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SOME NOTES ON THE CO-ORDINATION OF POWER AND TELECOMMUNICATIONS SYSTEMS

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INTRODUCTION

The present expansion both of high voltage power lines and telecommunication lines in Australia, which began in the immediate post-war period, has created problems in co-ordination which have made both parties aware of the necessity of co-ordinating their construction to ensure that telecommunication lines are not detrimentally affected by the operation of high voltage power lines.

As a result of conferences between power and telecommunication authorities called to discuss these problems, Joint Committees on Co-ordination of Power and Telecommunication Systems have been established in Australia as independent engineering advisory committees to both telecommunication and power authorities. These committees comprise a State Joint Committee in each State, with a Central Joint Committee in Melbourne. One of the primary functions of the Central Joint Committee is the preparation of Practices on Co-ordination for the use of the State Joint Committees to ensure that co-ordination problems are dealt with on a uniform basis throughout Australia. This article gives a brief account of the types of inductive interference which affect telephone circuits and the practices recommended by the Central Joint Committee to provide satisfactory co-ordination measures.

The article is divided into two parts, of which Part I is a brief account of the two principal types of inductive interference, low frequency induction and voice frequency induction. Part II covers the recommended practices for the co-ordination of high voltage power and telephone lines.

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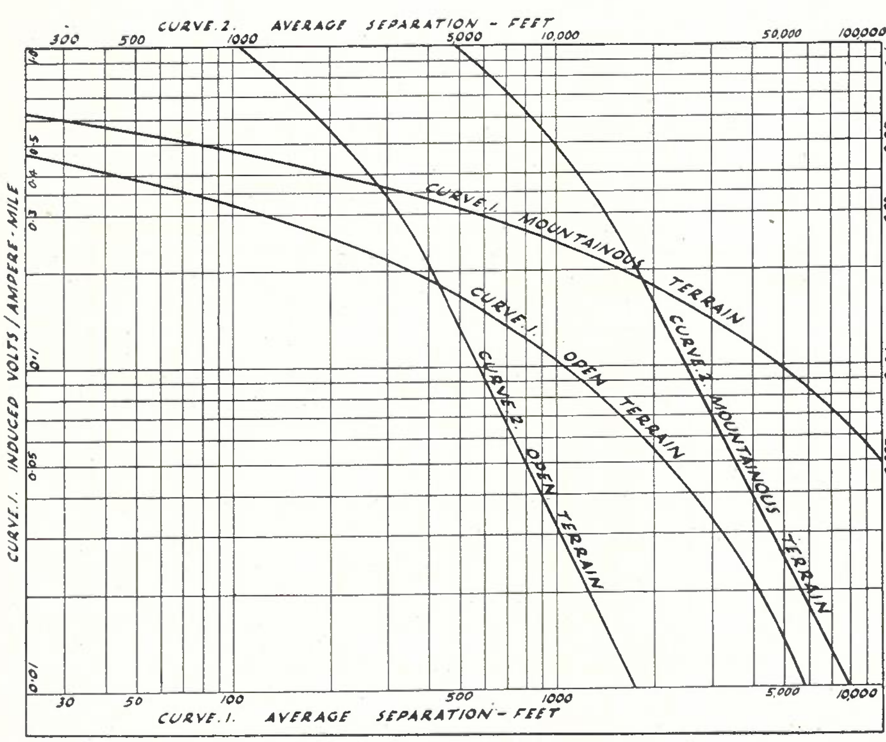


Fig. 1.—Induced Voltage v. Separation.

PART I.
LOW FREQUENCY AND V.F. INDUCTION

Low Frequency Induction

General: This type of induction is associated with the fundamental frequency of the high voltage power supply, which is normally 50 c/s in Australia. It appears as an induced longitudinal voltage on telephone lines during an earth fault in a neighbouring high voltage power line, and may have a value of hundreds, and possibly thousands of volts.

Such high values of induced voltage can be a source of considerable danger to the telephone plant, and in 1934 the C.C.I.F. (International Consultative Committee on Telephony) recommended that power lines should be so constructed that the maximum value of the induced longitudinal voltage on neighbouring telephone lines under fault conditions on the power line would not exceed 430 volts. Experience has shown that, with the growth of high voltage power lines, it is impracticable to provide conditions which would ensure that the maximum value of the induced longitudinal voltage would not exceed this figure, and special measures have had to be taken to protect telephone lines in cases where the maximum induced voltage would exceed 430 volts. At the same time, the C.C.I.F. is examining the desirability of increasing this limit in the case of power lines of high security.

The present practice in Australia is to regard as requiring examination those

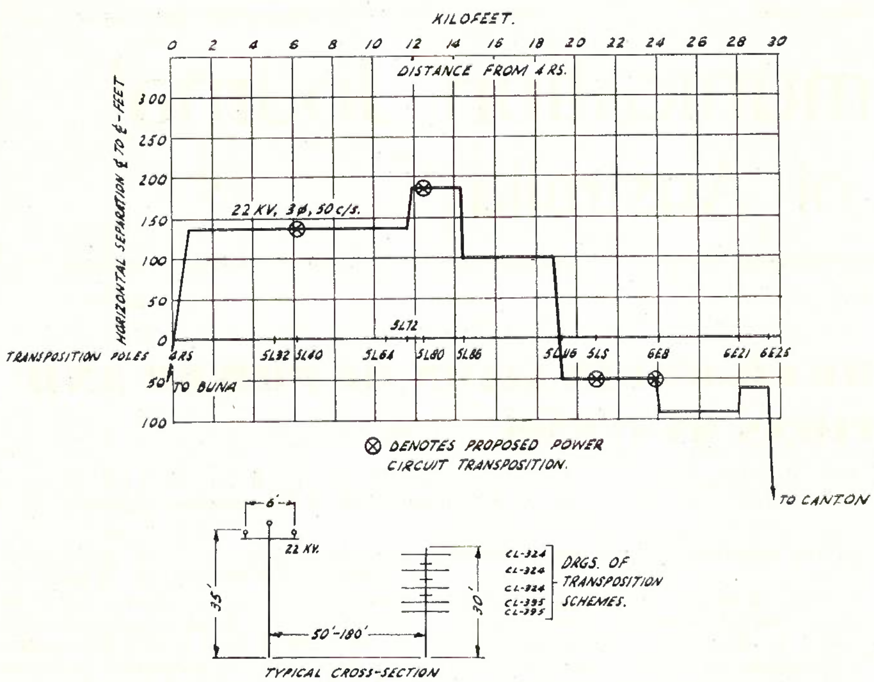


Fig. 2.—Power Exposure. Detailed Exposure Chart Como-Dale trunk route Buna-Sola repeater section. New 22kv, 3ϕ 50 c/s Buna-Canton circuit.

cases where the maximum induced longitudinal voltage is greater than 430 volts. Where the maximum value is less than 430 volts the condition is regarded as safe and receives no further consideration.

Calculation of Induced Longitudinal Voltage. The formula for the calculation of the induced longitudinal voltage in a telephone wire exposed to a power line carrying earth fault current, based on the C.C.I.F. formula, is

$E = 2\ \pi$ f. k. M. l. I ——— (1)

Where E = induced e.m.f. in volts (this will be an alternating voltage and will continue until the power circuit breakers trip out or until the telephone line protectors operate)

f = frequency of inducing current (cycles per sec.)

k = shielding factor

M = coefficient of mutual inductance between the two lines (henries per mile)

l = length of exposure (miles)

I = power fault current (amperes)

This is the basic formula for induced voltage and applies to any exposure of telephone wires and power conductors irrespective of whether either or both conductors are in cable or carried on aerial lines.

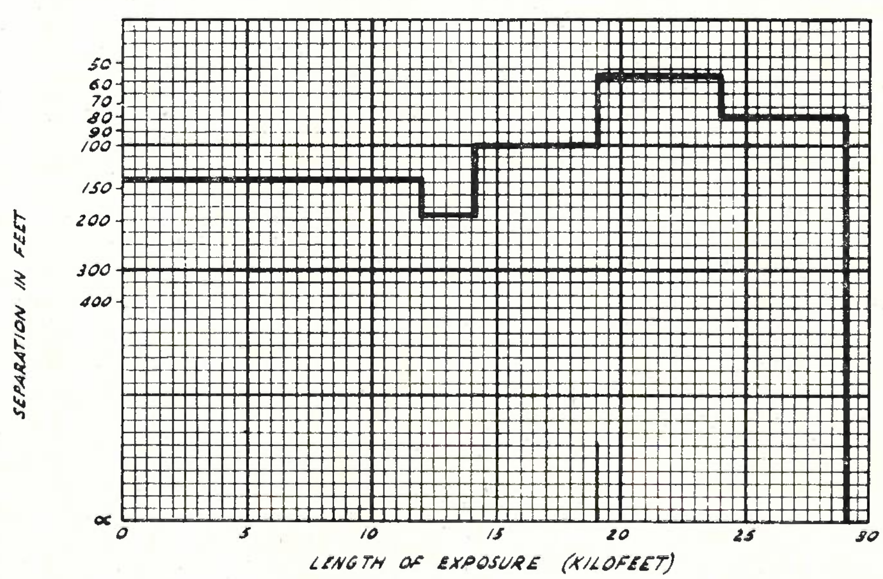
Mutual Impedance. Ignoring "k" for the present, it will be observed that the expression of $2\ \pi$ fM in the formula represents the mutual impedance per mile and can be expressed as induced volts/mile/amp fault current. Thus, if the value of M is known, the value of the mutual impedance per mile can be calculated and the value of the induced voltage for different values of earth fault current readily determined.

The value of the coefficient of mutual inductance (M) depends on the separation between the power and telephone lines and the earth resistivity. The value of M decreases as the separation increases, but increases as the earth resistivity increases. However, as the value of M does not vary in proportion to the value of the earth resistivity, it is not generally necessary to know the accurate value of the earth resistivity when estimating the maximum value of the induced voltage, and reasonable accuracy is obtained if the earth resistivity is taken as 50 ohm-metres as typical of open to moderately hilly country and 1,000 ohm-metres as typical of mountainous country. Fig. 1 shows values of the mutual impedance per mile for various average separations between power and telephone lines for these values of earth resistivity.

As the separation between the power and telephone lines is rarely uniform throughout an exposure, it is usually necessary to obtain the total mutual impedance by making a summation of the mutual impedance for lengths of comparatively uniform exposure. The total mutual impedance can also be obtained graphically by plotting an exposure chart of the exposure to suitable scales for separation and length of exposure. If the vertical scale for separation is based on 0.1 ohm mutual impedance per mile per inch, and the horizontal scale for length of exposure is 1 mile per inch, the area under the curve will give the total mutual impedance, as each square inch of this area will represent 0.1 ohm mutual impedance. An example of a curve of this type is given in Fig. 3 for the exposure shown in Fig. 2.

When a new high voltage power line is erected resulting in an exposure of a telephone line, a measurement of the mutual impedance will give an accurate value of induced voltage once the maximum value of earth fault current is known. It also enables relevant values of earth resistivity to be calculated. The value of the earth resistivity can also be calculated from measurements of the self-impedance of the power line, and these two are the most practical methods of obtaining the appropriate values of earth resistivity for the area.

Although in the foregoing the relationship of an open-wire telephone line to a power line has been considered, being the more common case met in practice, the curves (Fig. 1) should be used for the exposure of underground



AREA ENCLOSED = 17·45 SQ. INS.
MUTUAL IMPEDANCE = 1·745 OHMS

Fig. 3.—Power Exposure. Longitudinal Mutual Impedance Graph.

telephone cables to power lines. In this case the appropriate shielding factors, referred to later, should be applied.

Earth Fault Current. The value of earth fault current used in the preliminary calculation of maximum induced voltage is that resulting from an earth fault on the power line at the end of the exposure distant from the source of power, as this usually gives the greatest induced e.m.f. When calculating the value of the earth fault current, it is assumed that the resistance of the contact to earth is zero.

Shielding Factors. The shielding factor "k." which allows for the effect of any shielding on the values of the induced longitudinal voltage, is difficult to calculate, particularly in the case of underground cables, as it is a function of the leakage between the sheath and ground. It is not usual to consider shielding when the telephone line concerned is of open wire construction. However, it becomes important when the telephone line is in a cable, as there is considerable risk of breakdown of the insulation of the cable if the value of the induced longitudinal voltage is much in excess of 430 volts, and any reduction in the value of the induced voltage due to shielding can be significant.

It is proposed to use the values of shielding factors in use by some overseas administrations, and these are as follows:—

(i) Earth wire on power route.
If the earth wire is continuous and has an area equivalent to at least 0.068 sq. in. copper conductor, a value of $k = 0.66$ may be allowed. If the earth wire is smaller than this no allowance should be made.

(ii) Underground power cables.
(a) One 6.6 kV, 3-core armoured cable, 0.30.
(b) One 11 kV to 66 kV, 3-core armoured cable, 0.25.
(c) Two 11 kV to 66 kV, 3-core armoured cables with sheaths bonded in parallel, 0.12.

(iii) Underground telephone cables.

The various shielding factors which apply are set out in Table 1.

When there are several telephone cables in a multi-duct run of non-metallic ducts, the shielding factor is reduced to a shielding factor "y," where $y = 1/(1 + x^2)^{\frac{1}{2}}$ and "x" = the sum of the reciprocals of the resistance (R) in ohms per mile of the individual sheaths. Where more than one shield factor applies the total value of "k" for the formula is the product of the relevant factors.

Effect of Induced Longitudinal Voltage on Telephone Plant. If the exposure were uniform and extended over the whole length of the telephone line, the induced e.m.f. per unit length would likewise be generally uniform over the whole length of the line, as indicated in Fig. 4 (b). Assuming that the line is not connected to earth either metallically or through lumped capacitance of appreciable magnitude, its potential to earth will be distributed as in Fig. 4 (c); the areas between the graph and the axis on either side of the cross-over point are equal. Such uniform exposures are, however, rare. Fig. 4 (d) illustrates an exposure which is uniform over part of the telephone line; the remainder of the line is not exposed. Fig. 4 (e) shows the distribution of longitudinal e.m.f. per unit length, and Fig. 4 (f) the potential to earth. This now varies with uniform slope (corresponding to the e.m.f. per unit length) over the exposed portion, and remains constant over the part not exposed. Again, the areas of the two parts of the diagram on either side of the cross-over point are equal. The maximum values of potential to earth in the two sections are, however, different, and will be more so as the length of the unexposed section is greater. If the potential at the exposed end of the line is sufficiently high, it will operate the arresters at that point, so earthing the line; the slope of the potential distribution is not altered, but the whole graph is shifted parallel to itself to bring the potential to zero at the earthed point. (Fig. 4(g)). The potential at the other end will now be high enough to operate the arrester there. The resulting short-circuit will allow a longitudinal current to circulate in the line, bringing the potential to zero at that end, and also reducing that at all other points (Fig. 4h).

The impedance of this circuit is approximately equal to the resistance of the telephone wire, so that the maximum value of the induced current will be equal to the induced longitudinal voltage divided by the resistance of the telephone line between the operated arresters. This current will flow until the circuit breakers interrupt the faulty high voltage power line, and if the magnitude of this current for the period until the circuit breakers operate, which may be up to 2 seconds, is beyond the current carrying capacity of the arresters, they will fail and put a permanent earth on the telephone line.

Where the telephone line is in a cable there is a danger of breakdown of the

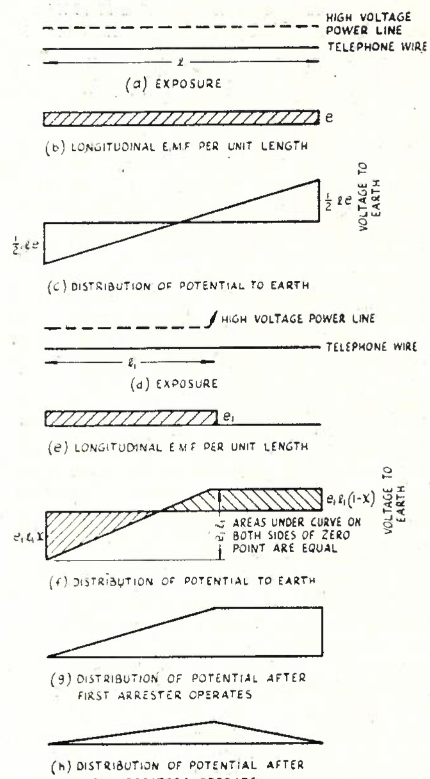


Fig. 4.—Distribution of Induced E.M.F. and Potential to Earth.

cable insulation if the value of the induced longitudinal voltage exceeds 650 volts, and values higher than this should therefore be carefully avoided.

Effect of induced longitudinal voltage on personnel working on telephone lines. No authentic record can be found of serious injury to personnel from this source, although injury attributed to lightning may in some cases have been more directly due to induced longitudinal voltage following the flashover of a high voltage line caused by the lightning.

Workmen avoid working on open wire lines during lightning storms, when the large majority of earth faults on high voltage power lines occur. However, jointers may be working on telephone cables associated with an exposure during a storm and could be subjected to danger from induced longitudinal voltages if an earth fault occurs on the power line.

Voice Frequency Induction

Characteristics of Power Lines. Three-phase high voltage power lines are normally operated in a manner which may be regarded as nominally balanced, as far as co-ordination requirements are concerned. Usually an earth connection is made to the neutral point of the transformer or machine feeding the line, or to some equivalent device at the point of supply, and all loads applied to the line are connected between either two or all three of the phase wires, and have no connection to earth. However, there are a few systems in operation in

TABLE 1.

External diameter of lead sheath inches	Lead covered cables		Tape armoured lead covered cable
	In non-metallic duct	In steel or iron pipe	
0.5	1.0	0.02	0.9
1.0	0.9	0.02	0.8
1.5	0.8	0.015	0.7
2.0	0.6	0.015	0.5
2.5	0.5	0.01	—
3.0	0.4	0.01	—

Australia in which the neutral is isolated or earthed through a Petersen Coil or earthing resistor. Balance of load currents from a co-ordination viewpoint does not imply equality of and uniform phase differences between the currents in the three wires, but only that the algebraic or vector sum of the currents should be zero. Equality of voltages and balance of currents in the three phases does not, however, ensure that their effects on neighbouring telephone circuits are also balanced. Differences in separation of the phase conductors from these telephone circuits and in the screening effects exerted by the phase conductors on each other bring about corresponding differences in the couplings to such circuits. It is possible, however, to balance these effects by transposing the power circuit, introducing at regular intervals a cyclic shift of the conductors so that, over an exposed section, any neighbouring telephone circuit is equally coupled to each of the three phase conductors.

Inductive effects may also be caused by the residual components of unbalanced currents flowing to earthed loads or to unbalanced sections of line outside the transposed section. These inductive effects cannot be reduced by transpositions in the power line within the exposure. However, where these residual currents are caused by unsymmetrical spacing of the power conductors to earth and to each other, they can be reduced by the overall transposing of the power line.

Characteristics of Telephone Lines. Telephone circuits are normally operated in a balanced manner, and where the lines are trunk circuits or long subscribers' lines they are transposed to standard transposition schemes as laid down by the Postmaster-General's Department. These transpositions are effective in balancing out electromotive forces induced directly into the metallic circuit from uniform parallel neighbouring circuits, including power circuits. Such balancing takes place in certain elements of the line, defined by balance or neutral points.

Balance points divide a transposition section into elements within each of which uniform metallic circuit induced voltages are balanced out. The number of balance points for the standard transposition schemes used in Australia are shown in Table 2.

TABLE 2.

Transposition scheme	Transposition section length (miles)	No. of balance points
12 channel carrier	{ 8.0 { 6.4	64
3 channel carrier	8.0	32
Voice frequency	8.0	16

Induction between Power and Telephone Circuits. Induction into a telephone circuit takes place in two ways: (i) induction into the longitudinal circuit and (ii) induction into the metallic circuit. Longitudinal induction causes noise to appear in the metallic circuit as a result of unbalance of either the circuit conductors or their terminating equipment. Induction into the metallic circuit appears directly as noise.

The actual magnitude of the voltage induced into a longitudinal circuit on a telephone pair is always very much greater than that induced into the metallic circuit, owing to the greater separation between the "go" and "return" sides of the circuit (the separation between wires and earth, as compared with the separation between the two wires of the pair). Also, metallic circuit induction may, theoretically, be reduced as far as desired by suitable transpositions in the telephone circuit. For this reason the preliminary examination of an exposure is directed to the estimation of longitudinal induction.

In the general case there may be obtained four different values of longitudinal noise, corresponding to four different types of induction—

1. Magnetic induction from residual currents.
2. Magnetic induction from balanced currents.
3. Electrostatic induction from residual voltages.
4. Electrostatic induction from balanced voltages.

Power circuits are, however, usually operated in such a way that residual currents and voltages are negligible. Where this is not so there is usually some special circuit condition which should be the subject of special investigation. Also, the great majority of exposures to high voltage lines are to those commonly routed along roads, and in these cases the electrostatic induction is of much greater importance than the magnetic.

Thus, of the four different types of induction it is only necessary to consider the electrostatic induction from the balanced voltages in the majority of cases. By applying transpositions to the power line in the exposed section, charges resulting from this type of induction are balanced out within the exposure. The length of the power line transposition section or barrel is not normally critical, and in long exposures at roadway separations about 6 to 7 miles will usually be satisfactory. For greater separations longer barrels may be considered.

Noise characteristics of Power Circuits. It is recognised as commercially impracticable to build rotating machinery and transformers which are entirely free from harmonics, and it is the harmonic frequency components which are of major importance from the noise standpoint. Normally, a delta connection to the transformer at the supply end of the high voltage power line suppresses 3rd harmonics. However, to ascertain co-ordination requirements for noise induction it is necessary to assess the interference-causing property of the power circuit.

For this purpose it is possible to define, for a given power circuit voltage, an "equivalent disturbing voltage" derived from the harmonic content of the given voltage by multiplying the voltage of each component by the appropriate psophometric weighing factor and by the ratio of its frequency in cycles per sec. to 800. The component voltages thus weighted are squared, added, and the square root taken of the sum, to give the "equivalent disturbing voltage". The result is the value of an 800 c/s voltage which, if present in the power circuit, would cause a disturbance in neighbouring telephone circuits equivalent to that caused by the given voltage. The ratio of the "equivalent disturbing voltage" to the R.M.S. value of the originally given voltage is termed the "telephonic form factor".

Where measurements of telephonic form factor are not available for a power system involved in an exposure, it is generally safe, according to the C.C.I.F. Directives, to assume a value of 0.02.

Co-ordination of Transpositions in Power and Telephone Lines. To avoid unbalanced metallic circuit induction in the telephone circuit, the location of the ends of barrels and power transpositions should be as nearly as practicable opposite balance points of the telephone transposition system. Discontinuities in the exposure, such as crossovers of the lines involved, changes in configuration of the power line, major branches or taps in the power line or major branches in the telephone line, should be regarded as dividing the exposure up into parts which are dealt with separately.

If the exposure is of uniform separation, each phase wire will occupy each wire position for an equal length of each barrel. However, where the separation varies, exact balancing of the longitudinal induction requires varying distances between the power transpositions. An induced voltage diagram for each barrel may be plotted from the Exposure Chart, using the appropriate curves to obtain the value of the induced open circuit volts for the various separations. The power transposition locations are then chosen to divide the voltage diagram into sections of equal area. Exact balance of the longitudinal induction is, however, of less importance than avoidance of unbalanced metallic circuit induction and the final locations of the power transpositions should be chosen to fall as nearly as practicable opposite balance points of the telephone transposition system. An induced voltage diagram for part of the exposure in Fig. 2 is shown in Fig. 5, with the appropriate induction curve as Fig. 6.

PART II.
CO-ORDINATION PRACTICES
General

Practices for the co-ordination of high voltage power lines and telephone lines comprise the procedures to be followed and measures to be taken to ensure that high voltage power lines and telephone lines can operate in reasonably close proximity without detrimental effect to the telephone plant and personnel. For co-ordination purposes a high voltage power line is one whose voltage is 6.6 kV or higher. As discussed in Part I, the effect of high voltage power lines on neighbouring telephone lines is (i) under earth fault conditions on the power line, to induce low frequency longitudinal voltages of sufficient magnitude to endanger telephone plant and personnel and (ii) to induce excessive noise in the voice frequency telephone circuits. Both these effects must be considered when deciding what, if any, co-ordination measures are necessary for any exposure of a telephone line to a nearby high voltage power line.

