical time scale. The diagrams read from left to right in a functional sense and from top to bottom in time. Each stage of the circuit operation is indicated in a column on the left-hand side, while on the right suitable explanatory notes are added as required. Circuit operational diagrams will not replace the usual Circuit Report, as the report is required to contain information relating to the design of the circuit and also an explanation of the need for certain amendments. However, Circuit Reports in future will be condensed to the essential design and historical information in cases where a circuit operational chart is issued concurrently.

The elements of the diagram are shown in Fig. 1 and are self-explanatory. The number of symbols has been kept to a minimum, but other symbols may become necessary in the future.

Correlation of Circuit Operation.

Circuit aid charts have not always afforded much assistance in the interpretation of a circuit unless accompanied by a somewhat comprehensive description. It is essential, therefore, to indicate the direct cause of the operation or release of each element (relay or other device) in the circuit to avoid the preparation of a circuit description for each stage. When the circuit has been studied and its operation understood, it is unlikely that either the circuit description or the operational chart will be required again except for brief reference when finding faults. In certain complex relay systems no circuit description is supplied, the whole of the operation being described by means of an operational diagram. Instances of this are found in certain crossbar systems, described entirely by a circuit operational diagram without any accompanying description other than an overall general description. A detailed circuit description in this case would be extremely cumbersome to use.

An example of the correlation of circuit elements is shown in Figs 2 and 3.

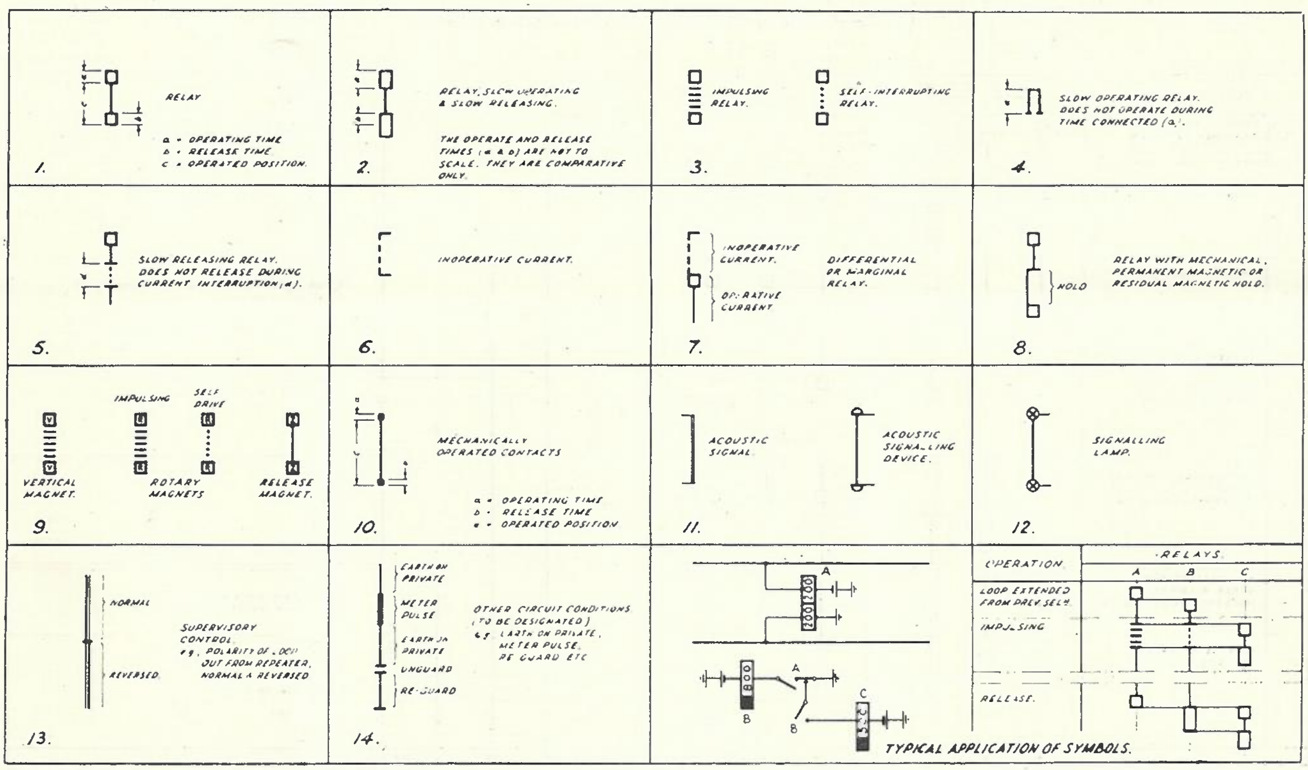

Fig. 1.

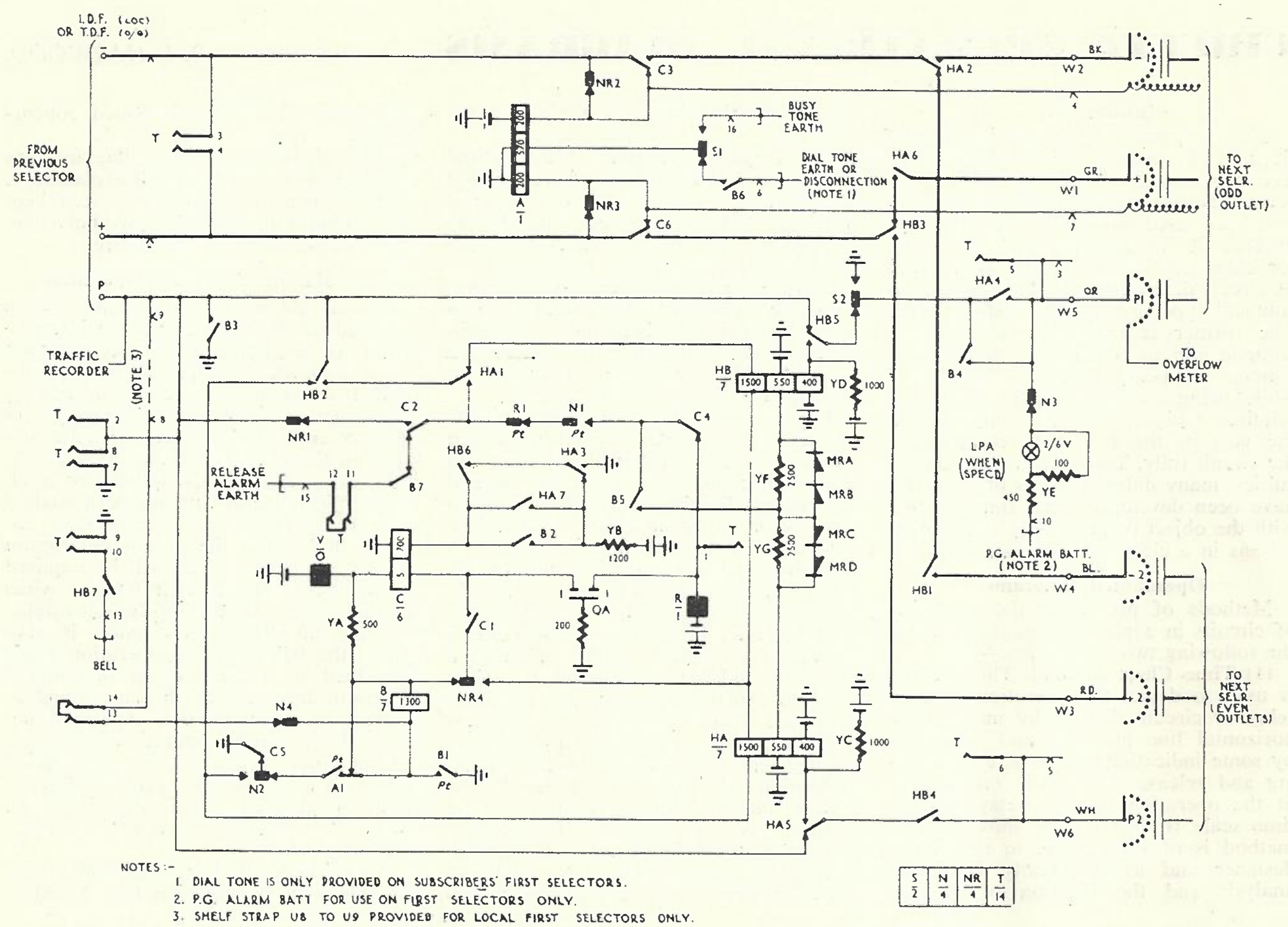

Fig. 2.—Circuit of 2000 type, 200 outlet group selector.

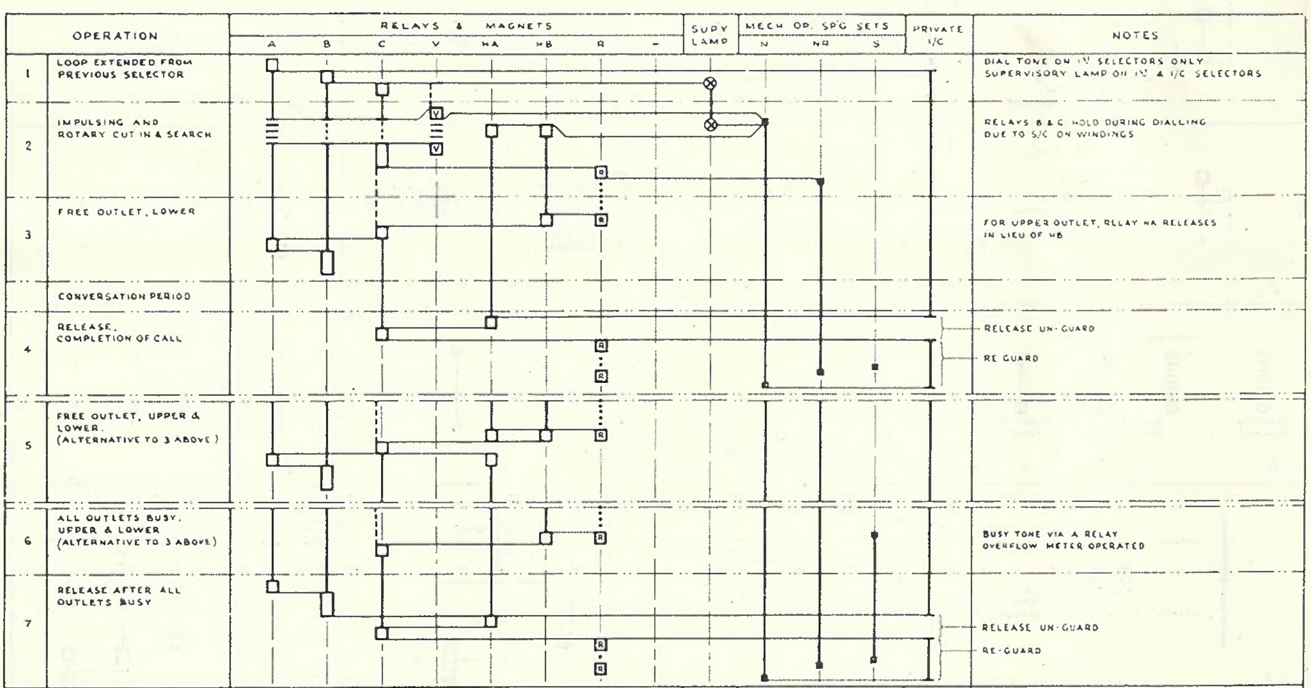

Fig. 3.—Circuit operational diagram.

Fig. 2 shows the circuit of standard 2000 type group selector, and Fig. 3 its associated circuit operational diagram. It will be seen that the horizontal line connecting each relay sequence rectangle originates from the rectangle **above** but in contact with the line. The consequential actions effected are shown by rectangles **below** but in contact with the horizontal line.

Additional information, if required may be added to the diagram by notes against the various rectangles. For example, if doubt exists regarding the contact which is responsible for the operation or release of a particular relay, this information may be added alongside the rectangle concerned. Similarly, if it is felt necessary to add reference to the operating or releasing time of certain relays, these details may be added against the rectangle concerned.

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CATENARY STRUCTURE AT RENISON BELL, TASMANIA

H. T. DAVIS, B.Sc. and D. C. ABBOTT, B.E.

Introduction: Between 1947 and 1952 the Burnie to Zeehan open wire trunk route was completely rebuilt and transposed for three channel working. This route is of importance in Tasmania, as it provides an alternate interstate route between Melbourne and Hobart, and is also the only link with Queenstown and other West Coast centres if the Hobart-Queenstown line fails. It traverses some of the most inaccessible country in Tasmania, and its reconstruction to modern standards presented many problems not normally associated with line work in Australia. Most of the route follows the Emu Bay railway line, but in the vicinity of Renison Bell, a mining village nine miles to the north of Zeehan, the route follows a newly constructed road. At the approach to Renison Bell the road crosses a gully about 70 feet deep and 360 feet wide on a high embankment. Fig. 1 shows the local topography and the location of the road and adjacent railway at this point. The problem was to erect eight pairs of 200 lb. wire across this gully and provide inspan transpositions.

Alternatives Considered. Several methods of meeting the problem were considered. These were:—

(i) Permission was sought from the Public Works Department to erect poles along the side of the road in the filling, but this was refused because of the possibility of soil erosion starting around the poles, and damaging the face of the filling.

(ii) Consideration was then given to the erection of tall poles in the gully, but these would have to be 70 feet high to maintain grading, and would require extensive staying. The space between the road filling and the railway is restricted for staying, and in the event of the poles failing, they could fall across the railway track.

(iii) A deviation would lengthen the route considerably, and involve construction in rough country, thus increasing maintenance costs.

(iv) The use of inspan transpositions was contemplated, but due to the exposure of the position it would be necessary to provide spacers for the wires to prevent contacts. It was felt that unsupported spacers and inspan transpositions would impose too great a strain on the wire in a long span, particularly when subjected to an additional loading of snow.

(v) The next consideration was to cross the gully with a single span catenary structure.

Design Features of the Catenary. The design of the catenary had to include the following features:—

(i) The structure must carry eight pairs of 200 lb. H.D.C. wire at the normal tension and transposed within the catenary span.

(ii) It must be easy to lower in the event of faults.

(iii) It must stand a high transverse wind loading as the gully is in an elevated position and exposed to westerly winds.

(iv) It would have to withstand the additional loading imposed by snow and ice.

(v) Standard line material should be used to facilitate erection and subsequent maintenance.

(vi) A simple construction procedure was desirable to enable the local lines staff to undertake the erection without assistance.

Details of the Design. The catenary support poles consist of two 36 feet 8″ x 6″ steel beams with a 4″ x 4″ arm bolted on each, six and eight feet respectively above the arms carrying the top line wires. Figure 2 is a photograph of the completed structure. These poles were of necessity high to give clearance over the mine railway and to maintain grading. The 4″ x 4″ arm is braced to the pole with independent 42″ braces. Short eyebolts to hold the catenary bearer wires were attached just outside the brace bolts. The remainder of the pole fittings were standard for two arm 28″ construction. As both the poles are on a slight angle, angle stays were attached to the poles midway between the catenary bearer arm and the cross arms to counter the side pull on the structure. Back stays were fitted to hold the poles against the pull of the suspension, and forward staying was provided to safeguard the poles during the lowering process.

The line wires in the 396 feet span were supported by two sets of inspan arms. These consisted of two Huon pine arms weighing only 10 lbs. each held together with combiners and braced on the opposite side with arm braces. This prevented the arms from twisting under the pull of the wires. The eyebolts to take the bearer wires were fitted in the top arm just outside the combiners. Two transposition plates were necessary on the top arm of one set.

It was originally intended to use 2″ x 1″ channel iron for the arms in preference to hardwood, but fortunately the Huon pine arms came to hand. They had the advantage of durability and lightness, and would cause less magnetic coupling between circuits than the steel.

The gauge of wire to be used as bearers was calculated on the following basis. Although the support poles were stayed in the line of the route, it was desirable that they have only a vertical loading. To achieve this, the line wires and catenary wires must be equally tensioned on either side of the pole. Since the bearer wires pass through eyebolts on the support arm their tension is equalised, but the line wires are terminated at the support poles to facilitate lowering, and so had to be tensioned equally on either side of the pole. The line wires in the route are tensioned to 110 lbs. so the sag of 200 lb. wire over a span of 396 feet was calculated from the formula:

$$\text{Sag} = [(\text{span in feet})\ 2/8] \times [\text{conductor weight}/5280] \times [1/\text{tension (lbs.)}].$$

The sag was found to be 6.75 feet.

Since the inspan arms were intended to act as spacers rather than supports for the wires, the bearer wires were sagged until the inspan arms were positioned in the sweep of the tensioned line wires. One inspan structure was heavier than the other, due to the presence of two transposition plates and fittings, and to ensure that this structure coincided with the line wires the bearer support arm at the end was placed two feet higher than the other.

