The
Telecommunication Journal
of Australia

VOL. 7, NO. 2 Registered at the General Post Office, Melbourne, for transmission by post as a periodical. OCTOBER, 1948

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The
Telecommunication Journal
of Australia

Vol. 7, No. 2 October, 1948

INSTALLATION OF JUNCTION CARRIER SYSTEM (NEWTOWN-MIRANDA)

O. J. Connolly, B.Sc. G. R. Lewis, B.E., A.M.I.E. (Aust.)

INTRODUCTION

Due to the shortage of junction cable facilities in the Sydney Metropolitan Area, and the large amount of conduit and cable work required on many of the routes, an investigation was initiated in 1945 of the possibility of providing junction relief by means of carrier systems superimposed on existing cable pairs.

In carrying out this investigation, routes on which there was no spare cable duct, and on which relief measures were not expected to be completed within 12 months, were given first consideration. Other factors which were considered included route length, conductor weight, expected attenuation characteristics, the extent of the shortage of junctions, and the amount of floor space available for the installation of carrier equipment.

Because of shortages of material and the demands existing throughout the Metropolitan network and the State generally for line plant, cases of this kind were not likely to be given relief for at least two years, and probably much longer.

After consideration of the various junction routes in relation to the above factors, and although the provision of junction circuits by carrier methods is in general more costly than by normal means, there was justification in several cases for the installation of carrier junctions.

Of these, the Newtown-Miranda route was an outstanding case. It was decided, therefore, to carry out tests to ascertain whether the provision of carrier systems could be applied to give relief on this route.

LINE MEASUREMENTS

Details of the cable facilities which were available on the Newtown-Miranda route are shown in Fig. 1. The cable pairs consisted of 40-lb/mile and 20-lb/mile conductors, and in the case of 106 pairs out of a total of 139 junction pairs the conductor weight was 40-lb/mile over a distance of approximately 9 miles, and 20-lb/mile for the remaining 3 miles. Between Newtown and Kogarah this cable was of the multiple twin trunk type, and between Kogarah and Miranda star quad local cable was in use.

Measurements were made of circuit equivalents on a few non-loaded pairs in the group of 106 pairs, and results of these measurements are shown in Fig. 2. The maximum noise level measured on these pairs was –66db referred to 1mw with a 3 kc/s high-pass filter interposed between the line and measuring equipment.

As two cables of suitable type were not available over the whole of the route, it was evident that a carrier system using different frequencies in the "go" and "return" directions would be required. Near-end crosstalk conditions in the junction cables would preclude the use of the same frequencies in both directions of transmission in the same cable.

The next stage of the investigation was concerned with ascertaining how many cable pairs in the group of 106 pairs could be selected, with satisfactory far-end crosstalk characteristics over the required frequency range.

As only a few non-loaded pairs were available on the Newtown-Miranda route, a preliminary investigation was made of crosstalk on a group of 26 non-loaded pairs in the 20-lb/mile star-quad cable between Newtown and Rockdale, a distance of 4.7 miles. It was expected that results on this cable would be similar to those to be obtained on the Newtown-Miranda cables. These measurements, made at a frequency of 50 kc/s, indicated that at least 25% of the pairs tested had satisfactory crosstalk between each other.

As a result of this investigation, orders were placed for the supply of twelve six-channel carrier systems, with grouped frequencies for "go" and "return" directions of transmission, for the Newtown-Miranda route. The next step, therefore, was the selection of cable pairs with satisfactory crosstalk characteristics, from the 106 available pairs.

It will be seen by reference to Fig. 1 that, due to the fact that there were two spacings of loading coils, namely, 6000 feet and 10,000 feet, on portion of the route, it was necessary to remove

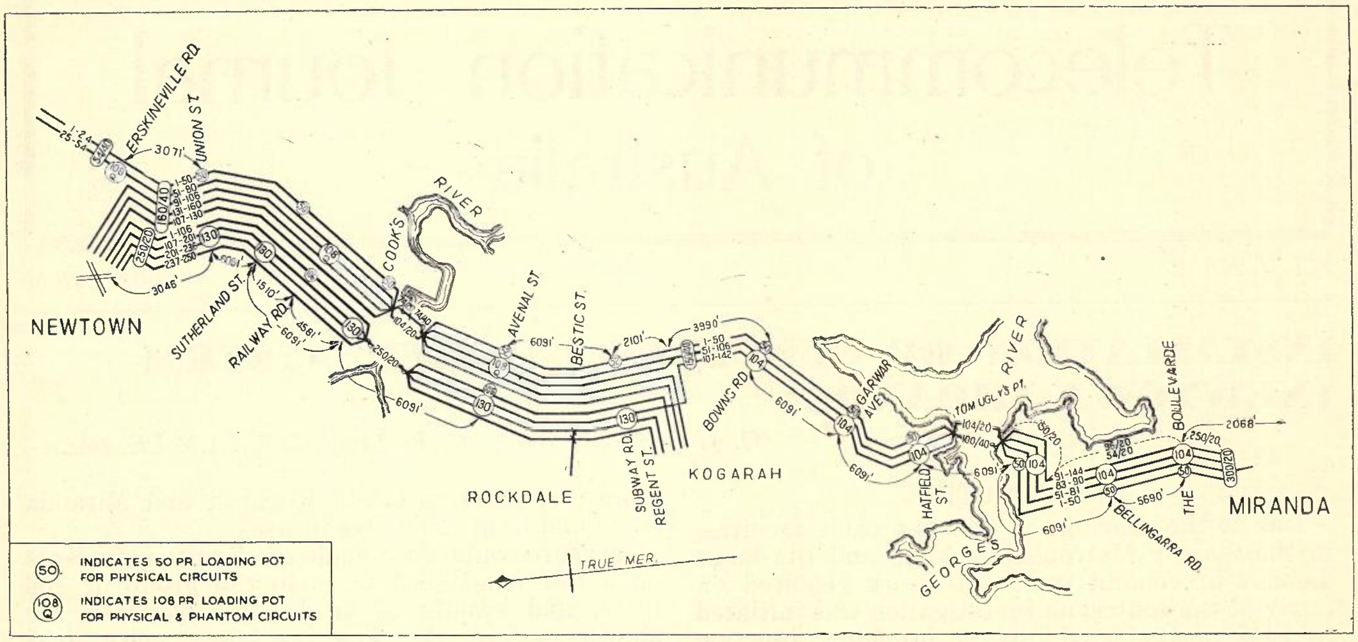

Fig. 1.—Map showing cable facilities, Newtown-Miranda.

loading coils at a total of 12 loading points before crosstalk tests could be carried out. In order to minimise handling of cable joints, it was decided to remove all loading coils at one operation, as expeditiously as possible, and to make crosstalk tests on all pairs before re-connecting the loading coils. In this way the full capacity of the cables to accommodate carrier systems was ascertained, and the necessity for any future operation on the cables, other than to remove loading coils from specified pairs, was obviated.

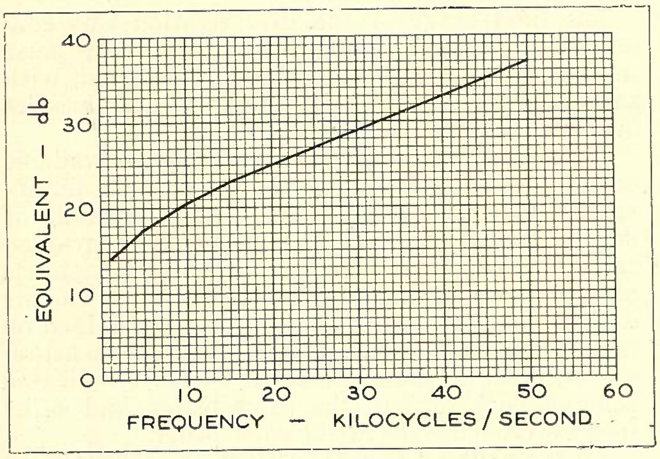

Fig. 2.—Typical cable pair equivalent, Newtown-Miranda.

During the removal of loading coils from the cables, a cable-jointer was located at each loading point, and, as soon as a group of a few cable pairs had been taken out of traffic, all jointers commenced the work of cutting out the loading coils.

An order wire circuit was provided between the controlling testing officer and each cable-jointer. The difficulties associated with correctly identifying the cable pairs at each loading point and cutting the pairs through clear of the loading coils will be readily appreciated. The work of removal of loading coils occupied about four days. After completion of removal of loading coils from each group of pairs, the pairs were tested and restored to traffic, and the removal of coils from the next group of pairs was commenced.

On completion of this work, the attenuation of each pair was tested at 50 kc/s to prove that all loading coils had been removed and in order to detect any other faulty condition.

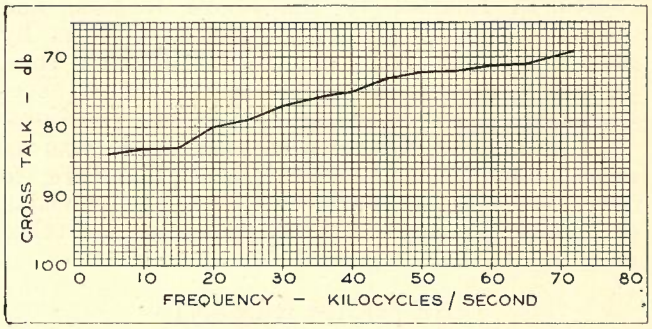

Fig. 3.—Far-end crosstalk versus frequency between two suitable pairs.

The far-end crosstalk measurements were made at night, in order to minimise interference to working junction circuits, and to enable speedy testing. As a number of measurements of crosstalk versus frequency (see Fig. 3) had established that crosstalk in the cable increased with frequency, the measurements were made at a frequency of 50 kc/s.

Approximately 5,000 measurements were required in order to ascertain the crosstalk conditions in the group of 106 cable pairs. From an analysis of the crosstalk figures a group of 30 pairs was selected, and details of the crosstalk between these pairs are shown in Fig. 4. The 12 pairs to be used immediately as carrier system bearers, plus a further 12 pairs for later use if required, were selected from this group. Impedance versus frequency measurements on a typical pair are shown in Fig. 5.

After completion of crosstalk tests, the loading coils were re-connected to all cable pairs except those selected for use with the initial installation of 12-carrier systems. A check of attenuation was then made on all pairs to ensure that the

PAIR NUMBERS OF CABLE

PAIR NUMBERS

	2	3	4	9	10	12	13	14	15	16	17	19	21	26	27	29	31	34	35	41	46	49	51	52	53	55	57	61	62	64
2																														
3	64	3																												
4	60	56	4																											
9	71	80	78	9																										
10	72	80	72	62	10																									
12	68	69	80	69	65	12																								
13	77	63	60	65	57	68	13																							
14	82	58	78	64	62	73	60	14																						
15	57	59	67	90	69	65	77	75	15																					
16	74	64	59	68	71	63	62	76	53	16																				
17	67	65	66	76	59	90	62	70	59	63	17																			
19	64	71	72	73	81	79	70	84	70	63	77	19																		
21	71	64	75	72	70	70	72	71	60	62	68	68	21																	
26	65	69	71	74	70	83	70	75	62	58	59	75	67	26																
27	63	63	67	69	84	69	80	76	76	77	76	80	80	69	27															
29	71	88	77	69	73	90	71	83	75	73	72	64	74	55	64	29														
31	88	80	67	66	84	77	72	61	73	82	74	71	72	75	60	73	31													
34	83	74	74	74	62	64	74	74	69	81	90	81	81	82	56	67	64	34												
35	83	76	77	73	69	56	70	79	72	68	67	80	84	68	61	78	61	58	35											
41	61	80	78	90	74	70	82	78	74	74	63	72	64	65	90	86	75	67	82	41										
46	62	71	74	88	70	83	85	76	78	68	66	57	73	89	78	63	81	75	83	63	46									
49	66	78	74	81	71	72	77	83	75	77	71	66	80	75	82	61	73	90	72	68	71	49								
51	83	67	72	68	78	65	70	73	78	73	74	74	73	67	78	80	59	63	65	90	72	82	51							
52	88	78	90	84	81	68	71	80	65	85	86	69	90	78	81	79	61	72	67	90	83	74	58	52						
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55	75	78	70	81	68	90	77	73	90	74	74	78	76	70	70	72	68	67	68	88	89	79	73	67	69	55				
57	84	82	84	61	64	81	65	77	84	74	82	87	78	75	77	64	80	70	90	89	83	73	84	83	71	59	57			
61	83	86	83	63	59	90	67	68	79	82	73	77	69	79	70	79	68	74	75	90	81	74	67	90	88	64	76	61		
62	85	71	82	56	60	77	65	67	81	79	87	73	80	75	71	74	69	81	72	81	76	77	71	72	77	55	61	46	62	
64	77	88	90	85	79	67	86	81	90	78	76	77	78	85	70	80	84	65	66	73	90	75	79	82	64	59	81	69	64	64
	2	3	4	9	10	12	13	14	15	16	17	19	21	26	27	29	31	34	35	41	46	49	51	52	53	55	57	61	62	64

MEASURED AT 50 Kc/s FROM NEWTOWN TO MIRANDA

Fig. 4.—Far-end crosstalk chart.

loading coils had been re-connected correctly and that the 12 selected pairs were still non-loaded.

Arrangements were made to terminate the 24 selected pairs, including the 12 non-loaded pairs, on a special cable head adjacent to the carrier equipment at each station. Pending completion of the carrier system installation the 24 pairs were connected back to the main frame at each exchange by means of a tie cable.

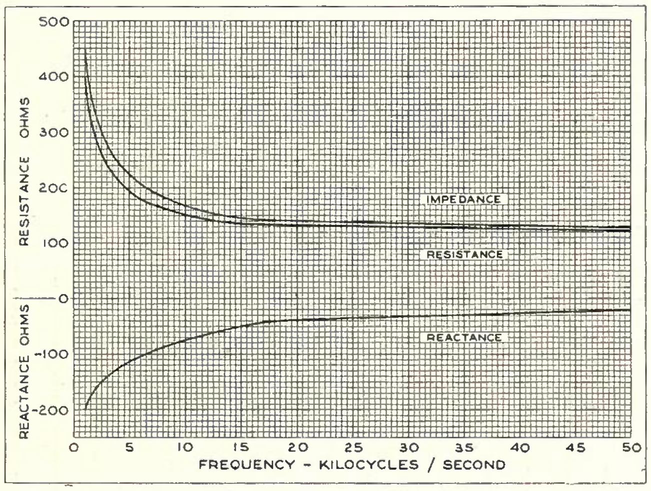

Fig. 5.—Characteristic impedance of typical cable pair.

GENERAL DESCRIPTION OF EQUIPMENT

Fig. 6 is a photograph of the junction carrier installation at Miranda. Four systems have been installed and additional systems will be brought into operation in the near future. The cable-terminating bay is at the left, situated next to the combined carrier supply and power bay. The two bays at the right each accommodate the terminal equipment for two systems.

Included on the carrier supply and power bay are six carrier frequency oscillators and associated carrier supply equipment. These are capable of supplying up to twelve carrier terminals. When the bay is fully equipped it accommodates seven power panels in addition to the carrier supply equipment. One of these panels is required for the operation of the carrier supply equipment, while the others are fitted, as required, on the basis of one for each carrier terminal. When more than six carrier terminals are installed, a second power bay is provided for mounting the additional power panels. This second power bay is not fitted with carrier supply equipment.

The bays are of standard 3 inches x 1½ inches channel iron construction, 10 ft. 6 inches high and 20¼ inches wide. The components of the various circuit units are mounted on steel mounting plates of the usual type and the plates are provided with dust covers, some of which have ventilation louvres in the sides to assist heat dissipation. On the carrier terminal bays, the panels are arranged so that the equipment for one carrier system is at the front of the bay, while that for the other system is at the rear. The jack field, however, is flush-mounted at the front of the bay and is common to both systems. The channel relay sets for both systems are also mounted at the front of the bay, together with the alarm circuit relays. Each set of relays is provided with a separate dust cover and is mounted on a relay mounting plate, which is fastened to the bay panel by two screws. The wiring of each relay set is of sufficient length to allow the mounting plate to be drawn forward, clear of the adjacent relay sets, as required, for maintenance purposes. A fuse panel, equipped with alarm-type fuses, is mounted on each bay and distributes the power supplies for the bay. The fuse panel is mounted on the front of the bay in a central position and is provided with a metal cover. The alarm signal lamps are also mounted on this panel. A talking and monitoring panel is provided adjacent to the jack field on the terminal bay and incorporates dialling facilities. The oscillator oven is mounted on the carrier supply bay in a position directly below the jack field and adjacent to the panel on which the carrier oscillators are mounted. The tuned circuit components of each oscillator are mounted as a separate screened unit, together with similar units of the other oscillators, in a copper container. This container and the heating element are enclosed in a steel container, which is lined with heat-insulating material. The whole unit is fixed on a steel mounting plate complete with dust cover.

The interpanel wiring on each carrier terminal bay is run in forms which are accomodated in the space inside the channel iron sides of the bay and is terminated on terminal strips at the top of the bay. The wiring on the carrier supply and power bay is arranged in a similar manner, but includes the 240-volt A.C. wiring which is run from the A.C. distribution panel at the top of the bay to the power panels, and is completely enclosed in screwed conduit.

The carrier pairs from the junction cables are brought to the line-terminating bay in a 24-pair, paper-insulated, lead-covered cable, which is terminated in the internal type cable head which is shown at the top left corner of the line bay. U-links and sockets are built in to the cable head and the connections are arranged so that the cable pairs are terminated in numerical order, and a pair of U-links is in series with each cable pair, in order to facilitate line-testing.

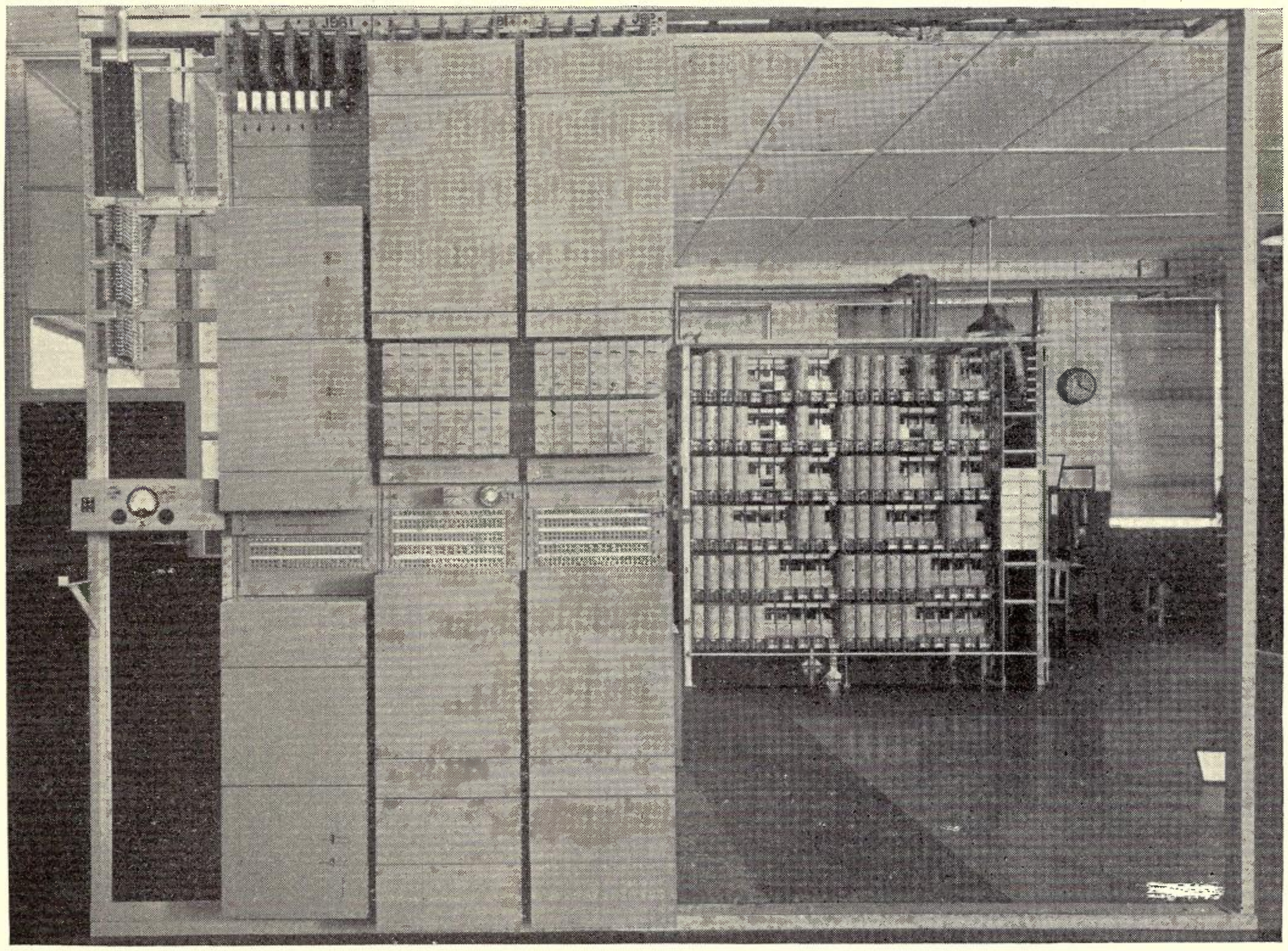

Fig. 6.—Junction carrier installation at Miranda.

Figs. 7a and 7b show the schematic arrangement of the 6-channel junction carrier system. The system is of the single side-band, transmitted carrier type, and different frequency groups are used in the two directions of transmission so that the equivalent of 4-wire operation is obtained over each cable pair.

The frequency allocation of the system is shown in Fig. 8. The channel numbering in the B-A direction has been arranged so that, as far as possible, the major portion of the near-end interference caused by transmitting on any particular channel in the A to B direction, will be received on the same channel in the B to A direction and will, therefore, be rendered substantially ineffective. Some of the factors which affect the near-end interchannel interference of a carrier terminal are the characteristics of the directional and band filters and harmonics of frequencies transmitted from the terminal. The interference will be greater at the terminal which receives the high group of frequencies, as this terminal will use relatively high gains in its receiving circuits.

The circuits of the carrier channels are identical, but, when connected between automatic exchanges, the channels will become either outgoing or incoming junctions, as far as an automatic exchange is concerned. The carrier terminal equipment includes a relay set for each channel, and this is connected between the carrier channel and the automatic exchange equipment. The relay sets are of two types for the outgoing and incoming ends of a channel respectively, and, as they are interchangeable, the channels of a system can be arranged as either outgoing or incoming junctions at a particular exchange. In the case of Newtown and Miranda, each carrier system provides three outgoing and three incoming junctions.

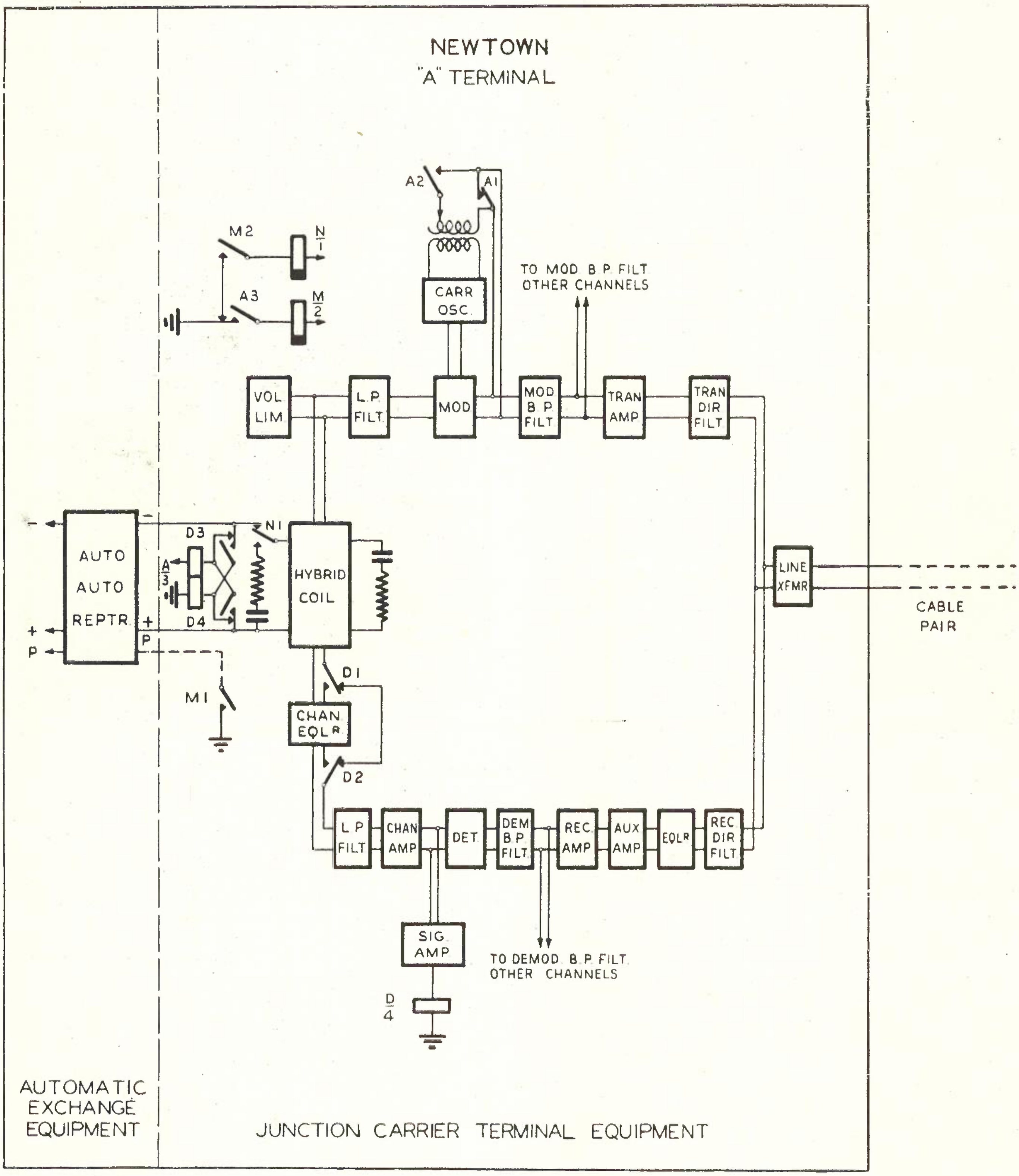

Fig. 7 (a).—Schematic circuit of junction carrier system—Newtown.

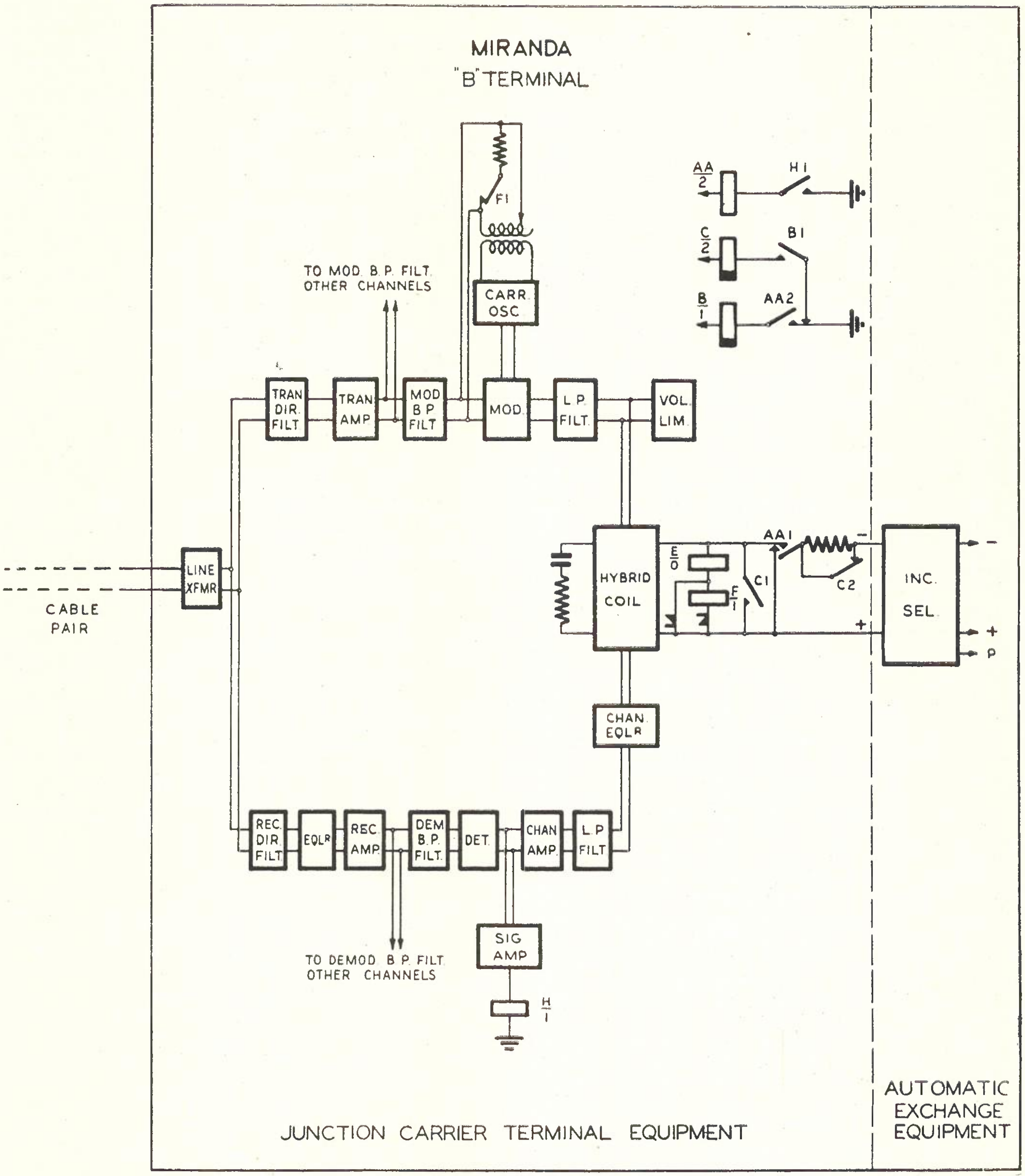

Fig. 7 (b).—Schematic circuit of junction carrier system—Miranda.

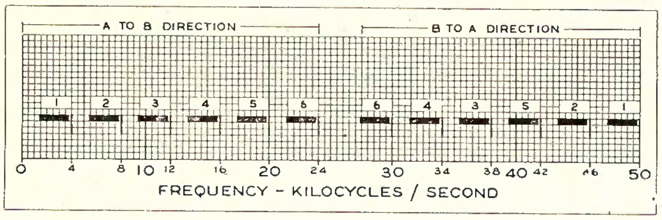

Fig. 8.—Channel frequency allocation.

CIRCUIT DESCRIPTION

Referring to Fig. 7, which represents a junction outgoing from Newtown, it is proposed to describe the circuit operation for the successive stages of a call, and to follow this with a brief description of each unit of the equipment.

Seizure of Junction Circuit

When the junction is seized, the auto-auto repeater presents a loop circuit to the A relay of the carrier channel. The A relay operates and at contact A2 completes a circuit for the transmission of carrier frequency current, from the carrier oscillator through a carrier transformer to the input of the modulator band pass filter. The secondary winding of the carrier transformer is tapped and is used to control the transmitted level of carrier frequency current. Contact A3 causes M relay to operate and prepare a circuit for the operation of N relay. Contact M1 connects ground to the private wire back to the automatic exchange equipment which, in some cases, may be a group selector instead of an auto-auto repeater. The band filters of the junction carrier system are not required to suppress those frequencies of the non-transmitted sideband, which are adjacent to the carrier frequency, to as high a degree as the band filters of a suppressed carrier system. Consequently, the attenuation offered by the band filters to the carrier frequency current is not high and is only about 5 db higher than the attenuation offered by the filter to a current of sideband frequency corresponding to the 1000 c/s frequency of the channel. After passing through the modulator band pass filter, the carrier frequency current is amplified to a level of +13 db with respect to 1 mw and is then transmitted through the directional filter and line transformer to the cable pair. As referred to later in the paper, high noise measurements were obtained at Newtown and, in order to improve the signal-to-noise ratio, the level of sideband current for each of the channels of the system was increased by 9 db. Under these circumstances the level of +13 db represents a limiting condition.

At the distant carrier terminal, the current, having been attenuated by transmission over the cable pair, passes through the line transformer, the receiving directional filter and equaliser and the receiving amplifier. At this point the level of the current is restored to +14 db with respect to 1 mw. The receiving amplifier is fitted with a gain control so that the level of current can be maintained at +14 db. The current is then accepted by the appropriate demodulator band pass filter and passes on to the demodulator. Rectification of the carrier frequency current results in reduced grid bias voltage of the signal amplifier valve, and the valve plate current increases as the input level rises. Fig. 9 is a graph showing the relation between carrier input level to the demodulator band pass filter and the signal amplifier valve plate current. The H relay, which is a high-speed type of relay connected in the plate circuit of the signal amplifier valve, operates. Contact H1 causes AA relay to operate. Contact AA1 completes a loop circuit via retard coil E to the incoming selector, which is seized ready for impulsing. Contact AA2 causes B relay to operate and prepare a circuit for the operation of C relay. Negative and positive battery potentials are fed back from the selector, but the connections of the metal rectifiers associated with coil E and relay F are such that relay F does not operate at this stage.

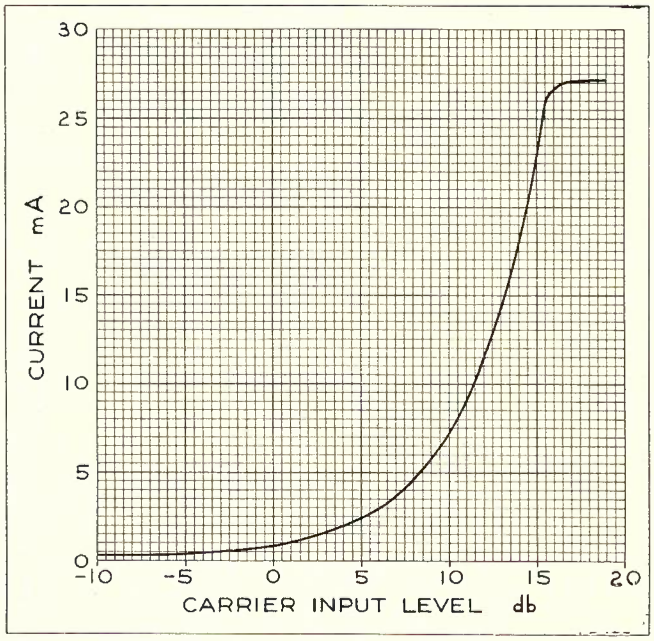

Fig. 9.—Typical relation of carrier input level at demodulator band pass filter and signal amplifier valve plate circuit.

Transmission of Dialling Impulses

When the calling subscriber dials, the dialling impulses are repeated into the A relay. On the first impulse, the A relay releases and contact A2 disconnects the carrier frequency current. Contact A1 short-circuits the modulator output circuit and contact A3 completes a circuit for the operation of N relay. Contact N1 disconnects the line side of the hybrid coil from the D.C. impulsing circuit and terminates it in a balance network. Following the break period of the first impulse, the A relay operates and carrier frequency current is re-transmitted. M and N relays are slow to release and remain operated during the train of dialling impulses. The transmission of carrier frequency current is interrupted in periods which are approximately proportional to the ratio of break and make periods of the dial impulses, and at the distant carrier terminal the H relay operates as the impulses of carrier frequency current are received. The AA relay repeats the impulses into the incoming selector, which steps vertically to the switch level corresponding to the number of impulses dialled. On the first impulse, C relay operates and, at C1 and C2 contacts, rearranges the impulsing loop circuit of the selector. At the end of the train of impulses the A, H and AA relays are held operated and the N and C relays release after a short interval. At the same time, the selector rotates over the bank contacts until a free outlet is obtained. If all outlets are engaged, however, busy tone will be transmitted back from the selector to the hybrid coil.

The same circuit operation applies for subsequent trains of dialling impulses. After the final train of impulses, ring tone will be superimposed on the battery potentials, which are fed back from the final selector, until the called subscriber answers, unless, of course, the number is engaged, in which case busy tone will be returned. When the called subscriber answers, the battery potentials will be reversed and F relay will operate. If the called subscriber is connected to the Cronulla manual exchange, which trunks through the Miranda automatic exchange, the reversal of battery does not occur when the exchange telephonist answers. In this case the telephonist switches the call to the subscriber's number, and reversal occurs when the subscriber answers.