For the purpose of ascertaining when an examination should be made of the need for co-ordination measures, an "exposure" of a telephone line to a high voltage power line may be defined as occurring whenever a high voltage power line and a telephone line are separated by a distance of less than three miles over a length not less than their separation. It does not follow that all such exposures will be sources of disturbance or of dangerous induced longitudinal voltages on the telephone lines. Noise disturbances, in fact, are not likely to occur except at smaller separation, less than one mile for the highest value of voltage used for power transmission lines in Australia.

The most effective and obvious co-ordination measure which is applicable to all forms of inductive interference is to provide a sufficient separation between the power and telephone lines, to ensure that neither dangerously high induced longitudinal voltages nor excessive noise can be induced in the telephone circuits. However, as both high voltage power and telephone networks expand it becomes increasingly difficult to provide the necessary separation and the position has now been reached where the control of inductive interference by this means is impracticable in many cases. It is therefore necessary to adopt other measures to ensure that the telephone lines are protected effectively.

Co-ordination Measures for Low Frequency Induction.

Introduction. In considering the hazard associated with induced longitudinal voltages on telephone lines it is necessary to consider the dangers to open wire construction and cable construction separately. In so far as the line plant itself is concerned, telephone lines in open wire construction using wooden poles normally have a breakdown voltage to earth of the order of 1,000,000 volts, whereas telephone lines in cables have a breakdown voltage of the order of 1,000 volts. Therefore, whereas a reduction of the value of the induced voltage to non-dangerous values is beneficial with both types of telephone plant, it is essential in the case of cable if breakdown of the line plant is to be avoided.

In considering means of reducing the value of the induced longitudinal voltage for any given exposure, it will be observed from an examination of formula 1 that this can be done either (i) by reducing the maximum value of the earth fault current applicable to the exposure or (ii) by providing shielding to give a low value of the shielding factor.

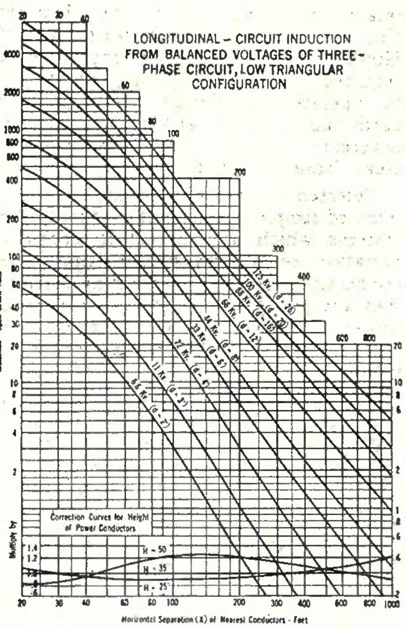


Fig. 6.—Longitudinal—Circuit induction from balanced voltages of three-phase circuit, low triangular configuration.

Reduction of Earth Fault Current. The earth fault current can be reduced by inserting a resistance, or a Petersen Coil, in the neutral earth connection. To ensure the efficient operation of the protective apparatus of the power system, the magnitude of any resistance in this earth connection is very limited. It is generally only practicable to use such a resistance to reduce the value of fault currents for earth faults close to the supply end of the high voltage line. This method has been used for reducing these large fault currents when the smaller currents will result in an appreciable reduction in the value of the induced longitudinal voltage in an exposed telephone cable near the supply end of the power line.

The Petersen Coil consists of an inductance connected between the neutral point and earth, and tuned to the power line system capacitance to earth. These coils suppress the current in the earth fault while in operation, and thus eliminate transient earth faults, which form the large majority of all earth faults on power lines. Petersen Coils are often used by power authorities in an attempt to maintain service in spite of phase to earth faults. From the co-ordination point of view, this condition is likely to be undesirable because of the noise induction resulting from unbalance of voltage on the power lines. Where no selective protection of different parts of the power line system is involved, it is possible to operate circuit breakers to clear an earth from voltage

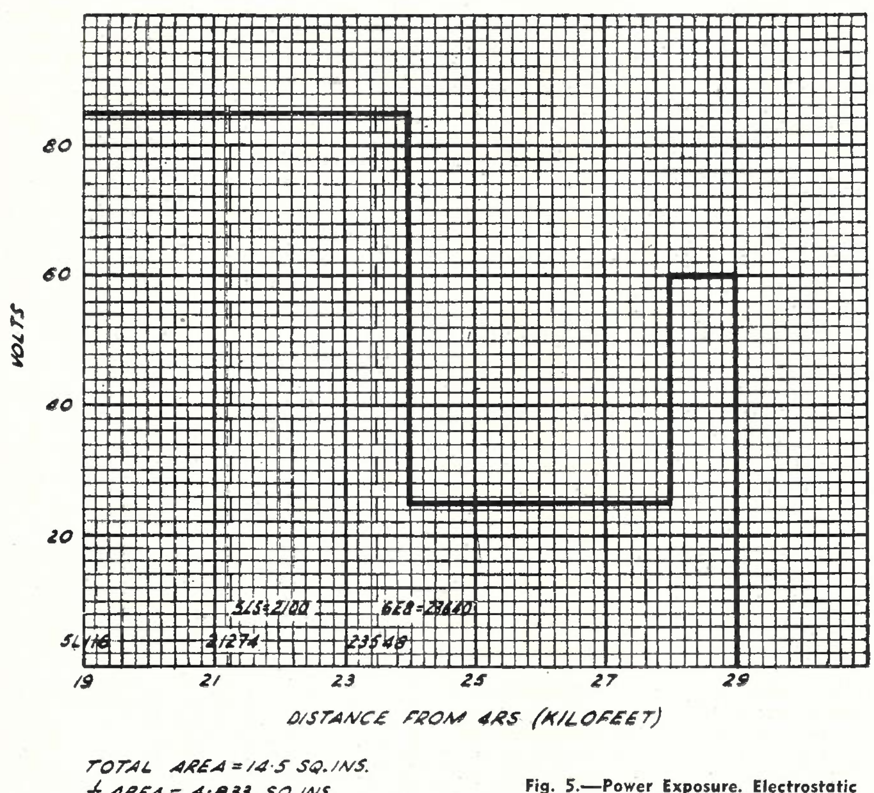


Fig. 5.—Power Exposure. Electrostatic Induction Graph.

relays connected across the Petersen Coil, or current relays in series with it. However, where selective protection is required it is generally only practicable to operate the circuit breakers from earth fault current, and it then becomes necessary to short circuit the coil to clear "solid" earth faults by this means.

Petersen Coils are most useful in systems of simple layout, but in distribution systems which are subject to continual variation, or systems with multiple interconnections between generating stations, they are generally unsuitable. In general, power authorities favour systems with solidly earthed neutrals, in order to ensure reliable operation with normal protective devices.

Petersen Coils are installed on some high voltage power lines in Australia and have given a good account of themselves in providing for the self-clearing of transient faults in areas subject to very severe lightning storms. A number are being installed in some new 66 kV lines in Queensland, and their effect upon the performance of these high voltage lines will be watched with interest.

Shielding. As previously mentioned, the value of the induced longitudinal voltage can be appreciably reduced if earth wires of adequate size are provided on the high voltage power line concerned. In the case of open wire telephone lines, a certain amount of shielding occurs when the arresters operate to earth some of the wires, but its effect varies and is usually neglected in calculations of the maximum value of induced longitudinal voltage.

In the case of telephone cables, which are particularly vulnerable to any induced longitudinal voltages in excess of a few hundred volts, shielding is usually an important factor in their protection. This is particularly so when the exposure is to a high voltage power cable, rather than to an open wire line. Under these conditions the shielding factor can have a very low value, which in itself ensures adequate protection of the telephone cable under the worst earth fault conditions on the power circuit.

It will also be observed that in the case of multi-duct runs of non-metallic ducts accommodating large size cables, as is found in all large cities, small values of the shielding factor are obtained. Thus, for four cables, each 2.5″ external diameter, in non-metallic ducts, the applicable value of the shielding factor is approximately 0.16.

Use of drainage on telephone lines. It will be appreciated from the foregoing that, with open wire telephone lines, cases will arise where it is impracticable to reduce the maximum induced longitudinal voltage under earth fault conditions on a nearby high voltage power line to a value which will not operate the normal protective equipment of the telephone line. The operation of this equipment, which usually consists of gap type arresters, earths the telephone line and, assuming a sufficiently low earth resistance, provides adequate protection against damage to equipment or personnel by the induced voltage. However, as discussed in Part I, the operation of these arresters will often cause a fairly large induced current to flow to earth, depending on the resistance of the telephone line between operated arresters, and if the duration of this current flow, pending the operation of the circuit breakers on the high voltage power line, is sufficient to lead to damage of the telephone arresters, the telephone line will be left permanently earthed until the defective arresters are replaced. This may cause both serious interruption to telephone and telegraph communications in the case of an important trunk route and appreciable cost in restoring service if the stations affected are remote from the lineman's or technician's station.

Where, therefore, it is necessary to rely on the telephone lines being protected from damage from induced longitudinal voltages, by the operation of the arresters in the telephone line, it is important to ascertain (i) whether the maximum value of the induced current is of sufficient magnitude to affect the self-restoring properties of the arresters after the power line fault is cleared; (ii) if so, whether the importance of the telephone line and the likely frequency of earth faults on the power line are such as to justify the installation of higher grade protection on the telephone line to ensure continuity of service.

If an examination of (ii) indicates that higher grade protection is necessary, this protection is usually provided by the installation of arrester relays which short circuit the arrester blocks until the power line fault is cleared. The circuit of an arrester relay is shown in Fig. 7. The relay coil has an impedance of less than 1 ohm at 50 c/s, and closes the contacts to short circuit the gap arresters, when a current of 1-1/2 amperes is passed through the coil. The contacts close within 1/100 second with a current of 5 amperes, and the coil will carry a current of approximately 150 amperes for one second and 30 amperes for five minutes.

The use of arrester relays is in its preliminary stage in Australia, but the few which have been installed have operated satisfactorily. Reports from overseas speak highly of their value to protect arresters from heavy induced currents under earth fault conditions on neighbouring power lines, and it is expected that more extensive trials will be undertaken in the near future on other important telephone lines which are subject to heavy induced currents under these conditions.

In many cases of exposures the maximum value of the induced current on open wire telephone lines will never approach the value of the current which can be safely passed by the arrester relay, and the use of comparatively cheap arresters, with a current carrying capacity of the order of 10 amperes for a period of two seconds, would have a wide application to many telephone lines involved in exposures to high voltage power lines. The Postmaster-General's Department is investigating various types of arresters to ascertain which are the most suitable for operation under conditions of induced longitudinal voltage from power lines.

Tests are also being made of the latest type of gas arresters. These arresters now have a speed of operation comparable with the carbon block arrester, and the types being tested have been designed to cater for low frequency induction and have a relatively large current carrying capacity. However, the principal objections to this type of arrester, that they "open circuit" when failure occurs, and the condition of the arrester in situ cannot be determined by any simple test at an exchange, have not yet been overcome. Owing to this characteristic the Postmaster-General's Department is not at present agreeable to any extensive use of this type of arrester.

Consideration is also being given to the use of 3 mil gap arresters to limit the maximum value of the induced voltage on small telephone cables in country areas, which parallel high voltage power lines over a distance which could give rise to induced voltages considerably in excess of 430 volts under earth fault conditions on the power lines. In these cases the arresters would probably be installed in a cabinet or pillar at loading manholes, the number of the arrester points being calculated to ensure that the induced voltage on the cable pairs will not reach dangerous values. This type of drainage may be applicable to minor trunk or long subscribers' cables where the shielding obtained is negligible, and it is impracticable to keep the maximum value of the induced voltage to within safe limits by providing sufficient separation between the high voltage power line and the telephone cable.

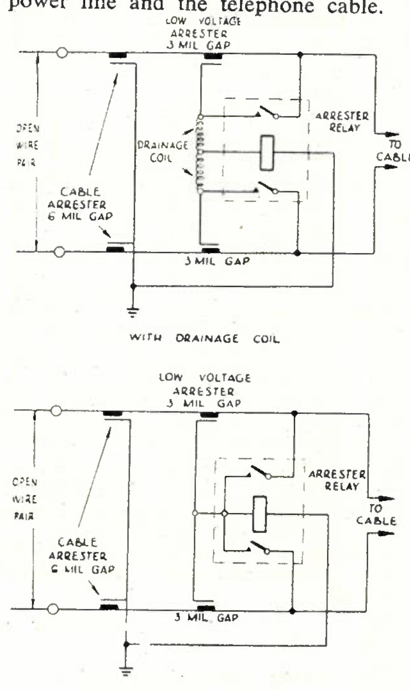


Fig. 7.—Circuit diagram of arrester relay.

Proposed Remedial Measures. It will be evident that the co-ordination of high voltage power and telephone lines during the early planning period of any new power or telephone route will be a most important factor in reducing the effect of any low frequency induction to a minimum and in enabling the most effective and economical remedial measures to be taken in each case where such action is necessary.

At this stage it is not proposed to lay down hard and fast rules regarding the type of protection to be provided in all cases of exposure resulting in values of induced low frequency voltage in excess of 430 volts, but to deal with most cases individually. Generally, it is proposed to install arrester relays on the open wire telephone lines on major trunk routes where the maximum value of the induced current is of sufficient magnitude to endanger the protectors on the telephone lines. In the case of minor trunk or subscribers' routes it is hoped, firstly that a cheaper form of drainage protection can be used in most cases, and secondly that, with the co-operation of the power authorities, the frequency of earth faults on the high voltage power lines will, as far as practicable, be such as not to result in a serious number of interruptions to telephone service from this cause.

Where it is impracticable to reduce the value of the induced voltage to less than 430 volts by providing sufficient separation between the power and telephone routes, the suitability of the high voltage power line for the installation of Petersen Coils would be examined. This solution will only be practicable in a limited number of cases, and even then the likelihood of future extensions or modifications to the power line which would necessitate the removal of the Petersen Coils must not be overlooked. In the majority of cases where the maximum value of the induced voltage will exceed 430 volts the remedial measures will consist in the installation of suitable protective equipment on the telephone lines.

Co-ordination Measures for Voice Frequency Induction

Introduction. Owing to the shielding effect of the lead sheath of telephone and power cables, voice frequency induction on telephone lines is not a problem where the telephone or power lines are in cable over the whole length of the exposure. The co-ordination measures proposed for this type of induction are associated with open wire power and telephone construction.

As mentioned in Part I, power circuits are usually operated in such a way that residual currents are negligible, and where this is not so there is generally some unusual circuit condition which should be the subject of special investigation. The general co-ordination measures will therefore be concerned with induction from balanced power currents and voltages and, as the electrostatic induction is of much greater importance than the magnetic in the majority of cases, the rules proposed to indicate the degree of co-ordination, particularly of transpositions, are based on the voltage of the high voltage power line.

As discussed in Part I, the co-ordination measures applicable to voice frequency induction comprise the transposing of both the high voltage power line and the exposed telephone lines and the co-ordination of the transpositions in both circuits. While valuable information can be obtained from a theoretical study of the requirements for a proposed exposure, the unpredictable factors are such that in the last analysis the co-ordination measures to be applied will be based on experience. At the present time there is a dearth of information on voice frequency induction and co-ordination conditions for existing exposures in Australia, and it has been necessary to base the proposed requirements principally on overseas experience.

As far as can be ascertained, little trouble has been experienced where telephone lines transposed to standard transposition schemes are exposed to properly constructed and operated three-phase high voltage power lines. However, it is considered that, to ensure that future exposures will not give rise to interference, definite rules should be adopted to indicate the degree of co-ordination required between the transpositions in the power and telephone lines for various voltages and separations. It has been decided to adopt the C.C.I.F. recommendations covering both limiting noise values in telephone circuits and the degree of co-ordination of transpositions to ensure that these values are not exceeded.

Values of Induced Noise. The C.C.I.F. limiting noise values in telephone circuits are expressed in terms of "psophometric e.m.f.," which is measured by an instrument called the psophometer. This instrument is constructed in accordance with a specification established by the C.C.I.F. and consists essentially of an amplifying vacuum tube voltmeter giving a true R.M.S. reading, preceded by a frequency weighting network. The reference frequency is 800 c/s, and values of voltage of this frequency are indicated directly. Voltages at other frequencies or of complex wave form are indicated as the value of the 800 c/s voltage which would produce equivalent interference and is referred to as the psophometric voltage. If a psophometric voltage is measured across a 600-ohm termination, matched to its sending circuit by a transformer if necessary, a voltage equal to twice the measured value is called the "psophometric e.m.f." Psophometric voltages can also be measured by the use of a Western Electric 2B Noise Measuring Set.

The limiting values of noise in telephone circuits at present quoted in the C.C.I.F. Directives are 5 millivolts for open wire circuits and 2 millivolts for cable circuits, which values may apply at points of relative level minus 7 db in voice frequency circuits. However, these values should include all sources of noise in a long circuit (1,000 miles), and for circuits of 125 miles or less, or for any single exposure, the psophometric e.m.f. should, if possible, be kept below 0.8 mV.

Determination of Degree of Exposure and Extent of Transposing. The steps to be taken in investigating cases of proximity will depend on the separation between the power and telephone lines, and also on whether the neutral point of the transformer or machine supplying the line is earthed. Various degrees of exposure in terms of separation can be determined from the following formulae derived from the C.C.I.F. Directives, with the constants modified to express all linear measurements in feet.

Isolated Neutral Systems. Systems with isolated neutrals **may** give rise to dangerous switching surges when the separation is within a distance of "a_1" feet, given by

$$a_1 = 1.1 \sqrt{E}$$

where E is the normal effective line voltage between phases in volts.

Such systems may also give rise to noise in the event of an earth fault on one phase which is not automatically cleared, at separations up to a distance of "a_2" feet,

given by $a_2 = 7 \sqrt{E}$

There will not be many occasions in Australia to consider systems with isolated neutral.

Balanced three-phase systems. Balanced three-phase systems (neutral, isolated or earthed) **may** give rise to noise at separations less than "a_3" feet, given by

$$a_3 = 1.2 \sqrt{E\,d}$$

where E is the normal effective line voltage between phases in volts, and d is the geometric mean of the distances between conductors of the power line in feet.

Where the separation is less than "a_3" feet, it may be assumed that noise induced directly into the metallic circuit will be less than 1 millivolt if the separation is not less than "a" feet, given by

$$a = 0.036 \sqrt{K\,E\,d\,l}$$

where K is the telephonic form factor of the line voltage,
E is the normal effective line voltage between phases in volts,
d is the geometric mean of the distances between conductors of the power line in feet,
l is the unbalanced length of exposure in feet and is a function of the telephone transposition scheme.

Ideally, the maximum value of "l" would be equal to the distance between balance points of the transposition scheme, but for the purpose of this formula, in order to allow for irregularities of the exposure, it is taken as being not less than 1,650 feet. Where the actual separation is less than the value of "a" feet, special attention must be given to the construction of the parallel to justify the assumption of a smaller value for "l".

Approximate separations in feet for "a_1," "a_2," "a_3" and "a" with values of

TABLE 3.

Voltage (kV)	d (feet)	Isolated neutral system		Isolated and earthed neutral system	
		a_1 (feet)	a_2 (feet)	a_3 (feet)	a (feet)
11	3	115	730	220	38
22	4	160	1,040	360	62
33	5	200	1,270	490	84
66	8	280	1,800	870	150
132	20	400	2,500	1,950	340
220	30	520	3,300	3,100	540

"d" based on typical line configurations, telephonic form factor $K = 0.02$ and $l = 1,650$ feet, are given in Table 3 to indicate the magnitude of the minimum desirable separations between telephone and high voltage power lines.

Extent of transposing for varying degrees of exposure. The distances of separation "a_3" and "a" are those concerned in transposition problems. There are, therefore, three conditions of separation, as follows:—

(i) Where a power line has no telephone lines exposed to it with a separation less than "a_3".

(ii) Where a power line has telephone lines exposed to it for a distance of two miles or more with a separation between "a_3" and "a".

(iii) Where a power line has telephone lines exposed to it for a distance of two miles or more with separations less than "a".

The transposition requirements proposed for each category are as follows:—

(i) No transpositions are required in the power line in so far as the possibility of interference is concerned.

(ii) The power line over the exposed section requires to have such transpositions as will minimise residual currents and voltage unbalance. With closer separations approaching "a" the power line should be transposed over the exposed section independently of the rest of the line, to reduce longitudinal-circuit induction from balanced line voltages.

(iii) At these separations direct induction into the metallic circuit of the telephone lines will be of importance, and it is essential to co-ordinate all discontinuities in the exposure with balance points of the telephone transposition scheme. The power transpositions should preferably be of the point type and should fall as nearly as possible opposite and within 50 ft. of balance points of the telephone lines. If a new power line is concerned, this requirement should be taken into account in locating poles. In some cases it may be necessary to transpose a portion of a V.F. transposed telephone line to a more intensively transposed transposition scheme, in order to provide co-ordination with the ends of the exposure or major discontinuities. Also, if either line is being newly built, all possible care should be taken to maintain uniformity of separation.

If the separation is generally less than "a" feet and is not uniform, the locations of the power transpositions for each barrel should be obtained by means of an induced voltage diagram similar to that shown in Fig. 5.

Co-ordination Requirements for a New Exposure. The action to be taken when investigating a proposed new exposure, which may arise from the erection of either a new telephone route or high voltage power route, will be generally as follows:—

(i) At as early a stage as practicable, estimate the maximum value of the induced voltage on the telephone circuits under earth fault conditions on the power line.

(ii) Where the estimated maximum value of the induced voltage is less than 430 volts, no further action is required beyond a later check if considered necessary when more precise information is available.

(iii) Where the estimated value of the induced voltage exceeds 430 volts and the separation is not uniform, an Exposure Chart as in Fig. 1 should be prepared, to assist in making more accurate calculations of induced voltage and also in determining transposition requirements of both the telephone and high voltage power routes.

(iv) In the case referred to in (iii) consideration should be given to the measures necessary either to reduce this value to less than 430 volts or, if this is impracticable, ascertain what action should be taken to ensure that the telephone circuits will not be rendered inoperative under earth fault conditions on the high voltage power line. The co-ordination measures to be considered comprise (a) increased separation; (b) limitation of earth fault current on power line; (c) effect of shielding in case of telephone and/or power cables and (d) installation of drainage protection on the telephone circuits.

(v) Examine the degree of co-ordination of transpositions required to ensure that the voice frequency noise induced in open wire telephone circuits is within the prescribed limits. Unless the exposure is very severe, rolling types of transpositions in the high voltage power line should be satisfactory. During the construction of high voltage power lines up to 66 kV, which are those principally concerned in the co-ordination of transpositions, the insertion of the transpositions required for co-ordination purposes entails little additional effort or cost. Major power authorities have no objection to inserting transpositions at this stage, and those required for the separations provided should always be inserted in these lines.
However, there are complications in providing transpositions in an existing high voltage power line and, where the exposure is created by the erection of a new open wire telephone line, care should be exercised to ensure that any transpositions proposed in the existing high voltage power line are essential. in the particular case being considered.

(vi) When the co-ordinated transposition requirements have been ascertained, they should be inserted on the Exposure Chart as the basis for the preparation of the appropriate instructions.

Conclusion

It is essential that the high voltage power and telephone networks be developed to meet the nation's requirements on a properly co-ordinated basis. For this purpose it is necessary that the appropriate co-ordination requirements in each case should be considered as a single engineering problem requiring the willing co-operation of both the power and telecommunication authorities. Also, the co-ordination requirements must be regarded as a basic factor in the planning of any high voltage power or trunk telephone line, and it is important that all authorities should examine the co-ordination requirements as early as practicable in the planning of any new route.

General experience is that, as co-ordination is primarily an engineering problem, it is best dealt with by mutual co-operation between the parties concerned. Joint Committees on Co-ordination have been formed in most countries and have taken an important part in the development of power and telephone networks. It is considered that the establishment of similar Joint Committees in Australia is an important step in co-ordinating power and telecommunication services in this country.

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THE ALARM TRUNK CIRCUIT

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Introduction

The installation of carrier communication equipment in localities not favouring the permanent stationing of maintenance staff has led to the use of auxiliary type unattended stations. The establishment of this type of office has necessitated the design of some form of equipment to report back to the parent station on the working conditions at the unattended office. The Bell System developed for this purpose a unit known as the Alarm Trunk Circuit, and it is proposed to briefly describe in this article the function of this piece of equipment.

