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SOME ASPECTS OF TELEPRINTER SWITCHING

R. D. KERR

Introduction. The rapid extension of teleprinter services in Australia has brought about an interest in those developments in teleprinter switching which have taken place in other countries. As the term implies, teleprinter switching envisages the interconnection of teleprinter lines at an exchange, or exchanges, as required for the interchange of messages. In other countries there has, in the past, been some development of systems whereby suitable voice-frequency carrier telegraph units are interposed between teleprinter units and ordinary telephone lines, so permitting interconnection through telephone networks. In general, it appears that such systems have fallen short of expectations, and that substantially all modern development is concentrated on purely telegraph switching systems which employ local cable circuits on a D.C. signalling basis, and which employ multi-channel voice-frequency carrier telegraph channels as trunk circuits. It is intended in this article to examine some of the technical problems in the introduction of such service, and some of the fields of application for it in Australia.

Inter-Operation. In any switching scheme it is essential that all points in the scheme be so equipped that all produce and receive the same sort of signals, with the additional proviso in the teleprinter case that all produce and receive signals at the same speed. In Australia the teleprinters in use comprise the Creed & Co., M7B, M8B (page printers), M85 (printing reperforator) and 6S (tape transmitter) units of United Kingdom manufacture and the M15, M19 (page printers) and M14 (printing reperforator and tape transmitter) units produced by the Teletype Corporation of U.S.A. When the Teletype machines were introduced in 1942 it was under pressure of emergency, so that they were accepted with the common American signalling speed of 45.5 bauds (unit impulse duration 22 milliseconds), and with a signalling code to U.S. Government specifications. The Creed machines had a signalling speed of 50 bauds and a different code from the American. As, in these circumstances, the two types could not inter-operate, it was necessary to permit two separate teleprinter networks to grow up in Australia. These could not be kept separated indefinitely and any general teleprinter switching scheme could not be practicable with the differing types of units.

The first step taken was then the standardisation of a signalling speed of 50 bauds. This involved speeding-up all Teletype units in service from a maximum cyclic transmitting rate of 368 characters per minute with a 45.5 baud signalling speed, to a maximum of 404 characters per minute with a signalling speed of 50 bauds conforming with Creed equipment and the C.C.I.T. recommended signalling speed for teleprinters. As at the time of changeover there were approximately 1000 Teletype units in service throughout Australia, it was necessary to make the speed change in accordance with a precise schedule to ensure that all points on a particular service were converted simultaneously.

There is a standard signalling code for teleprinters laid down in the International Telegraph Regulations, this standard being known as International Alphabet No. 2. The Creed, former Teletype, and present Teletype codes are shown in relation to International Alphabet No. 2 in Table 1. In determining a standard to be adopted in Australia, the International standard was to be preferred. The former Teletype code is only one of a number extant in the U.S.A. and "standardised" by various groups in that country. The upper case characters F, G and H have been left optional in International Alphabet No. 2, principally to accommodate the accented vowel characters variously used in Continental countries. In making the alterations to Teletype equipment, the changes of upper case characters D, F, G, V and Z required only replacement of the former type pallet and keytop in each case. In respect of upper case D, there is no "Answer Back" function available for Teletype equipment, but the signal was reserved to control such a function on appropriately equipped machines. The interchange of "apostrophe" and "Bell Signal" on upper case S and J required replacement of the Bell function

Table 1

International Signal No.	Lower Case character all codes	Upper case character			
		Former Teletype	Revised Teletype	Creed	International
1	A	—	—	—	—
2	B	?	?	?	?
3	C	:	:	:	:
4	D	$ or £	No		Symbol †
5	E	3	3	3	3
6	F	!	%	%	Optional
7	G	&	@	@	Optional
8	H	"Motor Stop"	£ *	£	Optional
9	I	8	8	8	8
10	J	'	"Bell"	"Signal"	
11	K	(	(	(	(
12	L	)	)	)	)
13	M	.	.	.	.
14	N	,	,	'	,
15	O	9	9	9	9
16	P	0	0	0	0
17	Q	1	1	1	1
18	R	4	4	4	4
19	S	"Bell Signal"	'	'	'
20	T	5	5	5	5
21	U	7	7	7	7
22	V	;	=	=	=
23	W	2	2	2	2
24	X	/	/	/	/
25	Y	6	6	6	6
26	Z	"	+	+	+
27	Carriage Return				
28	Line Feed				
29	Letters				
30	Figures				
31	Space				
32	Blank				

† — Used to control "Answer Back" unit where fitted.

* — On M15 and 19 Teletype units the Motor Stop function is now on the triple combination FIGURES-BLANK-H. On FIGURES-H the £ sign is printed.

levers on M15 and 19 Teletype equipment. The upper case H changes represented the biggest problem, in that the retention of the automatic "Motor Stop" function, originally operated on receipt of FIGURES-H, is most desirable from a machine maintenance point of view, while the most useful £ sign is commonly on this character in British countries. Happily there is available from Teletype Corporation a relatively simple mechanism which may be fitted to their M15 and 19 machines, and which permits a character (in this case £ sign) to be printed on FIGURES-H, but which suppresses printing of the £ sign and effects control of the "Motor Stop" function on receipt of the three characters FIGURES, BLANK and H. The work of changing the signalling code of Teletype equipment involved careful programming, as did the speed change, but this work was carried out without event during 1951.

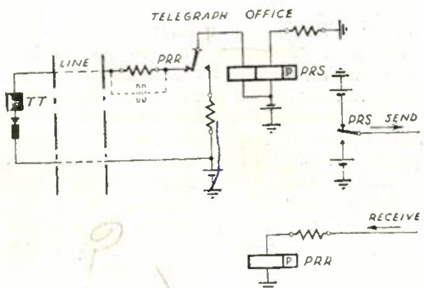

Fig. 1A.—Teletype equipment with single current transmission and reception, current through local line and machine, 50-60mA.

At the conclusion of these somewhat involved preliminaries, it became possible to envisage a nation-wide teleprinter switching network in which no matter what types of terminal machine were connected, all normal characters or signals, when transmitted, would be reproduced at the receiver. A not unimportant sidelight was the fact that, with the coming disappearance of the Murray Multiplex, there would in future be only two basic keyboards in Departmental Telegraph Offices, namely the standard teleprinter keyboard and the standard telegraph typewriter keyboard, with consequent benefits to operating personnel.

Circuit Types. Notwithstanding the previous considerations of standard signalling speed and code, if intercommunication in a switching scheme is to be effected, the various line circuits must be presented in a form capable of interconnection. These circuits which have in the past been used on the local lines between teleprinter units and the telegraph trunk channels are shown in Fig. 1.

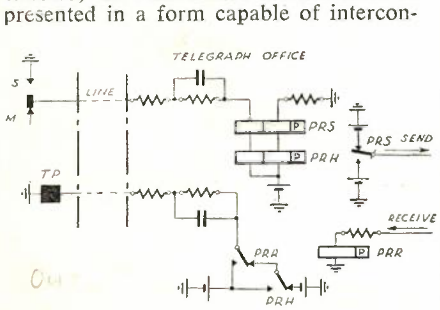

Fig. 1B.—Creed equipment with single current transmission and double current reception.

The arrangement of Fig. 1A is one method of making this connection for the single current closed circuit Teletype units. It is one of several arrangements currently extant but basically all forms resolve to this. Considering the nature of signals in a very short line with Fig. 1A, line resistance and capacity have little effect on signals which are most

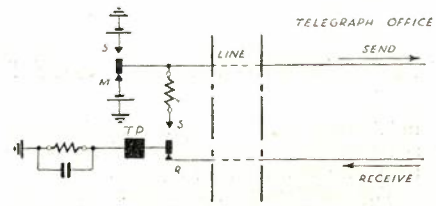

Fig. 1C.—Creed equipment with double current transmission and reception, and with "home record" taken through "send-receive" switch.

subject to printer magnet and line relay inductance, and the overall series resistance of the circuit. The wave form of current in the local line, with the Teletype unit contacts opening and closing, is as shown on Fig. 2A.

The delay in build-up of current on space to mark transitions causes a delay before the printer magnet and the line relay operate. Consequently, these are operated for a shorter period than the machine signalling contacts are actually closed. The printer mechanism is so designed as to accept this as normal, but the output signal of the relay is biassed to space. A little consideration of the

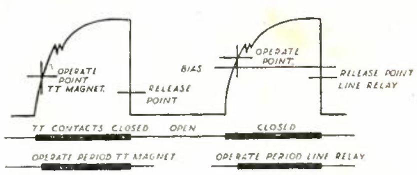

Fig. 2A.—Current wave form resistive local teletype line.

asymmetrical wave fronts on mark-to-space and space-to-mark transitions will indicate that there is no actual practical electrical bias of the line relay which will cause it to respond to the machine contact signals correctly. Alternatively, if part of the resistance in the circuit were shunted by a capacitor (dotted Fig. 1A), the wave fronts would be "squared" and it would be possible for the line relay to follow the machine contacts signals correctly. However, the "square" wavefront could cause the machine magnet to operate in advance of normal and the machine would exhibit an apparent marking bias. As line length is increased, due to the time constant determined substantially by line resistance and capacity, the form of the problem alters insofar as a "tail" is produced on mark-to-space transitions to which the machine magnet is much more subject than is the relay. This is illustrated in Fig. 3.

Thus, in essence, the difficulty is that what suits the machine magnets does not suit the line relay and what suits the line relay does not suit the machine magnets. However, with practical circuit conditions, it is possible over a range of 0 to 10 to 15 miles of loop (depending on cable make-up) to operate the Teletype units with distortion not exceeding 10%, and this is more acceptable than other more elaborate equipment arrangements necessary to overcome it.

When Creed equipment was first introduced in the mid-thirties, dry metal rectifiers were in their infancy, and so the arrangement of Fig 1B with signalling supplies centralised at the Telegraph

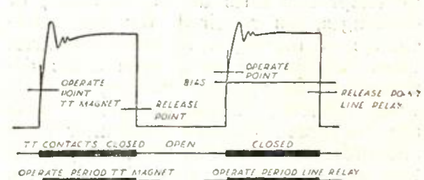

Fig. 2B.—Current wave form resistive local teletype line with shunted condenser.

Office was adopted, out-station plant being limited simply to the teleprinter. With the present-day elegance of the dry metal rectifier there has been a trend to the adoption of the arrangement of Fig. 1C, the signalling battery at the teleprinter being drawn from a rectifier while, on shorter lines, no repeating relays are required at the Telegraph Office. This latter arrangement of two path double current signalling, which is the usual method of local connection to telegraph trunk circuits (both voice-frequency carrier telegraph and physical trunk circuits), is the most satisfactory as the symmetrical electrical conditions for both marking and spacing signals and the unidirectional signalling on each path makes it the most advantageous transmission proposition.

These characteristics of the two path double current arrangement prompt its adoption as the basic signalling system

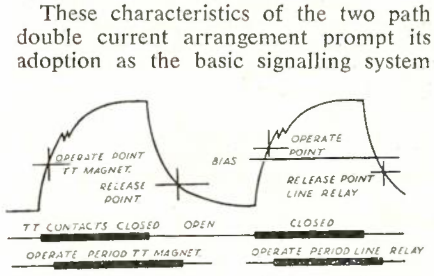

FIG 3

Fig. 3.—Current wave form reactive local teletype line.

within the switching equipment. However, with a view to simplifying the form of presentation of extension lines, of the possibilities of Fig. 1, that shown in Fig. 1A was explored further. Creed & Co. units have been so constructed that the receive selector magnet may be operated on a single current basis (as with Teletype equipment) by fitting a retractile biassing spring to the receive magnet armature. The problems outlined above with single current closed loop operation of Teletype equipment were, however, shown by tests to be somewhat aggravated with Creed equipment used in this manner. In addition, with pre-orientation Creed machines, which constitute more than half of the Creed equipment in use, it is necessary to have a telegraph transmission test set to determine the optimum adjustment of the selector armature retractile spring. This does not represent a problem in large centres having such equipment, but presents a severe restriction with isolated machines (see footnote).

In examining these possibilities for extension line operation it was decided firstly to abandon the old arrangement of Fig. 1B. The remaining possibilities then resolve to:—

(a) single current closed loop operation of Teletype units—simple, but with some transmission limitations;

(b) double current two-path operation of Teletype units—excellent transmission on line, but with equipment complication of a single current/double current converting relay set and rectifier beside each machine;

(c) single current closed loop operation of Creed units—simple, but with increasing transmission and maintenance limitations;

(d) double current two-path operation of Creed units—excellent transmission straightforward as far as the machine is concerned, only equipment complication the rectifier unit.

It was decided to accept two types of extension line, (a) and (d) above.

Low Voltage Operation. In contemplating the form which teleprinter switchboard equipment must take, and looking to a later stage involving automatic switching, it was evident that increasingly extensive use would be made of a great many of the highly developed standard components of the telephone switching field. In the past, however, the standard telegraph signalling voltages were ± 120 to 130V, which experience had shown imposed too severe stresses on the insulation of many of the telephone components. Consequently it was envisaged that lower operating voltages would be necessary in the teleprinter switching system and the first equipment has been designed to operate on the previous standard lower voltages, ± 60 to 65V (that is half of the normal voltage). It was also evident that in looking forward to automatic switching, and, in fact, achieving a useful standardisation of power plant used in the Australian Post Office, there would be a strong case for adoption of the existing automatic telephone voltage, ± 50V. The existing switching plant is readily convertible to these voltages of operation and future manual plant will be directly convertible, while automatic plant will be based exclusively on ± 50V. operation.

A series of tests made with the arrangement of Fig 1A shows that by using ± 50 V. in series around the loop, satisfactory transmission may be achieved up to the limit of loop imposed by the requirement that line current should be 50 mA. It might be pointed out that in the past ±120 to 130V. working has not been an unmixed blessing with this type of circuit, as it has been possible to obtain the required line current over such a length of circuit as to make certain that those problems mentioned in conjunction with Fig. 3 will arise in an acute form.

A series of tests made with the two-path double current arrangement shows that the polarised receive magnets of Creed equipment may, with slight modification to the receive shunted condenser values, be operated over 20 miles of cable with a transmission performance on ± 50V. working only 2-3% inferior to that with ± 120V. working. Moreover, tests with double current operation of polarised receiving relays (as, for instance, sending into the "carrier send" relay of a voice frequency telegraph channel) show that even over 20 miles of cable and with signalling speeds of 100 bauds there is no practical impairment of transmission.

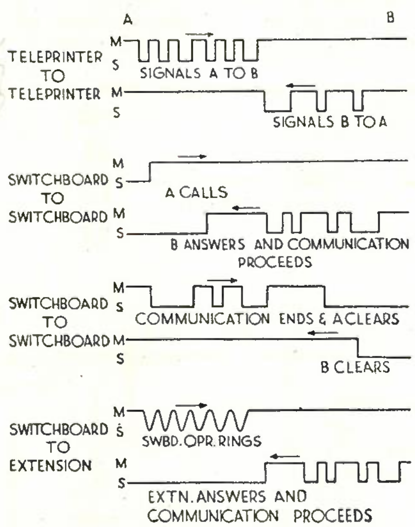

Fig. 4.—Teleprinter Switchboard, signalling conditions.

Supervisory Signals. The basic requirements of any switching system are:—

(a) positive calling signals.

(b) reliable through communication.

(c) positive supervisory signals, having particular regard to supervision through tandem switchboards.

The signalling conditions for the basic two-path unidirectional double current circuit when used for switching are shown diagrammatically in Fig. 4.

The normal teleprinter signalling conditions are "rest at mark" and signal to "space" with no spacing impulse exceeding 120 milliseconds' duration. The switchboard signalling conditions which have been chosen are "rest at space" and call down by inversion to the normal "rest at mark" condition, while the called station acknowledges the call by answering with a mark in lieu of the "rest at space" condition. Signalling proceeds with trains of short spacing impulses and clearing is indicated by reversion to the "rest at space" condition which may quite simply be recognised in either direction by the slow release telephone relays operated in leak from the passing signals. To meet the variety of conditions imposed by the variety of local loop conditions contingent on the use of both Teletype and Creed machines, the calling signal from switchboard to subscriber is the normal telephone sinusoidal ringing current operating a polarised bell.

To prevent the teleprinters from "running open" on the "rest at space" signal in the idle and clearing conditions the extension stations have line terminal units on which the operation of a key simultaneously sends a marking signal on the line and switches on the motor to call, while restoration of this key sends the clearing spacing signal and switches off the teleprinter motor. Those having some acquaintance with European practice, which is automatically to start the called station's teleprinter motor and to use the FIGURE D signal to trip off the "answer back" when establishing a connection, may find the ring-down system surprising. It must be pointed out, however, that there is no "Answer Back" mechanism on the Teletype equipment, nor is such a mechanism made by Teletype Corporation, that this equipment comprises rather more than half the equipment in service, and that the costs of devising and fitting an Answer Back mechanism locally may be expected to be considerably more per circuit than all other costs of the switching equipment.

Switchboard Circuits: The basic schematic circuit of a connection through a cord type lamp signalling manual switchboard with signalling paths and supervisory facilities as described above is shown in Fig. 5A, B and C. Fig. 5A shows a typical single current closed loop extension equipped with a Teletype machine. Fig. 5B shows a typical double current two-path extension equipped with a Creed machine. This

It is only correct to point out that while the original investigations were made in Australia, Messrs. Creed & Co. independently examined this problem. They now supply the "P" type electromagnet in lieu of the original "E" type. The new electro-magnet gives much improved single current performance but does not alone solve the problem of adjustment of the pre-orientation machines.

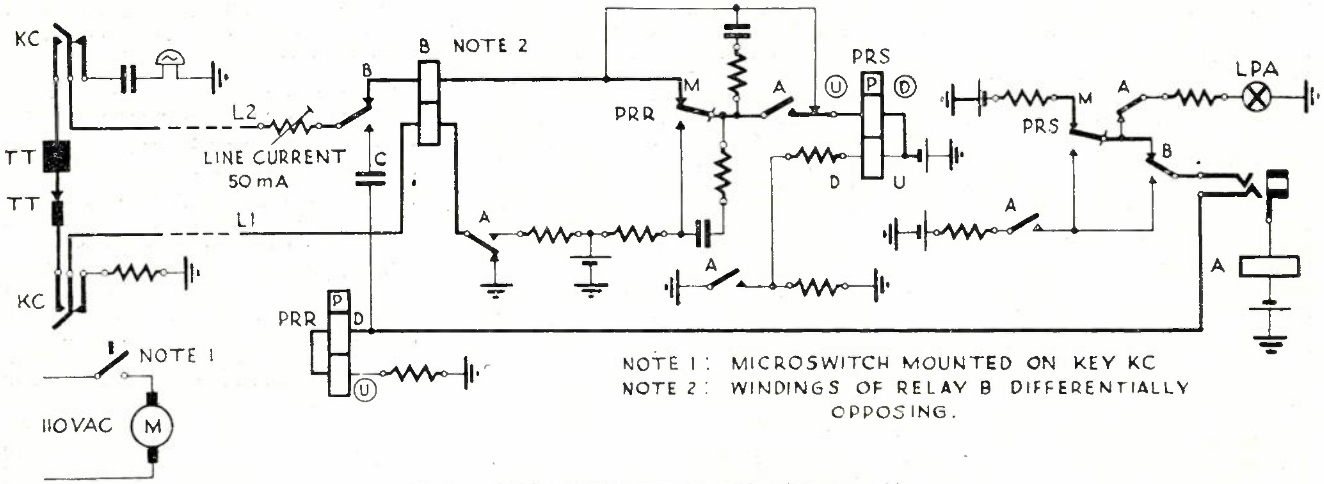

Fig. 5A.—Single current extension with teletype machine.

same termination is employed at two switchboards to terminate a trunk between them, the connection between the two-line legs L1 and L2 being reversed between the two boards in this case. When used to terminate a trunk circuit, spacing battery is fed to the L1 line in the rest condition as referred to in Note 2 of Fig. 5B. Any effective two-path double current output terminations (for example a channel of a multi-channel voice-frequency carrier telegraph system) may be interposed in such a connection. Fig. 5C shows a typical cord circuit with the operator's monitoring machine and associated circuit.

The respective sequences of circuit operation are as follows:—

Single Current Cct. (Teletype)

At rest no current flows in either L1 or L2, while PRS is held to space by 12mA current in its bias winding. To call, the extension operator throws KC, looping the line (current 25-30 mA) to operate PRS and simultaneously energising the teleprinter motor.

PRS contacts light the extension line lamp LPA. The switchboard operator inserts an answer plug in the extension line jack operating relay A, and extends a marking battery to PRR through cord circuit ring connection. Relay A operating removes the line lamp, completes battery supply to PRS contacts and the extension line circuit, the loop current becoming 50 mA, and increases PRS bias to the normal signalling value of 25 mA.

TT contact signals open and close the loop keying PRS which repeats double current signals to cord circuit tip. Double current signals from cord circuit key PRR which repeats them as single current signals to the loop and TT, PRS being locked to mark throughout by positive holding battery on PRR space contacts.

The differentially opposing windings of B relay prevent its operation and likewise minimise the effects of windings in the loop circuit.

To clear, extension operator restores KC to normal, switching off the teleprinter motor and causing B relay to operate from positive battery over the L1 leg. B relay contacts send permanent space into the cord circuit tip to give the clearing supervisory signal.

Clearing the cord circuit down permits relay A to release and B releases.

When the switchboard operator plugs up a calling connection relay A operates and operates relay B over L1.

An A.C. ringing signal on cord circuit ring connection is able to pass through condenser C, B contacts to L2 line, and ring the extension magneto bell. B contacts revert space to the cord circuit until the extension operator throws KC to answer.

Double Current Cct. (Teleprinter)

At rest a spacing current is received at the switchboard on L2 holding PRS to space, while a marking battery is applied to L1 on extension lines to Creed equipment.

To call the extension operator throws KC applying marking battery from the teleprinter contacts to L2, thus operating PRS to mark, and connecting the teleprinter magnet to L1.

PRS contacts light the extension line lamp LPA.

The switchboard operator inserts an answer plug in the extension line jack operating relay A and extends marking battery to PRR through cord circuit ring connection.

Relay A operating removes the line lamp, completes battery supply to PRS

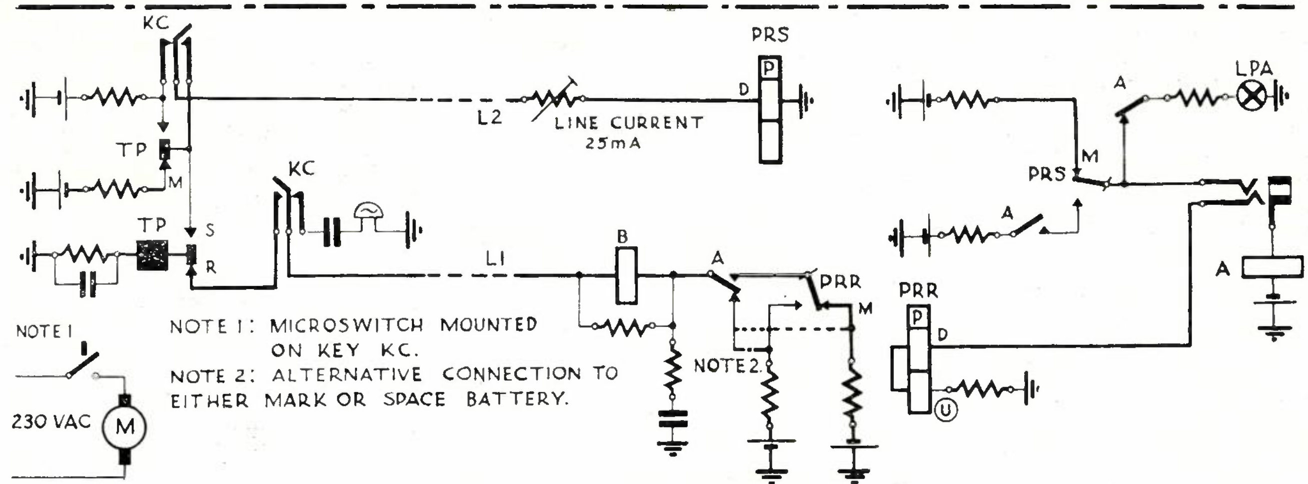

Fig. 5B.—Double current extension with Creed machine.

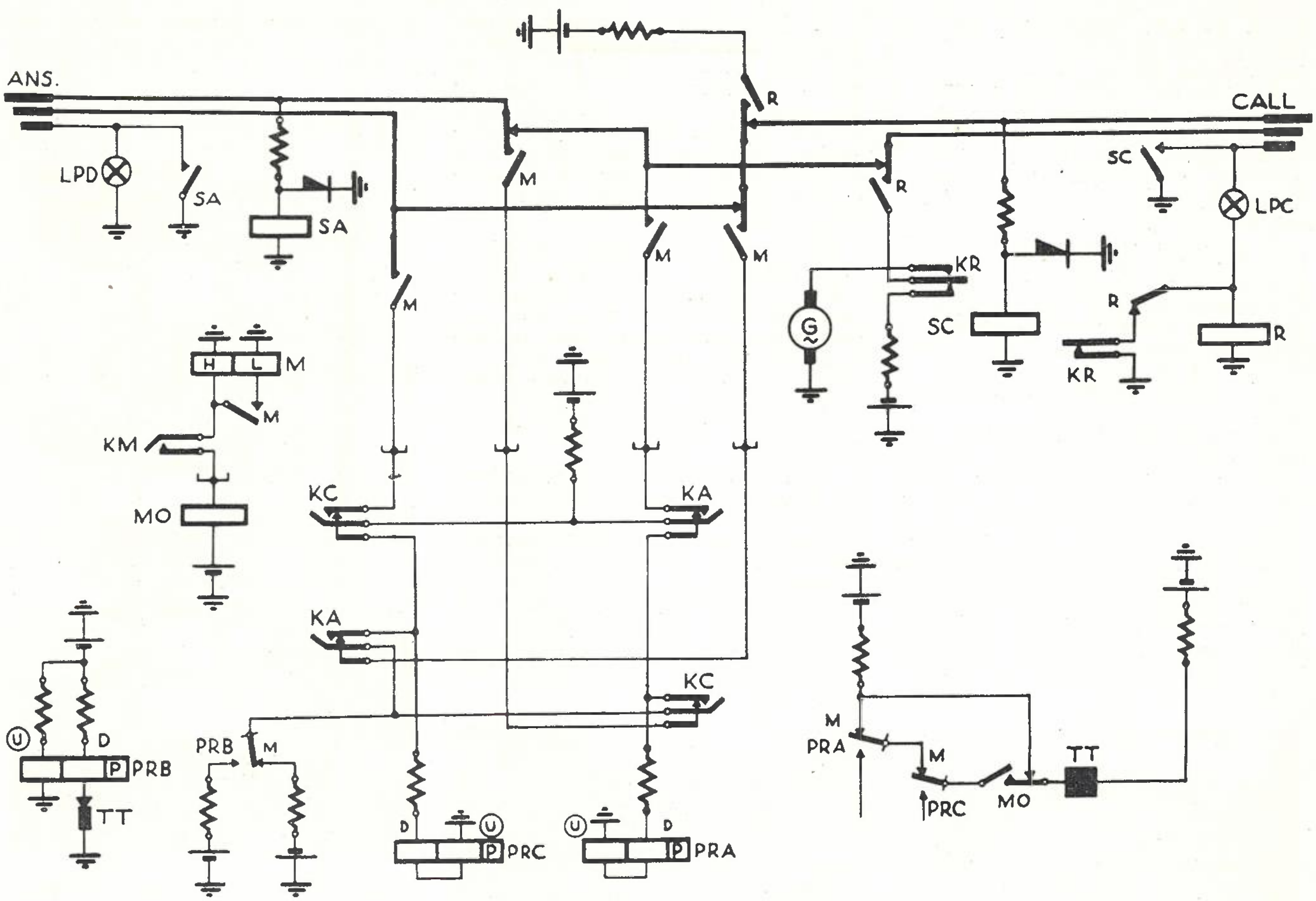

Fig. 5C.—Cord circuit and operator's circuit.

contacts, and connects the line L1 to PRR relay contacts. TP contacts send double current signals to PRS, which repeat them to the cord circuit tip.