The tension of the bearer wires for a sag of twelve feet and supporting the weight of the inspan arms was then calculated. Assuming the wire between the arm structures is horizontal—

$$T3 = \frac{148}{\sin\theta} \qquad \text{(See Fig. 1).}$$

$$= \frac{148}{12/132} \qquad \left(\begin{array}{l}\sin\theta \rightarrow \tan\theta \\ \text{when } \theta \rightarrow 0\end{array}\right)$$

$$= \frac{132 \times 148}{12}$$

$$= 1628 \text{ lbs.}$$

$$= 814 \text{ lbs. in each wire}$$

T1 is obviously less and therefore neglected ($\frac{1}{2}$T1 = 697 lbs.). Maximum safe working load of wire S.S. 7/14 = 1800 lbs. Because of small angles T4 = T3 = 1628 lbs. and T5 = T4$\sqrt{2}$ = 2300 lbs. Maximum safe working load of stranded stay wire 7/12 = 3000 lbs. This ensured that 7/14 stay wire would be adequate for the bearer wires, but that 7/12 would be required to back stay the structure.

Erection Procedure. The support poles and the line poles on both sides of the catenary were erected and stayed. The arms of the catenary support poles were fitted with "J" spindles, since it was intended to terminate the line wires at this point and connect them through with test bolts. Since the road paralleled the catenary, the assembled inspan arm structures were laid out along the road at the correct spacing and the 7/14 bearer wires were threaded through the eyebolts and extended three-quarters into the span beyond the support poles on either side. When the inspan arms were accurately positioned and 44 yards

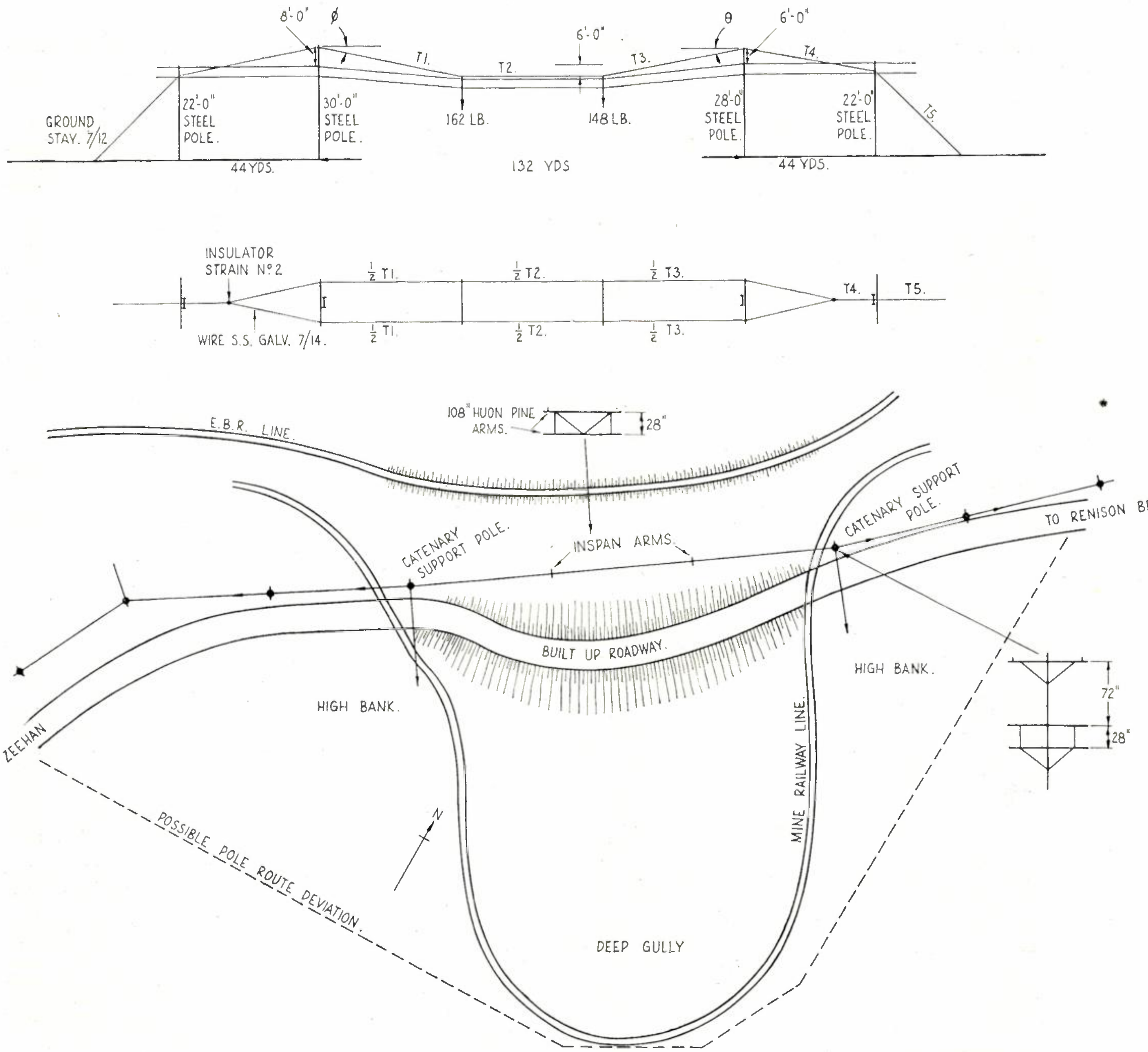


Fig. 1.—Plan of area and data used in design of the catenary structure.

apart, the bearer wire was served with binding wire and firmly lashed to the eyebolts in the arms. The free ends of the bearer wires were then threaded through the eyebolts on the support poles, and at one end were jointed together after passing through a No. 2 strain insulator. This was attached to the next line pole, which was backstayed to take the pull of the structure. The bearer wires at the other end were passed through the eyebolts and tied to the front bumper of a blitz buggy.

The line wires were then run out along the road and temporarily tied off on the inspan insulators with sufficient length to reach the support poles when pulled up. (See Figs. 3 and 4.) The truck was slowly backed, and as they lifted, the inspan arms were swung off the road into the gully. The truck then ran forward until the catenary was just above the floor of the gully. The depth of the gully made it impossible to tie off the line wires in the elevated position, so they had to be tied off with the catenary lowered and then checked when raised. They were first tied off to conform to the sweep of the bearer wires and then raised for inspection. The free ends of the line wires were taken up at the support poles and the set of the inspan arms noted. The catenary was then lowered and the line wire adjusted approximately. The ease of raising and lowering the catenary facilitated this operation.

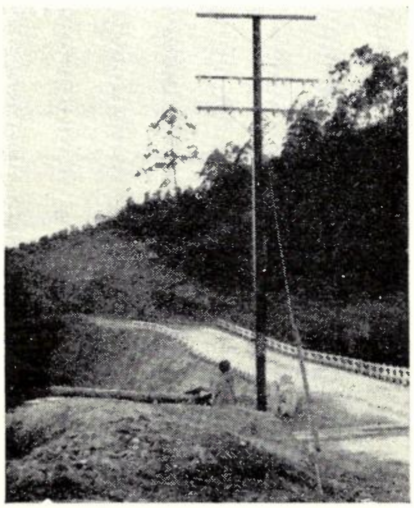


Fig. 2.—View of catenary structure.

The final adjustment of the bearer wires was made with a block and tackle attached to each bearer wire. The bearer wires were pulled up until the arms were parallel with the ground and square with the route. This adjustment was made possible by having the far end of the bearer wires looped in the strain insulator. The wires were brought together and marked. The structure was lowered and the bearer wires were terminated in a strain insulator connected to a forest devil. The bearer wires were again pulled up until they sagged the required twelve feet.

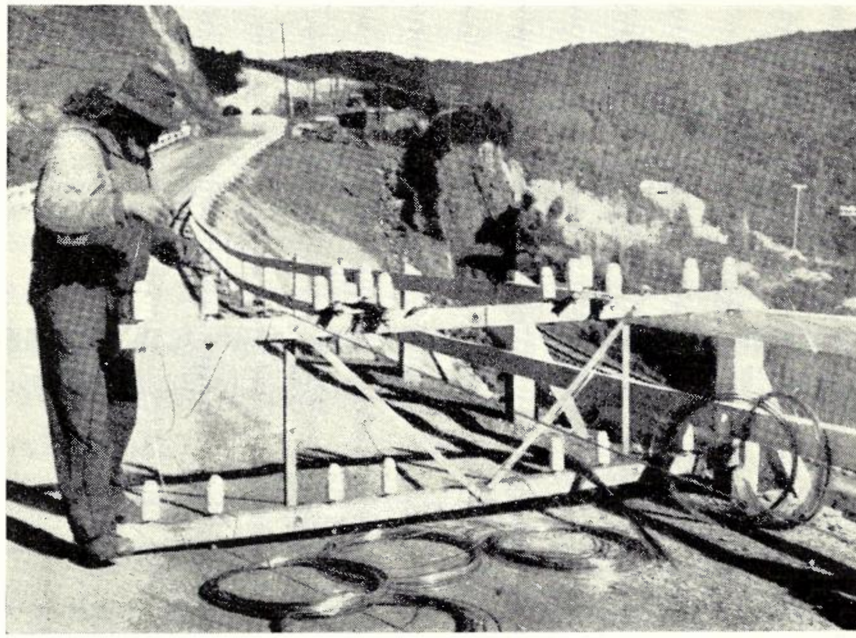


Fig. 3—Running out the line wires before erection.

The line wires were pulled up to the final tension of 110 lbs. and the set of the inspan arms noted. It was necessary to raise and lower the structure several times before the inspan arms hung vertically with the wires correctly tensioned. The strain insulator was then connected to a long threaded eyebolt set in the first line pole and the final adjustment of catenary sag was made by tightening the nut. The tension of the line wires on either side of the support poles was checked with the beat method and when equal, the wires were terminated with long loops on the "J" spindles. Test bolts were fitted at the end where lowering takes place to facilitate opening the wires prior to this operation.

The bearer wires were bound with 60 lb. galvanised iron wire for a distance of one foot on each side of the eyebolts on the catenary support arms to protect the wire from wear. The bearer wires were not tied at these eyebolts so as to reduce reflections in the wires at this point to a minimum.

Conclusions: Since this structure was erected in September, 1952, there have

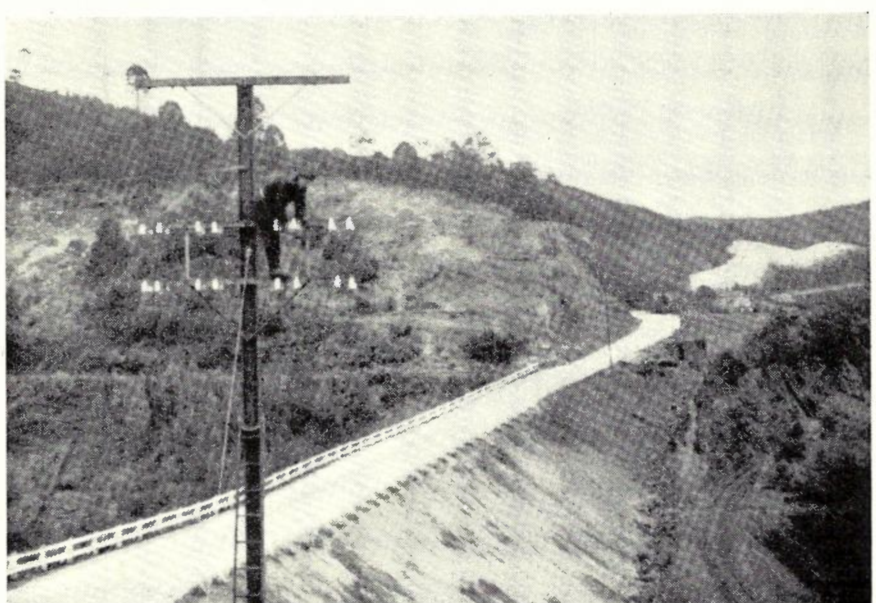


Fig. 4.—Final adjustment being made to the line wires.

been several severe storms and snow falls in this area and the catenary has been unaffected. As a result of the experience gained in the erection, the procedure could have been varied to advantage. Prior to erection it was not realised that the catenary could be raised and lowered so easily by connecting the bearer wires to a truck and driving backward and forward. Hence the inspan arms were firmly laced to the bearer wires and the line wires run out between them before the structure was lifted from the roadway.

It would have been preferable to temporarily tie off the inspan arms to the bearer wires and then lift them into position. They could then be adjusted and permanently tied off. The bearer wires could then be terminated at the correct length and the structure stabilised before the line wires were erected. This would then leave only the line wires to be correctly tensioned throughout the catenary. It is hoped that the experience gained in the designing and erection of the catenary will be of assistance in overcoming similar problems elsewhere.

OVERFLOW TRUNKING OF SWITCHING AND DISCRIMINATING SELECTOR REPEATERS

D. P. BRADLEY, B.Sc., A.M.I.E.Aust.

Introduction

The circuit of the standard discriminating selector repeater has been amended to allow alternative routing of calls between subscribers in the same exchange group. With the new circuit these calls are carried by direct interbranch junctions, if available, as a first choice, and if all direct junctions are in use, are automatically routed via the main exchange of the group. The circuit change is small, but a substantial reduction is made in the amount of line and switching plant required for intragroup working.

All future supplies of discriminating selector repeaters will be bought with the modified circuit and existing discriminating selector repeaters may be readily modified if required. However, the old and new circuits will work satisfactorily together and, in fact, discriminating selector repeaters of the two types can occupy adjacent positions on the same shelf without difficulty. The new circuit is shown in drawing CE.933 and described in Circuit Report No. 157. The purpose of this article is to describe the trunking principles associated with intragroup working and the effect on them of the new discriminating selector repeater.

Intragroup Working.

Intragroup traffic consists of calls between subscribers whose numbers start with the same letter. These subscribers are connected to the main exchange of the group, several branch exchanges, and possibly some satellite exchanges as well. The majority are usually connected to branch exchanges, and the bulk of the intragroup traffic consists of calls between subscribers connected to different branch exchanges and the main exchange. It is handled either via interbranch junctions, which directly connect various branch exchanges, or via the main exchange over branch-main junctions.

Branch exchanges are fitted with discriminating selector repeaters, and the two possible methods of trunking between branch exchanges, that is directly via interbranch junction or via the main exchange, are shown in Fig. 1. The question of whether or not to provide interbranch junctions is determined by economics, and the factors in favour of direct interbranch working are:—

(i) Fewer switches are required per call as Fig. 1 shows. However, the overall saving in switches may be less than appears at first sight, because the main junctions will carry a comparatively heavier volume of traffic and are consequently worked in a more efficient condition, that is proportionally fewer switches are required. As the relative volume of interbranch traffic increases, this advantage is reduced but the main junctions will always operate more efficiently because they trunk off 25 point uniselectors (junction hunters) whereas the interbranch junctions trunk off the 10 point discriminating selector repeater levels.

(ii) Transmission requirements of the interbranch routes are less stringent as they carry short distance calls only, whereas the main junctions are open for all types of traffic including trunk calls. Consequently higher attenuation circuits, such as unloaded 10lb. conductor pairs jointed through from exchange to exchange in subscribers cables can be used for interbranch junctions.

(iii) Direct routing takes a large volume of traffic out of the main exchange and main duct routes. These installations are always the oldest established in the group; they are the first to become congested and are usually the costliest to extend. It is

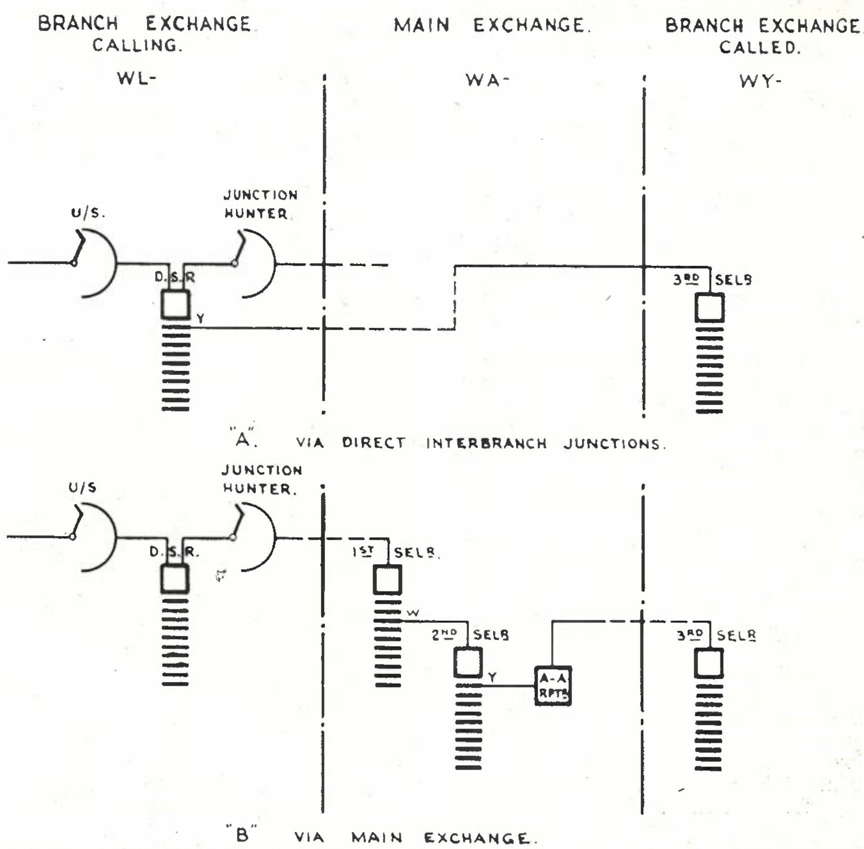


Fig. 1.—Trunking between two branch exchanges in the same group using unmodified D.S.R.

therefore usually good practice to divert as much traffic as possible away from the main exchange particularly in the older established areas.