The main application in Australia of the alarm trunk circuit is its operation between an auxiliary type J 12-channel open wire carrier telephone repeating office and its parent or the nearest main or attended station, which is normally between 60 and 70 miles distant. A description of an auxiliary type J repeating station was given in a recent issue of this Journal (1). The alarm circuit equipment is also designed for use with type K1 unattended cable carrier repeating offices, but as all 12-channel cable carrier systems in this country are comparatively short-distance, and maintenance staff is stationed close to most offices, it has not been necessary to provide a comprehensive system of alarm transmission for these systems.

General Description

The alarm trunk apparatus is subdivided into several units:

(a) A sending unit at the sending station—the unattended office;
(b) A receiving unit at the receiving station—the parent office;
(c) An alarm trunk control unit which will perform several functions at the auxiliary office under the control of the parent station; and
(d) An individual alarm circuit at the sending station.

The circuit has been designed for use between the sending station and receiving station to register at the parent or receiving station conditions of alarm at the sending office. The apparatus allows for a maximum of 10 alarm conditions, each being shown by the glowing of a switchboard lamp installed on a jack field. Each lamp can cover one or more alarms at the distant office. The alarm circuit can be a cailho or composite circuit, a metallic earthed return circuit or an individual cable pair dependent on local ruling conditions. In Australia, cailho or composite circuits are usually used. Facilities are also available for performing a re-check, that is, a complete check of the alarm indications as given at the receiving office.

A photograph of the alarm trunk circuit equipment at the receiving office is shown in Fig. 1. The alarm trunk equipment at the sending office is shown in Fig. 2.

The Individual Alarm Circuit is a unit which registers alarms at the office in which it is installed. It is a common piece of equipment provided at each station, and as well as operating the station alarm, causes, at an auxiliary office, the alarm trunk circuit to operate. At the auxiliary office, the various individual alarm circuits supply earths to the appropriate relays in the alarm trunk circuit. The operation of one or more of these relays causes a start signal to be transmitted to the receiving station where an interrupter is started and the receiving station alarm operated. This interrupter unit operates selector type rotary switches at both the receiving and sending stations. The sending station selector hunts for the earth on its bank contacts, which is set up by the registering alarm. When this earth is found, a signal is transmitted back to the receiving office and, through the operation of its selector, causes a lamp to be illuminated. By an examination of a reference chart, the alarm condition can be ascertained and appropriate action taken.

The alarm trunk circuit operates over a normally closed loop under condition of no alarm. In this paper, a cailho circuit with earth return is considered as a loop.

Under conditions of no alarm, battery is transmitted from the auxiliary or sending station via the cailho circuit to an earth at the receiving office to maintain a polarised relay in the operate condition. An alarm at the sending station will cause a relay to substitute earth at the sending station, which in turn will release the polarised relay at the receiving station. The receiving station audible alarm is operated at this time and the interrupter unit started. The receiving station also applies 130V positive battery to the alarm trunk cailho circuit which operates the sending station selector through an operating relay. The receiving station battery is alternately applied and removed from the alarm trunk circuit and the selectors at both sending and receiving offices are stepped around. An earth on a particular bank contact at the sending station, caused by an alarm condition, lights a corresponding lamp at the receiving station. Under conditions of alarm trunk circuit failure because of a line earth, an open, or the failure of the battery supply at the sending station, the audible alarm is operated and all the alarm lamps are caused to glow at the receiving station.

Detailed Operation

The circuit shown in Figs. 3 and 4 gives details of the circuit between a sending and receiving station as used in Western Australia. Table 1 gives the coding for the fault conditions of the lamps at the receiving station.

TABLE 1

Lamp No.	Fault
A1	Telephone call from sending station.
A2	Not used.
A3	Equipment room high-low temperature; Carrier repeater bay distribution fuses; Power bay alarm fuses.
A4	Not used.
A5	Pilot channel end alarm and pulse alarm; 24V and 150V high-low alarms.
A6	Engine failure; Low fuel.
A7	Engine operate; 24V and 55V distribution fuses (misc. bay);
A8	E-W pilot channel fail.
A9	W-E pilot channel fail.
A10	Open door.

Sending Station (Fig. 3): Under normal, "no alarms" conditions, the selector is at its home position and 140V battery is transmitted from the sending station via relay P1 to the receiving station and through relay L1 to ground. This current flow causes these two relays to be held in the operate direction.

Not shown in Fig. 3 are the leads designated AT1 .... AT10 of the individual alarm circuit which registers the alarm in the first instance. This circuit operates appropriate relays AT1 .... AT10 which in turn apply earths to the leads AT1 .... AT10 in Fig. 3, and operate relays A1 .... A10 which apply earths to the selector bank contacts. The earths on leads AT1 .... AT10 causes relay S1 to operate via resistances A1 .... A10. Relay S1 operates relay S2 via ON contacts and S1. Relay S2 also removes the battery sent to the alarm trunk circuit and replaces it with earth. Relay S2 closes one contact in preparation of the rotary magnet circuit of the selector.

The substitution of battery with earth at the sending station causes the relay L1 at the parent station to release, which rings a bell. Relay L1 also causes an interrupter to be started, which sends pulses of battery at approximately 20 interruptions per minute to the alarm trunk cailho. The first battery pulse operates relay P1 at the sending station, which in turn releases relay P2, which operates relay P3. Relay P3 opens the circuit from the brush ring of the selector and completes the circuit to the rotary magnet which causes the selector to advance one step. On this position, if the telephone key is operated, a bell will momentarily ring and a guard lamp is lit. The selector in position 1 operates the relay ON via ON contacts and also removes the earth from relay S2.

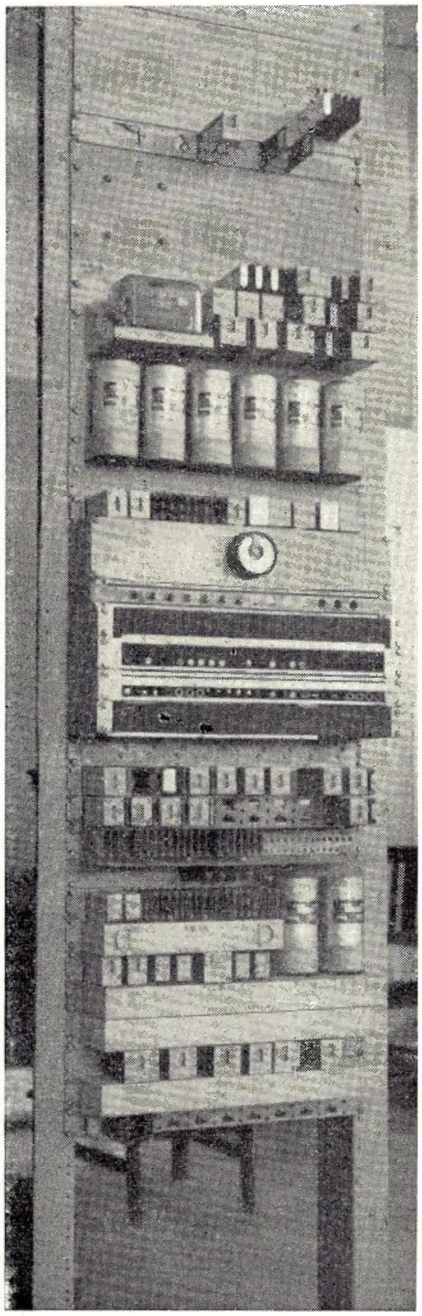


Fig. 2.—Alarm trunk circuit equipment—sending station.

Relay ON maintains a closed circuit for the rotary magnet of the selector when relay S2 is released. Relay ON also removes the earth on the telephone call bell.

At the receiving station the interrupter now releases and restores earth to the alarm trunk circuit. Relay P1 releases which operates relay P2 and in turn releases relay P3 and operates relay L. This relay L only operates if there is a ground on contact one of the selector, which is actually the AT lead AT1, the earth being obtained from the individual alarm circuit through the 1000 ohm winding on relay A1. Relay L re-operates relay S2, which causes the lamp to be lit at the main or parent station. If there is no ground on lead AT1, relays A1 and L will not operate. No alarm condition is indicated and the selector proceeds to its next position. When relay A1 does operate from the alarm condition ground through its primary winding of 1000 ohms, it locks up on its 2500 ohm secondary winding under the control of the relay RST. The operation of relay A1 opens the operating circuit for relay S1, which now releases unless there is another alarm ground on another AT lead. Relay L releases the relay P3 and steps the selector around.

The interrupter continues for 10 pulses and causes the alarm circuit to function as above. When contact No. 10 is reached relay RL operates through its 1000 ohm winding. This relay transfers the operating lead via a P3 contact from the operating winding of the selector to the release winding. The relay RL is held operated through its own contact and the ON relay contact. The 11th pulse from the receiving station interrupter causes the operation of relay P1, releasing relay P2, which in turn operates relay P3. Relay P3 connects ground to the release magnet of the selector, which homes and P3 relay also holds relay RL operated through its 2500 ohm secondary winding. When relay P3 releases, relay RL is also released as relay ON has removed the earth on the primary winding of the RL relay. The receiving station selector also restores on the 11th pulse and ceases to operate. Should under any circumstance the selector stick off normal and not return to its home position, the ground through the off normal contact operates the Adlake relay T1. After 2 or 3 minutes, T1 operates relay RST, which removes the ground from the rotary magnet and connects ground to the release magnet, causing the selector to restore. Relay RST also releases any alarm relays A1 . . . A10, which may be locked up. The homing of the selector causes the release of T1 and ON, which release relay RST.

If an additional alarm is registered during the transmission of an alarm condition, and it is too late to be recorded by the selector, that is, if the selector has already passed over the contact on which the new alarm ground is placed, the whole equipment will repeat its operation and this time include the new alarm.

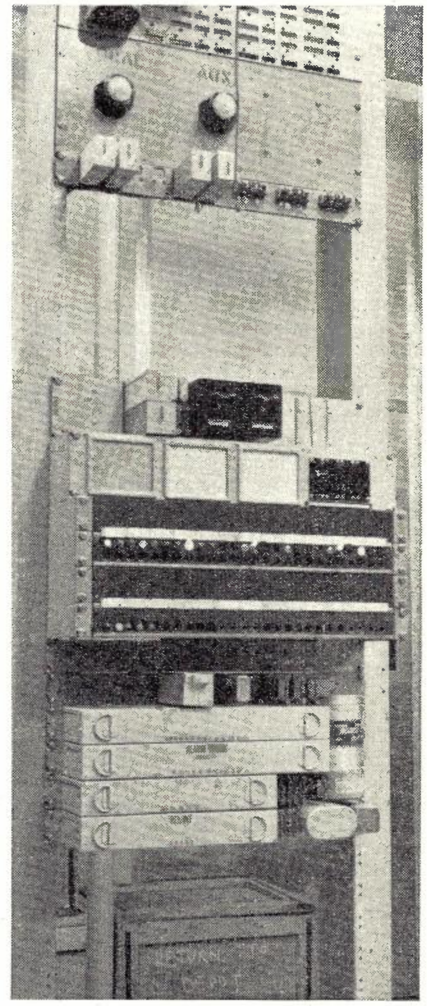


Fig. 1.—Alarm trunk circuit equipment—receiving station.

Receiving Station (Fig. 4): The connection of a ground to the alarm trunk circuit at the sending station causes the release of relay L1 at the receiving station, which provides a relief circuit for relay L2. Relay L2 releases after approximately 25 seconds and operates relay T3 which supplies ground to the relays S2 and ALM to cause them to operate. Relay ALM locks up through its own contacts and via the RLS key. Relay ALM also lights the ALM lamp and operates the station alarm. Both the ALM lamp and station audible alarm may be switched off by operating the release key. Relay ST applies earth to the release magnet of the receiving station selector should it be locked up and also feeds earth to the relay INT. Relay INT locks up by its own contact and starts the operation of the interrupter unit. The operation of relay ST also releases relays R1, RL and R2 if they are locked up. Relay INT also removes the earth from the battery side of relay R1 thus allowing it to operate at a later stage.

At this stage, it would be of interest to examine the operation to the interrupter circuit at the receiving station. The circuit of the unit is shown in Fig. 4 and its operation is as follows:—The INT relay provides a ground to the interrupter start lead ST which operates relay A. Relay A removes the delaying effect from relay B which operates and does likewise to relay C. Relay C causes relay D to operate to the earth on the ST lead. C puts a short across relay A which releases and restores the shunt to relay B which also releases. Relay B causes the release of relay C which previously, on operation put a short across relay E. As relay D has now operated and the short on relay E is removed when relay C releases, relay E will now operate. This relay provides an earth on the INT lead to operate relay P2 and also shorts relay D, which releases and releases relay E. The whole sequence then repeats itself with a speed of interruption of approximately 20 per minute.

Referring again to the general receiving circuit in Fig. 4, the interrupter supplies earth to operate P2 relay at 20 cycles per minute as long as the start lead is held to ground. Relay P2 operates relay RE which connects 130V positive battery to the alarm trunk circuit. This battery causes the sending station selector to operate. Relay RE also operates relay L1 which in turn operates relay L2 and releases relay ST. Relay P2 applies ground to the rotary magnet of the selector which advances one step. P2 also removes the earth from the selector brush ring and this prevents relay RL from operating when the selector reaches the 10th bank contact. At this stage, the interrupter takes the ground off the lead INT and relays. P2 and RE release. Relay P2 opens the circuit to the selector rotary magnet, and operates the ST relay. Relay RE restores earth to the alarm trunk circuit.

When the selector operated to the first bank contact, the off-normal contacts operated the relay TR. This relay transfers the earth from relay ST to the brush ring of the selector. Relay TR also opens the operating circuit for relay ALM and also operates relay DC via its primary winding of 1,100 ohms. Relay DC operates relay DA which prepares the earth lead for the operation to the alarm relays A1 . . . A10.

Now if an alarm condition is being transmitted from the sending station and is being registered on the first contact of the selector, relay L1 at the receiving station will release and in turn release relay L2. The falling out of relay L2 allows ground to be connected to the bank contact No. 1 of the selector at the receiving station which operates relay A1 and locks to earth via contacts RK. Relay A1 operates the alarm lamp No. 1 and the lamp ALM. The interrupter will continue to operate and will repeat the above sequence of operation for the 10 selector bank contacts.

On reaching position 10, relay RL operates and when relay P2 releases, relay RL holds to ground through the contacts of relay ST. Relay RL prepares a changeover of the earth from the rotary magnet of the selector to the release magnet and also prepares a circuit for relay R1 so that the 11th operation of relay P2 will cause the operation of relay R1.

The 11th interrupter pulse operates relays P2 and RE as earlier and completes the circuit for the release winding of the selector which in turn restores to its home position. The sending station selector also restores to home. On the 11th interrupter pulse, an earth was fed by relay P2 to operate relay R1 which prepares a circuit to allow the operation of relay R2 when relay P2 releases. Relay P2 removes the earth from relays INT, TR and RL which release. Relay INT opens the ST lead and stops the interrupter from operating and also short circuits relays R1 and R2 which release.

Alarm Recheck: If there is some doubt as to the correctness of the alarm indication, a recheck procedure can be used which will release the alarm trunk circuit and restore the equipment to normal. If the alarm circuit was correct in indicating an alarm condition, the alarm will still be in evidence at the receiving station and the alarm trunk circuit will repeat its sequence of operation.

The recheck operation consists of operating a recheck key at the receiving station for a period of 5 seconds or longer. This operation causes operations RK and RE to operate. Relay RK restores the receiving station selector if operated, releases relays A1 . . . A10 if operated and extinguishes operating lamps A1 . . A10. Relay RE supplies battery to the alarm trunk circuit at the receiving station, which operates relay P1 at the sending station. Relay P1 operates relay T2 at the sending station, which in turn operates relay R2 and relay RST. Relay RST releases all relays A1 . A10 should they be locked up. Relay R2 is a long period release, long enough to remain operated until relay P1 releases to re-operate relay P2, release relay P2 and release relay P3. Relays R2 and RST release and any alarm conditions still registering on the A1 . . . . . A10 relays again start up the sequence of operation.

Additional Functions

Several additional functions are provided by this alarm trunk circuit, which are of great importance to an auxiliary station. The functions available are:

(i) Under the control of the parent or receiving station starting up the prime mover at the auxiliary station, the prime mover usually being a petrol engine;

(ii) Dis-connection of the alarm trunk circuit from the line so that line tests can be carried out without interference from the alarm trunk circuit equipment, or battery supply or earth; and

(iii) Release of a locked-up relay control circuit of a pilot channel.

These operations are made possible by a series of short and long direct current pulses, which operate a special selector at the auxiliary station. The pulses are transmitted by a spring-operated telegraph selector key equipped with a governor. One selector key is provided for each operation required and is equipped with cams so that the pulses are automatically regulated and transmitted. The keys are designated: Engine Start, Line Test and Pilot Release, respectively, in accordance with the tests enumerated above. The operation of this facility is as follows, having reference to Figs. 3 and 4:—

The main switching key at the parent station, Fig. 4, is operated from NORMAL to AUX. STN. and the appropriate telegraph key operated. The telegraph key causes the operation of the A relay, which in turn operates the B relay. Relay B holds operated the RE relay, which will hold the L relay operated and will prevent the alarm trunk circuit from operating. Relay B also holds operated the DB relay.

The alarm trunk circuit applies 130V positive battery and earth from the parent station alternatively to the cailho circuit which operates and releases relay P1 at the auxiliary station, Fig. 3. Relay P1 operates relay SA which controls the operation of the special selector SEL as follows: Relay SA supplies earth to relays SB and SC and relay SB operates. Relay SC at this stage cannot operate because of a short circuit across its winding through its own contact. Relay SB locks up and also steps the special selector to its first position through the charging effect of the condenser in series with the driving magnet. When relay P1 releases, relay SA releases and removes the short from relay SC which then operates. Relay SB releases when relay SA re-operates on the next pulse and for each operation of relay SA, the special selector is stepped around one step. Thus the selector will finally settle on a particular bank contact under the control of the appropriate selector key at the parent office.

The code of the keys is as follows:

Line Test—13 short and 1 long pulse, all operating within approximately 10 seconds.

Pilot Release—17 short and 1 long pulse.

Engine Start—19 short and 1 long pulse.

The detailed operation of each is as follows:

Line Test: The second contact of the special selector is reached under the control of the line test key after 13 short pulses are received. The selector remains on this position for sufficient time to allow the operation of relay SF, which is slow to operate, thus preventing its operation when the selector drives over contact 2 to a further position. Relay SF operates relay SG which locks on its own contact operating relay SJ and opening the circuit to relays SH and S2, preventing their later operation.

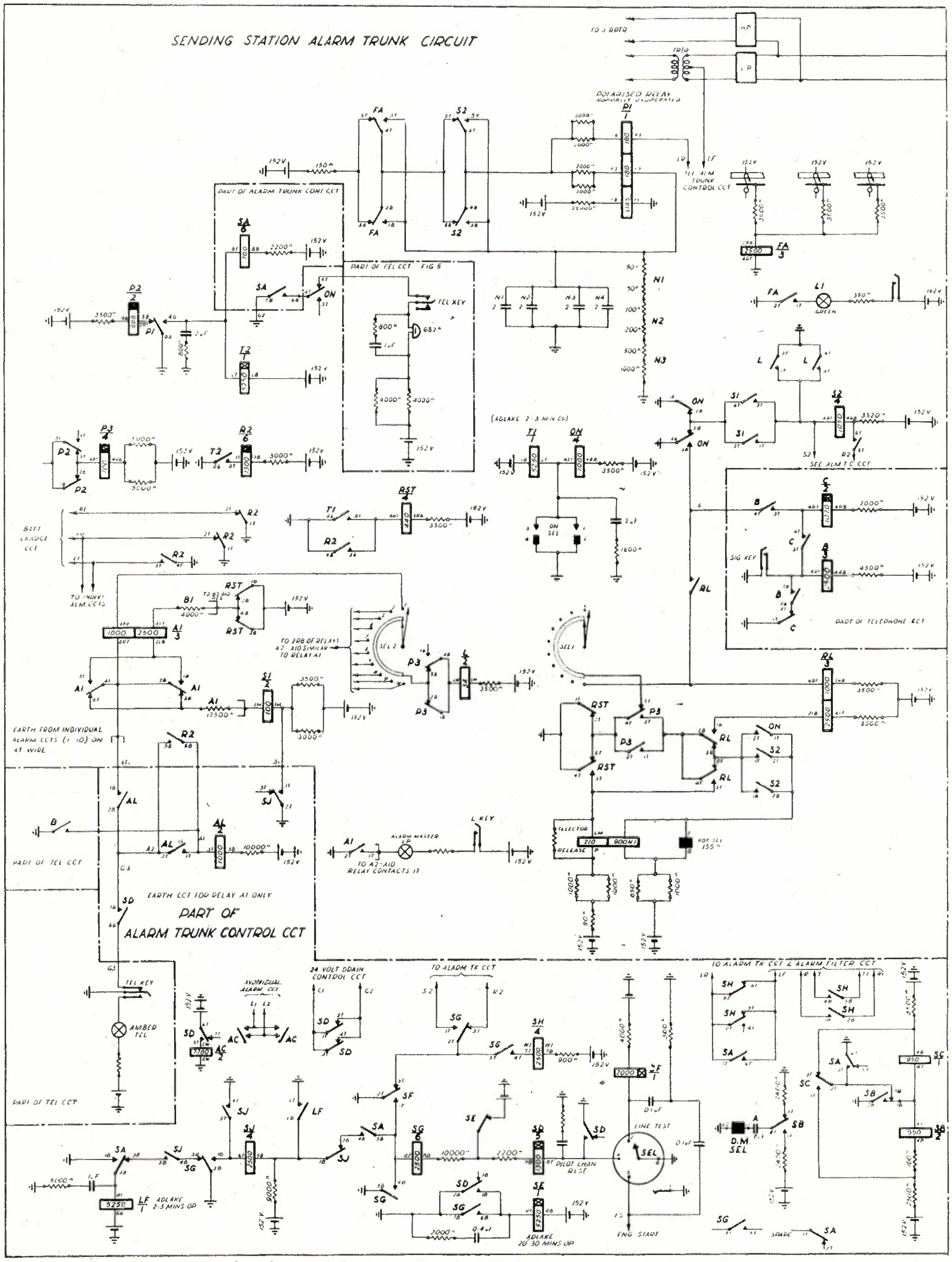


Fig. 3.—12-channel Type J2 alarm trunk and control equipment—sending station.

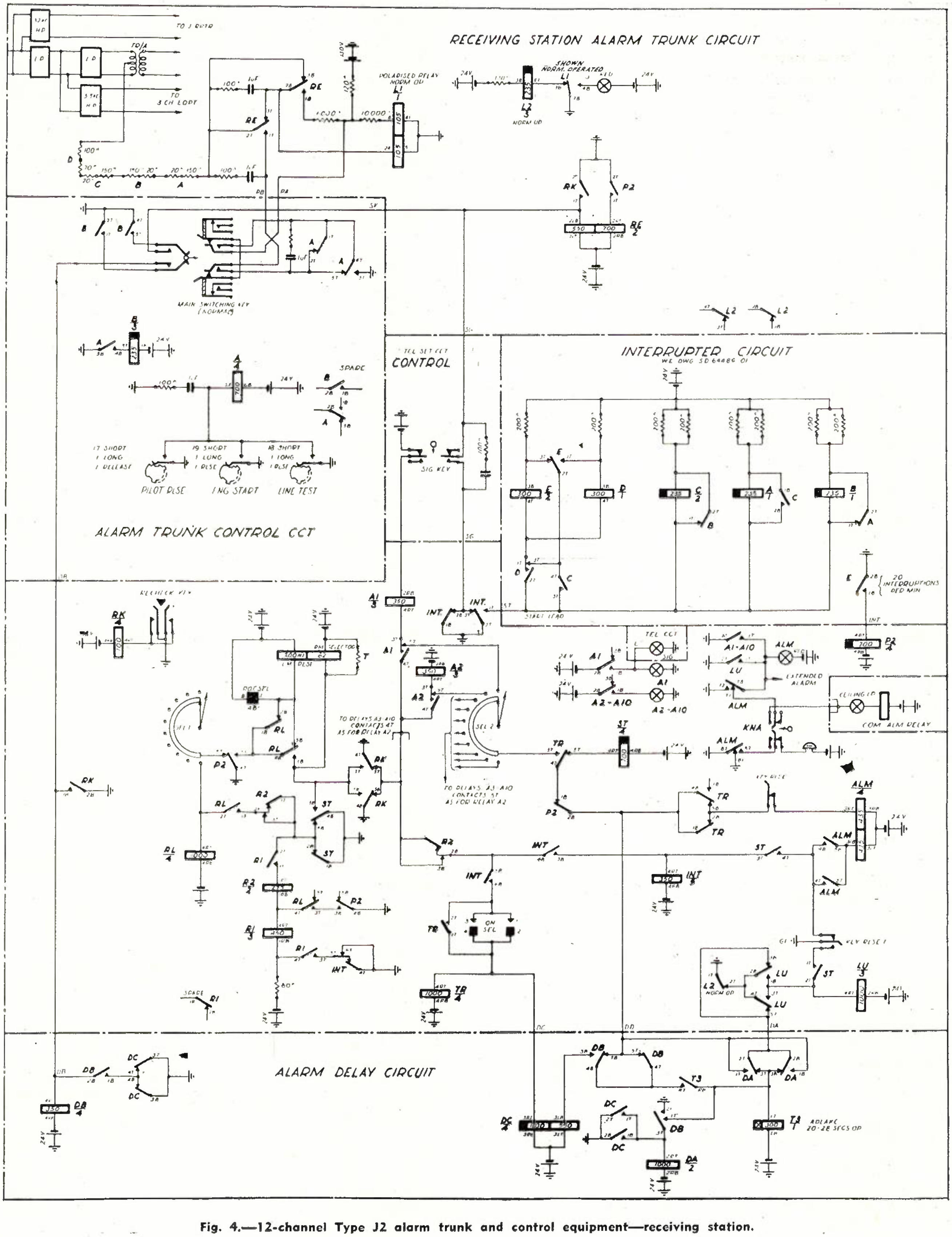


Fig. 4.—12-channel Type J2 alarm trunk and control equipment—receiving station.