A home record is obtained on the teleprinter by its send-receive switch, which connects its receive magnet in leak to the send contacts.

Double current signals from cord circuit ring PRR which repeats them to L1 and the receive magnet. Relay B is used as a retard to suppress peak surges into the line, and thus reduce noise from the telegraph circuit into adjacent telephone circuits.

To clear, extension operator restores KC to normal, switching off the teleprinter motor and sending permanent space over L2 to PRS, which repeats it into the cord circuit tip to give the clearing supervisory signal.

Clearing the cord circuit down permits relay A to release. When the switchboard operator plugs up a calling connection relay A operates. An A.C. ringing signal or cord circuit ring connection keys relay PRR which repeats this signal to L1 and rings the extension magneto bell. PRS contacts repeat permanent space to the cord circuit until the extension operator throws KC to answer.

Where it is required to connect a long distance extension over, for instance, a voice-frequency carrier telegraph channel, L1 connects to the carrier send and L2 to the carrier receive.

Where it is required to connect two switchboards together, two double current two-path extensions are connected, L1 to L2 and L2 to L1 respectively, while the rest condition battery applied to L1 through A contacts is made spacing. The act of plugging in on the circuit and extending a mark on L1 outgoing immediately causes the PRS relay connected to L2 at the incoming end to mark lighting the line lamp LPA. A permanent space is reverted to the calling switchboard until the called switchboard answers.

The switchboard cord circuit comprises the usual answer cord, call cord, monitor and ring key and supervisory lamps.

A connection through the cord circuit is extended answer tip to call ring and answer ring to call tip. In this condition the supervisory relays SA and SC are held operated by the marking signals on each side to the communication path. The spacing impulses during in signalling are by-passed around SA and SC by their respective shunt rectifiers, which act as short circuits keeping each supervisory relay operated.

On a permanent space signal from either side appropriate supervisory relay releases, its contacts removing the short-circuit from the associated supervisory lamp which lights from battery through the A relay of the extension line circuit on the cord circuit sleeve.

To monitor a connection, the switchboard operator throws the cord circuit KM key operating relay M in the cord circuit and relay MO in the operator's circuit.

The operation of M contacts diverts the communication path through the operator's circuit connecting polarised relays PRA and PRC in leak with the two signalling paths. Relays PRA and PRC repeat the passing signals to the operator's printer magnet. The cord circuit M relays are arranged so that only one may operate and hold through the operator's circuit MO relay at one time. Thus it is impossible to tie two cord circuits together by inadvertently throwing two KM keys simultaneously. To communicate with the extensions the switchboard operator may split the cord circuit and communicate to the answer side by operating KA, or to the call side by operating KC. Keyboard signals on the operator's printer key PRB, which repeats double current signals to the appropriate side, a home record being obtained either by PRC or PRA respectively operating in leak with PRB. A holding marking battery is applied to the side temporarily disconnected.

To ring an extension, the call cord is plugged up and the ringing key KR operated. KR removes the short circuit from R relay which operates from battery, A relay of extension circuit, sleeve circuit and LPC which lights. KR contacts, through R contacts operated connect ringing current to call and ring connection, while additional R contacts revert a holding marking battery to the answer cord ring connection preventing the calling teleprinter from racing while the called extension has not answered. When the called extension does answer, the marking signal on call and tip operates SC relay, which shorts supervisory lamp LPC and relay R, which drops out, establishing the through connection path.

Although the operator's machine is shown with single current operation of the printer magnet as for Teletype units, the circuit is readily convertible to double current operation as for Creed units.

As may be seen from the above outline circuit description, the operation of a teleprinter switchboard of this pattern would closely resemble the operation of a lamp signalling C.B. telephone switchboard. Full forward and backward supervision is provided, particularly in the case of a built-up connection through tandem switchboards where the use of the two-path unidirectional signalling arrangements gives immediate indication at all times of the state of the connection.

30 line jacks, whose first appearance may be on another switchboard. By mounting four such positions in two pairs side by side, it is possible to provide for 120 lines with full multiples within the reach of each operator. When used as a multiposition switchboard, "busy" guard lamps are provided on each line jack and energised by additional contacts on the extension line A relays.

There may be operating attractions, more particularly with multiple switchboards, in a special teleprinter switchboard carcase having an elevated and sloping cord and keyshelf with the operator's machine fitted beneath this. This would, however, have complicated procurement while it is doubtful if it presents any real advantage with small unit type boards.

A feature of the switchboard has been the mounting of the relay equipment in accordance with 2,000 type practice. The use of the TMC Carpenter Model 4 polarised relay, which mounts on 3,000 type relay drillings, has made this practicable. To facilitate testing of the polarised relays the coils and contacts have been wired out to extra U jack points so that the relay set may be placed in a 2,000 type relay set test stand (No. 17)

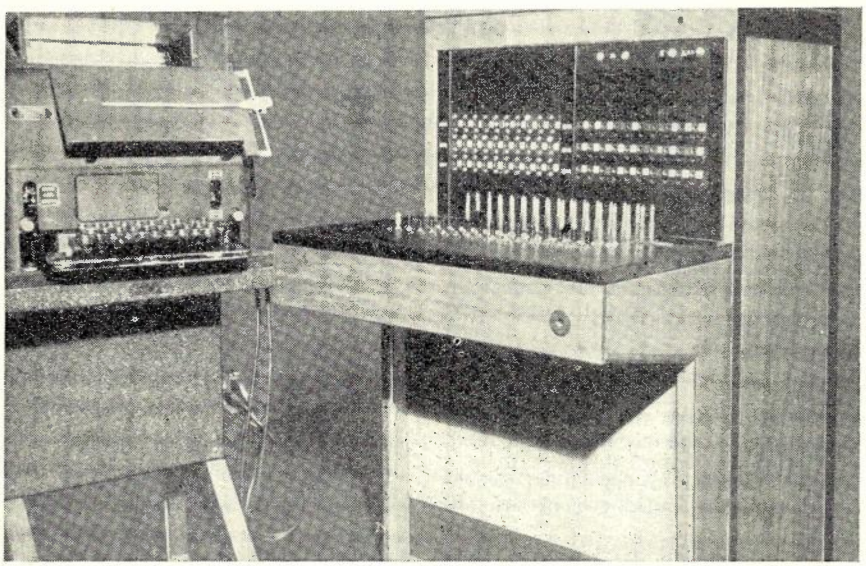

Fig. 6.—Manual teleprinter cord switchboard.

A Basic Teleprinter Switchboard: A basic unit type cord teleprinter switchboard has been designed, on these lines, using the Australian Post Office lamp signalling telephone P.B.X. carcase. The switchboard operator's teleprinter is mounted on a table placed alongside the switchboard carcase as shown in Fig. 6. The switchboard, with relay equipment in the rear of the carcase, is self-contained for 20 lines and 10 cord circuits, but may be extended with externally mounted relay equipment to provide for 30 lines and 15 cord circuits. The first 30 lines with associated calling lamps appear on the left-hand panel of the jack field, while on the right-hand panel is a multiple appearance of an additional

and connection is so obtained to the polarised relays. A typical relay set showing polarised telegraph and telephone relays mounted on a relay set base, providing for two extension line circuits and one cord circuit, is shown in Fig. 7.

The switchboard has been designed for ± 60 to 65V working as the lower of the present standard telegraph voltages. However, having regard to the probability of such switchboards having to be integrated in an automatic switching scheme using ± 50V signalling, the design is such as to permit ready conversion to these supply voltages.

As the switchboard must take its place in the present scheme of things, facilities have been provided whereby the ± 60 to 65V signalling battery supplies to the PRR relays of double current ex-

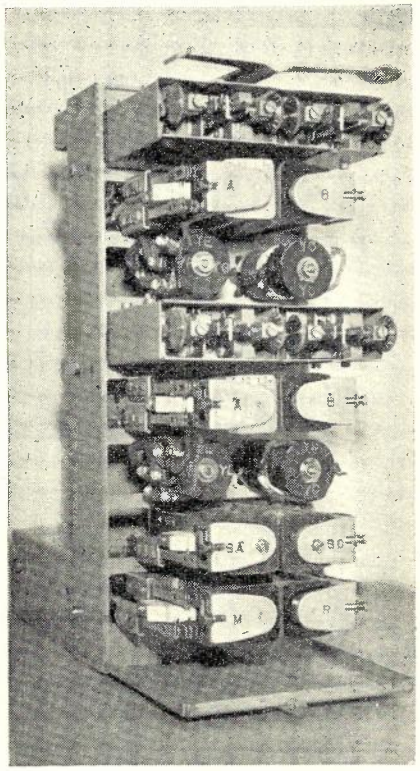

Fig. 7.—Telegraph relay set—2000 type mounting.

tensions may be replaced with ± 120 to 130V supplies clear of the other parts of the circuit. This permits connection to voice-frequency carrier telegraph channels using the old standard ± 120 to 130V supplies, although the switchboard and local loops use the lower voltages. Special care has been taken to isolate the high voltage parts of the circuit when they pass through components which are likely to be subjected to undue insulation stresses with such voltages.

Apart from the normal extension line and cord circuit relay sets, special relay sets are being provided which use the cord circuits 11-15 on each switchboard position, as and when required, to provide a cord-ended conference facility whereby up to five extension or trunk circuits may be plugged-up and so interconnected that any one circuit may transmit and all others receive the signals. The supervisory signals, in this case, are to the point of conference connection.

Although the foregoing description pertains to the cord type switchboard, similar circuitry and identical extension line and "cord circuit" relay sets have been employed in the design of a smaller unit type four lines plus operator key-type switchboard with two link circuits. In this switchboard the second link has been adapted so that any one extension or the operator may use it to make a broadcast (multi-point one way) transmission to any selected, or all, of the remaining extensions.

Transmission Plan: A general teleprinter switching scheme must be engineered so that any connection will be of such satisfactory transmission characteristics that communication may proceed immediately the connection is made no matter how it is built up. It is therefore necessary to envisage a Telegraph Transmission Plan and Standard Grade of Telegraph Local Line Transmission.

The general telegraph trunk circuit in the teleprinter switching scheme is the voice-frequency carrier telegraph channel. Although the systems in use in Australia are of various characteristics, the systems which form the backbone of the communications network conform to the C.C.I.T. recommendations for 18 or 24 channel systems having carrier frequencies at 120 c/s spacings from 420 c/s to 2460 c/s or 3180 c/s respectively, and using a single amplitude modulated carrier for each channel.

The transmission characteristics of such systems are very largely determined by these factors. World-wide experience has confirmed that there is no known method whereby the overall distortion of several such channels, connected in tandem, may be predicted. However, a large number of measurements, both in Australia and overseas (1), have shown that the distortion of three such channels, connected in tandem and in normal service conditions, may be as high as 22%, and of four channels as high as 26%, although the distortions will probably be less than these figures.

Local experience with point-to-point circuits, as shown in Fig. 1, has confirmed that three channels in tandem represent a stable transmission proposition. There has been only limited experience with four channels in tandem, and there is some doubt as to the significance of results so obtained. The double current two-path signalling circuits with which telegraph trunks are connected to, and through the switchboard, have, over the distances of 0-20 miles involved in practice, extremely good transmission characteristics which are not prejudiced either by the repeating relays or the supervisory relays in the switchboard. Three voice-frequency carrier telegraph channels may therefore be connected in tandem to provide three trunks between four switchboards, the transmission loss being that of the channels alone. The layout of the network may, reasonably, be on the basis that three trunks are the maximum which may be connected in tandem without regeneration.

The general pattern of voice-frequency telegraph systems in Australia is such that within a State there may be two voice-frequency carrier telegraph channels in tandem between a provincial centre and the capital city. Consequently a built-up intrastate connection may contain four channels in tandem. There are direct voice-frequency carrier telegraph circuits between the mainland capitals, excepting Perth, and, therefore, setting apart Western Australia, an interstate connection may comprise five channels in tandem. Thus it is evident that, in a general Australia-wide teleprinter switching scheme, there will be a requirement for regeneration.

A regenerative repeater (2) may be inserted at a switchboard in those connections which require it. Such a regenerative repeater may conceivably be interposed in a selected cord circuit or may be terminated on two extension line jacks so that by using two cord circuits to establish a connection from one trunk to another through the regenerative repeater, it may be inserted where required. In either case there should be no technical adjustment required. Notwithstanding the foregoing, it appears that most of the connections likely to be established in an Australia-wide switching scheme will not contain more than two voice-frequency carrier telegraph channels.

To enable this Transmission Plan to be met, it is essential that a Standard Grade of Telegraph Local Line Transmission be maintained. As discussed above under the heading of Circuit Types, it is necessary that:—

(i) the distortion of signals from an extension machine does not exceed ± 10% when measured at the line sending relay in the exchange;

(ii) the margin (that is, tolerance of distortion of received signals) of receiving teleprinter is not less than ± 35%;

(iii) the overall margin of receiving local circuit and teleprinter considered together and measured from the line receiving relay in the exchange is not less than ± 30%.

It appears that these standards may, in general, be met up to the maximum length of cable circuit over which the line current of 50 mA for Teletype units, or 20-25 mA for Creed units, may be supplied. In practice this implies that single current loops may have a maximum length of 10-15 miles and that double current lines may have a maximum length of 15-20 miles, depending in each case on the make-up of the cable circuit. Beyond these distances all extensions must be provided on a two-path double current basis with auxiliary relay equipment at the out-station. It appears that this will only be necessary for about 5% of extension lines and that this method of operation may be effective for cable circuits up to some 50 miles in length.

Although these transmission standards have been developed for a general teleprinter switching scheme, they have now been adopted for fixed point-to-point circuits. Experience to date seems to indicate that these standards provide an adequate factor of safety for reliable teleprinter service and provide an adequate tolerance for deterioration of teleprinter selector mechanisms, speed variations of teleprinter motors (including those due to reasonable power supply fluctuations), deterioration of repeating telegraph relays, and day-to-day service variations of telegraph trunk circuits from their "lined-up" condition.

Telex Service: Recent years have seen a great expansion in the number of private wire teleprinter circuits leased by the Post Office to Press, commerce and industry. The number of teleprinter units on such service now considerably exceeds those in Post Offices for the Public Telegraph Service. Similarly, a large proportion of telegraph channels on major routes is in use as private wires as instanced by the examples in Table 2.

Table 2
Allocation of Channels Mainland Inter-Capital Routes
April, 1952

Route	Departmental traffic incl. order wires and administrative	Private wire
Sydney-Adelaide	10	1
Sydney-Brisbane	12	11
Sydney-Canberra	15	25
Melbourne-Adelaide	12	12
Melbourne-Brisbane	9	7
Melbourne-Sydney	13	22
Melbourne-Canberra	7	20
Adelaide-Perth	11	5

In overseas countries this field of service has been extended by Subscribers' Teleprinter Exchange (TELEX) Service, in which each subscriber has a teleprinter connected to a telegraph exchange and may make calls to any other subscriber to the service. This service has been provided for some years in Germany on a fully automatic nationwide basis (3), and there are, on most recent reports, some 7000-8000 subscribers connected. The similar service provided in the United States by the Bell System, and known as Teletypewriter Exchange (TWX) Service (4), has now over 30,000 subscribers. The service also operates internationally in Europe and, by radio telegraph channels, between Europe and R.C.A. patrons in the U.S.A. In overseas countries the TELEX trunk tariff is generally 50% of the parallel telephone trunk tariff, and there is a C.C.I.T. Recommendation to this effect.

A TELEX service is now being introduced in Australia, the initial installations comprising three-position manual switchboards in Melbourne and Sydney respectively, each installation providing for a maximum of 60 subscribers and 30 circuits to Central Telegraph Office positions and trunks between exchanges. Initially these installations are to operate locally, principally to printergram positions in the Central Telegraph Offices, and it is expected to extend the service to interstate operation in the near future. In the past a minimum fixed period of service for part-time private wires has been too restrictive to a number of potential customers, but it is expected that TELEX service will enable them to have the advantages of teleprinter communication on a flexible traffic-handling basis and on financial conditions satisfactory to all parties. It is perhaps appropriate to mention that experience in both Australia and overseas countries has been that, notwithstanding financial problems with the Public Telegraph Service, private subscribers' teleprinter service is financially quite attractive to customer and administration alike.

It is envisaged that TELEX service will be extended to other centres in Australia. One problem which may be expected to arise is the necessity to provide service to groups of five to ten subscribers in provincial towns. Manual operation for 24 hours per day would be prohibitive and it is hoped to provide service in such localities with small automatic Satellite Exchange units trunked off parent manual boards in larger centres. Such units will have a number of trunks, each of which terminates in an automatic circuit arranged to function as a line-finder, connecting a calling provincial subscriber to a free trunk to the manual board, and as a final selector connecting a caller on a trunk from the manual board to the called provincial subscriber. This will permit a gradual introduction of the advantages of automatic working while retaining the advantages of supervision and call-accounting provided by a manual operator when dealing with long-haul trunk circuits.

Public Telegraph Service: The present mode of operation of the Public Telegraph Service in Australia is that, in general, all morse and teleprinter stations within a State have connection to a Central Telegraph Office in the capital city of the State. All messages originating at these stations are transmitted to the Central Telegraph Office, circulated, and those destined for some other office are retransmitted on appropriate circuits to the offices of destination. The system is known as "Manual Relay" operation. The problems associated with the centralised handling of large quantities of traffic in these Central Telegraph Offices have, in similar circumstances overseas, prompted efforts to set up teleprinter switching schemes whereby the office of origin of a telegram obtains a direct teleprinter connection, through telegraph exchanges, to the office of destination, and transmits the message directly. Systems of this sort have been introduced overseas (5, 6), and have even been integrated with TELEX service so that Post Offices and private subscribers connect to the same exchanges and use common trunks between them (7). So far the technical problems are similar to those of the subscriber to subscriber connection of TELEX, but in contemplating the changeover of Public Telegraph Service from Manual Relay to Direct Switching, two new problems arise.

An important traffic-handling problem is that process known as "tracing", which consists of determining the correct office of destination of a telegram from the address. With Manual Relay this is determined in the Central Telegraph Office, and the relevant information is kept centralised there, but with Direct Switching this work must be done in the office of origin for each telegram, and the relevant tracing information decentralised there. In addition, in a nation-wide switching scheme the information becomes much more massive as all the information for all localities must be decentralised, whereas with Manual Relay it is necessary to have in each Central Telegraph Office only that tracing information relevant to its own State or region. One particular difficulty in tracing is to decide, in the metropolitan areas, which office is concerned in the delivery of a telegram when, as frequently occurs, the locality given is on the borders of two or three districts, each with a Post Office, and the street named may traverse several localities. In practice it is found that 23% of traffic addressed to destinations in the Australian metropolitan areas has to be diverted to some other office than that indicated by the locality in the address. Another difficulty is in coping with the 9000 telephone offices, mostly in country districts and served through the 200 teleprinter and 1100 morse offices now existing in the Commonwealth. It might reasonably be asked what peculiar difficulties make this task so difficult in Australia by comparison with other countries. In the lack of any experience by individuals in other places, it appears that the Australian cities cover such large areas, and are expanding so rapidly, that the fundamental problem is not so much to cope with the bulk of the information, but rather to cope with its rate of change.

The other problem in a changeover from Manual Relay to Direct Switching lies in the traffic-handling capacity of circuits and it is proposed to review this under the following heading.

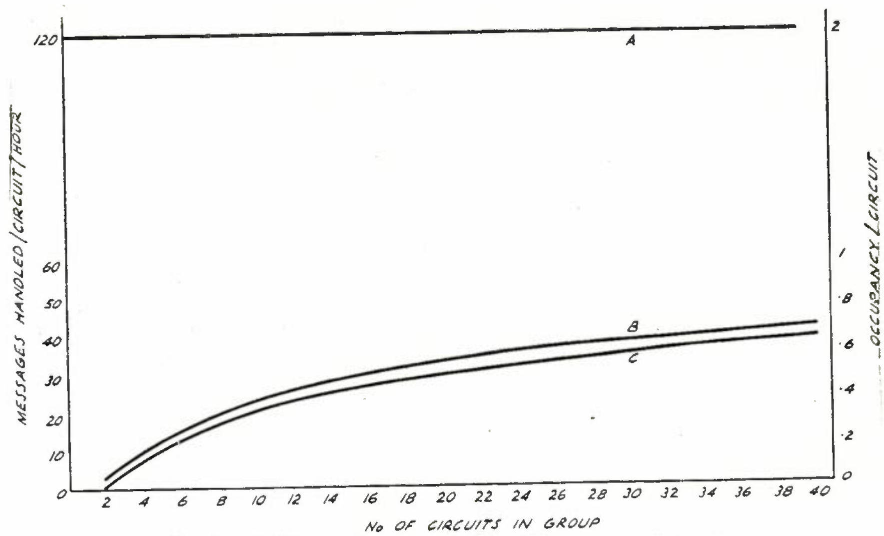

Fig. 8.—Traffic carrying capacity/circuit in groups of circuits.

A—Duplex point to point.
B—Trunk in teleprinter switching scheme, loss probability 1/200.
C—Trunk in teleprinter switching scheme, loss probability 1/500.

Traffic and Trunking: In the present form of point-to-point teleprinter network, with manual relay operation, circuits are provided on the basis of a peak busy hour loading of some 70 messages for a simplex circuit. This represents the maximum which the single operator, at each end of the circuit, is capable of handling. With separate sending and receiving operators at each end of the circuit and operation on a duplex basis, this loading increases to 70 messages per hour in both directions simultaneously.

In a direct switching system there is a little extra time spent in setting up the connection for each message and an average of one minute per message appears a reasonable duration. The existing highly developed studies of traffic carrying capacity of telephone circuits may then be applied to the telegraph switching problem, the holding time being one minute and the traffic handling capacity in the busy hour of a circuit loaded to full occupancy (that is, a traffic of 1 Traffic Unit or 1A) being 60 one minute calls or messages.

The long distance trunks in a direct switching system must necessarily be operated on a simplex basis, in lieu of the duplex basis in point-to-point operation. The number of messages which may be carried for various numbers of circuits with different grades of service is shown in Table 3. The information is also shown graphically in Fig. 8, with particular indication of the comparison with point-to-point duplex operation.

With groups of trunks of the order of 1-40 lines, as would be required in practice under Australian conditions, and loss probabilities of the order 1/100 to 1/500 the occupancy of each trunk is not greater than 0.67. Consequently the largest trunk route of this order in a direct switching system is likely to require at least three times the number of channels required between the two centres with duplex point-to-point operation.

Apart from the very large increase in long distance circuits necessary with direct switching systems, the reduction of the traffic carrying capacity of extension circuits within a local network appears to represent the final limiting factor. Thus the traffic handled by one circuit, with a loss probability in the busy hour of 1/20, is only three messages and for two circuits only 23 messages. This presupposes a method in which the switching equipment tests the called circuit and if it is busy returns a busy signal immediately to the caller.

If the switching equipment is arranged to test the called line and wait for it to become free ("camp on busy" or "queuing" types of circuit) the probability of the called line being busy (over some reasonable time of testing) is greatly reduced or the traffic handling capacity for a given loss probability is greatly increased. Figs. 9, 10 and 11 have been prepared from curves given

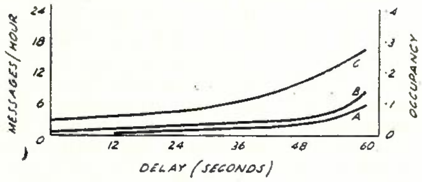

Fig. 9.—Traffic handling capacity of one circuit versus delay in completion of call—holding time of 60 seconds.
Loss probability: A—1/200. B—1/100. C—1/20.

by C. D. Crommelin (8). With a delay up to one minute (that is, equivalent to the holding time of a message) the traffic handling capacity of one circuit is now increased to 17 messages for the same loss probability of 1/20. It must be noted, however, that only three messages will probably be completed without delay, that only six will probably be completed with less than 30 seconds' delay, and that two-thirds of the incoming calls may be delayed from 30 to 60 seconds before completion. This must re-act unfavourably on the traffic carrying capacity of the sending circuit. The position improves in the cases of two or more circuits but it is apparent that a circuit occupancy of more than 0.5 implies a loss probability greater than 1/200 or delay greater than 30 seconds.

Table 3

Table showing the number of calls (messages) of 1 minute holding time which may be made on groups of 1 to 40 circuits during the busy hour with various grades of service.

Number of Circuits	Busy hour call with loss probability 1/500	1/200	1/100	1/20
1	—	—	—	3
2	4	6	9	23
3	15	21	27	54
4	32	42	52	91
5	54	68	82	133
6	79	97	114	178
8	139	164	187	272
9	171	200	227	322
10	206	237	268	373
15	395	443	486	639
20	604	667	722	915
25	826	900	967	1200
30	1056	1140	1220	1490
40	1535	1640	1740	2089

NOTE.—This information is calculated from the Erlang formula, with its usual assumptions, for pure chance traffic and for full-availability groups of circuits. This includes the assumption that the number of sources of traffic is very large compared with the number of circuits. When the number of sources is small compared with the number of circuits the capacities are somewhat greater than shown above.