In the balance, direct routing of interbranch traffic is usually cheapest. The only exception is between branch exchanges which only have a minor amount of traffic for each other. However, interbranch junctions can often be employed without reference to economics for the purpose of relieving congested junction routes or heavily loaded main exchange equipment. In recent years the rapid increase in the number of subscribers coupled with a steady rise in the calling rate has made heavy demands on junction and switching plant in the major Metropolitan telephone networks. Many junction cables and duct routes became congested and insufficient space was available in main exchanges for additional junction switching plant (first and second group selectors and repeaters).

These matters cannot be remedied overnight, and the increased use of direct switching between branch exchanges became imperative to reduce junction and main exchange congestion. Consequently, new interbranch routes were opened up wherever possible. In many cases, however, although cable pairs were available, new routes could not be brought into service because there were not enough pairs to provide standard grade of service. For instance, traffic between two branch exchanges might require 30 junctions; if 20 pairs only are available the standard grade of service cannot be given, the interbranch route cannot be opened up and the traffic must still be routed via the main exchange.

The initial object of the alternative routing facility was to open up interbranch routes irrespective of whether or not there were sufficient pairs available without degrading the service provided between the two exchanges.

Method of Alternative Routing

The circuit and trunking changes necessary to provide alternative routing are modest although the effect is far reaching. To explain the method, consider a subscriber to branch exchange WL calling a subscriber at another branch WY. Direct interbranch junctions connect the two. The process with the unmodified DSR is:—

(i) The WL caller seizes a free DSR and associated junction hunter at WL. The call is extended over a free junction to an incoming first selector at W main.

(ii) The caller dials W. The DSR at WL and first selector at W main are impulsed in parallel. Both step to the W level where the DSR discriminates for a W call and the wipers return to normal; the first selector at W main seizes a free local second selector.

(iii) The caller dials the second digit Y. The DSR at the local exchange and the second selector at W main both step to the Y level and cut in. Both switches commence to hunt for a free junction to WY.

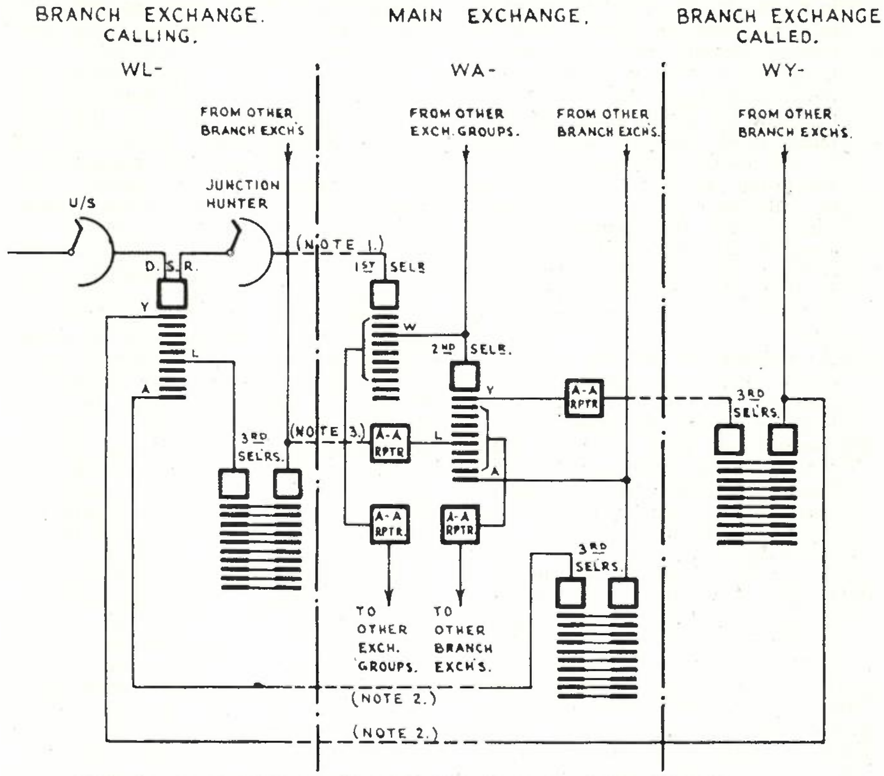
(iv) The DSR breaks the connection to W main immediately the wipers cut into the first contact of the level and discriminate for a WY call. The first and second selectors at W main then drop out.

(v) If the DSR finds a free outlet to WY the call proceeds in the usual manner. If there are no free outlets the DSR drives to the 11th contact of the Y level and busy tone is fed back.

With the modified DSR the process is unchanged for the first three steps. The alteration occurs in the fourth step where the DSR does not break the connection to W main when it discriminates for a WY call. Instead both switches hunt in parallel for a free outlet to WY.

If the DSR finds a free WY junction then, and only then, does it break down the connection via W main. In the meantime the second selector there will probably have seized a free junction to WY and there will momentarily exist two alternative parallel paths to WY. If the DSR does not find a free outlet then the call is routed by the alternative path via the main exchange. The DSR drives to the 11th contact and stays there for the duration of the call. As a consequence a call between two branch exchanges cannot fail as long as there are free junctions between each branch and the main exchange even though all direct junctions are engaged.

All ten levels including the local level on the DSR are modified in the same way. If the DSR cannot find a free local third selector for a local call it drives to the 11th contact and the call is automatically routed in and out of the main exchange in "full satellite" trunking style. If there are no interbranch junctions on any level, all contacts are earthed and the DSR drives straight to the 11th contact and the call is routed via the main exchange. Spare contacts on a level with less than ten outlets are likewise earthed. Calls for main exchange subscribers are handled in the same way; direct junctions are provided to incoming third selectors at the main to carry the bulk of the traffic and the remainder goes via the junction hunter to incoming first selectors at the main. Fig. 2 is a trunking diagram of the scheme.



NOTES :— 1. CARRIES a. ALL TRAFFIC WL TO OTHER EXCHANGE GROUPS
b. ALL TRAFFIC WL TO LOCAL BRANCH EXCHANGES WITHOUT DIRECT JUNCTIONS.
c. OVERFLOW TRAFFIC TO WA, WL & OTHER BRANCH EXCHANGES WITH DIRECT JUNCTIONS.
2. CARRIES BULK OF TRAFFIC WL TO WA & WY RESPECTIVELY.
3. CARRIES a. ALL TRAFFIC FROM OTHER EXCHANGE GROUPS.
b. ALL TRAFFIC FROM WA & LOCAL BRANCH EXCHANGES WITHOUT DIRECT JUNCTIONS.
c. OVERFLOW TRAFFIC FROM LOCAL BRANCH EXCHANGES WITH DIRECT JUNCTIONS.
d. OVERFLOW TRAFFIC WL TO WL

Fig. 2.—Trunking of modified D.S.R.

Efficiency of Alternative Routing

If building space and duct space are adequate to enable the selection of the cheapest method of trunking, considerable saving in plant cost will arise by using alternative routing trunking for intragroup traffic. The economies arise because this trunking method is more efficient; switches and junctions arranged in this manner will carry more traffic than the same amount of plant used in similar circumstances but without the alternative routing facility.

To demonstrate this point, consider the factors influencing the efficiency of a group of trunks. They are:—

(i) **Size of the group.** The efficiency increases as the number of trunks in the group increases. This increases rapidly and progressively until the number of trunks equals the availability of the switches with access to the group; then each additional trunk adds the same amount to the traffic carrying capacity of the group and the rate of increase of efficiency tapers off gradually. The result is, for example, that one group of 20 trunks will carry appreciably more traffic than two groups of 10 trunks, but one group of 200 is little better than two groups of 100.

(ii) **Availability of switches.** The efficiency increases rapidly with an increase in the availability of switches serving the group.

(iii) **Smooth or pure chance traffic.** Smooth traffic, which usually occurs between first and second selectors, requires fewer trunks, provided that the number of trunks outgoing from the switches of the group exceeds the availability of the switches.

(iv) **Grade of service.** The efficiency increases markedly as the grade of service decreases, that is, as the proportion of lost calls increases.

Tables 1 and 2 illustrate these aspects. Table 1 consists of extracts from commonly used switch quantity tables. Table 2 illustrates the effect of degrading the service. When examining Tables 1 and 2 it must be borne in mind that switch quantity tables show the number of trunks required to provide the appropriate grade of service for the traffic offered. The actual traffic carried is, of course, somewhat less than that offered; for example, in column C.10 (0.25) of Table 2 which represents a grade of service of 0.25 (one lost call in four), the traffic carrying capacity of 10 trunks is 10.8 T.U. but the traffic actually carried is 0.75 of this or 8.1 T.U. The only variable factor is the size of the trunking group. Availability of switches is governed by their mechanical design, the grade of service must conform to accepted standards and traffic is smooth or pure chance according to origin. Consequently trunking groups are always made as large as possible although, for other reasons, the number in a group never exceeds 240. As Table 1 shows, there is little gain in making them larger than this.

The reason why large groups are more efficient is that first choices in any group irrespective of size, are the most heavily loaded; traffic carried by the individual trunks decreases progressively to a minimum at the final choice. The number of lightly loaded trunks is more or less the same irrespective of the size of the group. Thus the last five trunks in a group of 20 carry about the same volume traffic as the last five in a group of 100—and, in each case, far less than the load of the first choice trunk alone. The proportion of lightly loaded trunks is thus greater in the small group and the overall efficiency is less since the number of lightly loaded trunks is approximately the same in each group.

The efficiency (average traffic per trunk) of each group would be improved if the last five choices were removed but there would be at the same time a reduction in the grade of service which is obviously much greater in the case of the small group. Thus the efficiency increases as the grade of service decreases. In effect, therefore, calls which normally would be carried by the last choices on the interbranch junctions are fed back into the branch-main junctions where they form a small portion only of the total traffic. Thus the interbranch junctions are operated in a highly efficient condition at a low grade of service but calls are not lost because the overflow is automatically diverted through the main exchange. A standard grade of service is thus provided between the two exchanges.

The bulk of the intragroup traffic is handled by direct junctions which are provided on a degraded basis and the remainder is routed via the main junctions. Normal practice is to allow 90 per cent. of the traffic to flow along the direct junctions. This is equivalent to a grade of service of 0.1 table C.10 (0.1) which is markedly more efficient than the standard grade of service table C.10 (0.002), see table I. The amount of traffic along any direct junction route is usually comparatively small but the small group of junctions is deliberately operated in a degraded service condition to improve the efficiency.

The small amount of traffic which is alternatively routed via the main exchange is carried by a large group working at high efficiency. There is a further gain because the busy hours in the various interbranch routes are not likely to coincide, hence the main junction route stays busier for a longer period than if it were not carrying alternatively routed intragroup traffic.

Advantages of Alternative Routing

The short term advantage is that overloaded main junction routes and junction switching plant can be cheaply and quickly relieved by opening up interbranch routes irrespective of whether or not sufficient pairs are available to provide standard grade of service. For instance, ten junctions may be required if trunked off a standard DSR level but, with the amended trunking, the route can be opened up even if one pair only is available.

As an example of the savings which can be made at short notice, 554 first, second and third selectors were required at one large main exchange to carry traffic originating at a busy branch. After modification of DSR's at the branch exchange for alternative routing 338 selectors at the main exchange were adequate. The saving arose partly because new interbranch routes were opened up and partly because of the increased efficiency of working made possible by the new method. In this case not only was there a net saving in

No. of trunks	Total traffic				Average traffic per trunk			
	Table C10	Table C20	Table C23	Table B23	Table C10	Table C20	Table C23	Table B23
1	.002	.002	.002	.002	.002	.002	.002	.002
5	.90	.90	.90	.90	.18	.18	.18	.18
10	3.43	3.43	3.43	3.43	.34	.34	.34	.34
20	7.9	10.1	10.1	10.1	.39	.50	.50	.50
50	21.3	28.8	29.95	32.9	.43	.58	.60	.66
100	43.6	60.1	62.7	70.55	.44	.60	.63	.71
200	88.2	122.6	128.2	145.1	.44	.61	.64	.72

Table C10 = Pure chance traffic from 10 availability switches
Table C20 = Pure chance traffic from 20 availability switches
Table C23 = Pure chance traffic from 23 availability switches
Table B23 = Smooth traffic from 23 availability switches

Table 1.—Extracts from switch quantity tables. Traffic carrying capacity of trunks at standard grade of service showing effect of availability size of group and smooth or pure chance traffic.

No. of trunks N	Grade of service B				
	C10 (0.1)	C10 (0.15)	C10 (0.2)	C10 (0.25)	C10 (0.002) (Standard)
1	.17	.23	.3	.4	.002
2	.65	.84	1.0	1.2	.065
3	1.40	1.69	1.9	2.3	.25
4	2.22	2.60	2.9	3.4	.53
5	3.05	3.55	4.0	4.6	.9
6	3.90	4.53	5.1	5.8	1.32
7	4.80	5.53	6.2	7.0	1.80
8	5.71	6.54	7.3	8.2	2.31
9	6.63	7.56	8.5	9.5	2.85
10	7.55	8.59	9.7	10.8	3.43
N > 10	.775N −0.2	.827N + .32	.85N + 1.2	.87N + 2.1	

NOTE: C10 (0.1) is the table showing traffic carrying capacity at a grade of service of 0.1 (1 lost call in 10) of 10 availability switches offered pure chance traffic.

Table 2.—Traffic which may be offered to a 10 availability group carrying pure chance traffic under varying grades of service.

plant but additional switch space was made available in an overcrowded main exchange building. On a long term basis substantial savings in capital cost occur when exchange group trunking is planned for the optimum use of interbranch junctions. In general, fewer first, second and third selectors are required at the main exchange as well as fewer main-branch junctions. More switches are required at branch exchanges but less than those saved in the main exchange.

Table 3 shows typical figures of the plant required to handle intragroup traffic. It is drawn up from two traffic readings made in a metropolitan exchange group consisting of a main exchange (5700 subscribers; originating calling rate 0.103 T.U.) and five branch exchanges (13,800 subscribers; 0.042 T.U.) Full interbranch junction working with unmodified DSR's was in use when the first reading was made, Case II in Table 3. DSR's were modified to alternative routing and the second reading was made, Case 1 in Table 3. The figures in Case III are hypothetical. A substantial margin in favour of alternative routing is evident. It will be observed that trunking is arranged so that 90 per cent. of the intragroup calls are directly routed and 10 per cent. go via the main exchange. This division is arbitrary and can be varied to suit circumstances. Factors which might influence the proportion are the geographical shape of the group, the telephone density, the traffic rate and the community of interest between the different branch exchanges.

There are two other important advantages arising from the use of alternative routing facilities. The first of these is is a lower fault liability. If interbranch junctions served off unmodified DSR's become faulty, the service is immediately degraded; if all pairs go faulty access is denied between the two branch exchanges. The remedy is to provide new pairs or, failing this, the strappings on every DSR in the exchange must be altered so that the traffic is switched via the main exchange but this operation is so difficult that interbranch routes should only be opened up if adequate spare pairs are available. With DSR's wired for alternative routing no difficulty arises; the defective pairs are merely busied out at the M.D.F. and the calls are automatically routed via the main exchange. The other advantage is the ease with which sudden changes in traffic conditions can be handled.

In a similar way a growth of traffic between any two interbranch exchanges will not necessitate immediate provision of extra interbranch junctions as the additional traffic can be automatically handled via the main exchange for the time being. This means that unexpected growth which takes place between the two yearly traffic readings will not cause any unnoticed congestion.

Trunking Congestion

One warning must be given about the use of alternative routing, namely: it may cause unexpected congestion between the first and second selectors at the main exchange. To see why this can happen, consider the nature of telephone traffic: it is spasmodic in character and the number of calls in progress at any moment vary widely with the hour of the day and from minute to minute in any hour. Sufficient switching equipment is provided to carry the average traffic in the busiest hour of the day. But the number of calls in progress at any minute of the busy hour may vary widely, see Fig. 3. There is such a big difference between the peaks and the troughs that it is not economic to provide enough switches to carry the peaks and some calls are deliberately allowed to fail for lack of switches. For instance sufficient switches might be provided to carry all traffic below the line AA (Fig. 3) and that above will fail because all switches are engaged. The standard grade of service provides for the failing of 0.2 per cent. of the total calls which originate in the busy hour but this does not mean that there will be an 0.2 per cent. failure of calls originating in any minute of the busy hour as in the trough all calls will probably succeed and at the peaks more will fail.

With alternative routing trunking the traffic below the line which goes via the direct route is of the type shown below

Table 3

Case	Loaded junctions; pair miles	Non-loaded junctions pair miles	Group selectors at main exchange	Group selectors at branch exchanges	Repeaters at main exchange
I	25	520	145	103	8
II	270	420	366	173	—
III	550	—	568	76	76

Case 1.—Direct junctions between all branch exchanges and from branch exchanges to third selectors at main exchange; alternative routing with 10 per cent. of intragroup traffic diverted via main exchange.

Case 2.—Direct junctions between all branch exchanges; no alternative routing facilities.