Transmission of Tones

When the call has reached the stage before reversal occurs, therefore, the F relay is not operated, and it is possible to receive either speech from a manual exchange telephonist or ring or busy tone back through the hybrid coil to the modulator. A low pass filter is connected between the hybrid coil and modulator, and attenuates frequencies above 2800 c/s. The products of modulation include the upper and lower sidebands of the carrier frequency, but the carrier frequency itself is suppressed except for a small amount of carrier leak due to imperfect circuit balance. The lower sideband is accepted by the modulator band pass filter and passes on to the transmitting amplifier. At the same time, carrier frequency current is transmitted through a carrier transformer in a similar manner to that already described for the A to B direction of transmission. Both carrier and sideband frequency currents are amplified and pass through the transmitting directional filter and line transformer to the cable pair. Contact F1, however, maintains the connection of a resistance across the input of the modulator band pass-filter, with the result that the levels of transmitted currents are attenuated by approximately 8 db, in comparison with the levels obtained when F relay operates to disconnect the shunting resistance. It will be seen, therefore, that there are high- and low-level conditions of transmission, and this is dependent on operation of the F relay, that is, on the called subscriber answering the call. The transmitting amplifier gain control is adjusted so that the level of sideband frequency current at the output of the transmitting amplifier is +5 db with respect to 1 mw for the high-level transmission condition, when transmitting 1 mw of current at a frequency of 1000 c/s at the input to the hybrid coil. Adjustment of the level of carrier frequency current at the output of the transmitting amplifier is obtained in the tapped carrier transformer, as previously described for the other terminal, and has an upper limit of +13 db with respect to 1 mw for the high-level transmission condition. The voltage limiter operates to guard the amplifiers against overload if peak voltages, corresponding to a power exceeding approximately 6 mw, are transmitted into the hybrid coil.

After being transmitted over the cable pair to the "A" terminal, the carrier and sideband frequency currents pass through the line transformer and receiving directional filter and equaliser to the receiving amplifier. The equaliser compensates for the attenuation versus frequency characteristic of the cable pair. The gain of the receiving amplifier is adjusted so that the level of carrier frequency current at the output of the receiving amplifier is +14 db with respect to 1 mw for the high-level condition of transmission. The carrier and sideband frequency currents are accepted by the demodulator band pass-filter and pass on to the demodulator, which operates as a linear detector. The V.F. component of the demodulated current is amplified in the V.F. amplifier, while the D.C. component is amplified in the signal amplifier. The D relay, which is a telephone type relay, is connected in the plate circuit of the signal amplifier valve, and is adjusted to operate on currents of 8 to 10 ma. The D relay operates only when high-level carrier frequency current is received, since, for other conditions, its current does not exceed 4 ma. In this case, as the called subscriber has not yet answered, low-level current is being received, and D relay remains unoperated, so that the channel equaliser is disconnected from the circuit at contacts D1 and D2. Products of demodulation other than V.F. currents are attenuated by the low pass-filter which follows the V.F. amplifier. The channel equalizer has an attenuation of approximately 8 db at a frequency of 1000 c/s, and, as it is disconnected from the circuit, the reduced level of 8 db, resulting from the low-level condition of transmission, is compensated for. The demodulated V.F. current, therefore, passes through the hybrid coil at the correct level. The V.F. amplifier is fitted with a gain control which allows for adjustment of the level of V.F. current at the line side of the hybrid coil. The overall channel equivalent is adjusted to a value between 0 db and 1 db. At this stage the calling subscriber can listen for ring or busy tone, or is able to converse with the manual exchange telephonist.

Transmission after Subscriber Answers

When the called subscriber answers, the F relay operates and results in transmission in the high-level condition. At the "A" terminal, the D relay operates and the level of demodulated V.F. current increases by 8 db. Operation of the D relay causes the channel equalizer to be connected in the circuit, and this compensates for the increased level of V.F. current, as well as providing channel frequency correction. Contacts D3 and D4 reverse the battery potentials, which are fed back to the auto-auto repeater, for metering purposes.

Release of Junction Circuit

On completion of the call, the loop circuit of the A relay is opened and the circuit is restored to normal, following release of the A, H and AA relays.

PANEL DESCRIPTION

Modulator: The circuit arrangement is shown in Fig. 10. The modulator is of the balanced type, using copper oxide rectifiers, and operates basically with a commutator or switching action under the control of the carrier. The carrier leak is proportional to the degree of unbalance of the circuit, and this can be adjusted by means of the potentiometer, which connects the carrier supply to the output transformer. The carrier leak should not exceed a level of –25 db with respect to 1 mw when measured at the output of the transmitting amplifier. Attenuation pads are connected in the input and output circuits of the modulator. These provide a masking effect to impedance changes and, in addition, allow of adjustment of the sideband level when it is required to equalize the level with levels of other channels at the output of the transmitting amplifier.

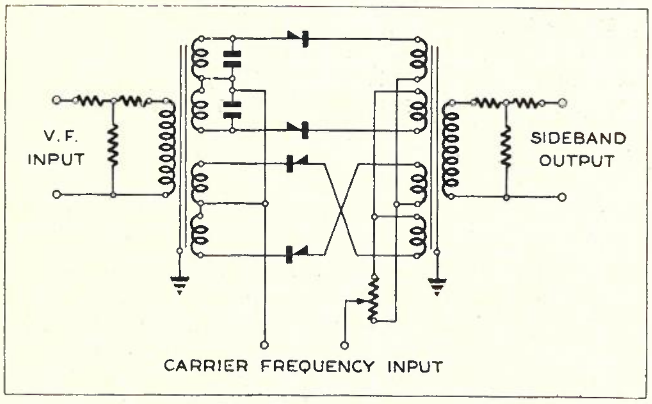

Fig. 10.—Channel modulator.

Carrier Oscillator: The circuit arrangement is shown in Fig. 11. The tuned circuit components for six oscillators are enclosed in a thermostatically controlled oven in which the temperature is maintained at approximately 125°F. The oven heater is operated from 24 volts A.C. or D.C. supply and is rated at 150 watts. A variable condenser in the oscillator-tuned circuit allows for frequency adjustment of the order of ± 20 c/s. The oscillator output circuit is coupled to a single-stage amplifier employing negative feedback. The output impedance is approximately 5 ohms and, as this is low in comparison with the impedance of the oscillator load, a number of channels can be supplied simultaneously. One carrier oscillator supplies current for a maximum of 12 systems. The amplifier gain control allows for the adjustment of the carrier output voltage to be maintained at 2 volts. A type VR.105-30 regulator valve is used to regulate the screen grid supply for six oscillators at 105 volts.

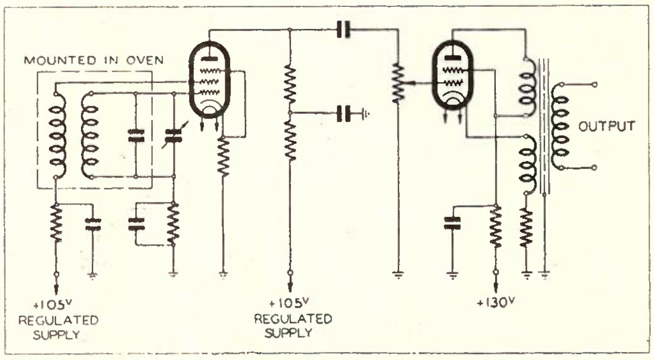

Fig. 11.—Carrier oscillator.

Demodulator: The circuit arrangement of the demodulator and associated amplifiers is set out in Fig. 12. The copper oxide bridge rectifier unit is arranged to operate as a linear detector. The level of the carrier frequency current is maintained sufficiently high above the sideband level to allow the V.F. rectified component to be substantially independent of alteration of the carrier level. Products of demodulation other than the V.F. and D.C. components are partially attenuated in the network which follows the rectifier unit. The D.C. component of the rectification is applied to the grid circuit of the signal amplifier valve in such a manner as to decrease the negative grid bias voltage. The V.F. component is amplified by the V.F. amplifier which has a gain control in its input circuit. A transformer is used to apply negative feedback voltages to the amplifier valve cathode circuit.

The screen grid voltage for the six signal amplifier valves of a carrier terminal is obtained from a common regulated supply, which is derived by connecting the system 130-volt plate supply through a series resistance to a type VR.105-30 regulator valve connected in parallel with the six screen circuits, which are then maintained at 105 volts.

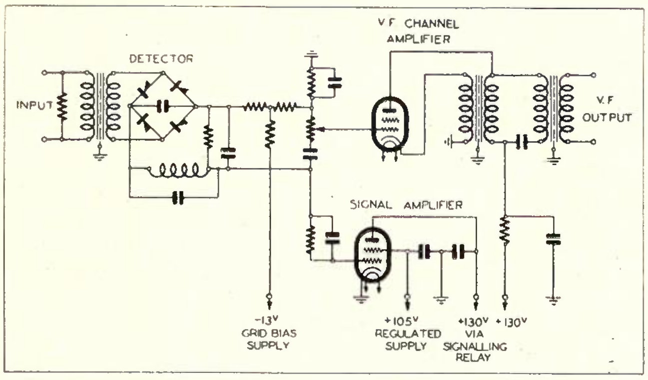

Fig. 12.—Demodulator and associated amplifiers.

The grid bias voltage supply to the demodulator panel is nominally —13 volts. This supply is also common to the six circuits of a carrier terminal and, as the voltage must be kept stable, it is derived from the output circuit of one of the carrier oscillators. The carrier frequency voltage is connected by a transformer to a copper oxide full-wave rectifier unit, the load circuit of which includes a resistance for each demodulator panel. The rectified current in each load resistance develops the required voltage. The transformer has a tapped secondary winding, which allows for adjustment of the voltage as required.

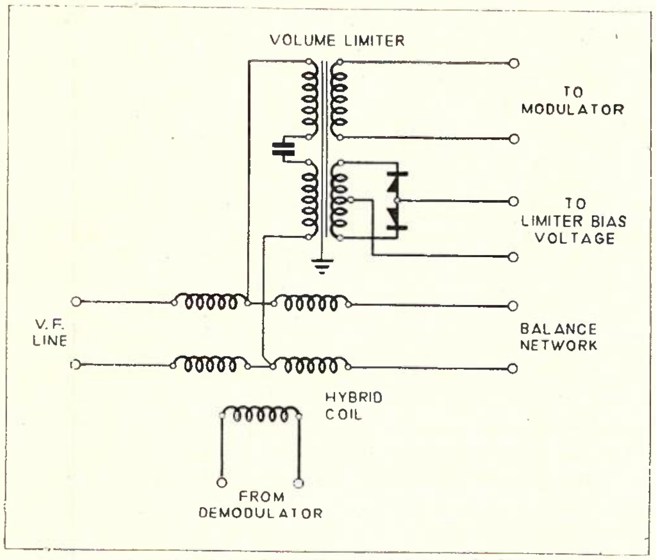

Fig. 13.—Hybrid coil and volume limiter.

The demodulator input and output impedances are 150 and 600 ohms respectively.

Hybrid Coil and Volume Limiter: The circuit arrangement is shown in Fig. 13. The hybrid coil is designed to terminate line, balance network and demodulator circuits of 600 ohms impedance and a modulator circuit of 300 ohms impedance. The modulator input impedance, however, is 2400 ohms, so that the impedance matching transformer is required. A condenser is connected in series with the primary winding of the transformer in order to block D.C. A winding of the transformer connects to the copper oxide rectifier unit which forms the limiter circuit. The negative bias voltage for the rectifiers is obtained by connecting the bias leads across a section of a resistance which is carrying current supplied from the system 48-volt battery supply. One resistance is arranged to provide bias voltage for twelve limiter circuits. The curves of Fig. 14 are typical curves, showing the effect of a limiter for two conditions of limiter bias voltage. The bridging loss of the limiter for levels below the level at which limiting occurs is negligible.

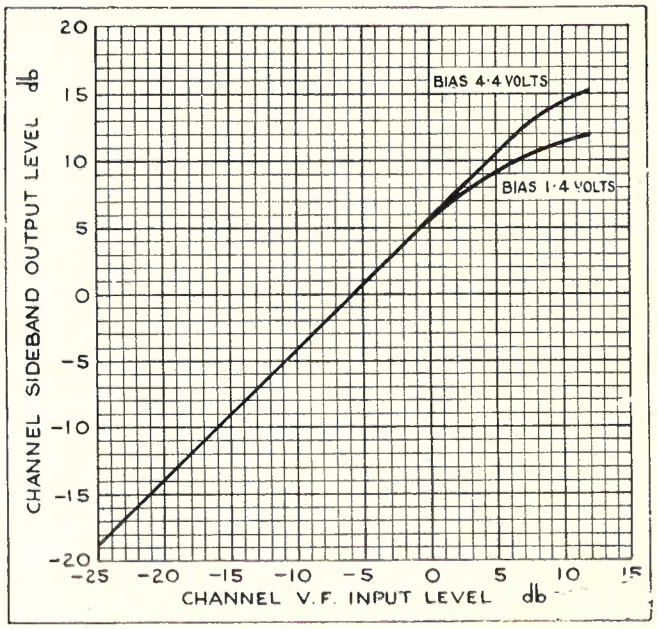

Fig. 14.—Sideband output versus channel input level.

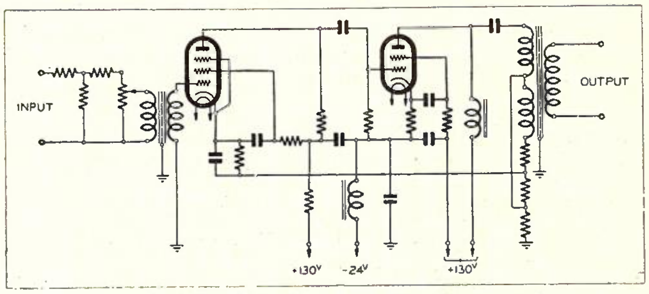

Fig. 15.—Line amplifier.

Line Amplifiers: The circuit arrangement is shown in Fig. 15. The amplifier is a two-stage amplifier with one stage of voltage amplification and the other of power amplification. The input and output impedances are 150 ohms. A 3 db attenuation pad is fitted in the input circuit and the gain control provides for variation of the amplifier gain in nine steps of 1 db. A large amount of negative feedback is applied over both stages of the amplifier. The maximum gain of the amplifier is 33 ± 1.5 db over the frequency range from 100 c/s to 50 kc/s. The plate supply is 130 volts, and, in order to obtain increased power output, the cathodes of the output valves are connected to –24 volts instead of to ground. A choke and condenser de-coupling circuit is connected in the cathode circuit in order to guard against noise originating in the –24-volt power supply. The receiving amplifier is identical with the transmitting amplifier. In the case of the "A" carrier terminal, which receives the high group of frequencies, however, the amplifier gain is insufficient, and an auxiliary amplifier is required. Fig. 16 shows the circuit arrangement of this amplifier, which is a single-stage amplifier employing negative feedback. The total gain is 52 db at 50 kc/s, and increases to 58 db at 26 kc/s. A high pass-filter is included in the input circuit and is provided to give high attenuation at a frequency of 24 k/cs. This assists the receiving direction filter in suppressing current at a frequency of 24 kc/s, which is the carrier frequency for channel 6 in the transmitting direction.

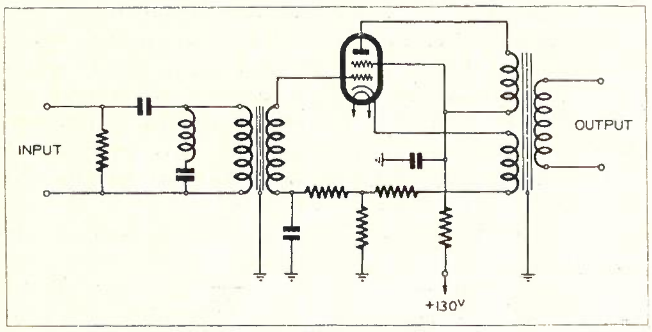

Fig. 16.—Auxiliary amplifier.

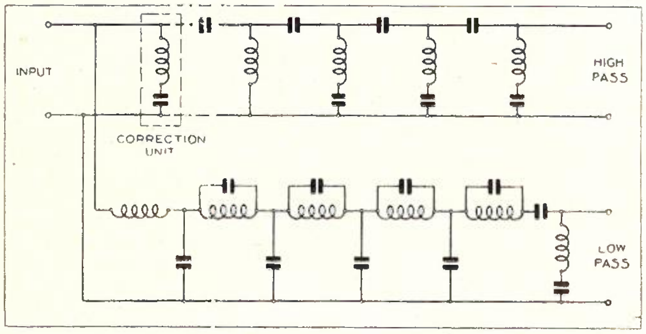

Fig. 17.—Directional filters.

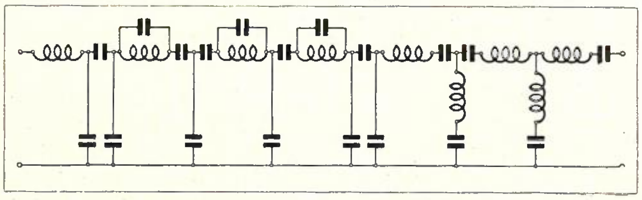

Fig. 18.—Demodulator band pass filter.

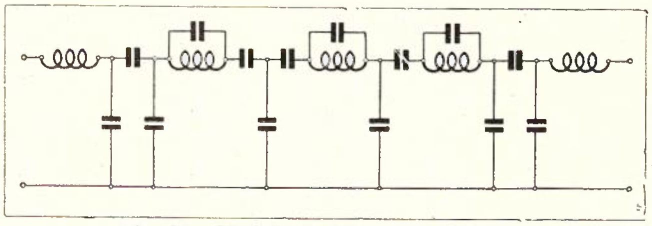

Fig. 19.—Modulator band pass filter.

Filters: Figs. 17, 18, 19 show the circuit arrangement of the directional and band filters. Figs. 20, 21, 22 show some typical attenuation versus frequency characteristics of these filters.

Alarm Facilities: Fig. 23 shows the junction carrier terminal alarm circuits. Plate circuit alarms are provided for the line amplifiers by means of relays, TP, RP and AP. Fuse alarms are provided for the 130-volt, 48-volt and 24-volt A.C. and D.C. supplies by means of relay FA. Battery fail alarms for the 48-volt and 24-volt supplies are provided by means of relays X and Y respectively. Visual indication is given by means of switchboard type lamps for all the abovementioned alarms and, in each case, the external alarm circuit lead is connected to ground when an alarm occurs.

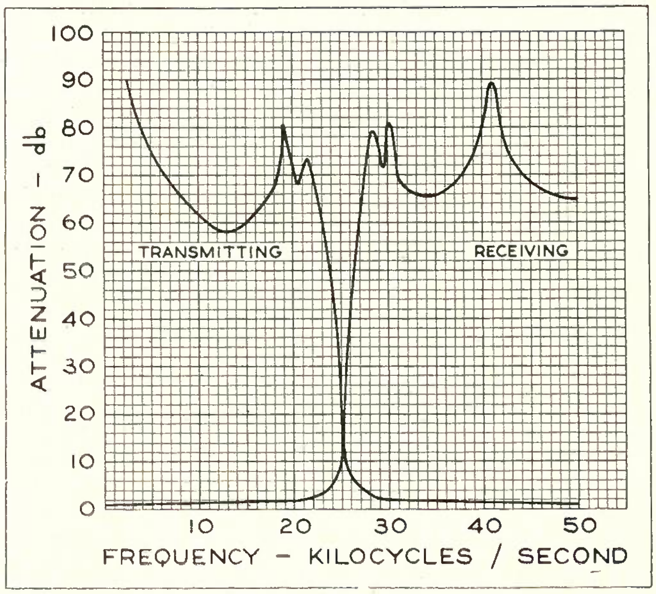

Fig. 20.—Attenuation curves of transmitting and receiving directional filters at "B" terminal.

When an alarm condition exists the circuit is arranged so that the outgoing junction circuits, at both local and distant carrier terminals, will have ground connected to the private wires. The six junctions will then test busy until the alarm

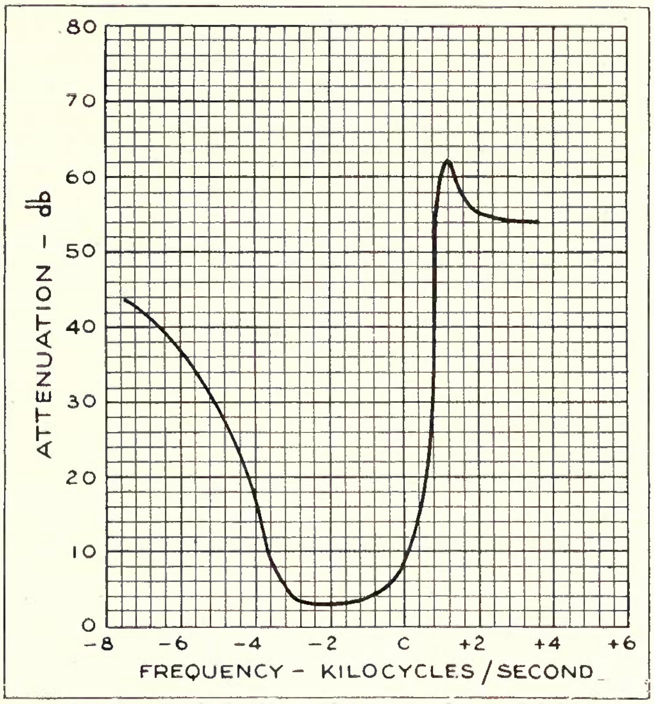

Fig. 21.—Typical attenuation curve for modulator band pass filter.

condition ceases to exist. The circuit operation is as follows. Relay S is normally operated from ground via T1 and DA1 contacts to battery. Contacts S1 to S6 disconnect ground from the private wires of channels 1 to 6 respectively, while S relay remains operated. When an alarm condition exists, however, relay T will operate from ground on the external alarm lead to –24 volts. The operation of T1 contacts causes relay S to release and connect ground to the private wires at contacts S1 to S6. At the same time, operation of T1 contacts causes relay U to release and contacts U1 and U2 short-circuit the condenser, which is connected between the two windings of the line side of the line transformer of the carrier terminal. This completes a circuit for the operation of the DA relay at the distant carrier terminal, where conditions are normal and relay U is still operated. When relay DA operates at the distant terminal, DA2 contacts connect ground to the external alarm lead and DA1 contacts complete a circuit for the alarm lamp which indicates an alarm condition at the other terminal. The operation of DA1 contact also causes release of relay S, without releasing relay U. Contacts S1 to S6 connect ground to the private wires at the distant terminal. At both carrier terminals, therefore, the junctions are guarded against seizure until the alarm condition ceases to exist.

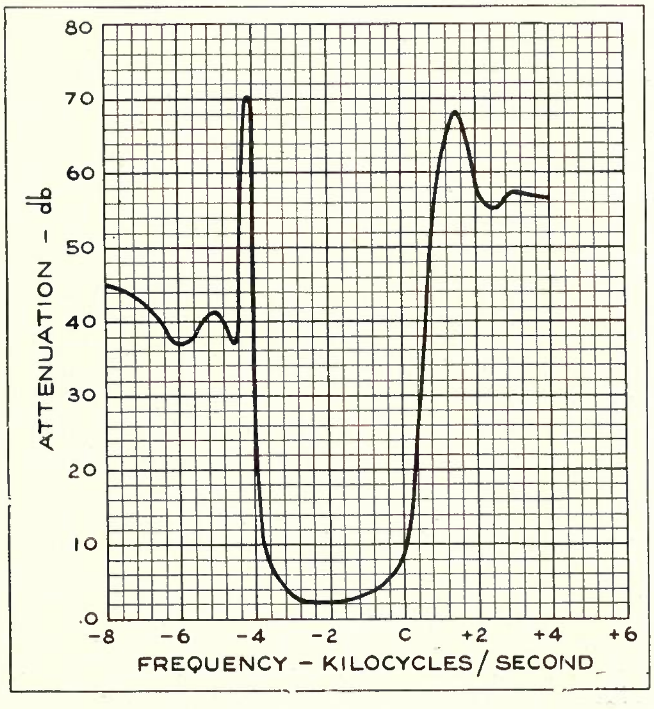

Fig. 22.—Typical attenuation curve for demodulator band pass filter.

The carrier supply and power bay alarm circuits include plate circuit alarms for the carrier oscillators, fuse alarms and battery fail alarms.

POWER SUPPLY

The following details indicate the power requirements of the carrier equipment and the methods of providing them. The system relay sets are operated from the exchange 48-volt battery supply, while the transmission circuits are designed for operation from 24-volt and 130-volt supplies, which are standard for carrier equipment.

(a) **48 Volts D.C.** for relay and alarm circuits operation and for the limiter bias circuits. Power leads from the exchange battery are terminated at the top of each bay, on a special terminal strip which is wired to the bay fuse panel. The load current varies according to the number of channels which are engaged, the maximum current being approximately 1.2 amps per system terminal.

(b) **130 Volts D.C.** for the plate and screen circuits of oscillator and amplifier valves. The supply is obtained by rectifying the A.C. mains supply, which is 240 volts, single-phase, 50 c/s. Four vacuum type rectifier valves are parallel-connected in a full-wave rectifying circuit. The maximum load current is 0.6 amps for the first system installed and 0.4 amps for each terminal installed subsequently.

(c) **24 Volts D.C.** for alarm circuits and valve cathode circuits. This supply is also obtained by rectifying the A.C. current. In this case, however, the rectifier is a full-wave, copper oxide type rectifier, and the maximum load current is 0.25 amps per carrier terminal.

(d) **24 Volts A.C.** for valve heaters and the oscillator oven heater. This is obtained from the

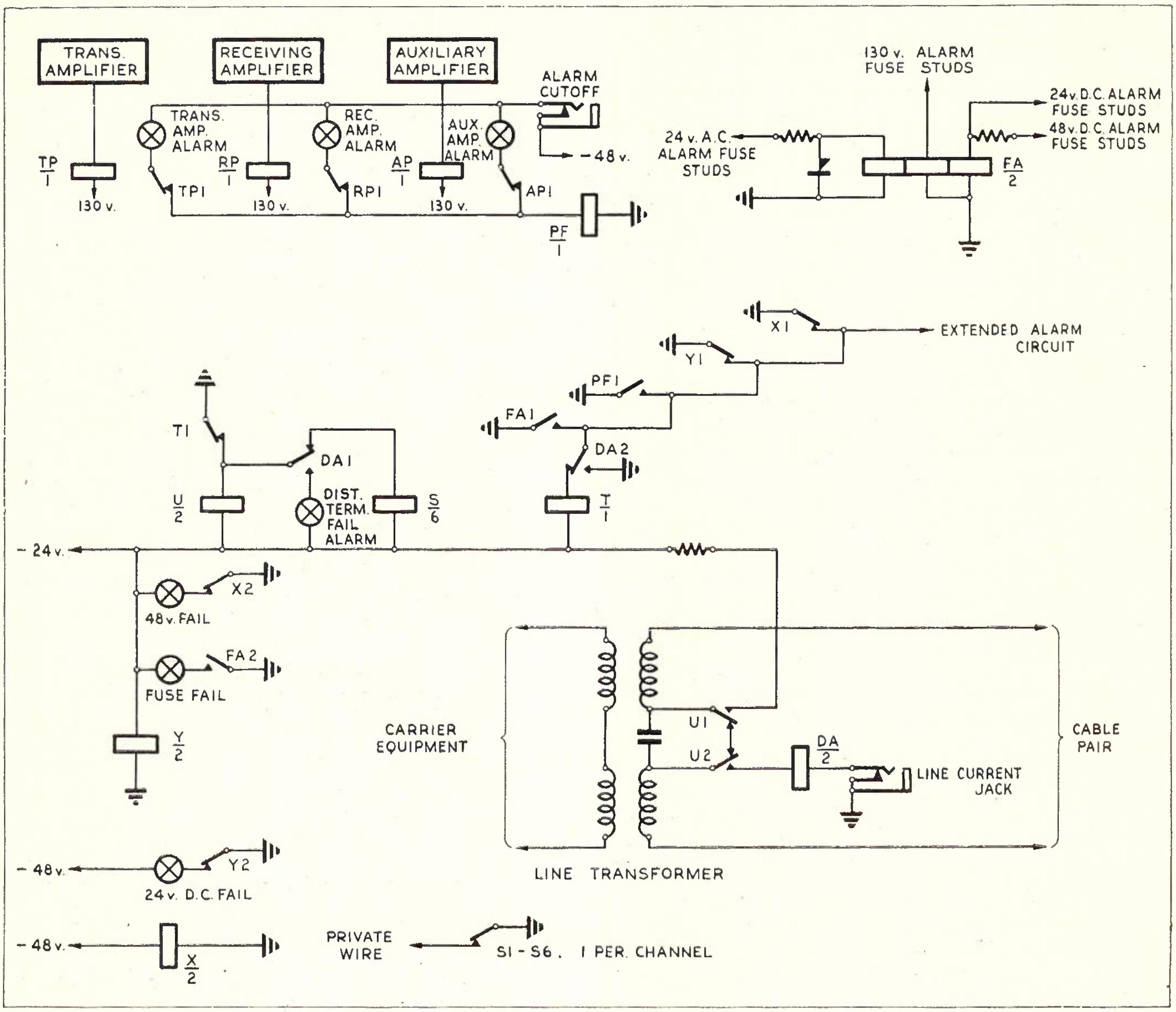

Fig. 23.—Alarm circuit.

240-volt supply by means of a power transformer. The load varies from 6 amps to 12 amps for the first carrier terminal installed, the variation occurring as the oven heater is connected or disconnected by the temperature regulating circuit. The additional load for each terminal installed subsequently is 4.3 amps.

The power transformers and rectifiers are mounted on separate power supply panels, and one such panel handles the supply for one carrier terminal. Seven power panels are mounted on the carrier supply bay and the power supply leads from each panel are wired to terminal strips at the top of the bay. Inter-bay cabling carries the supplies to terminal strips at the top of the carrier terminals bays, and the supplies are wired from there to the fuse panels for distribution to the various circuits.

INSTALLATION

The 40-lb/mile multiple twin trunk cable between Newtown and Kogarah is part of the Sydney-Hurstville trunk cable and carries trunks and several 3-channel carrier systems which serve the South Coast area of N.S.W. The three-channel systems transmit the high group of frequencies, 17 kc/s to 30 kc/s, in the direction from North to South, that is, in the direction from Newtown to Kogarah. The cable pairs over which the junction carrier systems are operated are also included in the Newtown-Kogarah section of the trunk cable, so that the problem of near-end crosstalk between the three-channel and junction carrier systems required investigation. As a result of the different frequency allocations of the three-channel systems as compared with the junction carrier systems, it is not possible to place the

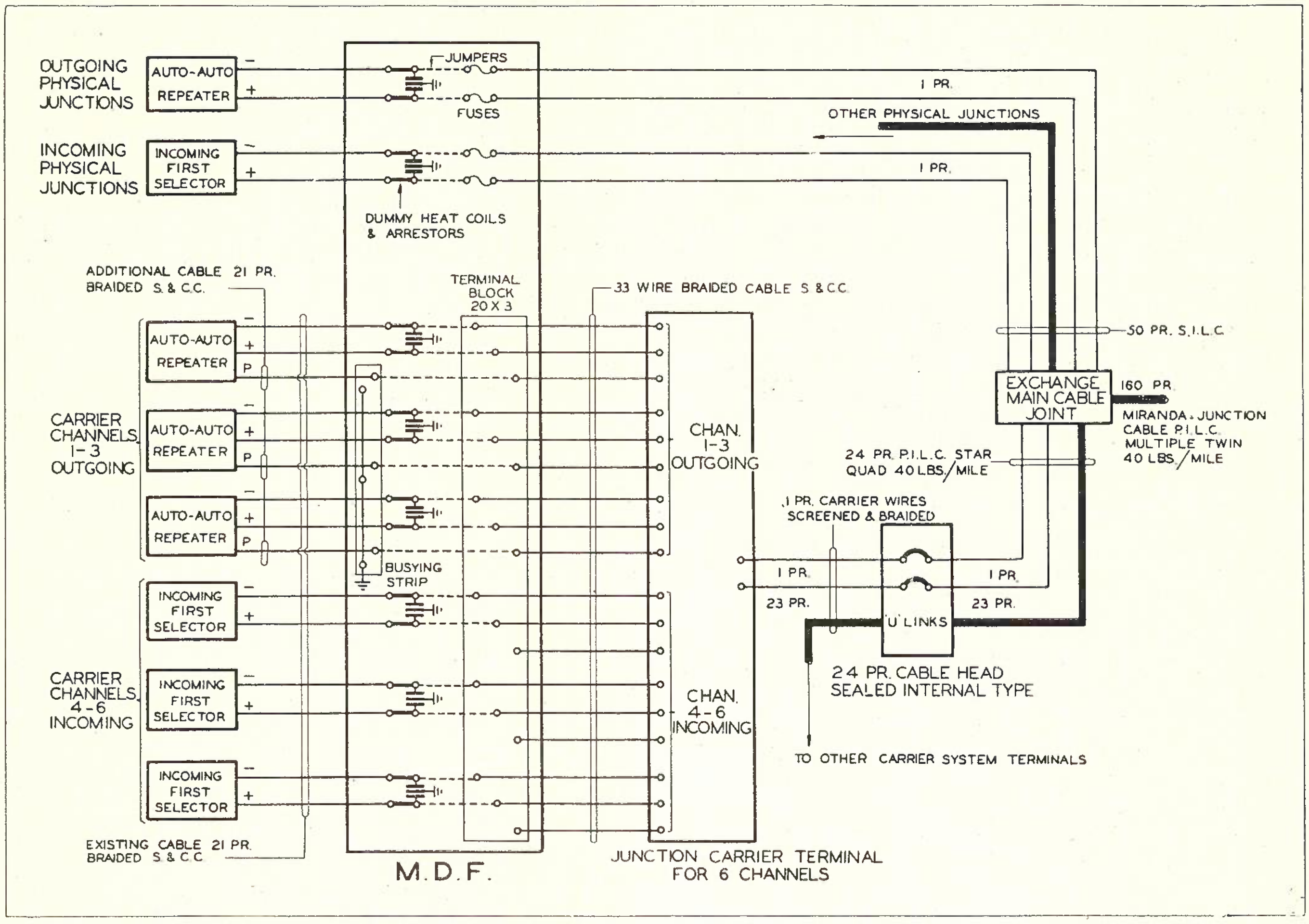

Fig. 24.—Cabling details.

junction carrier terminals so that both three-channel and junction carrier systems transmit the same frequency groups in the same direction. After consideration of this problem it was decided to instal the "A" and "B" junction carrier terminals at Newtown and Miranda respectively.

Fig. 24 shows the details of the connections of the junction carrier equipment to the junction cable and to the automatic exchange equipment at Newtown. The figure also shows an outgoing and an incoming junction of the normal type using physical lines. The cable pairs selected for carrier working are taken out of the junction cable at the main exchange cable joint which, at Newtown, is situated in the cable entrance tunnel underneath the main distributing frame.

It will be noticed in the case of the outgoing junction carrier circuits that the auto-auto repeater connects to the carrier terminal equipment and that additional cable has been provided in order to connect the private wire of the auto-auto repeater to the carrier equipment. The additional cabling is terminated on a busying strip which is mounted on the main distributing frame. The carrier terminal outgoing junction relay set gives identical busying, reversal and impulse repeating facilities as the auto-auto repeater. It does not, however, give booster battery metering facilities which are incorporated in the auto-auto repeaters at Newtown, and for this reason it was necessary to retain the auto-auto repeater in the circuit instead of cabling direct from the preceding selector frame to the carrier terminal equipment. It was also necessary to prevent contact M1 (see Fig. 7) of the carrier terminal outgoing relay set from connecting ground to the private wire, as this ground would prevent the correct operation of the metering circuit. Although contact M1 has been disconnected, the other connections to the private wire in the carrier terminal relay set are retained. These are connections to the carrier terminal alarm circuit and the system jacking, and ensure that the private wire is connected to ground while an alarm condition exists at the local or distant carrier terminals, or while the carrier channel voice-frequency line-jacks are in use during testing of the carrier channel.

The cabling details at Miranda are similar to those at Newtown, with the exception that discriminating selector repeaters are installed instead of auto-auto repeaters.

In order to reduce noise interference within the carrier equipment, precautions have been taken in arranging the earth connections of the carrier installation. A recent article (¹) refers to the particular sources of noise voltages which exist in an installation of this type, and shows how increased noise, at high frequencies, can be caused by incorrect earthing arrangements.

In this installation, the carrier bays are insulated from each other and from the overhead ironwork and runway. Each bay is provided with an earth bar for the termination of internal bay screen wiring, and these earth bars are connected to earth leads which are run independently of the silent and noisy battery earth leads. The lead sheath of the 24-pair carrier cable and the internal type cable terminating head are also insulated from the bay framework and cable runway. All carrier screened wiring has an outer cotton braiding so that the metal screens are insulated throughout their length. Each such metal screen is connected to the bay earth at one point only.

The object of these methods is to reduce the possible paths for earth circulating currents and so reduce noise interference in the junction circuits.

On completion of the installation work, the initial testing of the carrier terminal equipment was commenced. This work included tests, as follows:—

(a) Check of power supplies and D.C. valve tests.
(b) Adjustment of carrier oscillator frequencies and output levels.
(c) Check of limiter bias and channel amplifier bias supplies.
(d) Carrier leak adjustments.
(e) Adjustment of transmitted carrier and sideband current levels.
(f) Check of channel receiving gains and equalization.
(g) Check of return loss between the equipment and the cable pair.

The overall line-up tests were then made and included tests as follows:—

(a) Adjustment of receiving amplifier gain.
(b) Adjustment of overall channel equivalents.
(c) Check of circuit operation for high and low level carrier conditions.
(d) Linearity tests.
(e) Overall frequency response measurements.
(f) Noise measurements.
(g) Interchannel interference tests and intersystem crosstalk tests.
(h) Dialling distortion tests.

The transmitted levels of carrier and sideband frequency currents are measured at the transmitting amplifier output jacks, and, for limiting conditions, are +13 db and +5 db with respect to 1 mw, respectively, for the high-level carrier condition. For the low-level carrier condition the levels should be 8 db lower. The receiving amplifier gain is adjusted so that the level of carrier frequency current at the receiving amplifier output jacks is as close to +14 db referred to 1 mw as possible, for the high-level condition.