In general it appears that direct switching is a suitable traffic handling arrangement between single circuits loaded to 0.3 occupancy (beyond which the single circuits or groups of two to six circuits are relatively inefficient), and large offices having seven or more circuits with occupancies higher than 0.5 where the circuits can be used with reasonable efficiency. The most perturbing conclusions are that groups of two or three circuits are necessary to replace a single point-to-point circuit in a manual relay system, that while one operator may be able to attend to two circuits each loaded to occupancy of 0.35 it certainly appears that two operators will be necessary to attend to three circuits each loaded to an occupancy not higher than 0.38 and that these conditions represent the peak load capacity of a system which is apt to be unresilient when faced with break-down or overload conditions.

An important practical factor in the traffic handling capacity of groups of circuits is the increase in loss probability with the loss of circuits due to fault conditions. Referring to Table 3 it will be seen, for instance, that if ten trunks be provided to carry 200 messages with a loss probability 1/500 the failure of one trunk will increase the loss probability to 1/200 and the failure of two trunks will make the loss probability appreciably worse than 1/100.

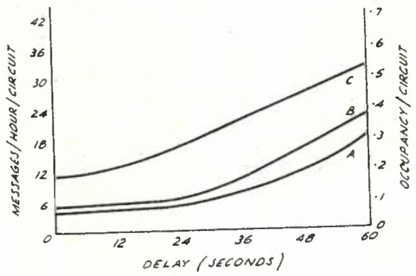

Fig. 10.—Traffic handling capacity per circuit in group of two circuits versus delay in completion of call. Holding time 60 seconds.
Loss probability: A—1/200. B—1/100. C—1/20.

Newcastle Teleprinter Switching Scheme: These difficulties of application of direct switching to the Public Telegraph Service are capable of examination to a greater or lesser extent on theoretical grounds. It is, however, evident that there is scope for a field experiment to assess the practical significance of theoretical factors. To this end a teleprinter switchboard has been installed at Newcastle (N.S.W.) and all the Newcastle suburban morse offices converted to teleprinter working. The stations connected to the switchboard are:—

Sydney C.T.O. (6 extensions)
Newcastle (3 home positions)
Newcastle West (2 extensions)
Melbourne, Victoria.

Suburban Offices:
Hamilton (2 extensions).
Mayfield (2 extensions).

Adamstown	Swansea
Belmont	Tighe's Hill
Broadmeadows	Toronto
Mayfield East	Wallsend
Merewether	Waratah
New Lambton	Wickham

Cross traffic between the Newcastle offices is exchanged by direct teleprinter connection through the switchboard. Traffic from Newcastle offices for Victorian offices is transmitted by direct connection through the switchboard to Melbourne C.T.O., thus bypassing Sydney C.T.O. Traffic for Sydney, other States, and New South Wales offices not served by the scheme is transmitted on the group of extensions to Sydney, where it is subsequently handled by Manual Relay. Although the proportion of traffic handled by direct working is in the restricted scheme only a fraction of the total, it has given valuable experience. A deciding factor in the choice of Newcastle as the venue for such an experiment is the fact that it is the largest metropolitan area in Australia, outside the capital cities, and with its population, in scattered suburbs, of some 150,000 people, may be expected to give a fair indication of the tracing problem encountered in direct switching. The tracing information has been prepared in book-form and is a sizeable volume with delivery instructions for business hours and after-hours for

1100 streets
350 telegraphic code addresses
1100 business houses.

A typical extract is shown in Table 4. Incidental to the general tracing question, it is interesting to note that the final reference authorities on Newcastle tracing are well-thumbed Commonwealth Electoral Rolls, for the Commonwealth Electoral Divisions of Hunter and Shortland, in the Newcastle Telegraph Office.

Apart from the above, Newcastle Telegraph Office serves over 100 telephone offices within a radius of some 20-30 miles. As may be expected, Newcastle suburban office cross-traffic being traced by men living in this district presents relatively little difficulty, but it is very difficult to "trace" Newcastle suburban office traffic in the Melbourne C.T.O., where few of the operating staff have any close local knowledge of the Newcastle district. In respect of the traffic-handling capacity of circuits, it is evident that the maximum manageable busy hour load, even in so restricted a scheme, which may be handled at a station with only one or two circuits, is of

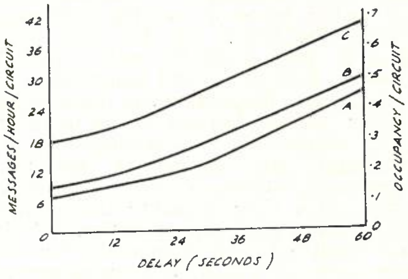

Fig. 11.—Traffic handling capacity per circuit in group of three circuits versus delay in completion of call. Holding time 60 seconds.
Loss probability: A—1/200. B—1/100. C—1/20.

the order of 0.3-0.5 A per circuit. Even the lightly loaded offices have busy hour loads of 0.2 to 0.3A, while the number of calls handled through the switchboard in the busy hour is of the order of 160-170. The calling and supervisory signals have proved equal to their task and have enabled the switchboard operator to

Table 4

Telegrams addressed to:	Monday-Noon Saturday	After noon Saturday
June St., Merewether	Merewether	Hamilton
Joan St., Adamstown	Adamstown	Hamilton
Kahibah Rd., Waratah	Waratah	Waratah
Kalsina St., Mayfield	Mayfield East	Mayfield
Karoola Rd., Lambton	Lambton	New Lambton
Keightley St., Newcastle	Newcastle	Newcastle
Kemp St., Hamilton Sth.	Merewether 2/22-1/47	Newcastle, 1/105-2/112 Hamilton 107 & 114 up
	N'cle Wst, 54/138-57/135	Newcastle, 1/105-2/112 Hamilton, 107 & 114 up.
	Hamilton, 147/148 up	Newcastle, 1/105-2/112 Hamilton, 107 & 114 up.
Kemp St., Wallsend	Wallsend	Wallsend

carry this load with some margin of effort in reserve. Each call, of course, may represent more than one message, but a limit of a maximum batch of six messages at one call was laid down in operating procedure to ensure that congestion did not occur with unduly long connections.

Experience with the scheme has indicated that:—

(i) decentralised tracing within a regional unit is practicable, but nation-wide decentralisation as required in a nation-wide direct switching scheme may be expected to prove unmanageable;

(ii) the traffic-handling capacity particularly of extension circuits in a direct switching scheme is strictly limited, and this must be a serious limiting factor;

(iii) the traffic which is handled directly on the system in lieu of being manually relayed is greatly expedited;

(iv) the teleprinters installed in the smaller Post Offices in lieu of morse equipment enable the limited staffs in those offices to do their work considerably more efficiently.

As a sidelight on this experience, the switchboard has proved technically satisfactory, notwithstanding its wide departures from previous telegraph engineering practices. Some curiosity was entertained as to whether the ring-down calling and dependance on the called-station to answer before proceeding with communication (unlike the European practice of tripping off the called station's Answer Back device and using this as an assurance to proceed) would cause undue delays, but this has not proved to be so.

It is appropriate to mention that the operating and engineering personnel concerned with the scheme in the Newcastle area have displayed the greatest enthusiasm, and their co-operation is in no small measure responsible for the emergence of a fairly clearcut picture of the possibilities of the scheme.

Teleprinter Reperforator Switching Scheme: These difficulties impose restrictions on the advantageous exploitation of direct switching in the Public Telegraph Service. The exploitation of automatic switching techniques as applied to this service is, however, by no means limited to the possibilities which have been discussed above. Although starting from somewhat different premises from those above, the Western Union Telegraph Company in U.S.A. has produced a series of reperforator switching systems, which in an elegant and powerful manner overcome a great many of the difficulties of direct switching.

The general pattern of a proposed Australian Post Office Teleprinter Reperforator Switching System (TRESS) is shown in Fig. 12. Incoming teleprinter lines (either simplex or duplex) terminate at the reperforator switching centre on incoming typing reperforators (RT/R). As each message is received (reperforated and typed on tape), the incoming serial number is checked off by the TRESS operator, the address is read, and the tape passes through a tape transmitter distributor (T/D) which the TRESS operator switches to the required destination office line. The switching technique is semi-automatic, that is, with manual setting of automatic switches, by key sender (push-buttons). There is no direct communication between incoming and outgoing lines, and, to positively identify each outgoing message from the centre, it is preceded by a serial number of a consecutive series appropriate to the circuit automatically inserted by a numbering transmitter (A/N) before transmission of the message.

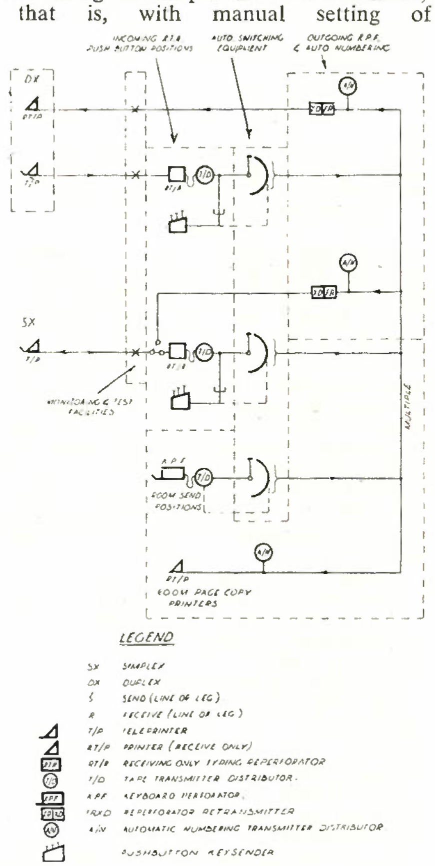

Fig. 12.—Teleprinter reperforator switching system.

Outgoing lines may be either simplex or duplex. In the former case the line may be working into the centre when a connection is established, so that to avoid holding up the message on the incoming side and the cross-office connection, individual to each outgoing circuit another reperforator transmitter distributor combination (FRXD) (9) is provided. This stores all outgoing traffic, serially numbered, and releases it when the line to the outlying station is free. In the duplex case a monitoring reperforator on the outgoing connection is required to associate messages and their serial numbers. This would otherwise be impossible if the outgoing line failed during a transmission to it. For technical reasons there are advantages in making this monitoring unit a reperforator transmitter distributor (FRXD), too. The tape from each reperforator transmitter distributor combination (FRXD) is stored on a reel beside the machine and forms a permanent record of all transmission from the centre to the outstation.

Each message sent into the centre has a "beginning of message" signal and an "end of message" signal. The former signal stops the tape in the transmitter until it is switched to a free outlet, while the connection across the office is broken down with the transmission of the latter signal to the outgoing storage reperforator (FRXD). The switching arrangements are such that when a cross-office connection is set up at a push-button position a potential connection is established and this is completed only when the outlet is free. Furthermore several transmitters may "camp on" one outlet and the switching arrangements are such that only one may start at a time, the process continuing until all have completed transmission.

Messages which are required in page copy form at the TRESS centre (for example, for local delivery, telephoning, repetition to manual morse office) are switched into page printers (RT/P), again each message being automatically numbered as a safeguard against loss. Messages originating at the TRESS centre are prepared on keyboard perforators (K.P.F.) the tapes passing through transmitter distributors which are switched automatically to the required outlet, transmission commencing when this is free. The automatic switching is controlled by a two-letter code (the call sign of the office of destination) perforated before each message.

Each TRESS operator may attend to three heavily loaded incoming reperforators, switching 150-200 messages/hour. Circuits which are not heavily loaded may be grouped in an automatic concentration system (not shown) whereby several outstations may have access to a common group of up to three incoming reperforators, the one operator again having all necessary checksheets for the incoming circuits. Machine omnibus circuits may similarly be terminated in the centre where required. In this case a common reperforator retransmitter may be used but separate outlets are provided on the switching multiple, for each station with individual automatic numbering transmitters.

In respect of the traffic handling capacity of the system automatic teleprinter transmission implies an effective average holding time for each switched connection of 20 seconds. Translating Fig. 9 into these terms, as shown in Fig. 13, the traffic handling capacity for one cir-

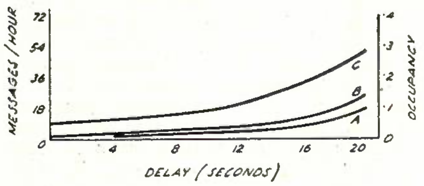

Fig. 13.—Represents curves of Fig. 9 translated into terms of 20 seconds holding times.
Loss probability: A—1/200. B—1/100. C—1/20.

cuit, is more than 50 messages/hour, with a probability of only one message in 20 being delayed more than 20 seconds. Actual tests and some evidence from Bell System sources indicate that occupancies up to 0.5 would probably not imply excessive delays, that is, a peak traffic handling capacity for one circuit of up to 90 messages/hour. This represents rather more than the load of a normal operator so that for Australian purposes there appears to be no point in higher speed cross-office transmissions (for example, 125 w.p.m. in lieu of normal 67 w.p.m.) as used on some of the Western Union installations (10).

The ability with TRESS to provide a full load for an operator on each circuit, which, however, the operator is able to handle in his own time, means so much more efficient use of operator time than direct switching. Consequently it appears that TRESS may be more economical and, practically, as expeditious as a direct switching system.

Conclusion: The past 20 years have seen in Australia, as in other countries, a great resurgence in telegraph communication. This is fundamentally due to the operating simplicity and mechanical reliability of modern teleprinter mechanisms used in combination with the cheap and efficient circuits provided by multichannel voice-frequency carrier telegraph systems. It is evident that there is a considerable field, as yet awaiting exploitation, in the application of the highly developed techniques of telephone switching to the problems of telegraph communication.

In Australia, notwithstanding the peculiar technical problems brought about by the necessity to reconcile, within our country, the wide divergencies of European and American telegraph practices, it has been possible to evolve a basic direct switching system. This system, although manual at present, presents a firm foundation on which applied automatic switching technique may grow. Such systems will find a new and useful application in the new field of TELEX service.

The application of such systems to the Public Telegraph Service has been examined. The contrary directions of overseas practices has led to the conception of two practical experiments within Australia, of which the Newcastle Teleprinter Switching Scheme represents one, and a projected TRESS installation in Launceston, Tasmania, the other. The work done on direct switching for TELEX service has permitted the Newcastle Teleprinter Switching Scheme to come into service first, but the experience gained from it confirms the view, developed originally from theoretical considerations, that TRESS provides the most efficient and economical solution to the problems of automatic operation of the Australian Public Telegraph Service. There is undoubtedly an extensive further field for application of automatic switching techniques in which the possibilities of temporary automatic call storage may be exploited, in a way without parallel in telephone switching practice, to provide an extremely powerful solution to the traffic handling problems of the Public Telegraph Service.

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TIMES NEW ROMAN

This issue marks a major change in the set-up of the Journal with a change in the type from 10 point Century to 8 point Times New Roman. After considerable research and design work this type was introduced originally by the London "Times" in its daily newspaper, and has since been extensively used by other publications.

The aim of the new type is to increase the density of letters and characters without decreasing the legibility. This was done by discreet condensation of curves of the letters, and the stems and curves of the new type are thicker and carry more ink than the previous type. The letters look blacker, and consequently greater legibility is obtained.

The saving of space has been such that it has been practicable to reduce the number of pages in the Journal from 64 to 48 without reducing the amount of subject matter. It is felt that all readers will agree that this represents a well worth-while economy in paper and printing costs, and consequently in the cost of the Journal to subscribers, without detracting from the quality of the printing.

Associated with the introduction of the new type a change has also been made from two columns to three per page. This has an advantage from a reader's point of view in scanning from line to line and also provides greater flexibility in the choice of block sizes in one, two or three column widths.

In order to provide a direct comparison with the type used in previous issues of the Journal, this paragraph is produced in the 10 point Century form. The density of the letters and the greater space between them in this type compares noticeably with the more compact and thicker lines of the Times New Roman type.

TELECOMMUNICATION CABLES

A. G. SMITH*

Introduction.

The earliest telecommunications cables were used for telegraphic purposes only and, after an initial construction of single wires insulated with various material, including glass beads, the first multi-conductor cables were made. These mostly consisted of seven stranded copper wires insulated with gutta percha to form a conductor, and seven such conductors were stranded to form a cable core, which was covered with tanned jute and protected with galvanised iron wires. The conductors were first used with an earth return, but later each conductor was surrounded with copper tape to serve as a return conductor and as a shield to reduce interference among the circuits. Thus the earliest cables were essentially composed of unbalanced coaxial circuits. The insulation resistance of these cables was quite reasonable, but the mutual capacity was naturally quite high. The unbalanced circuits later gave place to balanced circuits to eliminate interference still further.

The submarine cable has in the main remained a single coaxial circuit, except for short distance shallow water crossings, the central conductor being a solid round wire surrounded by seven flat tapes and the insulation being Polythene, Balata or K-gutta, an improved gutta percha produced for submarine cable use. The armouring wires surrounding the copper tape also assist in forming a return. The manufacture and installation of these submarine cables are very specialised operations; very few organisations exist capable of carrying them out, and as there are none in Australia, they will not be considered here.

The balanced circuit consists essentially of two or more insulated conductors uniformly twisted together in various arrangements, and with various lengths of twist selected to reduce interference and to obtain as far as possible the electrical quality desired for the purpose for which the circuit is to be used. Their development and use has proceeded with the development and use of the telephone cable, which today caters for both telephone and telegraph traffic, mostly on similar circuits.

Until about the year 1880, telecommunications circuits had been insulated at first mainly with textiles impregnated with insulating compounds and later with similarly impregnated paper. However, about this time the lead-press had been developed sufficiently by Borel, in Switzerland, for it to be used to produce a satisfactory cable sheath to ensure a watertight cable, whereby it was possible later for Patterson, in the United States of America, to produce the dry core paper insulated cable, and thus circuits having very low initial capacity and conductance were realised. The modern telecommunications cable can be taken to have started from this development.

An electric cable consists essentially of a conductor or conductors, their insulation, their combination to form the necessary circuits, their laying-up to form the cable and the outer protection of the cable. These items, together with some notes on the various types of cables produced for telecommunications use, will be discussed briefly in the following paragraphs.

Conductors.

For the conductors, copper wires have been used from the earliest times, and copper has continued to be used generally for cables, with occasional excursions into the use of aluminium. Even when a satisfactory conductor, at lower cost than copper for a given resistance, can be obtained from aluminium, there still remains the difficulty of jointing aluminium conductors, and the still greater disadvantage for cables that the overall diameter is considerably increased and, therefore, the cost of lead-sheathing and armouring. Alternatively, the number of circuits may be reduced for a given diameter, but it will be obvious that this is seldom likely to be attractive.

The only improvement in copper wires to the present day has been to use copper of the greatest purity. This resulted from Kelvin's investigations in connection with submarine cables, from which he found that relatively small amounts of impurities reduced the conductivity considerably. Fully annealed copper is almost invariably used as a solid wire or tape in the case of coaxial pairs. Further improvements have been found to be necessary quite recently in the development and use of coaxial cables to reduce the "slivers," or fine splinters of copper on the centre wire or return tape. These slivers, frequently originally flat on the conductor, are caused to protrude when the cable is bent during manufacturing or laying operations, particularly when a current is applied to the circuit, and cause contacts. To ensure the maximum freedom from such slivers, greater care is taken with the copper billets, which are frequently machined before rolling.

Insulants.

There has been more variation in the development and construction of the insulants used, as in addition to forming the insulation or part of it, they have to support and space the conductors mechanically. In the case of internal cables, which have to be opened up for connecting to frames, etc., it is still necessary to use non hygroscopic materials as far as possible, and for these cables impregnated textiles have mainly been used until the present day. Although a tight lapping of paper has been used in Continental Europe, this paper being of a very special quality, was expensive and is not now used. The more recent development is in the use of the various plastic materials, but these materials have far from superseded textiles at present.

Due to its high electrical quality, silk has been used considerably as the insulant placed immediately over the wire, and today this has been replaced largely by artificial silks which, generally, have some advantage over natural silk for this purpose, but they are still being further developed. Cotopa, an acteylated cotton, is also sometimes used. As an insulant, cottons, and sometimes wool, are mostly used for their better mechanical or fire resistant properties, respectively. The plastics used are mainly P.V.C., and sometimes polythene, but with these it cannot be said that the problem of "cold flow" has been satisfactorily overcome, nor is it generally considered that the colour combinations obtainable are satisfactory for all purposes. The tendency is to use the plastic as an insulant immediately over the conductor, which is then lapped with coloured textiles, both for protection against cold flow of the plastic and identification purposes, as multicolours can be obtained more satisfactorily than with plastics to date. By the use of the plastic over the wire it is hoped to obviate the use of enamelled conductors which have frequently been found necessary, particularly in Australia, with textile insulants in internal cables.

For external cables, dry paper has been used almost entirely until recently. To obtain the maximum air space immediately around the conductor where the strongest electric field exists, and so reduce the electrostatic capacity, paper in the United States was lapped around the conductor, and was wrinkled in such a manner that the wrinkles supported the paper away from the wire and trapped a large amount of air between the paper strip and the conductor. In Europe, a paper string was first applied to the conductor, followed by a paper tape, to form a more or less smooth tube. The string supported the paper and allowed a considerable amount of air to remain between the turns and thus between the paper tube and the conductor.

The paper used has been good quality Kraft paper made at first from manila stock, but later from a wood pulp, and now frequently a mixture of the two. Paper from manila stock is stronger and more flexible than paper from wood stock, and also has a slightly lower specific inductive capacity, but is more expensive. Wood pulp paper, made by the sulphate process only, is normally used as a cheaper alternative and it has a slight advantage in that it can be dried more easily, but the decision regarding the choice of paper is usually dependent upon availability and cost.

Apart from high insulating properties, the paper has to have considerable mechanical strength as it is applied to the wires generally at relatively high speeds and in order that it may be dried easily, must be highly hygroscopic. The normal papers are generally considered quite suitable for voice frequency circuits, but for carrier circuits operating at about 200 k/c or above, an advant-

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age can be obtained electrically with acetylated paper, but its reduced mechanical strength more than outweighs its improved electrical qualities. No other types of paper are satisfactory electrically.

For identification purposes in the field, coloured papers were originally used on different conductors, but in order to reduce the variations in electrical quality a plain undyed paper is now normally used which is printed when slit in the factory. This avoids many differences due to different dyes and allows paper from adjacent parts of a roll to be used for insulating the conductors of one circuit, and further reduces as far as possible the differences that result from variations in thickness of the paper.

More recently some experiments have been made with polythene insulated carrier cables. For coaxial cables operating at still higher frequencies after the early use of ebonite in the form of discs in the United States and Great Britain, and a special ceramic disc by some manufacturers in Germany, polythene or similar plastics are now used almost entirely. The polythene is most generally applied as a disc, but sometimes also as a cord or tape applied to include the maximum amount of air consistent with mechanical stability, and for short leads as a solid dielectric.

An interesting development which so far has been limited to the Bell System in the United States, is the application of paper pulp immediately to the wires to form conductors for local cable circuits. This was developed in the early thirties, when it was found that manila paper was becoming more difficult to obtain in the quantities and qualities required for use with the high-speed insulating machines. The process can be regarded as a mass-production method applied as far as possible to cable-making, and the machine consists essentially of a paper-making unit at one end, the wires picking up the pulp at the screens which are either of the cylindrical (mould) type or Foudrinier type. Following this, the pulp is formed into a cylinder surrounding the wire, very rapidly dried and taken up on bobbins at the far end. As the application of solid pulp to the wire resulted, due to its high density, in a high electrostatic capacity in the cables, the drying was made as fast as possible, which tended to "explode" the moisture out of the pulp and lower the pulp density. With this method a reasonably low mutual pair capacity can be obtained in the final cable with extremely high outputs. In fact, one of the smaller machines in which 32 wires are insulated simultaneously, could just handle the minimum requirements as known at present in Australia, whilst two such machines could easily handle the maximum requirements. It is interesting to note that the Western Electric Company has a large number of larger machines (60-wire) in operation, to supply the demands of the Bell System in the United States. There are, of course, many more considerations which are too complicated to discuss here regarding the types and application of insulants that can be adopted.

Circuit Arrangements.

In addition to the two arrangements of the conductors to form a circuit mentioned above, that is two conductors uniformly twisted about one another and generally known as the "twin" or "pair", and the coaxial pair in which an outer conductor surrounds and is coaxial with the inner conductor, there are several other arrangements in use or that have been used. The first development from the twin arrangement was the so-called "multiple twin" and quad in which two pairs ("twins") are uniformly twisted together to form a quad. The advantage of this arrangement was that a further circuit known as a phantom circuit could be obtained by using each pair as a single conductor, and thus superimposing a circuit on the quad. This arrangement is still used in the United States and also on the European Continent, where it is known as the "Dieselhorst-Martin" type, but it is no longer used in Great Britain or in Australia. The whole quad has to be very well balanced, which involves three intimately associated twists.

An earlier arrangement had been the "spiral-four" or "star-quad" arrangement, in which four wires are uniformly twisted together to form a quad, and the diagonally opposite conductors used to form pairs. This arrangement gives a lower mutual pair capacity compared with the multiple twin arrangement. However, it will not give an economical phantom circuit, for whereas the multiple twin can be produced to give a mutual capacity ratio of the phantom-to-pair circuits of about 1.6, the star quad cannot be produced satisfactorily to give a similar ratio much lower than 2.7. However, the star quad arrangement has been used for a considerable time in Great Britain and Australia, and to a smaller extent in other countries, but without using the phantom circuits except for occasional service or telegraph purposes.

An early development of the spiral four arrangement was the "spiral eight" in which four pairs were uniformly twisted together to form a unit, from which "superphantoms" could be obtained. This arrangement was rather inflexible and had a short life, and is not now used anywhere.

Cabling

Whatever the circuit arrangement or arrangements adopted, they are stranded together to form a cable core. During the early days of development it was quite common to strand together circuits of different arrangements and different conductor gauges, and frequently, different electrical characteristics. These composite cables needed very careful design and manufacture to obtain not only the electrical characteristics desired, but to maintain them uniformly from length to length, particularly for long-distance cables in which the different types of circuit were mostly desired.

However, there has been a constant tendency towards simplification, and today most countries have standardised a few cable types each of which contains only one type of circuit of one conductor gauge. The selection of twist lengths and stranding lays where balanced circuits are concerned needs very careful consideration, and standardisation of a few simple types of cable has reduced the problem of the cable maker considerably.