When the release pulse has been received, the selector releases and the code wheel returns to normal. This permits the relay SF to release and relays SH and S2 to operate.

If use is made of an alarm filter to transmit the alarm conditions, the alarm filter being actually a composite set, this line test facility causes the series condensers in the alarm filter to be shorted out and the drainage resistances to be open circuited so that line tests can be carried cut on the trunk circuit. This condition remains under the control of relay SE which has a delay time of between 20 and 30 minutes. After this delay period the circuit is restored to its original normal condition. Under the method of operation in Western Australia, however, the alarm filters are not used and the relay SH opens the circuit of the derived cailho and thus frees the trunk circuit for test purposes.

Pilot Release: For the pilot release facility, the selector is stepped to position No. 4 and causes the operation of relay SD which locks to ground. Relay SD operates relay AC, which short circuits the leads L1 and L2 and releases the locked up pilot control condition. Relay SD opens the leads C1 and C2 which stops the operation of the battery drain control circuit. Relay SD also operates relay AL via the telephone key and relay AL starts up the alarm trunk circuit. The recheck key at the parent station should now be operated which will cause the telephone call lamp to glow, giving indication that the relay SD has operated. When the long pulse is received at the auxiliary station, the selector restored to normal. The pilot release feature is held for approximately 20 to 30 minutes through the operation of relay SE via contacts of relay SD.

Engine Start: After 19 pulses of the relay SA under the control of the telegraph key at the parent station, the special selector will rest on contact No. 5. This applies an earth to the lead ES (Engine Start) operating a relay and starting up the petrol engine prime mover (1). When the engine fires, the engine start alarm will be extended back to the parent office. If, however, the motor does not fire, an engine fail condition will be transmitted after approximately 30 seconds and the defective motor locked out of operation.

Alarm Trunk Circuit Opened or Short Circuited: The failure of the auxiliary station battery sent to the alarm trunk circuit, or the opening or shorting of the alarm trunk circuit will cause relay L1 at the receiving office to release and in turn release relay L2. Relay L2 in the released condition operates relays ST and ALM. The latter relay lights up the lamp ALM and operates the station audible alarm. A release key RLS cuts off the station audible alarm and releases the ALM relay. This key also, if the relay ST is operated, operates the relay LU. When relay ST operated, the interrupter was started and relay TR was operated. This relay releases relay ST which prevents the locking up of relay LU until relay ST operates a second time, that is, when relay TR releases, always provided, of course, that the RLS key is maintained operated over this time.

References:

(1) Type J2 Auxiliary Carrier Repeater Station with 420B Power Plant, W. D. McKenzie; Telecommunication Journal of Australia, Vol. 9, No. 1, Page 8.

(2) Western Electric Circuit Description CD64642-01, Issue 17D, Alarm Trunk Circuit.

(3) Western Electric Circuit Description CD55055-01, Issue 8B, Alarm Trunk Control Circuit.

TRANSMISSION MEASUREMENTS ON LARGE CABLES

L. J. CHAPMAN

Introduction

In Adelaide recently, it was necessary to carry out transmission measurements on many existing junction cables, more particularly the older cables, as these formed the city's initial network, and from time to time had been extended to keep pace with developmental requirements. Consequently, these cables contained lengths differing in type and conductor weight. Moreover, much of the jointing had been carried out when cable jointing was not the precise practice we know today. The more important measurements required were insertion loss and near end crosstalk. It was found that a team of three men, using conventional testing equipment, that is oscillator, crosstalk test set and detector, were able to measure approximately 1,000 crosstalk combinations per day.

A 600 pair cable has approximately 180,000 crosstalk combinations, and even when limiting the combinations measured to those within quad and to adjacent quads, the use of conventional equipment would be prohibitive from the viewpoint of cost. To make the task economically possible, test equipment was developed which enables the following measurements to be carried out by two men:—

(a) Insulation resistance measurements between pairs or between wires and earth at the rate of 1800 pairs per hour.
(b) Insertion loss measurements at 600 pairs per hour.
(c) Near or far-end crosstalk measurements at 15,000 combinations per day.

Description of Equipment

The equipment embodies the following features:—

(a) Provides easy connection between the cable to be tested and test equipment.
(b) Mechanically selects cable pairs to be tested.
(c) Enables crosstalk measurements to be made on working pairs.
(d) Discriminates between crosstalk and signal on working cables.
(e) "Camps" on pairs at predetermined value of crosstalk.
(f) Directly reads crosstalk values with minimum manual manipulation.
(g) Avoids measurement of reverse order of crosstalk.
(h) Enables the measured signal to be identified.

The power supply is from A.C. mains and the 48 volt exchange battery. The equipment is mounted on a rack 20¼ inches wide by 4 feet high, fitted with castors for portability. The complete unit, weighing approximately 110 lbs., can be comfortably handled by two men. The test leads are plug ended and are connected to the equipment as required. With the use of this equipment a 600 pair cable can be tested for insulation resistance, insertion loss and near end crosstalk for approximately £70, which is a small percentage of the capital cost of such a cable. Figs. 1 and 2 show the equipment in use.

Cable Connecting Equipment

The cable fuse mounting strip of the M.D.F. was selected as the most convenient point at which to gain access to the cable pairs. An adapter was designed with blade type contacts which slide between the inner spring and the moulded insulating strip of the fuse mounting. The adapter is constructed as a 5 pair unit and provides anchoring for the 5 pair plastic covered test cable used between the M.D.F. and test equipment, and, being a snug fit, will support the weight of the test cable. The 5 pair unit caters for 20 or 25 pair fuse mountings. The test cables are 12 feet in length and fitted with a 5 pair Painton plug on the test equipment end,

Sending Equipment (Fig. 3): An oscillator built on a 3 inch panel provides variable output at 800 and 1600 c/s, for crosstalk and insertion loss measurements respectively, the required frequency being selected by a double pole double throw toggle switch. Included in the sending circuit is a 600 ohm sending bridge and output meter calibrated in db, as well as an 80 db pad, wired via a changeover switch, for calibrating the detector amplifier.

Measuring Circuit

This contains a highly selective detector amplifier tuned to 800 c/s, see Fig. 3, with sufficient gain to measure crosstalk of the order of 90 db. The selectivity is approximately 17 db per 50 c/s on each side of the tuned frequency. A 5 inch, 0-1 mA meter, calibrated in steps of 1 db (scale −10 to +3 db), is connected in series with a 209 FA relay between the plate and cathode of the output tube (6B8G).

The detector amplifier input potentiometer is graduated in steps of 10 db, from 0 to 80 db, and this control setting, in conjunction with the meter calibration, allows direct reading of crosstalk values. The 209 FA relay has been included in the meter circuit to provide discrimination between signal and crosstalk on a working cable pair.

The contacts of the 209 FA relay, which is biassed to operate on the zero graduation on the meter, close the circuit to the B relay, which has an opering lag of 800 ms. A zero meter reading, persisting for 800 ms. will therefore operate relay B, which causes the test equipment to camp on the pair under test. A tap is taken from the cathode of the first stage of the detector amplifier to operate a monitoring amplifier, which enables the operator to identify readily the signal being measured.

The input to the detector amplifier is high impedance and via blocking condensers. An ohmmeter is included to facilitate test for continuity and identification on the pair under test, also the measuring circuit lead is brought out to external terminals (Ext. Term.). The connection of the measuring circuit to detector amplifier, ohmmeter, or external terminals is controlled by key K.2.

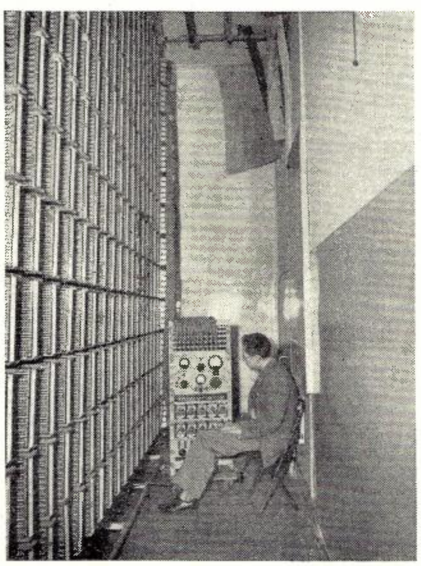


Fig. 1.—Cable test equipment connected to M.D.F.

Uniselector Equipment

Eleven uniselectors are used for the mechanical selection of cable pairs and the equipment developed has a maximum capacity of 600 pairs. Uniselectors 1 to 9 are 25 point, 8 bank switches, and 10 and 11 are 25 point 3 bank switches. Uniselectors 1, 10 and 11 are control switches and 2 to 9 are used for pair selection.

Uniselector 1. Wipers 1 and 2 are wired to the measuring circuit. The contacts of bank 1 and 2 are wired to wipers 2-4, 1-3, 6-8, of uniselectors 2 to 9 in that order. Contact 25 is not connected. Wiper 3 provides the stepping circuit for uniselectors 2 to 9 (Fig. 5 shows details of bank wiring). Wiper 4 provides a re-search feature. Wiper 8 provides the stepping circuit for uniselectors 2 to 9. Wiper 5 operates line group lamps to indicate on which group of 25 lines the search is being made. Wiper 7 provides a homing circuit for switches 2 to 9 when uniselector 1 wipers have stepped to the succeeding switch. Wiper 6 determines the repositioning of uniselector 1 during cross talk tests to avoid (within limits) measurement of reverse combinations, and this function is achieved in conjunction with uniselectors 10, 11 and switch SW2.

Uniselectors 2 to 9: These select the cable pair for test. 75 outlets from each of these 8 switches terminate on Pointon 5 pair sockets, mounted at the top of the test equipment rack. Of the two remaining banks, No. 7 completes the stepping circuit of uniselector 1, and No. 5 provides a homing circuit via its own drive magnet.

Uniselectors 10 and 11: These switches determine the repositioning of uniselector 1 to avoid crosstalk measurements in the reverse order to the original measurements.

Power Supply: The detector amplifier, monitoring amplifier and oscillator are mains operated. Uniselectors, lamps, relays, etc., operate from the 48 volt exchange battery.

Test Cable Connection: The test cables are connected between the cable fuse mounting strips and the test equipment rack. To preserve a neat appearance the test cables should be bound together at alternate fuse mounting strips along the length of the M.D.F. vertical.

Cable Pair Selection: This is in numerical order and is automatic. The starting point is determined by the setting of uniselector 11. The selecting switches step at 34 steps per minute, thus leaving the measuring equipment across the pair under test for 1.75 seconds, which is adequate for cross talk measurements. The setting of switch SW1, a 25 point potentiometer type, controls the point at which the stepping ceases. At this point the equipment is automatically reset to the position marked by wipers 3, uniselector 11.

Circuit Operation

Assuming a search is to be made over the maximum number of pairs, that is 600, and referring to Fig. 3, switch 1 is set to "600 PR". Uniselectors 10 and 11 are set to No. 1 contact. K1 is set to the locking position. Uniselector 1 will now drive to its No. 1 contact from battery, DM1, C.21-22, to

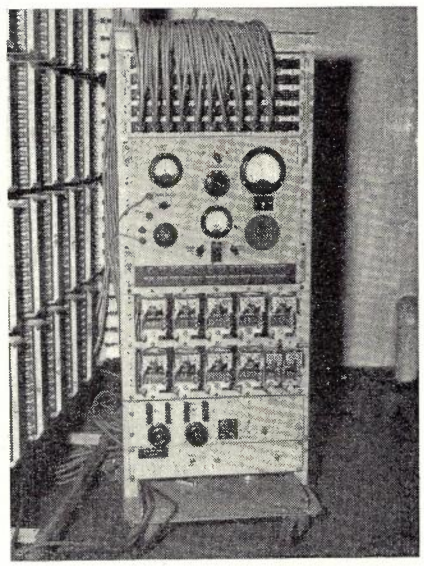


Fig. 2.—Face view of the equipment.

ground, where its DM circuit is broken at C.21-22, by operation of C relay via battery, wiper 6 contact 1 uniselector 1, wiper 3 contact 1 uniselector 11, to ground. C locks via C.3-4, D.21-22 to battery. C.1-2 completes the circuit of A.

Pulsing Circuit

"A" operates and breaks its own circuit at A.3-4, but has a release lag of 1.75 seconds after which it releases and again completes its own circuit through A.3-4, forming a self-pulsing circuit. Uniselector US2 now steps under the control of A.1-2 and camps on each contact for the duration of the release lag of A relay.

The measuring circuit wipers, 1-2 of US1, are thus placed across contacts 1-25, bank 2-4 of US2 in turn. On the release of A, after the 25th step of US2, US1 steps to contact 2, from battery, DM1, K1, A.23-24, wiper 8, contact 1 US1, wiper 7 US2, to ground on the 25th contact. The measuring circuit wipers, 1-2 of US1, are thus connected to wipers 1-3 of US2, (pairs 26-50). US2 again steps under the control of A.1-2 and on the 25th step of US2, US1 is stepped to contact 3, switching the measuring circuit to wipers 6-8 US2, (pairs 51-75).

At the end of the third search by US2, US1 steps to contact 4, wipers 2-4 of US3 (pairs 76-100). Since three drives only were made, US2 is resting on contact 26, therefore it is necessary to return US2 to its No. 1 contact in readiness for any later search. The homing circuit is battery DM2, wiper 5 US2, wiper 7 contact 4 US1, to earth. See Fig. 5 for bank wiring.

Re-search Feature.

The testing wipers can be returned to retest any pair in the group by operating K.1 to its non-locking side. This closes the driving magnet circuit of the switch in use. When the wipers are approximately positioned, K1 is reset to its locking side and the switch steps normally to the required pair. The setting of US1 is not altered as the drive circuit is broken at K1, 5-6.

Line Group Lamps.

A lamp is fitted and designated for each 25 lines, that is 1 lamp per bank of lines, connected to US, 2 to 9. The lamp designations are:—

1-25; 26-50; ————————— 576-600

The lamp therefore indicates the group in which the search is proceeding, and the drum designation indicates the pair in the group.

Resetting of Uniselector 1.

When the 600th pair is tested, US1 steps to its 25th contact via the circuit from the 25th contact bank 7 US9. Relay D operates from battery, wiper 6 contact 25 US1, SW1 (25th contact), K1. 7-8 to ground. D.21-22 opens the circuit of C. C has sufficient release lag to enable US9 to home drive via its wiper 5, 25th contact, bank 7 US1.

On release of C, US1 drives via C.21-22. When US1 steps off 25th contact, D releases, and when US1 reaches contact 1, C reoperates from battery wiper 6 contact 1 US1, wiper 3 contact 1 US11, to ground. US1 drive is cut at C.21-22.

Non-Measurement of Reverse Combinations.

The functions of US10-11 are utilised to avoid measurement of reverse order cross talk. On the release of D, as described, D.1-2 steps US10 to contact 2. After 25 searches, that is after the first 25 pairs have been used as disturbing circuits, US11 steps to contact 2. In the subsequent automatic re-setting of US1 the C relay cuts the drive of US1 when its wipers reach contact 2.

When the final combination is measured, that is pair 599 disturbing pair 600, US1 steps off contact 24, with US11 positioned on contact 24. D operates and steps US10 to contact 25. DM11 operates from battery, DM11 to ground at the 25th contact of bank 1 US10. US11 steps to the 25th contact and self drives to contact 1 from earth at its own 25th contact.

The circuit of C is broken by the operation of D and US9 homed during the release period of C. US1 is stepped to contact 1 via C.21-22. C is reoperated via contact 1 US11, to wiper 6 US1 and cuts the drive of US1. All switches are now standing on their No. 1 contacts.

Operation of Equipment

Near End Crosstalk.

The disturbing frequency is applied to the disturbing pair via a one pair lead from the "disturbing pair" terminals on the test equipment. The MDF end of the lead is fitted with blade type contacts, insulated on the inner surface, which slide between the inner spring and the adapter contact on the cable fuse mounting. The disturbing pair is selected manually.

In voice frequency circuits the effects of near end cross talk are more serious than those of far end cross talk because of its higher level, and the absence of blocking equipment. In measurement it allows all testing equipment to be located at the one terminal and the progress of measurement is controlled by one person. The Technicians' Assistant at the distant end does the necessary terminating of pairs, etc., under direction from the testing end.

The use of loud speaking telephones for communication between terminals has increased the efficiency in testing by allowing freedom of movement. The practice adopted has been to terminate 80 cable pairs, using the 5 pair MDF adapters with 1/4 watt, 600 ohm resistors wired across their terminals. When 5 pairs have been used as disturbing pairs, the terminations are moved forward, so that there will always be at least 75 terminated pairs beyond the disturbing pair. This ensures termination of all pairs in the first 5 layers, and at least all pairs in any subsequent layer of a 600 pair cable. 800 c/s is used as the disturbing frequency. 60 db has been taken as the worst permissible value of near end cross talk in junction cables.

Calibration of Detector Amplifier.

Throw SW2 to "Cal," adjust 800 c/s output of the oscillator to zero on the oscillator output meter, and adjust the gain of the detector amplifier to zero with the input control on 80 db. Restore SW2 and connect the disturbing pair.

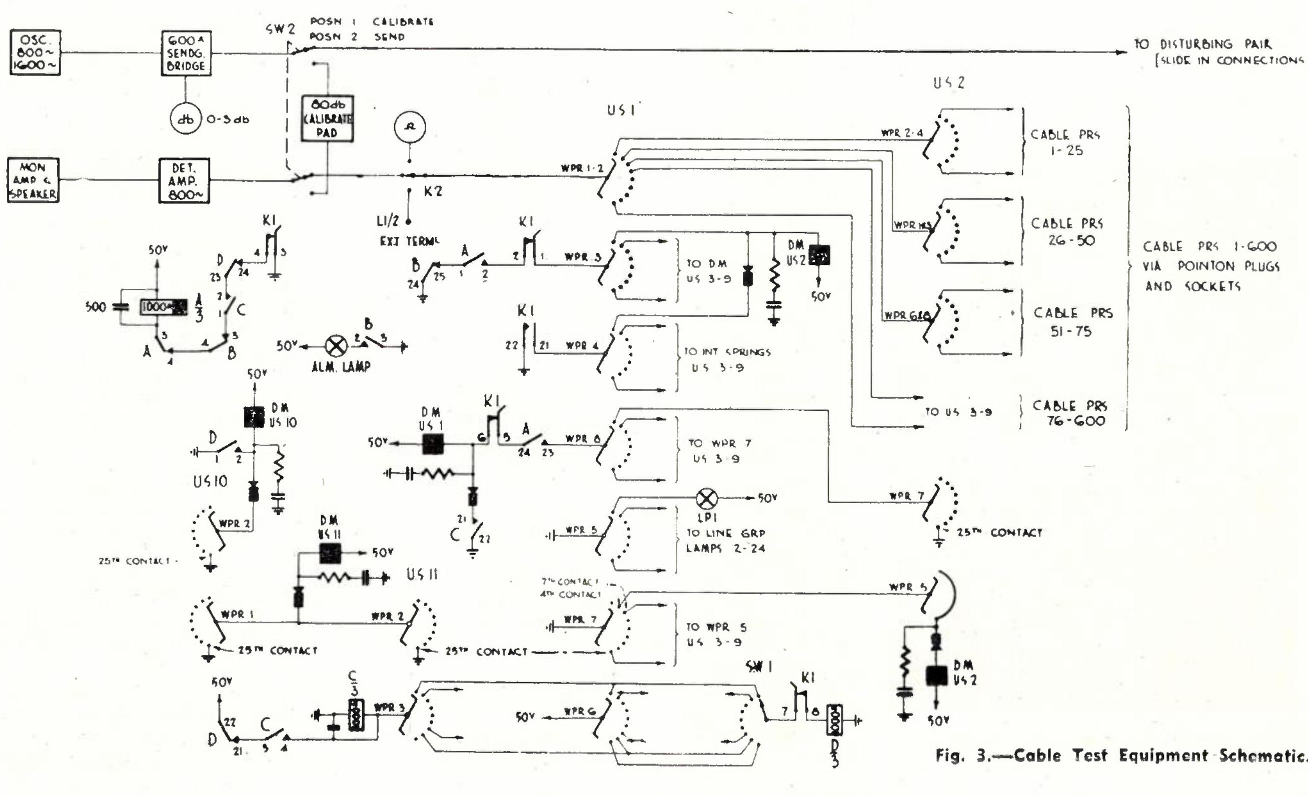


Fig. 3.—Cable Test Equipment Schematic.

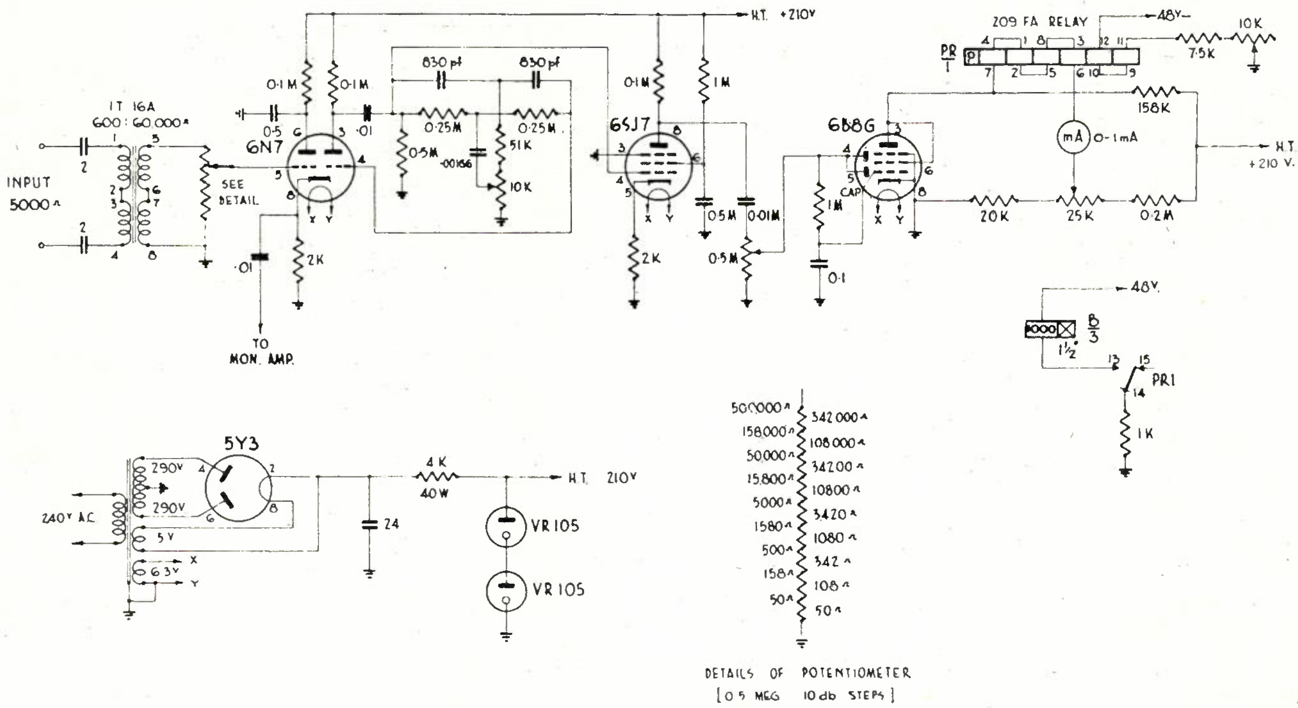


Fig. 4.—Tuned Detector-Amplifier Schematic.