The return loss between the equipment and the cable pair should exceed 14 db for frequencies below 30 kc/s, and should exceed 20 db for frequencies from 30 kc/s to 50 kc/s. The system line transformer matches the impedances of the equipment and cable pair, which are approximately 150 ohms and 135 ohms respectively.

The overall channel equivalents are adjusted to be within the limits of 0db and 1 db by means of the voice frequency channel amplifier gain control. The linearity tests indicate the point at which the volume limiters operate, as well as showing any evidence of a fault condition causing overloading.

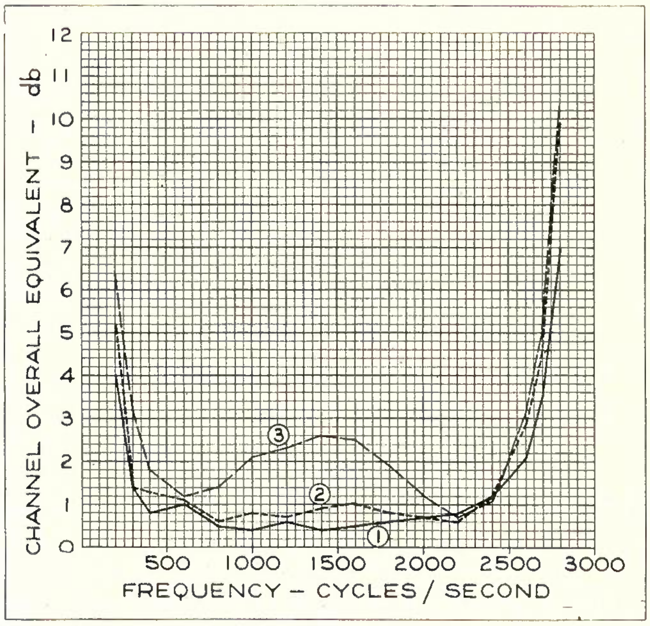

Fig. 25.—Typical overall attenuation versus frequency of junction carrier channel.

(1) In outgoing direction.
(2) In incoming direction with high level carrier.
(3) In incoming direction with low level carrier.

Fig. 25 shows the typical channel frequency response for both directions of transmission and for conditions of high and low level of carrier transmission.

During the initial overall tests, high noise measurements were obtained at Newtown. The noise measurements were made under conditions of maximum noise, that is, during the exchange busy hour and with all channels transmitting high-level carrier currents in both directions of transmission. Noise in the cable was transferred to the systems and made the channels noisy in the Miranda to Newtown or high-frequency direction of transmission. Tests were made to ascertain the cause of this noise, and it was eventually considered to be caused by dialling currents in physical junction circuits, inducing noise currents into the cable pairs on which the carrier systems were operating. Dialling and rotary switch noises were audible and the amount of noise was proportional to the volume of exchange traffic, and reached a maximum during the exchange busy hour.

In order to improve the signal to noise ratio, the level of sideband current for each of the channels of the systems was increased by 9 db, so that the level of sideband current at the transmitting amplifier output was +5 db instead of —4 db, which was the design level. The level of transmitted carrier current was not altered. The adjustment of the sideband level was obtained by reducing the attenuation of the resistance pads in the modulator input and output circuits. As a result of the increased sideband level it was necessary to re-adjust the limiter bias voltage and to modify the circuits of the voice frequency channel amplifiers in order to vary the range of the amplifier gain controls.

The final noise measurements were made under the condition when the junctions were extended via automatic switches to local exchange telephones. The maximum noise at the telephone, measured on a signal-to-noise ratio basis, was of the order of 44 db for unweighted measurements and 56 db for weighted measurements.

Tests were made of interchannel interference by talking on two channels so that the level into each channel indicated peaks at a level of +4 db referred to 1 mw. The figures obtained were of the same order as the figures mentioned in the preceding paragraph. This infers that the actual crosstalk is less than the level of interference due to noise from the cable. The value of noise obtained during the original factory acceptance test was of the order of 66 db for weighted measurements. Similar tests were made of inter-system crosstalk with satisfactory results.

Tests were made of the effect of interchannel interference caused by the transmission of dialling impulses. This interference exceeds that obtained during the talking tests. When measured at the system terminals, on a signal-to-noise ratio basis, the unweighted measurements varied from 36 db to 46 db for various channels, while weighted measurements varied from 50 db to 62 db. When the channels were extended via automatic switches to a local exchange telephone, however, the effect of the noise was considerably reduced and did not exceed 44 db for an unweighted measurement or 52 db for a weighted measurement.

Tests of dialling distortion were made over the junction carrier channels by transmitting a series of standard dialling impulses into each outgoing channel and measuring at the distant terminal with an impulse weight test set. Further testing of the dialling distortion included the automatic exchange switches at both ends of the junctions, when the normal exchange routine dialling tests were carried out, using standard impulses and testing under long and short line loop conditions.

During the routine tests, varying amounts of dialling distortion were experienced on the carrier junctions. Investigation showed that the distortion was caused by resistance in the A1 relay contacts, which were used to interrupt the transmission of carrier frequency current, during dialling, by short-circuiting the input circuit of the modulator band pass-filter. In practice these relay contacts developed high values of contact resistance. The circuit was, therefore, modified to include the A2 relay contacts, as shown in Fig. 7, and the dialling distortion can now be maintained within the workable limits.

CONCLUSION

The Newtown-Miranda installation shows that urgently required additional junctions can be provided by carrier methods, in certain cases where the work would be delayed for some years, if the normal methods were used.

24 carrier junctions are now in service between Newtown and Miranda, and the present installation, when complete, will total 72 carrier junctions.

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TELEPHONE RELAYS - PART 2

R. J. Kolbe

GENERAL DESIGN PRINCIPLES AND DATA

In the first part of this article the relationship between resistance and turns as determined by the winding space was discussed. A graphical method of evaluation for the resistance-turns ratio was given and its application shown on two examples. In both cases the problem was formulated to indicate the desired resistance value for the coils so that the calculation of the windings could be commenced with a definite resistance value. The question of optimum resistance for a relay winding will now be considered.

In the case of a winding which operates with the full battery voltage without series-resistances, the obvious solution is a winding of the highest resistance combined with maximum number of turns that will produce the required ampere turns (I N) and which can be accommodated in the available winding space. However, in practice, it is not desirable to use very fine gauge wires because of winding difficulties and higher costs. Furthermore, coils with a great number of turns have an excessive self-inductance which adversely affects the operating times. This aspect will be dealt with in detail further on.

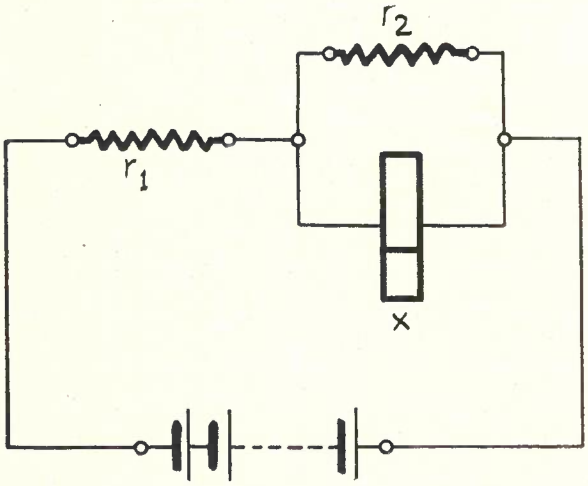

Fig. 9.—Equivalent circuit for relay coil in network.

For windings that have to function in series with resistances (line loops or other relay coils), and which might also be shunted by various resistances, the optimum resistance value is less obvious. Let it be assumed that a complicated circuit network has been designed and that all elements have fixed resistance values, with the exception of one relay winding for which only a limited winding space is available and which has, therefore, to be designed for optimum resistance. No matter how involved the network may be, it will be possible to represent its influence on the current in the unknown relay coil X, as far as D.C. values are concerned, by a series-resistance r_1 and a shunt r_2 (see Fig. 9). The values of these resistances can be found by step to step simplification of the network.

The ampere turns in the relay coil X are: $(IN)_x = i_x\ N_x$; and $R_1/R_2 = N_1^2/N_2^2$ . . . from equation (2) if space factors are disregarded and the winding space is kept constant.

$R_1/N_1^2 = R_2/N_2^2 = R_x/N_x^2 = 1/\kappa$ . . . constant;
$N_x = \kappa\sqrt{R_x}$; $(IN)_x = i_x\ \kappa\ \sqrt{R_x}$ and with

$$i_x = \frac{E}{r_1 + r_2\,R_x/(r_2 + R_x)} \cdot \frac{r_2}{(r_2 + R_x)};$$

$$(IN)_x = \kappa_2 \frac{r_2\ \sqrt{R_x}}{r_1r_2 + (r_1 + r_2)\ R_x} \text{ when } \kappa_2 = \kappa\ E$$

to find maximum: $\dfrac{d\ (IN)_x}{d\ R_x} =$

$$\frac{r_2\,[r_1r_2 + (r_1 + r_2)\ R_x]/2\ \sqrt{R_x} - (r_1 + r_2)\,r_2\ \sqrt{R_x}}{v^2} = 0$$

$$\text{or } R_x = \frac{r_1r_2}{r_1 + r_3} \text{ .... } (16)$$

The interpretation of equation (16) can be expressed as follows:—

> **"Bridge the battery terminals of the circuit network and then determine the apparent resistance between the leads to the unknown relay coil when the latter is removed. Make the resistance of the coil equal to the value thus found."**

The physical significance of equation (16) is simply that the resistance of the device consuming electrical energy is to be matched to the internal resistance of the network which supplies the electrical energy. This is a well-known theorem. The reason for short circuiting the battery terminals for the calculation of the "internal resistance of the generator" is that the battery resistance can be considered as negligible, compared with other resistance values in the circuit network.

Apart from the D.C. values which were considered here, the self-inductance of the coil winding and its ratio to other inductances and resistances in the circuit network, is of importance, because it influences the operating times.

It might therefore be necessary to choose windings with resistance values at variance with that indicated in equation (16). This aspect will also be dealt with further on.

To complete the remarks on the winding space, its influence on the energy consumption may be considered.

$$W = I^2R = \frac{(IN)^2}{N^2} R; \quad N = 4\,\sigma\, h\, l/d^2\, \pi;$$

$$R = \frac{4\,\pi\,\rho\,(Di + h)\,N}{\pi\, d^2}$$

$$\therefore W = \frac{\pi\,\rho}{\sigma} \cdot \frac{Di + h}{h\,l} (IN)^2$$

$$= \frac{\pi\,\rho}{\sigma} \cdot \frac{D_m}{h\,l} (IN)^2 \quad \ldots\ldots\ldots\ldots \quad (17)$$

when W = Energy consumption in watts

I = Current in amperes.

N = Turns.

(IN) = Ampere turns.

R = Coil resistance in ohms.

d = Diameter of wire.

σ = Space factor.

h = Height of winding space.

l = Length of winding space.

D_m = Average diameter of winding.

Di = Inner diameter of winding.

Equation (17) indicates that for full coils with equal and fixed number of ampere turns, the energy consumption is directly proportional to the average diameter of the winding, and inversely proportional to the cross-sectional area of the winding space (product hl). This result points to the conclusion that "l" should be made as large as possible and D_m as small as practicable. This is identical with the conclusions arrived at when the ratio between resistance and turns was investigated. In technical literature[1] the statement will be found that "energy consumption is inversely proportional to the coil length, other factors being constant." Among these other factors kept constant are the inner and outer winding diameter, so that this comparison applies to coils with constant ratio Di/h, but with varying winding volume which, in this case, is directly proportional to the coil length. The energy consumption is therefore inversely proportional to the winding volume, because Di and h were kept constant. To show the influence of both the winding volume and the average winding diameter on the energy consumption the equation (17) may be transformed as follows:—

$$W = \frac{\pi\,\rho}{\sigma}\,\frac{D_m}{h\,l} (IN)^2$$

from equation (6) $V = \pi\, l\, h\, D_m$; $l\,h = \dfrac{V}{\pi\, D_m}$

$$\therefore W = \frac{\pi^2\,\rho}{\sigma}\,\frac{D_m{}^2}{V} (IN)^2 \quad \ldots\ldots\ldots\ldots \quad (17a)$$

In this form the importance of the average winding diameter D_m is quite obvious, as the square of its value appears in the above equation.

Spring Load and Armature Movement: As stated in the introduction, it is desirable that the number of contact units that can be accommodated on a standard relay should be as large as possible in order to cater for involved circuit functions. The design of suitable spring sets and the adequate choice of adjustment values for various applications cover an extremely large field of problems, and a detailed discussion of all its aspects is outside the scope of this article. However, some references to literature published on this matter are given in the Bibliography.

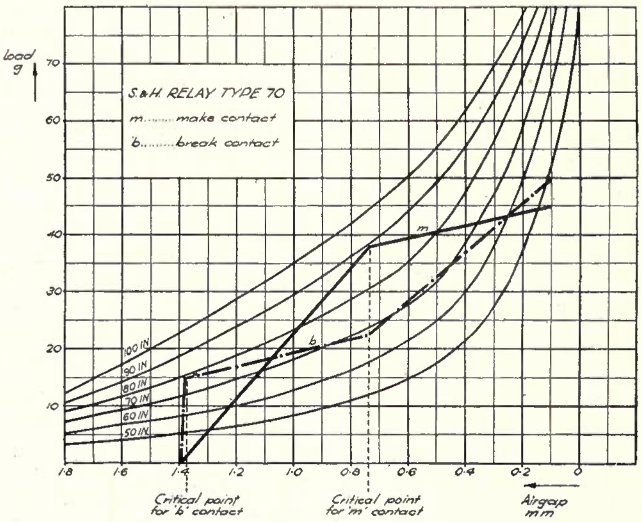

Fig. 10.—Mechanical load characteristic and magnetic characteristics for S & H. Relay 70 with make and break contacts.

The spring load on the armature can be determined when the choice of spring sets and adjustments has been made. This load varies with the travel of the armature from its non-operated position until it comes to rest against the residual when fully attracted. For convenience, all forces are to be calculated as corresponding pressures at the centre of pull of the armature. This calculation can be easily checked or altogether avoided by actual measurement if pilot samples are available. In order to gain a clear picture of the forces involved, it is necessary to find the so-called load characteristic of the springset, i.e., a graph showing the spring load versus armature movement. If the empirical method of measurements is to be used, the armature is held fixed in progressive positions corresponding to fractional parts of the stroke and the static spring pressure in those positions is measured at the centre of armature pull.

Fig. 10 shows such mechanical load characteristics for a make contact and for a break contact. The fundamental difference between these two load characteristics is quite apparent. The build-up of armature load for a large spring assembly is illustrated in Fig. 11, which shows the "pressure on bushing" versus armature position for a Strowger relay with a springset as indicated[2].

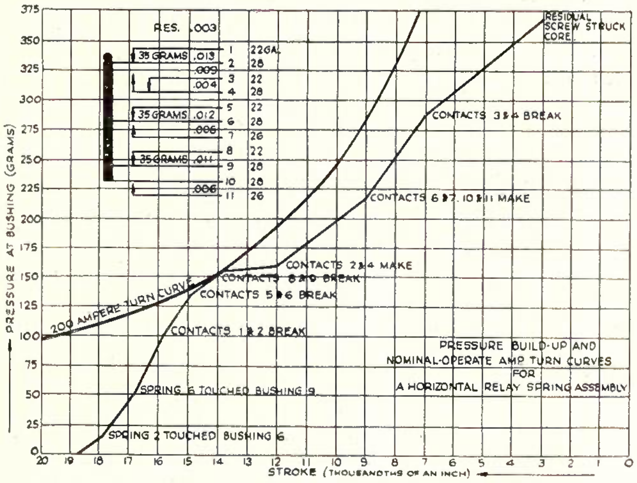

Fig. 11.—Mechanical load graph for Strowger relay, with springset as shown.

The irregular nature of this mechanical load graph should be noted, as it indicates that there will be a critical point during the stroke.

When the relay coil is energised, a pull will be exerted on the armature and the value of this pull will again be dependent on the armature position. If the magneto-motive force is assumed as constant, the pull will vary from a minimum at the start of the armature travel to a maximum for the fully-operated position. For a given relay type this characteristic can be calculated for various ampere turns or, again, simply measured on a model. In Fig. 10 these magnetic characteristics for various ampere turns from 50 IN to 100 IN are indicated. The curves shown apply to the S. & H. relay, Type 70, as shown in Fig. 1.

The magnetic characteristic for the Strowger relay is shown in Fig. 12. Only one of these curves, i.e., the one touching the mechanical characteristic at the critical point, has been shown in Fig. 11 in order to keep the graph as clear as possible.

By superimposing the load characteristic and the magnetic characteristic, both having the same abscissae, i.e., armature movement or airgap, it is possible to estimate the number of ampere turns (IN) required for operation of the spring-set in question. It also becomes apparent from these superimposed graphs that there are critical points for the operation of each spring-set type. For instance, it can be seen from Fig. 10 that the make contact requires 90 ampere turns and that

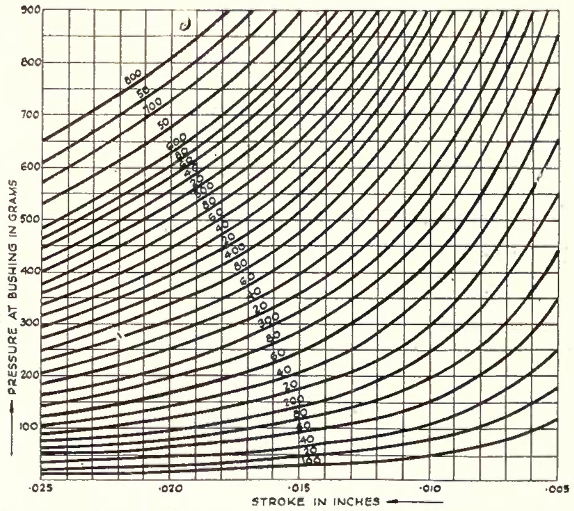

Fig. 12.—Magnetic characteristics for Strowger relay.

the critical point occurs at 0.75 mm airgap, whilst the break contact requires only 80 ampere turns with a critical point at 1.4 mm airgap.

However, it is important to remember that these relations were found for static conditions and are, therefore, strictly correct only for such. But the operation and release of a relay is essentially of a dynamic nature and it will, therefore, be necessary to consider this aspect. In particular, the magneto-motive force is by no means constant during the operation, as assumed in the first instance. The ampere turns available for magnetisation depend on the current flowing in the coil. After closing of the electric circuit, the rise of current follows the well-known exponential law:—

In the following formulæ L_t is shown as L':

$$i = \frac{E}{R} (1 - e^{-Rt/L'}) \quad .... \; .... \; .... \quad (18)$$

$$\text{and } p = \kappa N^2 \left(\frac{E}{R}\right)^2 (1 - e^{-Rt/L'})^2 \quad .... \; .... \; .... \quad (19)$$

if it can be assumed that the armature pull $p = \kappa (IN)^2$; but this is only correct when the iron path is not saturated, i.e., at the beginning of the armature movement. Herein, L_t/R is the time constant of the circuit, if L_t represents the inductance and R the resistance in the operating circuit. Equation (18) seems to give a fairly simple solution for the coil current, but the difficulty is that the self-inductance does not remain constant during the period of operation.

To show this, a formula for the approximate value of L_t is derived from Faraday's Law, in familiar manner.

$$e = -N\frac{d\Phi}{dt} = -L_t\frac{di}{dt};\quad N\Phi = L_t\, i;$$

$$\Phi = \frac{4\pi}{10}\, i\, N\, \frac{1}{S}.$$

The total reluctance

$$S = S_i + S_g = \frac{l_i}{A_i\,\mu'} + \frac{l_g}{A_g}$$

if stray fields are disregarded

$$\Phi = \frac{4\pi}{10}\, i\, N\, \frac{1}{\dfrac{l_i}{A_i\,\mu'} + \dfrac{l_g}{A_g}}$$

$$L_t = \frac{4\pi}{10}\, N^2\, \frac{1}{\dfrac{l_i}{A_i\,\mu'} + \dfrac{l_g}{A_g}} \quad \ldots\ldots\ldots\ldots\ldots \quad (20)$$

when S_i = reluctance of iron path.
l_i = lengths of iron path.
A_i = cross sectional area of iron path.
μ' = incremental permeability of iron path.
S_g = reluctance of air gap.
l_g = length of air gap.
A_g = cross sectional area of air gap.

To find the value of $l_i/A_i\ \mu'$, which represents the total reluctance of the iron path in equation (20), the individual reluctances of all parts of this path, i.e., core (c), yoke (y), armature hinge (h) and armature (a) have to be found and added up.

$$\frac{l_i}{A_i\,\mu'} = \frac{l_c}{A_c\,(\mu')_c} + \frac{l_y}{A_y\,(\mu')_y} + \frac{l_h}{A_h\,(\mu')_h} + \frac{l_a}{A_a\,(\mu')_a}$$

The calculation of the reluctance of the armature hinge presents the main obstacle. The magnetic path at this point may be regarded as consisting of a multitude of parallel magnetic paths. The reluctance of each of these fractional channels for the magnetic flux is then estimated and the total reluctance of the armature hinge arrangement calculated as resultant reluctance from these parallel elements. This method would also be applicable if it is desired to arrive at an estimate of the magnitude of the stray flux from the core. In the approximate formula given above, the influence of this stray flux has been disregarded.

From equation (20) it can be seen that during the stroke of the armature two factors will cause a change in the value of L_t. Primarily the movement of the armature progressively reduces the length of the air gap and therefore its reluctance. Secondly, the increased flux thus caused brings about a change of flux density in the iron path and, with it, a change of incremental permeability. With diminishing air gap, the self-inductance will increase sharply, but the greater flux density in the iron path will tend to reduce this increase in L_t. This latter influence will become noticeable as saturation point is approached.

The rise of current in the relay coil will not follow a simple logarithmic law, because the exponent itself [see equation (20)] changes. The current graph could be found by a step to step process in which small elements of logarithmic curves of varying steepness are linked together. Obviously, such a method would be inaccurate and useless for practical purposes. However, oscillographic methods can be used to acquire the desired information regarding the nature of current rise.

To begin with, the current rise for a relay with the armature held in a fixed position shall be considered.

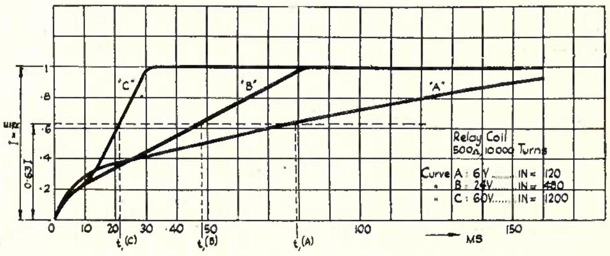

Fig. 13.—Current rise in relays with armature held in non-operated position.

To simplify the comparison the ordinates are made to signify not coil current itself but its ratio to the final coil current (I = E/R), which flows when the static condition has been reached. The three curves shown were obtained by using different voltage for energising the same relay coil[3]. For the low voltage (curve A) no saturation occurs, because of the low ampere turns, and the current rise clearly follows a simple logarithmic curve, as expected. The permeability of the magnet circuit did not change much with this low energisation, as the armature was kept fixed in its non-operated position.

In curves "B" and "C" the effect of saturation which occurs at higher coil current values is shown. As the self-inductance is proportional to the incremental permeability, it will decreaase with an increase in coil current. As saturation is reached the incremental permeability converges to unity, which causes a tremendous reduction of L_t and the time constant, so that the current rises very steeply.

The influence of the armature movement itself may be best shown on the example of a fully magnetised relay (see Fig. 14).

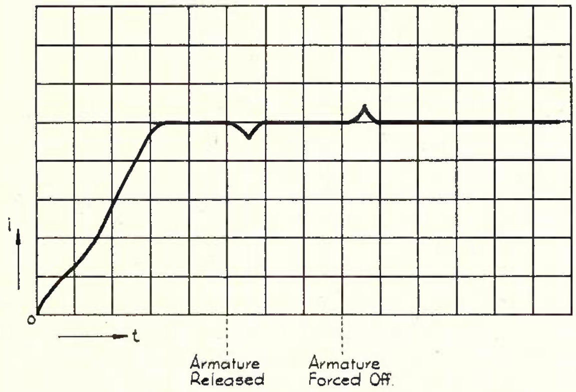

Fig. 14.—Current graph showing influence of armature movement on coil current in fully magnetised relay.

The armature is held fixed in the non-operated position with the circuit closed, and the current is allowed to reach its static D.C. value. Then the armature is released and allowed to operate. During the stroke the reluctance of the magnetic circuit decreases and the flux therefore increases. This increase in flux linkage induces a counter E.M.F. in the coil,

$$e = -N \frac{d\Phi}{dt} 10^{-8} \text{ volt ....} \quad (21)$$

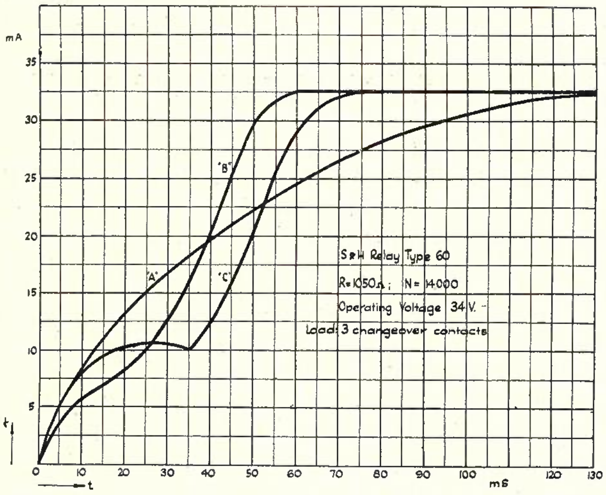

Fig. 15.—Current rise in relay with—"A" armature held in non-operated position. "B" armature held in operated position. "C" with freely moving armature.

which is opposed to the impressed voltage and, therefore, reduces the current. When the armature residual hits the core face the movement ceases and the counter E.M.F. disappears. The current then rises to its static value in accordance with the logarithmic law determined by the time constant. The result is a downward kink in the current curve, as shown in Fig. 13. Analogous conditions, but with reverse influence on the value of coil current, occur when the armature is forced off the core face, while the relay coil is fully energised. The coil current then shows an upward kink, as indicated in the above figure.

Finally, the current rise in the relay with freely moving armature is shown.

In Fig. 15, curve "A" shows the current graph with the armature held in the non-operated position. Curve "B," the current with the armature pressed on, and curve "C," the current for the freely moving armature. In curve "C," the current rise follows curve "A" up to the moment where the armature movement starts. During the stroke the increase nearly stops, or even shows a downward kink, due to the effect of the rapid change of the air gap. When the armature residual hits the core face the character of curve "C" changes suddenly, and a very steep current rise occurs, which is caused by the saturated condition of the magnetic circuit. This latter part of the curve is very similar to that obtained for condition "B."

As stated previously, it is not possible to determine the current rise from the self-inductance, but, if oscillographic methods are used to measure the current during operation, the equation found previously may be used for the determination of the effective self-inductance from the graph. In equation (18) the value L_t/R, which determines the steepness of the logarithmic graph, is the time constant of the energising circuit. At the time $t_1 = L_t/R$, the exponent in above equation becomes unity and

$$i_{t1} = \frac{E}{R}(1 - e^{-1}) = 0.63\ I$$

If an oscillographic record of the current rise is available, the time t_1, corresponding to above value of 0.63 I, can be determined, then

$$L_D = t_1 R \text{ ....} \quad (22)$$

The value L_D has been called the "dynamic self-inductance of the operating relay." In Fig. 13 the procedure for finding this dynamic inductance has been indicated. It should be noted that the curves A, B and C show different time constants t_1^A, t_1^B, and t_1^C, although they all refer to the same relay. As mentioned before, the relay was energised under fundamentally different conditions in each of these cases, and the result is that the dynamic self-inductance of the coil varies with these conditions. It is obvious that it is the saturation of the magnetic circuit which causes this variation of dynamic self-inductance. In this connection it should, however, be stated that an appreciable reduction of the operating time of a relay can be achieved only to a very limited extent by increasing the coil current if the operating voltage is kept constant. This condition applies to the majority of all practical applications.

Operating Time: The operating time of a relay may be divided into four distinct periods, i.e.:—

(a) From closing of the circuit for the coil current to the commencement of armature movement.
(b) From commencement of armature movement to the touching of the first spring contacts.
(c) From first spring contact to contact of last spring.
(d) From last spring contact to end of armature movement. (Residual against core face.)

For practical purposes the time intervals (a), (b) and (c) present the main interest, as they determine the delay between closing of the control current and the last function performed by the relay spring-sets. The time interval (d) is usually extremely short, as the armature movement is fast at the end of the stroke. When oscillographic studies of relay operating times are made, it is the sum of intervals (a), (b) and (c) that appears on the recording tape or film, if contacts are used for the deflection current. To measure the time interval (d), special arrangements, such as mirror deflection of light beams, or equivalent devices, are required.

It has already been shown that the pull on the armature is dependent on the time constant of the controlling circuit, and it is obvious that the operating time is in some way inversely related to this armature pull. A mathematical treatment is not practicable, for the reasons stated previously, but it might be of interest to mention the graphs published by Hebel[4], as their study will clarify the relative importance of various factors. In practice, neither formulae nor graphs are used, but accurate time measurements on batches of sample relays are made and conclusions derived from the tabulated results.

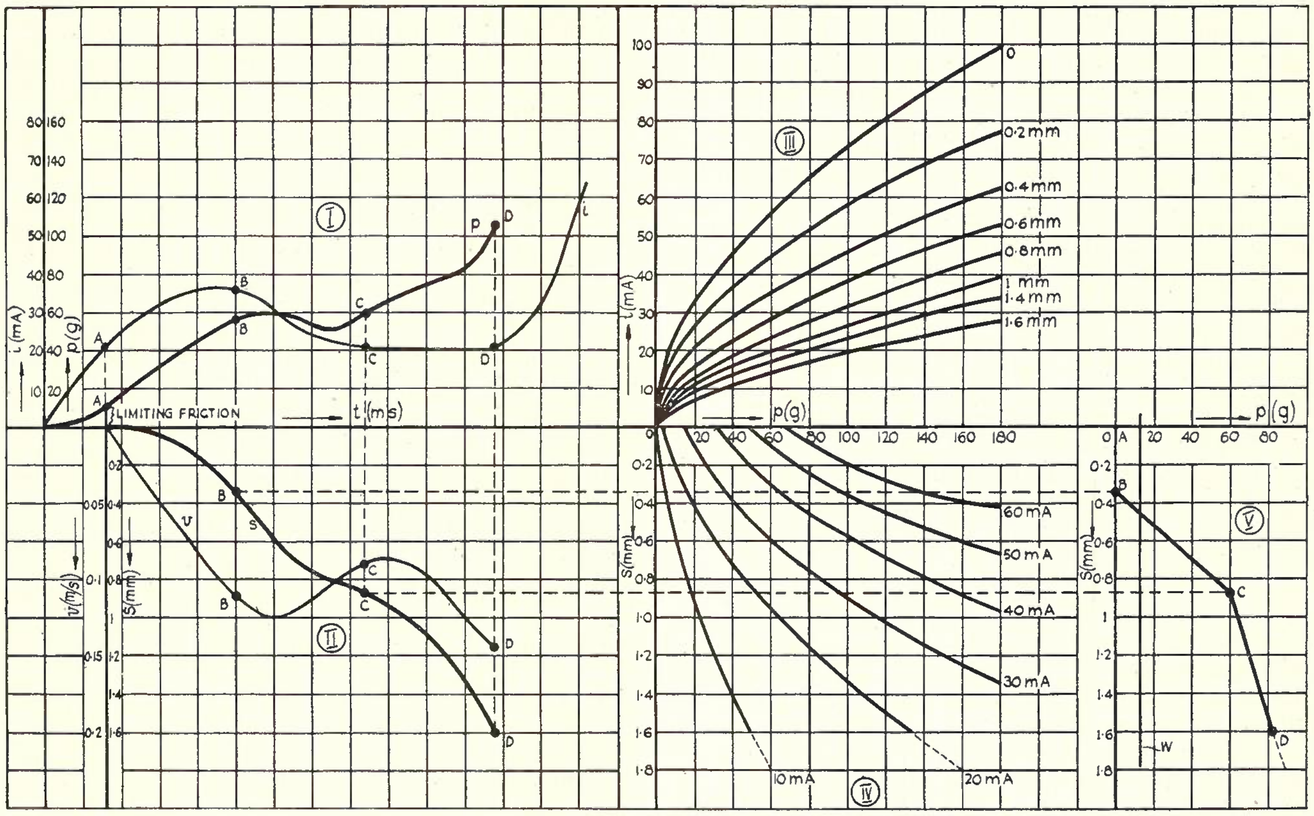

Fig. 16.—Hebel's graphs (five systems).

Fig. 16 shows two main and three auxiliary systems of co-ordinates, as follow:—

Main	Graph I:	Coil current and armature pull versus time.
	Graph II:	Armature travel (stroke) and velocity versus time.

Auxiliary	Graph III:	Armature pull versus operating current with various airgaps as parameter.
	Graph IV:	Armature pull versus armature position, with various operating currents as parameters.
	Graph V:	Springload versus armature position, and armature weight versus armature position.

The relay for which these graphs are shown has a very light load and works with a very small factor of safety. The pull available for acceleration of the armature is found as the difference between active and passive forces. The active force is the magnetic pull which is dependent on the armature position and the coil current at the particular instant. The passive forces are the spring load, the weight of the armature and friction. Before the armature starts to move, the pull must have reached a minimum value (margin) to overcome the forces of limiting friction for the static condition. The initial current rise and corresponding armature pull can be found from equations (18) and (19), which are applicable because the magnetisation is relatively low before the armature movement commences. To find the velocity of the armature after a small time interval Δt, the equation $\Delta v = p \,.\, \Delta t/m$ is used; then the corresponding distance of armature travel is found from $\Delta s = v_m \Delta t$, where v_m denotes the average velocity during the time interval Δt. For the first interval $|v_m|^1 = \Delta v_1/2$; for the time interval n, the average velocity is

$$|v_m|^n = |v_m|^{n-1} + \frac{|\Delta v|^{n-1} + |\Delta v|^n}{2}$$

When the armature starts to move, the change of flux, due to the reduction of the air-gap. induces a counter E.M.F., opposing the impressed voltage [see equation (21)], so that the rise in coil current is reduced. After commencement of armature movement, the use of equation (18) for finding the coil current is no longer practicable. It is necessary to have oscillographic measurements available. The magnetic pull on the armature may then be calculated from the coil current, taking into consideration the relative position of the armature at the particular instant. The balance of active and passive forces of the armature is then determined and used for finding acceleration, velocity and incremental armature travel, as shown above. A check can also be made by cinematographic measurements of the armature movement, from which velocity and acceleration can be calculated. As the armature-mass, the spring load and the friction are known, a graph of armature pull versus time can also be derived from these data. A comparison of the results thus obtained with those derived from the oscillographs of the coil current will then provide means of judging the accuracy or otherwise of the various measurements and calculations.

Summarising the influence of the various factors on the operating time, it can be said that it depends mainly on the time constant of the controlling circuit and is, roughly, proportional to it, provided the comparison is made between relays of the same type and with equal loads.

The influence of the operating voltage shall now be investigated. It may be desired, for example, to re-design relays in a given circuit for operation by 24 volt battery in lieu of 48 volt battery. It has to be assumed that the ampere turns are to be kept constant in order to achieve the working with the same factor of safety. Two possibilities are immediately apparent—

(a) Same number of turns and reduced D.C. resistance to obtain identical current at the reduced voltage. The inductance remains roughly the same as originally, but the resistance is smaller, so that the new time constant $L_1/R_1 < L_0/R_0$.

(b) Same D.C. resistance and increased number of turns to obtain the original ampere turns with the reduced current. In this case, the inductance of the re-designed coil will be bigger than that of the original coil, as it is roughly proportional to the square of the number of turns. Therefore $L_2/R_2 < L_0/R_0$.

In both cases, the time constant for the relay designed for the lower operating voltage has increased, if all other factors are kept constant. Under what conditions the operating time can be made equal for the re-designed relay will be shown further on.

It is convenient to relate the operating time to the "turns per volt," as this leads to a simple linear relationship. As indicated in equation (20), the self-inductance is proportional to N^2, provided that the magnetic field strength is not varied, which is the case if the ampere turns are kept constant. Taking the time constant as a measure for the operating time (t_0), the following equations are applicable:—

$$t_o = \kappa_1 L_D/R = \kappa_2 N^2/R = \kappa_2 (IN) N/E = \kappa_3 N/E \quad \text{..(23)}$$

For constant ampere turns the operating time is proportional to the turns per volt.

The next step is to show the influence of the ampere turns on the operating time.

The amount of ampere turns available exceeding the minimum operating turns is regarded as a measure for the safety of operation and, in the diagram, Fig. 17, this current factor of safety is used as abscissa. The operating time is shown for two relays with widely different turns per volt factors, and two graphs are shown for each relay. The curves marked "A" were found by altering the current safety factor through variation of the impressed voltage on a relay-coil with fixed resistance. The curves marked "B" show the operating times for a constant voltage if the current safety factor is varied through re-winding the coils to different resistances.