At voice frequencies it is generally necessary to consider only the capacity couplings between the circuits, for which it is necessary to ensure that the circuits adjacent to one another within a layer, and circuits in adjacent layers, have different twists. In other words, those circuits exposed to one another and not screened by intermediate circuits must have different twists. However, for unloaded carrier operated cables having lower impedances, magnetic couplings become of more importance when the screening effect of intermediate circuits becomes less effective, and then it is necessary to employ many more different twists for the different circuits. It is not sufficient to select different twists only, as, of course, the circuit twist is associated with the stranding lay, which also has to be considered, depending upon how the cable is actually stranded. In other words, consideration must be given to whether the circuits being stranded should actually receive another twist while being stranded, or whether provision should be made to avoid this. The subject is extremely complicated, and cannot be discussed further here, but it has been the practice in the United States, Great Britain, Australia and most other countries, to strand so that extra twists are given to the circuits, whilst in Germany the reverse has been the case.

The number of circuits in a uniform cable increases by approximately six in each succeeding layer as the pitch diameter increases by twice the circuit diameter, and therefore the pitch circle increases by 2π times the diameter of the circuit, or approximately six times, allowing for the change in the cross section of the circuit due to stranding. With such circuits as those of star quad construction it is necessary to adhere to this fairly closely, but with the multiple twin construction more latitude is possible without serious deterioration of the electrical qualities of the circuits.

Normally the succeeding layers are stranded alternately in reverse directions, but a smaller overall diameter can be obtained if some or all layers are stranded in the same direction; this latter arrangement also will tend to reduce the couplings between circuits in adjacent layers to some extent, as it reduces the number of cases in which the circuits in each layer are contiguous with one another. However, mechanically it is not quite so satisfactory. It has been remarked in the foregoing that in general the problem of the stranding lay is bound up with that of the twist of the individual circuits, and a common lay for all layers simplifies the selection problem to some extent, but mechanically it is desirable to use shorter lays on the outer layers whilst the reverse is the case electrically. For flexibility shorter lays are desirable, while for economic reasons longer lays are to be preferred. It is obvious, therefore, that the final decision is rather involved and frequently a compromise.

The stranded cable core is generally lapped with paper tapes or even cotton tapes in some cases. The primary use of these tapes is to ensure that the cable core is held together during subsequent operations, and that the circuits are insulated from the metal sheath, for the satisfactory insulation between two conductors generally depends on the combined insulation from both conductors, and that in a single conductor is not considered sufficient in itself in many cases. The core wrapper also serves other purposes. For external cables and many internal cables, a metal sheath is necessary to stabilise the electrical characteristics, and in order that the mutual pair capacity shall not be affected excessively by the metal sheath, a certain spacing is necessary, which is provided by the core wrapper. There is frequently a need to protect the cable core against damage from lightning or power failures, for which thicker core wrappers are provided to give a higher dielectric strength. Again, in carrier cables, eddy current losses in the circuits due to proximity to the sheath must also be considered, and these can be reduced by increased core wrappers.

Protection

The wrapped core of external cables must first be protected from moisture, and, therefore, these cables are almost invariably covered with a metal sheath, which is generally of pure lead or lead alloyed with a small amount of another metal, mainly to increase its resistance to fatigue. Formerly an addition of up to 3% of tin was usual, but due to the high price of tin, other metals were investigated, and the Bell System adopted very early an alloy containing about 0.85% of antimony, which today remains their standard. Quite a number of other alloys have been investigated and used, but in general the lead plus 0.85% antimony remains easily the best general alloy where resistance to fatigue is required, and has generally been adopted for this purpose.

Smaller amounts of antimony (0.1%) have been added to nominally pure lead sheaths for some time, to give a small improvement in the ability of the sheath to withstand fatigue, and it has been accepted by the British Post Office, and Australian Post Office. The main disadvantage of the use of the antimony alloy is that the cost is increased appreciably, as not only is there an extra cost for alloying, which needs to be done in two stages (first a master alloy of about 13% antimony, which is the eutectic, and then a final alloy of 0.85% antimony), but also there is a reduction in the output during manufacture at the lead presses.

For external cable plain lead-covered cables are generally satisfactory when drawn into ducts, but in certain areas the lead needs to be protected against corrosion, when perhaps the most usual method is to apply over the lead, lappings of paper tapes and hessian tapes with a coating of bituminous compound between each. However, much work has been done, and is still being done, to develop a satisfactory plastic protection for the lead of such cables. This is not solely a cable-making problem, but also a field problem of jointing and maintenance. One of the difficulties associated with such developments is that very little can be done in the laboratory, and extended field experience is very necessary; so that an improvement cannot safely be adopted for a considerable time after it has been first initiated. In passing it may be noted that where Italian railway cables are laid along tracks in which D.C. is used, they are completely rubber sheathed. Although this has proved very satisfactory it is, of course, very expensive.

Where a cable has to be laid directly in the ground, it is usual to protect the lead sheath in any case, and this takes the form of layers of paper, jutes, beddings, steel tapes or steel wires, or even a combination of both, and a final serving of jute yarns or hessian tapes, which is known as "armouring". Steel wires are rather more expensive than steel tapes, but add considerably to the tensile strength of the cable. Normally they are round galvanised wires in one or two layers, but sometimes flat wires, or even shaped interlocking (Z-type) wires are used. It is claimed that these give a little more protection to the lead from blows by picks, etc., but they must necessarily be applied so that the wires receive a twist which increases the tendency of the cable length itself to twist during insulation. Round wires are normally applied in such a manner that they are not twisted about their own axis in application to the cable, so that there is no torsion in the wires after application.

Lead is a metal that is said to be becoming scarcer, and, therefore, efforts have been made to replace it for cable sheaths by other metals, but due to its ductility at normal temperatures and comparative ease of extrusion in a plastic state at reasonably low temperatures to produce a pipe to fine tolerances, it is still used almost exclusively. However, the Western Electric Company of the United States has for some little time been producing alternatives for its local cables, and the most extensively used so far, has been described as "Alpeth", which essentially consists of a corrugated aluminium strip to give flexibility, wrapped around the core with a longitudinal overlapping seam. This is coated with a thermoplastic cement, which is intended also to seal the seam. Over this is applied a sheath of black polythene. A further and subsequent development has been that described as "Stalpeth", which consists of a corrugated aluminium strip lapped immediately around the paper wrapped cable core so as to leave a small longitudinal gap. Over this is applied a corrugated terne coated steel strip with an overlapping longitudinal soldered seam and, finally, as for Alpeth, a thermoplastic cement and a sheath of black polythene. So far extruded aluminium sheaths have not been used for telecommunication cables, although some work is being done in this direction.

Cables sometimes need to be protected against lightning damage, although generally, this is not very important in Australia. Many methods have been tried to give protection against lightning, but recently the Bell System has produced a protection known as "Lepeth," which is said to be very satisfactory. This consists of a natural polythene sheath over the cable core followed by a thermoplastic cement and the lead sheath.

Both the lead sheath and the armouring combined serve as a protection or shield against electrical interference in the cable circuits. Generally the lead sheath is required to be sufficiently thick for mechanical reasons to give the necessary protection, but for cables along electrified railways, special armouring wires have been produced in Europe, although generally they have not been considered to be justified and normally lead covered and armoured cables are considered quite good enough. For carrier operated cables with the circuits transmitting in opposite directions in separate cables which are laid together in parallel, it is necessary in some cases to specify a minimum sheath thickness to ensure satisfactory freedom from mutual interference.

Plastic sheaths may prove to be satisfactory for external cables, although as no plastic is completely impervious to moisture, it is still doubtful, and in any case, a metal tape will normally be needed apart from any screening needs, to stabilise the electrical characteristics, particularly the mutual electrostatic capacities.

Some internal textile insulated cables are protected with a lead sheath, but a large number are protected with a cotton braid which is finally treated with a flame resistant paint. Braiding is a slow operation and is in some cases replaced by a knitting process, but a more recent development has been to replace braiding to some extent by a plastic (P.V.C.) sheathing.

Types of Cable

The types of cable to be used for any particular purpose are generally a compromise decided by the Engineers of the Operating Department, who have first to consider the traffic requirements, after which the system as a whole, including transmission equipment available, as well as the cable types available, have to be considered. The cablemaker, therefore, does not deal with an entity, but at best only lengths forming part of a complete cable scheme, and more frequently only part of a complete system of cable equipment.

Until the advent of loading, telecommunications cables were limited in their use mainly to local circuits, and although some longer circuits were carried on heavy conductors in cables the majority were provided on open wire lines. However, early in the present century, development of long distance trunk cables commenced, chiefly in the United

States of America where they are known as "toll cables". Today these long distance circuits are more and more provided in various types of cables.

Local Cables: These cables comprise the lines required to connect the individual subscriber to his local telephone exchange, when the cables are frequently known as "subscribers' loop cables" or "distribution cables" and range in size from a single pair to 1800 or even more pairs, and also those cables connecting exchanges to one another in a local area, when they are frequently known as "junction cables."

The circuits in these cables were originally of the normal twin type, having conductors ranging in size between 4 and 40 lb. per mile, and the pairs being laid up in concentric layers to form a cable core. In general the first requirement is to include as many pairs as possible within a given diameter of lead sheath, particularly for the subscribers' cables, for which reason the diameters of the wires used have been continually reduced, the lowest in commercial use being 4 lb. per mile (0.0159") diameter, but even smaller wires have been experimented with down to 2½ lb. per mile (28 A.W.G.). However, these cables can only be used for comparatively short distances unless extra equipment is installed, as the conductor resistance becomes prohibitively high. Twin construction has always been used in the United States for these cables, but in the early thirties the British Post Office standardised the star quad for Great Britain for all types of cable. Although not of first importance for distribution cables, this allowed a lower mutual capacity to be obtained for a given cable diameter, but a further advantage was, in fact, a slightly reduced diameter for a given number of circuits in most cases. However, the capacity couplings between the two pairs of a quad were comparatively high, and there were additional couplings between the quads, but only in the case of junction cables were these couplings of importance.

Australia followed the example of the British Post Office, and the star quad cable is still the standard in this country, but since the war the British Post Office has reverted to twin construction for distribution cables, following United States practice in which the pairs are laid up in what is known as "unit type" construction. In this type of cable the pairs are first stranded together in concentric layers, in the same direction to reduce the overall diameter as far as possible, to form units of 50 or 100 pairs and these units are in turn stranded together to form the cable. In order to use all the space available as effectively as possible, the units are forced out of a circular shape and the number of units in succeeding layers do not in most cases increase by six.

The electrical quality of such cables is surprisingly good as in spite of the rather severe deformation of the units, the capacity couplings are comparatively very low. Unit type cable simplifies manufacture to some extent as no pair has to pass through a stranding machine more than twice, whatever the total number of pairs involved, while for very large cables in concentric layer construction the cable may need to be laid up in several operations, even in star quad construction, depending upon the size of the stranding machine available, which in turn needs to be very long to reduce the number of operations needed to strand very large cables. For these reasons it is preferable from the manufacturing point of view to use unit type cable for very large cables of relatively fine wire conductors, especially as for such cables, the overall diameter can be reduced to that of corresponding star quad cables. Unit type cables up to 1800 pairs having 4 lb. per mile conductors, are at present being made in Australia for the Department, who have, of course, to consider their use from the lines point of view. Unfortunately, for mechanical reasons it is not possible without considerable extra expense to reduce the amount of paper that can be used to insulate wires below 6½ lb. per mile. Thus the saving that can be effected by using smaller wires falls considerably below this gauge. In this respect pulp insulation has an advantage. For junction cables the concentrically laid up cable having twin or star quad circuits is more satisfactory, especially when it needs to be loaded.

Trunk Cables: Formerly this type of cable would have included all long distance cables, but today the classification tends to be limited to the shorter long distance cables in which only voice frequency operated circuits are included. The multiple twin type of cable, a natural development from the twin type, was first used, and is still used, in the United States and on the Continent of Europe, but the star quad cable, due to its lower relative mutual capacity, for the same overall diameter and simplified balancing and loading needed, is used entirely for this purpose in Great Britain and Australia. From the foregoing remarks it will be seen that from the cablemaker's point of view, the star quad cable has some advantages as the twist selection is simplified, and neither the mutual capacity nor the couplings of the phantom need be considered.

Carrier Cables: Special pairs have been included in trunk cables at various times which were carefully balanced and generally had lower mutual capacities, and on which carrier circuits were operated. However, today special carrier cables have been adopted in most cases for longer trunk circuits. In order to reduce near-end crosstalk as far as possible, two similar cables are laid in parallel for transmitting in opposite directions. All the circuits in one cable transmit in one direction only, so that only far-end crosstalk need be seriously considered within each cable. However, to reduce this to reasonable limits, it is necessary that each unit within each cable have a different twist length, and it is obvious that the star quad has a decided advantage in this respect as one twist only is needed for the two pairs of a quad. The two cables transmitting in opposite directions can have the same range and arrangement of quad twists. About 12 quads is a reasonable maximum which requires 12 different twists, and this can be arranged without excessive differences between the shortest and longest twist which would otherwise increase the non-uniformity of the other electrical characteristics. For a similar cable containing pairs, 24 different twists would be required, and for multiple twin 36 twists would be required to be considered whether the phantom were used or not.

It is difficult to make a satisfactory comparison between paired circuits and star quads otherwise, but the star quad circuits have some advantage over the paired circuits at carrier frequencies, as for the same number of circuits and a similar overall cable diameter the costs of the cables are approximately the same and in this case the mutual pair capacity is lower for the star quad circuits while the inductance is higher. This outweighs a slightly higher effective resistance to give a lower attenuation for the star quad circuits compared with paired circuits.

At the higher frequencies the proximity of the lead sheath has a marked effect on the circuits of the outer layer, due to the induced eddy currents, so that those circuits tend to have a higher effective resistance and lower inductance. The increase in effective resistance is about the same for star quads and pairs, although the inductance is reduced a little more in star quad circuits than paired circuits. The effect of the sheath can be offset to some extent by increasing the distance between the circuits and the sheath with increased core wrappers which is normally done, but to avoid excessive expense in this respect the circuits are jointed in the field between lengths to compensate for the residual differences that generally remain. However, it is necessary for the cablemaker to measure the parameters—effective resistance, inductance, capacity and conductance—over the frequency range it is intended to operate the cable, and as the frequency increases, this can only be done directly on comparatively short lengths. It is customary, therefore, to add a few yards to the first few lengths made, and at periodic intervals during manufacture, which are cut off for such measurements. Today the frequency range considered for carrier cables extends in some cases to 300 kc/s.

High frequency carrier and television cables: As higher carrier frequencies were used for telephone communication and later television was considered, specially balanced pairs having low mutual capacity were produced to provide the necessary circuits, but simultaneously the coaxial type circuit was developed for this purpose and has today practically superseded the balanced pair. Although this circuit is unbalanced, the outer conductor can be designed to ensure that the circuit is satisfactorily screened at reasonably low frequencies. The actual outer copper conductor is surrounded by steel tapes, and these combined prevent any great penetration of interfering currents induced from outside or the return currents of the circuits penetrating from the inside. Such coaxial pairs are usually cabled together as "go" and "return" circuits in multiples of two, together with paper insulated service circuits to form a single cable.

For optimum attenuation the ratio of the internal diameter of the outer tube to the external diameter of the central conductor has been found to be 3.6 when both conductors are of the same material. For normal telephone and television traffic, a circuit having an internal diameter of the outer copper tape of 0.375" has been generally standardised, although much larger diameters have been used for special television circuits. The central conductor is usually of solid copper surrounded by plastic discs or cords for the dielectric supports. Early units had shaped multi-copper tapes laid helically over the insulating materials, and the currents tended to follow the helical path of this conductor. Therefore, to reduce the attenuation to a minimum, the outer tape is now usually a single copper tape having a longitudinal seam. Up to eight such units are laid up with paper insulated service circuits to form a cable which is paper lapped, lead sheathed and armoured in the usual way as far as required. For special leads, coaxial circuits are frequently made with a solid dielectric, as are, of course, most submarine cables.

Internal Cables and Wires: Internal cables generally have the copper wires coated with tin or enamel or both. Tinning is necessary with rubber and plastic insulation, but is also useful to assist jointing in the field. However, to maintain the insulation resistance as high as possible in humid conditions, enamelled wires have been found desirable and tinning then loses much of its value. Tinned enamelled wire is not, therefore, used to any great extent. Various textiles are used to lap the tinned or enamelled wires to suit the requirements of the installation and operating conditions as far as possible, while plastics are applied to tinned wires only.

Plain plastic insulation although frequently used, has disadvantages which have not yet been satisfactorily overcome, such as the limitation of the colour schemes available, cold flow and damage when soldering during installation. For these reasons plastic insulated textile lapped and lacquered conductors which also have the advantages of enamelled wire are gaining popularity.

Single conductors, pairs, triples and multiple twin or star quads are stranded together to form the cables as required. The triples have generally been formed from a uniformly twisted pair and a straight single conductor laid in parallel, the whole being whipped with a cotton binding. There is now a tendency to twist all three conductors uniformly about a common axis, especially with plastic insulated conductors, or to lay the singles as a bunch in the centre of the cable with the associated pairs surrounding them, which allows some reduction in the overall diameter of the cable.

To prevent the cable absorbing moisture and the insulation unravelling during jointing of the conductors, the textile insulated cables are generally impregnated with a suitable insulating wax, but in many cases a cellulose lacquer is applied over the conductors for this purpose whether the conductor is entirely insulated with textiles or is plastic insulated and textile lapped. These remarks apply equally when uncabled switchboard wires are supplied.

The cabled core is protected with a lead, a braided or a plastic sheath. If the cable is to be impregnated and lead sheathed, it can be lapped with core wrappers and impregnated immediately before lead covering, but if it is to be braided overall, it is normally required that the braid shall be coated with a flame resistant paint, and to ensure that the insulation resistance of the cable will not be deteriorated by the paint, it is usual to impregnate the core before putting on the core wrappers which include an oiled paper to prevent any penetration through the wrapper. Metal foils are also included in the wrapper if required. Although not otherwise necessary, it is usual to wrap plastic insulated cores with a tape before applying a plastic sheath, to prevent the sheath from running into the interstices of the core.

Inspection and Shipping

All the cables are subjected to both mechanical and electrical inspection which, in some cases, is fairly extensive, in order to maintain and improve the quality of the product and also to develop cables for special requirements, but this subject requires separate treatment. With the exception of small switchboard cables, most cables are shipped on wooden drums which for convenience are made in standard sizes, but they vary widely in different countries, and in some cases metal drums are used, particularly by the Western Electric Co. in the United States.

It is necessary for the cablemaker to ensure that the diameter of the drum barrel is sufficiently great for the size and type of cable to be shipped, and that the drum is satisfactory to carry the cable when subjected to shipping and field conditions. Further, the drum must have the minimum satisfactory overall dimensions when shipped any distance, and conform to the limiting conditions set by the installers, and their equipment.

Conclusion

Today it can be said that all the normal telecommunication cables can be produced in Australia in the quantities required from locally produced raw materials, with the exception of the insulants, but even here progress is being made and within a very short time the country can expect to be self-sufficient in all respects.

ARTIFICIAL TRAFFIC EQUIPMENT

W. R. DEDRICK, B.Sc.

Introduction

The artificial traffic equipment is a new type of equipment installed about three years ago at City West Exchange, Melbourne. It is designed to perform two main functions, namely:—

(a) To set up calls within an automatic exchange or exchange network, record the number of faulty calls, and by comparison with the total calls made, assess the condition of the exchange equipment.

(b) Whilst performing function (a), to locate faults by holding the connection and indicating the stage at which the failure occurs.

The testing circuits are similar to those incorporated in automatic routiners with, however, one fundamental difference. Whereas the routiner tests individual items of equipment, which must be taken out of service for the purpose, the artificial traffic equipment checks the operation of apparatus under actual service conditions, and hence will detect faults not apparent to the routiner, for example, stop on busy, faulty metering, faulty trunking and wrong numbers.

The unit is rack mounted (6′ 6″ x 1′ 9″ approximately), is self-contained, and may be easily transported and secured in position. A photograph of the rack is shown in Fig. 1. An impulse unit and time delay circuit are included, and the only external connections are cables or jumpers to the I.D.F. to provide incoming and outgoing circuits, and power and alarm extensions.

The equipment was originally developed for use in the British Post Office, and a description has been published previously in Reference 1.

Facilities

Selection of Numbers: Connection is made via outgoing and incoming access uniselectors to 24 spare line circuits and 25 spare final selector numbers, and calls are made automatically to each final selector number in turn from each line circuit, the complete cycle comprising 600 calls. The subscribers' line circuits and final selector numbers should be uniformly distributed throughout all groups in the exchange, unless, of course, it is desired to concentrate on one section of the equipment, and calling equipment should, as far as possible, be chosen so that all the outgoing multiple is tested. Some final selector numbers should include spare lines in P.B.X. groups to check the P.B.X. rotary facility.

Testing Facilities: The testing facilities provided by the artificial traffic equipment fall into two main classifications:

(a) The testing of the loop and the private wire whilst a call is being set up.

(b) The testing of the operation of the final selector in a manner similar to a final selector routiner.

Meters are provided to register the total number of test calls made, the number of faults encountered, and the number of calls failing due to "all trunks busy". Lamp indications are given to show the progress of the call, and to indicate that failures have occurred as follows:—

1. A or B wire disconnection.

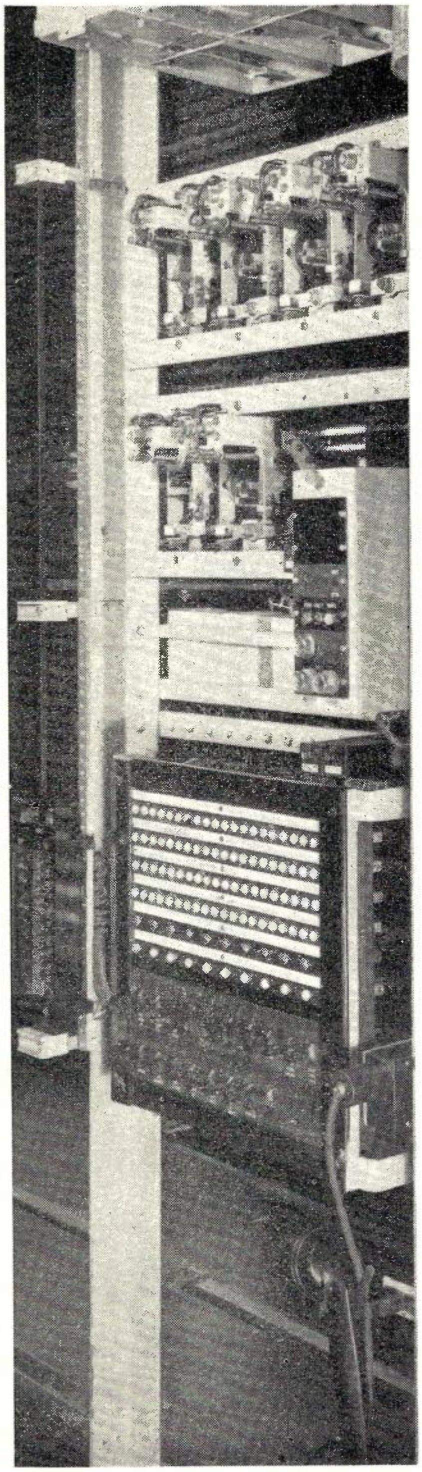


Fig. 1.—Artificial traffic equipment rack.

2. Full or intermittent private wire disconnection.
3. Ringing failure due to misrouting of the call.
4. Failure to trip the ringing current from the final selector.
5. Metering failure.
6. Premature release of the call during called subscriber flashing condition.
7. No release on completion of test cycle.

The following additional facilities are provided:—

(i) A non-standard tone (interrupted battery) to assist in call tracing.
(ii) A handset speaking point.
(iii) Impulses may be released one train at a time to observe the performance of individual switches.
(iv) A test jack on the 25th outlet of the outgoing access uniselector enables connection to be made to any required first selector.
(v) Access stepping and continuous test keys enable continuous tests to be performed on equipment suspected of being faulty.

Observe Service Operation: In this condition the equipment passes calls through the exchange at the rate of approximately 125 per hour and the number of calls which fail is recorded. From a comparison of the readings of the "total calls", "faulty calls" and "busy calls" meters, a direct indication of the grade of service on local calls within the particular exchange is obtained.

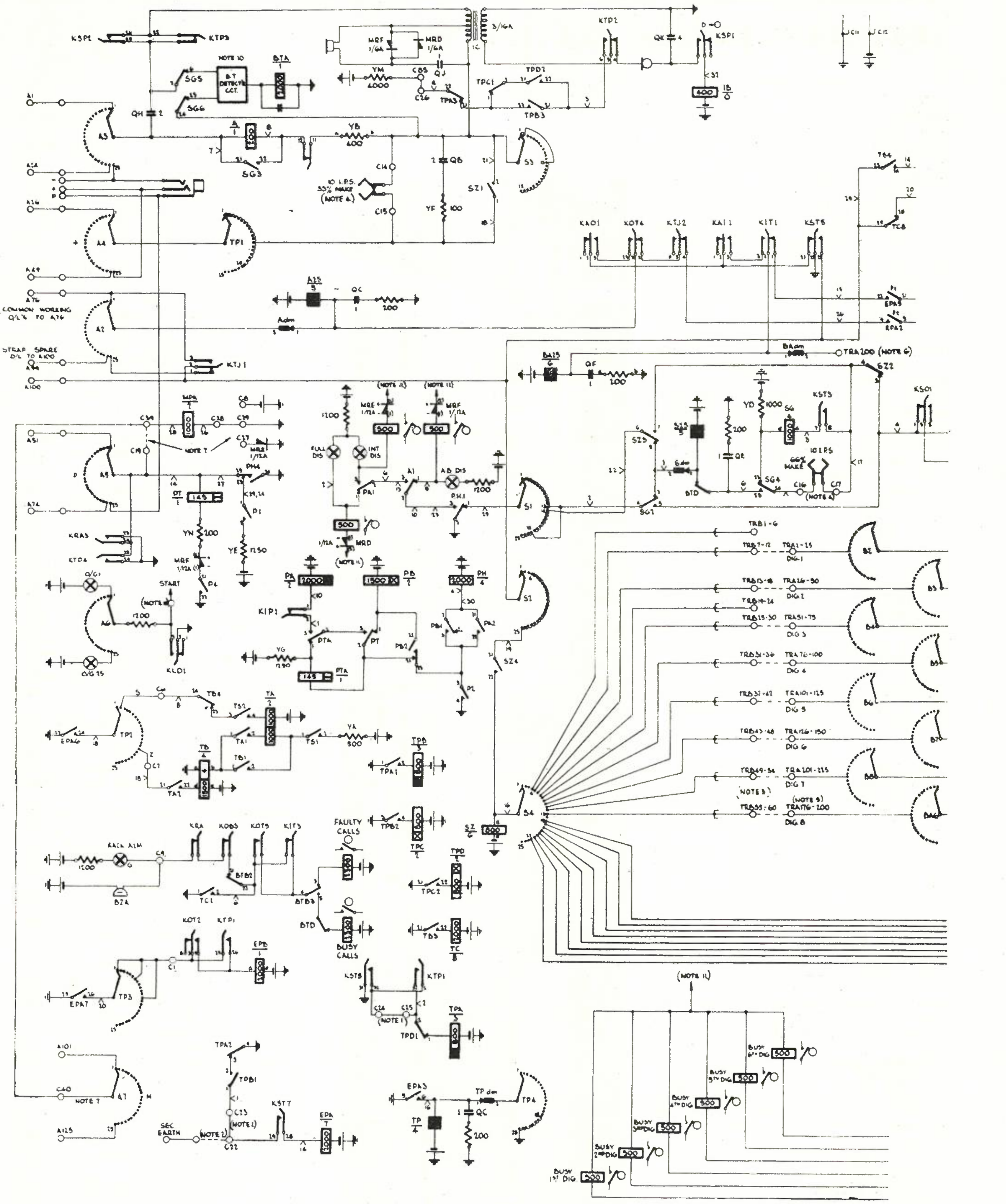
Operation as Fault Detector: When operating in this manner, the equipment stops when a fault is detected, a lamp indicates the cause of the failure, a visual and audible alarm is given, and the call is held by a forward holding earth to permit the location of the trouble. The meters, as under Observe Service conditions, record total, faulty and busy calls.