With the operation of K1, stepping proceeds as described previously.

Measurements of Near End Crosstalk on Working Pairs.

It will be seen from Fig. 5 that in a working cable, the disturbed pair is terminated only by the exchange equipment, with which the test equipment is in parallel at the measuring end. This shunting effect is negligible, however, because of the high impedance input of the measuring equipment, and the condenser input obviates interference to the DC element of the junction circuit.

Only the disturbing pair is removed from service and terminated. These are taken in groups of five which allows efficient operation of the test equipment without unduly restricting junction availability. Crosstalk in the disturbed pairs is measured in their working condition, those pairs which show crosstalk outside the predetermined limit are removed from service. The removal of the fuses will prove the crosstalk in the cable or the exchange equipment wiring, and if in the cable, the pair is tested under terminated conditions.

Discrimination Circuit.

When crosstalk worse than the predetermined value (this value is selected by the setting of the detector amplifier input potentiometer), is encountered, the uniselector stepping circuit is stopped by the operation of relay B after 800 milliseconds, and the combination is recorded. The 800 c/s component of speech is seldom of sufficient duration to operate the B relay circuit, and therefore speech is discriminated against. The B relay will restore when the holding signal drops 4 db below the zero calibration on the detector amplifier meter.

Signal Identification.

The monitoring amplifier (AWA 4 watt) allows measured signals to be readily identified as it is connected before the tuned section of the detector amplifier. When making crosstalk measurements on a new cable of more than 200 pairs, except for periodic check runs, it is unnecessary to test pairs more than four beyond the distributing pair, because of the improbability of contacts under present jointing conditions.

Insulation Resistance, Identification and Continuity Measurements.

By utilising the automatic selection of cable pairs in conjunction with a motor driven megger connected to the Ext. Terml, wire to wire and pair to earth measurements of a cable can be carried out very rapidly. Contacts within pairs will show up on wire to wire tests, and contacts other than within pair will have been detected in crosstalk measurements. Similarly, identification and continuity tests are provided by connecting an ohmmeter in the measuring circuit.

Insertion Loss.

This is measured on a "looped pair" basis, by connecting the "disturbing pair" lead to the first pair to be tested. The 1600 c/s output is then adjusted on the sending bridge. A battery operated transmission measuring set is connected to Ext. Terml. At the distant end pair 1 is connected to pair 2 by a cord fitted at each end with blade type contacts. Pair 1 is retained in the sending circuit, the pairs being progressively looped to this at the distant end as each is selected (K1 controlled) and the reading recorded at the measuring end.

Conclusion

The use of the equipment can be extended to test cables of more than 600 pairs by carrying out the tests on groups of 600 pairs. This equipment was designed for a specific work and met all intended requirements, enabling a considerable reduction in measurement costs. The scope of the equipment could be extended to include the rapid check of frequency response on loaded or unloaded cable pairs by replacing the two frequency oscillator and transmission measuring set with an automatic frequency response tracer suitable for operation between 100 and 3000 c/s.

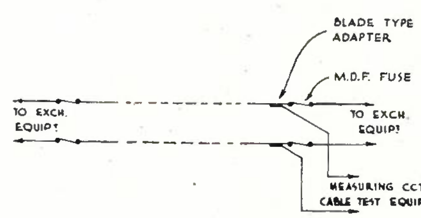


Fig. 5(b).—Method of attaching testing apparatus to cable pairs.

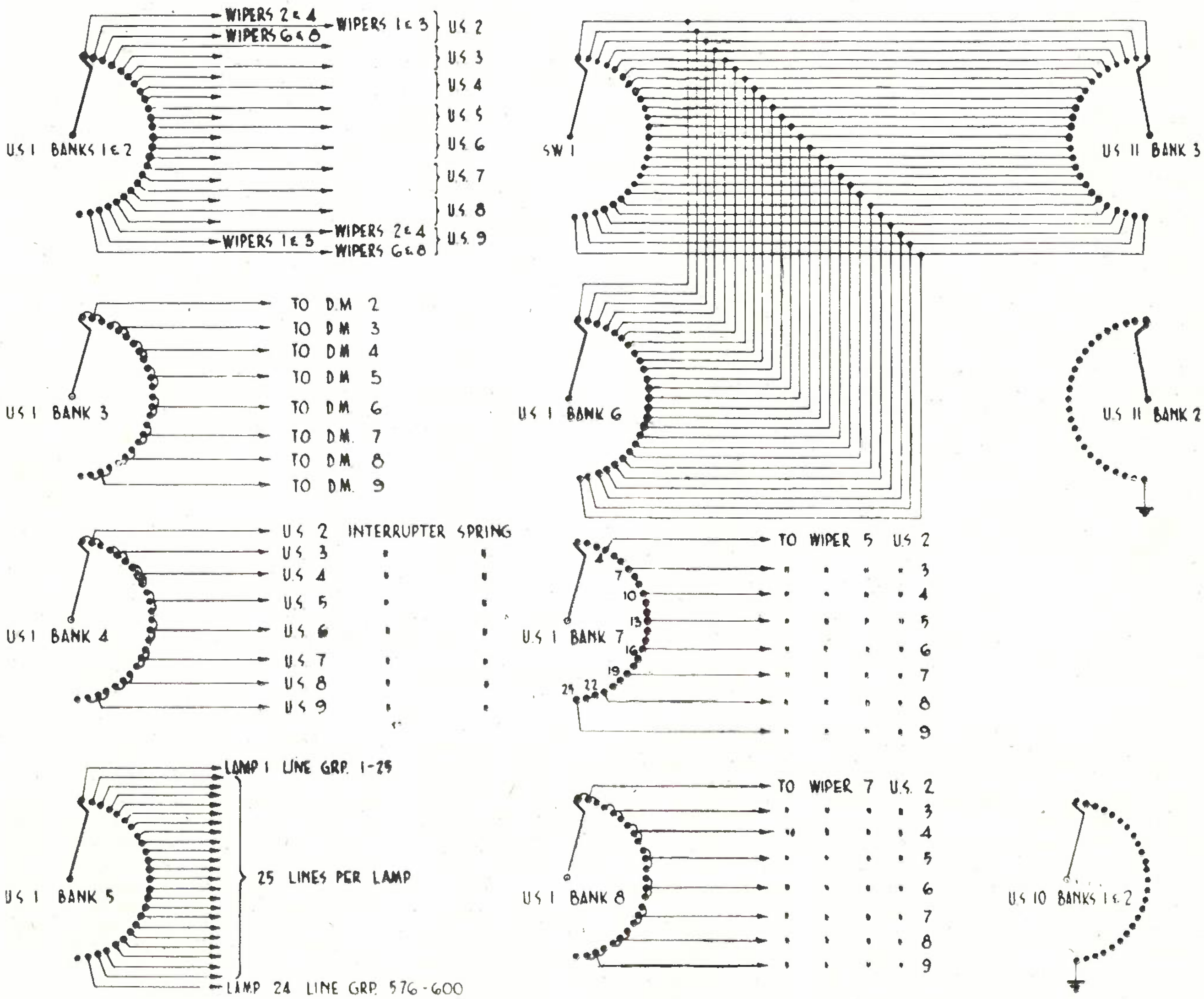


Fig. 5(a).—Cable test equipment connections to switches and uniselectors.

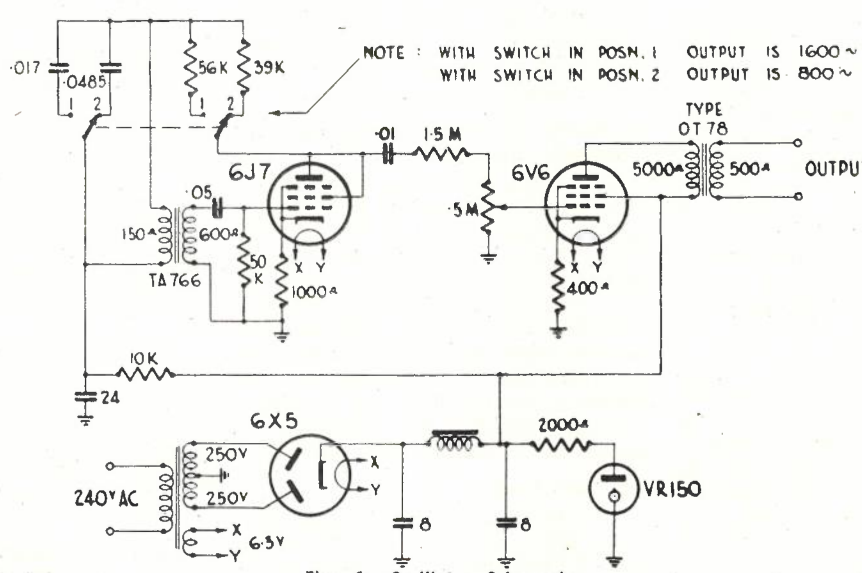


Fig. 6.—Oscillator Schematic.

AUTOMATIC MULTI-FEE METERING IN THE AUSTRALIAN TELEPHONE SYSTEM

E. G. WORMALD

Summary

Preliminary steps are being taken towards the introduction of facilities to allow some Australian telephone subscribers to dial short-distance trunk calls which may then be completed without manual operator assistance or intervention. Charging is to be effected by repeated periodical operation of the subscriber's meter, at present used only to count local calls. Considerable economies and speedier service are expected to follow this use of subscriber-controlled automatic equipment, instead of manual operators, to carry out switching and charging functions.

The paper outlines factors considered in selecting the recommended system and in preparing an equipment design to provide the required facilities.

Introduction

At present Australian telephone subscribers connected to automatic exchanges are allowed to complete automatically only local calls. (With minor exceptions, these are calls originating and terminating in exchanges not more than five miles apart, or both included in a statutory unit fee area, of either 10 or 15 miles radius from the G.P.O. in most capital cities or Newcastle. The cost of a local call is either 2½d. or 3d., depending on the number of subscribers to whom unit fee access can be gained, and is independent of its duration.) Each call beyond unit fee distance—i.e., "trunk" call—is now switched by a telephonist, although it is known that important advantages can be obtained by her elimination, at least for calls over the shorter distances. (See Fig. 1 for examples of the basis used in determining whether a call is to be charged at a trunk (timed) or (untimed) unit fee rate.)

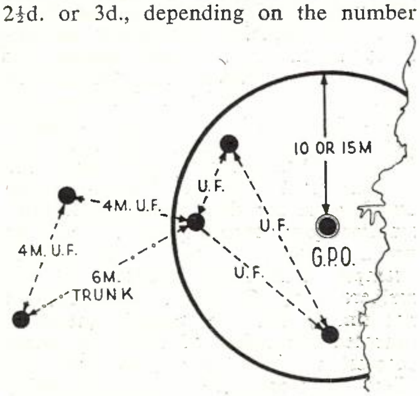


Fig. 1.—Examples of the basis used in determining whether a call is to be charged at a trunk (timed) or (untimed) unit fee rate.

This paper discusses the problems involved in selecting a charging system and designing automatic equipment to allow subscribers to be charged for dialled trunk calls, making possible extension of the dialling range allowed to subscribers. In effect, portion of the deliberations and recommendations of a Departmental (Engineering Branch) Committee on Multimetering are set down. The author, a Divisional Engineer in the Telephone Planning Subsection of the Department, was N.S.W. representative on the Committee which was set up in 1954 to investigate and make recommendations on the provisions of facilities to allow subscribers to complete short trunk calls automatically, with particular reference to calls from nearby exchanges into the metropolitan networks, including the specific cases of calls from Palm Beach and Avalon Beach into the adjoining Sydney network.

It was decided that general principles, applicable to a wide range of exchanges, should be examined and defined, rather than seek solutions applicable only to immediate problems and perhaps a few other similar cases. This has resulted in the definition of arrangements which will satisfy the immediate requirements of Avalon and Palm Beach exchanges in an economical way, while also providing for easy extension of the number of exchanges permitted extended-distance dialling, or of the range of such dialling. It will permit the number of new types of equipment required for all exchanges to be kept to a minimum, with consequent economies.

Reasons for Extension of Dialling Range

In Australia, as in many other countries, it is becoming clear that an important step in maintaining or improving the economic efficiency of the telephone system lies in extension of the distance over which automatic subscribers are allowed to dial. With a suitable method of charging for such extended-distance calls, the overall costs of the telephone system could be appreciably lowered, while maintaining the revenue level (for the same amount of traffic) and providing extra convenience for the subscriber. Experience in other countries is that, as a secondary effect, the increased convenience results in a higher calling rate, requiring increased plant provision. At the same time revenue increases at a rate which is adequate to compensate for the additional costs incurred by the extra plant.

In Australia at present, approximately 72% of all calls beyond unit fee distance (i.e., trunk calls) do not exceed 60 miles in radial distance, returning approximately 28% of the total trunk call revenue. As in most other telephone administrations, in recent years there has been increasing concern about the disparity between the costs involved in manually handling short-distance trunk calls and the revenue derived therefrom. Many such calls do not recoup sufficient revenue to offset the cost of the operator's time required to switch and docket them, apart from plant costs. Three factors have a bearing on this:—

(a) Relative to plant costs (per channel), the cost of staffing manual switchboard positions has increased greatly with the years.

(b) Relative to the cost of plant taken into use on a long distance call, the cost of plant required for an average short distance trunk call has increased. The changing balance of costs between internal and external plant has encouraged the more common use of amplifiers to allow the use of cheaper cable, and of multichannel carrier telephone systems over relatively short distances. These in turn have tended to make the cost of plant taken into use on a call far less dependent on the distance over which the call is made than was once the case.

(c) The ratio of charges for short and long distance trunk calls is not directly related to the ratio of their handling costs. It is only to be expected that many subscribers could or would not believe that a call over a distance of 40 miles should be charged at a major portion of the rate applicable to a call over a distance of 200 miles; particularly if they happen to make a preponderance of relatively short distance trunk calls. To them, the present charges of 2s. 1d. and 6s. 5d., per three minutes, respectively, would appear more equitable in ratio, as they were in the days when the major portion of all costs incurred on a trunk call was for external plant and consequently was approximately linearly dependent on the call distance.

As in other countries, it is the aim to alleviate this position by replacing manual operators with automatic equipment. Portion of the operator's work is to be transferred to the subscriber, by requiring him to dial an area prefix and the wanted subscribers' number-actions now performed by the operator under the callers' instructions. Automatic equipment will be required to perform the remaining two basic functions of a manual operator—switching and charging.

Switching problems associated with extended-distance dialling are not dis-

*Except for a few modifications necessary because of subsequent developments, this paper is printed as presented to the Sydney Division of the Institution of Engineers (Aust.), Electrical and Communication Engineering Branch.

cussed except where they touch on aspects of the charging problem. It can be stated that satisfactory means of automatically switching subscriber-dialled trunk calls are available, largely by the use of equipment and techniques commonly employed in local automatic exchanges; although there is still considerable scope for improvement in various ways. An early decision of the Multimetering Committee was that, for sub-metropolitan exchanges at least, call routing discrimination (if required) (see last paragraph of the Section—Outline of Equipment Functions in the Present Automatic System) should be divorced from charging discrimination by providing separate items of equipment for each. This has allowed a design for call charging equipment to be developed without too much consideration of unsolved switching problems.

Possible Types of Charging System

At present, subscribers connected to automatic exchanges are charged for calls in one or both of two ways:—

(a) In the exchange there is an individual meter for each subscriber connected. This meter is of the 4-digit cyclometer type with an electromagnet, pawl and ratchet drive. It is operated, increasing its indication by one, whenever a local call dialled by the subscriber is answered. It is operated only once for each call, irrespective of its duration. Meters are read periodically, and the difference in indication is multiplied by the unit fee rate to determine the charge due for local calls.

(b) All trunk calls are switched by telephonists, who prepare an individual record (docket) for each, showing the caller's and called numbers, duration of the conversation, time of day and other information, mostly relevant to the cost of the call. This is priced elsewhere for inclusion in the subscriber's account. The docket is kept for some time, so that details of trunk calls can be provided if requested by the subscriber. The cost of any trunk call is based on a rate, dependent on the radial distance between the originating and terminating exchanges, which is applied to each 3 minutes of conversation period, or part thereof. This practice has been in use for many years.

It would be possible to introduce equipment which would perform automatically, for dialled calls, charging duties closely parallel to those of a telephonist. Such equipment need not stop at preparing a "ticket" (generally a punched card suitable for use in conventional business accounting machinery), but can be made to compute the cost of the call, or even to prepare complete accounts ready for posting, similar to processes coming into common use overseas in the handling of trunk call dockets prepared by telephonists.

Automatic ticketing and automatic accounting systems for the performance of these functions are in use, notably in U.S.A. and in Belgium. At present their use in Australia does not appear very attractive, chiefly on account of the high costs involved in their provision and maintenance. Any economic study of automatic ticketing or automatic accounting systems, as against metering systems described later, must be adversely affected by three factors which apply here:—

(a) Outside the metropolitan networks, few exchanges are other than small in size. The application of automatic ticketing or automatic accounting (particularly the Bell System "Automatic Message Accounting") would be much less efficient than when used in situations where large amounts of trunk traffic can be handled.

(b) Unlike Australia, a large proportion of subscribers' lines in U.S.A. are not equipped with meters. (A flat rate is charged covering rental and all local calls). The presence of subscribers' meters predisposes us towards any system using them for trunk call charging purposes.

(c) The calling line requires to be identified automatically for automatic ticketing and automatic accounting systems. In our exchange system this would require much additional apparatus, although in other systems, notably those which are marker-controlled, the identity of the calling line can be ascertained more easily.

Automatic ticketing and automatic accounting systems possess the advantage that they are applicable to calls of any distance, whereas the application of a metered system to long-distance traffic may be objected to by subscribers because of the lack of detailed information regarding calls. On the other hand, it appears probable that it may be a long time before this advantage of the first-mentioned systems could be made effective, because of difficulties in providing the large numbers of additional trunk channels required if subscribers were to be allowed to dial over long distances. These systems also suffer from the difficulty that usually it is not possible to ascertain quickly the cost of any particular call (often required by hotels, clubs, etc.) or the cost of all calls originated by a particular subscriber (often required when closing down or transferring a service).

Instead of attempting to simulate the actions of a telephonist, charging for trunk calls may be carried out by repeated operation of the subscriber's meter, which at present is used only to count local calls. Schemes of this type, generally referred to as "multimetering", have the following properties:—

(a) The cost of any trunk call must be quantitized as an integral number of fee units.

(b) Where meters of a suitable type are already installed, as in most Australian exchanges, the cost of multimetering equipment should be only a fraction of that of a trunk ticketing installation, particularly as—

(c) calling line identification is not required, because—

(d) the cost of each trunk call is registered on a meter appropriate to the calling subscriber (together with other trunk and local calls—often referred to as "bulk billing").

(e) It follows that usually subscribers can obtain no details of multimetered trunk calls.

(f) It is not possible to make "particular person" multimetered calls. Most subscribers will find that this is more than compensated for by the ease with which short (and hence low-cost) "enquiring" calls can be made. At the same time, the Department is expected to gain more effective use of trunk lines, with further savings in operators' time.

(g) It may be necessary to read the subscribers' meters more often, or to replace 4-digit meters by 5-digit, for heavy-calling-rate lines at least.

It has been decided that, as soon as possible, some subscribers should be allowed to dial short distance trunk calls, using charging arrangements of the multimetering type. It will still be possible for these subscribers to seek manual operator assistance in setting up trunk calls to destinations within dialling range, but it is probable that slightly higher charging rates than those applicable under multimetering conditions will be applied, in order to discourage the practice. Overseas experience is that within a short time of the provision of multimetering facilities, the great majority (e.g., 95% in Germany) of diallable trunk calls are dialled.

Dependence of Call Charges on Time

A basic principle adopted at the outset is that charges for multi-metered calls are to be dependent on conversation time as well as distance. This parallels the arrangements adopted in charging for manually switched trunk calls, and (assuming the rates are reasonably chosen) gives all callers approximately equal value for their money. Untimed systems give some types of call an unfair advantage over others. For example, calls from London to subscribers in the Greater London area are not timed, but the caller's meter is operated a number of times in rapid succession when the call matures. In effect, brief calls are charged at a high rate per unit time to compensate for the low rates applied to lengthy calls. Perhaps the worst aspect of untimed rates is the lack of direct relationship between average holding time and revenue. If on a particular route subject to a 3 unit fee charge, the average length of calls increases by 33%, it would appear that the charge should be increased to 4 unit fees, but if the increase in holding time were not common to other routes, this would create an objectionable tariff anomaly.

Having decided that the cost of a call should be related to the conversation time (temporarily disregarding the effect of distance), the question is—how? It seems to be universal practice to operate the caller's meter once when the call matures, to cover setting up costs; but after that there is a wide divergence in the practices of the various countries using multimetering.

Some attempt to simulate manual charging methods by operating the meter (either immediately, or after a delay of the order of 10 seconds to allow cancellation of wrong number calls) a sufficient number of times to charge in advance for three minutes of conversation. Ten seconds or so before the end of the three minutes, a warning tone "pip" is applied to the line; and if the call is not quickly released, the meter is again operated repeatedly, sufficient to pay for another three minutes of conversation . . . . and so on. The cycle of circuit operations to be performed at the end of three minutes in equipment employing this charging principle would make it somewhat more costly than that of the preferred system, although both require an individual timing element for each trunk call handled.

The chief advantage of simulating manual timing arrangements seems to lie in the possibility of using a common tariff structure for both systems, but this is effectively ruled out by the use in Australia of two different unit fees, apart from fee determination difficulties described later. Whilst admittedly raising the revenue correspondingly, there is also the undesirable effect (observed also under manual switching conditions) of increasing the average holding time, and hence the trunk channel requirements. This comes about because callers who have paid for 3 minutes, (or 6) of conversation and concluded their business in 2 minutes (or 4) often carry on to obtain the maximum return for their outlay.

This effect can be eliminated by breaking up each group of meter operations, spacing them so that each precedes and pays for an equal portion of call. There is then an inducement to terminate each call as soon as possible. Even a slight delay in clearing may incur the penalty of an extra meter operation. An arrangement of this type is used in Sweden where, after the usual meter operation on maturity, the meter is connected (indirectly) to a common lead carrying pulses of the desired spacing. Different leads are provided for different dialling distances, carrying pulses at different intervals.

In many types of telephone system, an arrangement of this type has a pronounced advantage in that an individual timing element is not required for each call. After the actions involved in operating the meter when the call matures, the circuit is almost static, involving only pulse repetition. As discussed later, in our system this advantage can be largely nullified; and an important objection to the Swedish arrangement is regarded as of sufficient importance to prevent its adoption here. This is that the interval between maturity of a call and the first timed pulse is random in length over a wide range (from zero to almost the full pulse interval). In consequence, subscribers may be charged the same amount for conversations over the same distance although differing in duration by as much as almost 2 pulse intervals. It has been claimed that this is not of practical importance because when averaged over an accounting period, charge variations arising from the effect are negligible. The probabilities of various proportional differences between actual and average bills for a period have been calculated and tabled. It appears that the probability of overcharging or undercharging a subscriber by as much as 10% is quite small—but we are not prepared to neglect it.

The difficulty could be overcome by providing pulses at a multiple of each desired meter operation rate, with a simple counting circuit to allow only the desired pulses to operate the meter. For example, if it were desired to operate the meter once a minute, every sixth 10 second pulse could be used to reduce the randomness of the starting period by a factor of 6. However, such an arrangement would be more expensive than that proposed. The generation of pulses at suitable intervals (with provision for changes to suit possible future tariff variations) would not be simple, the exchange wiring would be complicated by a multiplicity of pulse leads, and it would be difficult to arrange for the provision of "pip" tone to keep the caller informed of the passage of time. A comparison between "per 3 minutes" and "spaced meter pulse" charging arrangements is shown in Fig. 2.