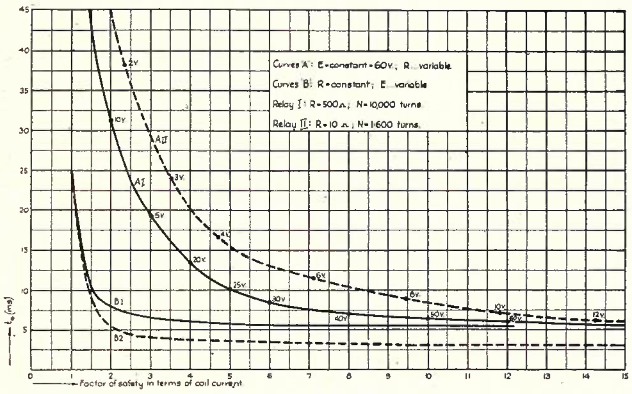

Fig. 17.—Operating time versus current safety factor.

As to be expected from the preceding considerations, the two types of curves corresponding to conditions "A" and "B" are very different. However, the fundamental fact that for constant voltage no worthwhile decrease in the operating time can be achieved by increases of the current safety factor within practical limits, emerges quite clearly. The curves marked "B," which represent the conditions of fixed operating voltage, show this explicitly.

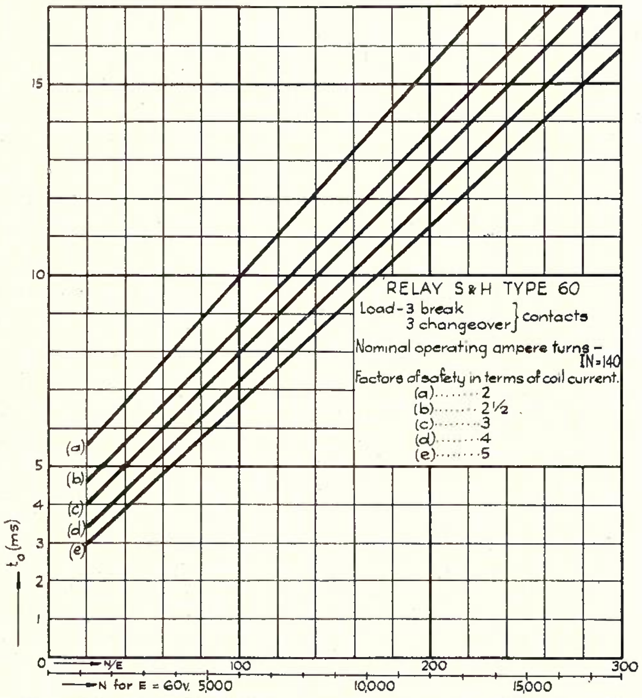

Fig. 18.—Operating time versus turns/volt with current safety factor as parameter.

A further illustration[3] might help to emphasise the statements made regarding the influence of the turns/volt and the current safety factor on the operating time. See Fig. 18.

The ratio between operating time (ordinates) and turns/volt (abcissa) is linear, as stated in equation (23); the current safety factor is used as a parameter. The distances between the curves of different current safety factors are determined by the properties of the magnetic path.

The influence that the choice of the working voltage for a telephone exchange has on the design of relays shall now be reconsidered. The problem may be presented in two ways:—

(a) The ampere turns (IN) are to be kept constant by keeping both the current and the turns constant.

(b) The operating time is to be kept constant, together with the ampere turns.

For condition (a):

$(IN) = \text{constant},\ I = \text{constant},\ N = \text{constant}.$

$I = E_1/R_1 = E_2/R_2;\ E_1/E_2 = R_1/R_2$

$(t_o)_1 / (t_o)_2 = E_2/E_1 = R_2/R_1$

The operating times to be expected in this case are inversely proportional to the operating voltage, e.g., the relays in the 24 volt exchange would have operating times twice as long as those in a 48 volt exchange, or two and a half times as long as those in a 60 volt exchange.

$$W_1 = I\,E_1;\ W_2 = I\,E_2$$
$$W_1/W_2 = E_1/E_2$$

The energy dissipation is directly proportional to the exchange voltage, so that under condition (a) the 24 volt exchange only uses half of the energy of the 48 volt exchange. The cross-section of the winding area taken up must be proportional to the cross-sectional area of the wire used, as the turns are to be kept constant.

$$(A_w)_1 / (A_w)_2 = d_1^2/d_2^2 = R_2/R_1 = E_2/E_1$$

The cross-sectional winding area required is, therefore, inversely proportional to the voltage, so that for 24 volt operation twice as much of it is required as for 48 volt operation. This fact explains the previously stated reduction in the energy consumption.

For condition (b):

$(IN) = \text{constant},\ t_o = \text{constant},\ \therefore\ N/E = \text{constant}.$

$N_1/N_2 = E_1/E_2 = I_2/I_1;\ R_1 = E_1/I_1,\ R_2 = E_2/I_2$

$R_1/R_2 = E_1I_2/E_2I_1 = N_1^2/N_2^2 = E_1^2/E_2^2$

$W = E_1I_1 = E_2I_2 = \text{constant}$

Under condition (b) the energy dissipation is therefore constant. In order to keep the operating times constant, the number of turns to be provided must be made proportional to the operating voltage, and the resistance of the windings has to be proportional to the square of the voltage.

This means that, comparing 24 volt working with 48 volt working, only half the number of turns is to be provided, but the winding wire to be chosen has to have double the cross-sectional area. This results in a winding taking up about the same cross-sectional winding area (disregarding variation of the space factor); under condition (b) the relays for various operating voltages are equivalent in energy consumption and operating time.

However, it should be noted that the operating currents are twice as large for the 24 volt operation as for the 48 volt operation. As far as local circuits are concerned, this is of little importance, as contacts and wiring are designed sturdily enough to carry these heavier currents. Some difficulty might be experienced with driving coils for selectors, but this does not present the main problem. It is the limitation on the signalling (dialling range of the system) which primarily influences the choice of the working voltage. This range depends on the admissible margins for line resistances and, as indicated above, the maximum resistance values are inversely proportional to the square of the chosen operating voltage. Therefore, for 24 volt working, the admissible resistances are only a quarter of those applicable for 48 volt operation. It is obvious that these conditions restrict the use of low voltage exchanges to installations with short lines to the subscribers (P.B.X.'s and P.A.B.X.'s).

The question in respect to the most suitable operating voltage for main exchanges is somewhat controversial. The general practice in English-speaking countries is to operate the main exchanges from 48 to 50 volts, while Continental practice is to have a 60 volt operating battery. One of the arguments advanced in favour of the low 50 volt battery is that the severity of electric shocks to be expected is less serious. On the other hand, the adherents of the 60 volt system claim distinct advantages as far as range of the system and operation of driving magnets is concerned.

It may be suggested that the fact that insurance underwriters in America regard installations carrying more than 50 volts D.C. as "dangerous to life," has had something to do with the original choice of the 48 volt supply. The Continental equivalents to this voltage bar are fixed at values of 65 to 75 volts which, in turn, might have prompted local designers to choose 60 volts in lieu of 48 volts, as used in America where the automatic telephone systems originated.

To conclude the notes on operating time, the influence of resistance and inductance in series with the operating winding should be mentioned. As an example, the case of a relay with resistance R and dynamic inductance L_D, and which operates with a current safety factor of four, shall be considered. If an external, non-inductive resistance, having the same numerical value as R, is connected in the operating circuit, the time constant will be doubled and the current safety factor will be reduced from four to two. This will also tend to increase the operating time, as the dynamic inductance of the relay will change. The result of both these influences is that the operating time under the new conditions will be about two and a half times the original value. This fact has to be closely watched when measurements of operating time are made under laboratory conditions, as artificial circuit arrangements which do not follow closely the actual operating conditions may give very misleading test results.

It may also be said that the practice of specifying tolerances for the number of turns, as well as for the resistance values of coil windings, has a certain disadvantage. The time constant of the coil which, primarily, determines the operating time, is proportional to N^2/R [see equation (23)], and it is obvious that fairly large variations of this value will occur when resistance and turns approach to opposite tolerance limits. For instance, with a turns tolerance of $\pm$ 3% and a resistance tolerance of $\pm$ 5%, the time constant will vary between limits of + 12% and — 10.5% of its nominal value.

A better degree of uniformity for the time constant can be achieved if the coils are wound to fixed turns. In this case it might be found necessary to increase slightly the resistance tolerance, but a net gain will still be obtained, because the turns influence the result in proportion to the square of the number, while the influence of the resistance values is linear. Furthermore, the practice of providing a few turns of resistance wire to bring the coil-resistance up to its nominal value can be used to keep the resistance variations in narrow limits.

The Magnetic Circuit: When the design of contact springs and the minimum clearances and deflections have been chosen, the size of the required working gap, i.e., the armature travel, is determined by the lever ratio of the armature. The maximum number of springsets that it is desired to provide and which show the most critical mechanical characteristics (see Figs. 10 and 11), is to be used for the design of the magnetic path. As it is necessary to base the calculation on static conditions, a "nominal spring load" is derived from the mechanical characteristic by determination of a load in the unoperated position requiring the same amount of ampere turns as are necessary to overcome the spring pressure at the critical point. The design of the magnetic path is then based on a maximum load figure, obtained by multiplication of the nominal load with a factor of safety. Therefore, the design can be started, assuming, as given:

P ... armature pull in grammes, in non-operated position.
g ... working airgap in mm; variable in narrow limits by choice of the lever ratio.

Furthermore, it has to be assumed that the mounting space for the relay has to be kept as small as possible. As part of this mounting space is reserved for accommodation of the springsets, the room available for the magnetic paths and the coil may be regarded as fixed within narrow limits.

The force of attraction between two equidistant magnetic planes of opposite polarity is

$$P = B^2A/8\pi \text{ dynes}$$

when B = Flux density in gauss
A = Area of pole plates in cm^2.

This applies, provided that the air gap is small in comparison with the pole area, as the formula does not include the effects of fringing at the edges and the lack of uniformity of flux in the gap. Actually, the armature and the core face are not parallel, but have an angle of obliquity which causes a non-uniformity of flux distribution, so that the force of attraction between two oblique faces is greater than the attraction between parallel faces. On the other hand, the momentum of this force about the axis of armature movement is diminished as the centre of pull is shifted. The actual net result is, in most cases, a small gain[1].

$$\Phi_W = B\ A \ldots \text{ Flux in working airgap.}$$

$$P = \frac{\Phi_W{}^2}{8\ \pi\ 981A} \text{ grammes;}$$

$$\Phi_W = \sqrt{8\ \pi\ 981}\ .\ \sqrt{A\ P} \text{ maxwell } \ldots\ \ldots\ \ldots\ (24)$$

$$\Phi_C = \Phi_W + \Phi_L = \Phi_W/(1 - \lambda)$$

when: Φ_C . . . Flux in core
Φ_L . . . Leakage flux

$\lambda = \Phi_L/\Phi_C$ . . . Leakage factor

As stated previously, the coil should be made as long as possible, to provide optimum conditions for the coil winding. There are, of course, definite limits to the useful coil length and, apart from mechanical factors, it is the increase of leakage flux which determines the practical limits. This leakage flux is that part of the total flux which passes through the middle section of the core, but does not pass through the working airgap and, therefore, does not contribute to the pull exerted on the relay armature. This leakage flux increases the flux density in the core and, through the change in permeability, increases the reluctance for the main flux. However, this effect is relatively small. More serious is the magnetic coupling with adjacent relays, which is caused by the leakage flux, and it is this effect that forces the designer to keep the leakage flux small.

In order to determine the cross-sectional area of the core, the flux density has to be chosen. It may appear desirable to select a flux density which gives highest permeability with full ampere turns and full armature gap, but, if the conditions due to the dynamic nature of the relay operation are studied, it will be seen that a working point below the maximum slope of the permeability curve is more advantageous, as it allows for improved efficiency at the critical point of the armature movement. The full ampere turns mentioned above have to include an adequate factor of safety margin above the nominal ampere turns. The choice of suitable values for these margins of safety is to be discussed under a separate heading, further on.

For the purpose of finding the cross-section of the core, the amount of leakage flux must be estimated on a percentage basis, and the figures chosen checked by measurement when pilot models have been made.

$A_c = \Phi_c/B$ when A_c .... area of core in cm^2.
B .... chosen flux density.

As stated previously, the size of the working airgap required is determined within narrow limits by the choice of the springsets and it will be through a variation of the pole-face area that the desired reluctance value for the airgap will be obtained. It can be shown that for any given airgap length an optimum poleface area exists which gives an airgap reluctance providing maximum pull for the given magnetomotive force, i.e., maximum sensitivity.

$$P = \frac{B^2A}{8\ \pi} = \frac{\Phi_W{}^2}{8\ \pi\ A} \text{ dynes } \ldots\ \ldots\ \ldots\ (24a)$$

with $\Phi_W = M/(\alpha + x)$
and $x = b/A$

$$P = \frac{M^3}{8\ \pi\ b} \cdot \frac{x}{(\alpha + x)^2} \ \ldots\ \ldots\ \ldots\ (25)$$

when Φ_W .... flux in working airgap.
A .... effective area of airgap.
b .... effective length of airgap (including residual airgap).
M .... magnetomotive force.
α .... reluctance of iron path, including incidental airgaps, but not the residual airgap.
x .... reluctance of airgap.

For maximum or minimum of P, with b and α kept constant:

$$\frac{dP}{dx} = \frac{M^2}{8\ \pi\ b} \cdot \frac{\alpha - x}{(\alpha + x)^3} = \theta$$

$$\therefore x = \alpha \ \ldots\ \ldots\ \ldots\ (26)$$

$$\frac{d^2P}{dx^2} = \frac{-(\alpha + x) - 3\ (\alpha - x)}{(\alpha + x)^4} = 2\ \frac{x - 2\alpha}{(\alpha + x)^4}$$

For the value of $x = \alpha$, the second differential quotient has a negative value, so that above condition indicates a maximum.

The derivation as given has been interpreted[1&5] that, for maximum pull, the reluctance of the "working airgap" should equal the reluctance of the "remainder of the magnetic circuit" (including the residual airgap). However, this is not quite correct in this general form, and it would be wrong to increase the reluctance of the iron path in order to achieve above balance of reluctances if the airgap reluctance cannot be made small enough. Furthermore, it is quite obvious that an increase of the reluctance of the residual airgap cannot result in a greater armature pull.

In equation (25) the condition for the maximum of the variable factor $x/(\alpha + x)^2$ at the value $x = \alpha$ does not apply to P unconditionally, but rather to the product (P.b), i.e., P becomes a maximum for a given length of effective airgap, if the poleface area A is chosen so that $x = \alpha$,

$$\therefore x = b/A; \; A = b/\alpha \quad \ldots \ldots \ldots \quad (27)$$

Assuming the iron path reluctance as constant, which is approximately correct for small energization, the pole-face area for maximum sensitivity may be calculated from equation (27). It should be noted that for any relay with a desired stroke length g this optimum pull condition can only be fulfilled at one position of the armature, and it should be the aim to have this position coincide with the "critical point of the mechanical characteristic of the springsets" (see Figs. 10 and 11).

In order to show why the residual air-gap must be included in the value for b it is only necessary to recall the physical significance of equations (24a) and (25). The case under consideration is a magnetic circuit comprising an iron path and an air-gap (residual and working air-gap) of given length. The variable to be determined is the pole-face area. The armature pull is proportional to this pole-face area and to the square of the flux-density in the air-gap. This can also be stated in the form: "It is proportional to the ratio of the square of the total flux to the pole area." By varying this pole-face area the armature pull is influenced by two factors, i.e . the pole area itself and the varied flux density. As long as the reluctance of the iron path is small compared with the air-gap reluctance, an increase in the pole-face area will produce an increased pull. When the pole-face area has been made so big that the air-gap reluctance equals the reluctance of the iron path, an optimum value for the pull is reached; further increases in the pole-face area result in a decreased pull as the flux density falls rapidly. These statements apply for a fixed length of air-gap, as mentioned previously.

The length of the residual air-gap must be included in this value for the air-gap, because its reluctance varies with the pole-face area in the same manner as the reluctance of the working air-gap. However the incidental air-gaps (joints between iron parts), the reluctance of which is not affected by a change of the pole area, have to be considered as part of the iron path.

An analogy might help to explain the influence of the reluctance ratio. It was stated that it is the product (P.g) which becomes a maximum when the reluctance ratio is unity. This product of force times distance has the dimension of energy. A certain analogy exists now with the transfer of electrical energy between generator and consumer, which becomes a maximum (for D.C. conditions) when their resistances are equal. In the case of the magnetic circuit, the product P.g becomes a maximum if the reluctance of the air-gap equals the reluctance of the iron path. This is so because the conditions for maximum are identical as far as their formulation is concerned. A study of the equations will show this quite clearly. But the analogy is by no means complete, and it would be wrong to assume that the residual air-gap may be regarded as forming part of the "remainder of the magnetic circuit" for the purpose of finding the optimum reluctance ratio, just because the analogy to the electric energy transfer seems to make this plausible. As shown previously, the residual air-gap must be considered as forming part of the total air-gap, the reluctance of which changes with the pole area chosen.

When the pole area is constant and the variation of the air-gap reluctance is achieved by variation of the air-gap length the formulae (26) and (27) do not longer apply.

From equation (24a) P (dynes) is given by:

$$P = \frac{B^2A}{8\pi} = \frac{\Phi_W^{\,2}}{8\pi A} = \frac{M^2}{8\pi A} \cdot \frac{1}{(\alpha + x)^2} \quad \ldots \ldots \quad (24b)$$

With constant A the force P becomes a maximum when $(\alpha + x)$ becomes a minimum. As there are no negative reluctances, the minimum occurs for constant α when $x =$ zero. This means that in the case under consideration now (pole-face area A constant) there is no optimum ratio of reluctances apart from the fictitious case of no working air-gap. There is also no objection now to adding the reluctance of the residual air-gap to that of the iron path (α) as the pole area is being kept constant. From equation (24b) it further follows that α should be as small as possible, i.e., that the iron parts have to be designed for minimum reluctance and that incidental air-gaps have to be kept as small as possible. The size of the residual air-gap is determined by the release conditions desired for the relay and can, therefore, not be chosen freely.

Fig. 19 shows the influence of the ratio x/α when α is constant and x altered by varying the air-gap while keeping the pole-area A constant. It will be noted that under these conditions the point corresponding to $x = \alpha$ has no special significance.

Summarising the influence of the reluctance ratio on the tractive force P the following formulations apply:—

For constant magneto motive force M the tractive force:

$P = f(\alpha, b, A) = f_1(\alpha, b, x) = f_2(\alpha, x, A)$

and $x = b/A$ when uniformity of field in the airgap is assumed.

Case I: Constant airgap, $b =$ constant
$P = f_3(A, \alpha)$ and becomes a maximum for $A = b/\alpha$ (equation 27)

Case II: Constant pole face area, $A =$ constant
$P = f_4(b, A)$ and becomes a maximum for $b = \theta$

Case III: Constant airgap reluctance x : $b =$ constant
$A =$ constant
$P = f_5(\alpha)$ and becomes a maximum for $\alpha = \theta$

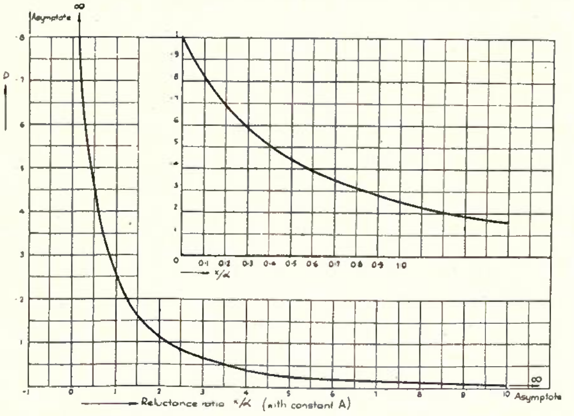

Fig. 19.—Armature pull versus χ/α with constant poleface area A.

From the preceding considerations the following conclusion may be drawn:—

The iron parts of the magnetic circuit are to be designed for minimum reluctance and the incidental airgaps are to be kept as small as possible; the residual airgap is to be kept to the minimum admissible under the release conditions applicable. If practicable, the pole-face area should be chosen in accordance with condition of equation (27).

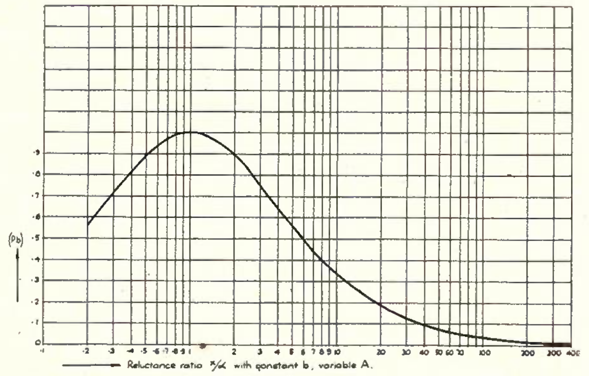

Fig. 20.—Sensitivity versus χ/α with constant gap and varying poleface A.

It will be realized that for standard relay types the latter reluctance ratio cannot be achieved, because the stroke required for satisfactory operation of the springsets and practicable values for lever ratio and pole-face area result in an air-gap reluctance which has a multiple value of the iron path reluctance. However, for high energization and the iron approaching saturation, "α" will increase considerably, and the reluctance ratio for small air-gaps will assume values near unity, but, notwithstanding this favourable ratio of reluctances, the sensitivity will be lower than for the lightly energized condition, because the value of α at which this balance occurs is high.

In order to demonstrate what influence on the sensitivity the reluctance ratio has, Fig. 20 shows the value of P for varying values of x with constant α; herein all reluctances apply to the same length of airgap, but to varying pole-face areas. The maximum at the value $x = \alpha$ is flat; for $x/\alpha = 2$ the pull is 89.5%, for $x/\alpha = 5$ it is 56% and for $x/\alpha = 10$ it is still 33% of the optimum that could be achieved with sufficiently large pole areas.

The next step to be taken is to determine how the number of ampere turns required is influenced by the choice of the dimensions for the working air-gap. Actually, the accuracy of the result of such a calculation will not be satisfactory, and measurement on pilot models will have to be made. However, it might be of instructive value to indicate the procedure. From equations (24) and (24a):

$$\Phi_W = M/(\alpha_i + \beta g) = \sqrt{8\pi\, 981} \cdot \sqrt{A\,P} \text{ maxwell}$$
when $x = \beta g$.

and α_i .... reluctance of iron path, including residual and incidental airgaps.
g .... length of working airgap.
β .... factor which, when multiplied with g, represents reluctance of that part of the magnetic circuit that varies with the armature movement.

$$M = 0.4\pi(IN) = \kappa_x \beta g \sqrt{8\pi\, 981}\sqrt{A\,P};$$
when $\kappa_x = 1 + \alpha_i/\beta g$.
$$\beta g = \delta g/A = g/A.$$

The factor κ_x now represents the reluctance ratio of working air-gap to the remainder of the magnetic circuit, including the residual air-gap. In first approximation, if the factor δ representing the influence of non-linearity of flux in the working air-gap is disregarded

$$(IN) = 125\,\kappa_x\, g\sqrt{P/A} \quad \ldots\ldots\ldots\ldots \quad (28)$$

Equation (28) gives the required armature turns (IN) in terms of length of working air-gap and pole-face area. These quantities have to be expressed in c.g.s. units, i.e., the gap in centimetres, the load in grammes and the area in centimetres square. It will be seen that the pole-face area A is of primary importance, as it influences the result to the same extent as the spring load —$(IN)^2$ being proportional to the ratio of these two quantities. However, there are very definite practical limits to the size of pole-face area that can be used in a relay of conventional design. If the pole-face area is made much larger than the cross-section of the core, the flux density will be uneven and the effective pole-face area (A/$^{\delta}$), therefore, smaller than A. It should be noted that equation (28) contains also the factor κ_x, which represents the ratio x/α and, therefore, depends on the values of g and A, as well as on the flux density in the iron parts.

Safety Margins: The nominal operate ampere turns which are found if the nominal spring load is used for calculation do not present a useful solution of the design problem for the required winding. As stated previously, it is necessary to operate relays with sufficient safety margins to ensure that they will fulfil their functions in the circuit under the most adverse conditions to be expected. Reasonable manufacturing tolerances for all adjustments have also to be admitted so that bulk production methods can be used. These safety factors can be either expressed in terms of spring load or in terms of coil current, and the relation between these two types of factors of safety has to be considered. If a relay with a certain number of ampere turns just manages to operate a certain contact load, it can be said that the load factor of safety and the current factor of safety are both equal to unity. As the operating current is increased beyond the absolute minimum required, these two safety factors assume different values. As long as the current increase above the minimum is small the armature pull is roughly proportional to the square of the ampere turns, so that the load safety factor will increase faster than the current safety factor. However, with further increases of coil current, which lead to saturation, the increase in armature pull is progressively diminished until for very large coil currents no additional armature pull results from further increases of the current factor of safety.

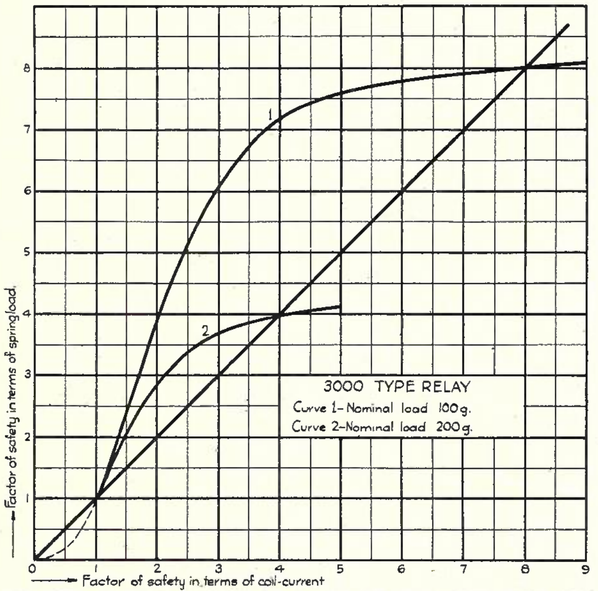

Fig. 21.—Safety factors in terms of armature load and coil current.

Fig. 21 shows two examples of the ratios between those two safety factors. The part of the graph (dotted) showing the ratio for currents with a factor smaller than unity has only theoretical interest. Graph 1 applies to a relay with a light load and which, therefore, requires only small energization. It will be seen that in this case the load factor of safety is greater than the current factor of safety for all values of the latter up to 8. Graph 2 applies to a relay of the same type as in Example 1, but with a contact load which is twice as heavy. It will be seen that in this case the load factor of safety cannot keep pace with the current factor of safety if the latter assumes values higher than 4.

It will be of interest to analyse to what extent the practice of expressing the factors of safety in terms of spring load on the armature influences the result, as far as the coil current is concerned.

For this purpose, the standard procedure for design of 3000 type relays is quoted as follows[6]:—

"(A) Test factor of safety (1.75); to cover the variations from the ideal performance of relays to reasonable adjustment and manufacture tolerances.

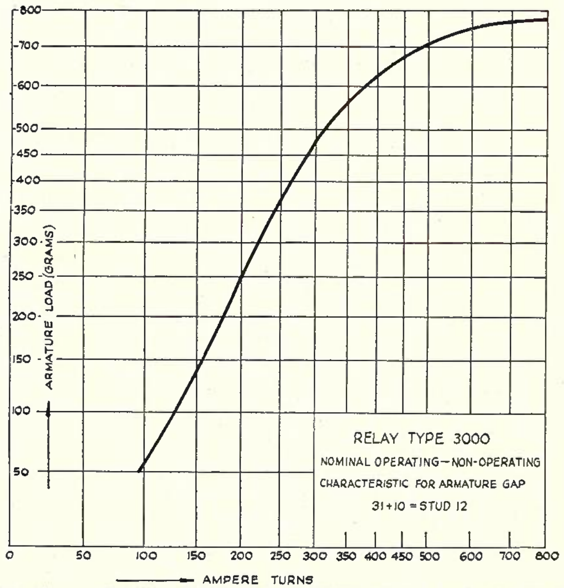

Fig. 22.—Nominal operating ampere turns and springset load graph.

(B) The circuit factor of safety (4 for operating); to cover the variation in relay performance due to handling and usage, as well as variations of circuit current due to voltage and resistance variation.

Let W = nominal armature load of the springset of a particular relay. The relay winding should then be so designed that under circuit conditions the ampere turns (IN) obtained should be capable of operating the load (W x 4). The operating test current specified for the relay should give ampere turns (IN) capable of operating a load of (W x 1.75)."

From Fig. 22, which shows a nominal load/ampere turns graph, the required ampere turns for a relay coil are obtained as abscissa by entering with "nominal spring load times factor of safety," the latter being expressed in terms of load, as an ordinate. Using a safety factor of 4 for the "operate" condition, various values for the corresponding factor of safety, expressed in terms of coil current will result; the value of these current margins depends, in this case, on the nominal spring load for which the relay is designed.

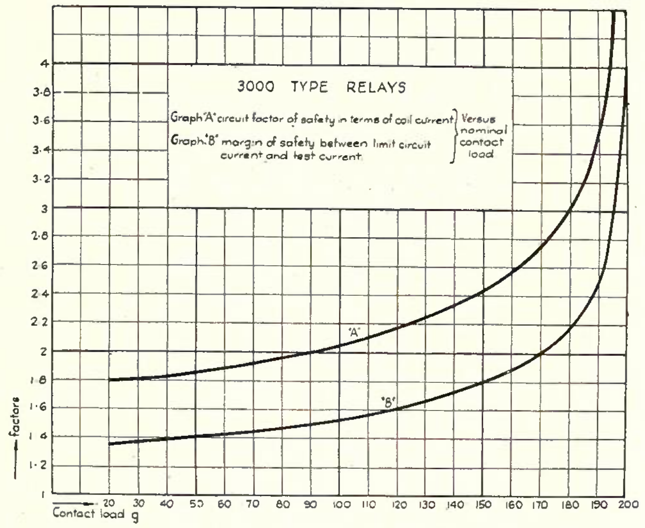

Fig. 23.—Current factor of safety versus contact load and marginal factor between limit circuit current and test current.

In Fig. 23 the values for this current factor of safety versus contact load are shown in curve "A." This graph was derived from Fig. 22 as the ratio between the coil currents (abscissae) which correspond to "nominal spring load times factor of safety," and the "nominal contact load" itself. It will be seen that this circuit factor of safety, expressed in terms of coil current, can vary from 1.8 for 20 grammes load to 4.5 for 200 grammes load. For loads higher than 200 grammes it is obviously not possible to apply the standard load factor of safety 4 at all, because saturation occurs at the corresponding coil current. The design procedure for relays with a high contact load stipulates a minimum factor of 2.5 (in terms of contact load), provided the result in ampere turns gives a margin of 10% + 10 (IN) against the test current figure. This implies that the margin between limit circuit ampere turns and test ampere turns expressed as a ratio of currents, is of importance.

The test factor of safety is desired to cover variations in adjustments, i.e., in the load on the armature and the gap at which the load is applied. Therefore, the ratio (test factor of safety) between nominal values and test values has to be expressed in terms of armature loads and air-gap. But this does not apply to the same extent to the circuit factor of safety which is chosen to cover the admissible margin for handling and usage and variations of coil current. These variations in coil current are due to admissible margins in the operating voltage and in various resistances (internal and external) in the circuit network. The minimum current provided under circuit conditions (limit circuit current) should be found with the lower margins of operating voltage and the higher margins of resistances in the circuit. If this is done, current variations due to normal tolerances are taken care of by the value of limit circuit current. As a further marginal factor of safety is desirable it should be expressed in terms of coil current and not in terms of contact load.

The practice of expressing this circuit factor of safety in terms of contact load results in a variation of the margin between limit circuit current and test current over a wide range, according to the contact load. Curve B in Fig. 23 shows the latter marginal factors for nominal loads from 20 grammes to 200 grammes. It will be seen that the margin at light loads is rather small while it becomes excessive at high loads. This explains why it is necessary to abandon the normal procedure for higher contact loads and to substitute marginal values expressed in terms of coil current. Because this is so, the argument that a simplified design procedure results, if both safety factors are expressed in terms of spring load, loses some of its force. It is suggested that it would be more satisfactory to express the margin between limit circuit currents and test currents in terms of ampere turns for all relays independent of the contact load.

Conclusion: Fundamental problems of relay design covering the utilisation of the winding space, the dynamics of operation, the influence of various factors on the "operate" times, as well as the properties of the magnetic circuit, have been discussed. While some of the problems can be solved by mathematical methods, quite a number has to be approached empirically. But even in this case, theoretical formulation of the problem can help considerably to put the results obtained from tests in their proper perspective; an attempt to do this has been made in this article. However, it has not been possible to cover all problems which arise in relay design, and the most serious omission concerns the conditions of "delayed release and operation," and of "holding under transient current conditions," which play such an important part in circuit functions. The treatment of these questions, as well as of methods of relay-time measurements, has to be left to the future, as it necessitates investigations for which, due to the pressure of other work, no opportunity exists at present.

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STANDARD CARRIER TRANSPOSITION SCHEMES IN AUSTRALIA

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Introduction: One of the most important geographical features which affects the provision of trunk line facilities in Australia is the great distances between the larger centres of population and the concentration of population in the capital cities. With the exception of Newcastle, none of the provincial towns has more than 50,000 inhabitants. For this reason, within the next few years the installation of long trunk cables will be concerned mainly with the more heavily-loaded long routes in this country, such as Melbourne - Ballarat, Sydney - Melbourne and Sydney-Orange.

It appears, therefore, that even with a rapid development of radio communication for trunk telephone purposes, the open wire route will be the most widely used method of providing trunk telephone circuits for many years. Since the installation of the first carrier system between Sydney and Melbourne in 1925, which was, incidentally, the first carrier system installation in the British Empire, long-distance trunk circuits have been provided more and more by the use of 3-channel and 12-channel carrier systems. The full exploitation of the channel-carrying capacity of existing open wire routes and the construction of new high-grade carrier routes are consequently most important factors in the trunk line programme in Australia. A previous article published in Vol. 3, No. 2 (1940) of this journal dealt with "Principles of Transposition Design." The present paper is supplementary to the previous article and surveys generally the changes in transposition practices since 1940 to meet the increased 12-channel system requirements. To simplify the context of the paper, definitions of terms used are grouped in an appendix.

Electrical Requirements of Multi-Channel Carrier Routes

To meet the electrical requirements for open wire routes consideration must be given to the following:—

(i) Use of suitable transposition types.
(ii) Control of third circuit effects.
(iii) Reduction of couplings between pairs.
(iv) Uniform construction to allowable tolerances.
(v) Impedance matching to specified limits between different types of construction.
(vi) Layout of transposition sections.
(vii) Use of suitable junction transposition schemes.

Tranposition Types

For 3-channel carrier operation at frequencies up to 30 kc/s suitable transposition types are chosen to give satisfactory direct cross-talk conditions and a sufficient number of common transpositions to control normal third circuit effects.

In practice this requires the use of single extra transposition types for E. Sections of 8.0 miles and corresponding types for the shorter 4.0 mile, 2.0 mile and 0.5 mile transposition sections.

The introduction of 12-channel carrier systems operating at frequencies up to 143 kc/s increased the importance of certain factors in the selection of transposition types. These were, briefly:—

(a) Provision of a smooth attenuation curve up to the greater maximum angle of phase change concerned.
(b) Control of the more important third circuit effects.
(c) Necessity to design primarily for far-end cross-talk and ensure a low reflection coefficient (¹), particularly between open wire and cable sections.
(d) To restrict impairment of the far-end cross-talk by reflected low near-end cross-talk attenuation between certain combinations.

Peaks in the attenuation curve due to absorption are primarily a function of the coupling between the pair concerned and the longitudinal earth circuit formed by the two wires of the pair and earth. The relative transposition type in this case is the same as the transposition type of the pair of wires concerned. If the curve of near-end type unbalance (²) of the transposition type concerned is regular up to the maximum phase change angle, no appreciable absorption peaks will occur in the attenuation curve. However, if pronounced isolated peaks exist in the type unbalance curve undesirable absorption peaks will occur in the attenuation curve. This characteristic limits the number of transposition types available as compared with those used to 30 kc/s.

Third circuit effects are due to interaction cross-talk per medium of other physical pairs or via neighbouring phantom transposed circuits. The former type is controlled primarily by the use of transposition types containing a suitable number of common transpositions. This requires the adoption of at least double and triple extra transposition types for both 6.4 miles and 8.0 miles E. transposition sections.

To obtain satisfactory direct far-end cross-talk as well as smooth attenuation curves, the number of transposition types available for E. sections, particularly those up to 8.0 miles in length, is limited. In general, these types are confined to the double extra and triple extra derivatives of fundamental transposition types a, b, c, d, and M, N, O, P, with single extra P(P_1) and single extra b (b_1) (³), as the best relative types. This restriction gives high values of near-end cross-talk between some combinations and care must be taken to ensure: (i) That these relatively poor near-end cross-talk conditions do not become additive over repeater sections, and (ii) that constructional irregularities are impedance matched to give a reflection co-efficient (¹) of less than 5% in all cases.