Case 3.—No interbranch junctions; all traffic routed via the main exchange.

AA whereas that which goes via the main exchange is of the type above AA. The latter is plainly of different character from normal traffic and consists of a series of bursts of traffic interspersed with intervals of no traffic. The proportion of peak to average traffic is much higher and the application of standard grade of service tables would give insufficient switches, that is, at times the switches will be "swamped" by the peaks and too many calls will fail. The trouble is alleviated somewhat because firstly this traffic forms a small portion only of the total branch to main traffic and secondly because the alternatively routed traffic from all branch exchanges is handled together; it is unlikely that their peaks and troughs will coincide and an averaging effect results.

However, there is a possibility that blockages will occur between first and second selectors and to reduce this possibility, incoming and local first selectors should be carefully mixed together so that as far as possible local incoming switches from each branch exchange in the group appear on every first selector shelf or multiple. In this way traffic from up to nine separate branch sources can be mixed together and added to calls originating from the main exchange subscribers and a considerable smoothing effect results. Experience is that mixing is adequate but a careful watch should be kept on the position and more second selectors provided if necessary.

Traffic Reading

A modified procedure is necessary when making traffic readings on DSR's wired for alternative routing because the traffic on each outgoing route cannot be read directly. Traffic carried by the main exchange route includes calls for branch exchanges as well as calls outside the group and the traffic observed on any one interbranch route is less than the total because portion is diverted via the main exchanges. For design purposes it is necessary to know how much traffic originates for each other exchange in the group. Direct

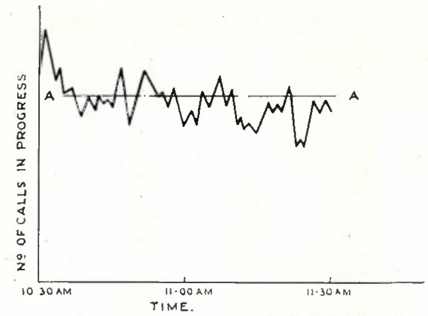


Fig. 3.—Fluctuations in busy hour traffic.

observation will give a smaller figure than the true one and a table has been drawn up which enables the true traffic figure to be assessed from the observed one. Portion of the table is reproduced in Table 4. The traffic carried by the junction route, as read by a recorder, is selected on the line corresponding to the number of junctions on the route (left hand vertical column) and the traffic offered is read off across the top of the table at the vertical column corresponding to the traffic carried. Interpolation is necessary.

The table was drawn up from Erlang's formula for full availability trunks.

$$B = \frac{\dfrac{A^N}{N!}}{1 + A + \dfrac{A^2}{2!} + \dfrac{A^3}{3!} + \dots + \dfrac{A^N}{N!}}$$

where N = The number of outlets
A = The traffic offered
B = The grade of service or proportion of traffic lost to traffic offered.
then traffic lost = A x B
and traffic carried = A – A x B.

The problem was to construct a table from which A the traffic offered could be read if the traffic carried (A—A x B) were given together with the number of trunks N. This is done by a repetition process of allotting fixed values to A and N and working out corresponding values of B. Since the table is intended for application to ten outlet switches the process is only repeated up to a value for N equals 10. Beyond that, Erlang's modified formula is used.

Conclusion

The modified method of trunking off DSR's enables intragroup traffic to be carried with less plant because the switches or junctions involved are virtually made to do more work, that is, they are occupied for a much greater period during the busy hour. Taking the long range view this trunking offers a substantial reduction in capital costs. From the short range point of view the scheme is very attractive if duct space and junction cable accommodation is limited, as well as space for more switching plant in the main exchange building. With the rapid post-war growth in all classes of junction traffic the provision of additional junction line and switching plant has absorbed a large volume of material, manpower and building provision. The introduction of alternative routing means that a large growth in an important portion of the junction traffic can be handled with the provision of very little extra plant.

One of the major attractions of the scheme is the ease with which it can be introduced. Pre-2000 type DSR's require wiring alterations only involving about one manhour, while 2000 type DSR's need additional springs and the modification takes about four manhours. In spite of the profound effect of the modification no difficulties have arisen in carrying them out since alterations can be carried out piecemeal as opportunity arises. The necessary jumpering is carried out on the M.D.F. and T.D.F.'s and then switches are progressively altered to the new circuit as time is available. A modified switch and an unmodified switch may occupy adjacent shelf positions indefinitely.

Traffic offered T.U.	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
No. of trunks	Traffic carried T.U.									
1	.5	.67	.75	.80	.83	.86	.88	.89	.90	.91
2	.8	1.2	1.4	1.54	1.62	1.7	1.7	1.76	1.8	1.8
3	.94	1.6	2.0	2.2	2.35	2.46	2.54	2.6	2.64	2.68
4	.98	1.8	2.4	2.76	3.0	3.2	3.3	3.4	3.47	3.54
5		1.93	2.7	3.2	3.6	3.84	4.0	4.16	4.23	4.36
6		1.98	2.84	3.53	4.04	4.4	4.7	4.9	5.0	5.15
7			2.93	3.75	4.4	4.9	5.26	5.54	5.73	5.9
8			2.98	3.88	4.65	5.3	5.75	6.12	6.4	6.6
9			2.99	3.95	4.8	5.55	6.14	6.6	6.95	7.3
10				3.98	4.9	5.74	6.45	7.06	7.5	7.85

EXAMPLE: Four trunks available, traffic carried as read on recorder 3.4 T.U., then traffic offered is 8 T.U.

Table 4.—Table for computing traffic offered from traffic carried.

DIRECT DIALLING BY MELBOURNE SUBSCRIBERS TO COUNTRY EXCHANGES

K. W. MACDONALD, B.Sc., D.P.A.

Introduction: Until 1948 all trunk calls originated by Melbourne metropolitan subscribers were handled by operators at the Melbourne Trunk Exchange, where a very good grade of service was provided, and a high percentage of incoming calls were completed on demand. The procedure for a call to Frankston, say, was then as follows:—The subscriber dialled MO71 for Trunk Lines and was connected via a call queueing distributor to a trunk operator. The operator recorded the call details on a docket and usually completed the call on demand by immediately seizing an idle trunk to Frankston. The equipment involved in such a call is indicated in block schematic form in Fig. 1.

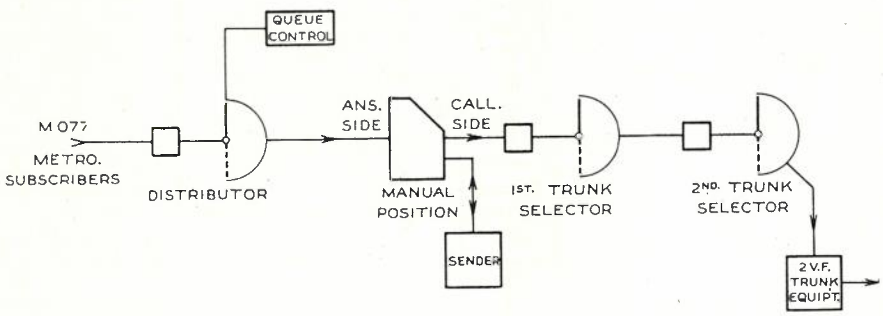


Fig. 1.—Melbourne trunk exchange—demand working trunking.

While the grade of service to the subscriber was good, two telephonists were involved in the connection, one at Melbourne and the other at Frankston, a manual exchange. Since practically all the large country exchanges in Victoria are manual, this expensive operating provision applied to the majority of calls handled at Melbourne Trunk Exchange. On occasions when a sustained traffic peak to a particular centre was experienced, it would be found necessary to institute delay working for calls on that route. This meant that all calls were booked, and later reverted by a delay operator. The equipment involved in a delay call is shown in Fig. 2. It can be seen that a much greater amount of equipment is used and the actual operator effort required is much greater for a delay call, as both parties must be called instead of the caller presenting himself to the Melbourne operator.

During 1948, great difficulty was experienced in maintaining the required staff of trained operators throughout the State. The staff shortage was most apparent and caused the greatest dislocation at the large Melbourne Trunk Exchange, where the available staff in the busy hour fell to only approximately 70% of the traffic requirements. It was manifestly impossible to maintain standard practices and service under these conditions, and the alternatives appeared to be:—

(a) Maintain standard practices to complete 70% of the traffic offering, and merely refuse service on the balance which could not be handled.

(b) Resort to booking all calls originated during the busy hour, thereby reducing the number of calls actually completed in that period. All calls booked would be reverted later, when operators became available as the incoming calls decreased.

The latter method was adopted, as representing a better service to the subscribers than the first alternative, but this method was not without its drawbacks, particularly in the matter of quoting to the subscriber the anticipated delay before his call would be reverted. The delay period was really unpredictable since it depended largely upon the time for which the heavy booking rush continued. Consequently the delay times arbitrarily quoted to the callers were generally inaccurate and the volume of inquiry traffic which was thereby generated further decreased the effective operating staff actually engaged upon call completion.

Evolution of Subscriber Dialling to Country Centres. Since no reasonably prompt means of overcoming the operator shortage was apparent, consideration was given to some change in operating procedure wihch could lighten the operating load at Melbourne. The solution which was finally applied was both expedient and realistic. Some of the largest routes in point of numbers of channels were to the nearer centres, particularly seaside resorts such as Frankston, and the fringe suburbs approaching the Dandenong Ranges. Examination of the channel traffic carrying capacity showed that only small increases were required to enable trunk calls to these centres to be carried direct from an automatic level with a satisfactory grade of service. Since all the exchanges concerned were manual an incoming operator was required at the country end on every call, so that a ready means of recording the trunk line fee on the metropolitan subscriber was available. Spare number levels were conveniently available in the City West Subscribers' Automatic Exchange which was located in the same building as the Trunk Exchange and Long Line Equipment terminal. Accordingly, trunks to a number of such centres were connected from the banks of group selectors in the subscribers' automatic exchange, and metropolitan subscribers were asked to call new individual numbers for the particular centres so treated. A trunking diagram of the arrangements is shown in Fig. 3.

The only variation made in standard circuit arrangements comprised minor circuit amendments to the standard auto-manual relay set to permit working into a 2VF trunk line relay set in lieu of a 2 wire junction.

At the inception of the scheme in December, 1948, 3 towns were included, namely, Frankston, Chelsea and Dandenong. The codes allotted were 5 digit numbers in the MU group, MU023, MU025, and MU026, with 20, 10 and 20 unidirectional trunks respectively. It was found that the scheme worked very smoothly and nearly 20% of the load was taken from the Melbourne Trunk Exchange, thus enabling reasonably efficient service to be given on the other routes during the pre-Christmas rush.

The success of the initial experiment led to consideration of the possibilities of extending the scheme. However, several conditions necessary for reasonably efficient operation needed to be fulfilled—

(a) A group of the order of 10 trunks was required to achieve reasonable traffic carrying capacity under the

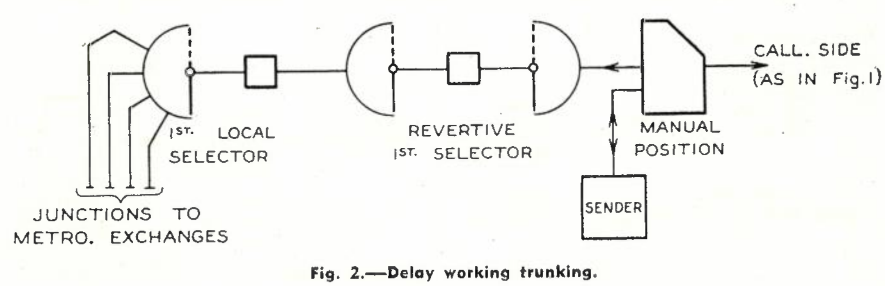


Fig. 2.—Delay working trunking.

random conditions of subscriber dialled traffic.
(b) Equipment and staffing provision at the country station needed to be adequate.
(c) The trunk group needed to be capable of expansion to cope with increased traffic which could develop because of the better grade of service given.

Because of these considerations expansion of the scheme has been limited to Werribee, Mornington and Croydon, with the last-mentioned station switching for Bayswater and Lilydale also. The total number of channels serving the six levels then in use was 87, and the busy hour traffic of 50 T.U. represented an operator saving at Melbourne of the order of 20 operators.

Advantages of the Scheme:

1. The first and controlling advantage was the reduction of the operating load at Melbourne. While this was the compelling reason for initiating the scheme, there are also administrative advantages in limiting the size of the main trunk exchange, which tends to become unwieldy as the total staff continues to increase. A small increase in the staff at the country centres tends to increase their efficiency and the staff recruitment problems are easier to handle in the country towns.

2. A large number of trunk calls were now handled by one operator only where formerly two were required. Since the country exchanges are manual, and an incoming operator is unavoidable at that end of the connection, the elimination of the Melbourne operator represents a distinct saving in operator effort, and not merely a transfer of operating load from city to country.

3. Through calls from most of the main country centres in Victoria to the subscriber dialled centres could be completed by the originating telephonist. Previously, a manual operator at Melbourne had been necessary. Thus, a call from say Mildura to Frankston would involve 3 operators, and reduction to two operators greatly expedited the completion of such calls. One result of the experience in this matter was that work was put in hand to incorporate automatic transit working at the Melbourne Trunk Exchange so that all transit traffic in Melbourne could be handled automatically. This equipment is described in a companion article by G. E. Hams in this issue of the Journal.

Disadvantages:

1. In effect, trunk channels are being used for the booking of calls, as well as for the actual conversations. In fact the practice of telephonists handling more than one call at a time by overlapping operations almost eliminates this apparent disadvantage.

2. Subscribers are asked to discriminate in the codes used for different trunk line routes. Apparently the subscriber is prepared to accept this feature as long as good service is given on the special levels, but the process of making trunk calls is rather more complicated.

3. Under demand service conditions no real check is available of the accuracy of the quoted calling number. This leaves the system open to abuse by unscrupulous callers, and the practice of periodically reverting all calls booked does not completely solve this problem even though it has indicated an exceedingly low percentage of error or dishonesty.

4. Since the trunk channels are connected to the banks of automatic switches and the traffic reaches them in a random manner the effective occupancy of the channels tends to be lower than under operator control. Hence a given amount of traffic offering for a particular route would require more trunk channels under subscriber dialling conditions, than when an outgoing operator intervenes. It is in the direction of giving a greater traffic carrying capacity to such trunks that an interesting development on original lines has taken place.

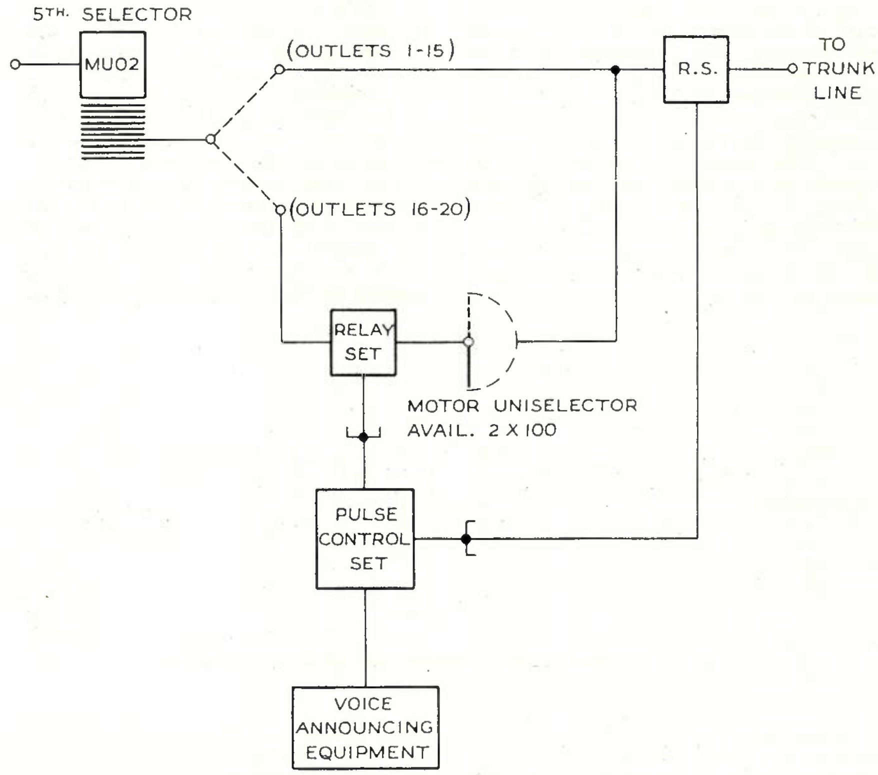


Fig. 4.—Repeated search equipment schematic.

Repeated Search Equipment: Comparison between the subscriber dialled and operator controlled methods of operation clearly showed that the improved trunk line occupancy in the latter case was due to two major factors—

(a) The semi-automatic trunk exchange equipment provided for all trunks to be contained in a single fully-available group, whereas the limitations of the subscribers' automatic switches required larger groups to be graded with a maximum possible availability of 20 (certain manual overflow conditions provided, effectively limited the availability to 16).
(b) The actual test for a free trunk was based upon an instantaneous search over the available trunks. In the case of an operator controlled call the calling subscriber would often be persuaded to wait for some appreciable time during which a line in the required group would become free.