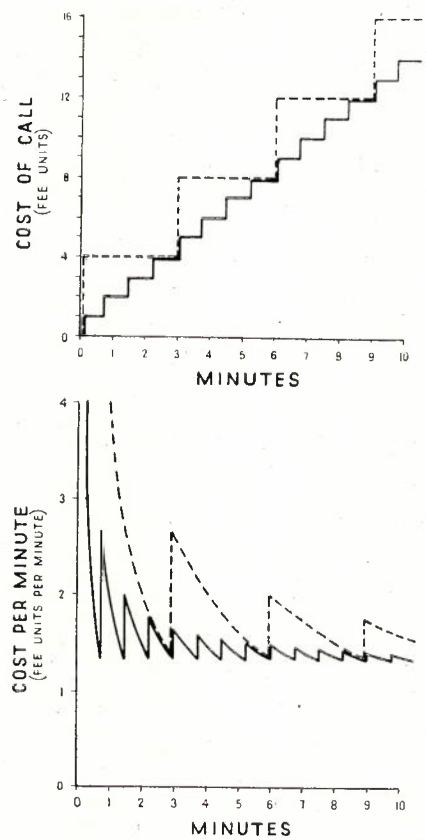


Fig. 2.—Comparison between "per 3 minutes" (dotted lines) and "spaced meter pulse" (full lines) charging arrangements, showing how actual charge (top) and effective average charge rate (bottom) vary with the length of call.

The charging system to be introduced in Australia for dialled trunk calls is of the variable-interval time-zone metering type; based on repeated operation of the calling subscriber's meter at approximately equal intervals, starting with one operation when the called party answers. A means of doing this economically has been found, by re-using a major circuit component required for fee determination. This is a 25-outlet uniselector (a unidirectional stepping switch) of which only 20 outlets are effective under timing conditions. When a call matures, the uniselector is stepped under control of a basic pulse (normally once every nine seconds) which is common to all circuits in the exchange. When the uniselector reaches certain outlets, preselected in accordance with the required fee rate, the caller's meter is operated. After twenty steps (i.e., three minutes normally) the uniselector rotates automatically over five steps, to commence a fresh timing cycle. Pips of tone are returned to the caller when the uniselector is on contacts 19 and 20, and again on 1, to indicate the passing of each three minutes of conversation time.

This arrangement restricts possible charging rates to an integral number of fee units per basic timing cycle. The system does not eliminate all variations in timing, but reduces them to negligible proportions. Variations may arise from:—

(a) The variable interval (normally 0 to nearly 9 seconds) between the instant when a call matures and the first following basic pulse. The circuit is arranged so that this is a free period, always in the subscriber's favour.

(b) The fact that it is impossible to divide 20 uniselector steps into (for example) 3 equal parts. Certain operations of the meter must be displaced from their ideal timing to coincide with a basic pulse. The proposed design never allows an error in timing from this source to exceed 6 seconds (at the 9 second basic pulse rate). Such errors are not cumulative, but average to zero at the end of each timing cycle.

Dependence of Call Charges on Distance

With certain exceptions, the present scales of charges for manually switched trunk calls is based on the radial distance between originating and objective exchanges, in steps of 5 miles between 5-40 miles, of 10 miles between 40-60 miles, of 20 miles between 60-100 miles, of 50 miles between 100-400 miles, and thence of 100 miles. From a table prepared for a particular originating exchange, it is easy to find the rate appropriate to a call to any particular objective exchange, for pricing under manual switching conditions.

Determination of the charging rate appropriate to a dialled trunk call must be dependent on the digits dialled by the caller, in turn dependent on the numbering plan. Fee determinations for dialled trunk calls could be made to correspond closely to those performed under manual switching conditions, but the fee determining equipment would be so complex that common control working would be necessary (i.e. only one or two fee determining equipments would be provided per exchange) and so costly that the provision of multimetering equipment, particularly in small exchanges, would often not be justified.

The difficulty is that the fee-determining equipment would be expected to specify different rates for calls to exchanges lying astride any charge-rate boundary, even though as many as the first 5 digits dialled for such calls may be identical—i.e. the 6th digit would determine which of 2 such exchanges was required, and hence the charge rate applicable. (The first 5 digits serve only to distinguish those 2 exchanges from all others). However, it is known that the cost of equipment to discriminate between more than about 1,000 dialling codes, for fee-determining or any other purpose such as route discrimination, increases disproportionately and so rapidly that it would seldom be economical to examine more than 3 dialled digits when discriminating.

It is clear that, if multimetering is to become a practical proposition generally, the degree of discrimination is to be markedly reduced in comparison to that used under manual switching conditions. This implies correlation between the telephone network numbering plan and the grouping of exchanges for charging purposes. The only possible solution lies in "area-to-area" charging, in which exchanges are grouped into charging areas coinciding with major subdivisions of the numbering plan, with call rates based on the distance between arbitrarily chosen "charging centres" in the originating and objective areas, instead of the radial inter-exchange distance. From the subscribers' point of view, it is as though every subscriber were connected to an exchange at his charging centre, with no local exchanges.

One effect of area-to-area charging is that apparent anomalies in charging are possible — indeed, probable. For example, if the charging centres for areas A and B happen to lie close to, but on either side of, a charge-rate dividing line drawn around a charge centre C, so that calls from C to any exchange in A are charged at a higher rate than from C to any exchange in B, it will usually be found that some exchanges in the portion of B remote from C are farther from C than exchanges in the portion of A closest to C. Thus some calls will be charged at lower rates than other calls having a shorter radial distance (see Fig. 3).

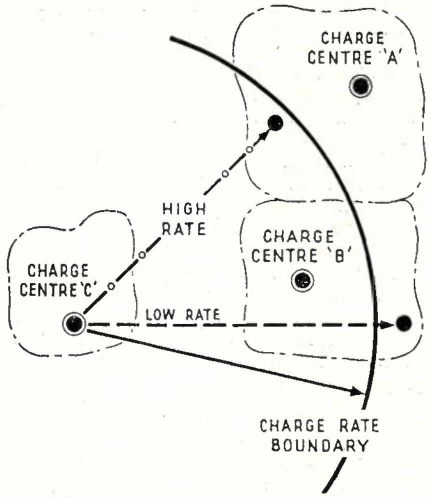


Fig. 3.—Illustration of charge-rate "anomalies" possible under area-to-area charging arrangements.

Many such anomalies will appear only because of the radial distance basis of charging. There is justification for ignoring these, in that the major portion of the costs involved in a trunk call are usually associated with the circuit between the trunk centres of the areas concerned, and that consequently the distance between charging centres, usually equivalent to the distance between trunk centres, would be better than radial distance as a criterion of value received. Also, examination shows that most of the apparent anomalies would disappear if charges were based on route distance, as in railway practice. (Route distance is, of course, a measure of the amount of line plant taken into use by a call, and was used as a charging basis many years ago.)

The number of apparent anomalies can be kept down by making charge areas as small as possible within numbering scheme limitations, and by keeping the number of charge-rate steps to a minimum. Of course, there are limits to what can be done in the latter direction—carried to the extreme it would result in a standard charge rate for all trunk calls. Care in the location of charging centres, which do not necessarily coincide with the charging area trunk centre, nor even an exchange, will also help in some cases. It should not be forgotten either that there is a compensating effect in that while approximately half the anomalies are brought about by area-to-area charging distances which are greater than the corresponding exchange-to-exchange radial distance, and hence adversely affect the subscriber, the other half are caused by area-to-area charging distances less than the corresponding exchange-to-exchange distances—which are in the subscribers' favour.

The size of any basic trunk area, i.e., of a local exchange network, is generally dictated by long line plant considerations. Australian population distributions, which generally follow a sort of multiple star pattern, are such that the establishment of a nation-wide numbering scheme based on more or less rigid grid-like subdivisions, as is proposed in Great Britain, appears totally impractical. Many of the basic trunk areas are so large that they must be subdivided for charging area purposes. It is proposed to do this in accordance with the first digit (only) of the local network numbering plan. (As discussed later, this is vital to the proposed equipment design). It follows that usually there will be a maximum of 8 charging areas in a trunk area (level 1 being left spare to avoid wrong number troubles, and level 0 used for trunk purposes).

Some basic trunk areas will probably not be subdivided for charging purposes. For example, Avalon and Palm Beach exchanges are on a promontory, forming a compact and isolated trunk area. At present they are charged identical rates on almost all trunk calls. Also, although provision is made for the application, if necessary, of different charge rates on calls from a sub-metropolitan exchange to different first-digit subdivisions (i.e., main exchange areas) of the parent metropolitan network, it is not clear if or when the facility will be used, except perhaps to prevent the useless holding of trunk lines on calls to barred or spare levels (e.g., "A").

For multimetering exchanges this will have the effect of abolishing the perimeter zones around (for example) the Sydney network. That portion of the Unit Fee Area lying between circles 10 and 15 miles from the G.P.O. is divided into 8 approximately equal zones (plus a zone for Liverpool exchange as a special case), the charge for a manually switched call from an exchange outside the Unit Fee Area to an exchange within one of these zones being computed on the distance between the outlying exchange and a charging centre midway along the outer length of the zone perimeter. The result is that, unless or until differential rates are applied on calls to the different main exchange groups in the Metropolitan Unit Fee Area, both the comparatively cheap rates applying to calls to nearby zones and the comparatively high rates applying to calls to distant zones will be averaged out to a uniform rate applying to all calls into the metropolitan network from any outlying exchange converted to multimetering.

Area-to-Area charging is used in all known multimetering schemes, although the extent to which it is applied varies widely, depending on the degree of importance placed on the appearance of charging anomalies, which tend to assume proportionally greater significance at shorter distances. Most, but not all, administrations drop it in favour of exchange-to-exchange charging over the shorter distances. For example, in Great Britain it is proposed to use exchange-to-exchange fee rate determinations for calls up to 30 miles radial distance, with area-to-area charging beyond that.

The most serious anomaly possible if area-to-area charging is applied to short distance calls is that calls between closely neighbouring exchanges with a substantial community of interest may be charged trunk rates, unless special arrangements are made. Where two exchanges in different charging areas are less than five miles apart and there is sufficient traffic to justify the provision of direct junctions between them (influenced of course by the cost involved, as a measure of convenience or practicability), unit fee service will probably be provided. If the two charging areas concerned are part of the same basic trunk area, route discriminating equipment must be provided for access to such junctions. Dependent on the type of equipment installed in the originating exchange, it will be arranged that whenever the route discriminating equipment switches to a local outlet, either the multimetering equipment will be released to allow unit fee metering to be applied from a normal outgoing repeater on calls over direct junctions, or else a special signal will be sent from the route discriminating equipment to cause the multimetering equipment to over-ride any prior fee determination and apply unit fee metering conditions. Alternatively, if the two exchanges are in different trunk areas (which could require route discrimination on about the fifth digit, for which suitable equipment may not be available, or which may cause an objectionable amount of pre-discrimination false traffic on trunk lines) it will probably be necessary to fit each into the numbering plan for both areas. The resultant extra demands on the available number ranges is the price to be paid for obviation of the more serious anomalies in charge rates; although it is possible that future development in the way of register-discriminator equipment may change this state of affairs. Directory entries and dialling instructions can be simplified if it can be arranged that such exchanges are allotted identical number ranges in both numbering plans, although this is not always possible.

For example, Mona Vale exchange in the Sydney metropolitan unit fee network is less than five miles from Avalon, and unit fee service is provided between the two. A typical Mona Vale subscriber's number is XW9123, and this applies to calls from other Sydney metropolitan unit fee network subscribers or from Avalon subscribers, the 9th level (X) at Avalon being reserved for this purpose. On the other hand, for calls from Mona Vale into Avalon, it is necessary to use a dialling prefix, because the Sydney network first digits corresponding to the first digits of the Avalon-Palm Beach subscribers' number range are all in use. Mona Vale subscribers are trunked to a form of route discriminating equipment (Switching Selector Repeaters arranged to switch locally on the third digit) which makes XXJ a convenient prefix for calls to Avalon. (The junctions to Avalon are connected to the banks of the S.S.R.'s only, and hence are not accessible to subscribers in other Sydney network exchanges.)

Influenced by the large savings to be made in small and medium sized exchanges by simplifying the fee determining equipment sufficiently to avoid major-scale common control working, it is proposed to apply area-to-area charging to multimetered trunk calls over any distance, except for the above arrangements, (where warranted) for unit fee calls across charging area boundaries. It should not be difficult to keep the incidence of unfavourable charge rate anomalies down to such minor proportions that, with other disadvantages (lack of multimetered trunk call details), their effect will be so obscured by the advantages (extra convenience, lack of operator intrusion, savings on odd-length calls, anomalies in call charges favouring the subscriber, and often slightly cheaper overall rates) that multimetering will receive the general approval of subscribers.

Outline of Equipment Functions in the Present Automatic System

At this stage, and before dealing with the principles of multi-metering equipment, it is desirable to describe briefly current practice in the Australian telephone system, which is mainly of the step-by-step type employing dialled-impulse-driven bimotional switches. Some of the older exchanges use metering systems which differ in various respects from the positive pulse arrangements described, and these will require modification or even replacement before multimetering can be introduced in

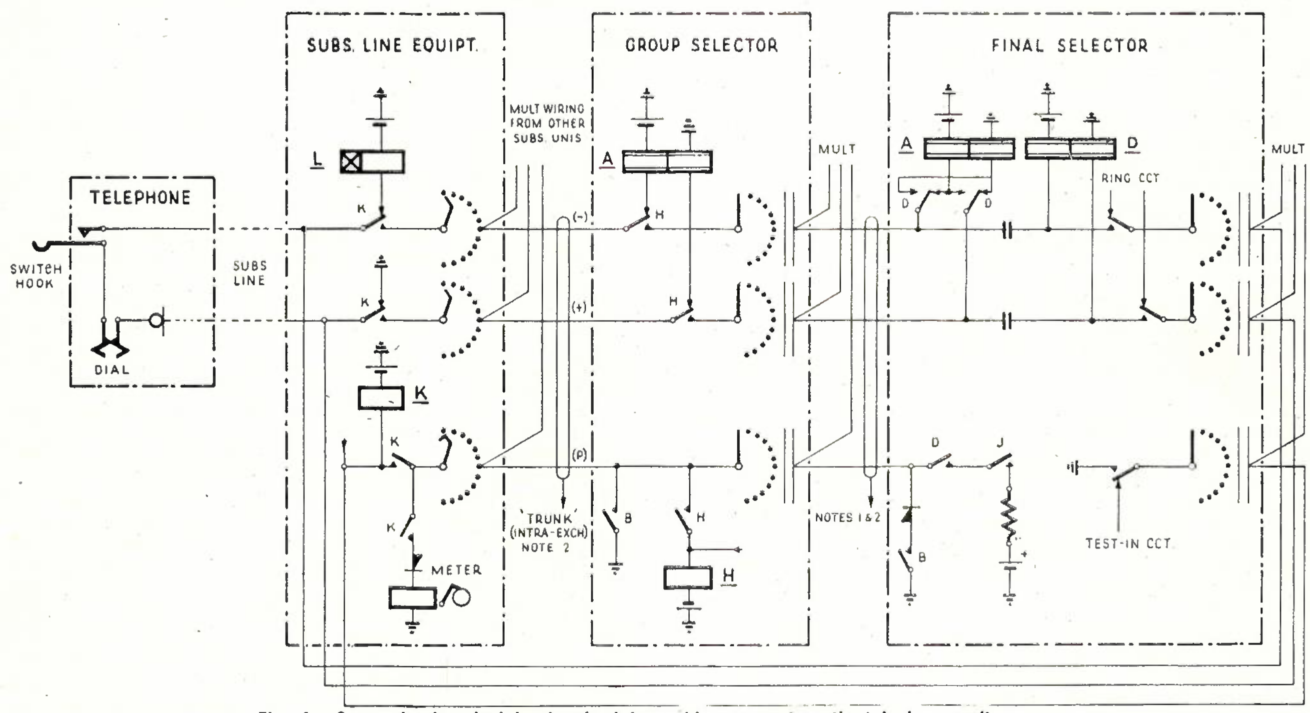


Fig. 4.—Some circuit principles involved in making an automatic telephone call.

Note 1.—As necessary, depending on the number of digits in the numbering scheme other ranks of group selectors may be inserted before the final selector.

Note 2.—Group or final selectors may be located in different exchanges to the preceding selector rank, in which case auto-to-auto repeaters (relay sets) and 2-wire lines are used instead of 3-wire trunks between selector ranks.

them. R.A.X.'s (Rural Automatic Exchanges, of up to 200 lines capacity) also differ, but present standard types employ a pulse metering system which is amenable to the introduction of multi-metering.

Any automatic telephone is connected to its exchange equipment by a 2-wire line. In the resting state (i.e. switch-hook unoperated) a magneto bell and series capacitor are left across the line, to respond to the "ring" (17 c/s A.C.) applied by an incoming call. Lifting the receiver operates the switch-hook to place a comparatively low resistance, which includes the telephone "transmitter" (a carbon granule microphone), across the line. The exchange equipment always keeps a potential of 50V (positive pole earthed) connected to the line through a relay winding, so that loop current of the order of 100 mA always flows when the switch-hook is operated. In the telephone this powers the transmitter, and the state of the series relay in the exchange is used for signalling purposes, for example to cut off the ring on an incoming call. During conversation, V.F. speech currents, sending and receiving, are superimposed on the loop (direct) current (see Fig. 4).

In the exchange, each subscriber's line is connected to a line circuit consisting of two relays and a uniselector (a stepping switch with self-interrupting electromagnet, pawl and ratchet drive). The subscriber's meter is associated with the line circuit, which functions to differentiate between incoming and outgoing calls. One of the line circuit relays is in series with the line to detect operation of the switch hook for an outgoing call, when it earths the P-wire (the 'Private'—a third wire, with holding and guarding functions, associated with the two line wires of each major item of equipment in an exchange), to cause attempted incoming calls to receive busy tone instead of intruding, and causes the subscriber's uniselector to rotate its wipers over the bank contacts.

Each outlet (i.e., set of bank contacts on which the wipers are positioned after each step) is shared with other uniselectors, being wired in multiple from bank to bank of a group, and connects to a first group selector, or equivalent. At each step, the uniselector tests the outlet P-wire to determine whether the corresponding group selector is already engaged; driving until a free outlet (P-wire not earthed) is found. The subscriber's line is then switched through the uniselector to the group selector, "seizing" it. The subscriber's loop operates a battery feed relay in the group selector to earth the P-wire and so prevent other uniselectors from attempting to seize the same group selector. The P-wire is extended back through the subscriber's uniselector to hold the switching relay in the line circuit and so continue to mark the calling line as engaged to attempted incoming calls. The first selector applies dial tone to the line as an indication to the caller that dialling may proceed; or alternatively, if all group selectors accessible to the subscriber's uniselector happen to be engaged, busy tone is applied to the line. Subscriber's uniselectors are used in this way to concentrate originating traffic on to a comparatively small number (usually of the order of 10% of the number of subscriber's lines) of first selectors, which are relatively costly and bulky items of equipment.

The telephone loop is broken by dial impulse springs a number of times cor-

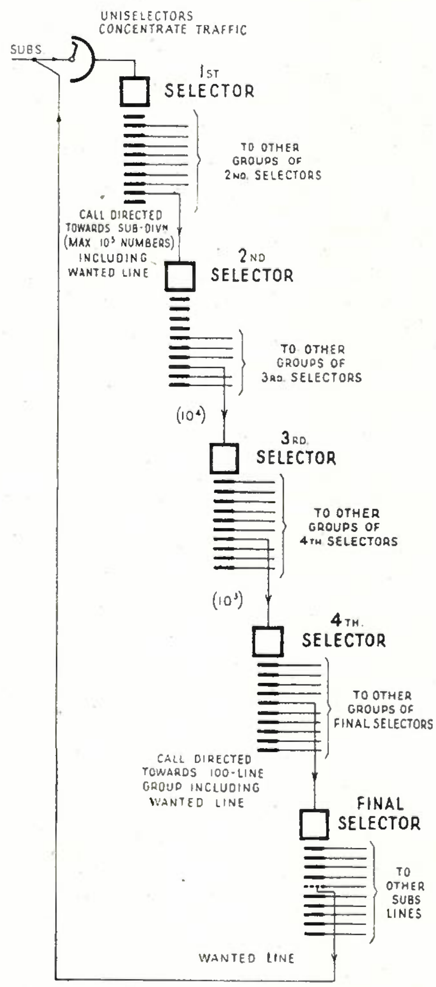


Fig. 5.—Showing how automatic exchange equipment directs a call step by step towards the wanted line, under control of the caller's dial.

responding to each digit dialled, the impulses being normally 66% break at 10 impulses per sec. The battery feed relay in the first selector, a bi-motional switch, follows the impulses of the first digit, inverting them to 66% make impulses which are applied to the vertical magnet. The associated pawl and ratchet lift the wiper carriage to a level corresponding to the digit.

At the end of the digit, as determined by a relay whose release is sufficiently slowed by a short-circuited winding to enable it to hold between vertical magnet current pulses, the rotary magnet is energised to step the wipers into the (contact) bank. In a first-group-selector exchange, a hunting action takes place until the first selector seizes a free second selector connected to an outlet of the dialled first selector level (similarly to the way in which the subscriber's uniselector sought out a free first selector) or busy tone is connected if all outlets on the required level are already engaged. A group of second selectors is connected to each working first selector level, each serving a different group of subscribers, so that the first selector chooses for the caller one major-sub-division of the entire network number range.

The dialled first selector level may correspond to a first digit of the originating subscriber's exchange range, in which case the second selectors are located in the same exchange. Usually there are also first selector levels corresponding to the number range of other exchanges having their own second selectors. In this case a junction (line) is interposed between the first selector outlet and the second selector. Since 3-wire junctions can be economically justified only over very small distances, a repeater (relay set) is usually trunked between the first selector outlet and the junction, to provide an earth on the P-wire to hold the subscriber's line circuit and the first selector in the switched condition. As implied by its name, the repeater also repeats subsequent dialled impulses, to prevent low transmitter current and relay performance difficulties which would arise if the subscriber's loop were merely extended by addition of the junction, increasing the resistance between the subscriber's telephone and the impulsing (i.e., battery feed) relay.

The second selector responds to the second dialled digit in the same way as described for the first selector, narrowing down the section of the number range required by the caller. The call proceeds in this way through a number of ranks of group selectors, until all digits have been dialled except two, by which time the section of the number range required has been narrowed down to a 100-line group. Outlets of the group selector which accepts the 3rd-last digit are trunked to a final selector, which is also a bi-motional switch, but with different functions. The penultimate dialled digit positions its wipers vertically, but there is no further action until the last digit rotates the wipers into the bank. Subscribers' line circuits are connected to the final selector bank multiple, and the final selector tests the P-wire to determine whether the required line is engaged or otherwise, returning busy tone to the caller or returning ring tone and connecting ring to the called line (see Fig. 5).

As mentioned previously, ring is disconnected from the called line when the telephone loop is detected (in the final selector). The final selector provides forward and backward battery feeds, coupled together by speech-path capacitors in series with the line pair. At the same time, the polarity of the battery feed on the incoming side is reversed, and one short positive pulse is impressed on the P-wire. If the final selector is in the same exchange as the caller's line circuit, the two are connected together by a complete 3-wire circuit through a number of group selectors, and the positive pulse on the P-wire is communicated to the subscriber's line circuit, where it causes the operation of the subscriber's meter which is connected from earth to the P-wire through a rectifier rendering it sensitive to positive voltages only. The positive pulse does not release the selectors, for their holding relays are returned from the P-wire to exchange (negative) battery. In this case the reversal of battery feed by the final selector achieves nothing unless the call is from a public telephone where it cuts out the transmitter until coins are collected, or from certain types of switchboard, where it is used for supervisory purposes. On the other hand, if one or more junctions are involved in the call, the positive pulse from the final selector achieves nothing, but each repeater incorporated in the switch train detects reversal on its outgoing side and correspondingly reverses its backward battery feed, simultaneously delivering a positive pulse on its P-wire. Although in any intermediate exchange this pulse achieves nothing, in the originating exchange it meters in the same way as described above for a local final selector.