Control of Third Circuit Effects

Indirect far-end cross-talk is an important component of the total far-end cross-talk between carrier pairs. In addition to the use of transposition types containing a suitable number of common transpositions, tests have shown that consideration must be given to the presence of phantom transpositions and high-coupled minor trunk circuits on the route as these can give rise to high-coupled third circuit paths.

The insertion of phantom transpositions in pairs transposed with single extra transposition types for carrier operation up to 30 kc/s seriously impairs the far-end crosstalk conditions at the higher frequencies. Improvements in the far-end cross-talk between the side circuits of a phantom group of from 10 db to 30 db have been measured over 3-channel carrier repeater sections after the removal of the phantom transpositions. Typical examples of measured values of far-end cross-talk between side circuits transposed for 3-channel carrier operation both before and after the removal of the phantom transpositions are shown in Fig. 1. While phantom circuits have a very high coupling to neighbouring physical pairs, particularly those vertically above or below them, experience to date has not shown that the existence of phantom transpositions in the voice frequency pairs on a 3-channel carrier route has any serious effect on the far-end cross-talk between the carrier pairs. However, the existence of phantom transposed voice frequency pairs below the carrier pairs on a 12-channel carrier route can degrade appreciably the far-end cross-talk between the high-frequency circuits.

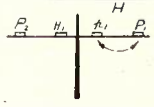
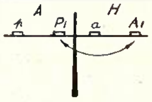
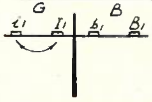
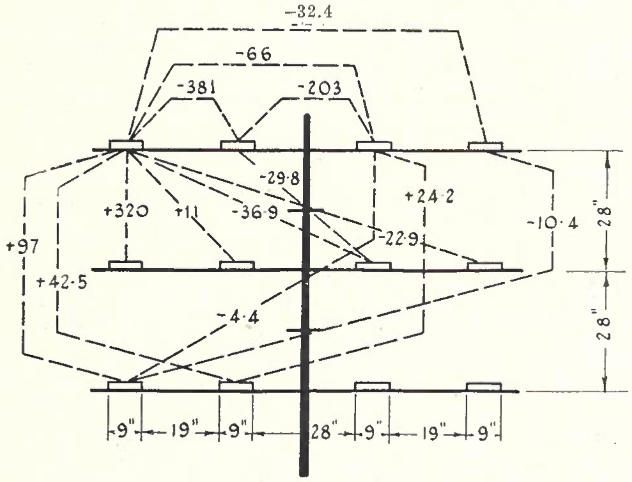
TRANSPOSITION TYPES WITH 9"-19"-9" WIRE SPACING	LENGTH OF SECTION OF ROUTE	MEASURED WORST VALUE TO 30 kc/s			
		WITH PHANTOM		WITHOUT PHANTOM	
		NEAR END	FAR END	NEAR END	FAR END
1	2	3	4	5	6
	1E SECTION 8.0 MILES	db 62	db 62	db 64	db 77
	1E SECTION 8.0 MILES	63	67	61	95
	145 MILES	53	44	53	65

Fig. 1.—Influence of phantom transpositions on the crosstalk to 30 kc/s.

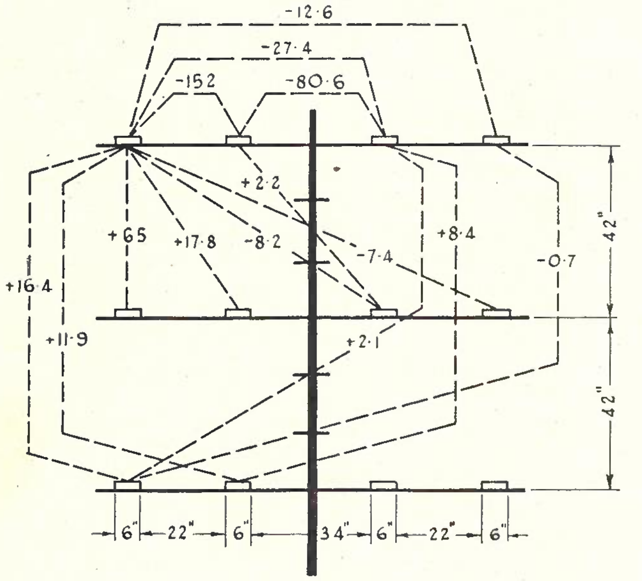
Even non-transposed voice frequency pairs in close proximity to 12-channel carrier pairs have been found to impair the far-end cross-talk between the carrier pairs. Thus, for 12-channel carrier work, it has been necessary to eliminate phantoms from all pairs, both carrier and voice frequency, and to provide adequate separation of voice frequency pairs from carrier pairs.

Reduction of Coupling Co-efficients

The value of the coupling co-efficients (⁴) between the various carrier pairs is an important factor in determining the crosstalk to be expected between the combinations of pairs and, particularly for 12-channel carrier operation, it is most desirable that the values of the coupling co-efficients be as low as practicable. For this reason, the wire spacing of 9"–19"–9" and arm spacing of 28" which was adopted for 3-channel carrier routes has been modified to a wire spacing of 6"–22"–6" and arm spacing of 42" for new 12-channel carrier routes. The shorter span length of 44 yards adopted on these routes permits the use of the closer wire spacing without danger of contacts. The use of the shorter span of 44 yards gives a 6.4 mile E section of 256 spans compared with the normal 8.0 mile E section of 256 spans at 55 yards involved with a 9"–19"–9" spaced route. These modifications give a worthwhile reduction in the coupling co-efficients between similarly disposed pairs. The values of the near-end coupling co-efficients for both spacings are shown in Fig. 2.



28" ARM SPACING



42" ARM SPACING

Fig. 2.—Comparison of near-end coupling coefficients for 28" arm spacing and 9"-19"-9" wire spacing with 42" arm spacing and 6"-22"-6" wire spacing.

Regular Construction

The four principal components of far-end cross-talk are:—

(a) Direct cross-talk.
(b) Indirect cross-talk.
(c) Irregularity cross-talk.
(d) Reflected near-end cross-talk.

Direct cross-talk, and to a large extent indirect cross-talk, are controlled by the transposition types chosen and depend on the values of the type unbalance (2) of the relative transposition types.

The irregularity crosstalk is that due to constructional irregularities and is concerned primarily with pole and wire spacing irregularities.

It will be appreciated that the calculated values of type unbalance for any transposition type assumes that all transposition poles and wires are accurately spaced to conform exactly to the theoretical patterns of the transposition types. In practice, owing to natural obstructions, it is impossible to locate every transposition pole in its correct position and it is also impossible to keep wires accurately spaced and perfectly uniform. Any irregularities thus caused impair the cross-talk to some extent, but their effect is not important, provided the type unbalance crosstalk is controlling. Thus, some latitude can be tolerated in both pole and wire spacings provided that the limiting values of the pole spacing irregularity factor and differences in the sagging of the wires are not exceeded.

Pole-Spacing Irregularities: The limitations, which have been laid down in Australia for the pole-spacing irregularities to ensure that irregularities do not become controlling, are that the values of the pole-spacing irregularity factor k (5) should be 1.0 for the number of transposition intervals concerned for each individual transposition section and 0.33 for each repeater section. These conditions are usually readily obtained when erecting new routes, but with existing routes extensive repoling would often be necessary to meet these conditions. As a considerable period will usually elapse before most of the pairs on such a route are required for 12-channel carrier operation, it is usual to erect only those poles which are needed to reduce the value of k to less than 3.0 for each individual transposition section initially. The normal pole replacements will tend gradually to reduce the value of k and the additional poles to bring the value k to within the prescribed limits will be erected when necessary to meet the increasing carrier requirements of the route. In addition to conforming to the above values of the pole-spacing irregularity factor the maximum deviation of an actual transposition interval from the average interval should not exceed 50 ft. Also, the transposition poles at the quarter and half points of all E sections are to be placed as close as possible to their theoretical locations. The maximum allowable distance from the correct location of the $\frac{1}{4}$ and $\frac{1}{2}$ points is 100 feet.

Wire-Sag Irregularities: The wires should be sagged as accurately and regularly as possible with a maximum difference between the wires of all pairs of 1.0" initially with subsequent tests to ensure that the maximum difference never exceeds 2.0". All routes require to be well constructed mechanically, and carefully maintained to ensure that these sag limitations are retained during the life of the route.

Apart from these irregularities, it is most important that a uniform disposition of pairs is maintained over repeater sections, and that the wire spacings do not vary appreciably from the standards adopted.

Impedance Matching

In view of the necessity of limiting reflected near-end cross-talk, it is essential to ensure that no unsatisfactory impedance irregularities occur throughout the route. This requires uniform construction throughout the open wire portion of the route, particularly as regards type of conductor, gauge of conductor and wire spacing. The standard wire spacing of 6″ or 9″ must be strictly maintained, and lengths of O.D.T. wire must not be included in any of the carrier pairs. The most important cases, however, are at junctions between the open wire route and lead-in or intermediate cables. Considerable care is required at these points to obtain the desired return loss of 25 db. (reflection co-efficient 5%) (1) to control the reflected near-end component of the far-end cross-talk. The lead-in cable from the terminal pole is accurately loaded to obtain the desired impedance and, except for very short lengths of cable, a loading unit is installed on the pole as close as possible to the termination of the open wires, to ensure that the impedance will be within the required tolerance. The effect of irregular wire spacing was the subject of an article entitled, "Some Notes on the Impedance Testing of Open Wire Lines at Frequencies up to 150 kc/sec," by J. White, page 28, Vol. 6, No. 1, of this Journal.

Layout of Transposition Sections

The layout of transposition sections can be designed either for E. transposition sections of 8.0 miles maximum length and corresponding lengths for shorter transposition sections, or for E. sections of 6.4 miles maximum length and corresponding lengths for shorter types of transposition sections. Because of the superior electrical and mechanical qualities, the latter basis has been adopted for all new routes in Australia. However, there is a considerable number of existing routes laid out on the basis of 8 mile E. sections, which it would be impracticable to convert to 6.4 mile E. sections. Thus it will be necessary, for many years, to deal with routes under both categories. In determining a layout of transposition sections under either scheme certain basic factors must be considered. These comprise the following:—

(a) E. transposition sections should be used as far as possible.

(b) If it is necessary to include shorter transposition sections, they should be confined to the ends of repeater sections.

(c) Points of discontinuity for "through" carrier pairs should be reduced to a minimum and confined to:
   (i) The terminal pole at a terminal or repeater station;
   (ii) Terminal poles where cable is introduced into the open wire route;
   (iii) Points where one or more carrier pairs leave the route;
   (iv) Points where at least one full arm of minor trunk wires leaves the route.

Where it is necessary to provide an S. pole for minor trunks but not for carrier pairs, a satisfactory compromise is to transpose the minor trunks to a layout of shorter transposition sections over a portion of the route to provide an S. pole at the required location, while retaining the layout of consecutive E. sections for the carrier pairs.

Junction Transpositions

The primary crosstalk consideration is the terminal to terminal crosstalk. However, it is impracticable to compute this, and the accepted method is to base the expected value of the overall repeater section crosstalk on the calculated crosstalk for the transposition sections. This crosstalk is the resultant of the summation of the crosstalk between the various combinations for the transposition sections concerned. This summation is controlled by the insertion of junction or S. pole transpositions. Transposition schemes for S. poles are designed to give relative transpositions at each S. pole, which will provide sufficient reversals to prevent a building-up firstly of far-end crosstalk and secondly of near-end crosstalk.

For transposition schemes for operation to 30 kc/s it has generally been found satisfactory to adopt continuous positive poling, i.e., the wires are transposed to occupy the same pin positions at the beginning of each transposition section. With transposition schemes for operation to 143 kc/s, however, a junction transposition scheme giving many more relative transpositions is required. A well-designed junction scheme is essential to obtain the optimum crosstalk values over repeater sections at higher frequencies. Tests indicate that with such a junction transposition scheme, far-end crosstalk over a repeater section is of the order of 4 db worse than that measured over a single section. Without the application of such a junction scheme the overall results may be as much as 12 db worse than for a single transposition section.

Transposing for 12-Channel Carrier Operation in Australia

Initial Stage: Prior to the introduction of carrier systems into Australia in 1925, mechanically well-designed open wire routes had been constructed between the main coastal centres from Townsville to Adelaide and transposed for voice frequency operation. Subsequent installation of 3-channel carrier systems necessitated the transposing of a number of pairs to single extra transposition types (3) over the major portion of this route.

The establishment of the first Sydney-Melbourne 12-channel system just before the outbreak of the Second World War required the retransposing of one pair to a double extra P (P_2) (3) transposition type between these centres.

With the entry of Japan into the war and the arrival of the U.S. Forces in Australia, plans were drawn up for the installation of 12-channel systems over the whole of the main route between Townsville and Adelaide. This scheme contemplated up to four systems between Melbourne and Sydney.

In view of the extensive defence programme then in hand and the importance of providing suitable pairs as soon as possible, it was decided that the most satisfactory arrangement would be to retain as far as possible the existing layout of transposition sections and transpose selected pairs for operation to 143 kc/s. Particulars of "J1" and "J2" transposition schemes had been supplied by the A.T and T. Company, of U.S.A., but these applied only to transposition sections where the length of the E. section did not exceed 6.4 miles. Both schemes were designed to provide for 12-channel carrier systems on all pairs, the "J1" system being applied to existing routes and the "J2" system to new routes.

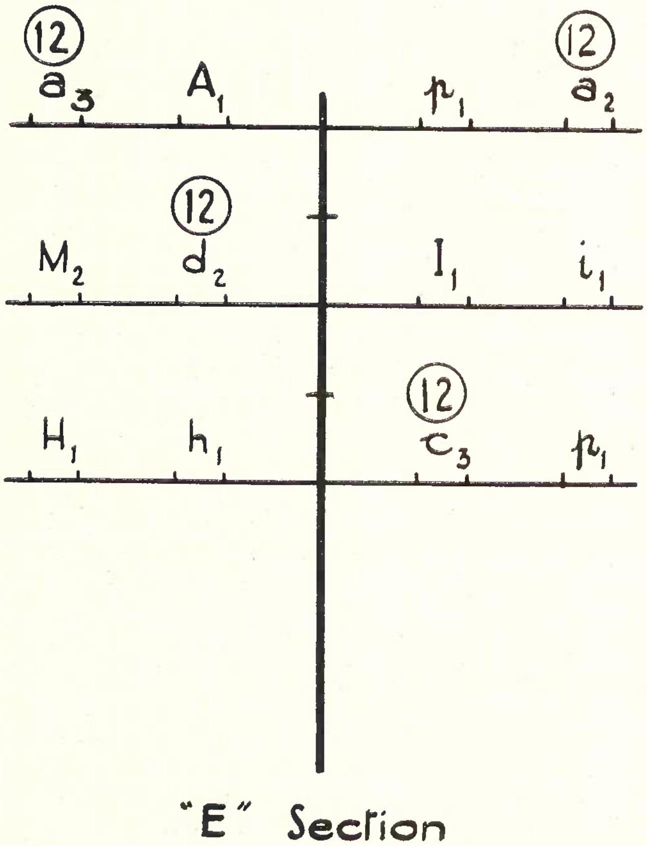


Fig. 3.—Typical "E" section transposition design showing selected pairs for 12-channel carrier operation.

However, as the nominal maximum length for the existing E. sections was 8.0 miles on the routes concerned, the selection of suitable transposition types was investigated primarily from tables of near-end type unbalance (2) which were calculated for the purpose. From this examination types P_2, P_3, d_2, d_3, M_2, c_3, O_2 and O_3 (3) were selected for trial on a test E. section. The first four types and similar suitable types for L, R and X transposition sections were applied to pairs selected to provide low coupling coefficients (4) for direct crosstalk, and the subsequent transmission measurements indicated that these types were generally suitable. Subsequently, types M_2, c_3 and O_3 were applied to further selected pairs in order to increase the capacity of the route to seven 12-channel pairs.

However, the application of these types to a route 500 miles in length with differing pole configurations and conditions presented many problems. The main difficulty was that due to third circuit effects, particularly those caused by the proximity of phantom transposed pairs. Based on the analysis of the transmission measurements, the more serious sources of crosstalk impairment were eliminated and suitable pairs eventually provided. Similar principles were adopted in providing 12-channel carrier pairs on the Melbourne-Adelaide, Sydney-Brisbane and Brisbane-Townsville routes. The E. section transposition types for a typical design as applied to these routes are shown in Fig. 3.

Standard Transposition Schemes

At the cessation of hostilities, the Department was faced with the problem of providing a large number of additional trunk telephone channels throughout Australia in order to overtake a big lag in circuit demands which had been built up during the war. The trunk development involved was so heavy that it was realised that 12-channel carrier systems must be the main basis of meeting the demand. It was thus essential to abandon the wartime policy of considering each route individually and specially transposing selected pairs for 12-channel carrier operation, in favour of standard transposition schemes based on 12-channel carrier operation for the majority of both new and existing routes.

An examination of open wire trunk route requirements in Australia indicated that both new and existing routes could be divided into four main classes, as follows:—

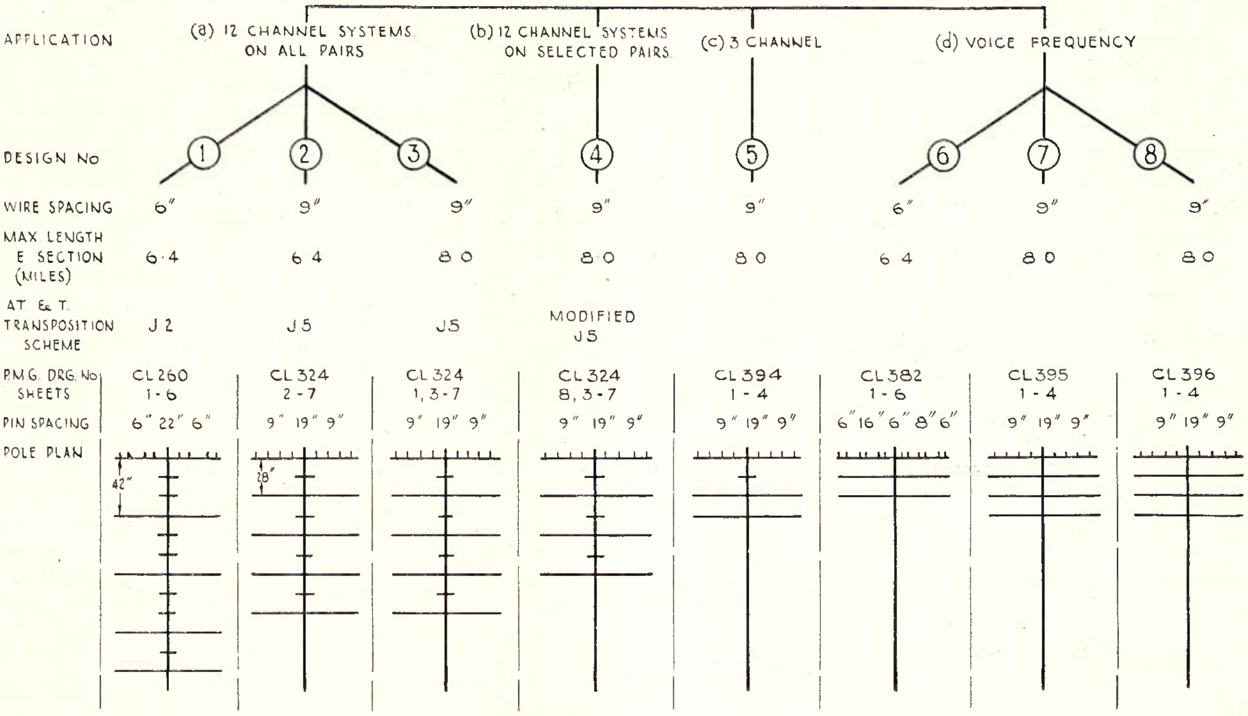
(a) 3- and 12-channel carrier systems operating on every pair.

(b) 3-channel carrier systems operating on every pair and 12-channel carrier systems operating on selected pairs.

(c) 3-channel carrier systems operating on all pairs.

(d) Voice frequency.

The majority of routes are in classes (a) and (b), but some provision was necessary in class (c) for 3-channel operation only on shorter routes. In addition to a very limited number of short distance minor trunk routes in class (d) it was necessary to consider the provision of voice frequency pairs for minor trunk requirements on routes in classes (a), (b) and (c). The standard transposition designs adopted for each of these classes of route, together with related details of wire and arm spacing, length of section, etc., are set out in Fig. 4. The transposition types and the number of transpositions per section for each of the standard designs are shown in Figs. 5 and 6 respectively.



DESIGN 4. 1. THIS SCHEME CATERS FOR 6 TO 8 - 12 CHANNEL SYSTEMS ON ARMS 1, 3 AND 5 DEPENDING UPON THE LENGTH OF ROUTE

DESIGN 6. 1. THIS SCHEME IS DESIGNED FOR MINOR TRUNK ARMS ON ROUTES TRANSPOSED TO DESIGN 1 DRAWING No CL 260
2. SELECTED PAIRS ARE SUITABLE FOR 3-CHANNEL SYSTEMS.

DESIGN 7. 1. THIS SCHEME IS DESIGNED FOR MINOR TRUNK ARMS ON ROUTES TRANSPOSED TO DESIGNS 2, 3 AND 4 DRAWING No CL324 AND DESIGN 5 DRAWING No CL394 WHERE PHANTOMS ARE NOT REQUIRED.
2. SUITABLE ALSO FOR EITHER 9″ OR 14″ WIRE SPACED V.F. MINOR TRUNK ROUTES WHERE PHANTOMS ARE NOT REQUIRED. SELECTED PAIRS SUITABLE FOR SINGLE CHANNEL SYSTEMS.
3. APPLIES TO LONG SUBSCRIBERS LINES WITH 8-PIN 80″ ARMS.

DESIGN 8. 1. THIS SCHEME IS DESIGNED FOR MINOR TRUNK ARMS ON ROUTES TRANSPOSED TO DESIGN 5 DRAWING No CL 394 WHERE PHANTOMS ARE REQUIRED
2. SUITABLE ALSO FOR EITHER 9″ OR 14″ SPACED V.F. MINOR TRUNK ROUTES WHERE PHANTOMS ARE REQUIRED. SELECTED PAIRS ARE SUITABLE FOR SINGLE CHANNEL SYSTEMS.

PIN SPACING :- DESIGN 1 :- 3″, 6″, 22″, 6″ 34″ 6″, 22″, 6″, 3″.
" " 2, 3, 4, 5, 7 & 8 :- 3″, 9″, 19″, 9″, 28″, 9″, 19″, 9″, 3″
" " 6 :- 3″, 6″, 16″, 6″, 8″, 6″, 18″, 6″, 8″, 6″, 16″, 6″, 3″

Fig. 4.—Summary of standard transposition schemes.

In view of the experience gained by the A.T. and T. Company of U.S.A. in the construction of open wire routes for 12-channel carrier operation, it was considered that the best course would be to base the standard transposition schemes for 12-channel carrier operation on A.T. and T. standard transposition schemes. The Company had very kindly forwarded details of their schemes to Australia previously, and it was then necessary to choose the most suitable transposition designs and investigate their application to Australian standard construction. Two of the A.T. and T. Company transposition schemes, the "J2" and "J5" (which was generally similar to the "J1" system), were chosen. The "J2" transposition scheme was considered to be the most suitable for new routes, while the wire spacing and lengths of transposition sections associated

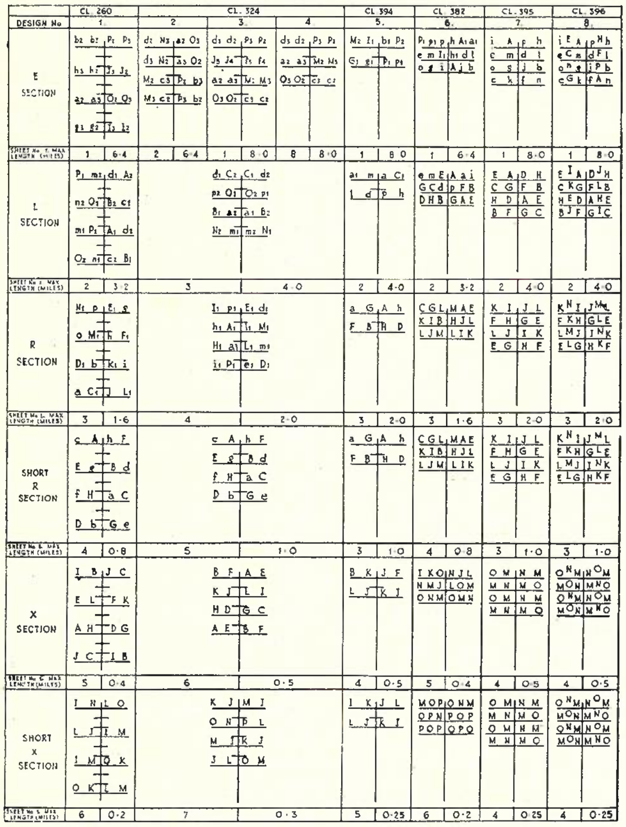


Fig. 5.—Standard transposition schemes—transposition types.

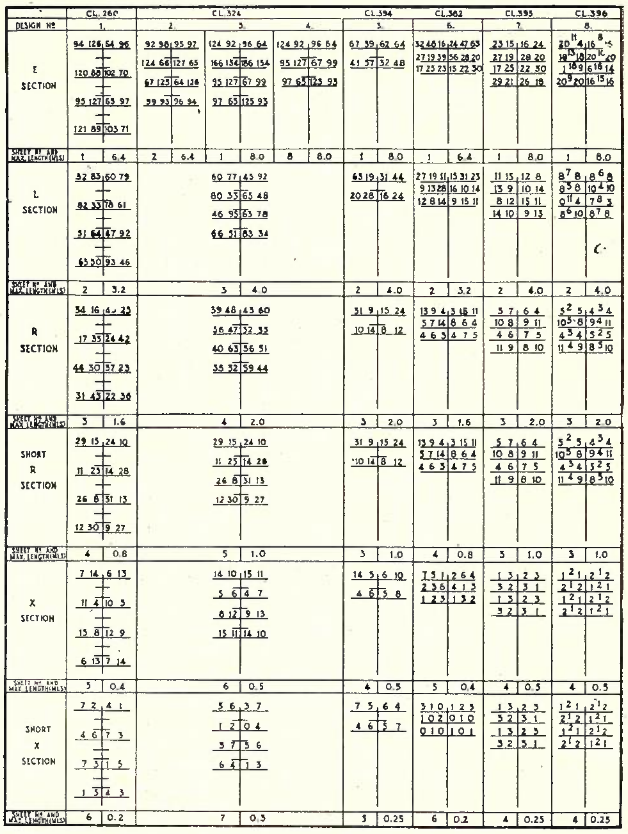


Fig. 6.—Standard transposition schemes—numbers of transpositions.

with the "J5" transposition scheme approximated more closely to the existing Australian standards, and was considered the most suitable for use on existing routes.

The lengths of the various types of transposition sections for the "J2" and "J5" transposition schemes are:—

Section	"J2" (Miles)	"J5" (Miles)
E	6.4	8.0 and 6.4
L.	3.2	4.0
R.	1.6	2.0
short R.	0.8	1.0
X.	0.4	0.5
short X.	0.2	0.25

The "J5" scheme includes two E section designs to cater for 8.0 mile and 6.4 mile sections.

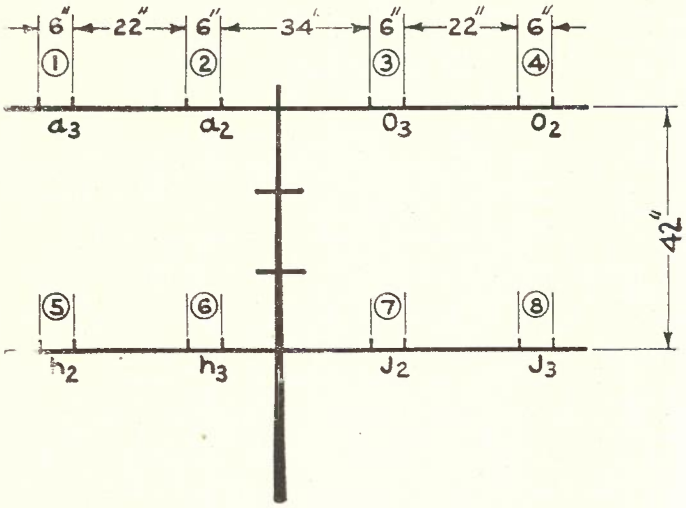
Class (a): 3 and 12-channel carrier systems on all pairs. Although new routes are primarily concerned under this heading, provision was considered desirable for two additional cases occasionally involved. The three cases covered are:—

(i) New routes.

(ii) Existing routes where the adoption of a 6.4 mile E. section was practicable, but the existence of a proportion of existing spans exceeding 44 yards precluded the reduction of wire spacing between pairs from 9″ to 6″. In addition, existing pole heights prevented increase of the arm spacing to 42″.

(iii) Existing routes with 8.0 mile E. sections and 9″ wire spacing between pairs where 12-channel operation is required on each pair.

As referred to previously, all new routes are erected with 44 yard spans, resulting in E. sections of 6.4 miles in length and permitting 6″ spacing between wires of a pair. As shown in Fig. 2, the wire spacings for a standard 108″ cross-arm for new 12-channel carrier routes are 3″—6″—22″—6″—34″—6″—22″—6″—3″, and the arm spacing is 42″. The most suitable scheme applicable to these conditions is the "J2," which is shown as Design (1) in Fig. 4. Typical results of far-end and near-end crosstalk measurements over one E. section of 6.4 miles between the pairs on two arms of wires transposed to Design (1) are shown in Fig. 7. On certain existing routes where the conditions referred to in (ii) applied, it was considered desirable to provide a design capable of giving 12-channel carrier operation on every pair. For this purpose, the 6.4 mile E. section design of the "J5" scheme was used—Design (2), Fig. 4. For cases included in (iii) the 8.0 mile E section design of the "J5" scheme was used—Design (3), Fig. 4. Typical measurements of far-end and near-end crosstalk for designs (2) and (3) are shown in Figs. 8 and 9. These values are inferior to those obtained with the "J2" scheme, and the application of designs (2) and (3) is restricted to routes not greater in length than 400 miles from terminal to terminal.



DISTURBING PAIRS

	7	6	5	4	3	2	1	PAIR POSN
db. kC/s	63 140	70 34	68 126	71 128	71 58	78 142	78 128	8
		63 142	68 124	72 58	70 132	74 114	77 130	7
			75 142	81 58	69 130	65 140	73 128	6
				81 132	75 100	73 56	69 136	5
					68 122	70 126	76 128	4
						64 128	69 130	3
							65 134	2

DISTURBED PAIRS FAR END

NEAR END DISTURBED PAIRS

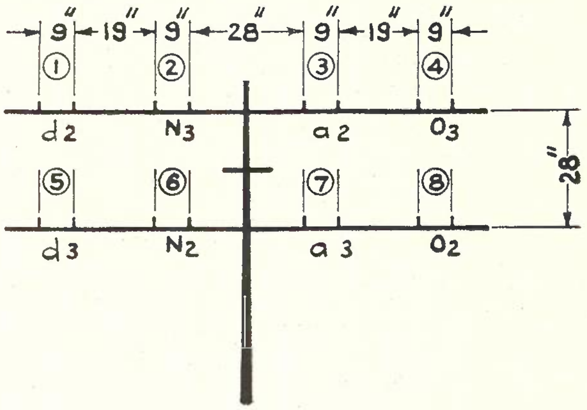
PAIR POSN	1	2	3	4	5	6	7	
2	52 120							
3	59 130	52 130						
4	73 128	58 130	52 136					
5	61 56	53 56	73 66	69 68				
6	53 56	64 56	68 66	74 66	50 138			
7	72 68	70 72	63 58	52 56	59 132	53 128		
8	71 66	68 74	52 58	61 56	74 127	59 128	50 138	db. kC/s

DISTURBING PAIRS

Fig. 7.—Typical far-end and near-end crosstalk results for modified design (1), Fig. 5, combinations. Worst values to 143 kc/s and relevant frequency at which this value occurs. 6.4 mile "E" Section.

Class (b): 3-channel carrier routes with 12-channel on selected pairs. There is a considerable mileage of existing open wire route in good mechanical condition where the rate of development can be met for many years by the operation of 12-channel carrier systems on a proportion of the available carrier pairs.

Such routes involve 8.0 mile E. sections, 9" spacing between wires and 28" spacing between arms. For such conditions the application of a modification of the "J5" scheme was considered the most satisfactory compromise. The application of this scheme—design (4), Fig. 4—will permit the operation of a high proportion of the pairs for 12-channel carrier purposes using similar transposition types to design (1), namely, double and triple extras. See Fig. 5. The application of quadruple and quintuple types similar to arm 3 of design (3) in Fig. 5, would have in-



DISTURBING PAIRS

	7	6	5	4	3	2	1	PAIR POSN
db. kC/s	62 129	67 140	78 143	68 140	79 142	70 141	73 141	8
		65 133	67 138	72 139	63 138	63 133	73 142	7
			62 128	73 133	73 142	63 129	72 129	6
				75 137	77 140	67 135	57 142	5
					68 123	66 140	77 142	4
						58 137	65 142	3
							63 127	2

DISTURBED PAIRS FAR END

NEAR END DISTURBED PAIRS

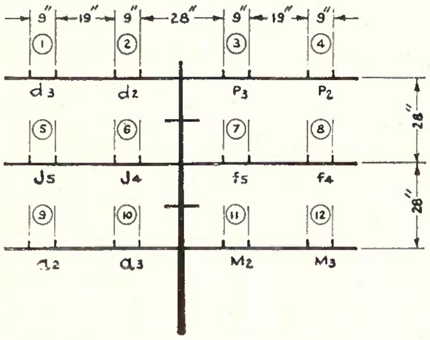
PAIR POSN	1	2	3	4	5	6	7	
2	41 130							
3	42 29	43 135						
4	65 135	47 29	41 131					
5	45 138	56 136	57 143	61 134				
6	65 70	46 139	50 135	56 143	41 130			
7	66 88	51 137	47 139	57 121	46 28	43 135		
8	59 136	67 87	60 129	46 138	65 135	47 29	41 130	db. kC/s

DISTURBING PAIRS

Fig. 8.—Typical far-end and near-end crosstalk results for design (2), Fig. 5, arms 1 and 3. Worst values to 143 kc/s and relevant frequency at which this value occurs. 6.4 mile "E" Section.

creased the 12-channel carrier system capacity of such routes, but the considerable increase in transpositions and the added difficulty of poling [every pole may be a transposition pole in design (3)] was not warranted. Typical measurements of far-end and near-end crosstalk for design (4) are shown in Fig. 10.

As the number of L, R or X sections involved in any route is small compared with the number of E. sections, and relatively small differences in design are involved, the same design of section was used for designs (2), (3) and (4).



DISTURBING PAIRS

11	10	9	8	7	6	5	4	3	2	1	PAIR POSN
53 117	60 142	69 141	60 117	60 139	70 116	67 138	60 138	60 129	67 116	61 116	12
	59 127	64 141	63 127	57 128	64 132	66 142	56 138	65 99	61 117	65 122	11
		57 140	65 127	66 128	65 127	63 142	72 132	66 121	66 137	65 128	10
			71 120	71 115	68 116	58 140	71 139	63 139	68 138	63 143	9
				61 137	70 116	73 115	61 116	66 121	71 124	71 127	8
					66 116	65 137	67 130	66 140	65 118	63 117	7
						65 138	72 112	70 123	70 116	63 116	6
							69 141	67 136	65 138	60 116	5
								57 94	66 119	70 117	4
									65 139	64 140	3
										58 115	2

db.
kC/s

DISTURBED PAIRS FAR END

NEAR END DISTURBED PAIRS

PAIR POSN	1	2	3	4	5	6	7	8	9	10	11
2	39 135										
3	43 118	39 118									
4	58 117	43 118	40 124								
5	43 129	58 137	60 136	62 135							
6	61 122	45 128	52 133	67 96	39 135						
7	73 135	52 133	42 129	57 128	43 117	40 117					
8	>58 143	>60 143	59 130	42 128	59 117	43 117	39 135				
9	46 118	52 23	66 117	69 109	44 132	58 139	63 131	72 115			
10	53 115	50 119	64 137	71 99	58 133	45 131	60 117	61 130	40 135		
11	62 93	60 130	49 118	51 116	61 128	57 122	46 131	58 132	44 117	39 118	
12	66 99	64 143	52 24	46 118	68 142	61 131	61 110	45 131	61 117	43 118	40 135

db.
kC/s

DISTURBING PAIRS

Fig. 9.—Typical far-end and near-end crosstalk results for design (3), Fig. 5, arms 1, 3 and 5. Worst values to 143 kc/s and relevant frequency at which this value occurs. 8 mile "E" Section.

Class (c): 3-channel carrier on all pairs. Previously a two-arm transposition scheme using single extra transposition types for E sections and equivalent types for shorter sections had been used for 3-channel carrier operation, and to avoid extensive alterations to routes transposed to this scheme it has been retained generally, except that double extra transposition types in the E. section and equivalent types on shorter sections have been provided for the two pairs on the ends of arm 1. See design (5), Fig. 5. This not only improves the crosstalk to 30 kc/s, but also facilitates the conversion of arm 1 to a 12-channel carrier scheme if required subsequently. A transposition scheme has not been provided for single-channel carrier systems, as the proportion of single-channel carrier systems to other systems is low. When a single-channel carrier system is installed it is usually preliminary to the installation of a 3-channel carrier system, and it is generally preferable to apply design (5) at the outset.