An effort was made to design equipment which would artificially reproduce conditions approximating to manual

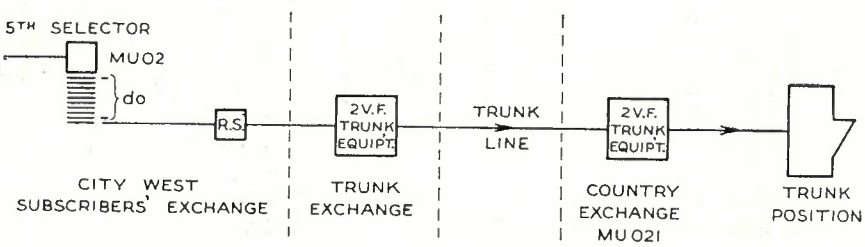


Fig. 3.—Subscriber dialling trunking.

operator control, and the result is shown in block schematic form in Fig. 4.

The later contacts on the level of the standard 2000 type group selector giving access to the subscriber-dialled trunk group were taken to the wipers of motor uniselectors serving as a tandem trunk hunter switch. Since the motor uniselector has an availability of 100 outlets, this ensured that every incoming call could make a full search over the complete group of trunks. Thus the trunk group has an effective traffic carrying capacity as a fully available group, an increase over that under limited availability, graded conditions. The relay set controlling the motor uniselector has the added feature that after the initial search of the group has been made the connection is held by the calling loop. Whenever any trunk in the required group becomes free, a free line signal is fed to the trunk hunter relay set, and a further search is made over the group for a free line.

In order to encourage the calling subscriber to hold the connection, and to avoid subjecting him to a long period with no apparent progress, provision has been made for the connection of a "Recorded Voice" on all calls which are directed to the repeated search equipment. The phrase used is "Hold the line, please — Hold the line." It was found after trial and observation that this phrase appeared to enlist the greatest degree of co-operation from subscribers, and a very high percentage of the calls which are diverted to the repeated search equipment are sustained for a sufficiently long period to ensure the successful completion of the call. When a free line has been seized by the repeated search selector, the calling subscriber is fed ring tone until the called country operator answers, as in the case of a call which finds a free trunk line on the initial search by the ordinary group selector.

The effect of this circuit arrangement is to artificially provide for a number of further tests for a free trunk to the required destination, in a manner which is analogous to the handling of a call by a manual operator. The overall effect is to greatly increase the traffic carrying capacity of the trunk group, or in other words to reduce the number of trunk channels required to carry a given amount of offered traffic for a certain equivalent grade of service. The time during which repeated searches over the group may be made is of course limited by the patience of the calling subscriber, but the aim is to provide only sufficient tandem motor uniselectors to ensure that there is a reasonable probability for connection to a free line within a period of not more than 60 seconds.

It has been found in practice that very substantial increases in traffic carried at busy periods can thereby be obtained without imposing undue waiting times which would be considered as poor service by the subscribers. Expressed in other words, an increased amount of traffic on the trunk route is being carried without having provided additional trunk channels. To carry this traffic on the old basis would have entailed a much greater expenditure on channel provision than has been needed to provide the repeated search equipment.

Voice Announcing Equipment: The equipment used to provide the voice announcements is exactly similar in principle to that described in a previous issue of the Journal (Vol. 7, No. 5, page 308). Briefly, the arrangements are that a strip of sound film mounted on a cylindrical drum revolves past an optical source. The variations in light intensity caused by the sound track are recorded by a photo-electric cell, and suitably amplified to yield sufficient audio output at a low impedance to serve as the common source for a number of simultaneous connections. The only modifications needed were the substitution of a strip of sound film carrying a recording of the new phrase and the reshaping of the cam which controls the period for which the announcing equipment is connected to the subscribers' automatic equipment to permit the longer phrase to be accommodated.

Control Relay Set for Repeated Search "Trunk Hunter": The schematic circuit for the relay set controlling the trunk hunters is shown in Fig. 5. It is seen that the circuit is not particularly involved containing only 11 relays.

Operation is as follows:—

An incoming call engages a fifth selector which searches first over its early contacts for a direct connection to a trunk line. Failing a trunk available to the particular switch being free, the A relay of an associated overflow trunk hunter is looped. A operates, B operates, and BA operates slowly. Contacts of BA complete the drive circuit for the motor uniselector which drives around the bank. The test relay TA tests the outlets for a free trunk, indicated by the presence of 500 ohm battery on the P wire. If a free line is encountered on

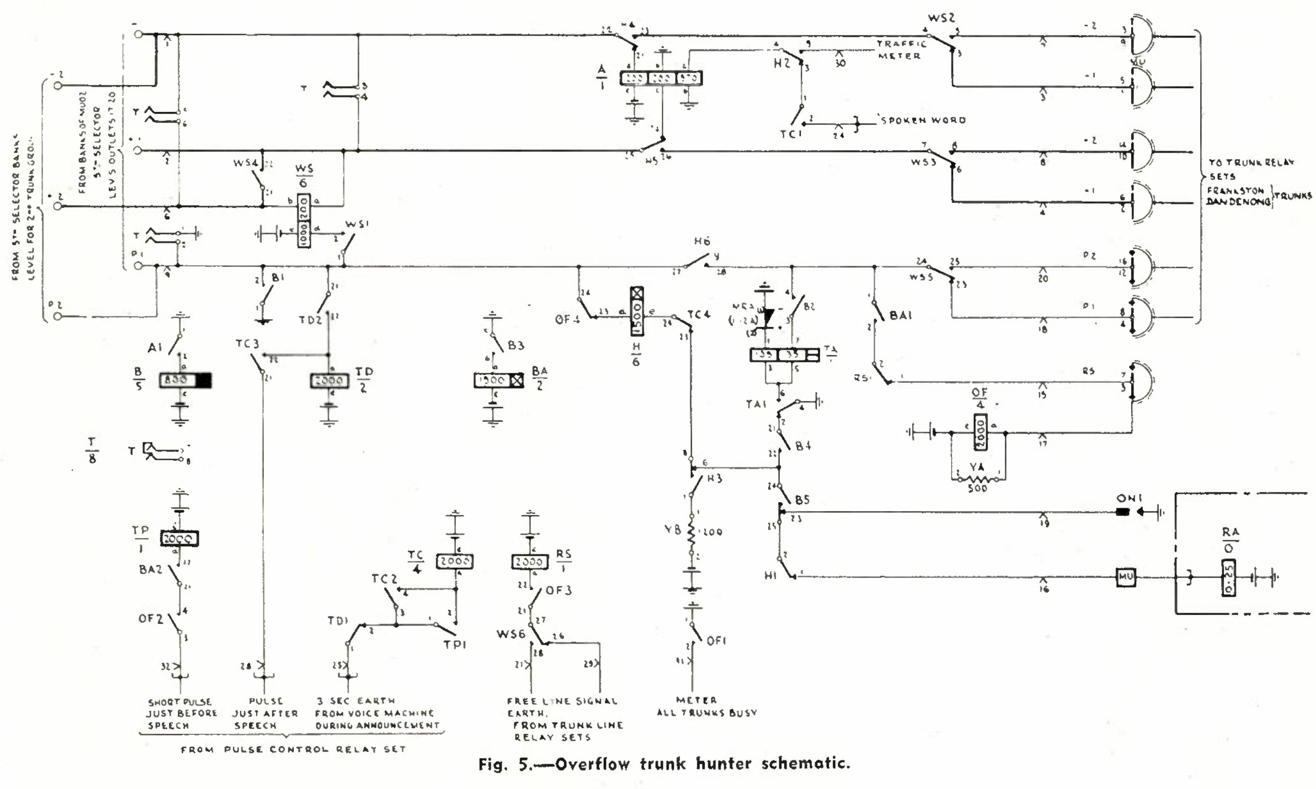


Fig. 5.—Overflow trunk hunter schematic.

the first sweep over the full group of trunks, TA operates to the marking battery, and opens the drive circuit to stop the switch. TA's operation removes the short circuit from H, which then operates in series with the motor uniselector magnet, and locks to battery via resistor YB.

The call is then switched through to the trunk relay set—relays A, B, and BA release and H holds to earth fed back from the P wire of the seized trunk.

If no free trunk is encountered, the switch returns to the normal contact, where TA operates to battery via the spool YA across OF relay. OF also operates and prepares the circuits of TP and RS, and prevents the operation of H.

A pulse fed from the Voice Machine control set before the speech phrase commences causes TP to operate. TP operates TC which locks via a TD break contact to a sustained earth from the Voice Machine. TC connects the "Spoken Word" to the third winding of A relay, which acts as a transformer to deliver the message, "Hold the line, please — Hold the line," to the calling subscriber.

At the conclusion of this phrase, a pulse from the Voice Machine operates TD which locks and prevents any subsequent repetition of the phrase.

The motor uniselector now waits on the normal contact until any one of the trunk lines in the group becomes free —then a "Free Line Signal" earth is fed to operate RS. RS opens the circuit of TA, which releases and causes the motor uniselector to drive again over the group, searching for the free line. If the line has been seized before the switch arrives, it will return home, and await a further free line signal before eventually obtaining a free trunk.

Wiper Switching Feature—Service on Two Routes: Since only four arcs of the motor uniselector are required for each connection, the switch is effectively a 200 outlet switch. For practical applications, an availability of 100 is quite sufficient, so a further measure of equipment economy is introduced by making the overflow trunk hunter common to two separate trunk routes, that is, two levels from the preceding fifth selectors. Calls directed to one destination cause the operation of WS relay in series with A, and the motor uniselector then hunts via the wiper-switched arcs for a free trunk to the required centre. Calls for the other destination come into the relay set independently from WS and the normal wipers search for trunks to the other destination. A dual reduction in the number of overflow trunk hunters needed is then effected, firstly because the combined group is more efficient than two smaller groups, and secondly, because traffic peaks will rarely coincide on the two routes.

Results in Service: The facility has been available on subscriber dialled levels to Dandenong and Frankston for a period of twelve months, and has substantially improved the traffic carrying capacity of the trunk groups to those centres. The overflow trunk hunters have been brought into use only at periods of peak traffic, and observations have shown that at these busy periods, increases of the order of 15 per cent. have been achieved, without requiring subscribers to wait for unduly long periods. In fact, in the particular case, less than one per cent. of calls undergoing the overflow hunt for a trunk line would be delayed for a period of one minute. Expressed in another way, handling of the subscriber dialled traffic by orthodox means would have required the provision of a number of additional trunk channels to ensure that a reasonable grade of service was provided at the short-period traffic peaks. Because of the ability of the overflow trunk hunters to spread short term traffic peaks, the trunk groups have needed only to cope with the long-term rather than the short-term peaks. The economies achieved on the trunk channel provision side have greatly exceeded the cost of the overflow trunk hunter equipment. The conclusion has been reached that provision of the facility is warranted in the case of trunk groups of the order of 20 channels, and the savings achieved will increase as the group increases in size. Extension of the facility to other trunk groups to country manual exchanges will therefore follow the growth of traffic to the smaller centres.

AUTOMATIC TRANSIT SWITCHING AT THE MELBOURNE TRUNK EXCHANGE

G. E. HAMS, B.Sc.

Introduction: On the 15th August 1953, automatic transit (or through) switching equipment was put into service at Melbourne. By the addition of one rack of selectors, any centre having 2VF signalling trunks to Melbourne was enabled to call 35 intrastate and 5 interstate centres without the assistance of a telephonist at Melbourne. For example, the telephonist at Garfield, a small town with one 2VF trunk to Melbourne, can now call directly subscribers in the Sydney or Adelaide automatic networks, or the telephonists in most of the larger Victorian country towns.

Trunking: It will be seen from Fig. 1, the basic trunking diagram of the Melbourne Trunk Exchange, that two digits are required to effect the through switching. Thus the first two trains of V.F. impulses are converted to D.C. impulses at Melbourne and used to position the selectors. The first digit is taken by the VF selector and determines whether the call is to go to the Melbourne automatic network, the Melbourne through or suspense operators or to one of the groups of transit selectors.

The second digit causes the transit selector to find and search over the trunks to the required centre. If all the trunks in this group are engaged, busy tone is returned to the calling telephonist. N.U. tone is returned if an unused code is dialled. Although not at present in use at Melbourne, the facility can be given for routing calls, for routes in delay, to a Melbourne "Through" operator without searching over the trunks to the centre called.

The transit selector switches the –ve, +ve, net–ve, net+ve, P and S wires enabling automatic four wire and pad switching to be accomplished.

Signalling: When the switching is completed through the transit selectors, circuit action takes place between the 2VF trunk line relay sets. These VF relay sets at Melbourne are then rendered inoperative to all but the longest of the 2VF supervisory signals, the clear forward. This signal persists long enough to overcome the guards imposed. The two trunks when connected will thus behave as a single trunk from the calling and called exchanges, the 2VF signals passing through without effect on the Melbourne equipment until the appearance of the clear forward.

The train of signals for a transit call to a centre with an automatic network is shown diagrammatically in Fig. 2. A comparison can be made with a similar diagram in Telecommunication Journal Vol 4, No. 2, for a call over a single 2VF trunk.

As the signalling takes place over the two trunks in tandem, sufficient level of signalling tone must be received for reliable 2VF receiver operation. This puts a limit of 15db as the maximum equivalent for the tandem connection.

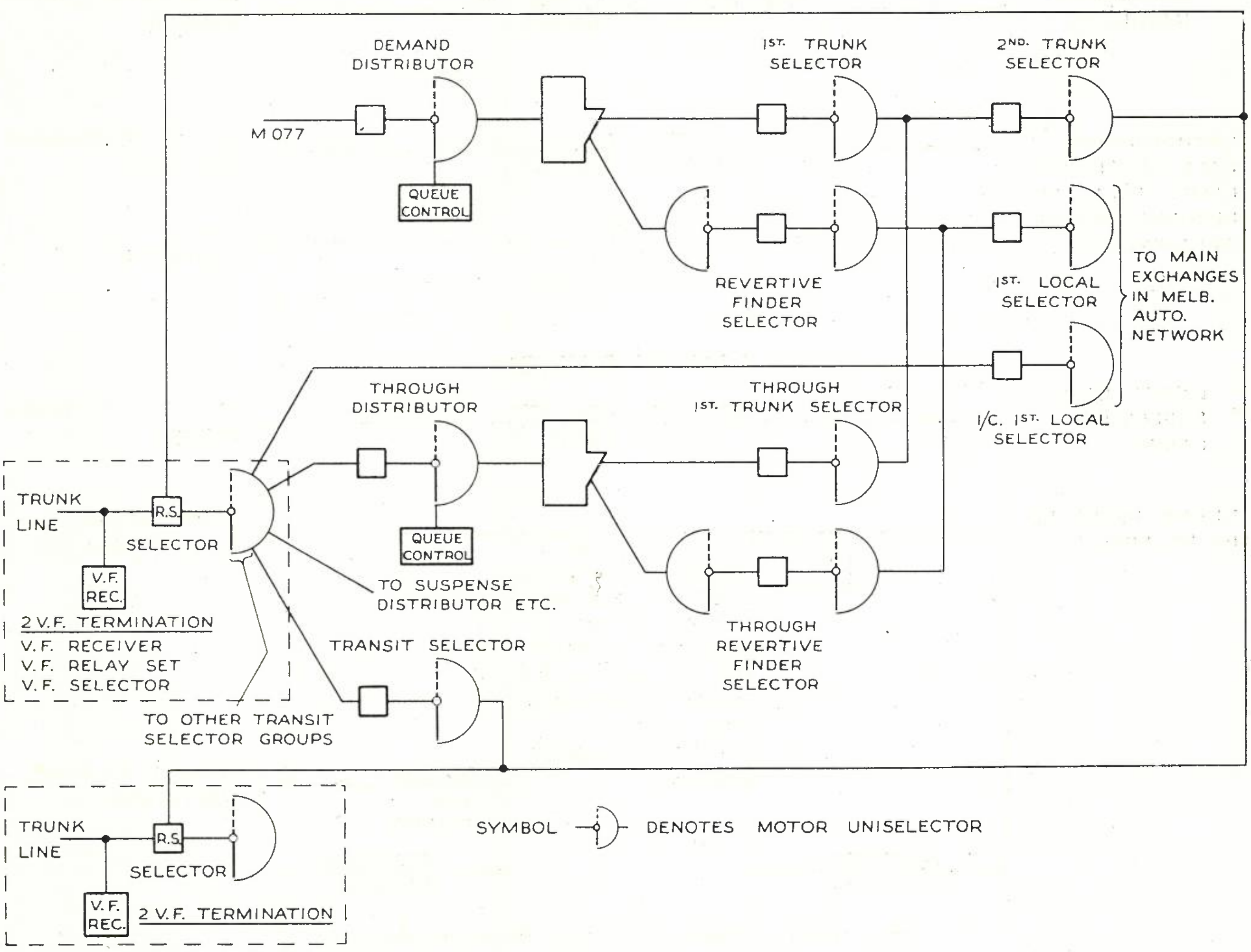


Fig. 1.—Basic Trunking—Melbourne trunk exchange (Siemens M.U.).

Therefore, trunks having a greater equivalent than 7db cannot be given access to the transit selectors or used as trunks connected to the banks of these selectors.

Conclusion: The advent of transit switching represents a step towards the automatisation of the Victorian Trunk network and enables more efficient use to be made of the existing trunk lines.