At the finish of the call, the calling line is opened by restoration of the switch-hook. The open circuit condition is passed on by any repeaters in the switch train, and after a delay due to a slow release relay (which is necessary to prevent a similar action during the momentary periods of open circuit which form the dialled impulses) the holding earth on the P-wire is opened in the final selector to release the switching relays in all dependant preceding switches, allowing them to return to normal, ready for another call. If the call passed through other exchanges, their repeaters control the release of their own dependant switching stages, back to the subscriber's line circuit, in a similar way to the final selector, and at the same time.

To avoid the relatively high costs which would be incurred if a mesh of junctions were required to link each first-digit ("main") exchange with every other, in sub-metropolitan and country networks, it is usual to group the first selectors for all exchanges in the exchange at the trunk centre. Nearby exchanges may pass all originating calls from subscribers' uniselectors through repeaters and over junctions to first selectors at the parent exchange. This arrangement requires local traffic (e.g., Palm Beach subscriber to Palm Beach subscriber) to take two junctions into use (e.g., to Avalon and return) and is hence sometimes known as "trombone" trunking. The absence of group selectors between the subscriber's line circuits and the outgoing repeaters makes no effective difference to the actions of metering and release outlined above.

Alternatively, particularly if the originating exchange is remote from its parent and/or a high proportion of the originating traffic is local, it may be more economical to connect the subscribers' uniselectors to one of the many forms of discriminating equipment, instead of to repeaters. Discriminating equipment is relatively costly, but in suitable locations can effect substantial

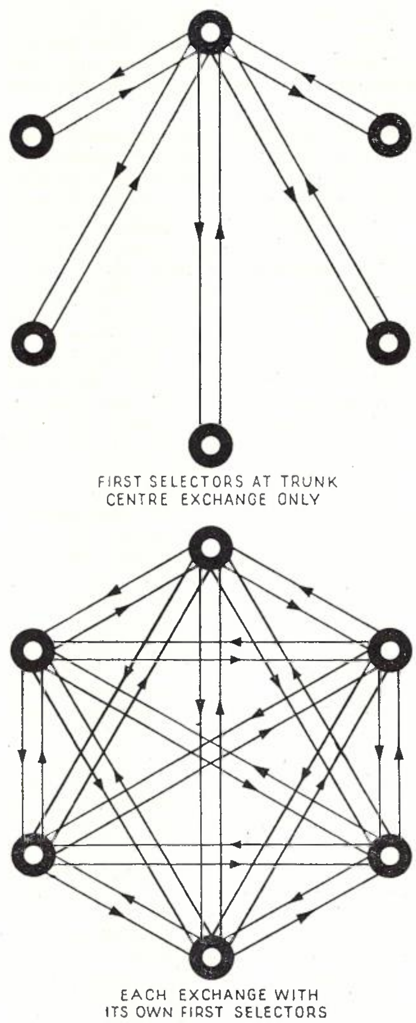


Fig. 6.—An illustration of the way in which concentration of first selectors at one exchange can simplify junction network layout.

savings by its ability to avoid the use of junctions to the parent exchange for local calls and calls to any nearby exchange to which direct junctions can be relatively cheaply provided. Discriminating equipment allows an originating call to seize a parent exchange junction, through a repeating element; and monitors the dialled digits (which may be used to operate a selector mechanism or some form of counting circuit) until the stage is reached where a decision is made as to whether a locally available selector or junction group is required. If so, a free circuit is sought (by a uniselector or bimotional switch, depending on the type of discriminating equipment), and on its seizure the junction to the parent exchange is freed for other traffic. Otherwise, if a local outlet is not taken into use. the call continues via the parent exchange junction. Discriminating equipment includes an element similar to a standard repeater which is brought into play on calls over junctions to other exchanges, and which may be retained or dropped (depending on the particular equipment design) on intra-exchange calls. The result is that as far as the application of metering pulses is concerned, discriminating equipment acts in a similar way to that of a repeater, subject to the exception that on intra-exchange calls certain types act instead like a group selector in that they do not generate their own metering pulses but merely provide a through circuit on the P-wire for the metering pulse from the final selector. These principles are illustrated by Figs. 6, 7 and 8.

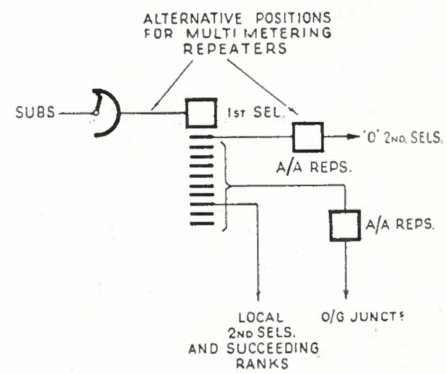
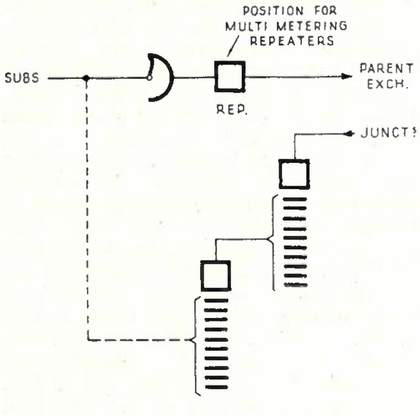


Fig. 7.—Trunking arrangements in ("main") exchanges with first selectors.

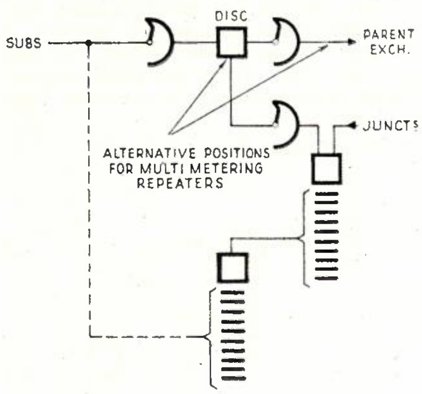
Some Principles Incorporated in a Design for Multimetering Equipment

For non-discriminating exchanges it is evident that the application of meter pulses, repeated or otherwise, would best be effected in the repeater which is taken into use on calls to remote exchanges, as this will allow multimetering facilities to be introduced into working exchanges with a minimum of interference with existing trunking, and into new exchanges with a minimum of alteration to existing planning and installation methods. Usually the only substantial change will be the substitution of multimetering repeaters for ordinary auto-auto repeaters on routes over which access to exchanges beyond unit fee distance is to be gained; although sometimes other variations of trunking will be necessary for various reasons. Ordinary repeaters will be retained on any routes (to neighbouring exchanges) not requiring multimetering.

Problems involved in the possible introduction of multimetering into discriminating exchanges are still being examined. This work has shown that future designs for route-discriminating equipment are likely to be influenced by



TROMBONE TRUNKING



DISCRIMINATOR TRUNKING

Fig. 8.—Trunking arrangements in exchanges without first selectors.

multimetering requirements. The possibility of multimetering in R.A.X.'s has also been considered. Although present standard types (A.P.O. 40-line and 50/200 line) appear amenable, involving some alteration to existing circuits but using otherwise standard multimetering equipment as the major additional items, many of the older types are totally intractable and would require replacement if provision of multimetering facilities can be justified and is required.

The multimetering repeater differs from the normal repeater in that its functions are dependent on the digits dialled through it, and on time. Fee-determining and timing elements are required either on the basis of one per repeater, or shared (common control working). but as previously stated, the avoidance of equipment sharing on a major scale has advantages in exchanges of the small to medium size common in our sub-metropolitan and country areas. By the adoption of an area-to-area charging scheme closely linked to the numbering plan, of certain standardised numbering arrangements, and by the use of a small number of auxiliary bimotional "fee selectors" as a simple form of shared equipment required on only a minor proportion of calls if at all, it has been found possible to develop an equipment design which uses one uniselector per repeater for both timing and fee-determining.

It is convenient to separate the components of the multimetering repeater circuit into two closely associated relay sets—one (the "repeater" proper) performing functions somewhat similar to those of a standard auto-auto repeater (impulsing and reversal repetition, meter control) and the other ("fee relay set") with rate-determining and timing functions.

Because of the similarity in functions, the circuit of the multimetering repeater resembles that of an ordinary auto-auto repeater. The chief points of difference are:—

(a) The multimetering repeater does not by itself automatically generate a positive meter pulse when (junction) reversal occurs, but contains an extra relay (M) which applies positive pulses to the P-wire under control of the associated fee relay set.

(b) Except for the meter pulse immediately following reversal, the timing of meter pulses from different repeaters is controlled indirectly by a multi-metering pulse relay set which is common to the exchange. The result is that a large number of meter pulses may be coincident. In order to avoid the high peak currents which could be drawn from a conventional positive battery supply, the positive metering pulses are derived from a 500 micro-farad capacitor which is normally charged through 1000 ohms from the 50 v. negative battery supply. This eliminates the need for any positive battery supply to the multi-metering equipment.

(c) Provision is made for about 15 necessary connections between each multi-metering repeater and its associated fee relay set.

(d) Certain classes of call may be forcibly released by the application of an earth from the fee relay set to short-circuit one of the relays (H) in the repeater. This is required to prevent the useless holding of trunk lines under certain conditions.

(e) The multi-metering repeater contains an extra relay (N) which, as well as functioning to provide portion of the release guard delay, is used to inactivate the fee relay set when the repeater is seized by way of its "alternative" access connections. This is used in exchanges where access to a common group of trunk lines is gained from two groups of first selectors, one serving local subscribers and another serving incoming circuits from other exchanges. In these circumstances, of which the Avalon exchange trunking is typical, an appreciable saving of valuable trunk channels can usually be obtained by combining the O (trunk line) level of both groups of first selectors in one grading, the outlets of which fall into three classes:—

(i) Those individual to incoming first selectors, and which consequently do not require fee discrimination or timing facilities. Ordinary auto-auto repeaters are provided for these outlets.

(ii) Those individual to the local first selectors, and which consequently require full multi-metering facilities, each connect to a multi-metering repeater and its associated fee relay set, using only "normal" access.

(iii) Those which appear in both parts of the grading. Although their P-wire commons are continuous, the line pairs of the grading commons are severed at the line of segregation, with one jumper from the local first-selector portion of the grading to the "normal" access connections of a multi-metering repeater, and another from the incoming first selector portion of the grading to the "alternative" access connections of the same repeater.

The effect of this arrangement is to gain the trunk-saving advantage of an overall (even if unsymmetric) level O grading, using few more multi-metering repeaters and fee relay sets than would be required if separate gradings were arranged for local and incoming first selectors.

(f) A relay (G) is provided to busy the repeater if the terminating selector at the parent exchange is busied or removed from service, or if the junction is affected by an open circuit or short circuit. The facility is provided in a similar manner to that adopted in the latest standard auto-auto repeater.

The fee relay set consists of a group of 18 relays and a five level uniselector, with a terminal block to allow the cross connection of uniselector outlets to suit any particular installation. The fee relay set tests whether a call originates from an ordinary subscriber or from a public telephone, and determines the appropriate fee discrimination from the digits dialled into its associated repeater. It subsequently controls relay M in the repeaters, and through it the application of meter pulses to the calling subscriber's meter over the P-wire. It is also responsible for forcibly releasing some calls.

The fee uniselector (MFU) is used for fee discrimination, being stepped in accordance with digits dialled into the repeater, and subsequently after reversal on multi-fee calls, is used for timing, being stepped periodically at a "basic" pulse rate, usually once in each 9 seconds. It completes a "basic" timing cycle" of one half-revolution over 20 effective contacts usually one each 3 minutes. MFU is responsible for the generation of meter pulses and tone pips at the desired points in each timing cycle.

At the end of the first 1, 2, or 3, digits dialled into the repeater, earth is connected to one or two of the MFU wipers, to operate whichever relays may be appropriate to the code dialled. Actions possible at the end of a digit include:—

(a) A relay (MP) may be operated to switch the discriminating action from one pair of MFU wipers to another wiper, or released to reverse the action. This facility is used to obtain different discriminations for dialling codes containing the same total number of impulses, such as 03 and 01-2.

(b) It may be that no action occurs, MFU having been stepped to a "rest" position, to await the next digit.

(c) One of the fee selector coupling relays may be operated to extend the discriminating range on "cross-country" calls, except that alternatively, if a fee selector is engaged when required, another relay (MW) will operate instead to open the line circuit on the outgoing side of the repeater and return busy tone to the caller. The operation of a coupling relay diverts subsequent dialled impulses from the fee uniselector to a fee selector, operating it instead of MFU. After one or more digits have been dialled into the fee selector, it returns a fee signal on one or more of a group of five leads, for the same effect as in (e), (f) or (g). The fee selector is then released for use on other calls.

(d) Barred or spare codes are arranged to operate a relay (MN) which returns N.U. (Number Unobtainable) tone to the caller and opens the line circuit on the outgoing side of the repeater to release any remotely switched plant.

(e) The unit fee (untimed) rate is determined by the operation of a relay (MU). ("Free Service" codes are usually connected for this rate, the lack of reversal on such calls omitting the usual operation of the subscriber's meter.)

(f) Multi-fee (timed) charge rates are determined and "remembered" until the call is over, by the operation of some combination of a group of "fee storage" relays.

Either multi-fee or unit fee discriminations cause the operation of a relay (MG) whose operation is slowed by a copper slug around the armature end of its coil to allow time for all wanted fee storage relays to operate, before MG (in co-operation with an intermediate relay MH) cuts off the discriminating signal and returns MFU to its home position.

There is no further action until dialling is concluded and the called subscriber answers. The resultant junction reversal is detected in the repeater, repeated to the subscriber and used to operate a relay (MF) in the fee relay set, which locks for the rest of the call. Relay MF releases MG and during the period over which both are operated (MG being slow to release because of its slug) relay M is earthed to cause the delivery of a positive pulse on the incoming P-wire. For unit fee and free calls MFU remains at normal for the rest of the call, the repeater performing the function of a normal auto/auto repeater only.

On timed calls the operation of relay MF connects a relay (MP) to a basic pulse lead, common to all fee relay sets. Each basic pulse (normally once every 9 seconds) causes MP to operate for a short period, and this results in MFU being advanced by one step. To avoid heavy current surges which could arise from the simultaneous stepping of many fee uniselectors, and thus minimise exchange power supply noise and voltage regulation problems, it is arranged that MFU is energised by connection to a charged 500 microfarad capacitor instead of to the normal exchange battery supply. As MFU steps around its bank while timing a call, it connects earth to certain contacts, preselected by the operated fee storage relays, to energise relay M through MP contacts. For meter operation rates exceeding 20 per timing cycle, auxiliary pulses from a selected common source are connected to relay M, causing it to operate once, twice or thrice between each movement of MFU. (It seems appropriate to mention that the fee storage relay contact network used for this purpose posed a formidable problem in circuit design, and provides an excellent example of the use of the design method known as "switching algebra"). The result is that at the appropriate times relay M is operated to deliver extra meter pulses. To keep the caller informed of the passage of time on a trunk call, a 'pip' of 400 c/s tone (N.U. tone) is connected to the line (normally) 9 seconds before, at the close of, and 9 seconds after, each timing cycle. Release of the call at any stage stops the timing action and the circuit restores it to normal.

Precautions are necessary to avoid the useless holding of trunk lines and switching plant under certain conditions. It has already been mentioned that the call is forcibly released if a barred or spare code is dialled. A similar action will occur if dialling does not proceed to the stage of a fee discrimination within three to six minutes; or on a timed call, if dialling and ringing are not completed (i.e. an answer is not received from the called subscriber) within a similar period, or if the caller holds a matured call from which the called party has cleared for a period of three to six minutes. (The latter condition arises if the calling subscriber inadvertently fails to clear the connection down at the finish of a call). Timing for this function is based on the usual telephone exchange practice involving the use of a pair of pulses ('S' and 'Z') generated each 3 minutes, and requires the provision of an intermediate relay (MS) as well as that (MN) which forcibly releases the circuit.

Unlike other designs for multimetering equipment, because of the many inherent disadvantages, it is intended not to separate public telephone lines from those of normal subscribers, but to distinguish them by a 520 ohm shunt from their P-wire to battery. The fee relay set is equipped with a relay (MK) which in effect measures the current flowing in the P-wire, and is consequently able to distinguish between public telephones and normal subscribers. Although the circuit action of relay MK is to apply a marginal test to the current flowing in the P-wire, its operation is not marginal because it is equipped with a compensating winding, so that there is a wide difference between the conditions under which it is expected to operate and not to operate. On calls from the public telephones of present designs the fact that relay MK is unoperated will have the following effects:—

(a) The first timed earth pulse, which is normally delivered to relay M to cause the second meter operation on timed calls, is diverted instead to relay MN. This arrangement will allow short calls for multi-fee destinations to be handled from public telephones of present designs, such calls being forcibly released (following the operation of relay MN) if the call is carried on to the limit of the period allowed for one unit fee. It is anticipated this facility will be appreciated by the public, as well as economising by diverting some traffic from manual operators. Longer calls can be made from multi-coin (audible signal) public telephones with manual operator assistance, although it is hoped to obtain, later, multi-coin instruments which will be capable of handling multimetered calls automatically.

(b) Certain dialling codes (those for demand trunks and phonograms) are allowed to ordinary subscribers but barred to public telephones in order to reduce the possibility of fraud, and the Time Service dialling code is similarly barred to non-paying traffic from public telephones. This is arranged by the use of MK relay contacts in the appropriate MFU outlets.

(c) Dialling codes for demand trunks and phonograms from public telephones are barred to subscribers, by similar means, to minimise the useless holding of trunk lines and eliminate wrong number traffic.

The previously mentioned fee selectors will be required for auxiliary discrimination on "cross-country" calls to trunk areas other than that immediately associated with the parent trunk centre. For example, fee selectors will not be required initially at Avalon and Palm Beach, the fee determination for any call to the Sydney network being effected on the uniselector in the fee relay set —but when and if the dialling range is extended to other sub-metropolitan exchanges, fee selectors will be required to extend the range of discrimination. A fee selector will be taken into use by a caller dialling a code such as 06, 07 or 08. Each group of fee selectors will serve a rack of 30 fee relay sets, on a common equipment basis. Access will be gained by a coupling relay, whose action is controlled over 2 ("test" and "hold") of a group of 8 leads commoned over all 30 fee relay sets and the fee selector. Another will be used to carry dialled impulses from the fee relay set to the fee selector, with the remaining 5 leads used in various combinations to effect multi-fee or unit fee discriminations, or forced release, depending on the strappings applied between them and the set of bank contacts on which the wipers are positioned by dialling.

The fee selector circuit includes two uniselectors and a bimotional switch with an 880-point bank. One uniselector is connected in a self-balancing bridge circuit to determine the resistance inserted in the "hold" lead by the fee relay set, and hence to determine which of the many possible fee selector access codes was dialled. Another uniselector responds to the first digit dialled into the fee selector circuit. If more digits are required to effect a fee determination, the bimotional switch will lift its wipers in accordance with the next digit, then take one automatic rotary step. On some levels this will be sufficient to effect a discrimination, but on many levels the first contact will be strapped to a special tag to prepare the circuit for receipt of a further digit, which steps the selector further into the bank. Discrimination will be effected according to the strappings applied to the set of uniselector and bimotional bank contacts on which the wipers come to rest. It is particularly important that shared equipment should not be unduly monopolised by any one call. To avoid this, the fee selector is arranged to signal a forced release to the fee relay set if dialling is so delayed that the fee selector has not discriminated within a short period after seizure.

Occasions will arise when a route to be multimetered leads to exchanges in only one charging area, so that all calls require the same charging rate. A simplified version of the "universal" type of fee relay set already described has been designed for use in these circumstances. Known as the "fixed" fee relay set, it is to be used with the same repeater as the "universal" type, and consists of 7 relays and a uniselector, only timing and not fee-determining functions being required of it. Its comparative simplicity is reflected in its space requirements—50 fixed fee relay sets and their associated 50 repeaters can be accommodated on a standard 10′ 6½″ x 4′ 6″ rack, which is the space required for 30 universal type fee relay sets and their associated 30 repeaters, after allowing for a shelf of fee selectors.

The only other items of equipment specially required for multimetering exchanges are the Pulse Relay Sets, to control the timing of calls by stepping the fee uniselectors. The Basic Pulse Relay Set is arranged to count 1-second pulses from the exchange master clock. Delivering a basic pulse to the fee relay sets early in each counting cycle, it is reset to commence a fresh cycle whenever the count reaches a value determined by shelf strappings, i.e., usually 9. The counting circuit consists of 4 relays and capacitors arranged as a 4-bit binary chain which, unless otherwise constrained, would recycle every $2^4 = 16$ seconds. Shelf straps can be arranged to cut short the count at any desired integer, and if necessary, to bring into play an auxiliary capacitor/relay binary counting stage to provide alternatively different 'finish' counts for basic pulse periods averaging values intermediate between adjacent integral numbers of seconds. (For example an average pulse period of 11½ sec. would be obtained by counting .....11, 12, 11, 12....secs.). The result is that by a suitable choice of shelf straps, the basic timing cycle (i.e. the length of 20 basic pulses) may be set to the usual 180 secs. or to any desired value in steps of 10 secs. from 320 secs. downwards. The pulse relay set does not function continuously—to minimise relay wear and current drain the circuit is arranged to operate only when a fee relay set pulsing relay is connected to the output pulse lead.

Normally one pulse every 9 seconds will be the only requirement, although subject to variation under certain conditions. It is possible that a different relationship between trunk and local (unit fee) call charges may be required later without affecting the proportionality of the various trunk charging rates. This would be met by changing the shelf straps to vary the basic pulse interval. Also, the use of a longer basic pulse interval provides a convenient way to simulate the concession rates now applying to trunk calls beyond a certain distance outside the busy hours. To this end the fee relay sets are arranged, to select one of three basic pulse leads (through fee storage relay contacts) according to the selected charging rate. During the day all three leads will connect to the normal (that is 9 sec.) pulse relay set. After hours, the pulse lead corresponding to the lower values will not be affected (that is, no concession), but if concession rates are to be applied the others will be time-switched from the normal pulse relay set to another (or others) strapped for slower pulsing. The provision of the three pulse leads mentioned allows a degree of freedom in choice of the line of demarcation between concession and non-concession rates, or (at the cost of an extra pulse relay set) of differential concessions.

An Auxiliary Pulse Relay Set is used to provide extra pulses between basic pulses for meter operation rates exceeding 20 pulses per timing cycle, if and when these are used. It consists of two relays which operate when certain combinations of operated counting relays occur in the associated Basic Pulse Relay Set, to earth the three auxiliary pulse leads one, two and three times respectively during each basic pulse cycle.

Numbering Considerations

As already mentioned, certain standardised numbering arrangements will be required in exchanges having multimetering facilities. For use before the introduction of national numbering, interim numbering arrangements have been so determined for multimetering exchanges as to allow a simple design for multimetering equipment, entirely avoiding the use of common control working in early installations. These will require multimetering facilities only for some calls within the local trunk area (possibly), to the nearby capital city subscribers' network and to the various manual services—discriminations which will be effected entirely within the fee relay set. Later on, dialling access to other trunk areas may be provided. Using either "open" numbering arrangements or conforming to a linked national numbering plan, common equipment (i.e., fee selectors) will then be required to extend the fee determination range for calls requiring such access.

It has been common practice to use the first selector level "O" in sub-metropolitan and country exchanges for access to manual operators. That is, dialling "O" advances the call to a situation where trunk switching can be effected. For subscribers connected to major exchanges this may involve only a selector action, but in other cases it involves extension of the call over a trunk or junction line to a trunk switching centre, which may be within the originating trunk area or outside it (e.g., at Sydney for Avalon). The substitution of switching equipment for manual operators on trunk calls will not usually affect the exchange-to-exchange routing of such calls, but only their handling within exchanges. In many cases there will be no difference in routing within exchanges other than the trunk centre at which the telephonist is located. Subscriber-dialled and operator-dialled traffic may even share switching equipment and trunk channels.

Usually, for the larger automatic exchanges, second selectors have been provided to sub-divide the "O" level for various purposes, such as:—

- 01—Demand trunk calls and trunk booking, from subscriber.
- 02—Trunk enquiry.
- 03—Information.
- 04—Time Service.
- 05—Phonograms, from subscribers.
- 06(5)—Phonograms from public telephones.
- 07—Demand trunk calls and trunk booking from public telephones.
- 00—Complaints.