Class (d): Voice frequency. The design of the voice frequency schemes was determined to a large degree by the carrier transposition design with which it would normally be associated. Thus design (6), Fig. 4, is used for minor trunk pairs below pairs transposed to design (1). Because of the detrimental effects of phantoms on carrier crosstalk, these are excluded from the design. In addition, advantage is taken of the 6″ spacing between wires to obtain six pairs on each arm. The wires spacing adopted are 3″–6″–16″–6″–8″ 6″–18″–6″–8″–6″–16″–6″–3″, which allows for the operation of some 3-channel and single-channel carrier systems on pairs on the two top arms with 14″ spacing between voice frequency arms. Design (7) for association with carrier designs (2), (3) and (4) similarly excludes phantoms, but is limited to four pairs per arm because of the 9″ spacing between wires of a pair.

To reduce the third circuit effects of minor trunk circuits accommodated on the minor trunk arms below the 12-channel carrier circuits, the top minor trunk arm is fitted 28″ below the lowest 12-channel carrier arm.

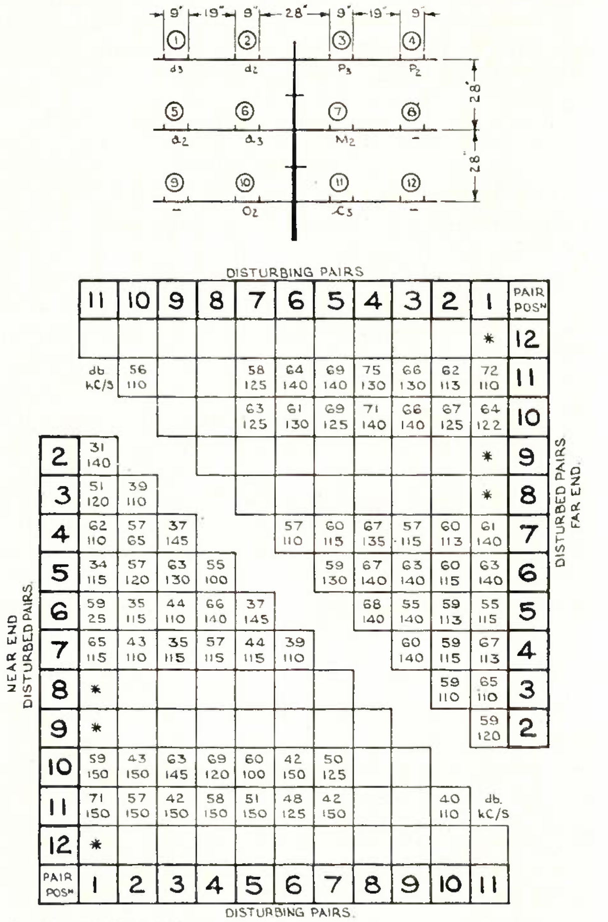
In the case of design (5) for three-channel carrier systems, it is permissible for voice frequency pairs below the carrier arms to operate with phantoms. For these cases, therefore, and on exclusive voice frequency routes where phantoms are required, design (8) has been provided.

Previous standard voice frequency transposition schemes are not being extended, but pairs erected on routes already transposed to these schemes will need to conform to the existing transposition scheme of the route. Where some pairs on an existing voice frequency route are to be carrier re-transposed, the transpositions in the remaining voice frequency pairs will, in general, remain unaltered.

Application of Standard Transportation Schemes

The use of standard transportation schemes for new routes is straightforward, as these routes can be constructed to provide the required conditions of arm and wiring spacing, lengths of transposition sections, etc. With existing routes, however, there will be some difficult problems to be solved in adapting routes which were erected for voice frequency purposes to meet multi-channel carrier operation requirements. Generally, these include:—

(a) Existence of a limited number of transposition sections which exceed the maximum allowable lengths.
(b) Routes with uniform pole spacings and span lengths exceeding 55 yards.
(c) Large number of phantomed voice frequency pairs.



DISTURBING PAIRS 11	10	9	8	7	6	5	4	3	2	1	PAIR POSN
										*	12
db kC/S	56 110			58 125	64 140	69 140	75 130	66 130	62 113	72 110	11
				63 125	61 130	69 125	71 140	66 140	67 125	64 122	10
										*	9
										*	8
					57 110	60 115	67 135	57 115	60 113	61 140	7
						59 130	67 140	63 140	60 115	63 140	6
							68 140	55 140	59 113	55 115	5
								60 140	59 115	67 113	4
									59 110	65 110	3
										59 120	2

NEAR END DISTURBED PAIRS											
2	31 140										
3	51 120	39 110									
4	62 110	57 65	37 145								
5	34 115	57 120	63 130	55 100							
6	59 25	35 115	44 110	66 140	37 145						
7	65 115	43 110	35 115	57 115	44 115	39 110					
8	*										
9	*										
10	59 150	43 150	63 145	69 120	60 100	42 150	50 125				
11	71 150	57 150	42 150	58 150	51 150	48 125	42 150			40 110	db. kC/S
12	*										
PAIR POSN	1	2	3	4	5	6	7	8	9	10	11

DISTURBING PAIRS.

* PAIRS 8,9 AND 12 NOT ERECTED

NEAR END & FAR END CROSSTALK RESULTS, WORST VALUES IN DECIBELS UP TO 143 kC/S & RELEVANT FREQ. 8.0 MILE E SECT

Fig. 10.—Typical far-end and near-end crosstalk results for design (4), Fig. 5, arms 1, 3 and 5. Worst values to 143 kc/s and relevant frequency at which this value occurs. 8 mile "E" Section.

(d) Retention of voice frequency arms 14" from 12-channel transposed arms.
(e) Routes on which selected pairs have previously been transposed to double and triple extra transposition types.

One or more of these factors may apply to a particular route and, necessarily, the course adopted will involve a compromise allowing an assessment of each of the factors involved. Briefly, the more important considerations which apply in each instance are referred to in the following:—

(a) To reduce long E sections to within the allowable length it is possible to divide a long E section into a normal E section and a shorter type of section. However, this procedure involves complete rearrangement of transposition poles and introduces short types of sections into the transposition layout, which is undesirable, as it interrupts the continuity of E sections. To retain consecutive E sections and ensure that all these sections are less than the maximum permissible length, the preferable procedure is to divide the long E section into two short E sections each of 128 spans.

(b) Where a route consists of uniform spans in excess of 55 yards, a normal E section of 256 spans will necessarily exceed the limiting length for such sections. Any modification to such a route to provide a 256 span E section within the allowable limit, would involve excessive poling, and thus one or other of the following alternatives require consideration:
  (i) Layout of transposition sections on a 128 span basis as referred to under the previous heading (a).
  (ii) Layout of transposition sections on a 192 span basis. This results in three spans between even-numbered transpositions and requires the erection of an additional pole for the odd-numbered transpositions.
  (iii) Subject to an examination of the crosstalk results obtained for each pair combination, the longer length of section is accepted, with the consequent reduction in the number of pairs suitable for carrier purposes.

The choice of arrangement (i), (ii) or (iii) depends on the conditions to be met in the case being considered. From the point of view of electrical design the order of preference is (i), (ii) and (iii).

(c) Where a high proportion of existing voice frequency pairs are phantom transposed, removal of all phantom circuits immediately from such pairs is sometimes difficult. Under these circumstances the need for their immediate removal requires review in the light of the extent and rate of the expected 12-channel carrier development. If only a limited number of 12-channel systems is involved, initial removal of the phantom transposition may be arranged in convenient stages subsequent to the initial carrier installation. It is often convenient to arrange for the replacement of the phantom circuits by the erection of new physical pairs required for carrier purposes.

(d) Due to the limited height of existing poles, it is sometimes impracticable to obtain 28" spacing between the bottom carrier arm and the first voice frequency arm. Rather than embark on an extensive reconstruction involving higher poles, it is generally preferable to accept the 14" spacing between carrier and voice frequency arms with some reduction in availability of carrier pairs and plan for a new route or underground cable when the existing route has been fully exploited on this basis.

(e) To obviate uneconomical retransposing of a route which has already been transposed to a carrier transposition scheme, the normal practice is for the existing transposition scheme to be retained and new pairs to be transposed to the standard design. An examination of the existing transposition types in relation to those of the standard transposition scheme is necessary, as it may be found that some of the existing transposition types are the same as types in the standard transposition scheme to be used. Also, on the existing route there may be transposition types which, when used with the standard transposition schemes, result in unsuitable relative types. In such cases, it is necessary to modify to the standard transposition type, the existing transposition type which conflicts.

After considering the foregoing factors, and taking the age and mechanical condition of the route into account, it will in many cases be found more economical to build a new route than to reconstruct the existing route.

the actual construction work and in providing the high-grade carrier pairs required.

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APPENDIX

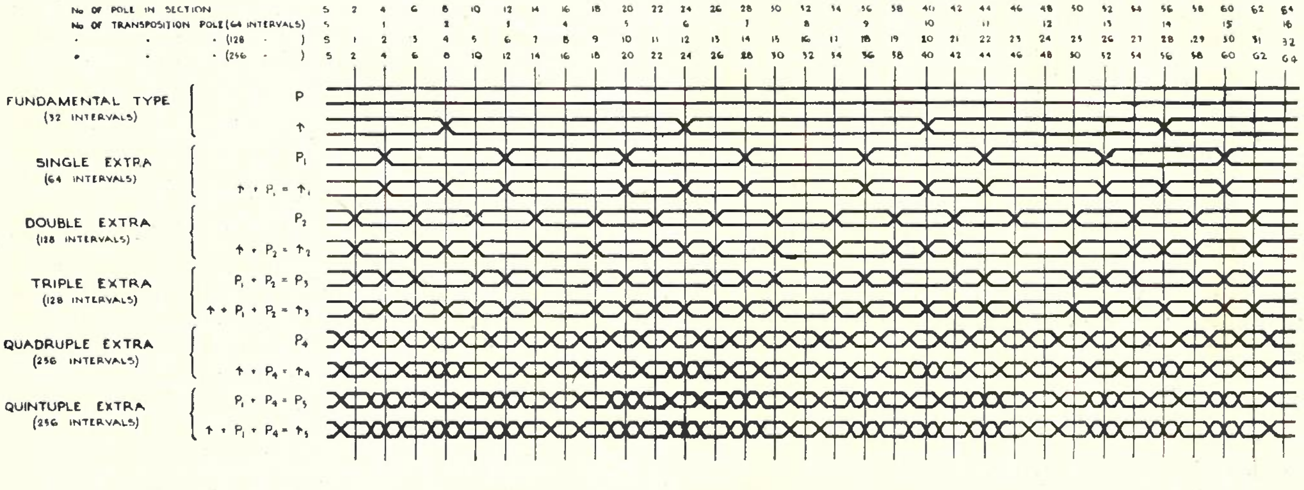
Definitions

(1) **Reflection Co-efficient:** When power is transmitted into a load, the impedance of which is different from that of the source, a portion of the power is reflected or returned.

This condition exists where parts of a circuit have different impedance, such as at the junction of an open wire and cable section. The magnitude of the reflected power in these cases is calculated from the reflection co-efficient, which can be determined from the impedance values, as follows:

If the impedances of the two circuits viewed from the junction point are Z and W respectively at the frequency being considered, then the reflection co-efficeint is the modulus of the ratio (Z — W) / (Z + W).

(2) **Type Unbalance:** By transposing circuits the crosstalk coupling in any short length of line is nearly balanced in another short length of about the same size but about opposite in phase. For this balance to be perfect, it would be necessary to divide the circuits into infinitesimal sections. Therefore, in practice, there is always a residual unbalanced coupling, due to attenuation and the change in phase in the disturbing circuit and resultant crosstalk currents as they are propagated along the circuits. This residual un-



(Note: Only one-quarter of a 256-span transposition section is shown.)

Fig. 11.—Extra transposition types.

Conclusion

The provision of the additional trunk telephone channels now contemplated in Australia will necessitate the erection of many hundreds of miles of new open wire carrier trunk route and the carrier retransposing of long sections of existing route. This work will be a large and complex operation, but the application of the standard carrier transposition schemes will be a major factor both in facilitating both the designs and balance is called the "type unbalance," and is expressed as an "equivalent untransposed length."

(3) **Symbols for Extra Transposition Types:** The extra transposition types are denoted by numerical suffixes, 1 being for single extra, 2 double extra, etc. The derivation of each extra type is shown in Fig. 11.

(4) **Coupling Co-efficient:** Also called "the crosstalk per mile per kilocycle" is the crosstalk which would be obtained between two circuits occupying the same relative positions for one geographical mile, and having no transpositions relative to one another, but being frequently similarly transposed.

(5) **Pole-Spacing Irregularity Factor:** The effect of the irregular spacing of transposition poles on the crosstalk characteristics of a transposition scheme is largely a question of probability. A quantitative estimate of the effect of this irregularity on the crosstalk for any transposition section is obtained from the expression $S = kL$.

Where L = Length of the section in feet
S = the sum of the squares of the irregularities in the lengths of the individual transposition intervals in feet
k = the irregularity factor.

IMPULSING IN MULTI-EXCHANGE NETWORKS

W. King

Tests of a practical nature were conducted recently in the Sydney and Melbourne Metropolitan Networks to determine the resistance limits of junctions, and the following notes, which were prepared after the completion of the tests, may be of interest.

Two series of tests were made: the first series covered tests over the actual network, while the second series covered tests using repeaters fitted with 3000 type relays. It was appreciated that the wave form of the impulses would undergo appreciable distortion due to inductive and capacitive elements of the circuits concerned, and, therefore, where possible, all ratio tests were made directly from the contacts of the impulsing relay involved. The impulse ratio was measured on a moving coil voltmeter, suitably calibrated for the purpose. This method is well known to most readers, because it is used for ratio testing on all exchange test desks. It was chosen, in this case, in preference to the use of more elaborate equipment, because of its simplicity and speed of operation, and also because past experience has shown that the average current values observed give a reliable guide to the behaviour of a selector switch under the influence of the impulses thus measured.

Tests Over the Network: At present, both in Sydney and Melbourne automatic exchanges, a combination of Strowger side armature type relays and 3000 type relays is in use, both in repeaters and bimotional switches.

The impulsing characteristics of Strowger type relays are well known, and, while this type of relay only was in use in repeaters and switches, no difficulties were found which could not easily be overcome by simple adjustment.

However, the advent of the 3000 type relay has introduced many impulsing problems, and tests have been conducted to determine the resistance limits of junctions and also the permissible number of repetitions which may occur without distorting the impulses beyond the operating limits of the switches, when this type of relay is used. The introduction of the 50/50 ohm impulsing relay in repeaters in conjunction with the barretter has introduced further problems in connection with "pick-up" and "reversal" troubles.

The limits stipulated by the British Post Office for repeaters using 50/50 ohm 3000 type relays with barretters, are as follow:—

(i) Not more than three repeaters to be connected in tandem.
(ii) Resistance limits of any one junction must not exceed 800 ohms.
(iii) Overall resistance of the three junctions must not exceed 1800 ohms.

Outside the above limits some type of regenerative repeater is used.

The above conditions allow for all adverse conditions, such as low exchange voltage, fast dials (12 I.P.S.), low insulation lines, etc., occurring simultaneously. It will be appreciated that the above conditions are greatly exceeded in both the Sydney and Melbourne networks, but a large proportion of the calls originated in these cities are completed via repeaters and switches having Strowger type relays.

The operating limits of bimotional switch magnets and relays are as follow:—

(i) Time taken to completely saturate B relay, 17 milliseconds.
(ii) Time taken to fully operate switch magnets, 33 milliseconds.

One of the functions of the B relay, which is operated from the A relay, is to prepare a circuit for the switch magnets. During impulsing, relay B must hold so that a circuit to the switch magnets will be completed each time relay A releases. This means that relay B must be re-saturated each time relay A re-operates during a "make" period. At a dial speed of 10 I.P.S. the two extreme lower limits are:—

Make	17%
Break	33%

It is obvious, of course, that both of the conditions could not occur simultaneously on any one impulse.

The standard impulse delivered by a dial is $33^1/_3$% make, $66^2/_3$% break, but the actual ratio of the impulses received by terminating switches varies considerably from this figure, owing to the following factors:—

- (i) Conditions in the subscriber's telephone.
- (ii) Line conditions—
  - (a) Resistance.
  - (b) Insulation Resistance.
  - (c) Capacity.
- (iii) Speed of dial.
- (iv) Type of repeater and resistance of junction.
- (v) Number of repetitions.

Conditions in Subscriber's Telephone: The condenser and resistance across the dial in the modern telephone has a shunting effect on the impulsing relay and increases the make ratio at the telephone to 37%.

Line Conditions: Low resistance loops have the effect of increasing the make ratio of impulses measured at the contacts of the receiving relay. As the resistance increases, the make ratio drops, but, where the terminating switch is a repeater, the capacity, due to the transmission condensers, more than compensates for the resistance, and the net result is an increase in the make ratio in all cases, but very high loops have a slight compensating effect. Insulation resistance and line capacity both have a shunting effect and increase the make ratio.

Speed of dial: A high speed dial decreases the operating time of the terminating switch B relay and magnets, as the time taken for one complete impulse is something less than 100 milliseconds. For instance, if the speed is 12 I.P.S., each im-

TABLE No. 1

TESTS FROM STANDARD TELEPHONE TO VARIOUS SWITCHES (3000 TYPE RELAYS)

D.S.R. Non-Modified		D.S.R. Modified		Repeater with 150 + 150 Spools Replacing Barretter	
Loop	Make Ratio	Loop	Make Ratio	Loop	Make Ratio
0	36	0	34	0	33
750	36	750	34	100	33
900	36	900	34	500	33
1000	36	1000	33	700	33
1100	36	1100	33	900	33
1200	36	1200	32	1000	33
1300	36	1300	32	1200	32
1400	36	1400	32	1500	31
1500	36	1500	31	1700	29
1600	36	1600	31	2000	28
1700	36	1700	31		
1800	36	1800	31		
1900	35	1900	31		
2000	34	2000	30		

Group Selector		Group Selector			Final Selector	
Non-Inductive Resistance		Standard Cable				
Loop	Make Ratio	Loop Miles	Loop Res.	Make Ratio	Loop	Make Ratio
0	36		0	36	0	35
100	36	1	88	36	100	35
500	37	6	528	38	500	36
700	37	8	704	39	700	37
900	38	10	880	39	900	38
1000	39	12	1056	40	1000	38
1200	39	14	1232	41	1200	38
1500	40	17	1496	41	1500	38
1700	40	19	1672	41	1700	38
2000	40	23	2024	41	2000	38

pulse will have a time duration of 83.3 mS. at this speed in lieu of 100 mS. at 55 I.P.S. On standard ratio this is equivalent to 15 mS. break and 27.7 mS. make, in lieu of 66-2/3 and 33-1/3 respectively. The more serious effect in this case is the decreased make period. A reduction in dial speed will have the opposite effect and, if extreme limits are reached, will result in the B relay releasing during impulsing, owing to the break period being too great.

Exchange Apparatus: In all types of repeaters the transmission condensers have a severe shunting effect on the impulsing relay during impulsing, but while in the case of 3000 type relay repeaters the resistance of the junction loop has a slight compensating effect, in the case of Strowger repeaters, even with junction loops as high as 1300 ohms, the make ratio, due to the repeater, is slightly increased.

In the case of terminating switches, impulses from a Strowger repeater to a Strowger bimotional switch show a marked **decrease** in make ratio. This varies from 6% in the case of low junction loops to 10% for high junction loops. In the case of Strowger repeaters to 2000 type switches, the **decrease** is from 2% for a low junction loop to 4% for a high junction loop.

On the other hand, with impulses from 3000 type relay repeaters to Strowger bimotional switches, an **increase** in make ratio from 2% to 4% is evident, while from 3000 type relay repeaters to 2000 type switches the make ratio **increase** is from 3% to 5%, depending upon the junction resistance.

With Strowger type repeaters the first repeater or D.S.R. in the train has the effect of increasing the make ratio for average loops by approximately 5%. With repeaters using 50/50 ohm relays of the 3000 type in conjunction with barretters, there is no appreciable gain or loss on the first repeater, irrespective of the resistance of the line.

By replacing the barretter with 150 + 150 ohm resistances a **decrease** in the make ratio of 4% for low loops and 6% for high loops is noticeable. This appears to be a decided advantage when dialling through several 3000 type relay repeaters and terminating on 2000 type switches (see Table No. 1).

For a call passing through several exchanges, the impulsing conditions likely to be encountered may be summarised as follow:—

Switches with Strowger Type Relays

1st Repeater or S.S.R. in train. Gain of 5% make ratio with subs. loops up to 700 ohms.

Intermediate Repeaters. Gain of 4% make ratio for very low loops to 1% for high junction loops.

Terminating Switches. Loss of 6% make ratio for low loops to 10% for high junction loops.

Switches with 3000 Type Relays
50/50 ohm A Relays with Barretters

1st Repeater or D.S.R. Gain of 1% make ratio with low resistance loops. No gain or loss for higher loops.

Intermediate Repeaters. Gain of 2% to 3% make ratio for low loops, loss of 1% for very high junction loops.

Terminating Switches. Gain of 3% make ratio for low loops to 5% for high junction loops.

Switches with 3000 Type Relays—Barretters replaced by 150 + 150 ohm Resistances during Impulsing

1st Repeater or D.S.R. Loss of 4% make ratio with low loops, 6% loss for higher subs. loops.

Intermediate repeaters. Same as with Barretters.

Terminating Switches. Same as with Barretters.

D.S.R. (2000 Type) to Strowger Repeater

Low Resistance Junctions. Make Increase, 6%.
High Resistance Junctions. Make Increase, 5%.

Strowger Repeater to 3000 Type Repeater

Low Resistance Junctions. Make Decrease, 3%.
High Resistance Junctions. Make Decrease, 5%.

3000 Type Repeater to Strowger Repeater

Low Resistance Junctions. Make Increase, 5%.
High Resistance Junctions. Make Increase, 1%.

Strowger Repeater to 2000 Type Selector

Low Resistance Junctions. Make Decrease, 2%.
High Resistance Junctions. Make Decrease, 4%.

3000 Type Repeater to Strowger Selector

Low Resistance Junctions. Make Increase, 2%.
High Resistance Junctions. Make Increase, 3%.

It will be appreciated from the above that conditions could occur in calls through the networks which may seriously affect the impulsing ratio, such as the following cases:—

3000 Type Relays with Barretters.

Tel.	Sub-Branch	Branch	Main	Main	Branch	Sub-Branch
	Repeater	D.S.R.	Repeater	Repeater	Repeater	Selector 2000 Type
37%	38%	41%	44%	46%	49%	54%

Make Percentage.
(Low Resistance Junction Loops.)

Combination of Strowger and 3000 Type Relays.

	Sub-Branch	Branch	Main	Main	Branch	Sub-Branch
Tel.	Repeater Strowger	S.S.R. Strowger	Repeater Strowger	Repeater 3000 Type	Repeater 3000 Type	Selector 2000 Type
37%	43%	47%	51%	46%	49%	54%

Make Percentage.

(Low Resistance Junction Loops.)

	Sub-Branch	Branch	Main	Main	Branch	Sub-Branch
	500	750	750	500	750	500
Tel.	Repeater 3000 Type	D.S.R. 3000 Type	Repeater 3000 Type	Repeater Strowger	Repeater Strowger	Strowger Selector
37%	33%	33%	33%	29%	32%	24%

Make Percentage.

(High Resistance Junction Loops.)

Pick-up Trouble on Repeaters: There are three aspects of pick-up trouble in connection with 3000 type relay repeaters, and, for the benefit of readers who may not be familiar with the term, the following definitions are given:—

(a) **"Initial Pick-up"**: This refers to the initial operation of the repeater and distant selector A relays upon seizure of the junction and the preparation of the circuit to receive the train of impulses which follows.

(b) **"Subsequent Pick-up"**: During a train of impulses the C relay associated with each repeater is operated, and the E and F relays are short-circuited by C relay contacts. At the end of the train of impulses, relay C, after its release-lag period, restores, and the E and F relays are again included in the loop to the switch ahead. This is termed "subsequent pick-up."

(c) **"Pick-up after Reversal"**: When the reversal is received, contacts of the D relay in the repeater reverse the current over the calling line. Whilst this is occurring the flux goes through a neutral period and the A relay momentarily releases, to re-operate immediately. The A relay must re-operate over the junction loop, plus the holding loop of the repeater in the distant main exchange. This re-operation is termed the "pick-up after reversal."

Further information on this aspect may be obtained by reference to an article by O. C. Ryan, in Vol. 5, No. 6, February, 1946.

The actual impulsing limits, using 50 ohm + 50 ohm A relays apart from pick-up trouble, is approximately 1900 ohms. It will be seen, therefore, that with the earlier type repeaters, the reversal condition limits the junction to 1600 ohms, whereas with the latest type repeater, the operating limits of the impulsing relay during impulsing, i.e., 1900 ohms, determine the maximum resistance limit of a junction.

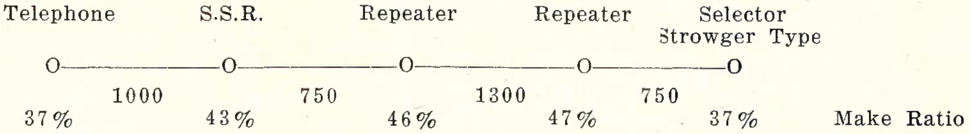
The following tests indicate that high resistance junctions may be used without a failure occurring with calls passing through three or four repeaters:—

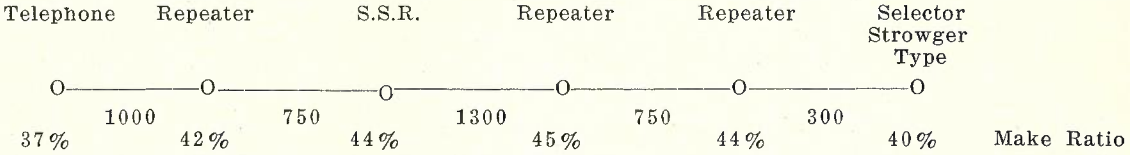
Repeaters with 3000 Type Relays without Barretters.

Telephone		D.S.R.		Repeater		Repeater		Selector 2000 Type	
	1000		750		1300		750		
37%		31%		31%		29%		34%	Make Ratio

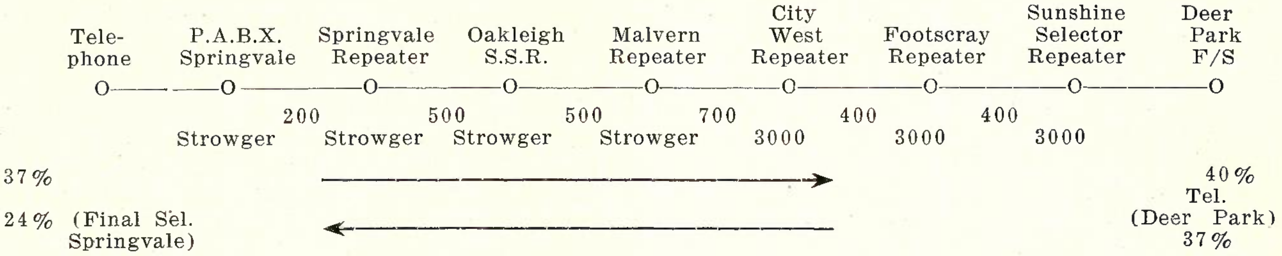
Telephone		Repeater		D.S.R.		Repeater		Repeater		Selector 2000 Type	
	1000		750		1300		750		300		
37%		36%		39%		38%		36%		38%	Make Ratio

Repeaters with Strowger Relays.





As an example of actual conditions existing in Melbourne, tests were made over the following route:—



Conclusions: The tests made indicate that, with Strowger type repeaters or D.S.R's, no trouble should be experienced in completing calls through the network involving up to four repetitions and including one junction of 1300 ohm resistance and two junctions each of 750 ohms resistance.

For repeaters with 3000 type 50/50 ohm relays, the above conditions also apply, but in order to overcome pick-up and reversal troubles when high resistance junctions are used, certain modifications to the standard 3000 type relay repeater have been made. The modifications are:—

(a) Replacement of the barretter filament by a 150 ohm + 150 ohm resistance during impulsing.

(b) Provision of an 800 ohm non-inductive resistance across the loop after each train of impulses.

(c) Provision of a holding circuit for the A relays during reversal.

These conditions are now included in the Standard Repeater—Drawing CE.59B—and are described in greater detail in the second series of tests.

Tests also indicate that calls involving five and, in certain cases, six repeaters appear to be satisfactory, but ratio readings prove that many of these calls are border-line cases and, where such calls terminate on pre-2000 type switches, any adverse conditions, such as a dial exceeding 10 I.P.S., low exchange voltage, etc., would undoubtedly cause failure.

The stage is being reached in the larger cities where a call passing through the network from one boundary to the other may encounter repeaters with 3000 type relays in each exchange through which it passes, and further tests in Melbourne, to determine the resistance limits of junctions in these cases, will now be described.

Repeaters and D.S.R's with 50/50 ohm 3000 Type Relays and Barretters: A series of tests have been carried out on repeaters and D.S.R's equipped with 50/50 ohm 3000 type relays and barretters. Particulars of these tests, a number of which are contained in Table No. 2, have been included in these notes, and, in connection therewith, the following explanatory comments are offered.

The tests were made with repeaters and D.S.R's supplied by the different contractors, and the standard adjustment of the impulsing and other relays was maintained throughout the tests. Standard cable boxes were used for all junction loops.

The normal operating current for 50/50, 3000 type relays with barretters is 23 mA., and this limits the safe impulsing loop to 1900 ohms. Two other factors, however, limit the junction loop to figures well below this resistance, and these are:—

(a) Pick-up after reversal.

(b) Subsequent pick-up.

Regarding pick-up after reversal, after completion of an impulse train, an additional holding loop of approximately 800 ohms replaces the short circuit dialling loop. On reversal, the A relays in repeaters drop back and re-operate and, under this condition, the A relay must re-operate over the junction loop plus the holding loop, therefore, to obtain a complete re-operation of the A relay, the total resistance external to the A relay should not exceed 2000 ohms. This limits the junction loop between repeaters to 1200 ohms, with repeaters other than the latest standard.

On the tests made, subsequent pick-up trouble was not in evidence until the junction loop exceeded 1400 ohms, but, as the tests were conducted in a 2000 type exchange with the voltage controlled at 50 volts, it is possible that pick-up trouble may be experienced on much lower junction loops with this type of repeater installed in pre-2000 type exchanges.

It appears, however, with the non-modified repeater, that the reversal pick-up condition determines the junction limits between repeaters. The junction limits for this repeater circuit may, therefore, be summarised as follow:

Single Junction

Subs. Loop J1
T——R1——SEL——FS
2000

Two Junctions

Subs. Loop J1 J2
T——R1——R2——SEL——FS
1200 2000

Three Junctions

Subs. Loop J1 J2 J3
T——R1——R2——R3——SEL——FS
1200 1200 2000

In the case of the single junction, the terminating switches will be provided with 200/200 ohm relays, and no impulsing or subsequent pick-up trouble will occur with junctions up to 2000 ohms. No reversal trouble can occur on the repeater, as the A relay will re-operate after reversal, on the subscriber's loop.

In the case of two or more repeaters in tandem, the reversal condition limits the junction loop between the repeaters to 1200 ohms.

Repeaters in Tandem: The tests indicate that with a number of repeaters connected in tandem the worst impulsing conditions occur when the junction loops are of very low resistance, but dialling is possible with six repeaters in tandem over zero loops. With this condition the make ratio at the terminating switch is 60%, which is very near the operating limit of the switches. See Test 1(a), Table No. 2.

No similar conditions to those indicated in 1(a) could obtain in practice, and it is doubtful whether shunt conditions more severe than those indicated in test 1(d) would be found in any network requiring six repetitions.

Regarding high resistance junction loops, no impulsing difficulties were found with six 1500 ohm junctions in tandem. This condition would,

TABLE No. 2

TESTS WITH SIX 3000 TYPE RELAY REPEATERS IN TANDEM

(REPEATERS TO DRAWING C656, SHEET 9)

TEL——R1 X——R2 X——R3 X——R4 X——R5 X——R6 X——SEL X——FINAL SEL.

Test No.	Loop Resistance	Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Zero Res.	Remarks
			Miles	Res.		Miles	Res.		Miles	Res.		Miles	Res.		Miles	Res.		Miles	Res.			
1 (a)	0	36	0	0	40	0	0	44	0	0	48	0	0	52	0	0	55	0	0	60		Type 2000. Sel. & final Sel. Impulse O.K.
1 (b)	0 750	36 36	1	88	39 39	1	88	43 42	1	88	45 45	1	88	51 51	1	88	53 53	1	88	54 54		O.K.
1 (c)	0 750	36 36	1	88	40 40	3	264	42 42	3	264	43 43	3	264	46 46	3	264	49 49	1	88	51 51		O.K.
1 (d)	0 750	36 36	3	264	39 39	6	528	41 41	6	528	41 41	6	528	47 47	6	528	47 47	3	264	49 49		O.K.
1 (e)	0 750	36 36	6	528	39 39	9	792	41 41	9	792	41 41	9	792	45 45	6	528	45 45	5	440	48 48		O.K.
1 (f)	0 750	37 37	9	792	39 39	11	968	40 40	11	968	40 40	11	968	43 43	9	792	43 43	5	440	46 46		O.K.
1 (g)	0 750	36 36	6	528	39 39	15	1300	39 39	9	792	40 40	6	528	43 43	6	528	44 44	5	460	47 47		O.K.
1 (h)	0 750		11	968		15	1320		11	968		11	968		10	880		3	440	44 44		O.K.
1 (j)	0 750		5	+ 800 1300		15	1320		15	1320		15	1320		15	1320		15	1320	40 40		O.K.
1 (k)	0 750		5	+1040 1500		18	1584		18	1584		18	1584		18	1584		18	1584	38 38		Impulsing O.K. 2nd, 3rd and 4th Repeater A relays drop out on reversal.

D.S.R. THROUGH FIVE 3000 TYPE RELAY REPEATERS

T-———D.S.R. X———R1 X———R2 X———R3 X———R4 X———R5 X———SEL. X———F.S.

Test No.	Loop Resistance	Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Make Ratio	Junct. Res.		Standard D.S.R. Make Ratio	Modified D.S.R. Make Ratio	Remarks
			Miles	Res.		Miles	Res.		Miles	Res.		Miles	Res.		Miles	Res.		Miles	Res.			
2 (a)	0 750		0	0		0	0		0	0		0	0		0	0		0	0	61 61	56 56	Type 2000. Sel. & final Sel. Impulse O.K.
2 (b)	0 750		1	88		1	88		1	88		1	88		1	88		1	88	54 54	51 51	O.K.
2 (c)	0 750		5	440		5	440		5	440		5	440		5	440		5	440	50 50	46 46	O.K.
2 (d)	0 750		5	+ 800 1300		15	1320		15	1320		15	1320		16	1408		15	1320	45 45	40 40	O.K.

of course, be impossible in any network, both from a geographical and transmission viewpoint.

It would appear from the tests that the non-modified repeater in general meets the conditions required in the various metropolitan networks, but in certain cases junctions between two exchanges may exceed the 1200 ohms laid down as a proposed limit. This is the case in Adelaide, where junctions from Glenelg, Unley and Norwood to Port Adelaide exceed this figure. Certain modifications to the standard repeater circuit have been made in these cases and are entirely satisfactory. The modifications made are as follow:—

(a) To overcome pick-up after reversal trouble, a 1000 ohm holding resistance is connected across the repeater "A" relay coils during reversal. This prevents the A relay from flicking during reversal and allows the resistance of the inter-repeater junction to be increased to 1400 ohms or higher. The A relay in this case does not have to re-operate over the high resistance junction, plus holding loop, but is required only to hold on this resistance.

(b) To overcome subsequent pick-up trouble, an 800 ohm non-inductive resistance is connected across the repeating loop momentarily, when C relay restores after each train of impulses. This allows the field of the A relay in the repeater ahead to build up quickly. Both these conditions are included in the latest repeater circuit.

With the above modifications, it should be possible to repeat satisfactorily over junction loops of 1400 to 1600 ohms.

Discriminating Selector Repeaters: The tests indicate that these switches can be substituted for repeaters at any stage without altering the impulsing characteristics to the terminating switches. As in the majority of cases, these switches are held by the subscriber's loop, the modification suggested above for repeaters in connection with pick-up after reversal is not required. Should these switches be connected to a main exchange over very long junctions, however, some modification may be necessary to avoid subsequent pick-up trouble.

Conclusions: There appears to be no reason why calls involving the use of six repeaters or a D.S.R. and five repeaters should not be completed satisfactorily, providing that the following conditions are observed:—

(a) Repeaters should be in accordance with Drawing CE.59B, with a rectifier across the reversing relay.

(b) Junction loops between repeaters should not exceed 1200 ohms (unless the latest standard repeater is used, when the junction loop may be extended to 1600 ohms).

(c) The impulsing relays of all 3000 type relay repeaters should be maintained in standard adjustment; no variation to this adjustment appears necessary, even under extreme impulsing limits.

(d) Barretter filaments in D.S.R's or repeaters used as 1st selector equivalents should be replaced by 150 ohm plus 150 ohm resistances during impulsing. This is necessary to protect the barretters, and also improves impulsing, with calls passing through more than three repeaters.