Automatic Network Application: To date the equipment has been utilised solely to check calls within one main exchange, as owing to the congested junction position, it has not been practicable to make three wire circuits available in junction cables between subscribers' line equipment and final selector numbers in branch exchanges.

Functions of Uniselectors

Outgoing access switch A: Referring to Fig. 2. A switch has spare line circuits cabled to A3, A4, A5 banks (−, +, P) and the switch steps over contacts not in use and which are commoned. The A2 bank and key KTJ1 are used to drive the switch to the 25th contact to connect the test jack used for testing any selected piece of equipment. A6 and lamps indicate the position of the switch. A7 is used in connection with metering (see note 7 on the drawing). Tests are applied via A3, A4, A5 banks.

The switch may be stepped manually by means of keys KAO, KOT, and is set on the first contact at the start of tests. The trains of impulses are sent out via A3, A4 and at the end of a success-



NOTES—

1. CONNECT FOR INTERNAL 1 SEC. EARTH
2. CONNECT FOR EXTERNAL CLOCK PULSE
3. TRANS FIELD TYPICAL CROSS CONNECTIONS
4. FOR INTERNAL CONNECTIONS :—
   STRAP C13 TO C33
   " C14 " C34 WHEN REQUIRED.
   " C15 " C35 " "
   " C16 " C36 " "
   " C17 " C37 " "
   " CONDENSERS TO MEET IMPULSE REQUIREMENTS
5. 4 DIG WORKING COMMON AS REQD TRA101-150 & 176-225 & STRAP TO DCO (Tdm)
   5 " " " " " TRA126-150 " 176-225 " " " " "
   6 " " " " " TRA176-225 " " " " "
6. SPARE O/L'S COMMON AS REQD TRA 151
7. CONNECT AS REQD FOR APPLICABLE METERING CONDITIONS
8. STRAP NORMALLY APPLIED. REMOVE WHEN NOTE 7 APPLIES
9. U JACKS APPLY TO BASE WHERE RELAY OR CONTACT IS MOUNTED.
10. CITY WEST RELAY LAYOUT :—
   BASE 1 PA, PB, P, PT, MPA, PTA, PZ, PRA, MP, MRF, YE, YG, YN
   BASE 2 TPA, TPB, TPC, TPD, TS, TC, TA, TB, EPB, IB, YD, YA,
   BASE 3 IP, IPA, EPA, IPB, PH, PO, QZ, BTB, BTC
   BASE 4 SZ, SG, AD, AC, IA, D, A, PS, MRB, MRA, MRC, YD, YC, YH, QA
11. BUSY TONE DETECTOR CIRCUIT (SEE SHEET 2)
12. BATTERY FOR FAULT AND BUSY METERS VIA TCG

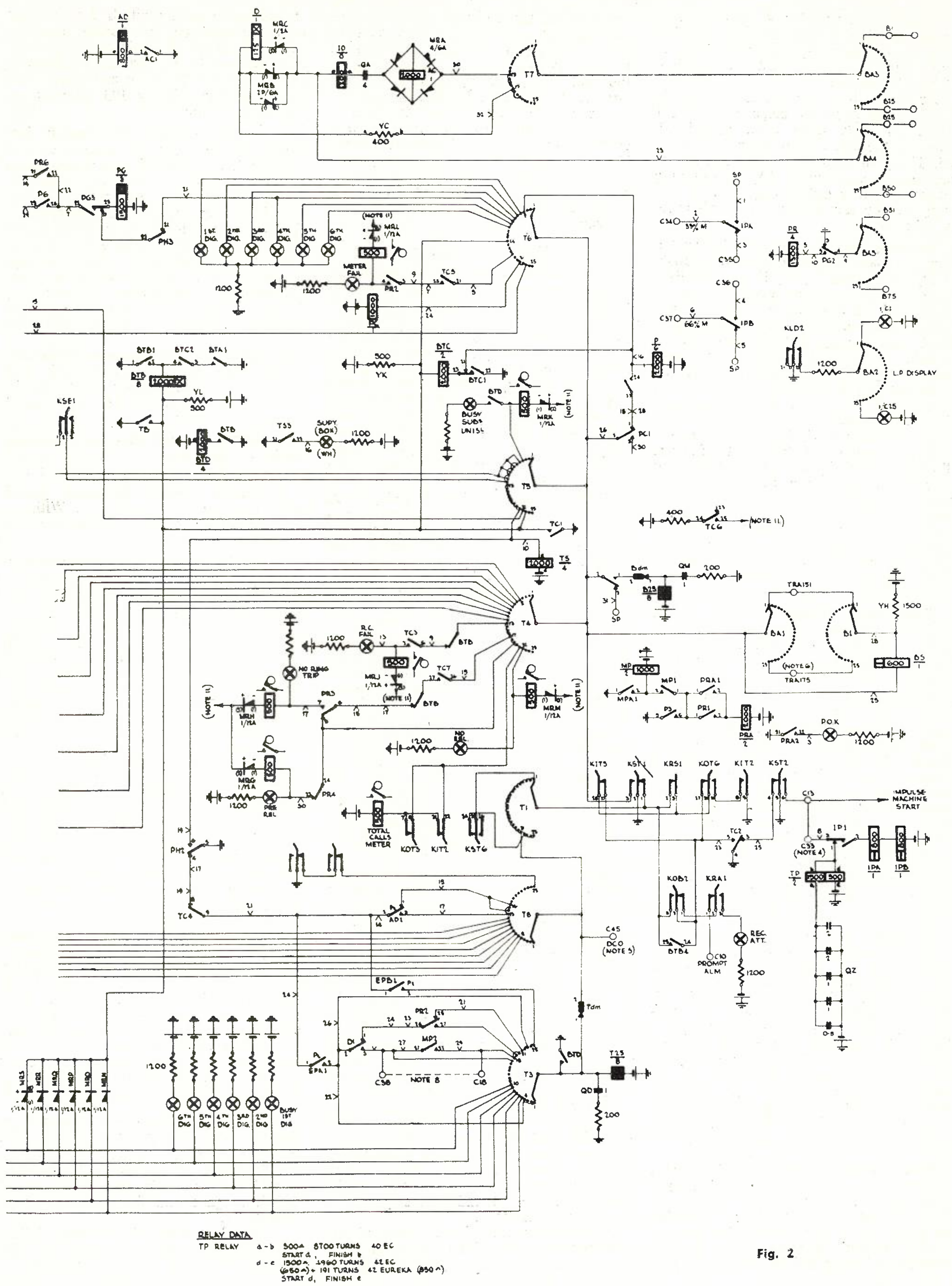

L.P. DISPLAY
IMPULSE MACHINE START
TOTAL CALLS METER
NO RING TRIP
PROMPT ALM
REC ATT.
RELAY DATA
TP RELAY a - b 500 8700 TURNS 40 EC
START a, FINISH b
d - e 1500 1960 TURNS 42 EC
(650)+ 191 TURNS 42 EUREKA (850)
START d, FINISH e

Fig. 2

ful call access switches A and BA (the called number is connected to the latter) receive step-on impulses, but BA steps first, via T switch 22 contact, then A via 23 contact.

As the A1 bank contact 25 is normally earthed, the A switch steps to contact 1 when 24 calls have been completed, whereas the BA switch steps to contact 25. Thus, on each half revolution of the incoming access switch BA, the outgoing access switch is out of sequence by one step, and by this means a 600-call cycle is achieved.

Incoming access switch BA: BA switch has 25 spare numbers cabled to BA3, BA4, BA5 banks (−, +, P) and the BA1 bank contacts are commoned as required to provide for stepping over contacts not being used (see note 6 in drawing). BA2 bank and lamps indicate position of switch. BA6 bank contacts are commoned to DCO terminal so that the T switch self drives over the 12th contact which relates to 8 digit working. The switch may be set manually by means of keys KAI, KIT, and is set on the first contact at the start of tests. Tests are applied via BA3, BA4, BA5 to check that the call is successful in regard to ringing, reversal, metering, etc., and BA then steps to the next number via T22 contact. Thus, switch BA makes one step at the end of each successful call, and self drives over any contacts not being used in the event of less than 25 lines being available for tests.

Time pulse switch TP: TP switch steps one step per second under the control of the EPA relay, which is operated by a pulsing relay set and is used to provide 6 sec. pulses and 17 sec. pulses.

T switch: The T switch steps one step per second in unison with the TP switch, under the control of EPA relay, via T3 bank, until the T switch wipers reach contact 5. Further stepping of the T switch occurs after each digit has been dealt with as a result of the S4 wiper passing over contacts 15-22. After the digits have been completed, the T switch steps after each test, but on contacts 22 and 23 the earth pulse via EPA1 is employed. Then on 24 and 25 an earth causes the T switch to self drive to contact 1. The T switch can be controlled by keys to reset the switch.

B switch: The B switch remains on contact 1 until the first call is completed; then when BA steps to the next connected line the short circuit via banks BA1 and B1 is broken, BS operates, the B switch self drives until the B1 wiper overtakes the BA1 wiper and the short circuit is restored. Thus, as the BA switch steps to each connected number in turn, the B switch then steps to the corresponding position on the B banks where the contacts are jumpered to the S4 bank in accordance with the sequence of digits required to be impulsed via the A switch.

Sender switch S: The S switch remains on contact 1 until the T switch has been stepped by earth pulses to contact 5, when SG operates via wiper T5 during an open period of the impulse springs. The S magnet is stepped via impulse springs and after the 2nd step, wiper S3 removes the short circuit from the dialling springs and impulses are sent to line. When S4 reaches the contact marked by wiper B2 (corresponding to the first digit) SZ operates and short circuits the impulses to line. S then self drives via SG2 and S1 bank to earth at PH1 until contact 14 is reached when it continues under impulse spring drive via SZ3 until contact 22 is reached when self drive continues via SG2 to contact 1. When S reaches contact 22 the T switch is stepped on as described previously.

Circuit Description

When the start key (KST) is operated, the one second earth pulse circuit is connected to relay EPA via KST7. Earth via EPA3 steps the TP switch one step per second. If a faulty condition occurs while impulsing or while the ringing, ring trip, reversal or metering functions are being tested, the T switch will stop and with relay TS operated, relay TA operates from earth via wiper TP2, and if the fault condition is maintained until the TP switch wipers reach contact 17, relay TB operates and locks, and an alarm is given.

T Switch contacts 1 to 4: Relay EPA operating to the earth pulse circuit connects earth via wiper T3 to the T switch magnet and the T switch steps to contact 5. Earth via KST1 is connected to wipers T4, T5 and T6, KST4 completes the loop to the first outgoing test line and relay A should operate. When wiper T6 reaches contact 4, relays BTC and P operate and lock. Contacts of P complete the operating circuit of the high speed relay PT connected to the P wire, but if the outgoing circuit is correct earth returned on the P wire short circuits relay PT. If the loop to the outgoing line is not complete, relay A will fail to operate and earth will be removed from the P wire. In this case, relay PT operates; this allows relay PB to operate and lock to earth via P2 contacts. With relay PB operated, the circuit for relay PH is completed and this relay operates, prevents the T switch from stepping and operates relay TS. The operation of relay TS completes the delayed alarm circuit. If the outgoing line conditions are not faulty relay PT will remain short circuited and the T switch steps to contact 5.

T Switch contact 5—first digit: Wiper T5 connects earth to relay SG which operates during an open period of the 10 I.P.S. impulse springs. This allows the S switch to step via the 10 I.P.S. impulse springs. The first number to be dialled is determined by the jumpering from the first contacts of the B switch to the S4 bank. When wiper S3 passes the second contact, impulses are sent to line until wiper S4 reaches the contact marked by wiper B2 when relay SZ operates and short circuits the impulses to line; relay SZ locks until the S switch reaches contact 1. When the S switch reaches contact 22, earth via KST5, wipers S2 and S4 and SZ4 steps the T switch to contact 6.

T Switch contacts 6 to 12—second and subsequent digits: The operation is as described for contact 5; the T switch is stepped after each digit. If 5 or 6 digits only are required, the wiring from the remaining B switch banks and BA6 bank is commoned to the digit cut off terminal DCO, and the T switch self-drives over these contacts. Relay PG operates on the 4th digit and locks.

T Switch contact 13—ringing first cycle: When wiper T5 reaches contact 13 relay TS operates; a loop is connected across the outgoing line via wiper S3. Wiper T7 connects AC relay and retard IA across the called number. Relay AC operates during the ringing period and in turn operates relay AD. An earth pulse via AD contacts operated is connected to the T switch magnet via wiper T8 and the T switch steps to contact 14. If ringing current is not received the T switch will stop and the RC fail lamp lights.

T Switch contact 14—open period following ring: Relay AC falls back after ringing pulse and releases relay AD. An earth pulse via wiper T8 steps the T switch to contact 15.

T Switch contact 15—ringing second cycle: As for contact 13. With relay AD operated, T switch steps to contact 16.

T Switch contact 16—open period after ring: As for contact 14. With relay AD normal, earth pulse via wiper T8 steps T switch to contact 17.

T Switch contact 17—ring trip-reversal: When wiper T7 reaches contact 17 relay D in series with a rectifier is connected across the called loop. The ring should trip and a reversal of battery should take place and operate relay D. The operation of relay D connects earth pulse to the T switch magnet via wiper T3 and the T switch steps to contact 18. Should the reversal not take place, relay D will remain unoperated, the T switch will fail to step and the no ring trip lamp will light.

T Switch contact 18—metering: The metering pulse returned on the P wire of the outgoing line should operate relay MPA, which in turn operates relay MP. The operation of relay MP, which locks to earth via P3 contacts, completes the stepping circuit of the T switch magnet and the switch steps to contact 19. If the meter pulse is not received, relays MPA and MP will fail to operate and the meter fail lamp will light.

T Switch contact 19—called sub flashing: When the T switch reaches contact 19, the loop is removed from the called line. Relay D releases, but relay PR should remain operated. With D relay normal and relay PR operated, earth is connected to the T switch magnet and the switch steps to contact 20. If the final selector releases prematurely, relay PR will restore, prevent the T switch stepping and light the premature release lamp.

T Switch contact 20—called sub flashing: When the T switch reaches contact 20, the called loop is restored. Relay D should re-operate and with MP relay locked, earth is connected to the T switch magnet and the switch steps to contact 21.

T Switch contact 21—release. When the T switch reaches contact 21, the calling and called loops are opened and the switches should release. Relay PC operates via wiper T6 and opens the locking circuit of relay P which restores. Relay PG is now held via PR6 contacts, and if earth is maintained on the incoming P wire, relay PR will remain operated and prevent the T switch from stepping. In this case, the no release lamp will light. If the call releases correctly, earth will be removed from the P wire and relay PR will restore thereby allowing the T switch to step to contact 22.

T Switch contact 22—B and BA switches steps to next number. The total calls meter is operated via wiper T4 and an earth pulse is sent to the BA switch magnet via wiper T5 and contact EPA5. The BA switch steps to the next connected line. An earth pulse via EPA1 steps the T switch to contact 23. When the BA switch steps to contact 2 the short circuit via banks BA1 and B1 is removed from high speed relay BS which operates and connects earth via the interrupter to the B switch magnet. When wiper B1 reaches the next connected number, the bridge between banks BA1 and B1 again short circuits relay BS which restores and opens the stepping circuit of the B switch.

T Switch contact 23—A switch steps to next number: Earth via wiper T6 is connected to the A switch magnet via the earth pulse relay EPA contacts, and the A switch steps to the next connected number. An earth pulse, via EPA1 steps the T switch to contact 24.

T Switch contacts 24 and 25: Earth via KOT and KTJ keys and the interrupter steps the T switch to contact 1. This completes the cycle of tests. A similar cycle is now repeated on the next connected number. It is important to note that—

1. Should a momentary open occur on the outgoing P wire during the cycle of tests, relay PT should operate as the short circuit is removed. This allows relay PTA to operate. Relay PTA prepares an operating circuit for relay PA when delay PT restores. The operation of relay PA completes the circuit of relay PH which operates, opens the stepping circuit of the T switch and operates relay TS. An alarm is given and the Int. Dis. lamp lights.

2. For Observe Service calls, operate Key KOB. With this key operated, should a fault occur, relay TC operates and TC2 connects earth to wiper T1 via the interrupter, TC1 operates the faulty or busy call meter. The T switch will rotate to contact 22 and the cycle of tests will continue on the next number.

3. If at any stage of the call, all trunks are busy, relay BTA will operate to the busy tone, followed by BTB via BTC2. Contacts of BTB disconnect the alarm, operate the busy calls meter via TC1, and complete a drive circuit for T switch through T1, BTB4, TC2, and step the equipment to the next test cycle.

Conclusion

The unit has been in operation since 1951, and has proved a valuable aid in determining the performance of the exchange under operating conditions. Typical results of tests are given in Table 1.

References

1. E. C. Elstree-Wilson and C. Lawrence, "The Artificial Traffic Equipment"; P.O.E.E. Journal, Vol. 40, page 159.

2. Note—"Artificial Traffic Equipment at Swansea Exchange"; P.O.E.E. Journal, Vol. 45, page 44.

Table 1—Results of Tests.

	Feb.	Mar.	(1951) Apr.	May	June
Number of test calls made	5072	3534	3691	6015	3452
Number of busy calls	699	346	424	430	286
Number of faulty calls due to—					
(a) No progress	60	39	51	56	64
(b) Wrong number	3	1	2	2	1
(c) Stop on busy	—	—	—	1	—
(d) Meter fail	1	4	2	—	—
The causes of failures which were traced were as follows:—					
Wipers	5	5	7	8	10
Wiper cords and tags	13	12	17	14	19
Springsets and relays	8	2	3	7	2
Wiring	—	2	3	—	—
Mechanical	4	5	11	6	11
Miscellaneous (barretters, etc.)	2	3	2	5	—
Totals	32	29	43	40	42

RIVER CROSSING BY SUBMARINE CABLE

R. T. FRASER B.Sc., and R. G. SPRATT, B.A., B.Sc., A.M.I.E.Aust.

On two important cable projects in Victoria recently, it was necessary to cross rivers about 100 yards wide and 30 feet deep. These were a trunk entrance cable for the new Sydney-Melbourne open-wire route crossing the Murray River at Echuca, and the Melbourne-Ballarat carrier cables and City West-Footscray junction cable crossing the Maribyrnong River at Footscray. As floods in recent months had damaged two cables which had been laid on the bed of the Maribyrnong River, it was decided in each case to lay the cables in a trench cut into the bed of the rivers.

An underwater examination of the bed of the river by a diver is of considerable assistance in determining a suitable track and in removing snags. A diver was not available for the Echuca installation, and considerable time was lost by the trial run methods which had to be adopted after soundings had been taken to ascertain the nature and contours of the bed. The Footscray crossing was to follow the track of the Melbourne-Geelong trunk and other cables, and the new cables were to enter the same manholes. A five yard separation was chosen as a compromise to reduce the risk of damage to the existing cables without adding too much to the length of the new cables. An inspection by a diver confirmed that this track would be suitable.

The trench was excavated in each case by dragging a bucket backwards and forwards across the river. The ideal power unit for this operation is a double-drum winch, but as none was available one winch was placed on each bank. A drag scraper bucket (Fig. 1) was used at Echuca, and a drag line excavator bucket (Fig. 2) at Footscray. The drag scraper is self-emptying and is the more suitable type, as the drag line excavator bucket requires a separate winch for satisfactory emptying. The type of drag scraper bucket used at Echuca was not equipped with teeth as shown in the photograph of a model bucket (Fig. 3). A bucket fitted with teeth would have facilitated the operation. The equipment used at Echuca, a Standard Chevrolet winch truck for the forward pull, a light friction winch for the return pull, and ½" diameter steel ropes (later changed to ⅝" ropes), was largely unsuitable owing to the rope drums being too small and the rope too light for the heavy pull. The time taken for the trenching operation after setting up on the first day was approximately two weeks using two men. The depth of trench, determined by soundings, was 18". Using a double drum winch, the operator of which has complete control of the movement of the bucket, and a second man at intervals for removal of spoil, steel ropes of a minimum of ¾" diameter, and a diver for locating and clearing snags, it is estimated that the whole operation would have taken four days.

Two 24-pair 40 lb. steel wire armoured carrier cables for the trunk route and a 74-pair 10 lb. star quad local type steel tape armoured cable for subscribers was used, and as the manholes were situated some distance up the banks, sufficient cable to reach from the water's edge to the manhole was floated across ahead of the bucket (See Fig. 4). The floating portion was drawn across by a separate winch, the speed of which was controlled to keep the last drum float,

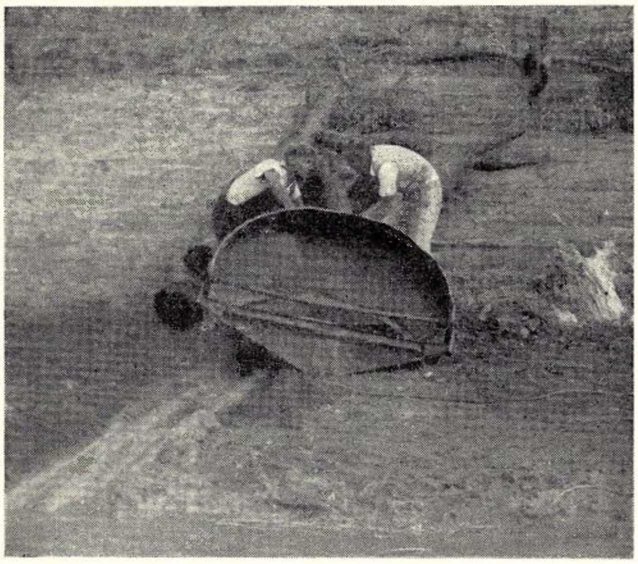


Fig. 1.—Drag Scraper Bucket.

Fig. 2.—Drag-Line Excavator Bucket.

(attached to the cable at a distance beyond the point of attachment to the bucket equal to a few feet greater than the depth of the river) ahead of the bucket and thereby avoid kinks in the cable. The operation took one day with six men.

In the Maribyrnong crossing, heavy equipment, TD18 and HD14 dozers fitted with logging winches, cranes and 1" diameter steel ropes, was available. The trenching operation occupied five men for four days and a smoothly sloping trench of average depth of 6 feet was obtained. Depth gauging was carried out by a diver.

On the west bank of the Maribyrnong crossing an old disused wharf hindered the operation (see Fig. 5). Sheet piling 30 feet long formed the outside face, and it had deteriorated around the water line. It was estimated that a 5-ton pull would be necessary to withdraw a sheet, but the wharf timbers would not stand this loading. Finally a pile was cut below low water level (the river is tidal) and a steel chute was placed between the pile and the end of the trench. To ensure that the cables were laid centrally in the trench, they were attached to the bucket and pulled in behind it.

Two 24-pair 40 lb. steel wire armoured carrier cables (Melbourne-Ballarat trunks), three 400-pair 10 lb. star quad local type steel wire armoured junction cables (City West-Footscray) and a 200-pair 10 lb. star quad local type steel tape armoured subscribers' cable were laid. The Maribyrnong River is bounded by a road on the east side and road and rail siding on the west side The crossing could not be made without serious interference to heavy industrial traffic, and was therefore performed on a Sunday when the two roads and the siding could be closed. The six cable drums were brought to the job on trailers and set up fanwise (Fig. 6). The cables were drawn together through sheaves (Fig. 7) and taken over a roller (Fig. 8) to enable lashings to be placed around the six cables as they were moving. The main purpose of the lashings was to reduce the strain on the 200-pair tape armoured subscribers' cable, which was used as no wire armoured cable was available. The cables emerged on the far bank well lubricated with river mud and still lashed together (Fig. 9). The diver inspected the crossing shortly after it was completed and reported that the cables were centrally located in the trench and were being silted over. The operation took eleven men one day.

No interruption with the river traffic or flow was caused in either operation. The river traffic in both cases was light. Although giving maximum protection this method of laying a number of cables together in a trench precludes any subsequent repairs on them individually. The risk of damage to the remaining cables would be very high and the only practicable method would be to abandon and replace a faulty cable.

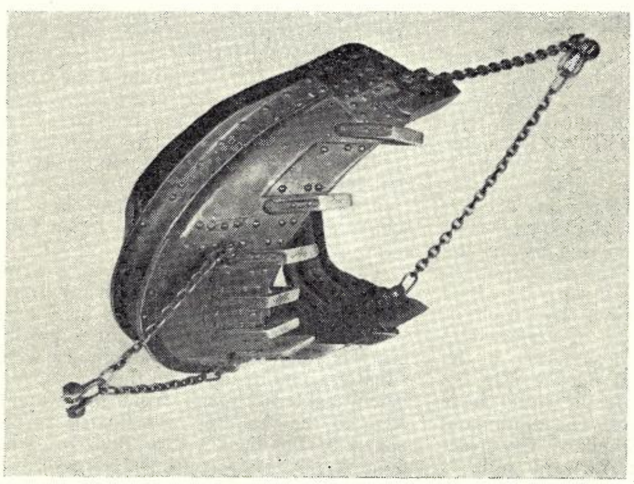


Fig. 3.—Model of Drag Scraper Bucket.