Bibliography

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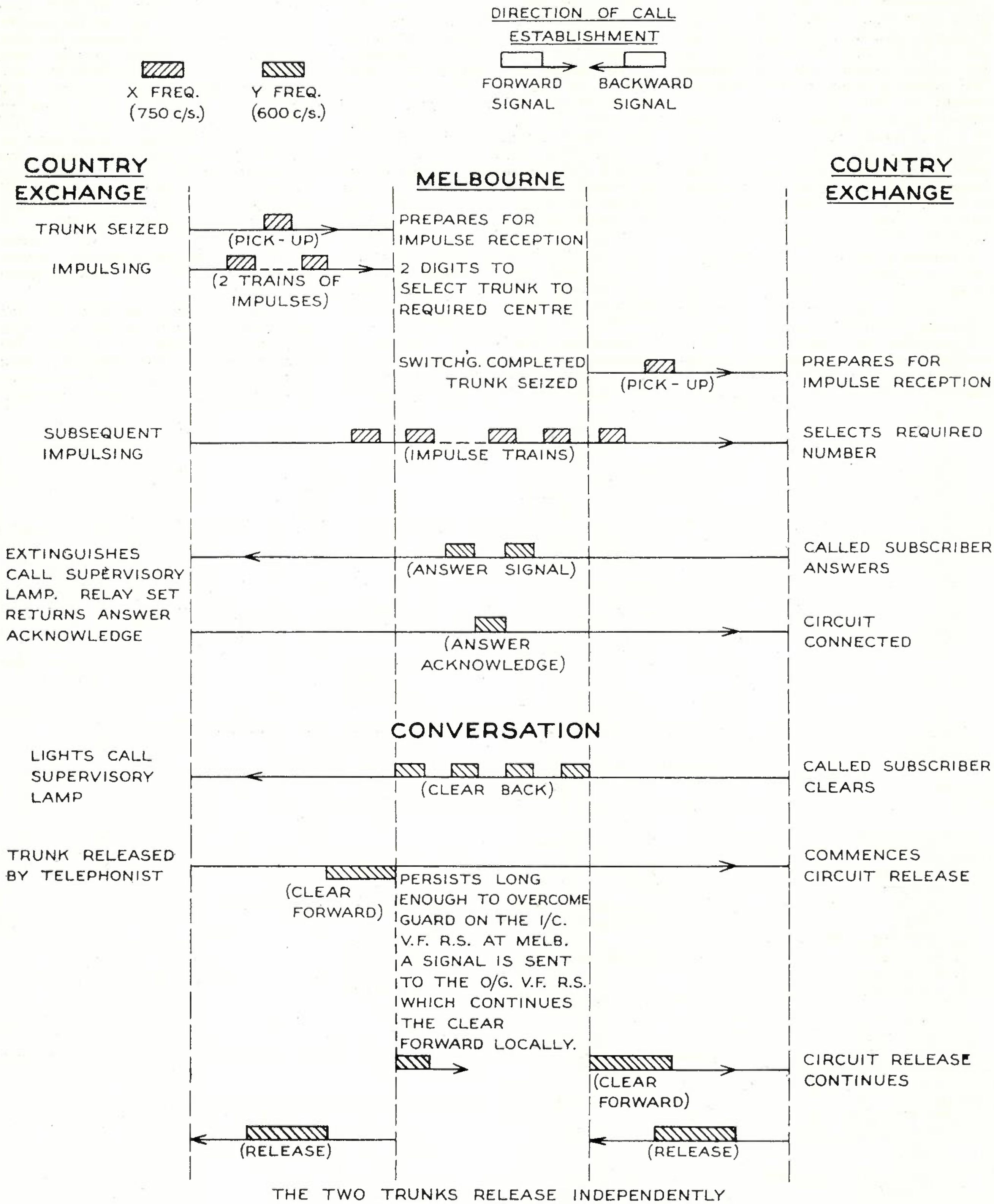


Fig. 2.—Signals involved in transit switching.

CIVIC EXCHANGE TRUNKING

E. K. JEFFERY.

Trunking arrangements of the Melbourne Civic exchange have been dictated by the circumstances influencing development since 1949, when the exchange was opened. An endeavour is made here to trace this development up to the present and to indicate possible future trends. At the time of establishment of the Civic exchange the Melbourne network development plan provided for the city area to be served by four large exchanges. City West and Batman exchanges were to be connected to "M" group, while Russell and Civic were to be attached to the "F" group.

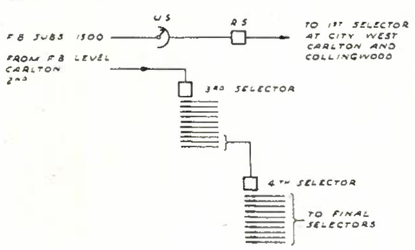


Fig 1.—Initial trunking arrangements.

Accordingly, Civic exchange was opened in its present temporary location in the Central Telegraph Office building, using the prefix "FB" in conformity with the development plan. Trunking arrangements at the time of opening are shown in Fig. 1.

Shortly after the establishment of the Civic exchange changes in the growth pattern of the metropolitan network indicated the necessity for a review of the development plan. The modified plan which emerged from this review provided for all the City exchanges to be connected ultimately to the "M" group. An important feature of this modification to the numbering scheme was the advantage of routing traffic between subscribers in the City area through a minimum of switching stages and junctions. In addition, "F" levels, formerly reserved for Russell and Civic, would be released for use, as required, for suburban exchanges developing the "F" group. Because of reluctance to change again the numbers of the subscribers recently cut over to Civic exchange, and because of temporary difficulty in making a level of the "M" group available, the prefix "FB" will be retained for some time.

During the years 1950 to 1952, a considerable increase in traffic was apparent in the network generally, and more particularly in the City where difficulty was experienced in providing sufficient switching equipment because of the lack of floor space at the City West exchange. Incoming junctions from all other main groups, which were then terminated at City West, were planned to terminate at the first City exchange encountered, but as both the Batman, and Russell buildings would not be completed for some years it was necessary to look to the Civic exchange for provision of short term relief. This was attained by diverting the "M" level incoming junctions from the "W" and "J" groups to Civic second selectors with outlets to all exchanges in the "M" group. The equipment used was cabled in such a manner that when these junctions are later transferred to their correct location at the Russell exchange, the selectors can be readily converted for local use.

First selectors were also installed at Civic in order to handle the growing traffic to the city exchanges as well as to establish direct routes to other main exchanges. No local switching was provided, as a check of outgoing traffic indicated that the proportion directed to the "F' group was too small to justify junction groups to all "F" branches.

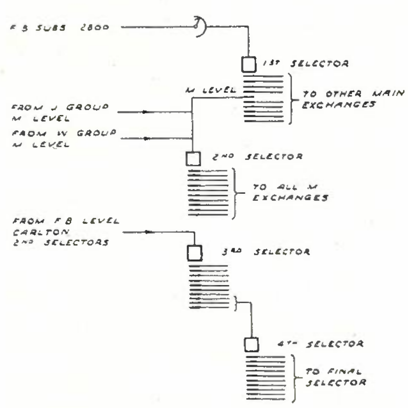


Fig. 2.—First interim trunking arrangement.

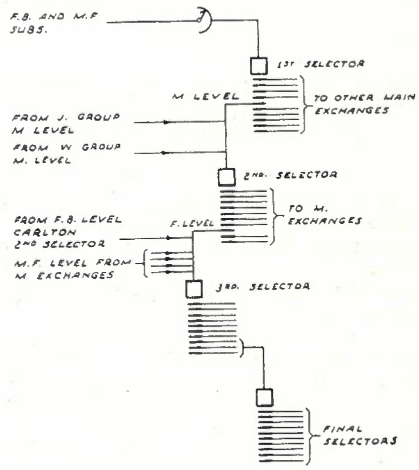


Fig. 3.—Second interim trunking arrangement.

This arrangement, as well as the incoming "M" junctions from the "J" and "W" groups is illustrated in Fig 2.

The trunking was involved in further changes during 1952 by the necessity to open the Russell exchange level "MF" to provide service for some important large group subscribers in such a manner that a later number change would not be necessary. Duplication of equipment was avoided by merging the "MF" and "FB" traffic at the third selectors and using common third, fourth and final selectors. "MF" traffic originated by the "FB" and "MF" subscribers was switched locally at Civic; but the "FB" traffic continued, as before, to be routed via Carlton ("F" main) back to Civic third selectors, which were now in a common MF/FB group. Trunking was then as in Fig. 3.

The first step in the restoration of the Civic exchange trunking to normal will probably be the transfer of Russell exchange subscribers, together with the incoming "J" and "W" junctions to their correct location in the new Russell exchange building during the year 1955. Civic will then only require a prefix change to the "M" group to become a normal exchange. It is expected that Civic exchange will be transferred ultimately to a new location in the projected Commonwealth block in the north eastern section of the City area.

ANSWERS TO EXAMINATION PAPERS

The following answers generally give more detail than would be expected in the time available under examination conditions. The additional information should be helpful to students.

EXAMINATION No. 3701—SENIOR TECHNICIAN, TELEPHONE. TELEPHONY II Section II

H. G. Hodge

Q.5.—Draw a schematic circuit of a static sending relay for a V.F. telegraph system and briefly describe its operation. What adjustments are necessary to ensure the proper operation of the relay when the system is being installed?

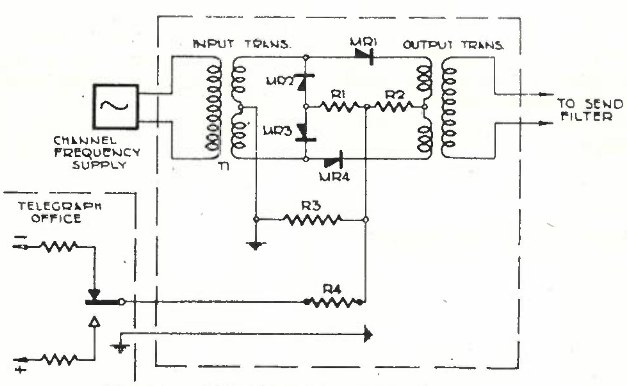
A.—The static modulator unit consists of an input transformer T1, modulator unit comprising copper oxide rectifier units MR 1-4, resistors R1, R2 and output transformer T2. Resistor R4 is the current limiting resistor and its value is chosen to limit the current in the send loop to the standard value of 25 milliamps. The shunt resistor R3 ensures that the voltage applied to the rectifier network is limited to the correct value.

When the telegraph sending equipment is in the mark condition, negative potential is applied to the static modulator and rectifiers MR1 and MR4 become conducting. At the same time rectifiers MR2 and MR3 become non-conducting, and thus offer a high impedance shunt across the secondary winding of T1. Thus carrier from the channel frequency supply is allowed to pass freely to the send filter unit, the attenuation in the static modulator being that due to the transformers alone.

When a spacing signal is applied from the telegraph equipment, the potential applied to the static modulator is reversed and the rectifiers MR1 and MR4 become non-conducting, while MR2 and MR3 become conducting, resulting in a low resistance shunt across the secondary of transformer T1 together with a high resistance series path to the passage of carrier to the output transformer. As a consequence, only an extremely small amount of carrier is able to pass through the static modulator to the send filter.

The difference in the values of carrier which reach the send filter in the mark and space conditions is known as the "discrimination" of the static modulator.

During installation the following tests and adjustments should be made to ensure the correct operation of the static relay:—



STATIC MODULATOR CIRCUIT

Q.5—Fig. 1.

The current limiting resistor should be adjusted to allow 25 milliamps to flow in the send loop from the telegraph equipment.

In some types of static relay a resistor network is included which should be adjusted to give the correct carrier level at the send filter output.

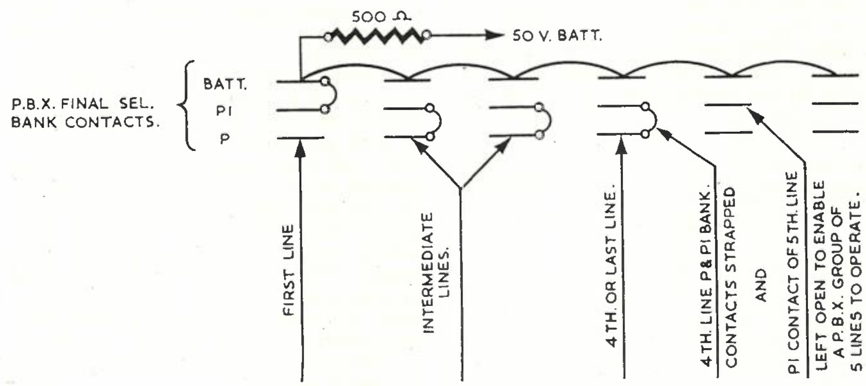
The level of carrier from the channel frequency supply should be checked and adjusted if necessary.

The discrimination of the static relay should be checked and should be a minimum of 40 db.

EXAMINATION Nos. 3813 & 3814: TECHNICIAN: TELEPHONE INSTALLATION AND MAINTENANCE

K. Mounsey

Q.1.—A P.B.X. group in a pre-2000 type automatic exchange consists of 4 lines. State what connections are made to the auxiliary bank contacts of—
(a) The first line of the group;
(b) The second line; and
(c) The fourth line.



Q.1—Fig. 1.

If a fifth line is added to the group what alterations should be made to any of the existing connections?

A.—(a) 50 volt battery is connected to the first line P1 bank contacts of the P.B.X. final selector via a 500 ohm resistance.

(b) The second and all intermediate lines have their P and P1 bank contacts of the final selector strapped together.

(c) The fourth and last line of the P.B.X. group has the P1 bank contact of the final selector left open.

If a fifth line is to be added to the P.B.X. group it is necessary to strap the P and P1 bank contacts associated with the fourth line and leave the P1 contact of the fifth line open. This may be seen from Fig. 1.

Q. 2.—(a) List the functions of a subscriber's homing uniselector circuit in a modern automatic exchange;

(b) Why do the wipers return to the "home" position at the end of every originated call?

A.—

(a) 1. Will hunt for, and seize the first free outlet upon the subscriber lifting the receiver.
2. Guards the selected outlet from intrusion.
3. Guards the calling subscriber's line from intrusion.
4. Keeps the wipers disconnected during hunting, thus preventing interference with contacts over which they are passing.
5. Extends the calling party's line to the switch ahead for the next stage of operation and removes all "bridges" from the line wires.

6. Prepares the circuit of the calling subscriber's meter for ultimate operation when the called party answers.
7. When release conditions are applied, will release itself and return the wipers to the "home" position.

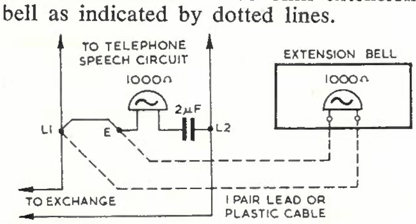
(b) 1. By using "homing" type uniselectors, the outlets from the switch may be graded, resulting in a saving of up to 20% in the total number of first selectors required.
2. The switch will step-on over open-circuit trunks.
3. Due to the cleaning action of the wipers on the bank contacts, the "homing" type switch is less liable to contact troubles as compared with the non-homing type.
4. Due to the wipers returning to the home position standard line and cut-off relays are used, whilst special relays have to be used with the non-homing type uniselector.

Q. 3.—(a) A magneto type extension bell is to be connected to a subscriber's handset telephone in an automatic exchange area. Show, by means of a simple sketch, how the extension and telephone bell are connected.

(b) What precautions should be taken in the location of the extension bell and what tests should be made at the completion of the installation.

A.—(a)

Fig. 1 shows how the extension bell is connected. Remove strap between L1 and E and connect 1000 ohm extension bell as indicated by dotted lines.



Q.3—Fig. 1.

(b) 1. The extension bell should be placed in a location where it will not be physically damaged, yet in a convenient position for maintenance. Likewise it must be protected from the weather and corrosive fumes if located in industrial premises.
2. At the completion of the installation, the technician must contact the local exchange and get a ring applied to the telephone and check that both bells reliably operate. If not, adjustment is given.
The I.R. of the telephone line is also checked from the exchange.

Q.4.—(a) Omitting the key contacts, sketch the apparatus in circuit on an extension to extension call on a C.B. cordless P.B.X.

(b) What is the disadvantage of this type of battery feed system?

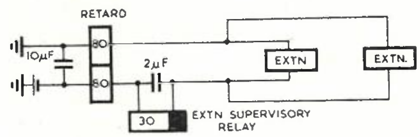
A.—(a)

Fig. 1 shows the apparatus in circuit on an extension to extension call on a C.B. cordless P.B.X.

(b) If the resistance of the line to one of the extensions is much higher than the other, then the low resistance line will shunt that of the higher resistance, causing much less transmitter battery feed current to pass through the transmitter in the high resistance line than that in the low resistance line.

The transmitter in the high resistance line will not operate efficiently due to the low current flowing in the extension circuit.

For this reason, this type of battery feed is used only where all lines are of approximately the same length and resistance.



Q.4—Fig. 1.

Q.5.—Two resistances, one of which has a resistance of 60 ohms, are connected in series across a battery of negligible resistance and a current of 1.2 amperes flows.

When a further resistance of 100 ohms is connected in series with the first two the current is reduced to 0.6 amperes.