THE RECRUITMENT AND TRAINING OF STAFF, ENGINEERING BRANCH, N.S.W. - PART 2

G. Buckland, B.Sc., A.M.I.E. (Aust.)

General

The rapid expansion of telecommunications in the late 1930's created a pressing need for more staff highly skilled in the various phases of Engineering Branch activities. Prior to 1938, normal technical staff training was undertaken by the Technical College—a State organisation—by agreement with the Department. However, the need for specialised training in communications was such that in 1938 the Department established its own Linemen's Training School and, a year later, a similar school for the training of Technicians. The Technical College, however, continued the training of Departmental trainees in the normal artisan trades and with courses in the pure science field. The Departmental schools undertook the training in the practical work and theory associated with communications.

During the recent war, recruitment of trainees was considerably reduced and the Departmental facilities and instructional staff were given over to the training of Service personnel engaged in communication work. The present training requirements have far outgrown the original accommodation, and now there are four schools in the metropolitan area and seven temporarily set up at the Divisional Engineer's headquarters in various country centres. Except for the Line School at North Strathfield (Fig. 1) all schools are housed in buildings temporarily converted for training purposes. The establishment of a central Departmental training college to accommodate all training activities in the metropolitan area is now under consideration.

Fig. 1.—The Training School, North Strathfield.

The total number of trainees attending all schools during the year on a part- or full-time basis varied from 750-900. The need for staff to be trained quickly for the post-war period has resulted in a large proportion of the training effort being directed towards short-term courses. A summary of the approximate number of trainees attending various courses now and likely to be in attendance in 1949 follows:—

Group of Trainees	1948	1949
Cadet Engineers	27	44
Cadet Draftsmen	13	18
Clerks (Part-time)	—	130
Technicians—		
Technician-in-training, permanent	467	687
Primary Courses—exempt staff	32	32
Secondary Courses—exempt staff	212	136
Linemen—		
Linemen-in-training, permanent	Nil	450
Primary Courses—exempt staff	88	64
Secondary Courses—exempt staff	81	16
Total	920	1577

Organisation of Courses

Separate schools in the metropolitan area train line and technician staffs, but the schools in country centres cater only for line staff. The school courses are designed to cover sufficient basic practical exercises and correlated theoretical training to give each trainee sufficient knowledge to enable him to apply himself to most problems associated with his daily work. Syllabuses are prepared for use on a day-to-day basis. A representative syllabus is indicated below:—

Practical Work (Transmission)

Day	Explanation	Demonstration	Practical Exercises
1	Superimposed circuits	(i) Film strips on: (a)—Transformer theory. (b)—Electromagnetic induction. (ii) Working model showing effects of induction. (iii) General quiz and discussion.	Wire and test out superimposed circuits under differing conditions.
	2 hours	1 hour.	4¼ hours.

The arrangement of the syllabuses in this form ensures that the subject matter is dealt with uniformly by different instructors and that full use is made of the instructional aids available. Instructors know beforehand the periods set aside for revision and examinations, and the progress of the class can readily be checked by supervisory staff. It is not always possible to carry out the practical work in the school and, in such cases, lectures are given in conjunction with field work and appropriate roneoed or printed notes issued.

Field experience without adequate preliminary school training has disadvantages which hinder efficient and systematic training. Working staff normally concentrate on doing the job in hand rather than on giving instruction, and the trainee remains idle for lengthy periods and only observes what is being done. Quite often the practical field man is lacking in teaching ability and temperament therefor. The difficulty is being overcome by installing standard equipment in the schools which can be used for training purposes only, and, with the aid of a skilled instructor, it is hoped the trainee will be given sufficient knowledge to enable him to take an active part when in field training. The following equipment has been installed in the schools for the foregoing purposes, and further installations are proposed:—

- Telephone Equipment:
  - Subscribers' instruments of various types;
  - Multiple magneto and trunk switchboards;
  - Standard magneto exchanges;
  - Test desks, I.D.F's, M.D.F's;
  - Eye-ball and lamp-signalling type P.B.X's, power and battery rooms.
- Radio Equipment:
  - Two 100-watt transmitters (allotted wavelength 2728 kc/s) and associated studio and control rooms; disc recording equipment;
  - Receiving and portable transmitting equipment;
  - Electronic testing and experimental equipment.
- Long Line Equipment:
  - Three-channel SOS system;
  - R Type telegraph system;
  - Voice-frequency repeaters of various types;
  - B Type telephone and telegraph systems modified for use in experimental exercises.
- Telegraph Equipment:
  - Teleprinters, teletype, multiplex and manual systems.
- Line Construction:
  - Sample installations of the types of aerial and underground construction in general use.

Classrooms are equipped with every modern aid for teaching, including large blackboards, charts, tool shadow-boards, working models and sample equipment. Sound track and strip films are used to augment the lecturer's presentation of subject matter, and a separate theatre is also available. Trainees are taught standard methods in the use of tools, and the operation and maintenance of various types of equipment. A typical lecture room is shown in Fig. 2.

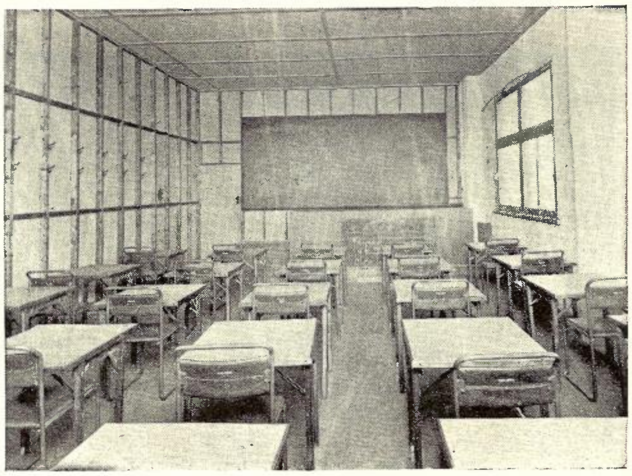


Fig. 2.—Typical lecture room.

Each trainee, when taking up duty in the school, is allotted a work bench equipped with all the tools necessary to undertake the practical exercises associated with each particular section (see Fig. 3). When proceeding to field training he is issued with a general-purpose kit which he retains throughout the whole of his training course. Special kits for use on sectionalised training are drawn from the school tool store as required, and these are returned as each trainee completes the allotted period of training on that type of work.

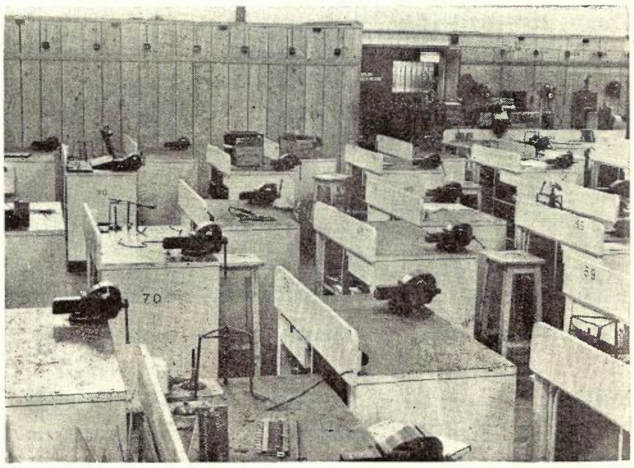


Fig. 3.—Section of Training School at Alexandria showing layout of individual benches for first-year technician trainees.

It will be appreciated that a detailed description of syllabuses and method of treatment of each of the many sections of instructional work involved is beyond the scope of this paper. In Figs.

4 to 8 inclusive, therefore, illustrations of various sections of the training schools' activities and methods adopted for demonstrating the use and operation of different types of equipment have been included to give some impressions of the schools' work.

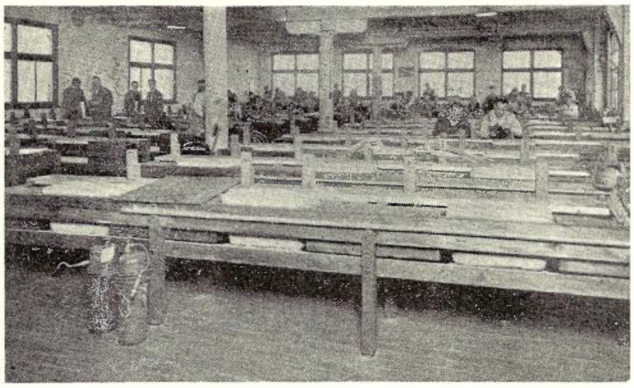


Fig. 4.—Cable jointing section, Annandale—capacity for 93 trainees.

Staff Organisation

An Assistant Superintending Engineer administers the operation of the training section, which is divided into professional, technical and clerical divisions. Divisional Engineers in the professional and technical fields respectively and the Clerical Training Officer are responsible for the control of each division. A summary of the functions of each is as follows:—

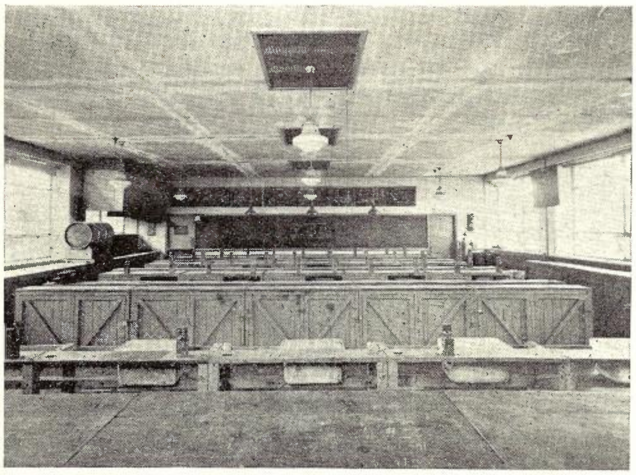


Fig. 5.—Practical work room, Linemen's Training School, North Strathfield.

Professional Training deals with the training of Cadet Engineers, Cadet Draftsmen and the induction and short-term training of Engineers appointed from outside the Service.

Technical Training includes employment of manipulative staff, the administration and development of the various technical schools in the metropolitan area and the control of the associated trainee and instructional staff. Country schools are controlled by the local Divisional Engineer concerned, and their activties are co-ordinated by the Assistant Superintending Engineer.

Clerical Training deals with the training of newly-appointed clerks, and refresher courses for existing clerical staff.

In comparison with the field staff, the training of professional personnel necessarily involves to a greater degree tuition in the basic sciences by external university and technical college courses. These are supplemented by courses of lectures and demonstration covering the various sections of the Engineering Branch. In addition, the trainees are given field training on the job in all sections of the Engineering Branch activities. In the case of field staff, which is primarily concerned with manipulative work, the range of Departmental training is appreciably greater and, for this reason, the following more detailed description is given of the extent of the training syllabuses.

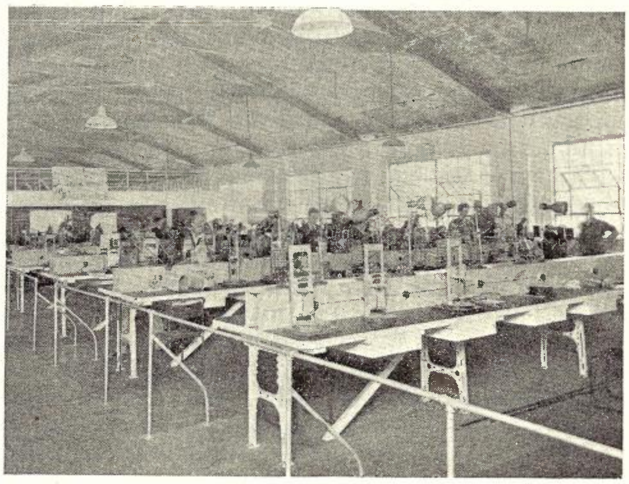


Fig. 6.—Automatic switch adjustment section—positions for 80 trainees.

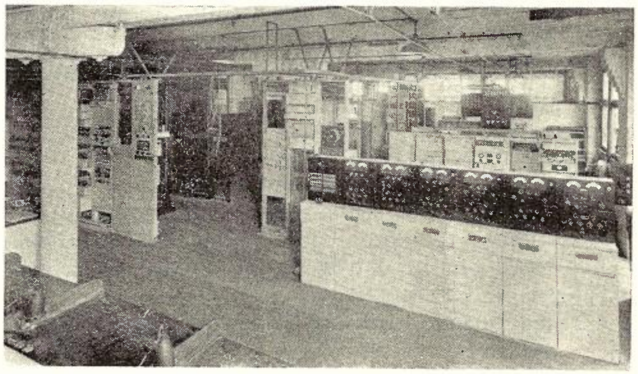


Fig. 7.—Section of carrier room, Technicians' Training School, Annandale.

Separate Supervisors control and co-ordinate the Technician and Line training activities respectively. Assistant Supervisors for Technician and Senior Instructors for line staff control regional schools or particular functional activities, such as field training and theoretical instruction.

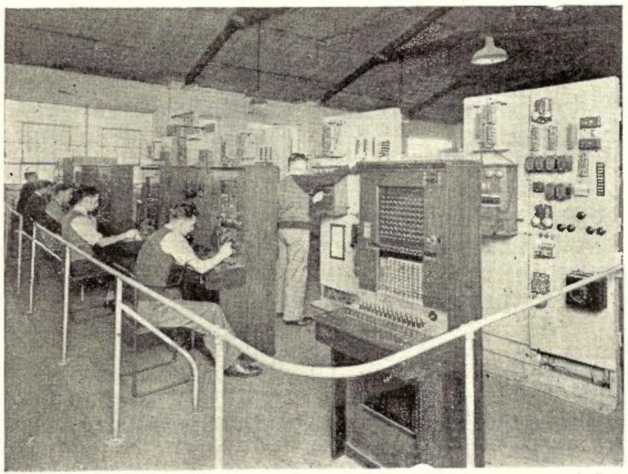


Fig. 8.—Portion of section allotted for training in magneto exchange work.

The instructional staff are classified as follows:

	Equivalent Grade of Position	
Title	**Technician Schools**	**Line Schools**
Supervisor	Supervising Technician, Gr. IV.	Line Inspector
Asst. Supervisor	Supervising Technician, Gr. III. Supervising Technician, Gr. II. Supervising Technician, Gr. I.	
Field Supervisor Senior Instructor Lecturer	Supervising Technician, Gr. I.	Line Foreman, Gr. II.
Instructor	Senior Technician	Line Foreman, Gr. II.
Demonstrator	Technician	Line Foreman, Gr. I.

The duties of the instructional staff may be summarised as follows:—

Supervisor: Controls either line or equipment training and the associated staff.

Assistant Supervisor: Takes charge of a school or a particular functional activity.

Field Supervisor: Supervises the practical field training and ensures that each trainee in his area receives adequate experience and training in accordance with a pre-arranged roster.

Lecturer: Teaches the theoretical aspects of communications; this is done in parallel with the practical work undertaken in the school or in the field.

Senior Instructor: Under the control of the Assistant Supervisor, takes charge of a group of instructors and demonstrators. In country Line Schools he has the status of a supervisory officer.

Instructor: Is responsible for the training of a group of trainees in the practical work, such as cable jointing, sub-station installation, etc.

Demonstrator: Assists the Instructor with the demonstrations and supervision of the class exercises.

These officers are assisted by a technical and clerical staff who carry out the duties ancillary to actual training.

Selection and Training of Instructors

The number of instructional staff required not only depends on the number of the trainees, but also on the variety of training to be given. In the case of technicians-in-training, the ratio of trainees to instructors on practical work varies from six to one for automatic switch adjustments to fourteen to one for the simpler exercises undertaken during the first year. The ratio adopted in the line construction work is eight to one for all classes of practical instruction.

The instructional staff is drawn, normally, from volunteers for employment on this class of work. Selection is made by personal interview of each applicant and depends upon ability, experience, personality and aptitude for teaching. Such factors as age, health and appearance are also taken into consideration. Before taking up teaching duties, new instructional staff are associated with experienced instructors to enable them to become adjusted to the new environment and familiar with teaching methods in use. In addition, they attend a lecture course in modern teaching methods and educational psychology.

During the break periods at the end of each term, conferences of the instructional staff are held with the Divisional Engineer as Chairman. Matters of interest bearing on the organisation and functioning of the school are discussed, and many improvements have originated from this source. Opportunity is taken on such occasions to give refresher training to the staff in one or more of the following ways:—

(a) Lectures on communication or teaching practices given by Departmental Engineers, or specialists from outside the Department;
(b) Screening of educational films with a technical interest;
(c) Visits to engineering projects in progress (or completed) in the Department or outside industry;
(d) Placement of staff for short periods in exchanges or other work centres to obtain refresher experience.

The standard of efficiency of the instructional staff is gauged by periodical analysis of class results. Instructors also assist in their own improvement by a study of rating charts prepared periodically by the trainees. This information is considered of a confidential nature and is retained by the instructor concerned.

Progress of Trainees

It has been found from past experience that it is desirable to review the progress of trainees at least every six weeks, either by examination or written assignment. Examinations are more extensively used as they are easier to apply and are suitable to trainees of all ages. In addition, written homework of up to four hours per week is given to all trainees during their first year in the school.

Trainees receive a grading mark for every phase of practical work undertaken in the school. This enables the progress of each individual to be closely supervised, and instructors are required to cover every aspect of a lesson. Term examinations are usually of the short-answer variety, including incompleted, matched and jumbled-sentence types. Final examinations in the longer courses contain questions of both the essay and short-answer variety.

Cultivation of a desire in the trainees to learn is a primary function of the instructional staff. Keenness for the work or the knowledge that qualification as a technician or lineman will give salary, seniority and security advantages must be considered as prime motives. However, incentives such as graded passes at examinations help in the development of individual progress and self-esteem. Instructors are encouraged to take a personal interest in each trainee. When trainees are posted to field work—from second year onward—they undertake more complex tasks as they gain experience. The opportunity to perform work of greater responsibility gives a measure of satisfaction and pride in achievement. The trainee gains self-confidence and standing among his fellow students and is more readily absorbed into each new training group or work situation.

Reports on Trainees: In addition to the periodical examinations and assignments, reports are submitted on each trainee by the controlling Supervising Technician in the field. These are prepared in answer to a questionnaire which is divided into a number of headings classified under five gradings. A typical example is:—

Performance of Work

(a) Plans work; very neat, accurate and methodical.
(b) More methodical than average—makes few mistakes.
(c) Satisfactory.
(d) Less systematic than average—makes more than average number of mistakes.
(e) Very careless—far too many mistakes and repetition required.

Thus all trainees are reported on in a uniform manner by their supervisors, and oversight of both technical advancement and character building can be co-ordinated.

Trainees failing at a term examination are interviewed by the Assistant Supervisor concerned, and a written report is furnished for the information of the Divisional Engineer who, in turn, will further interview the more difficult cases. Where the progress of a trainee continues to be unsatisfactory, or he is incapable of reaching a minimum standard of efficiency, he is transferred to another position in the Department more in keeping with his general ability.

In the case of juniors an annual report is forwarded to the parent or guardian setting out the trainee's progress during the year.

Working Conditions

Training in the Departmental schools and Technical College is conducted during the normal working hours of duty, except for some courses in the artisan trades, where only night courses are available at the college.

Trainees work 36¾ hours per week and the instructional staff 38¾ hours—the latter being engaged a short time longer than the former each day for preparing and finalising courses of study.

Good working conditions and an appreciation by both instructor and trainee of the importance of good human relationships, encourage the trainee to apply himself with a will and develop proper interests. Contentment of mind is the first essential of physical and mental well-being, and school activities, whether work, study or recreation, are designed to give a measure of satisfaction at all times. Trainees require to be taught the conditions of work that they are to regard as standard, as these young men will be the Supervisory officers of the future.

All first-year trainees are given a short course in "First Aid," and this year arrangements were made with the St. John's Ambulance Association to conduct the course which gave every trainee the opportunity of obtaining a First Aid certificate.

A welfare officer is stationed at the Technical Training School at Annandale, but other metropolitan schools are visited periodically each week. This officer handles personal problems and difficulties likely to contribute to poor workmanship, laxity or absenteeism. He also edits a Training School Bulletin and assists the staff generally in all matters relating to trainee welfare.

Conclusion

The effectiveness of the training scheme has been demonstrated in greater efficiency and development of leadership.

The efficiency of the training has stimulated new interest in supervisors and older employees in the adoption of improved methods, and the need for and the benefit of refresher courses has been recognized by all grades of staff.

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. 2721—ENGINEER—TELEGRAPH EQUIPMENT

A. F. Hall

Q. 6.—(a) What is the maximum transmission speed in bauds at which it is possible to operate over one of the channels of an 18-channel V.F. system? Give reasons.

(b) What is considered to be the maximum number of V.F. channels (18-channel sysem) usable in tandem for teleprinter working? Give reasons.

(c) Give your opinion as to what % distortion at 50 bauds would be likely over 3 channels in series.

(d) What % distortion is the teleprinter, model 7C, able to tolerate?

(e) Explain why it is that the band width required for teleprinter working is independent of the rapidity with which the keys on the keyboard are operated.

A.—(a) The specification for an 18-channel V.F. system requires that each channel shall be capable of transmitting at a speed of 66 bauds with not more than 25% distortion. This requirement must be met with 7.5 d.b. variation in bearer circuit attenuation, ± 10% variation in power supply voltage and ± 0.25% carrier frequency variation. The various telegraph channels are arranged with a spacing of 120 cycles. The channel filters have a nominal width of 70 to 80 cycles at those points on the curve where attenuation is not greater than 4 to 5 d.b. for the sum and difference frequencies, and this width provides satisfactory discrimination between channels. If these points (upper and lower cut-off frequencies) be denoted f2 and f1, it can be shown that the time required for the modulated carrier envelope to increase from zero to maximum value = $1/(f_2 - f_1)$ secs.

To prevent abnormal distortion the shortest signal element should not have duration less than this value. Hence the maximum speed in bauds = $1/[1/(f_2 - f_1)]$ = the effective channel band width in cycles per second. Cut-off is not definite, but occurs over a limited range of frequencies. With excessive signalling speed the sum and difference frequencies extend further into those portions of the pass bands subjected to greater attenuation due to band filter characteristics.

Distortion, therefore, increases rapidly at these speeds and may reach values not acceptable to receiving equipment.

(b) The teleprinter will accept 35% distortion, but experience has proved that if distortion greater than 25% is introduced, the period of field service of machines will be very severely restricted. One V.F. channel as a single link may introduce 10-12% distortion. The effect of adding a channel in tandem is to increase the distortion beyond that introduced by either channel as a single link. Thus, three links may introduce 20-22% and four links in tandem up to 26% distortion. If four links in tandem are used, the additional distortion introduced by the local loop and relay set working on a single current basis may leave insufficient working margin for the machines. This is borne out from experience, which indicates that three V.F. channels in tandem should not be exceeded for teleprinter working.

(c) Three V.F. channels in tandem at 50 bauds may introduce 20-22% distortion.

(d) A 7C teleprinter will accept distortion of the start signal with relation to the remainder of the signal train up to 35% early and late.

(e) After each key is operated, the teleprinter keyboard is locked during the transmission period of the appropriate signal train. The speed of transmission is governed by the speed of revolution of the transmitting cam shaft, which is driven from the mainshaft at constant speed. It is designed to give each element of the signal train a duration period of 20 m.s., which corresponds to 50 bauds.

Q. 7.—Explain, with the aid of sketches:—

(a) The action of the automatic start-stop switch as fitted to teleprinters for controlling the starting and stopping of the motor.

(b) The operation of the transmitting unit of a teleprinter.

A.—(a) The automatic start-stop switch is diagrammatically shown in Fig. 12, the condition being motor switched off and the mechanism at rest.

Switching On: Reception of a start (spacing) signal moves the starter trip lever extension forward to displace the start boss and spindle. The weight lifting pin is moved clear of the hole in the worm-wheel and the weight falls, striking the switch-operating lever and throwing the switch to the "On" position. The worm-wheel shroud masks the holes in the worm-wheel to prevent the weight-lifting pin from entering a hole during descent.

Switching Off: The worm-wheel runs continuously whilst the motor is running. Under steady marking conditions, the weight-lifting pin is thrust into a convenient hole in the lower part of the slowly revolving worm-wheel by the tension of the end thrust spring. The weight-lifting pin and weight-lifting arm are slowly raised by the worm-wheel to the position shown in Fig. 12. The shroud is pushed clear during ascent of the weight-lifting pin, and the weight, acting on the switch-operating lever, operates the switch, cutting off the power to the motor. The time for one entire operation is approximately 1½ mins.

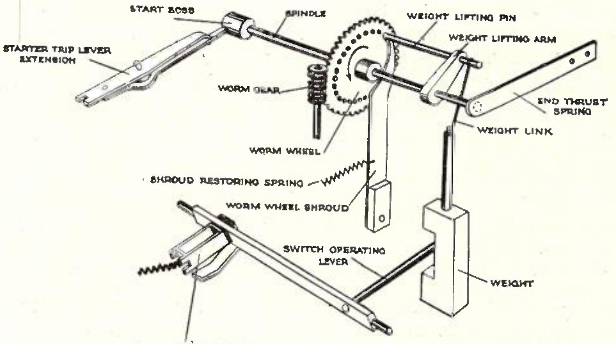


Fig. 12.—Automatic start-stop switch.

(b) The operation of a link-operated transmitter, shown in Fig. 13, will be described. The operation of any key depresses the Trip Bar, which moves the Trip

Bell Crank and the attached Trip Lever to the right. To the Trip Lever is connected the Trip Finger, which raises the Transmitting Cam Pawl abutment. The Transmitting Cam Ratchet Pawls engage with the Ratchet Wheel, and the Transmitting Cam commences its revolution.

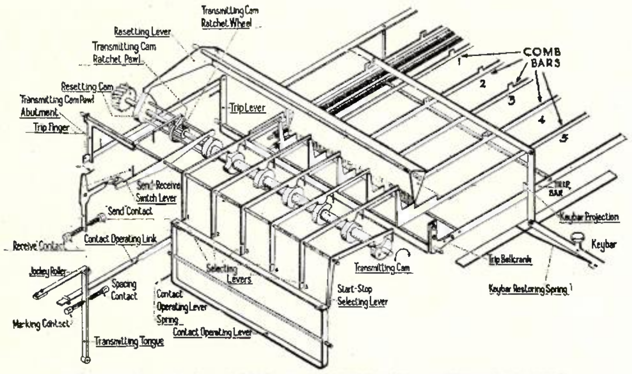


Fig. 13.—Transmitting mechanism, link operated.

The Send-Receive Switch Lever rides off the projection of its cam, moving the Send-Receive Switch Blade to "Send." The start-stop selecting lever rides out of its cam opening, freeing the contact operating lever, the upper part of which is pulled to the right by its restore spring, and moves the Transmitting Tongue to "Space" via the Contact Operating Link. Thus the Start Signal (spacing) is transmitted to line. Simultaneously, the Resetting Lever rides off its cam projection and moves to the right, permitting each selected comb bar to be pulled by its spring clear of its corresponding selecting lever. The opening of each Signal Cam, 1, 2, 3, 4, 5, is presented in sequence to its corresponding selecting lever. Where a Comb Bar has been withdrawn, the Selecting Lever may enter the Cam opening and move the Contact Operating Lever so that a Marking signal will be transmitted from the Transmitting Tongue. The position of the latter, whether Marking or Spacing, is confirmed by the Jockey Roller shown.

After the start and 5 signal elements have been transmitted, the Start-Stop Selecting Lever drops into its cam opening and the contact operating lever moves the tongue to Mark to send the Stop signal. This marking signal is maintained while the transmitter is at rest.

The Resetting Lever, under the influence of its cam, draws the comb bars to the left, each under its corresponding selecting lever. The Send-Receive Switch lever rides on to its cam projection and moves the Send-Receive Switch to Receive. The Transmitting Cam Pawl abutment disengages the Transmitting Pawls and the motion of the Transmitting Cam ceases.

Resetting of the Transmitting Cam Pawl abutment into the path of the pawls is performed by the cam repressing the Trip Finger about half way through the revolution of the Cam Sleeve.

Q. 8.—Describe the advantages and disadvantages that would be produced by replacing shaft and belt driving of machines in a workshop with electric drive of each individual machine or each set of machines.

A.—The advantages which would be derived from an individual drive system in a workshop are:—

(a) Greater flexibility in the use of machines, since any machine may be operated independently.

(b) Greater convenience in arrangement of machines, which may then be placed to suit production flow without consideration of relationship to a line shaft.

(c) Better distribution of lighting which, under these conditions, is not obscured by overhead equipment and belting.

(d) Cleaner workshop conditions. From overhead line shaft and belting, oil and other foreign matter may be thrown, tending to discolour walls, ceiling and floor. With individual drive this is less likely, and motors and drive may be more easily enclosed, resulting in cleaner conditions.

(e) Individual motor troubles will not cause entire stoppage of plant.

(f) Less risk of accident. Protection of motor and belting is greatly simplified with individual drives.

The main disadvantage is the increased installation cost, as a number of small motors with individual power supplies will prove more expensive than one larger motor of equivalent horsepower. Furthermore, the horsepower of individual motors must equal the maximum power required to drive the particular machine under worst load conditions.

Other factors which must be taken into consideration are as follow:—

(a) With shaft and belt drive, additional frictional load is introduced. This is offset to some extent by the fact that some diversity of load is permissible under these conditions, and less total horsepower may be required.

(b) Individual motors would often be operating below their rating and hence would have lower efficiency. The single large motor for the entire shop or group of machines would, in general, be operating more closely to the rated horsepower.

(c) Additional man-hours would be necessary to satisfactorily maintain a number of small motors. To some extent this would be offset by the comparative ease with which a faulty motor could be replaced, thus facilitating its repair in the maintenance workshop. Furthermore, with a common motor installation, considerable costs are incurred in maintenance of belting and bearings.

(d) In certain cases where a group of machines may be working on a particular process, greater convenience may be gained by providing one motor for the group.

Q. 9.—It is proposed to provide, between two offices, a single pneumatic street tube for both way working. The route length is 2000 feet and internal diameter of tube is 2¼ inches.

(a) Discuss the air supply and power requirements for operating the tube.

(b) Describe, with the aid of sketches, the terminals necessary at each end of the tube.

(c) State the speed of carriers at the air pressures recommended.

(d) Give the air volume in cubic feet per min. that would be provided for a busy 2¼″ tube.

A.—(a) In considering the above proposal, it is assumed that expansion of the service is unlikely. A pressure of 2½ lb. per sq. inch above atmosphere would give satisfactory carrier speed, but for the clearance of ordinary blockages a pressure of 5 lb. per sq. inch may, at times, be necessary. Under these conditions a low vacuum system would suffice, and a blower of the Root's or other positive rotary type would meet the requirements.

Blower.—A blower is necessary of size capable of delivering 100 cub. ft. per min. at a pressure not exceeding 5 lb. p.s.i. With a Root's blower, the speed should preferably not exceed 200 R.P.M. to avoid undue noise, but positive rotary blowers of other types are usually driven at higher speeds.

Motor.—With D.C. supply, a shunt-wound motor would be provided. With single-phase A.C. supply, owing to the heavy starting torque required, a repulsion induction motor would be advisable. With three-phase A.C. supply a three-phase squirrel cage motor would be suitable. A motor of 5 B.H.P. is recommended. Transmission by multiple Vee belt would give a compact installation in the case of the Root's blower. Direct coupling may be adopted for blowers operating at higher speeds.

Auto. Operation.—Traffic requirements outside ordinary hours would govern the provision or otherwise of automatic push-button control.

Duplication.—Under the conditions assumed, no duplicate plant would be supplied.. Service by messenger would be arranged on the few occasions when the plant would require complete shutdown.

(b) At the main office a terminal, diagrammatically indicated in Fig. 14, would be installed. The diagram shows the terminal in the "sending" position. The movable head, H, connects the tube to the pressure side of the blower. Air flow is indicated by the feathered arrows, i.e., from atmosphere, A, via H to R, the receive side of the terminal, and blower intake I, then from blower outlet, O, via valve V, to the send side of the terminal. When H is moved to the receive position, the tube is connected to R and valve V connects the pressure line to atmosphere. Air flow is indicated by plain arrows, i.e., from the tube via H and R to I. From O via V to atmosphere. Manual switching to the Send position would be provided with automatic restoration to the Receive position after a suitable time limit.

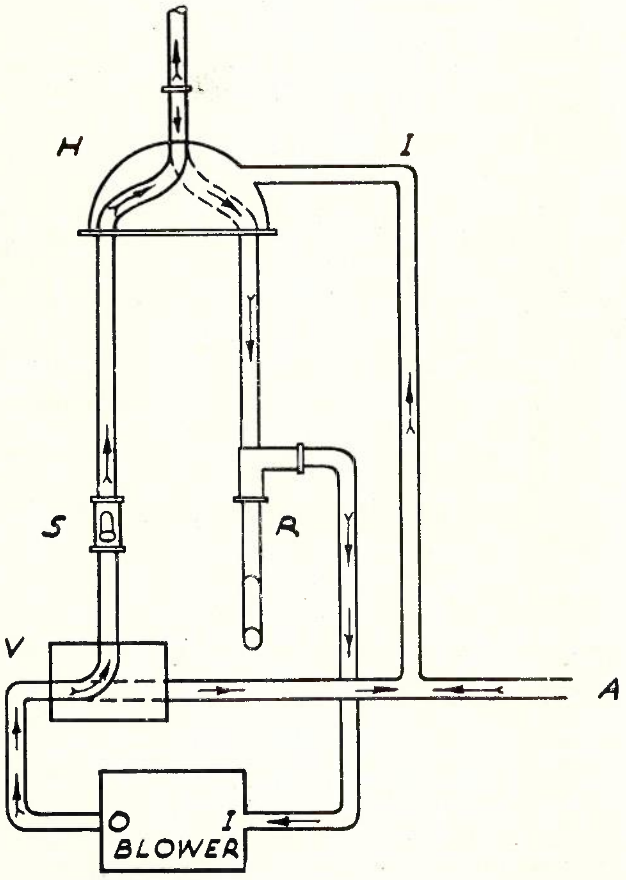


Fig. 14.

A device known as a Terminal Flap may be used for the distant terminal. It is indicated in Fig. 15. The arriving carrier is deflected against an aluminium flap with soft leather seating. The flap opens, discharging the carrier into the wire basket provided. To despatch a carrier the vacuum is first switched on, the flap is lifted and the carrier inserted buffer foremost. On release the flap closes automatically. If the impact of carrier arrival is excessive a bypass and valve, indicated dotted in Fig. 15, may be provided. The valve is operated by Bowden cable and located within 15 feet of the terminal. The bypass is located approximately 30 feet from the terminal. When the bypass is fitted, the pressure behind an arriving carrier is reduced to atmospheric pressure after passing the bypass. The valve is closed when a carrier is being despatched from the terminal.

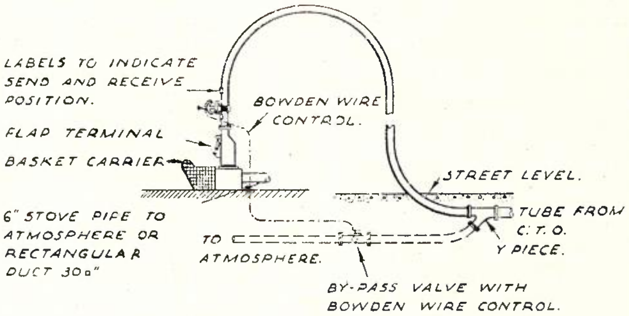


Fig. 15.—Terminal pneumatic flap arrangement and connections with by-pass, etc.

In many installations, the distant terminal consists simply of the open-ended tube terminated horizontally on the tube table and leading into a suitable open receiving trough or chute, in which the momentum of the carrier is dissipated—see Fig. 16. The vacuum should be switched on before the carrier is inserted for despatch. With this terminal, running costs are greater, but maintenance of equipment at the distant terminal is reduced.

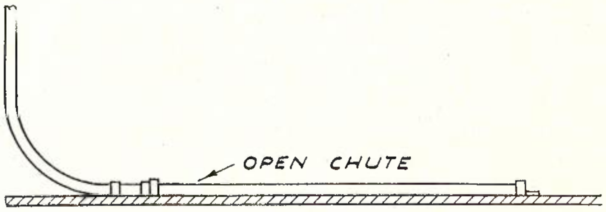


Fig. 16.

(c) The minimum air pressure which must be maintained for a $2\frac{1}{4}''$ tube of 2000 feet is $2\frac{1}{2}$ lb./s.i. above atmosphere. Vacuum requirements are $2\frac{1}{4}$ lb./s.i. below atmosphere. Carrier speed at these pressures is 30 ft./sec.

(d) 70 c.ft. per minute would suffice, but to allow for air leaks and losses 100 cub. ft./min. is desirable.

EXAMINATION No. 2721—ENGINEER—LINE CONSTRUCTION
PART C—AERIAL WIRES

Q. 9.—Briefly describe the recognised methods of tying in, terminating and jointing copper line wires. Discuss each from installation and maintenance aspects. Include in your answer the factors which rise to faults at such points, and any aspects to which attention should be given in order to reduce the fault liability as far as possible.

A.—The methods used in tying-in, terminating and jointing of line wires are of major importance in the serviceability of line construction. The major features influencing the methods of tying-in, terminating and jointing of wires are serviceability and economy.