Fig. 4.—General view of crossing, showing drag scraper bucket and drums used to float cable.

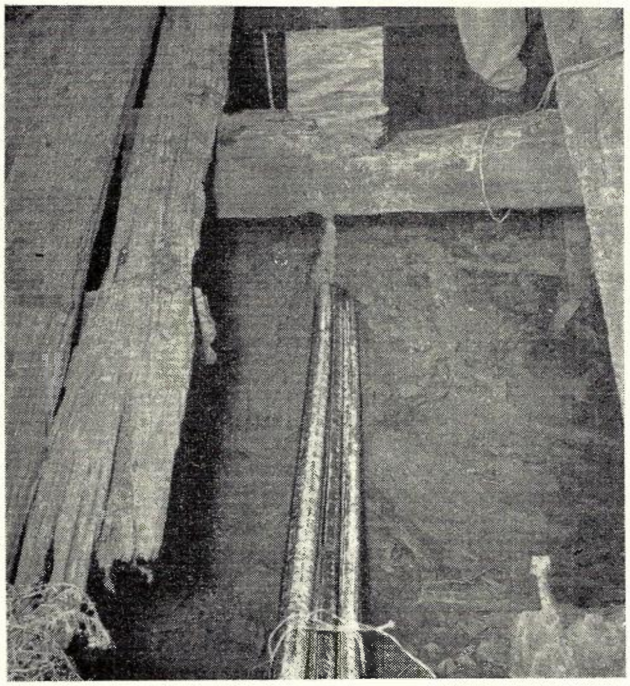


Fig. 5.—Cables leaving west bank of river through sheet piling.

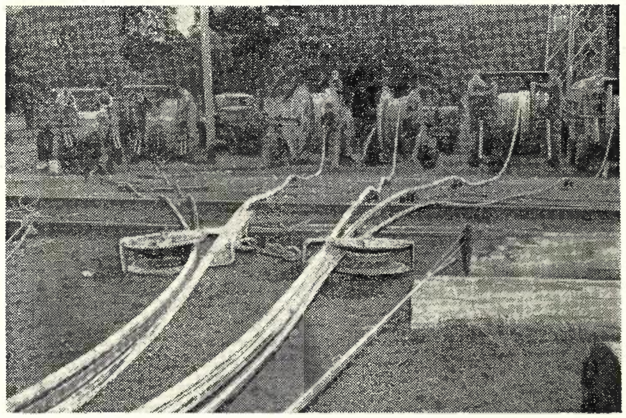


Fig. 7.—Cables leaving drums and passing through sheaves.

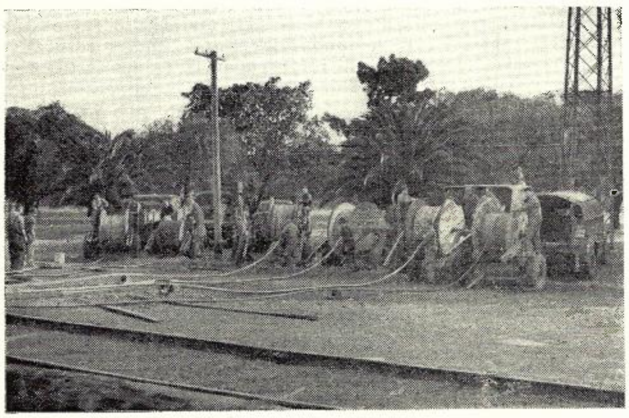


Fig. 6.—Cable drums in position.

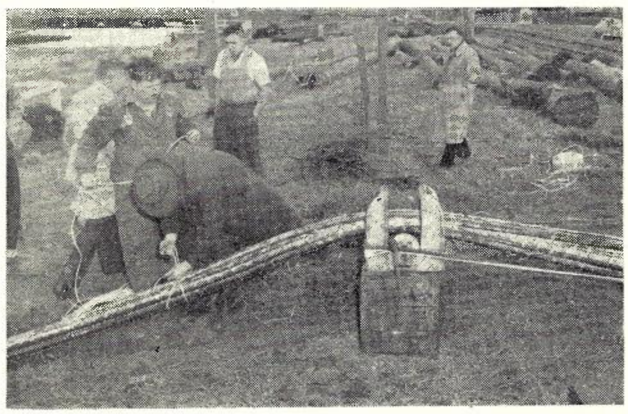


Fig. 8.—Cables being lashed together and passing over a guide roller.

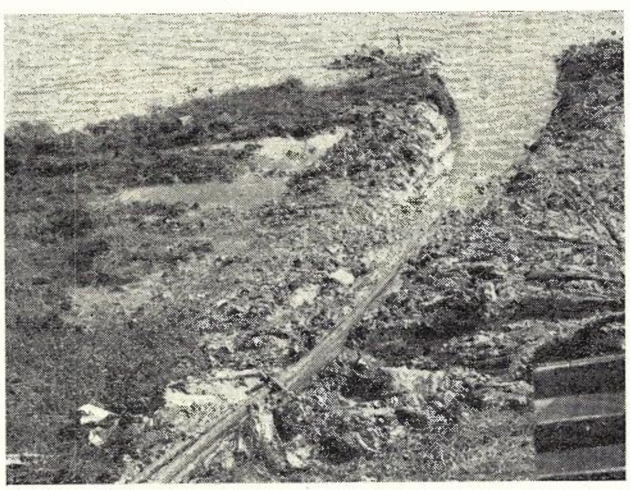


Fig. 9.—Cables emerging at east bank.

LOSS CHARACTERISTICS OF TANDEM CONNECTED TRANSMISSION EQUIPMENT

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Introduction: To obtain a specified standard of overall performance from a transmission system over which complex signals are to be propagated, it is necessary to obtain certain unique performance characteristics from the individual equipment units of the system. These individual equipment units are, in general, of the four-terminal type, and for convenience will be referred to as networks in this article.

A study of the classical theory of the four-terminal network reveals that its overall electrical properties at any given frequency can be expressed in terms of three independent network parameters. These network parameters may be defined in many ways, and among those commonly encountered in the literature are the image and iterative parameters. The image parameters, which are of interest here, consist of the image transfer constant and the image impedances.

The design engineer, who is mainly concerned with the determination of a suitable configuration of elements for a network, and the calculation of the element values, can make considerable use of the image parameters, because they may be expressed solely in terms of the elements of the network. Thus, by pursuing established methods of design, the configuration and values of the elements of a network which will have prescribed image transfer constant and image impedances may be determined. This leads to prescribed electrical performance under conditions of image operation.

There is, however, another aspect of network performance which the equipment user encounters. This aspect differs somewhat from that of the design engineer, since, unlike the latter, the equipment user is not predominantly interested in the detailed circuit arrangements existing within a network, but rather in its resultant performance when appropriately connected in a transmission system. From the equipment user's viewpoint, therefore, it may be said that an equipment unit is merely a box, possessing four terminals, and, in general, acceptable if its performance characteristics conform with certain prescribed requirements.

It follows that one of the problems facing the user or purchaser of transmission equipment is that of specifying the performance requirements of the individual units of equipment in such a manner that the overall performance requirements of the complete transmission system are satisfied, irrespective of the source from which equipment purchase is made, and at the same time allowing the equipment designers the greatest freedom possible.

In many cases it has been found more practicable to specify the insertion characteristics of a network between appropriate reference impedances rather than to specify its required performance characteristics in terms of, say, its image transfer constant. Further it is convenient to specify the network impedances in terms of the return loss of the input impedance of one pair of terminals against a reference impedance, the other pair of the network terminals being terminated with an impedance equal to the reference impedance, rather than in terms of the image or iterative impedances.

A treatment of network performance in terms of insertion loss and return loss appears to be lacking. The authors have, therefore, in this paper developed some formulæ for the performance of tandem connected four-terminal networks in terms of the insertion and return losses of the individual networks. It should be noted that the word network is taken to cover all units from, say, the simple transformer to a complete carrier system and that the formulæ developed may be universally applied.

Insertion Factor, Insertion Loss, and Operating Loss: With reference to Figs. 1a and 1b, the insertion factor of a

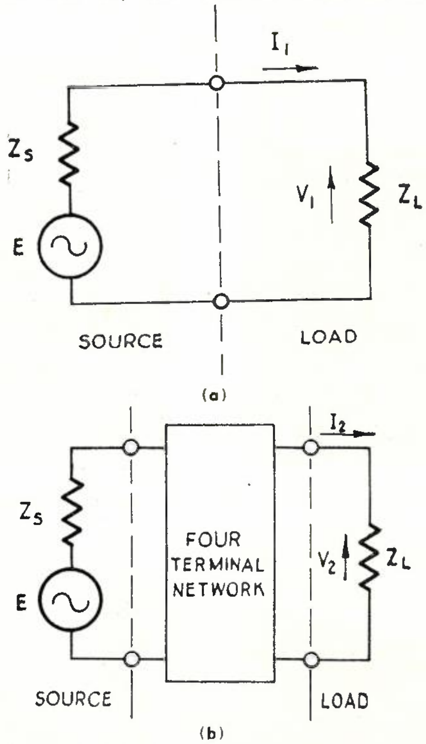


Fig. 1.—Illustration of definition of insertion loss.

four-terminal network may be defined as follows. In Fig. 1a, a source, having an e.m.f. of E volts and an internal impedance Z_S, is connected directly to a load impedance Z_L. Let the voltage and current in the load impedance in this condition be represented respectively by V_1 and I_1. In Fig. 1b a network possessing four terminals has been introduced between the source and load. Let the voltage and current now existing in the load impedance be represented respectively by V_2 and I_2. Then $Z_L = V_1/I_1 = V_2/I_2$, so that $V_1/V_2 = I_1/I_2 = G$.

The parameter G, which is a complex number, is defined as the insertion factor of the inserted four-terminal network when operated between Z_S and Z_L.

The insertion loss of the network is given by IL (db) $= 20 \log_{10} |G|$, where the vertical bars surrounding G indicate that in this formula the magnitude of G is concerned. Further, the insertion phase shift of the network is given by the expression $\Phi =$ angle of G. Thus, if G is represented by the complex number $a + jb$, $\Phi = \text{Tan}^{-1} b/a$.

Reverting to the expression for the insertion loss, expressed in decibels, of a four-terminal network, it is seen that it may be written in the following alternative form:

$$\text{IL (db)} = 10 \log_{10} |G|^2$$

Before proceeding with an examination of $|G|^2$, it will be helpful to recall that in the symbolic method of representing alternating currents and voltages, complex quantities are used to represent the vectors corresponding to current and voltage. V_1, V_2, I_1 and I_2 are such complex quantities, and their respective modulii represent peak values in the corresponding sine-wave expressions for voltage and current at any instant of time.

Using $|V_1|$, $|V_2|$, $|I_1|$ and $|I_2|$, in accordance with definition $|G|^2$ may be written:

$$|G|^2 = \left|\frac{V_1}{V_2}\right| . \left|\frac{I_1}{I_2}\right|$$

If now the phase angle of the load impedance Z_L is defined as Φ_L, then simple extension leads to:

$$|G|^2 = \frac{\frac{1}{2} . |V_1| . |I_1| . \text{Cos}\, \Phi_L}{\frac{1}{2} . |V_2| . |I_2| . \text{Cos}\, \Phi_L}$$

Since $\frac{1}{2} . |V_1| . |I_1| . \text{Cos}\, \Phi_L = P_1$ is recognised as the power dissipated in the load impedance under conditions of direct source to load connection, and $\frac{1}{2} . |V_2| . |I_2| . \text{Cos}\Phi_L = P_2$ as the power dissipated in the load under inserted network conditions, the network insertion loss may be written in terms of the power ratio P_1/P_2 as IL (db) $= 10 \log_{10} P_1/P_2$. Thus the insertion loss of a network may be defined as the loss of load power, expressed in decibels, experienced as a result of inserting the network into a given transmission system.

It should be noted that the insertion of, for instance, an amplifier or an impedance matching transformer may result in a negative insertion loss, which may be interpreted as an insertion gain. A study of the insertion factor G shows that it may be written as the product of five terms, so that the insertion loss, expressed in decibels, becomes the sum of five loss terms:

IL (db) $= 20 \log_{10} |G| = -L_1 + L_2 + L_3 + L_4 + L_5$

The mathematical significance of the terms L_1 to L_5 is stated in Appendix I. The physical significance of these terms may be stated in the following manner. Firstly, $-L_1$ is due to the mismatch existing between Z_S and Z_L. L_2 is due to the mismatch between the input image impedance Z_{01} of the network and Z_S, while L_3 is due to the mismatch between the network output image impedance Z_{02} and Z_L.

L_4 accounts for a phenomenon called interaction, which may be physically explained as a repeated transfer of diminishing electrical energy within the network, between input and output terminals. Interaction arises from the imperfect matching conditions existing at both input and output of the network; it vanishes if either the network input or output is image matched, and becomes negligibly small if the network attenuation is high. L_5 is due to the image attenuation constant of the network.

It will now be realised that the estimation of the performance of a particular network from a study of its insertion loss and insertion phase shift characteristics over a range of frequencies can lead to a more representative result than a study of the real and imaginary parts of the image transfer constant over the same range of frequencies, simply because it is unlikely that the network will, in practice be operated on a strictly image matched basis between equal source and load impedances, under which conditions the insertion loss expression reduces to the single term L_5 (See Appendix 1).

The foregoing remarks may be illustrated by the following example. Consider an ideal differential or hybrid transformer as shown in Fig. 2. The turns ratio may be chosen to provide a perfect impedance match at the four impedance junctions a-a, b-b, c-c and d-d so that no reflection of energy occurs at these junctions. It is well known that under these conditions, if P_1 is the input power at the line terminals an equal division of power occurs between the two side circuits, so that in a perfect transformer $\frac{1}{2}.P_1$ is dissipated in the 600 ohm, zero angle termination of side circuit 1, and $\frac{1}{2}.P_1$ in the 300 ohm termination of side circuit 2, no power being dissipated in the balance impedance of 600 ohms. In the case of each side circuit it would be said that the attenuation loss expressed in decibels is $10 \log_{10} 2$, or 3 db.

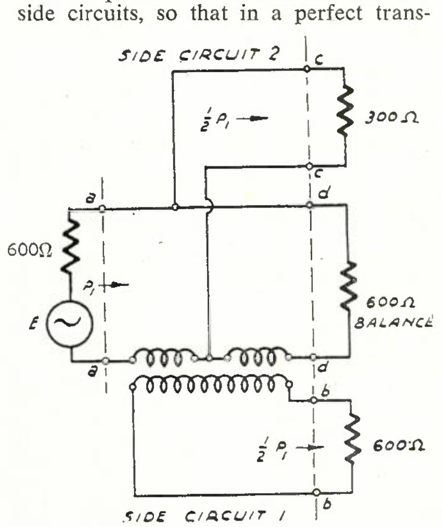


Fig. 2.—Differential or Hybrid Transformer.

Consider now the loss due to the insertion of the network having the four terminals a-a, b-b, between a source and load each of 600 ohms, zero angle. The terms L_1 to L_5 must be considered in turn, and since no mismatch exists at the impedance junctions a-a, b-b, the terms L_1, L_2, L_3 and the interaction term L_4 all have zero values when expressed in decibels. Thus the insertion loss in this case is simply L_5, or the actual attenuation of the network. In practice this will measure a little over 3 db because the transformer will not be ideal.

Consider now the loss due to the insertion of the network having the four terminals, a-a, c-c, between a source of impedance 600 ohms, zero angle, and a load of impedance 300 ohms, zero angle. When the source and load are directly connected, a loss in load power occurs, as compared with the perfectly matched condition of equal source and load resistance. This loss of power, expressed in decibels below the maximum load power that can be obtained with perfect matching, can be calculated as 0.5 db approximately. (See Appendix 1.) This is the term L_1. When the network now under consideration is inserted between the source and load, the conditions that exist are as follows:—

(a) The impedance junction a-a is matched. Thus L_2 expressed in decibels, is zero.
(b) The impedance junction c-c is matched. Thus L_3 is zero db.
(c) From (a) or (b) it follows that the interaction term L_4 is zero db.

Thus IL $= -L_1 + L_5$, where L_5 is the actual attenuation loss of the network, known to be 3db. Using the value of L_1 given above: IL (db) $= 3 - 0.5 = 2.5$ db approximately.

The physical significance of the subtraction of 0.5 db from the attenuation loss of 3 db is simply that, upon insertion of the hybrid between the originally mismatched source and load (corresponding to transmission from the hybrid line terminals to side circuit 2), the ratio of power input at terminals a-a to power output at terminals c-c still corresponds to an attenuation loss of 3 db, but the hybrid has acted as an impedance matching device between source and load, and has thus removed the original transmission loss of 0.5 db. The effective loss upon insertion is, therefore, only 2.5 db.

In connection with the loss resulting from the insertion of a four-terminal network between a source and a load, it may, therefore, be said that:

(a) The network image attenuation constant, expressed in decibels, does not accurately represent the decibel change of load power resulting from the insertion, except in the somewhat idealistic case of symmetrical image operation.
(b) The insertion loss of the network, expressed in decibels, accurately represents the decibel change in load power resulting from the insertion, but can lead to somewhat misleading results, as instanced in the example dealing with the hybrid transformer, because, in such cases the direct connection of source and load impedance results in a mismatched condition.

In view of the foregoing it would appear that a "loss" term, representing a comparison of load power under inserted network conditions and under conditions of transmission from source to load impedance via a suitable ideal matching device, is required. Such a loss term would account for the image attenuation constant of the network and the various reflection phenomena mentioned, but would avoid source to load mismatch. In this paper, therefore, the conception of "operating loss" is used, after the style of F. B. Llewellyn in his paper dealing with stability in transmission systems. (1).

Operating loss may be defined in terms of the following expression: OL (db) $= 20 \log_{10} |G/B|$, where B is the insertion factor of an ideal transducer which, when inserted between source and load impedances, effects perfect or image matching between them. To understand this more clearly, let P_0 be the load power under conditions of direct connection, P_1 the load power when source and load are connected via the ideal transducer or matching device, and P_2 the load power when operation is carried out via the four-terminal network corresponding to a practical equipment unit. Then, by definition,

$$|G|^2 = P_0/P_2 \text{ and } |B|^2 = P_0/P_1$$

The square of the operating factor modulus, which corresponds to P_1/P_2 therefore becomes $|G/B|^2$. Expressed in decibels, the operating loss may be written:

$$\begin{aligned} \text{OL (db)} &= 10 \log_{10} |G/B|^2 \\ &= 20 \log_{10} |G/B| \\ &= 20 \log_{10} |G| - 20 \log_{10} |B| \end{aligned}$$

in accordance with the definition given.

It is seen that the expression for operating loss is simply that for insertion loss less the term $-L_1$. Thus, when a four-terminal network is inserted between a source and a load impedance, and no reflections occur at its input and output terminals, the operating loss becomes equal to the image attenuation constant of the network, expressed in decibels. This case has been encountered in the example dealing with the hybrid transformer.

In the problem considered in this paper the reference source and load impedances are restricted in the sense that they are assumed to be purely resistive. It is convenient to refer to the condition of four-terminal network operation between resistive reference source and load impedances as the nominal reference condition, since these impedances will

1. F. B. Llewellyn: Some Fundamental Properties of Transmission Systems. Proceedings of the Institute of Radio Engineers (U.S.A.), March, 1952, Vol. 40, No. 3.

normally be the zero angle nominal design impedances of the associated network.

Under nominal reference conditions the ideal transducer of insertion factor B takes the form of an ideal transformer having a ratio corresponding to the nominal reference impedances, and the term $-L_1$ may thus be identified as the insertion gain of the ideal transformer operating under these conditions. By equating the expression for $-L_1$, obtained from Appendix 1, to $20 \log_{10} |B|$ it is seen that the ideal transformer has an insertion factor of

$$B = (2\sqrt{Z_S \, . \, Z_L}) / (Z_S + Z_L)$$

where Z_S and Z_L are of zero angle. This result may, of course, be easily verified by direct calculation.

Return Current Coefficient and Return Loss: The term return loss was probably used originally as an aid when describing the operating conditions of a transmission line. It is closely related to the term reflection coefficient or return current coefficient, and is a logarithmic measure of the amplitude relationship existing between the current reflected from a mismatched junction of impedances, and that transmitted under matched or reflectionless conditions.

Return loss is frequently used as an implicit measure of impedance, partly because it is more convenient to express and measure an impedance in terms of its return loss against a nominal reference impedance than in any other terms, and partly because the return loss is, in many respects, a more convenient indication of performance than the impedance value.

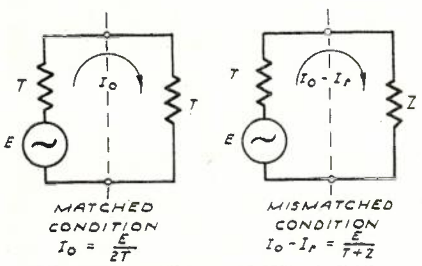


Fig. 3.—Calculation of return current coefficient.

Before pursuing this latter aspect of the use of the term return loss, it is instructive to derive an expression for the return current coefficient. Considering Fig 3, a direct application of Ohms Law leads to:

$$I_0 - I_r = \frac{E}{T + Z}, \text{ or:}$$

$$\frac{I_r}{I_0} = 1 - \frac{E}{I_0} \cdot \frac{1}{T + Z}$$

where I_r is the return current.

Substituting $I_o = E/2T$,

$$I_r/I_o = 1 - \frac{2 \, . \, T}{T + Z} = \frac{Z - T}{Z + T}$$

The expression, $(Z - T)/(Z + T)$ is called the return current coefficient. The return loss may now be written:

$$RL \text{ (db)} = 20 \log_{10} |I_o/I_r|$$

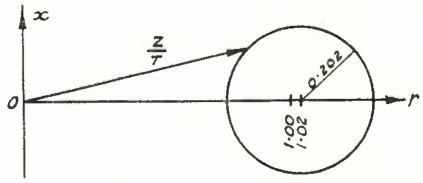


Fig. 4.— Circle representing Z/T for a return loss of 20 db.

The inverse return current coefficient is a vector quantity, and may be represented by a complex number A. In polar form it is represented by $|A| \angle \alpha$, where α is the angle of A. Calling $|A| = a$, the return loss may be written:

$$RL \text{ (db)} = 20 \log_{10} a$$

$$\text{and } a = \left| \frac{Z + T}{Z - T} \right| = \left| \frac{Z/T + 1}{Z/T - 1} \right|$$

It is now apparent that "a" may be looked upon as a known real number indicating the degree of inequality existing between Z and T. T is generally a known nominal reference impedance of zero angle, for instance 600 ohms or 135 ohms.

In order to obtain an interesting geometrical illustration of the relationship existing between "a", T and Z, it is convenient to define the real and imaginary components of the complex number Z/T respectively r and x, so that $Z/T = r + jx$.

Substitution of $Z/T = r + jx$ into $a = \left| \frac{Z + T}{Z - T} \right|$ gives:

$$a = \left| \frac{r + jx + 1}{r + jx - 1} \right|$$

$$\text{or } a^2 = \frac{(r + 1)^2 + x^2}{(r - 1)^2 + x^2}$$

$$= \frac{1 + 2 \, . \, r + r^2 + x^2}{1 - 2 \, . \, r + r^2 + x^2}$$

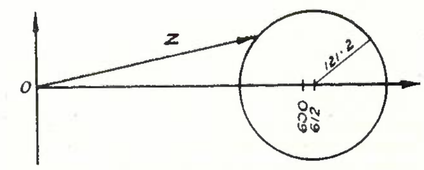
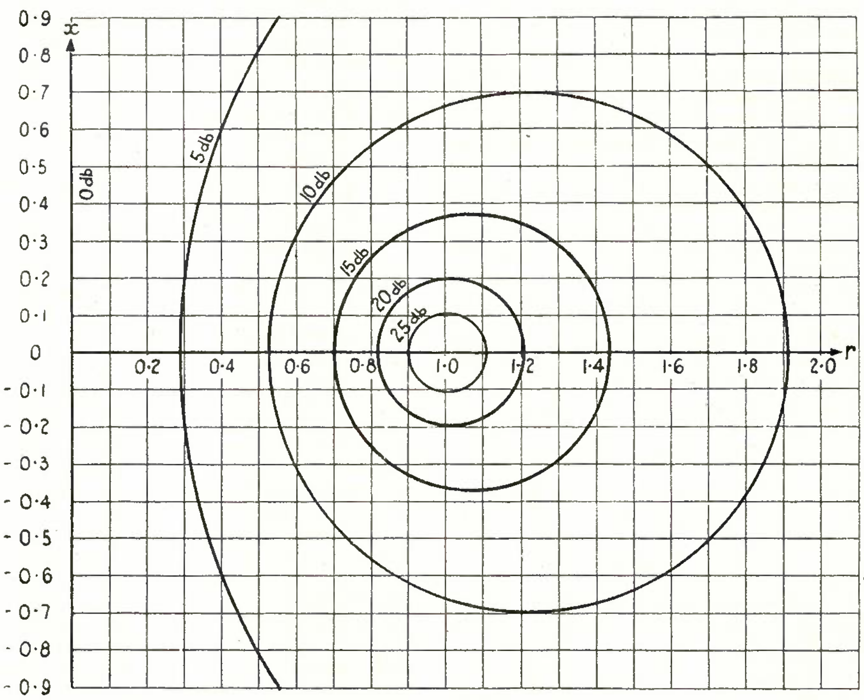


Fig. 5.—Circle representing Z for a return loss of 20 db, when $T = 600\Omega \underline{|0}$.



RLdb	CENTRE	RADIUS
5	1·93	1·65
10	1·22	0·70
15	1·07	0·37
20	1·02	0·20
25	1·01	0·11

Fig. 6.—Circles picturing $Z/T = r + j \, . \, x$ for some typical return loss values.

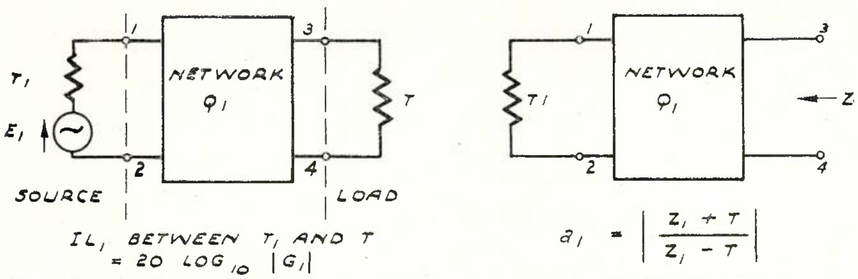


Fig. 7a.—Four terminal network Q1, illustrating the known parameters G_1 and a_1.