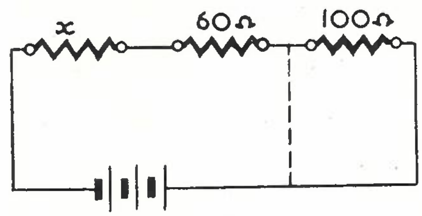
What is—

(a) The value of the unknown resistance?

(b) The E.M.F. of the battery? and

(c) The difference in power dissipation in the unknown resistance before and after the third resistance of 100 ohms was connected?

A.—(a)



Q.5—Fig. 1.

x + 60 = 1.2 amperes.
x + 60 + 100 = 0.6 amperes.

If the additional 100 ohms reduced the current by 50%, then by $R = \frac{E}{I}$ if E remains unchanged and the I is reduced by 50% then R must have been doubled.

$\therefore x + 60 = 100$
$x = 100 - 60$
$x = 40$ ohms.

(b) $E = I \times R$
$E = 1.2 \times 100$
$E = 120$ volts.

(c) Power dissipation in former instance $= I^2 R$
$= 1.2^2 \times 40$
$= 57.6$ Watts

Power dissipation in latter instance $= I^2 R$
$= 0.6^2 \times 40$
$= 14.4$ Watts

Difference in power dissipation $= 57.6 - 14.4 = 43.2$ Watts.

Q.6.—(a) Draw the schematic diagram of the connections of an overload and reverse current switch in an automatic exchange power circuit;

(b) State the reasons for the use of each component of the switch.

A.—(a)

Fig. 1 shows the schematic diagram of the connections of an overload and reverse current circuit breaker as used in an automatic exchange power circuit.

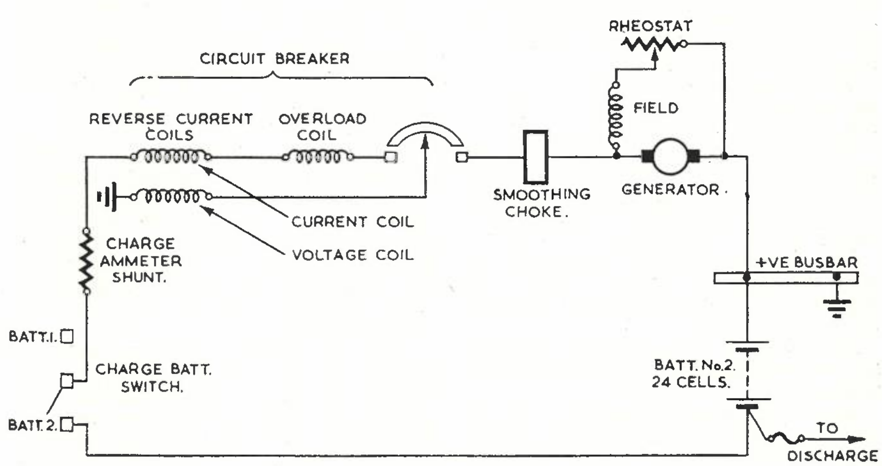
(b) The overload coil is used on the circuit breaker to protect the charging generator from damage due to an overload in the current output.

If the charging current as supplied from the generator goes above the rated specification, the overload electromagnet will operate.

In so doing it releases the mechanical latch and allows the circuit breaker to trip-out of circuit.

If the power supply to the motor driving the generator were to fail, then the battery would supply power to the generator, using it as a D.C. motor.

The generator will still continue rotating in the same direction whilst the exchange battery will be rapidly discharging and no alarm is given.



Q.6—Fig. 1.

To overcome this the reverse current feature is added to the circuit breaker.

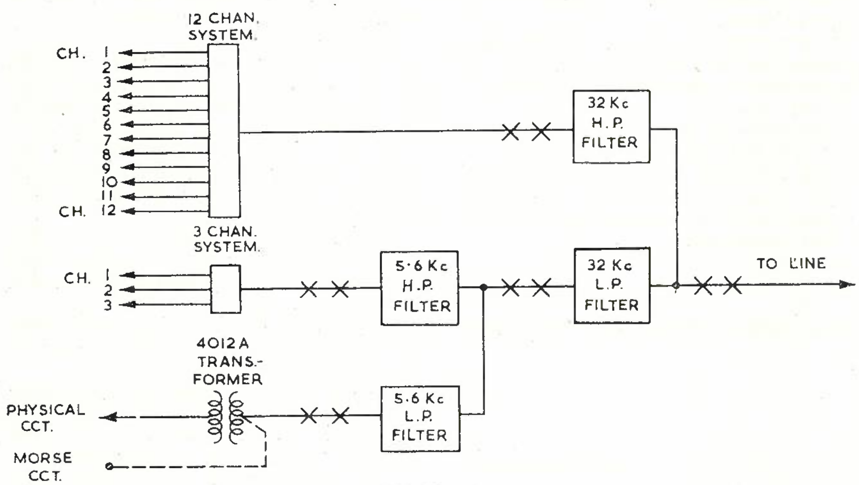
In the normal condition the flux about the current and voltage coils oppose each other. Should the above condition occur then the current through the current coil will reverse and the fluxes will be aiding, so operating the reverse current relay.

The operation of this relay likewise mechanically trips the circuit breaker out of circuit.

Q.7.—By means of a block schematic circuit, show how a 12 channel type J carrier telephone system, a 3 channel carrier telephone system and a cailho morse circuit can operate on one open wire line. Represent the carrier terminals, excluding line filters, by single blocks. State the frequency bands sent to line by each carrier system.

A.—Fig. 1 indicates the terminal equipment required at one end of the line.

The terminal equipment for other end of line is exactly identical except for the frequencies transmitted, which makes one the "A" terminal equipment, and the other "B" terminal equipment.



Q.7—Fig. 1.

The frequency bands transmitted by the 12 channel type J carrier system are A – B direction, 92 – 143 Kc/s, whilst in the B – A direction the frequency band is 36 – 84 Kc/s.

The above bands transmitted may be any of the four J system types SA, SB, NA and NB.

The frequency bands transmitted by the 3 channel system, if in the case of a type S.O.S. system, are A – B direction, 6.5 – 15.7 Kc/s, whilst in the B – A direction 17.9 – 28.2 Kc/s.

The frequency bands transmitted by other 3 channel system types will slightly vary to those quoted depending on the system type.

Q.8.—Why is it necessary to synchronise the oscillators of a carrier telephone system?

A.—In a carrier telephone system only one side-band is transmitted to line, the carrier frequency and the other side-band are suppressed.

At the receiving end it is necessary that the demodulator oscillator frequency be identical with that of the modulator oscillator frequency at the transmitting end.

If this condition can be satisfied, then the received signal will be a faithful reproduction of that transmitted from the transmitting end.

In practice it is difficult to keep the channel oscillators stable over a period of time, therefore it is necessary to synchronise the channel oscillator frequencies periodically.

For example, assume a 1 Kc/s audio signal is applied to the modulator at the transmitting end to which a carrier frequency of 10 Kc/s is also applied, and that the upper sideband of 11 Kc/s is transmitted to line.

At the receiving end, assume that the demodulator oscillator frequency has shifted from 10 Kc/s to a value of, say, 9.5 Kc/s. The incoming sideband of 11 Kc/s, when demodulated, will now appear as an audio signal of 1.5 Kc/s, and not 1 Kc/s as originally sent.

Similarly, if an audio frequency range of 300-2600 c/s were applied to the modulator, it would appear as a range of 800-3100 c/s when demodulated. The effect of this frequency shift is to make the received speech sound "hollow" and unnatural. To prevent this, it is necessary to synchronise the demodulator and modulator oscillator frequencies.

Q.9.—What is the purpose of a static modulator in a carrier telegraph system?

A.—The purpose of the static modulator is to act as a "switching gate" allowing pulses of tone at the particular channel frequency to be transmitted to line depending on whether a mark or space condition is to be transmitted to the distant end.

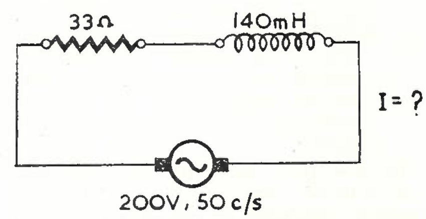
When a negative D.C. potential is applied to the static modulator, a V.F. tone for the channel concerned will pass through the static modulator and be transmitted over the line and give a "marking" indication at the distant terminal.

When a positive D.C. potential is applied to the static modulator, no V.F. tone is transmitted to line, therefore indicating a "spacing" condition at the distant terminal.

The static modulator may, therefore, be said to modulate the carrier frequency of the channel with which it is associated, in accordance with the polarity of the telegraph signals applied from the telegraph office, resulting in pulses of carrier to line corresponding to a "marking" signal and cessation of carrier during a "spacing" signal.

Q.10.—A resistance of 33 ohms in series with a pure inductance of 140 millihenries is placed across an A.C. potential of 200 volts, 50 c/s.

What is the current flowing through the circuit?



Q.10—Fig. 1.

A.—

$XL = 2\pi fL.$

$XL = 2 \times 3.14 \times 50 \times 140/1000 =$ 44 ohms approx.

$Z = \sqrt{R^2 + X^2}$

$Z = \sqrt{33^2 + 44^2}$

$Z = \sqrt{1089 + 1936}$

$Z = \sqrt{3025}$

$Z = 55$ ohms.

$I = E/Z = 200/55 = 3.63$ amperes

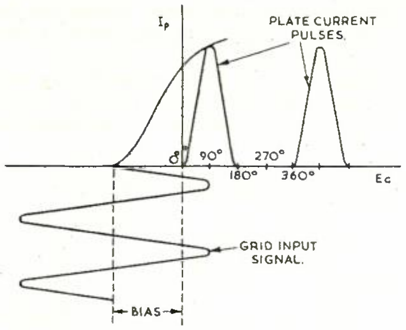
$I = 3.63$ amperes flowing in cct.

EXAMINATION 3106—SENIOR TECHNICIAN

Radio I

Q.1.—What do you understand by—
(a) Class B radio frequency amplifier;
(b) Class C radio frequency amplifier?
Describe the operating characteristics of each type of amplifier and give an example of the use of each type in a radio broadcasting transmitter.

A.—**(a) Class B R.F. Amplifier.**—A Class B amplifier is defined as one in which the plate current flow of the valve or valves is restricted to approximately 180°; i.e., plate current flows during the positive half cycle only of the input signal. The use of a tuned anode load provides a "tank" circuit which is able to store energy during current flow through the valve, and re-supply energy to the succeeding load during the negative half cycle of input signal. The operating characteristics of such an amplifier is shown in Fig. 1. The valve operating bias is adjusted to "cut off". By correctly adjusting the input or drive voltage, and the load impedance, the class B radio frequency amplifier is capable of providing an output voltage which varies linearly with the input voltage. This linear Class B amplifier is widely used to amplify amplitude modulated

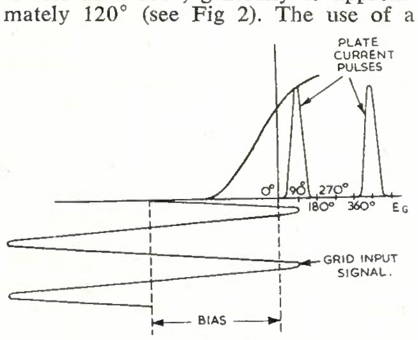


Q.1—Fig. 1.

radio frequency signals in low level modulated transmitters used in the National Broadcasting Service. An undesirable feature of the Class B R.F. amplifier is the variation in input impedance with variation in the modulated grid signal. For this reason it is essential that the R.F. driver have good regulation and that the grid bias supply be obtained from a low resistance power supply of good regulation.

The plate circuit efficiency of the Class B R.F. amplifier varies with the amplitude of the input signal and reaches a theoretical maximum of 78%. Average operating efficiencies of 30% to 60% are realised with Class B linear amplifiers under conditions of 0% to 100% modulation of the steady carrier.

(b) **Class C R.F. amplifier.**—A Class C amplifier is defined as one in which the valve plate current flow is restricted to less than 180°, generally to approximately 120° (see Fig 2). The use of a



Q.1—Fig. 2.

tuned circuit as the anode load permits energy to be stored during the non-operating portion of the input signal and the output energy may be essentially sinusoidal. The output power is a linear function of the applied plate voltage and for this reason the Class C R.F. amplifier may be used as an efficient low distortion modulated amplifier in amplitude modulated transmitters. The operating efficiency of the Class C amplifier is very high and practical figures of 75% are often obtained, distinguishing characteristics of Class C amplifiers include high power output and relatively low power amplification. By adjustment of the plate current operating cycle, together with the characteristics of the anode tuned circuit, the Class C amplifier may be made to operate efficiently as a frequency multiplying amplifier.

Q.2.—What do you understand by the following terms as applied to a radio telephone transmitter employing amplitude modulation:—

Carrier, Sideband, Carrier Noise, Percentage Modulation?

A.—Carrier.—In transmitting signals from an amplitude modulated radio telephone transmitter the intelligence to be radiated is combined with radio frequency energy of constant amplitude and frequency. This radio frequency signal, with which the audio frequencies are combined, is referred to as the carrier.

Sideband.—A sideband is the new radio frequency signal produced when a radio frequency carrier is modulated by an audio frequency tone. Two sidebands, upper and lower, are produced when a radio frequency carrier is amplitude modulated by an audio frequency tone, and each sideband contains the audio frequency intelligence. In general, the upper sideband will have a frequency equal to the sum of the carrier and modulating frequencies and the lower sideband will have a frequency equal to the difference between the carrier and the modulating frequencies.

Carrier Noise.—In the generation and amplification of the carrier signal to be radiated from an amplitude modulated radio telephone transmitter, unwanted modulation of the carrier by hum voltages from power supplies, clicks from relays, ripple from generators, etc., may occur. This residual modulation of the carrier is referred to as carrier noise.

Percentage Modulation. — When a transmitter signal is amplitude modulated the instantaneous value of the output energy will vary at an audio frequency rate. The ratio of the instantaneous value of the modulated carrier to its unmodulated value is expressed as a percentage—100% modulation occurs when the radio frequency output voltage rises to twice its unmodulated value.

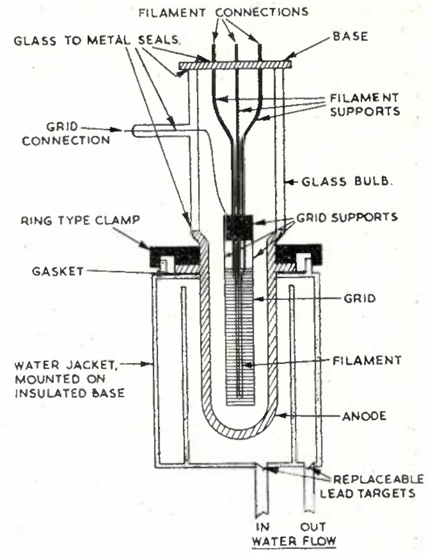
Q.3.—Describe the construction of a high power water-cooled transmitting tube. What precautions would you take when first placing such a tube in service?

A.—(a) **Construction.**—The accompanying diagram (Fig. 1) shows the basic type of construction used for high power water-cooled tubes.

The anode, which is made of copper, serves as part of the wall of the tube, thus allowing it to be directly cooled by a flow of water. The tube is clamped to the water jacket which, also being made of copper, serves as the H.T. connection. To prevent undesirable pitting and wearing of the anode and jacket by electrolytic action, lead targets placed in the inlet and outlet of the water circuit, take the brunt of this electrolysis.

Quite often the grid connection is taken out through the side of the bulb, thus affording greater insulation strength and lower interelectrode capacities (C_{gc} and C_{ac}) than if it were taken out through the base.

The electron emitter is usually a tungsten filament which requires a large amount of power to operate it because



HIGH POWER WATER COOLED TUBE.

Q.3—Fig. 1.

of the great electron emission required. Consequently, the supply to it may be either 2 phase (3 wire) or 3 phase (3 or 4 wire), which has the added advantage of also lowering the overall noise factor of the tube.

In the manufacture of these tubes great care must be taken with the metal to glass seals and with the production of the vacuum.

(b). **Precautions.** — The precautions necessary may be divided under two main headings:—

(1) General precautions due to the high power nature of the tube.

(2) Special precautions due to the water cooling.

1. The tube should be examined carefully and any foreign matter should be removed from the glass bulb, particularly around the terminals. The leads become hot during operation so that any foreign material may become charred and cause puncture of the tube. When first placed in operation the tube should be run without plate voltage for fifteen minutes at rated filament voltage. Care should be taken that the phase voltages applied to the filament on 2 or 3 phase types, are balanced to within 10%. After the initial preheating period plate voltage can be applied. Firstly it should be operated for fifteen minutes at approximately one-half the working plate voltage. Full voltage may then be applied and the tube operated under normal load conditions.

2. When placing the tube in its jacket care should be taken to see that it is centred accurately and firmly fastened. This should be done before making the electrical connections. When the jacket-clamping device is tightened the contacts must seat properly on the tube flange. Proper seating in the jacket will be obtained by use of the correct jacket. A new gasket must be used whenever the tube is placed in the jacket. The gasket should be treated with a substance capable of preventing sticking so

that the tube will not be damaged when next it is removed.