These manual services will still be required for multimetering exchanges, although traffic to the group should fall substantially due to diversion of trunk calls from manual operators to automatic routes. (As mentioned already, it will still be possible for subscribers to seek manual operator assistance in setting up trunk calls to destinations within dialling range, although usually subject to financial discouragement). This reduction in traffic, coupled with new requirements of second selector levels for extended dialling, justifies displacement of the manual services to 3rd selector levels (for multimetering exchanges, of course — existing standard codes will otherwise be retained). The addition of an extra "O" in front of the present manual area dialling codes, as listed above, is the most convenient arrangement, being ideal for discrimination purposes in the fee relay set and presenting little extra effort to subscribers who have memorised the existing manual codes.

The fact that this will often result in apparently spare "O" second selector levels—which could be utilised for some manual services (the number varying from place to place according to level requirements) with a consequent small reduction in the required number of "00" third selectors—is offset by the advantage of standardised dialling codes. In rare cases where (among other conditions) it is desired to provide the manual trunk services within the originating trunk area, although necessary to route level "O" outside the area, it may be necessary to depart from the standard numbering by substituting X01-X00 or (rarely) A01 – A00 for 001–000. This has been allowed for in the design of the fee relay set.

The parent metropolitan unit fee network is usually the major destination for traffic leaving sub-metropolitan areas, receiving well in excess of any other kind of traffic. An important principle, that heavy traffic should be carried through as few switching stages as possible, indicates that an "O" second selector level should be used for this purpose. To minimise switch wear and current consumption, it is convenient to standardise on level "01" for this traffic which, on leaving the "O" second selector, will be routed to a local unit fee network first selector to take the first digit of the desired subscriber's number. The result is that subscribers at (say) Avalon will prefix "O1" to dialled calls to (say) Sydney network numbers. As previously mentioned, the fee-rate may be determined by the first digit of the wanted subscriber's number, i.e., by the digit following "O1", although fee determination on "O1" is likely to be the usual arrangement ultimately.

Other selector levels in the "O" range are required for "cross-country" calls. It is desired to provide for the possibility of eventually reaching over 10 basic trunk areas (i.e., local network areas), which would require the use of "O" third selectors trunked from "O" second selector levels. Fee discrimination would be effected usually on the first digit of the required subscribers' network number—i.e., the fourth digit dialled, using fee selectors to postpone and extend the range of fee determination. For spare network codes, and the Mobile Radio Telephone code O61, the third digit will suffice—a condition specially catered for in the design of the fee selector.

The arrangements described in the previous two paragraphs will be suitable until a linked national numbering scheme comes into use for subscriber-dialled trunk traffic. The provision of extended dialling facilities without linked national numbering will complicate telephone Directory dialling instructions, although to a degree which is not expected to be important for years. However, prior necessity for linked national numbering on subscriber-dialled trunk calls is likely to arise from the mixing on common trunk routes of subscriber-dialled traffic with register-routed traffic from operators using national numbering arrangements. Work is proceeding on a fee selector design along the lines indicated earlier, to cater for national numbering conditions as well as the simpler interim numbering conditions, in an effort to ensure that the multimetering equipment should not be out-moded as long as switching equipment to present or compatible designs continues to be put into service.

Possibility of Introducing Multimetering on Widespread Scale

Although there appear to be many cases where multimetering could result in substantial overall savings in the cost of running the telephone system, its introduction will be cautiously restricted at first. The initial installations, either at St. Marys or Avalon and Palm Beach exchanges to multimeter traffic to the adjoining Sydney unit fee network, will be carefully watched to assess public reaction to the system. Future ordering of multimetering equipment is likely to be very much influenced by the degree of enthusiasm shown by the public towards the early installations.

This is of course not the only factor to be considered. The additional costs involved in new exchanges by the use of multimetering equipment instead of auto-auto repeaters will be quite a small part of the total, but installation in existing exchanges of suitable type will be relatively more costly, even though the major part of the recovered material will be readily reusable. Some of the older exchanges have unsuitable metering systems which would require replacement or radical modification for multimetering The resultant high costs would render the installation of multimetering equipment unlikely although, as in suitable manual exchanges, it may be practicable to instal a relatively small separate group of modern automatic equipment with multimetering (as an exchange within an exchange) for the connection of high-trunk-usage subscribers to obtain substantial manual operator relief. Such equipment is likely to consist of subscribers' uniselectors, meters, repeaters and fixed fee relay sets only, to couple special lines from suitable subscribers to a special group of trunk channels terminating in a capital city network (i.e., on first selectors).

However, a factor tending to limit the extent of multimetering will be the necessity to provide additional trunk channels in many cases. The multimetering equipment installation programme must be closely linked to that for trunk channel provision, and since the latter is lagging well behind present requirements, the installation of multimetering equipment may be rather restricted for some time at least. A seriously inadequate number of trunk channels can be used successfully (although with substantial delays to callers) under manual switching conditions, but would provide intolerably poor service under automatic access conditions. Some automatic exchanges like Avalon and Palm Beach are at present arranged for subscriber's automatic access to their parent trunk centre over trunk circuits whose number has been kept up to a level sufficient to avoid serious congestion, and these should present little difficulty in this regard.

One point which remains to be elucidated, although of great interest, because in effect it determines the maximum range of calls to be multimetered, is—what is the maximum meter pulsing rate which will be generally acceptable to subscribers? Only experience yet to be gained with working multimetering exchanges can supply the answer.

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. 3747—Engineer, Transmission
Section 1—Long-Line Equipment.

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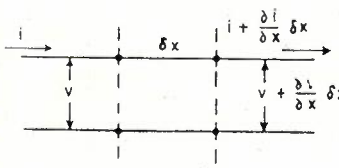
Q.1.—Derive an approximate formula for the velocity of propagation on a symmetrical transmission line.

Indicate approximate values of the velocity of propagation at 100 c's and 100 kc/s on 200 lb., 9 inch spaced open wire and 40 lb. carrier cable pairs. Explain why such values are realised.

A.—Consider the voltages and currents in the element δx of a symmetrical line with the primary constants per unit length of R ohms, L henries, G ohms, C farads.



Q.1—Fig. 1.

The element is shown diagrammatically in Fig. 1, and the following relationship can be derived.

$$v - \left(v + \frac{\partial v}{\partial x}\delta x\right) = R\,\delta x\, i + L\,\delta x \frac{\partial i}{\partial t}$$

(Considering i constant with respect to x) and

$$i - \left(i + \frac{\partial i}{\partial x}\delta x\right) = G\,\delta x\, v + C\,\delta x \frac{\partial v}{\partial t}$$

(Considering v constant with respect to x)

whence
$$-\frac{\partial v}{\partial x} = Ri + L\frac{\partial i}{\partial t} \;.\;.\;.\;.\;.\; \text{(i)}$$
$$-\frac{\partial i}{\partial x} = Gv + C\frac{\partial v}{\partial t} \;.\;.\;.\;.\;.\; \text{(ii)}$$

Equations (i) and (ii) are the partial differential equations governing the conditions on the line. Partial deviations are used as both v and i are functions of the two variables x and t.

The particular solution of these equations which is required is that for which v and i are simple harmonic functions of the time t

let $v = Ve^{j\omega t}$
$i = Ie^{j\omega t}$

where V and I are functions of the variable x only. Then substitution in equations (i) and (ii) gives

$$-\frac{dV}{dx} = (R + j\omega L)\, I \;.\;.\;.\;.\;.\;.\;.\; \text{(iii)}$$
$$-\frac{dI}{dx} = (G + j\omega C)\, V \;.\;.\;.\;.\;.\; \text{(iv)}$$

eliminating I from equation (iii)

$$\frac{d^2V}{dx^2} = (R + j\omega L)(G + j\omega C)\,V$$
$$= (\alpha + j\beta)^2 V \;.\;.\;.\;.\;.\;.\;.\;.\;.\; \text{(v)}$$

Differential equations of this form are satisfied by the steady state condition

$$V + Ae^{-(\alpha + j\beta)x} + Be^{-(\alpha + j\beta)x} \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\; \text{(vi)}$$

where A and B are arbitrary constants $\therefore$ from (iii)

$$I = -\frac{1}{R + j\omega L}\, A\left[-(\alpha + j\beta)e^{-(\alpha + j\beta)x}\right.$$
$$+ \beta(\alpha + j\beta)e^{-(\alpha + j\beta)x}$$
$$= \frac{\alpha + j\beta}{R + j\omega L}\left[\, A\,e^{-(\alpha + j\beta)x}\right.$$
$$\left. -\beta\, e^{-(\alpha + j\beta)x}\,\right] \;.\;.\;.\;.\;.\;.\; \text{(vii)}$$

Expression (vi) represents two voltage waves travelling in opposite directions and subject to an exponential decay $e^{-\alpha}$ per unit length of line, and a phase change of $-\beta$ radians per unit length.

Expression (vii) represents a similar current wave except that the phase of the backward travelling component is reversed relative to that of the voltage wave.

The change of phase of these waves equals βx, and for each wave length βx will change 2π radians.

i.e. $\beta\lambda = 2\pi$

or $\lambda = \dfrac{2\pi}{\beta}$

and as $\lambda = \dfrac{\text{velocity}}{\text{frequency}}$

$\therefore$ velocity of the waves $= \dfrac{2\pi f}{\beta} = \dfrac{\omega}{\beta}$

Velocity on 40 lb. carrier cable.

The primary constants of this cable are $R \doteqdot 44$ ohms/mile. $L \doteqdot 1$ m.H./mile. $C \doteqdot .06\ \mu$f/mile. $G \doteqdot 1\ \mu$ mho/mile.

at 100 c/s $R \gg \omega L$ and $\omega c \gg G$

$$\therefore \alpha + j\beta = [(R + j\omega L)(G + j\omega C)]^{1/2}$$
$$\doteqdot (j\omega CR)^{1/2}$$
$$\doteqdot \left(\frac{\omega CR}{2}\right)^{1/2} + j\left(\frac{\omega CR}{2}\right)^{1/2}$$
$$\therefore \beta \doteqdot \left(\frac{\omega CR}{2}\right)^{1/2}$$

i.e. $\dfrac{\omega}{\beta} \doteqdot \left(\dfrac{2\omega}{RC}\right)^{1/2} \doteqdot 22{,}000$ miles/sec.

i.e. velocity at 100 c/s approximates 22,000 miles/sec. on the assumption made above.

at 100 Kc/s $\omega L \gg R$ and $\omega C \gg G$

$$\therefore \alpha + j\beta = [(R + j\omega L)(G + j\omega C)]^{1/2}$$
$$\doteqdot [j\omega(RC + LG) - \omega^2 LC]^{1/2}$$
$$\doteqdot j\omega\sqrt{LC}$$
$$\therefore \beta \doteqdot \omega\sqrt{LC}$$

i.e. $\dfrac{\omega}{\beta} \doteqdot \dfrac{1}{\sqrt{LC}} \doteqdot 130{,}000$ miles/sec.

i.e. velocity at 100 kc/s approximates 130,000 miles/sec.

Velocity on O/W line

The primary constants of a 200 lb 9″ spaced line are approximately
$R = 8.8$ ohms/m. $L = 3.5$ m.H/m.
$C = .009\ \mu$f/m. $G = 5\ \mu$ mhos/m.

at 100 c/s $R > \omega L$ and $G \doteqdot \omega C$

$$\therefore \alpha + j\beta = [(R + j\omega L)(G + j\omega C)]^{1/2}$$
$$\doteqdot [RG + j\omega(RC + LG) - \omega^2 LC]^{1/2}$$
$$\doteqdot [j\omega(RC + LG)]^{1/2} \doteqdot (j\omega CR)^{1/2}$$
$$\doteqdot \left(\frac{\omega CR}{2}\right)^{1/2} + j\left(\frac{\omega RC}{2}\right)^{1/2}$$
$$\therefore \beta \doteqdot \left(\frac{\omega RC}{2}\right)^{1/2}$$

i.e. $\dfrac{\omega}{\beta} \doteqdot \left(\dfrac{2\omega}{RC}\right)^{1/2} \doteqdot 125{,}000$ miles/sec.

i.e. velocity at 100 c/s approximates 125,000 miles/sec. on the assumptions made above at 100 kc/s $\omega L \gg R$ and $\omega C \gg G$ therefore as for the cable case above $\beta \doteqdot \omega\sqrt{LC}$

i.e. velocity $\doteqdot \dfrac{1}{\sqrt{LC}} \doteqdot 180{,}000$ miles/sec.

The above results indicate the various velocities resulting from the application of the different frequencies to the different types of line, and show that these velocities depend on the primary constants.

Q.2.—Define the following terms and write down the equations relating thereto:—

(i) return loss.

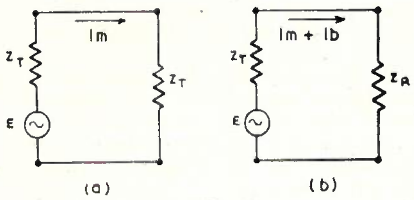
(ii) reflection loss.

Where are these losses significant in the design and installation of carrier systems?

A.—(i) Return Loss.

Return loss is a logarithmic measure of the relationship between the current reflected from a mismatched junction of impedance to that which would be transmitted under reflectionless conditions. Consider the conditions in figure 1 (a) and (b).

from Fig. 1 (a) $E = 2\, Z_T I_m$
from Fig. 1 (b) $E = (Z_T + Z_R)(I_m = I_b)$
where I_b reflected current
i.e. $I_m\,(2Z_T - Z_T - Z_R) = I_b\,(Z_T + Z_R)$



Q.2—Fig. 1.

i.e. $\frac{I_m}{I_b} = \frac{Z_T + Z_R}{Z_T - Z_R}$

and the return loss

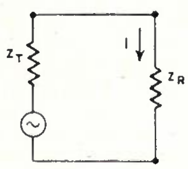
$$= 20 \log_{10} \left| \frac{Z_T + Z_R}{Z_T - Z_R} \right|$$

This relationship also derives directly from the ratio of the forward and backward current and voltage waves given by the long line equations for a terminated line. It also expresses the relationship between the voltamps reflected from the mismatch to that which would be delivered under matched conditions.

The inverse reflector coefficient $\frac{Im}{Ib}$ is a vector quantity and a relationship exists between its modulus and Z_R and Z_T, when Z_T is a fixed resistance, such that all the possible impedances Z_R which give a fixed return loss against Z_T lie on a circle whose radius and centre depend on the return loss.

(ii) Reflection Loss.

The reflection loss in a circuit relates the voltamps delivered under unmatched conditions to that delivered under matched conditions. Consider the circuit of Fig. 2.



Q.2—Fig. 2.

voltamps delivered to load

$$P = I^2 Z_R = \frac{E^2}{(Z_T + Z_R)} \cdot Z_R$$

under matched conditions voltamps delivered $P_m = \frac{E^2}{4 Z_T^2} \cdot Z_T$

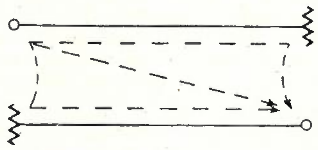
$$\therefore \frac{P_m}{P} = \frac{(Z_T + Z_R)^2}{4 Z_T Z_R}$$

$$= \left[\frac{Z_T + Z_R}{2 \sqrt{Z_T Z_R}} \right]^2$$

i.e. reflection loss in db

$$= 20 \log_{10} \left| \frac{Z_T + Z_R}{2 \sqrt{Z_T Z_R}} \right|$$

Considerations (i) and (ii) above are important because they can degrade the cross talk characteristics of installations, increase the total insertion loss of equipment, and cause frequency and delay distortions. On carrier bearer circuits near end cross talk can be reflected and appear as far end cross talk, as indicated in Fig. 3.



Q.2—Fig. 3.

paths II and III are alternative termination reflections, and show the need for the termination of both ends of a carrier bearer in an impedance which closely matches the bearer impedance. It is also important to have the bearer impedance constant throughout its length, as for example in the close matching of carrier cable sections with respect to mutual capacity characteristics.

The reflections at junctions of cable and open wire lines must also be controlled, and one means of doing this is by loading the cable so that its impedance is raised to that of the open wire. Office wiring should also be considered with respect to mismatches. The equipment impedance of 3 channel open wire systems approximates 600 ohms and office cable 130 ohms which means that the length of cable used cannot be longer than approximately 60 feet for a 26 db return loss (5% reflection). For similar reasons incoming paper insulated cables should not be terminated with silk and cotton tails.

The balance between the compromise network in the four wire terminating sets and the equipment drops is important, as the return losses have a considerable effect on echo performance and singing margin.

Reflection effects from mismatched junctions cause circuit impedance variations with frequency. These impedance variations cause variations in the power being absorbed by the equipment concerned so that distortion results in the gain frequency response. Impedance changes throughout carrier equipment are carried out by means of matching transformers or pads.

Reflection losses will give measuring errors if the impedance of the circuit differs from its nominal impedance, and the impedance of the meter used equals the nominal impedance. The error can be calculated directly from the reflecttion loss formula and should be added to the reading obtained. To obviate this the impedance of system measuring points are specified with a minimum return loss of 20 db and the design of the equipment must take this into account.

Q.3.—What performance characteristics would you include in a specification for a multi-channel carrier amplifier? On what basis would you determine the specification limits for each characteristic?

A.—The performance characteristics required for a multi-channel carrier amplifier would include the requirements for impedances and levels, gain and frequency response, power handling capacity, harmonic distortion, and noise output. Details of the characteristics required and the basis of the limits are as follows.

General. The amplifier should not oscillate under any working condition, or if the input and output circuits are open or short circuited.

Impedances and Levels. The input and output impedances would be specified together with the allowable return loss from the nominal impedance, which would be based on the crosstalk characteristics of the associated circuits. This would lead for example to a specified output of 140 ohms for a cable carrier amplifier, with a return loss limit of 20 db against this nominal impedance. Specification of these impedances would also obviate measuring errors as discussed under Question 2 above.

The relative level required per channel would also be stated. The level required is based on the system and circuit characteristics.

Gain and Frequency Response. These requirements would set down whether fixed or adjustable gain is required, the frequency range to be covered, the actual gain required, and any particular gain-frequency response required. The frequency responses are usually flat over the normal working range of the amplifier. These requirements are also based on the system and circuit characteristics.

Power Handling Capacity. This would normally be specified so that the overall gain would not decrease by more than 1 db when the output power is increased from one specified level to another. For example this 1 db limit would apply to a J line amplifier for an increase in output power from +30 dbm to +36 dbm. The testing frequency would be the mid-frequency of the band transmitted. This requirement is based on the number of channels to be provided, the level to which each channel must be amplified, and the probable fluctuations in the speech power in the channels. Allowance is also made for factors which can cause variations between different installations, as for example power supply variations.

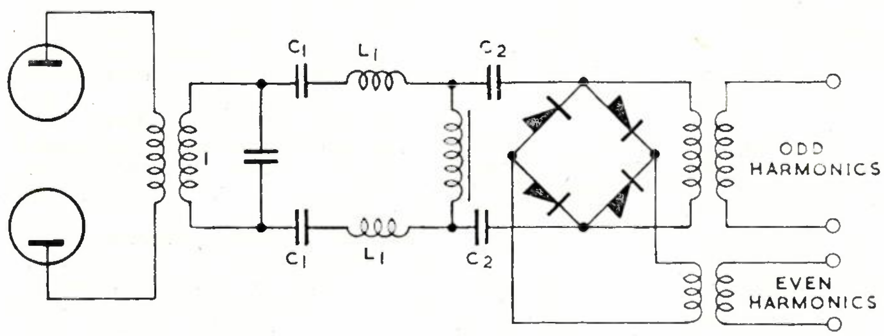
Harmonic Distortion. To avoid inter-channel interference the amplifier should not produce any appreciable harmonics of any frequency within its frequency range. An acceptable figure is −70 db below the relative level, which means for a K amplifier that for a single frequency output of +5 dbm in the range 12-108 Kc/s, the harmonic products cannot be greater than −65 dbm.

Noise. The noise produced by the amplifier should be specified to such a figure that the required circuit signal-noise ratio is maintained. The normal specification is that the total noise at the output of the amplifier in any 4 Kc/s band throughout the transmitted frequency range weighted in accordance with C.C.I.F. 1949 specification shall not exceed −70 db below the relative level.

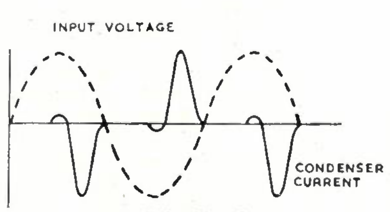
Q.4.—Discuss the principles and methods of generating carrier frequencies in a modern multi-channel carrier telephone system.

Give reasons for the choice of all carrier frequencies used throughout the terminal equipment of a 12 channel open wire system using crystal filters.

A.—The channel carrier frequencies used in modern multi-channel carrier systems are derived from a base frequency of 4 Kc/s by means of harmonic producing devices. In J and K systems the base frequency is generated by an oscillator controlled by a tuning fork or crystal, the long term stability of which is better than 5 parts per million. Group carrier frequencies are generated as harmonics of the 4 Kc/s supply and also the harmonics of a 5 Kc/s master oscillator as required. The 5 Kc/s oscillator is of similar stability to the 4 Kc/s oscillator, and the above figure of 5 parts per million is met with power supply variations of ± 10% and ambient temperature variations of 50°F - 115°F.



Q.4—Fig. 1.



Q.4—Fig. 2.

The output of the master oscillator is amplified in two stages to an output of approximately 4 watts and is then applied to the circuit sketched in Fig. 1.

The tuned circuit I is resonated to 4 Kc/s and so effectively removes other frequencies present, and the series condensers C1 and inductances L1 are resonant at 4 Kc/s so that a pure sine wave of 4 Kc/s reaches the non linear coil L2. This coil is physically small and has a core of permalloy ribbon which saturates at relatively low current values.

When the core saturates the charge on the condensers C2 discharges through the low impedance presented by the coil, giving the sharply peaked current waves sketched in Fig. 2. A Fourier analysis of this wave shows that it is rich in odd harmonics of the applied 4 Kc/s wave, and that up to very high frequencies the amplitudes of all these harmonics are approximately equal. To produce the even harmonics the full wave rectifier shown in Fig. 1 is used, and the odd and even harmonics are then selected by appropriate filters. This separation of odd and even harmonics simplifies the design of the selecting filters, as the frequencies in each output are separated by 8 Kc/s. The carrier frequencies are supplied from a low impedance source to a separate distribution busbar, and the distribution to the individual terminal units is effected through balanced isolating resistances. The higher powers required for group modems are obtained by suitable amplification after the group supply filter.

Master oscillators are provided in duplicate, one normally carrying the load, and the other automatically picking up the load on the failure of the regular carrier supply. No appreciable interruption is caused by this transfer. The emergency oscillator is held inoperative by a bias voltage derived from the regular supply, and the outputs of both oscillators are taken to the filters via hybrid coils.

The group frequencies required for "staggering" purposes are derived by modulating a suitable frequency from the 4 Kc/s master oscillator with the output of the 5 Kc/s master oscillator.

The choice of the carrier frequencies used in the terminal equipment of a 12-channel open wire system using crystal filters is based on the following factors.

Line frequencies of approximately 36-140 Kc/s are used to enable a 3 channel system to be operated on the same bearer. In the low frequency direction (B-A) the line frequencies for normal and staggered systems are the same but only require inversion. In the A-B direction both staggering and inversion is necessary to obtain suitable crosstalk characteristics.

The channel frequencies used are the lower sidebands of the 12 carriers 64 . . . 108 Kc/s. This band is selected because it allows an economical design of crystal channel filter which in turn gives a compact filter with a steep cut off in the stop band. It also ensures that all second harmonics fall outside the band so that interchannel interference is reduced.

As this band of channel frequencies overlaps the line frequencies necessary, group modulation is required. The first group modulation is done with a frequency of 340 Kc/s, and the upper sideband of 400-448 Kc/s is selected. This group is well outside the channel frequencies and final line frequencies. The band 400-448 Kc/s is then group modulated a second time to produce the line frequencies required, that is 36-84 Kc/s in the case of a B terminal or 92-140 Kc/s (approx.) in the case of an A terminal. This second group modulating frequency is chosen to give any staggering or inversion required.

Pilot frequencies are injected at the first group modulator and allow the operation of automatic gain regulation. The pilot line frequencies in the A-B direction are 143 Kc/s (slope) and 92 Kc/s (flat) and in the B-A direction 80 Kc/s (flat) and 40 Kc/s (slope).

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