Then $(a^2 - 1)\, x^2 + (a^2 - 1)\, r^2 - 2\,(a^2 + 1)r + (a^2 - 1) = 0$ and

$$x^2 + r^2 - 2\frac{a^2+1}{a^2-1}r + 1 = 0$$

By completing the square this expression may be written as follows:

$$x^2 + \left\{ r - \frac{a^2+1}{a^2-1} \right\}^2 = \left\{ \frac{2a}{a^2-1} \right\}^2 \qquad (1)$$

The geometrical interpretation of expression (1) takes the form of a circle having a radius $2a/\,(a^2 - 1)$ and centre in the point $[(a^2 + 1)/(a^2 - 1),\ 0]$.

If "a" is, for example, equal to 10, the

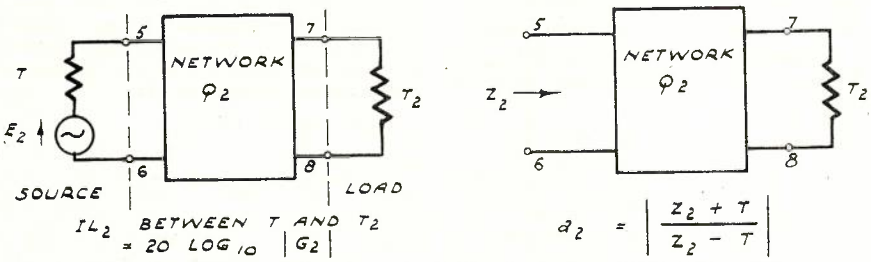


Fig. 7b.—Four terminal network Q_2, illustrating the known parameters G_2 and a_2.

return loss is 20 log 10 = 20 db, and the corresponding circle for Z/T, shown in Fig. 4, has a radius of 0.202 and centre in 1.02. Asuming further that the nominal reference impedance T is 600 ohms, zero angle, then the circle representing Z may be found by multiplying all dimensions of the circle for Z/T by 600 as in Fig. 5. The radius of this circle is 600 . 0.202 = 121.2 ohms, and the centre 600. (1.02,0) = (612,0). It will thus be seen that any impedance Z having a return loss of 20 db against a nominal reference impedance T = 600 ohms zero angle, terminates on a circle having a radius of 121 ohms and centre, at (612,0).

Similar circles may be drawn for other values of return loss. In order that the circles may be generally applicable they are usually drawn to represent the complex ratio Z/T rather than the complex values of Z corresponding to a chosen nominal reference impedance T. Fig. 6 shows a family of return loss circles representing Z/T for various values of return loss.

Insertion and Operating Loss of Tandem Connected Four-Terminal Networks: The particular problem treated in this paper may be stated in the following manner. Assuming that the individual insertion losses of the four-terminal networks Q_1 and Q_2 are known, what is the insertion loss of networks Q_1 and Q_2 when connected in tandem?

The problem and related assumptions may be stated in more exact terms with reference to Figs. 7a, 7b, and 7c. Thus, the performance of network Q_1 is known in terms of G_1 and a_1, where G_1 is the insertion factor of Q_1 between source and load impedance T_1 and T, and $a_1 = \left|\frac{Z_1 + T}{Z_1 - T}\right|$, T being the nominal reference impedance at network Q_1 output terminals, and Z_1 being the output impedance of network Q_1 with the input terminals terminated in the input nominal reference impedance T_1. It is found convenient to analyse in terms of the actual insertion factor, later converting to insertion loss and operating loss by means of the expressions already discussed.

In a similar manner the performance of network Q_2 is known in terms of G_2 and a_2, where G_2 is the insertion factor of Q_2 between source and load impedances T and T_2, and $a_2 = \left|\frac{Z_2 + T}{Z_2 - T}\right|$, Z_2 being the input impedance of network Q_2 with the output terminals terminated in the nominal reference impedance T_2.

The problem is thus that of expressing the insertion factor G_3 of networks Q_1 and Q_2 in tandem, operating between source and load impedances T_1 and T_2, firstly in terms of G_1, G_2, Z_1 and Z_2, together with the nominal reference impedances T, T_1 and T_2; and secondly, in terms of G_1, G_2, a_1 and a_2, and the same nominal reference impedances.

Referring to Fig. 8, and considering the terminals 3 and 4, an application of Thevenin's theorem enables network Q_1 and its source to be replaced by an e.m.f.E_{11}, in series with an impedance Z_1, without disturbing the current and voltage conditions at these terminals. The expression for E_{11} may be found in terms of the known insertion factor G_1 as follows. If the load T is connected directly across the source E_1 of impedance T_1, the load current is $I_1 = E_1/(T + T_1)$. The insertion of network Q_1 between source and load now causes the load current I_1 to change to $I_2 = I_1/G_1 = E_1/G_1(T + T_1)$. To obtain this current I_2 in the load, asuming now that terminals 3 and 4 are driven by a source of voltage E_{11}, and internal impedance Z_1, E_{11} must have a value such that the expression $E_{11}/(T + Z_1) = E_1/G_1(T + T_1)$ is satisfied.

Thus $E_{11} = (E_1/G_1)\,(T + Z_1)/(T + T_1)$.

Considering Fig. 9, which indicates the conditions relating to network Q_2, it will be seen that, in a similar way the current in the load T_2, when Q_2 is inserted between the source and load, is given by the expression:

$$I_4 = \frac{I_3}{G_2} = \frac{E_2}{G_2\ (T + T_2)}$$

By simple potentiometer theory the voltage developed across the input terminals 5 and 6 is $V_2 = E_2.Z_2/(T + Z_2)$, since the input impedance between these terminals is Z_2, when terminals 7 and 8 are terminated in the load impedance T_2. The load current may now be written as

$I_4 = V_2(T + Z_2)\,/G_2Z_2\,(T + T_2)$.

by using $E_2 = V_2.(T + Z_2)/Z_2$.

Thus the relationship existing between any voltage developed at the input terminals of network Q_2 and the current produced by it in the load impedance T_2 terminating terminals 7 and 8 may be written as:

$$\frac{I\ (\text{load})}{V\ (\text{input})} = \frac{1}{G_2} \cdot \frac{T + Z_2}{T + T_2} \cdot \frac{1}{Z_2}$$

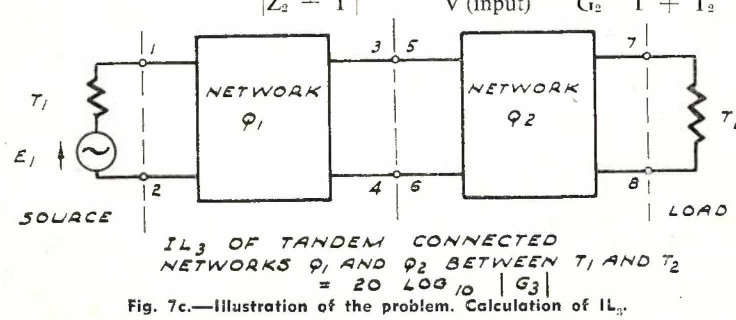
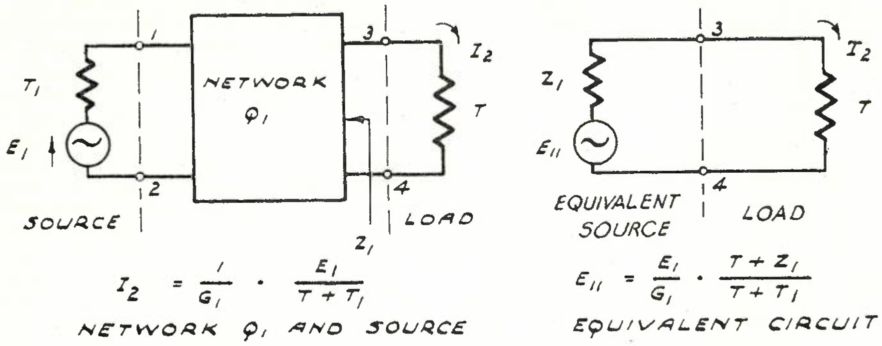


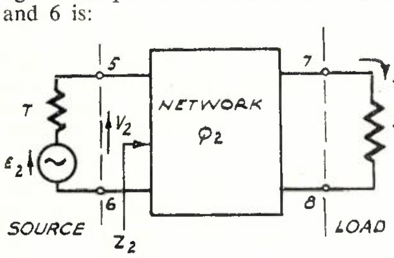
Fig. 7c.—Illustration of the problem. Calculation of IL_3.



$$I_2 = \frac{1}{G_1} . \frac{E_1}{T+T_1} \qquad E_{11} = \frac{E_1}{G_1} . \frac{T+Z_1}{T+T_1}$$

Fig. 8.—Application of Thevenin's theorem to network Q_1 and source.

Fig. 10 shows the conditions existing when the networks Q_1 and Q_2 are connected in tandem. By replacing network Q_1 and its driving source by the equivalent circuit obtained (Fig. 8) and at the same time simply replacing network Q_2 by its input impedance Z_2, it can be seen from potentiometer theory that the voltage developed across Z_2 at terminals 5 and 6 is:



$$G_2 = \frac{I_3}{I_4}$$

$$I_3 = \frac{E_2}{T+T_2}$$

$$I_4 = \frac{E_2}{G_2} . \frac{1}{T+T_2}$$

$$= \frac{1}{G_2} . \frac{V_2}{Z_2} . \frac{T+Z_2}{T+T_2}$$

$$\text{Where } V_2 = \frac{E_2 . Z_2}{T+Z_2}$$

Fig. 9.—Conditions relating to Network Q_2.

$$V_2' = \frac{E_1}{G_1} . \frac{T+Z_1}{T+T_1} . \frac{Z_2}{Z_1+Z_2} \text{ where}$$

V_2' is the input voltage for network Q_2 under these conditions of tandem connection. Using the relationship:

$$\frac{I\,(\text{load})}{V\,(\text{input})} = \frac{1}{G_2} . \frac{T+Z_2}{T+T_2} . \frac{1}{Z_2} \text{ for}$$

network Q_2, the current I_6 which now flows in the load impedance T_2 may be expressed in terms of the original source e.m.f. E_1 as:

$$I_6 = \frac{E_1}{G_1 . G_2} . \frac{(T+Z_1).(T+Z_2)}{(T+T_1).(T+T_2).(Z_1+Z_2)}$$

If now the load impedance T_2 is connected directly to the source of e.m.f. E_1 volts and impedance T_1, the current I_5 that flows is $I_5 = E_1/(T_1 + T_2)$. By definition the insertion factor, G_3 of the tandem connected arrangement of network Q_1 and network Q_2 operating between source and load impedance of T_1 and T_2 respectively is $G_3 = I_5/I_6$.

Thus the insertion factor G_3 becomes:

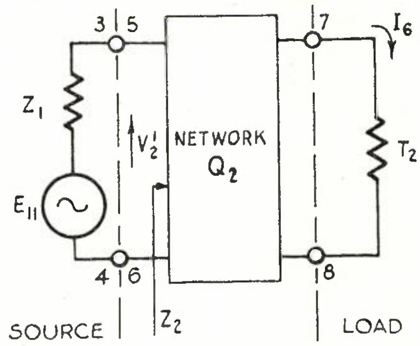
$$G_3 = G_1 . G_2 . \frac{(T+T_1).(T+T_2).(Z_1+Z_2)}{(T_1+T_2).(T+Z_1).(T+Z_2)}$$

Before proceeding with a rearrangement of the expression obtained for G_3, it will be recalled that in the section of the paper dealing with operating loss an expression $B = (2\sqrt{Z_S . Z_L})/(Z_S + Z_L)$ was obtained for the insertion factor, under nominal reference conditions, of an ideal transformer having an impedance ratio $1: Z_L/Z_S$, when operating between Z_S and Z_L, each of zero angle.

Considering the expression for G_3, the following rearrangement may now be made:

$$G_3 = G_1 . G_2 . \frac{(T+T_1).(T+T_2).(Z_1+Z_2)}{(T_1+T_2).(T+Z_1).(T+Z_2)}$$

$$= G_1 . \frac{T+T_1}{2\sqrt{T.T_1}} . G_2 . \frac{T+T_2}{2\sqrt{T.T_2}} . \frac{2\sqrt{T_1.T_2}}{T_1+T_2} . \frac{2.T.(Z_1+Z_2)}{(T+Z_1).(T+Z_2)}$$



$$E_{11} = \frac{E_1}{G_1} . \frac{T+Z_1}{T+T_1}$$

$$V'_2 = \frac{E_1}{G_1} . \frac{T+Z_1}{T+T_1} . \frac{Z_2}{Z_1+Z_2}$$

$$I_5 = \frac{E_1}{T_1+T_2}$$

$$I_6 = \frac{E_1}{G_1 . G_2} . \frac{(T+Z_1)(T+Z_2)}{(T+T_1)(T+T_2)(Z_1+Z_2)}$$

Fig. 10.—Networks Q_1 and Q_2 in tandem, with the equivalent circuit of Fig. 8 substituted for network Q_1 and its source.

so that:

$$G_3 . \frac{T_1+T_2}{2\sqrt{T_1.T_2}} = G_1 . \frac{T+T_1}{2\sqrt{T.T_1}} . G_2 . \frac{T+T_2}{2\sqrt{T.T_2}} . \frac{2.T.(Z_1+Z_2)}{(T+Z_1).(T+Z_2)}$$

and

$$\frac{G_3}{B_3} = \frac{G_1}{B_1} . \frac{G_2}{B_2} . \frac{2.T.(Z_1+Z_2)}{(T+Z_1).(T+Z_2)}$$

The expression for the operating loss, in decibels, may thus be written:

$$OL\,(db) = 20 \log_{10} \left|\frac{G_3}{B_3}\right|$$

$$= 20 \log_{10} \left|\frac{G_1}{B_1}\right| + 20 \log_{10} \left|\frac{G_2}{B_2}\right| + 20 \log_{10} |K|$$

$$\text{where } K = \frac{2.T.(Z_1+Z_2)}{(T+Z_1).(T+Z_2)}$$

Expression of K in Terms of Return Loss: The impedances Z_1 and Z_2 are very often not known explicitly, but may, however, be represented in an implicit fashion by their respective return losses RL_1 (db) and RL_2 (db) against the nominal reference impedance T.

Thus may be written:

$$\left|\frac{Z_1+T}{Z_1-T}\right| = \text{antilog} \frac{RL_1}{20} = a_1$$

and

$$\left|\frac{Z_2+T}{Z_2-T}\right| = \text{antilog} \frac{RL_2}{20} = a_2$$

The limitation of this implicit representation of the impedances Z_1 and Z_2 becomes apparent when calculation of K is contemplated, as no precise value can be obtained. However, a mathematical treatment of this problem (Appendix II) reveals that extreme values of $|K|$ may be determined, expressed as functions of a_1 and a_2 only. These extreme values become the real numbers:

$$|K|_{min} = \frac{a_1 . a_2 - 1}{a_1 . a_2} \text{ and}$$

$$|K|_{max} = \frac{a_1 . a_2 + 1}{a_1 . a_2}$$

The analysis further shows that $|K|$ may assume any value between $|K|_{min}$ and $|K|_{max}$.

Considering now the expression obtained for the operating loss of networks Q_1 and Q_2 operating in tandem between impedances T_1 and T_2, it is possible to predict the maximum and minimum values of operating loss which may be encountered, by inserting into the expression the extreme values of $|K|$ obtained. The operating loss may thus be in the range:

$$20 \log_{10}\left|\frac{G_1}{B_1}\right| + 20 \log_{10}\left|\frac{G_2}{B_2}\right| + 20 \log_{10}|K|_{min} \leq 20 \log_{10}\left|\frac{G_3}{B_3}\right| \leq 20 \log_{10}\left|\frac{G_1}{B_1}\right| + 20 \log_{10}\left|\frac{G_2}{B_2}\right| + 20 \log_{10}|K|_{max}.$$

This expression may be simplified by writing:

$$OL_1 = 20 \log_{10}\left|\frac{G_1}{B_1}\right|$$

$$OL_2 = 20 \log_{10}\left|\frac{G_2}{B_2}\right|$$

$$OL_3 = 20 \log_{10}\left|\frac{G_3}{B_3}\right|$$

and
$$k_{min} = -20 \log_{10}|K|_{min} = 20 \log_{10}\frac{1}{|K|_{min}}$$

$$k_{max} = 20 \log_{10}|K|_{max}$$

Whereupon,

$$OL_1 + OL_2 - k_{min} \leq OL_3 \leq OL_1 + OL_2 + k_{max}.$$

The results obtained in Appendix II for the extreme values of $|K|$ are therefore important, because they enable, as a result of simple return loss measurements which determine a_1 and a_2 an estimation to be made of the maximum and minimum values of the operating loss OL_3. In order to facilitate rapid calculation, curves are presented in Fig. 11 which show the variation of k_{max}, k_{min} and $(k_{max} + k_{min})$, expressed in decibels, as the return loss sum,

$$RL_1 + RL_2 = 20 \log_{10} a_1 \cdot a_2,$$

varies between 20 db and 60 db.

Since the impedance requirements of transmission equipment units are often specified in terms of return loss under nominal reference conditions, it becomes apparent that computation of operating loss limits in the manner indicated forms an attractive alternative to a precise calculation of operating loss, which involves evaluation of the expression

$$|K| = \left|\frac{2 \cdot T \cdot (Z_1 + Z_2)}{(T + Z_1) \cdot (T + Z_2)}\right|,$$

using measured values of Z_1 and Z_2.

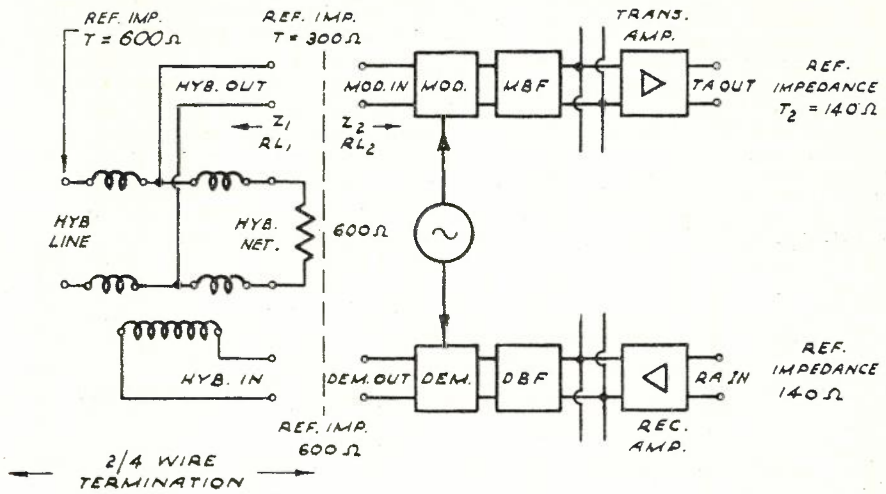


Fig. 12.—Hypothetical cable carrier terminal with 2/4 wire termination.

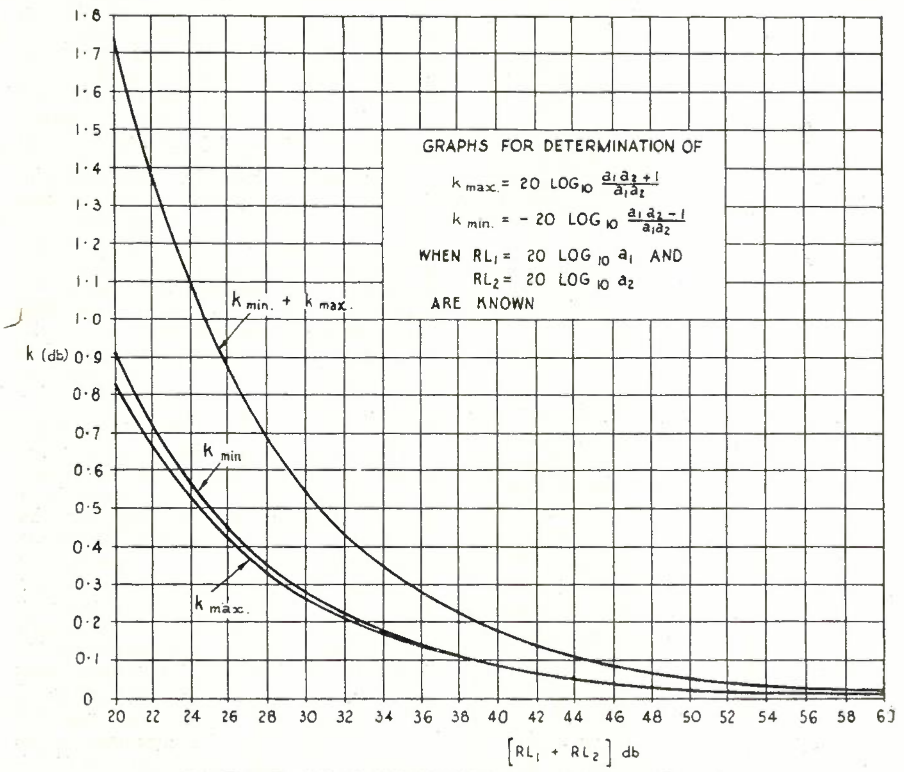


Fig. 11.—Graphs for the determination of k max and k min.

In order that a clear conception of the application of the foregoing principles may be obtained, the following examples 1 and 2 are included.

Example 1: 2/4 Wire Termination of Carrier Telephone Channels: This example refers to a hypothetical case of 2/4 wire termination of a carrier system by means of the differential or hybrid transformer dealt with earlier in this paper. Fig. 12 shows the arrangement and indicates the zero angle nominal reference impedances 600 ohm, 300 ohm and 140 ohm.

The "Hyb. Out" impedance corresponds to Z_1, and it will be assumed that the return loss RL_1 of Z_1 against T is not less than 20 db when the other three pairs of terminals are terminated in 600 ohms, zero angle. Use is now made of the facts that the return loss RL_1, and the operating loss between 600 and 300 ohms, zero angle, measured from "Hyb. Line" to "Hyb. Out", do not depend on the impedance in which "Hyb. In" is terminated, so that the operating loss and return loss remain the same whether "Hyb. In" is terminated with 600 ohms, zero angle, or with the "Dem. Out" impedance. The "Mod. In" impedance corresponds to Z_2, and the return loss RL_2 of Z_2 against T is also assumed to be not less than 20 db.

Since the 2/4 wire termination and the equipment bounded by the terminals "Mod. In" to "Trans. Amp. Out" may be identified respectively as the networks Q_1 and Q_2, the operating loss of Q_1 and Q_2 in tandem, when operating between the impedances T_1 and T_2, may be obtained at any given frequency from the expression:

$$OL_1 + OL_2 - k_{min} \leq OL_3 \leq OL_1 + OL_2 + k_{max}.$$

Considering now the channel frequency response, or more precisely, the operating loss relative to that at the channel reference frequency, over the appropriate frequency range, it is assumed that OL_1, OL_2 are the actual operating losses of networks Q_1 and Q_2 at the channel reference frequency f_0 ($f_0 = 1000$ c/s), and that the respective response limits, expressed in decibels, are $+ d_1, - d_2$, and $+ d_3, - d_4$, as shown in Fig. 13a.

It then follows that the response limit at f_1 becomes $- (d_2 + d_4)$, whilst that at f_2 becomes $+ (d_1 + d_3) + (k_{min} + k_{max})$. The resultant limits so obtained are also shown in Fig. 13a, and it is noted that the range between these limits is $(d_1 + d_2 + d_3 + d_4) + (k_{min} + k_{max})$, and that the upper limit has been widened by an amount $(k_{min} + k_{max})$ relative to the direct summation of individual response limits, $(d_1 + d_3)$.

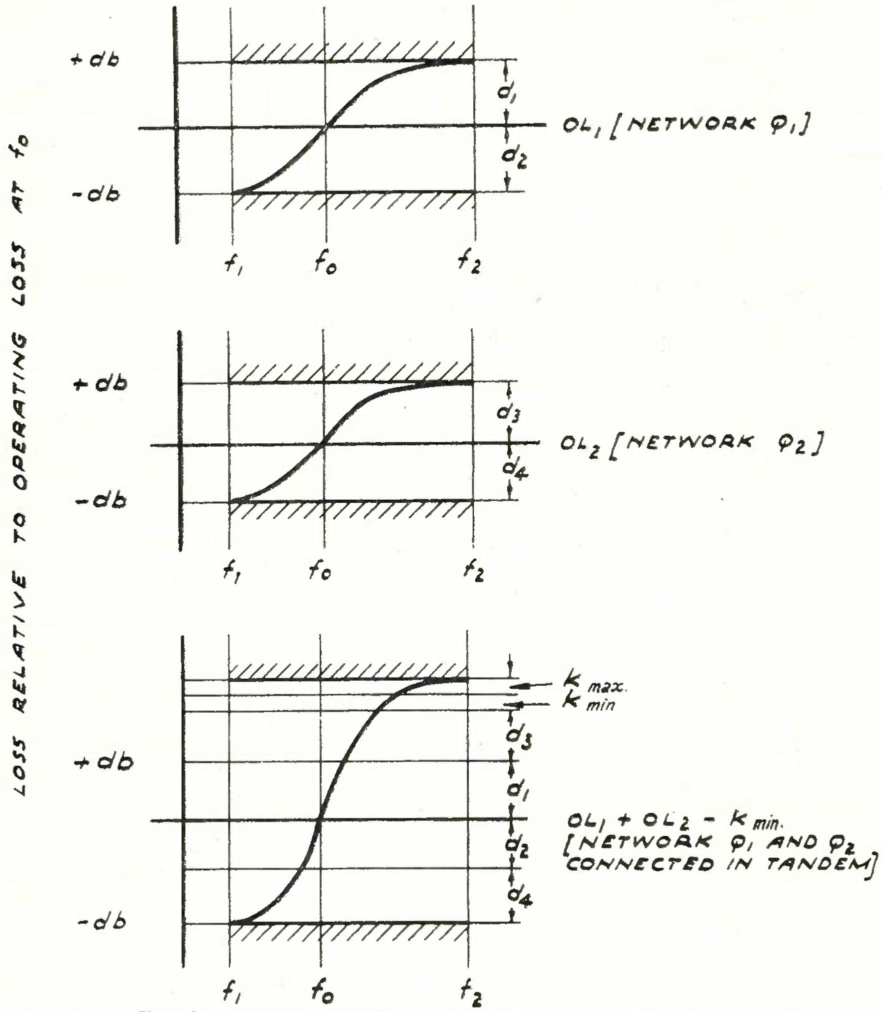


Fig. 13a.—Tandem connection of networks Q_1 and Q_2. Case (a).

In order to determine the overall response limits of the tandem connected arrangement of networks Q_1 and Q_2, it is convenient to analyse in two stages, later combining the results.