The grid and filament leads should not be taut, but should allow for some movement without placing a strain on the bulb.

Outlet and inlet water thermometers should be in the water flow circuit, and it is important that there be a water flow meter. Before filament voltage is applied the water should be turned on at low pressure at first and an examination made for leaks. The water should be then brought up to the required rate of flow and if there be no evidence of leaks the filament voltage may be applied and the procedure above carried out.

The water flow should be upwards around the anode and the outlet temperature should never exceed 70°C. Before any tests are carried out it should be ascertained that the electrical and chemical characteristics as well as the inlet temperature of the water are satisfactory.

Q.4.—What do you understand by the following terms as applied to a superheterodyne receiver:—

Sensitivity, Image Ratio, Selectivity, Intermediate Frequency, Signal to Noise Ratio?

A.—When applied to a superheterodyne receiver:—

Sensitivity is the minimum signal input (microvolts) at the operating frequency of the receiver and modulated 30% at 400 c/s, which is required to produce standard output (usually 50mW) from the receiver. The method of aerial connection must be stated for the sensitivity to be comparable with other receivers.

Image Ratio is

$$\frac{\text{image signal sensitivity}}{\text{wanted signal sensitivity}}$$

where the image sensitivity is the sensitivity of the receiver to a signal input modulated as above, but at the image frequency of the receiver (the image frequency of the receiver being spaced from the oscillator frequency by the same amount as the wanted frequency but on the opposite side of the oscillator frequency, e.g., wanted signal 1000 Kc/s, oscillator frequency 1455 Kc/s, then image response 545 Kc/s).

Selectivity is

$$\frac{\text{unwanted signal sensitivity}}{\text{wanted signal sensitivity}}$$

Normally the receiver selectivity is the product of the selectivity of individual stages of the receiver, however, at some unwanted frequencies (spurious responses) the selectivity will be reduced as the selectivity of all stages is not attained, e.g., in the case of the image response only the selectivity of the tuned circuits in front of the mixer is operative, the full gain of the intermediate frequency amplifier being applied to the image response after its production in the mixer.

Intermediate Frequency is the difference frequency generated by mixing the signal frequency with a local oscillator which is arranged to differ in frequency from the signal by a constant amount for all incoming frequencies, i.e., the intermediate frequency of a given receiver is independent of the received frequency, but its value is fixed by the design of the receiver.

Signal to Noise Ratio is

$$\frac{\text{audio output with modulation}}{\text{audio output without modulation (noise)}}$$

For a particular receiver, the signal to noise ratio (S/N) will be dependent on the operating frequency of the receiver, the location of the receiver if an aerial is used, the signal input to the receiver, and the volume control setting of the receiver.

Under specified conditions the S/N allows the performance of different receivers to be readily compared or, by calculation, enables comparison of actual results with design expectations, or the comparison of receiving sites, of signal strengths, or of aerial gains.

Q.5.—Explain the principle of operation of a hot cathode mercury vapour rectifier tube.

What are the main advantages of this type of tube?

Give a circuit diagram of single phase full-wave rectifier employing hot cathode mercury vapour tubes.

A.—The tube consists of a cathode, either directly or indirectly heated, in an evacuated chamber with anode and a small quantity of liquid mercury. The space inside the tube contains vapourised mercury and when the cathode is heated by the filament more of the liquid mercury vapourises until a steady state is reached.

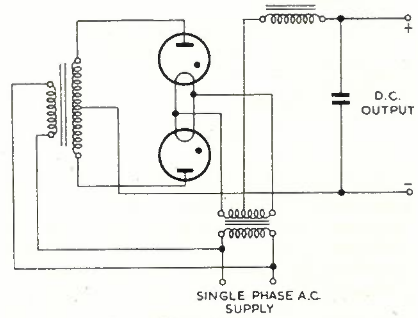
If the anode is made positive with respect to the cathode, electrons will be attracted from the cathode towards the anode. The electrons leaving the cathode will tend to repel other electrons back towards the cathode, and so produce a negative space charge. Most of the electrons which move towards the anode will collide with molecules of mercury vapour before reaching the anode, and their kinetic energy will be sufficient to displace other electrons from the vapour molecules, thus producing more free electrons, called negions, to move towards the anode. The positively charged vapour molecules produced when the vapour molecules lose electrons, are called posions, and will drift towards the cathode and tend to neutralise the space charge surrounding the cathode. This will allow the current flow in the tube to be high and the potential drop from anode to cathode to be low, generally in the range of 10 to 15 volts.

In the above action the mercury vapour has been vapourised and on recombining it emits a blue coloured light which is peculiar to mercury.

This type of tube is generally used for rectifying a high voltage source at high current, and has many advantages over other types of rectifiers as:—

(a) higher efficiency due to low potential drop across the tube.
(b) better regulation due to low plate resistance.
(c) requires less filament power as the mercury vapour carries most of the current.
(d) initial cost is lower as rectifying supply using this type of tube is simpler than other supplies to achieve the same result.

Fig. 1 shows a circuit diagram of a single phase full wave rectifier.



Q.5—Fig. 1.

Q.6.—What is meant by neutralisation of a radio frequency amplifier? Why is neutralisation necessary?

Give a diagram showing a method of neutralising a push-pull radio frequency amplifier.

A.—In a radio frequency amplifier many undesirable effects result from the physical or mechanical construction of the circuit and components. These effects may be eliminated or "neutralised" by suitable circuitry.

The term "neutralisation" may be best explained by considering its most common applications. If a triode electron tube is used as an amplifier some energy passes from the grid circuit to the anode circuit and vice versa, through the anode-grid capacity and other stray capacities of the circuit. This power, when fed back to the grid circuit, is in phase with that of the grid circuit, hence positive feedback has occurred and oscillation of the amplifier is liable. To eliminate this feedback the C_{ag} is neutralised, by feeding a power, equal but opposite in phase to that due to C_{ag}, into the control grid of the tube. Q.6, Fig 1 indicates a practical circuit for a push-pull RF amplifier. The neutralising voltage is obtained from the oppositely phased anodes and is fed by Cn_1 and Cn_2, to the appropriate grid.

A further application of neutralising, in particular at V.H.F., is in the eliminating of unwanted impedances in the grid, screen, or cathode leads of an R.F. amplifier. For example, grid lead impedance, may be neutralised. By considering the grid lead as short length of transmission line and applying transmission line theory to it the undesired impedance may be eliminated. This may be accomplished by making the input impedance of the grid lead non-reactive or eliminating phase shift between the input voltage to grid lead and ground and the voltage at the grid and ground. In Fig. 1, L1 C1 tune the filament leads to series resonance, thus the cathode is at ground potential.

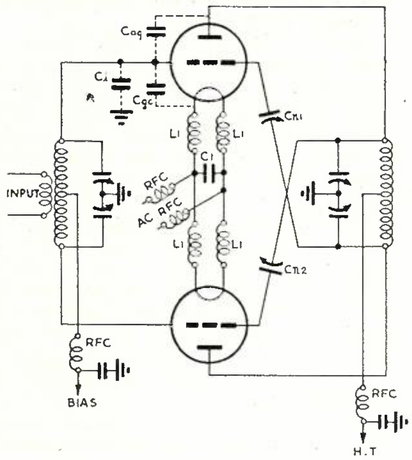
In a triode amplifier neutralisation is necessary to prevent
(a) instability (generally oscillations) due to feedback via C_{ag}
(b) any reaction on preceding stage due to changes in input impedance caused by "Miller Effect"

In a triode the input capacity is

$$C_i = C_{ge} + (1 + \mu) C_{ag}$$

where C_{ge} = grid/cathode capacity

μ = effective voltage amplification of tube



Q.6—Fig. 1.

But as μ varies with anode lead impedance, Ci varies, consequently the preceding stage is detuned if a tuned circuit. By neutralising, the effects of (a) and (b) are eliminated.

In general most neutralising circuit can be reduced to an equivalent bridge type of circuit which is practically independent of frequency.

Q.7.—What is meant by the "Q" factor of a coil? Indicate the main factors which determine the "Q" of a coil.

A.—In a radio frequency circuit a measure of the losses in a coil (an inductance) in such a circuit is obtained from its "Q" factor.

The "Q" factor is defined as the ratio of voltamps to the watts dissipated in a circuit.

Now an inductance may be represented by an equivalent circuit comprising a series resistance (the components dissipating power), and a pure inductance (the wattless component). From this the "Q" factor of a coil may be defined as the ratio of inductive reactance to the equivalent series resistance at a particular frequency.

$$Q = \frac{2\pi fL}{Rf}$$

where

$2\pi fL$ = reactance of coil at frequency "f"

Rf = equivalent resistance at that freq.

Therefore, the "Q" of a coil is dependent on the frequency and Rf, L being fixed. Rf is governed by the following factors.

(a) skin effect—whereby the current distribution over a cross-section of a conductor is modified due to the more central portion of a solid conductor having a higher inductive reactance than that at the outer portions.

(b) proximity effect, whereby adjacent conductors in the coil modify the current distribution in one another due to the magnetic flux linkages between them.

(c) dielectric losses due to the dielectric of self capacity of the coil.

(d) eddy current losses due to induced currents into the surrounding conducting material.

All these losses rise with frequency, but may be controlled within certain limits. At low frequencies the principal losses are due to skin and proximity, whilst at higher frequencies the dielectric losses dominate. Skin effect is reduced by using insulated stranded conductors (Litzendraft wire) up to 2 Mc/s. Above 2 Mc/s silver-plated tubular conductors, which provide a conducting material only where current density is high are used. Proximity and dielectric losses are reduced by using special types of coil windings, e.g., sectionalised windings keeping conductors of high potential difference well separated. Further reductions are obtained by using particular shapes, e.g., length to diameter of coil ratio 1 : 2, using smaller diameter wire, or by using coil formers of low dielectric loss. Another is to use a special magnetic material, usually a compressed powder for the inductance. As a result of the magnetic core, for a given inductance, fewer windings are required, thus the above losses are reduced. The eddy current losses are reduced by increasing the physical separation of neighbouring conducting materials and increasing the conductivity of this material. The former also reduces the self capacity of the coil.

For a coil of optimium "Q" a compromise of the factors governing the radio frequency resistance is necessary. However, "Q"'s of the order of 100 to 500 are frequent in commercial equipment.

Q.8.—What do you understand by the following terms as applied to the transmission of radio frequency waves:—
Direct ray;
Indirect ray;
Heaviside layer;
Skip distance;
Fading?

A.—Direct ray. In the propagation of radio waves from a transmitting aerial to a distant receiving aerial energy may travel over a straight or curved path without reflection from intervening objects or surfaces. The energy transmitted by this means is referred to as the direct ray.

Indirect ray. Energy reflected from intervening surfaces (e.g., the earth or ionized layers of the atmosphere) before reaching the distant receiving aerial is referred to as the indirect ray.

Heaviside layer, is the name given to the region of ionized atmosphere existing above the earth's surface, at heights from 60 to 250 miles, which is capable of returning to the earth radio frequency waves incident upon it. The amount of energy returned varies with the frequency and the angle of incidence of the waves.

Skip distance is the distance measured on the ground between a transmitter aerial and the first point at which indirect rays from the ionosphere are returned. The term is chiefly used in referring to propagation in the high frequency portion of the radio spectrum.

Fading of a radio frequency signal is the random variation in the intensity or the fidelity of a received signal due to changes in the nature of the atmosphere. Changes in the atmosphere, or ionosphere, may vary the strength of either direct or indirect rays, or may change the relative phase of the energy received via the different paths with resultant variation in intelligibility of the received signal. The four principal classes of fading are—
(a) interference fading,
(b) polarization fading,
(c) absorption fading,
(d) skip fading.

Interference to reception of high frequency signals is usually due to a combination of the first two types of fading.

EXAMINATION No. 3106—SENIOR TECHNICIAN, RADIO AND BROADCASTING.

Radio II

Q.1.—What do you understand by the following terms as applied to an audio frequency amplifier used for transmission of studio programmes—
Gain;
Frequency response;
Harmonic distortion?
Indicate three possible causes of harmonic distortion occurring in an amplifier.

A.—The gain of an amplifier is usually understood to be power gain (as opposed to voltage gain or current gain) and is a measure of the amount of power amplification of the amplifier. The unit of gain is the decibel.

$$\text{Gain in db} = 10 \log_{10} \frac{W_2}{W_1}.$$

W_2 = power output.
W_1 = power input.

This is irrespective of the input and output impedances.

The voltage gain is the ratio (as a number) of the voltage output to the voltage input. This may be converted to db (power) gain by the formula—

$$\text{gain in db} = 20 \log \frac{V_2}{V_1} - 10 \log \frac{Z_2}{Z_1}.$$

When v_1 and V_2 are input and output voltages,

Z_1 and Z_2 are input and output impedances.

Frequency response is a comparison of the gain of the amplifier at all frequencies in the frequency band to be amplified. This may be shown as a graph with gain (relative to gain at a reference frequency) plotted against frequency, or stated as a tolerance of gain between the two extremities of the frequency band (for example, ∓ 2db, 30 c/s to 15 kc/s).

During transmission or amplification of signals, the resultant signal may not be equal in all respects to the original signal. The addition of features not in the original or the absence of features present in the original are distortion. Harmonic distortion is the production of harmonics not present in the original.

Three causes of distortion:—

(a) Incorrect grid bias.

(b) Incorrect anode voltage.

(c) Overloading due to high input signal.

Q.2.—In lateral disc recording, why is it necessary to limit the amplitude of the groove at frequencies below 250 c/s?

What do you understand by the term recording characteristic?

What is the effect of the recording characteristic on the reproduction of a recording and what steps are taken in the replay circuit to allow for this effect?

A.—When a sine wave of varying frequency and constant amplitude is applied to an ideal disc recording cutting head of the moving iron type the amplitude of the groove produced is inversely proportional to frequency, while the velocity of the cutter is constant. If this constant velocity characteristic is used in recording at frequencies below 250 c/s the amplitude of the cutter excursions would be so great that the cutter would cut into adjacent grooves.

The effects of constant velocity and constant amplitude recording techniques upon the recorded disc and upon the fidelity of the replayed material, together with a discussion of recording characteristics, are covered very completely in the following references—

"Sound Recording and Reproducing," Part I. The Telecom. Journal of Australia, Vol. 6. No. 5, Oct., 1947, and Part II, The Telecom. Journal of Australia, Vol. 7, No. 1, June, 1948.

Q.3.—Explain the following terms as applied to an auditorium or studio used for broadcasting—

Reverberation time;

Optimum reverberation time.

Explain how the fidelity of reproduction from a studio may be affected by the acoustic design of the studio.

A.—(a) Reverberation time is the time taken for a pulse of sound to decay to one-millionth of its original intensity, and can be expressed by the following approximate formula:—

$$T = 0.050 \frac{V}{A}.$$

Where T = time in seconds.

V = volume of room in cu. ft.

A = absorption of the room surfaces in Sabine units.

(b) Optimum reverberation time is that value of reverberation time which, for a particular studio and a particular programme purpose, that is, music, speech, etc., will ensure the most natural and pleasing performance of the original sounds.

(c) The studio should not be affected by external sounds or mechanical vibrations—it should preferably, therefore, have sound and mechanical insulation, that is, double walls, sound locks for doors and windows and, if possible, should float on its foundations.

The studio should be designed for optimum reverberation time. This can be achieved by using absorbing surfaces to obtain the appropriate value of A in the above formula. Various types of commercial surfaces are made for this purpose, for example, celotex, fibre glass, acoustone tiles, etc. Absorption coefficients of these materials and others, and also coefficients for audience members, seats, etc., which also have to be taken into account have been measured and can be obtained from many published sources.

In order to avoid resonance of the walls, floors and ceilings, these should be supported at many points, and to smooth out the natural excitation frequencies (eigentones) of the studio, it is preferable that the shape of the studio should be asymmetrical and that the surfaces should be serrated or irregular in surface contour. This avoids repeated reflections from the same surfaces and diffuses the sound.

Equipment used in studios, for example, announcers' desks, should also be treated to remove natural mechanical resonances.

Q.4.—Why is it necessary to equalise a cable pair used for the transmission of musical programmes?

Indicate what tests you would carry out on an equalised cable pair to ensure that it is suitable for the transmission of a musical programme.

A.—Because of the high value of shunt capacity which exists between the conductors of a cable pair the higher audio frequencies are attenuated more than the lower frequencies, that is, the frequency response of the cable circuit departs widely from the desired flat response.

The irregularity in response of the cable may be corrected by the use of an equaliser having a frequency response which is the inverse of that presented by the cable pair. The cable response and equaliser response taken in conjunction produce a uniform frequency/attenuation curve over the range of frequencies to be transmitted.

To test the performance of an equalised cable circuit, the following procedure should be adopted—

(a) Insertion loss/frequency measurement. Using a variable frequency oscillator at the remote point send standard levels of tone over a range of frequencies from 30 c/s to 10,000 c/s via the equalised cable pair to the studio switchroom. Measure the received levels after amplification and equalisation and check for uniformity of the received level over the range of frequencies.

(b) Noise and distortion measurement. Using a single frequency tone of low harmonic and noise content at the remote point send standard level to the studios. Check the distortion content of the tone received at the switchroom and by terminating the line at the remote point measure the signal to noise ratio of the circuit.

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