Tying-in: Where wires pass insulators at intermediate poles, the wire has to be bound to the insulator so as to be held securely, and this involves, for Australian practice, the binding of a soft copper wire over the copper line wire. To prevent chafing of the line wire, a soft copper tape is first wrapped spirally over the line wire. A soft copper wire is bound around the insulator and the line wire so as to hold the wire firmly against the insulator. The soft copper tapes are in four sizes to suit specific line wires—40/70-100/20, 300/400 and 600/800, and the binding wire used is 20 lb. soft copper for 40 lb. per mile cadmium copper and 50 lb. per mile soft copper for copper and cadmium copper wires of larger sizes.

From the installation and maintenance aspect of the tying-in of wires, this method fulfils fairly satisfactorily the requirements for tying-in.

(a) Simple and quick to make.
(b) Wire is held securely to insulator.
(c) Wire will not slide past tie in event of a wire-break in a span.
(d) Wire does not chafe against either insulator or tie.
(e) Reinforcement against bending is provided.

The faults to which this tie is liable are due to fatigue or "inter-crystalline fracture" and chafing. The fatigue effect is caused by repeated bending stresses, due to aerolian vibrations, which exist in any line wire, and cause the metal to lose its strength. The method of binding used aims at steadily reducing the reinforcement provided at the insulator to the end of the tie, so that the vibrations are damped out over a larger area of wire. However, the method is not ideal, and an appreciable number of faults is caused by fatigue at tying-in points.

Chafing of the wire is avoided by the use of the thin, soft copper tape, which is wrapped firmly on the line wire so the wire cannot move independently of the tape. If the tape is too thick in relation to the wire size, there is a tendency for the tape to harden and spring loose, and cause more rapid chafing. Under present practice, the only factors which influence maintenance of wires in regard to tying-in, is to ensure that the correct size tape is used and properly applied, and that the binding wire is not applied so strongly as to pull the line wire out of its normal direction.

Terminating: Terminating of wires introduces the necessity for the wire to be held firmly and yet not be over-subject to fatigue. The wire is taken around the insulator, and soft copper binding wire is used, wrapped for ten turns on line wire near insulator, 35 turns over double wire, and 10 turns along the line wire. The making off along the line wire rather than down the drip point has reduced the likelihood of fatigue failure considerably. Ten turns of bared and properly cleaned outdoor distributing wire are made off on the drip point, and soldered. From the installation and maintenance viewpoint this method is not ideal, being comparatively slow to make, requiring the use of a soldering tool, and the wire is subject to fatigue.

Jointing: The jointing of line wires is necessary in installation for joining coils of wire together, and in maintenance for repairing broken wires, and cutting in transpositions. The joint must perform two major functions:—

(a) Provide sufficient strength for line wire to be tensioned;
(b) be of a conductivity equivalent to the line wire conductivity.

In this regard, the press-type sleeve with the press-type jointing tool is the nearest approach to the ideal, as it—

(i) provides a joint at least 95% as strong as the wire;
(ii) the method of making almost eliminates the possibility of an open circuit joint, and the conductance approaches that of the conductor;
(iii) the mass is the minimum consistent with strength, and so represents the ultimate in regard to fatigue failures;
(iv) simple and quick to make;
(v) corrosion aspect is limited, as sleeve is tightly pressed against the wires;
(vi) the wires butt together, so broken wires can be repaired without cutting in another length of wire, introducing additional joints.

The press-type sleeve consists of a cylindrical, copper tube, with an inside spraying of a harder metal to provide a gripping surface. The wires are pushed back into the tube, and crimped with pliers to hold the sleeve in position. A press-type tool is used with the approproate groove to crimp the sleeve firmly to the wire by two compressions at right angles on either side of a central depression, which ensures that the two ends of the wires are correctly placed. (For 40 lb. per mile cadmium copper, three crimps are made at 60° each.)

In view of the advantages of press-type joints, this method will be extended to wires up to 300 lb. per mile H.D.C. Wires of heavier gauge than this will use a twist-type sleeve consisting of a thin, copper tube, and twist-type clamps, whereby the sleeve is twisted for 3½ turns, to provide a strong and conductive joint, though not equal to the press-type joint.

Installation practice to ensure satisfactory joints for press-type sleeves lies mainly in the correct adjustment of the press-type tool, and ensuring that the ends of the wires are clean. For twist-type sleeves, the use of clean wire, and keeping the sleeve straight when twisting, are the main factors in avoiding faults.

The above indicates the main factors associated with lines practice in Australia to ensure reliability in line construction. Careful attention to the factors above-mentioned will overcome all but the fatigue problem, and this, in turn, is minimised by correct procedure.

EXAMINATION No. 2721—ENGINEER—TRANSMISSION

SECTION 1

J. T. McLeod

Q. 1.—What advantages are possessed by the "Decibel" over the "mile of standard cable," the "800-cycle mile," or the "Napier" or "Neper," as a standard unit for the measurement of telephone transmission?

Given that 2.303 is the relation between "Naperian" and "Common" logarithms, convert N Nepers to Decibels.

A.—The answer requires definitions of the units listed. They are as under:—

Mile of Standard Cable: The insertion loss of one mile of cable pair of constants 88 ohms per loop mile and mutual capacity 0.054 μf per mile. Its use consists of comparing the insertion loss of any piece of transmission equipment with that of a length of cable and expressing the loss in miles of standard cable. The unit was widely used when a talking test was the common method of measurement and when the distortion produced by the majority of circuits approximated that of the standard cable.

800-Cycle Mile: The definition is as for that above, except that a single measuring frequency is specified.

Napier or Neper: A circuit has an attenuation of one neper when the natural or Naperian logarithm of the ratio of input current to output current is equal to 1, i.e., when the ratio is equal to "e." It follows that a circuit will have an attenuation of N nepers when the current ratio is equal to e^N.

Decibel: A circuit has an attenuation of one decibel when ten times the common logarithm of the ratio of input power to output power is equal to 1, i.e., when the ratio is equal to $10^{0\cdot1}$. It follows that a circuit will have an attenuation of N db. when the power ratio is $10^{0\cdot1N}$.

The relative advantages of the decibel compared with the other units are—

(a) the decibel is absolute unit of attenuation, i.e., it is based on the ratio of two powers. This is better than either the mile of standard cable, which is a comparison unit the value of which varies with frequency, or the 800-cycle mile, which is also a comparison unit and requires a definite measuring frequency;

(b) it is a more convenient unit than the neper, as it is based on common logarithms to the base ten. This makes for easier computation of the numerical ratios;

(c) the neper is too large a unit for convenient use in common measurements.

Convert N nepers to db., given that—

$\log_e X = 2.303 \log_{10} X$

if $N =$ loss in nepers then power ratio

$= e^{2N} = X$

then $N = \frac{1}{2} \log_e (e^{2N})$

$N = \frac{1}{2} \log_e X$

loss in db $= 10 \log_{10} X = Y$

$N = (2.303/2) \log_{10} X$

$= (2.303/20)\ Y$

$Y = (20/2.303)\ N$

$= 8.686\ N$

loss in decibels $=$ 8.686 loss in nepers

Q. 2.—It is required to determine the location of an irregularity in an open wire line upon which it is intended to superimpose a 3-channel carrier telephone system.

Detail the apparatus you would use, give a block schematic of the connections and describe the procedure you would follow to locate the irregularity.

From the results obtained indicate the method and develop any formula you would adopt to fix the position of the irregularities.

A.—It is assumed that the irregularity is one which would not show up on D.C. tests but is due to a change in circuit impedance at some point, caused by faulty equipment. The method used to locate this irregularity is as follows:—

The far end of the circuit is terminated in it's characteristic impedance, and the input impedance at the near end is measured over the frequency range concerned. In this case, from 5 kc/s to 30/kc/s.

The magnitude of the impedance is plotted on a graph against the measuring frequency. If an irregularity is present, this impedance curve will show maxima and minima at regular frequency intervals over the range.

The average frequency interval between two successive impedance maxima is determined, and it can be shown that the distance (d) to the irregularity from the measuring point in miles is—

$$d = V/2S$$

d = distance to irregularity (miles).

V = velocity of propagation on the circuit (miles/sec).

S = frequency interval between successive impedance maxima (cycles/sec).

The method of derivation of the above formula is as below:—

It can be shown that the difference in electrical distances to the irregularity between those at the frequencies at which successive input impedance maxima occur, is equal to a half wave-length at the higher frequency.

Let the frequencies at which two successive input impedance maxima occur be—

f_1 and f_2

then the electrical length at $f_1 = \lambda_1 N$

where $\lambda_1 =$ a wavelength at f_1

$N =$ any number not necessarily an integer

then the length at $f_2 = N\lambda_2 + \lambda_2/2$

where $\lambda_2 =$ a wavelength at f_2

then $N\lambda_1 = N\lambda_2 + \lambda_2/2$

Let $V =$ the velocity of propagation on the line

then $V = f\lambda$ or $\lambda = V/f$

$\therefore \lambda_1 = V/f_1$ and $\lambda_2 = V/f_2$

$\therefore NV/f_1 = NV/f_2 + V/2f_2 = V(2N + 1)/2f_2$

$2NV/f_2 = V(2N + 1)\ f_1$

$f_2 = [(2N + 1)/2N]\ f_1$

$f_2 - f_1 = [(2N + 1)/2N]\ f_1 - f_1$

$= f_1/2N$

let $f_2 - f_1 = S$

then $S = f_1/2N$ or $f_1 = 2N.S$

but $d = NV/f_1 = NV/2NS$

$\therefore d = V/2S$

The above proof assumes that the velocity of propagation is constant between f_1 and f_2.

In the case of an open wire line the velocity of propagation is approximately 180,000 miles/sec.

The apparatus used would include—

(a) variable frequency oscillator to cover the range required, 5 to 30 kc/s;

(b) termination equal to the line characteristic impedance. The purpose of this is to terminate the far end of the line under test, and thereby prevent reflections which would influence the input impedance and tend to mask the variations produced by the irregularity;

(c) impedance measuring set. As the magnitude only of the impedance is of importance, a voltmeter which measures the voltage across the circuit input terminals, used in conjunction with a high impedance source, forming a constant current generator. This is approximated by connecting high value resistors in series with the output of the oscillator. Impedance peaks are noted, as peaks in voltage across the circuit input occur. The absolute value of the impedance may be determined by substitution methods. A diagram of connections is shown in Fig. 1.

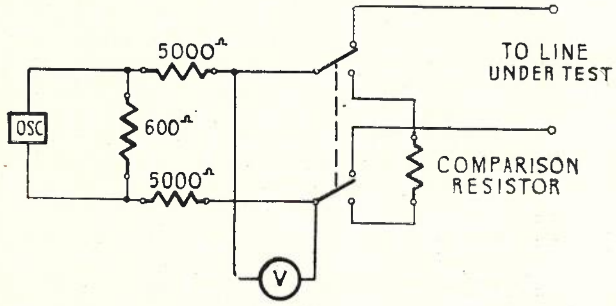


Fig. 1.

Q. 3.—Describe in detail the operation of a 3 channel carrier telephone terminal, type CS5 or CU5, equipped with pilot automatic gain control, illustrating the answer by means of a block schematic of one channel and indicating the connection points of the remaining channels. Illustrate your answer by a skeleton schematic circuit of all electronic apparatus.

What is the frequency of the transmitted pilot and why is that frequency chosen?

A.—The answer will refer to channel 2 of the A terminal of a CS5 system. Voice frequency currents from the switchboard pass to the 4-wire terminating set, which consists of a hybrid transformer, balance network, impedance matching transformer and level adjusting pads. The hybrid transformer divides the power, part passing to the matching transformer and thence to the modulator, the remainder being dissipated in the output of the demodulator amplifier. The speech currents from the hybrid pass through the modulation input transformer and low-pass filter, which suppresses undesired high-frequency components of speech and noise, to the copper oxide modulator, where they are modulated with a source of carrier frequency from the vacuum tube oscillator. The modulated high-frequency currents, including the upper and lower sidebands, pass through the channel transmitting gain pad to the channel modulator band filter. The pad is required to provide adjustment of the modulator output, and also to improve the circuit impedance. Carrier frequency power, at a frequency of 9.4 kc/s, is supplied to the modulator by a vacuum tube oscillator utilizing a type 328A tube. The frequency of the oscillator is adjustable over a small range by means of taps on the oscillator coil and a variable condenser.

The output of the modulator is connected to the modulator band filter, which substantially suppresses all frequencies present in the modulator output except those of the sideband desired; in this case, from 9.6 kc/s to 12.2 kc/s. The output of the band filter is connected in parallel with those of the other channels and connected via an impedance matching transformer to the input of the transmitting amplifier. The pilot oscillator output is also connected to the transmitting amplifier at this point. The amplifier is a two-stage amplifier employing negative feedback, and has a gain of 52 db. over the range of frequencies covered by the 3 channels. The output of the amplifier is connected via a high-pass filter and transmitting pad to the transmitting directional filter. The filter suppresses frequency components in the voice frequency band which may be generated in the transmitting amplifier. The pad is for the purpose of adjusting the transmitted level of all channels simultaneously to the desired figure. The output of the transmitting directional filter is connected in parallel with the input of the receiving directional filter. These two filters serve to separate the two frequency bands used for the two directions of transmission, and to prevent interaction between them. The sideband then passes to the high-frequency bearer circuit and to the distant terminals.

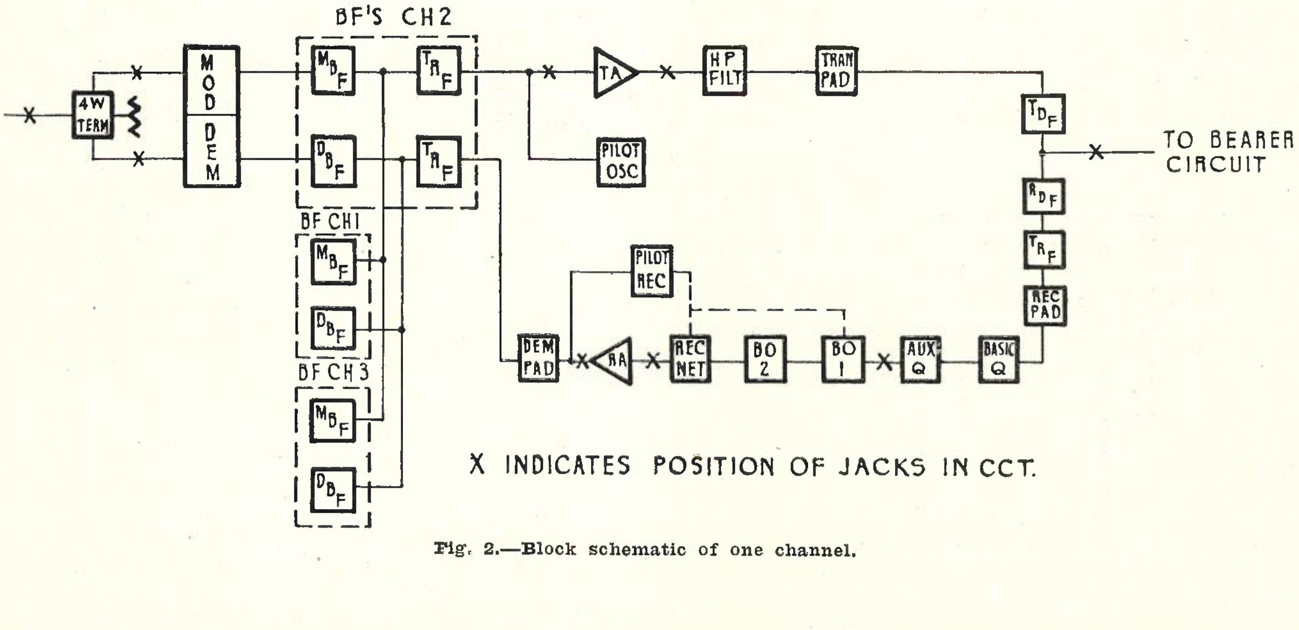


Fig. 2.—Block schematic of one channel.

In the receiving direction, the incoming sidebands are directed by the receive directional filter, via a transformer and receiving pad, to the equaliser and building-out networks. The equaliser is designed to compensate for the distortion introduced by approximately 250 miles of average line under wet conditions. The building-out networks are provided to build out the line to produce characteristics complementary to that of the basic equaliser. The equaliser also compensates for the distortion introduced by the directional filters at frequencies close to their cut-off frequency. If the bearer circuit of the system is equipped with 30 kc/s line filters, an auxiliary equaliser is provided at the A terminal to correct the distortion introduced into the highest frequency channel by these filters.

From the building-out networks the sideband passes to the regulating network, which, under the control of the incoming pilot level, automatically compensates for changes of line attenuation, and keeps the output channel level constant. The output of the regulating network is connected to the receiving amplifier, which is similar to the transmitting amplifier, except that the gain is 2 db less. From the output of the receiving amplifier the sideband passes to the demodulator band filters which, at this point, are all connected in parallel. The input of the pilot receiver is also connected at this point. The sideband is selected by its appropriate filter and is passed to the demodulator, where it is modulated with a carrier frequency of the same value as the distant terminal transmitting carrier. The resulting modulation products will contain frequencies corresponding to the original voice frequencies. From the output of the demodulator the voice signals pass to the demodulator amplifier, via a low-pass filter, which suppresses all frequencies above 3 kc/s. The amplifier is a single-stage, negative feedback type, having variable gain for channel level adjusting purposes.

From the output of the amplifier the signals pass to the 4-wire terminating unit and thence to the switchboard. The hybrid transformer prevents any power from the output of the demodulator from being passed to the modulator, and hence causing the channel to sing.

The frequency of the transmitted pilot from the A terminal of this system is 9.45 kc/s, and is chosen for the following reasons:—

(i) it is approximately in the centre of the band of frequencies utilized for transmission from this terminal, and so gives the best compromise value for single frequency regulation.

(ii) It is only 50 c/s from the modulator frequency of channel 2, and hence the modulator and demodulator band filters effectively prevent interference from the pilot in this channel and the adjacent channel 3. In the later systems the demodulator output low-pass filter of channel 3 has a somewhat higher attenuation above 3 kc/s than early systems, to suppress pilot interference in this channel, in which the pilot would demodulate at a frequency of about 3.45 kc/s.

Q. 4.—In a negative feedback amplifier the feedback voltage may be derived from the
(a) load voltage;
(b) load current;
(c) load voltage and load current.
Discuss the relative advantages of the three methods.

A.—Negative feedback from any of the above sources will produce the usual advantages of negative feedback, viz.—

(i) improved stability of gain with power supply variations or tube changes;

(ii) reduction of non-linear distortion;

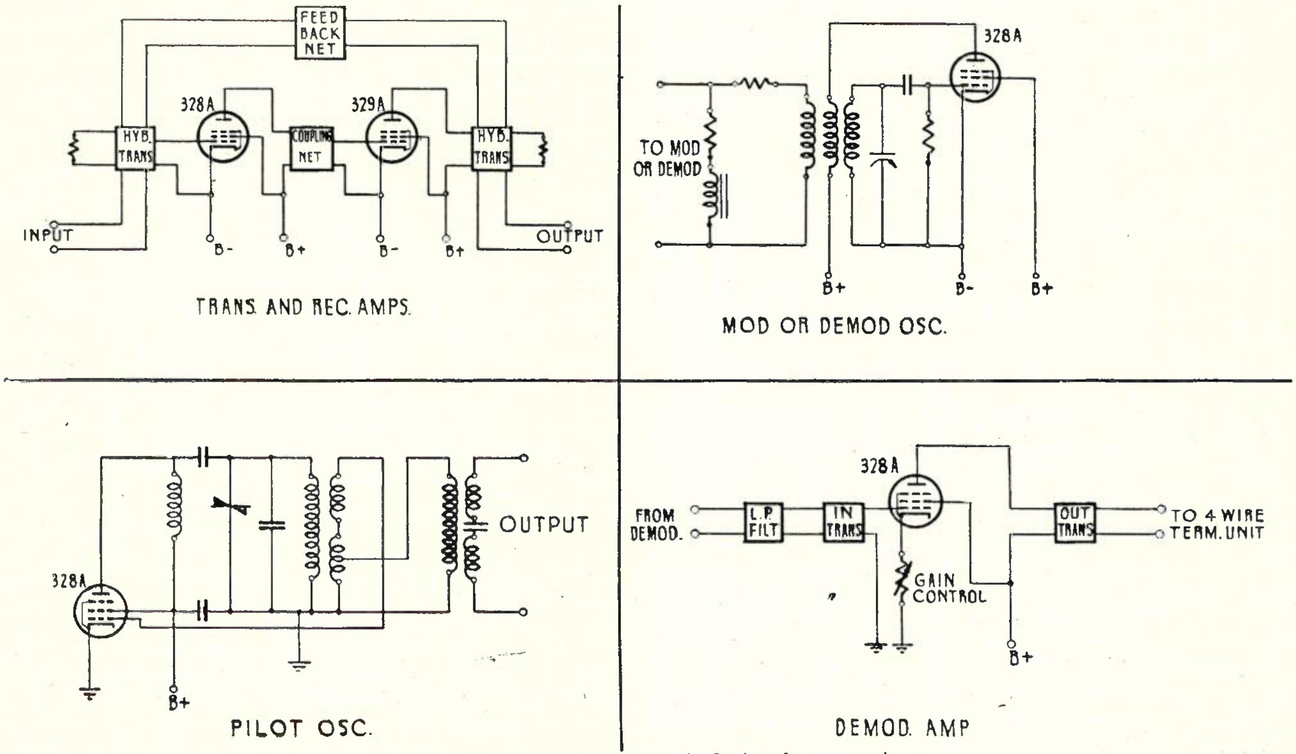


Fig. 3.—Skeleton schematic of electronic apparatus.

(iii) reduction of noise output due to power supply noise;
(iv) control of frequency response by varying feedback network characteristic.

However, the different methods will produce some individual effects when the amplifier has a transformer to couple the output to the load.

(a) Voltage feedback.

This form of feedback tends to make the output voltage across the transformer primary follow accurately the wave-shape of the input signal, and so improves the low frequency response and reduces amplitude distortion. It does not, however, improve the high frequency response.

As the output voltage tends to be constant, the effective output impedance of the amplifier is lower than the value without feedback. For amplifiers used to drive a dynamic load, such as a loudspeaker, this effect is beneficial, as it increases the damping factor of the amplifier on the load. Thus pentode or tetrode type tubes may be employed with negative voltage feedback to replace triodes, with improvement in amplifier sensitivity, reduction of power supply hum and greater efficiency for equal power output.

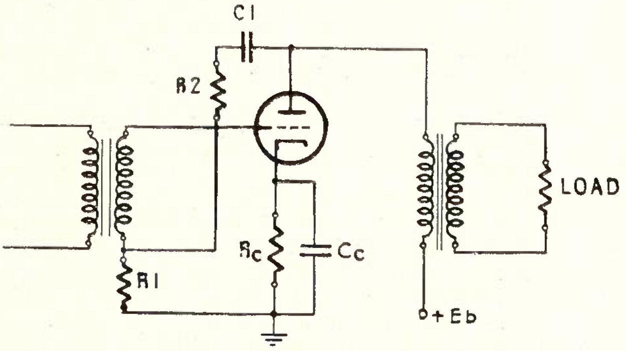


Fig. 4.

(b) Current feedback.

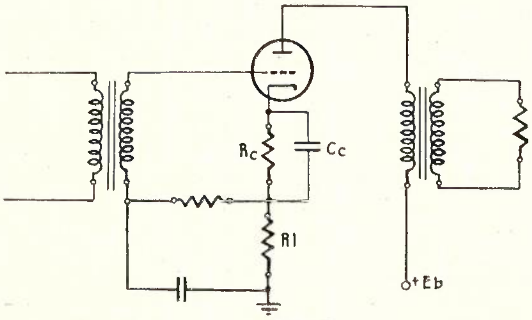


Fig. 5.

This type tends to make the current through the transformer primary reproduce the wave-shape of the applied signal, and be independent of the applied frequency. The output then tends to be constant at high frequencies, but falls off more at low frequencies than in the absence of feedback. At low frequencies the amplitude distortion will be increased, due to saturation of the transformer core. The output impedance of the amplifier with current negative feedback is increased.

(c) Combined current and voltage feedback.

By a combination of voltage and current feedback the frequency response and amplitude distortion at both high and low frequencies can be improved and, depending on the proportion of each type employed, the output impedance of the amplifiers may be modified as desired.

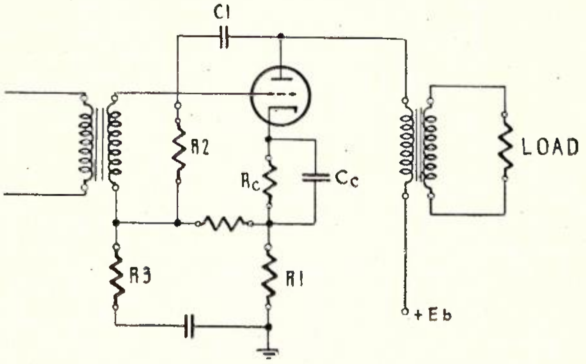


Fig. 6.

Q. 5.—Describe the functions of the essential components in one channel of an 18-channel voice frequency telegraph system, giving a full description (with diagrams) of the process of modulating the voice frequency with a telegraph signal.

State what you understand by the terms, "bias distortion," "characteristic distortion" and "fortuitous distortion."

Indicate the causes of each type which can occur in the voice frequency telegraph system.

A.—The essential components of one channel of a VFT and their functions are as under:—

Transmitting

i. A source of voice frequency carrier upon which the telegraph signal may be modulated. This can be supplied by either an oscillator or a tone generator.

ii. A modulator in which the telegraph signals are impressed on the carrier.

iii. A send-filter which limits the extent of the sidebands transmitted by each channel and helps to prevent interchannel interference by suppressing undesired components of the carrier frequency, and also by limiting the transmitting band width to a value suited to the desired signalling speed.

The sending filter also incorporates an input resistance network for adjusting the power transmitted by each channel and to maintain the output impedance of the modulator, as seen by the filter relatively constant. The outputs of all send filters are connected in parallel, with a compensating network also connected, to improve the characteristics of the highest frequency channel filter.

iv. Transmitting pad and transformer for adjusting the power of all channels and connecting the system to the bearer circuit, respectively.

v. Send leg resistance by which the current in the sending telegraph level may be adjusted to the standard value.

Receiving

i. Receive amplifier by which the level of all channels is adjusted.

ii. Receive band-filter which selects the correct channel signals and feeds them to a detector amplifier.

iii. Detector amplifier where the received signals are first amplified and then detected, to restore the telegraph signals.

iv. Receive relay which responds to the detected telegraph signals and regenerates them for transmission on a double-current basis to the telegraph office.

The process of modulation is as under:—

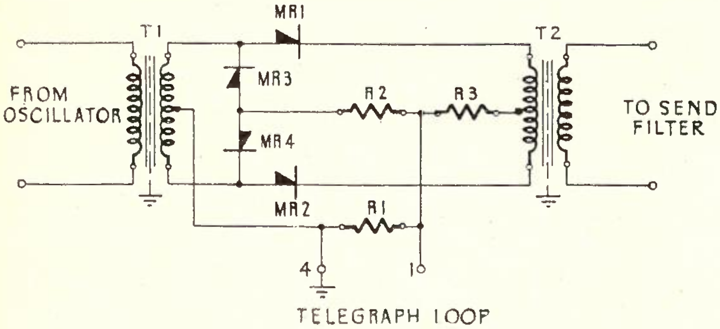


Fig. 7.

Referring to figure 7—

When a mark signal is applied to the telegraph leg, a potential appears across terminals 1 and 4, such that terminal 4 is positive to 1. This potential is also applied to the metal rectifiers MR1, 2 3, and 4. This potential is applied to MR1 and 2 in such a direction as to cause a large current to flow and the impedance to fall, and to MR3 and 4 in such a direction as to cause their impedance to increase greatly. The carrier supply which is applied to T1 will, therefore, have a low impedance connection to T2, and carrier power will pass to the send filter. Since MR3 and 4 are high impedance, they will have no appreciable shunting effect on the through circuit.

When a space signal is applied to the telegraph loop, the potential between terminals 1 and 4 is reversed and rectifiers MR1 and 2 become high impedance, while the impedance of MR3 and 4 becomes very low. The carrier supply is shunted by MR3 and 4, while MR1 and 2 present a high impedance in the through path. No carrier will pass to T2, and hence none will be transmitted. The resistance network of R1, R2, R3 is for the purpose of limiting the current flowing in the rectifiers to safe value, in this case about 17 mA, with a send leg current of 25 mA. The DC is connected differentially to the windings of T1 and T2; there is no DC magnetisation of the cores.

(a) Bias distortion is the lengthening of marking signals and the corresponding shortening of spacing signals (or vice versa) during their transmission through a circuit. Lengthening of the mark signals is known as marking bias, and lengthening of space signals as spacing bias. Bias distortion can occur in a VFT channel, due to assymetrical adjustment of the receiving relay, faulty adjustment of relay biasing current, or unequal mark and space battery potentials.

(b) Characteristic distortion is that arising from the inherent electrical characteristics of the transmission circuit, including the normal sending and receiving terminations, and is the distortion occurring consistently with any given combination of signal elements. In a VF telegraph system characteristic distortion can occur when the speed of signalling becomes such that the build-up time of the channel band filters exceeds the length of the shortest signal element. This occurs in the 18-channel VFT at a speed of about 70 bauds. A further cause of characteristic distortion is the automatic gain control arrangement in the amplifier detector. If a train of signals having a preponderance of spacing elements is sent over the channel, the gain tends to rise during the space intervals, and is not fully restored to the correct value during mark intervals. Thus, at the end of a long space interval, the gain is higher than normal, and the space to mark changeover tends to take place early. The effect is not noticeable during normal signals, due to the relatively long time constant of the A.G.C., but is quite marked when, for example, a continuous train of signals having six elements spacing and one element marking is transmitted.

(c) Fortuitous distortion is that which arises from random influences upon the circuit apparatus. In a V.F.T. it can arise from interference from other channels in the same system not completely suppressed by the channel band filters, and from effects of second order intermodulation products resulting from the transmission of VF signals through non-linear elements in the line circuit. Crosstalk from other telephone circuits and random noise on the bearer circuit can also cause this form of distortion. It may be caused by mechanical faults in the receiving relay, such as magnetic particles in the air-gap between pole pieces and armature.

EXAMINATIONS No. 2822, 2823 AND 2824—SENIOR TECHNICIAN, RADIO AND BROADCASTING, TELEPHONE AND RESEARCH ELECTRICAL THEORY AND PRACTICE

N. S. Smith

Q. 1.—(a) State briefly the meaning of the following terms:—

Magnetomotive Force.
Magnetic Flux.
Reluctance.

(b) What relationship exists in a magnetic circuit between the three units listed in (a)?

A.—(a) Magnetomotive Force is the magnetic equivalent of electrical e.m.f. It is the potential power of a magnetic circuit to perform work. Unit, the "Gilbert."

Magnetic flux is the name given to the field set up by a magnetic force. It is analogous to current in electrical circuits. Unit is the Maxwell.

Reluctance is the opposition offered to the setting up of a magnetic field. It is analogous to resistance in electrical circuits. A unit is not standardised.

(b) From the above definitions it may be deduced that the following relations hold:—

$$M = \phi R.$$

where M = magnetomotive force
ϕ = magnetic flux
R = reluctance.

Q. 2.—(a) What do you understand by magnetic hysteresis? Sketch a hysteresis loop for a typical sample of iron and describe the magnetic properties of the sample shown in the curve.

(b) Calculate the intensity of a magnetic field when a ring of soft iron which is placed in it has an induced flux density of 15,000 gauss (Permeability = 300).

A.—(a) Hysteresis may be defined as the tendency of a magnetic substance to persist in any magnetic state it may have acquired.

If a piece of ferrous material is magnetised to a certain known degree and the magnetising force gradually decreased, it will be found that when the magnetising force has been reduced to zero, the metal still possesses some magnetism. In order to reduce the flux to zero a reversed field must be applied to the metal. This characteristic is termed "hysteresis."

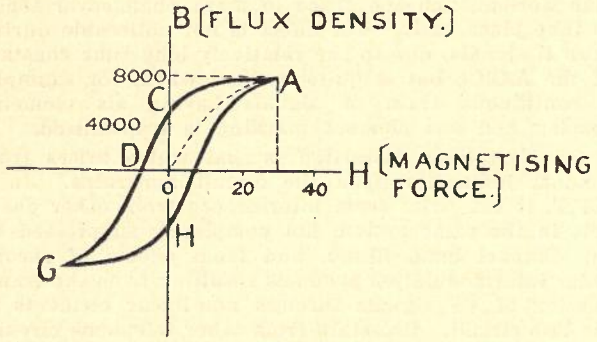


Fig. 1.

Fig. 1 illustrates an hysteresis loop. It is obtained by commencing with zero magnetising force and zero flux at point O. The magnetising force, H, is gradually increased and plotted against resultant flux, B, until a convenient point, say, A, is reached, giving the dotted curve, OA.

If the magnetising force is now gradually decreased, the flux will follow the path AC, and thus will not return to O. In order to reduce the flux to zero a reversed magnetising force OD must be applied. Continuation and completion of the magnetising cycle will result in the enclosed loop ACDGHA. This is called an "hysteresis loop," and the characteristic which produces it, "magnetic hysteresis."

The metal giving the loop of Fig. 1 would possess medium magnetic qualities:—

(i) The retentivity (OC) is somewhat high for electromagnet applications.

(ii) The coercive force (OD) is not great enough for the requirements of a good, permanent magnet, but could be used for second-grade magnets.

(iii) The area of the loop is a measure of the amount of energy which is transformed into heat during a magnetic cycle. Thus, this metal would not be altogether suitable for A.C. applications such as transformers, etc.

(b) The permeability of a metal is a measure of its relative effectiveness in building up flux density from a given field.

Thus, iron with a permeability of 300 will have a flux density of 300 times that of the normal field.
Therefore, field intensity = 15,000/300 = 50 gauss.

Q. 3.—(a) A P.B.X. switchboard requires a maximum current of 800 milliamperes. Under these conditions, find the voltage across its busbars, assuming that the power is supplied from a 50-volt battery over power leads consisting of 4 pairs of a cable, each wire having a resistance of 240 ohms (the resistance of the earth return may be neglected).

(b) Calculate the resistance of the P.B.X. load under the conditions given in (a).

(c) What amount of power is dissipated in the power leads at maximum lead?

(d) If full load is maintained at the P.B.X. for 50 hours, how long would it take to replace the energy in the battery at a charging rate of 5 amperes, assuming the efficiency is 100 per cent.?

A.—(a) Total resistance of lead = 240/8 = 30 ohms.
Voltage drop over cable = IR = 0.8 × 30 = 24 volts.
∴ voltage available at P.B.X. = 50 — 24 = 26 volts.

(b) R = E/I = 26/0.8 = 32.5 ohms = resistance at P.B.X.

(c) Power lost over cable = EI = 24 × 0.8 = 19.2 watts.

(d) Total drain for 50 hours = 50 × 0.8 = 40 amp. hrs.
∴ time for charging at 5 amps. = 40/5 = 8 hours.

ANS.: (a) 26 V. (b) 32.5 ohms. (c) 19.2 W. (d) 8 hrs.

Q. 4.—(a) An alternating current of 4 amperes flows in a circuit consisting of a resistance of 50 ohms in series with an inductive reactance of 100 ohms and a capacitive reactance of 75 ohms. Calculate the P.D. across (i) the resistance, (ii) the inductive reactance, (iii) the capacitive reactance.

(b) Draw a vector diagram for the circuit and from the diagram determine the applied voltage. Also mark the angle showing the phase difference between the E.M.F. and current.

(c) Calculate the power expended in the circuit.

A.—(a) Since it is a series circuit the current will flow through each element, and the voltage drop across each will be equal to IR.
Thus, voltage P.D. across R = 4 × 50 = 200 volts
,, L = 4 × 100 = 400 ,,
,, C = 4 × 75 = 300 ,,

(b)

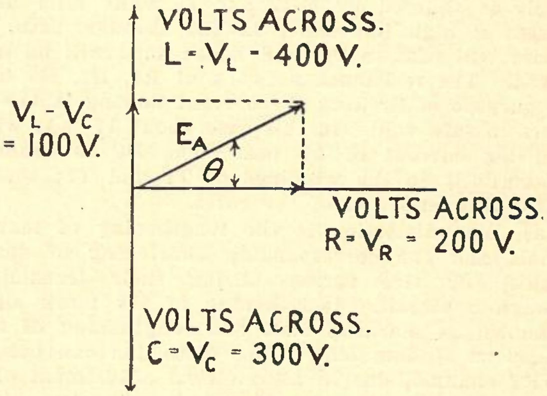


Fig. 2.

Applied Volts E_A = diagonal = $\sqrt{200^2 + 100^2}$ = 224 volts
θ = phase difference between E.M.F. and current.
(c) Power expended in circuit = power dissipated by real resistance of circuit.
$W = I^2R = 4 \times 4 \times 50 = 800$ watts.

ERRATA

Vol. 7, No. 1, Page 56.
Cause of N.U. tone supervisory alarm should read:
"A short circuit or earthed negative fault in the exchange equipment associated with any of the 100 numbers connected to each N.U. tone relay."

(A similar correction applies to Vol. 1, No. 5, Page 199.)

The Ruskin Press
123 Latrobe Street
Melbourne