(a) Referring to Fig. 13a, which shows certain chosen extreme response characteristics for networks Q_1 and Q_2, leading to a most unfavourable combination upon tandem connection, let it be assumed that at the channel reference frequency, f_0, the operating loss is $OL_1 + OL_2 - k_{min}$. Let it also be assumed that at f_1 the operating loss attains a minimum value of $OL_1 + OL_2 - (d_2 + d_4) - k_{min}$, and that at f_2 a maximum value of $OL_1 + OL_2 + (d_1 + d_3) + k_{max}$ is attained.

(b) Referring to Fig. 13b, the same response characteristics are chosen for networks Q_1 and Q_2, but in this case it is assumed that the operating loss at the channel reference frequency, f_0, is $OL_1 + OL_2 + k_{max}$, while at f_1 and f_2 the operating losses are as before. The response limit at f_1 thus becomes $-[(d_2 + d_4) + (k_{min} + k_{max})]$, and at f_2 simply $+ (d_1 + d_3)$. Once again the range between the limits is seen to be $(d_1 + d_2 + d_3 + d_4) + (k_{min} + k_{max})$ and in this case the lower limit has been widened by an amount $(k_{min} + k_{max})$ relative to the direct summation of the individual response limits, $(d_2 + d_4)$.

(c) Summarising the results obtained from cases (a) and (b), it is seen that in each case the response limits are asymmetrically disposed about the operating loss at the channel reference frequency, f_0, and that they are, in the first case, $+ (d_1 + d_3) + (k_{min} + k_{max})$ and $- (d_2 + d_4)$, and in the second case $+ (d_1 + d_3)$ and $- [(d_2 + d_4) + (k_{min} + k_{max})]$. In each case it is seen that the total range between limits is the common value $(d_1 + d_2 + d_3 + d_4) + (k_{min} + k_{max})$.

It is convenient to combine these results as shown in Fig. 13c, and since it will be recalled that the operating loss of networks Q_1 and Q_2 in tandem, at the channel reference frequency, may range from $OL_1 + OL_2 - k_{min}$ to $OL_1 + OL_2 + k_{max}$, it becomes essential, in the light of the results obtained from the extreme cases (a) and (b) considered, to widen both the upper and lower response limits from $(d_1 + d_3)$ and $- (d_2 + d_4)$ to $[(d_1 + d_3) + (k_{min} + k_{max})]$ and $- [(d_2 + d_4) + (k_{min} + k_{max})]$ respectively.

However, it should be clearly recognised that the range between the extreme turning points of an overall response characteristic plotted on Fig. 13c cannot, from the study of cases (a) and (b), exceed $[(d_1 + d_2 + d_3 + d_4) + (k_{max} + k_{min})]$ although the range between the response limits of Fig. 13c is seen to be $[(d_1 + d_2 + d_3 + d_4) + 2 . (k_{max} + k_{min})]$.

Assume now that the frequency responses of the 2/4 wire termination, or hybrid, and the carrier terminal are respectively within the limits shown in Fig. 14. Using, also, the fact that both RL_1 and RL_2 are not less than 20 db, it is possible to obtain from Fig. 11 the value $(k_{min} + k_{max}) = 0.17$ db, corresponding to $RL_1 + RL_2 = 40$ db.

Thus, considering Fig. 14, to obtain the upper response limit of the tandem connected equipment, it is necessary to add 0.17 db to the sum of the individual limits corresponding to d_1 and d_3, while the lower response limit is obtained by adding 0.17 db to the sum of the individual limits corresponding to d_2 and d_4. The result of this process of summation to obtain the upper and lower response limits of the tandem connected equipment is also shown in Fig. 14.

The treatment of the frequency response of the receive path of the distant terminal can, of course, be made in a manner similar to that used for the transmit path, and by adding the effects the overall influence on a channel may be obtained. In most practical cases the return loss at the channel reference or line-up frequency, f_0, exceeds the return loss at the extreme frequencies of the band. If, for instance, the return losses at f_0 are not less than 26 db, and at all other frequencies in the band not less than 20 db, then the amounts to be added to the sums $(d_1 + d_3)$ and $(d_2 + d_4)$ of the hybrid and carrier terminal responses will no longer be 0.17 db, but (0.086 + 0.022) = 0.11 db, 0.022 db being obtained from Fig. 11 for (RL_1 + RL_2) = 52 db.

Example 2: Patching of Group Amplifier: The formulæ developed may be used to investigate the influence on the channel frequency response of a carrier system operating with different group amplifiers. This situation arises in practice when a fault develops on a group amplifier, necessitating its replacement, at least temporarily, by a process of patching with a non-faulty amplifier, possibly of a different type, but meeting the same specification requirements.

It will be assumed that the input and output return losses against the appropriate nominal reference impedances are known to be not less than a certain value (for instance, 20 db). It will further be assumed that the two amplifiers have the same operating loss between the appropriate nominal reference impedances at the amplifier reference frequency, and also that the operating losses of both amplifiers are within $+ d_3$ and $- d_4$ db of the operating loss at that frequency (refer to Figs. 15b and 15d).

With reference to Fig. 15a, assume that the operating loss from "Hyb. Line" to "Trans. Amp. Out" between the appropriate nominal reference impedances is OL_{ch} at the line-up frequency (on the drawing the corresponding sideband frequency is referred to as the "reference sideband frequency of channel"), and that the operating loss at other sideband frequencies is within the frequency response limits shown. The curved line indicates (over a small part of the sideband) a possible frequency response.

Fig. 15b shows part of a possible operating loss curve for the "regular amplifier" between the appropriate nominal reference impedances, together with the operating loss limits permitted. It should be noted that the group amplifier reference frequency does not normally coincide with the reference sideband frequency of the channel.

As an intermediate step, the regular amplifier is now replaced with an "ideal amplifier", that is, an amplifier with an operating loss between the nominal reference impedances at all frequencies equal to the operating loss OL_{Reg} of the regular amplifier at the amplifier reference frequency, and with infinite input and output return losses against the appropriate nominal reference impedances. By using the formulæ arrived at, it can readily be seen that the original 'Hyb. Line" to "Trans. Amp. Out" operating loss curve as shown in Fig. 15a, may by this process be changed into the curve of Fig. 15c.

The ideal amplifier is now replaced with an "emergency amplifier" meeting the same specification requirements as the regular amplifier, but of a different type with a different operating loss curve and different input and output impedances. The operating loss curve (between the appropriate nominal reference impedances) assumed is shown in Fig. 15d. By this process the "Hyb. Line" to "Trans Amp. Out" operating loss curve may further deteriorate as shown in Fig. 15e.

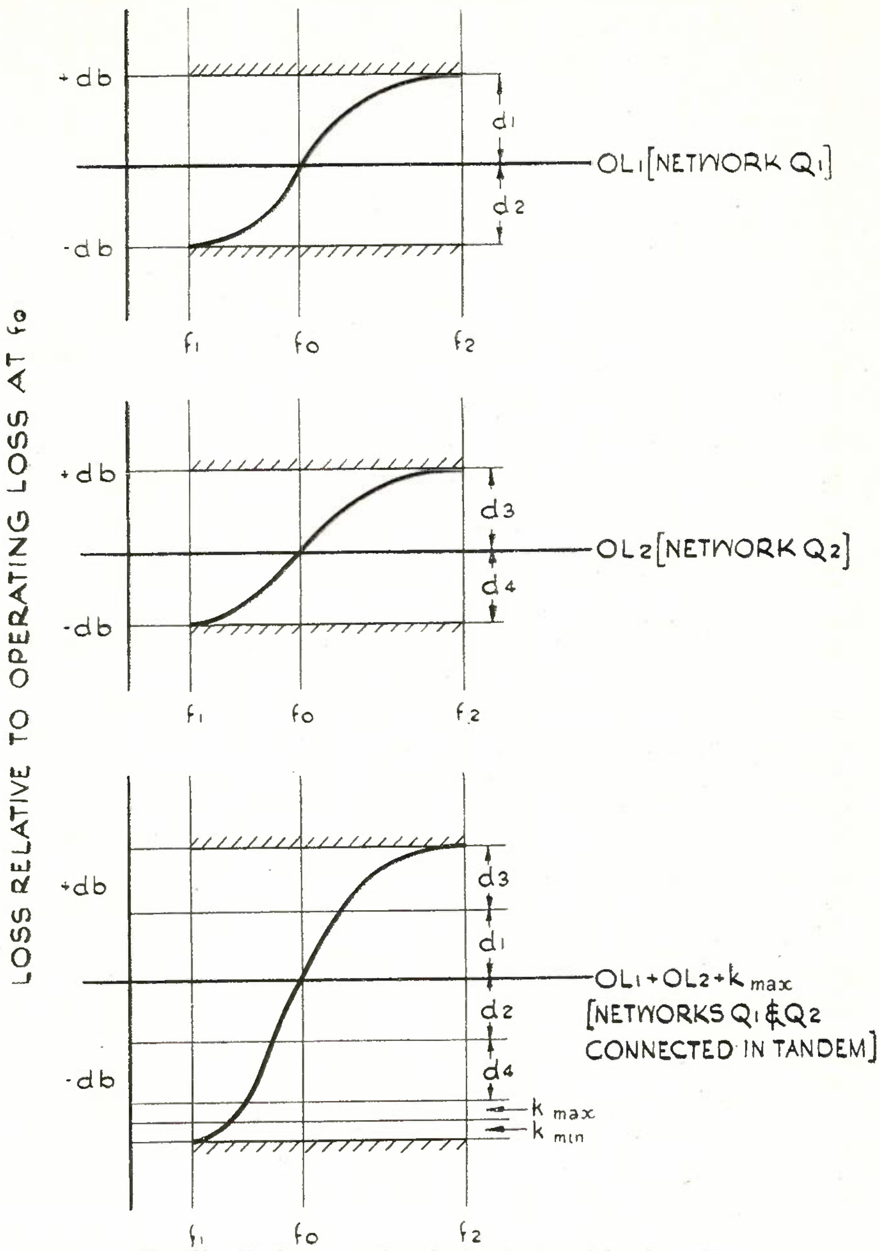


Fig. 13b.—Tandem connection of networks Q_1 and Q_2. Case (b).

In a similar fashion it may be found —assuming differently shaped operating loss curves of the regular and emergency group amplifier—that the "Hyb. Line" to "Trans. Amp. Out" operating loss curve could assume the form shown in Fig. 15f. A closer study reveals that the two cases shown in Figs. 15e and 15f are the "worst" possible cases, and also that the difference between the operating loss at the peak and at the trough is $(d_1 + d_2) + 2(d_3 + d_4) + 2(k_{max} + k_{min})_{Amp\ In}$, whereas the original difference was $d_1 + d_2$ only.

Considering now the frequency response from "Hyb. Line" to "Trans. Amp. Out", that is the operating loss over the sideband frequency range relative to the operating loss at the reference sideband frequency of the channel, it is seen in Fig. 15g that the original frequency response limits $+ d_1$ and $- d_2$ are widened to:

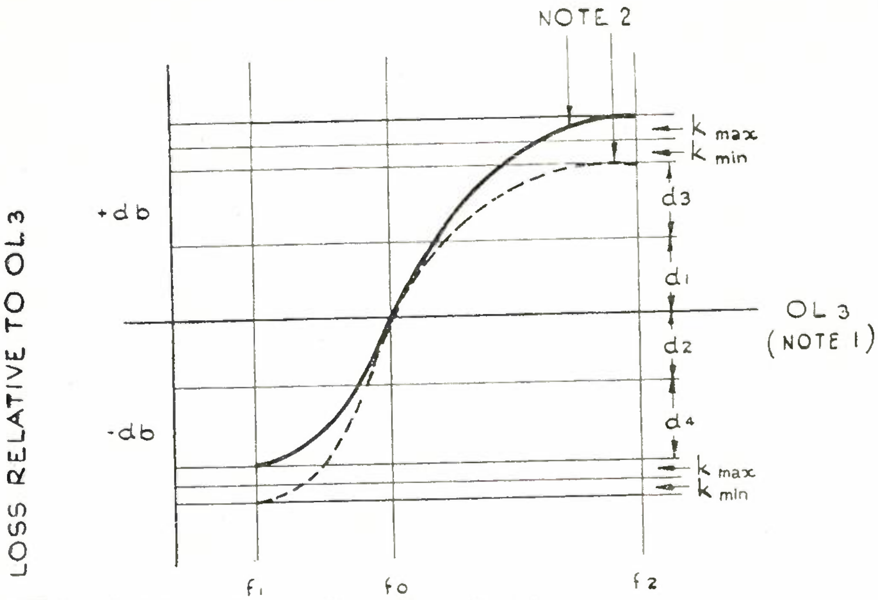
$$+ d_1 + 2(d_3 + d_4) + 2(k_{max} + k_{min})_{Amp\ In}, \text{ and}$$
$$- d_2 - 2(d_3 + d_4) - 2(k_{max} + k_{min})_{Amp\ In},$$

so that the difference between the possible upper and lower frequency response limits is:

$$(d_1 + d_2) + 4(d_3 + d_4) + 4(k_{max} + k_{min})_{Amp\ In}$$

in spite of the fact that the difference between peaks and troughs cannot exceed

$$(d_1 + d_2) + 2(d_3 + d_4) + 2(k_{max} + k_{min})_{Amp\ In}$$



NOTE 1.—$OL_1 + OL_2 - k_{min} \leq OL_3 \leq OL_1 + OL_2 + k_{max}$

NOTE 2.— Dotted characteristic corresponds to $OL_3 = OL_1 + OL_2 + k_{max}$. Full line characteristic corresponds to $OL_3 = OL_1 + OL_2 - k_{min}$

Fig. 13c.—Summation of response limits for networks Q_1 and Q_2 in tandem. (Refer Figs. 13a and 13b)

Assuming now, that the amplifiers have "buffered" input and output circuits, that is, the input impedance is independent of the impedance in which the output is terminated and vice versa, (which is the case with most amplifiers in common use), the formulæ may be extended to apply to the overall channel performance from "Hyb. Line" to "Hyb. Line."

Thus, if the original or regular frequency response from "Hyb. Line" to "Hyb. Line" is within the limits $+ d_1$, and $- d_2$, the replacement of the regular group amplifier with an emergency amplifier may widen the channel response limits to $[d_1 + 2(d_3 + d_4) + 2(k_{max} + k_{min})_{Amp\ In} + 2(k_{max} + k_{min})_{Amp\ Out}]$ and $-[d_2 + 2(d_3 + d_4) + 2(k_{max} + k_{min})_{Amp\ In} + 2(k_{max} + k_{min})_{Amp\ Out}]$, despite the fact that the difference between peaks and troughs, which originally was $d_1 + d_2$, cannot exceed:

$$(d_1 + d_2) + 2(d_3 + d_4) + 2(k_{max} + k_{min})_{Amp\ In} + 2(k_{max} + k_{min})_{Amp\ Out}$$

The results obtained may be applied to a 3-channel open-wire carrier telephone system in accordance with P.M.G. Specification No. 808A.

Only the middle of the VF-band, that is 400-2400 c/s is considered. The specification requirements are in this case:

(a) Original or "regular" channel response limits $d_1 = d_2 = 0.75$ db.
(b) Group amplifier response limits : $d_3 = d_4 = 1$ db.
(c) Return loss against 600 ohms of all input and output circuits concerned not less than 20 db at all sideband frequencies.

The channel frequency response limits when operating with emergency amplifier are, from the formulæ developed:

$$\pm [0.75 + 2.(1 + 1) + 2 \cdot 0.17 + 2 \cdot 0.17] = \pm (0.75 + 4 + 0.68) = \pm 5.43 \text{ db}$$

and the difference between peaks and troughs cannot exceed:

$$1.5 + 4 + 0.68 = 6.18 \text{ db}$$

It should be noted that these results are not always representative of the equipment in actual use for the following reasons:

(a) Measurements have shown that the operating loss curves of group amplifiers are in most cases considerably better than asked for in the Specification. Thus it has been found that the operating loss at any channel sideband frequency is usually within 0.1 db of the operating loss at the relevant reference sideband frequency. The channel and amplifier responses are now referred to the same reference sideband frequency, and an investigation reveals that the emergency channel frequency response limits are $\pm (0.75 + 0.2 + 0.68)$ db $= \pm 1.63$ db and that the difference between peaks and troughs cannot exceed $1.5 + 0.4 + 0.68 = 2.58$ db.
(b) The return loss of the modulator bandpass filter output circuit has been found to range from a few decibels for some types of systems to values well above 20 db for other types of systems, and considerable variation over the sideband frequency range is also often encountered. Attention must also be drawn to the fact that the input circuits of the regular and emergency amplifiers would often be of similar types, so that the full deterioration $2 \cdot (k_{max} + k_{min})_{Amp\ In}$ would not be encountered.
(c) The return loss of amplifier output and the transmit directional filter input has often been found to exceed the specification requirements, so that the term $2 \cdot (k_{max} + k_{min})_{Amp\ Out}$ will be less than the value 0.34 db, applicable when both return losses are 20 db.

Conclusion: The authors have indicated an approach to the theory of four-terminal network performance differing somewhat from the classical approach. The practical use of the parameters, operating loss and return loss, rather than the image parameters of a network, has been demonstrated, and formulæ have been developed which enable a prediction to be made of both the precise operating loss resulting from the tandem connection of four-terminal networks Q_1 and Q_2 of known individual operating losses OL_1 db and OL_2 db respectively, and the maximum and mini-

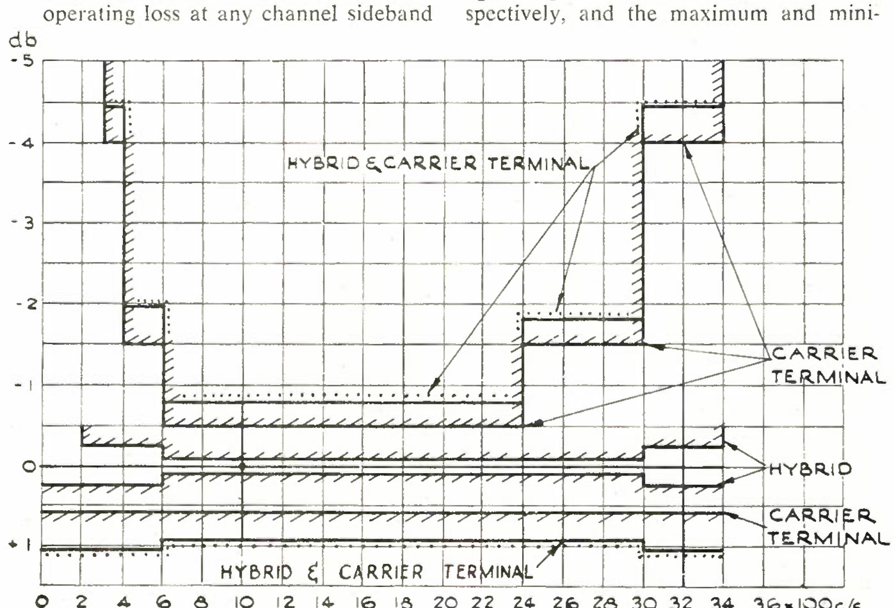


Fig. 14.—Frequency response limits for Hybrid and Carrier Terminal together with the calculated limits for the tandem connection.

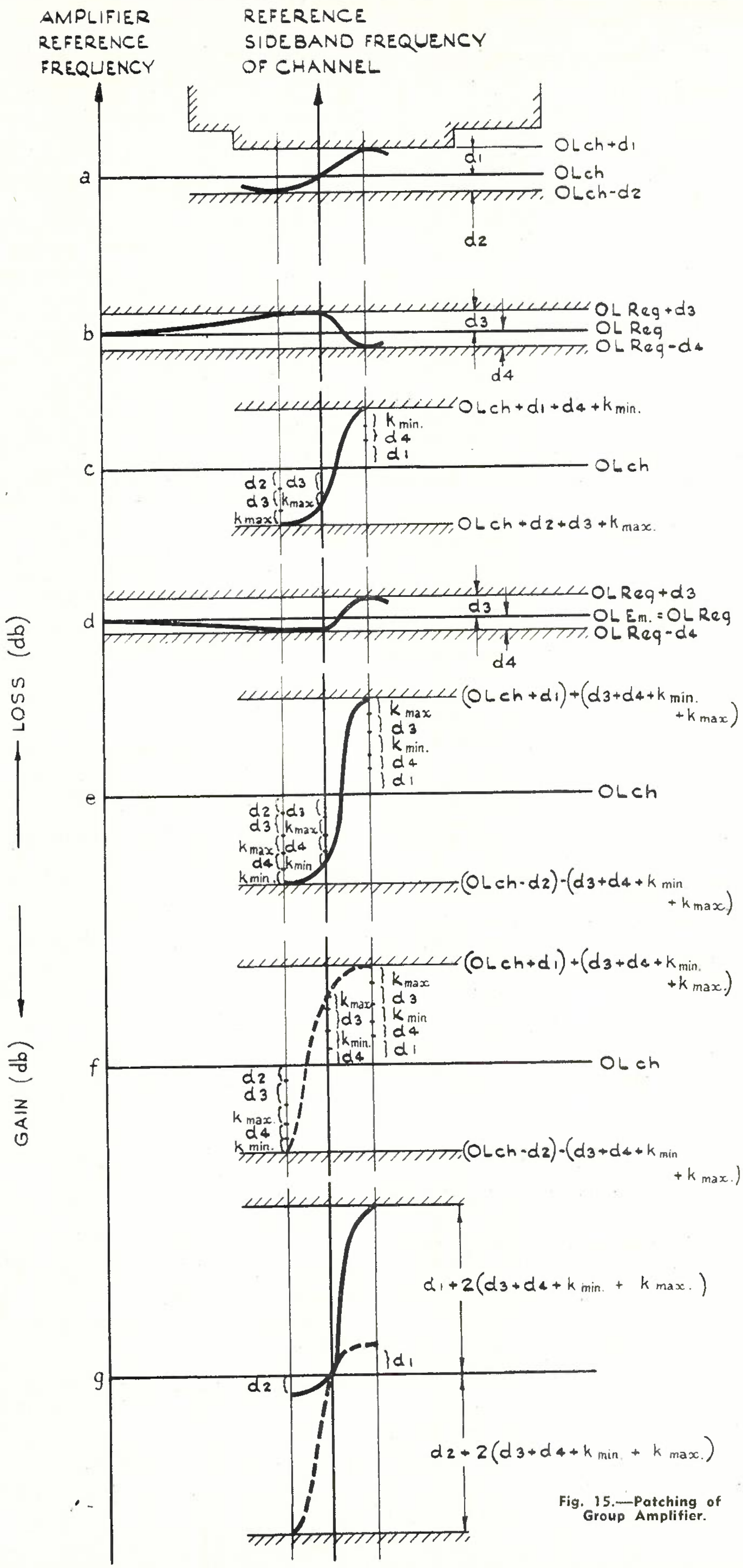


Fig. 15.—Patching of Group Amplifier.

mum operating losses that may be expected as a result of this connection.

The former case applies when the network impedances Z_1 and Z_2, discussed in the paper, are explicitly known, while the latter case applies when Z_1 and Z_2 are known implicitly in terms of their respective return losses against a chosen nominal reference impedance. It is of interest to observe that the approach to network performance specification outlined in this paper can also lead to accurate and convenient methods of production quality control.

The formulæ presented in this paper are applicable to certain special conditions of network tandem connection only, but a general theory for the composition of transmission systems from four-terminal networks has been developed, the results of which are as yet unpublished. Results of measurements performed have been completely demonstrative of the validity of the formulæ.

APPENDIX 1

Mathematical significance of the five loss terms in the expansion of the expression IL (db) $= 20 \log_{10} |G|$

Fig. 16 shows a four-terminal network of image impedances Z_{01}, Z_{02}, and of image transfer constant θ, operating between source and load impedances Z_S and Z_L respectively. Z_{01} is the geometric mean of the input impedances corresponding, respectively, to open circuit and short circuit conditions at the network output. Similarly Z_{02} is the geometric mean of the output impedances corresponding, respectively, to open circuit and short circuit conditions at the network input. If the network output is terminated with an impedance Z_{02}, its input impedance becomes Z_{01}. Similarly, the network output impedance becomes Z_{02} when its input terminals are terminated in Z_{01}.

Using the notation of Fig. 16 and assuming $Z_S = Z_{01}$, $Z_L = Z_{02}$, the image transfer constant θ may be implicitly defined at follows:

(a) Original operating loss, Hyb. Line to Trans. Amp Out, between appropriate reference impedances.
(b) Operating loss of regular amplifier between its appropriate reference impedances.
(c) Operating loss, Hyb. Line to Trans. Amp Out, as it may appear after the regular amplifier has been replaced by an ideal amplifier, with same operating loss at the amplifier reference frequency as the regular amplifier.
(d) Operating loss of emergency amplifier between its appropriate reference impedances.
(e) Operating loss, Hyb. Line to Trans. Amp Out, as it may appear after the ideal amplifier has been replaced by the emergency amplifier, with same operating loss at the amplifier reference frequency as the regular amplifier.
(f) Alternative operating loss, Hyb. Line to Trans. Amp Out, as it may appear if the regular and emergency amplifiers have characteristics different to the characteristics assumed above (but within the amplifier limits assumed throughout).
(g) Frequency response limits, or the limits for operating loss over the frequency band relative to the operating loss at the channel reference frequency, from Hyb. Line to Trans. Amp Out. The two alternative frequency responses arrived at are shown in full line and dotted line respectively.

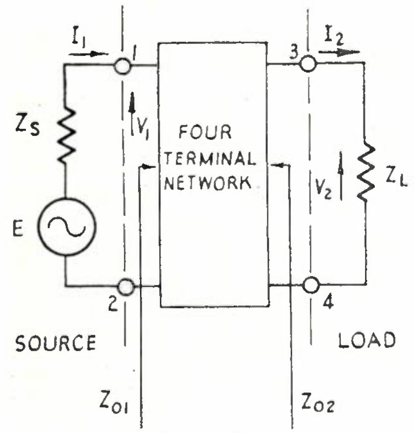
$$e^{2\theta} = \frac{I_1\ V_1}{I_2\ V_2},$$ which, using $\frac{V_1}{I_1} = Z_{01}$,

and $\frac{V_2}{I_2} = Z_{02}$, transforms to:

$$\frac{V_2}{V_1} = \sqrt{\frac{Z_{02}}{Z_{01}}}\ e^{-\theta}$$

$$\text{or } \frac{I_2}{I_1} = \sqrt{\frac{Z_{01}}{Z_{02}}}\ e^{-\theta}$$

The real part of θ, expressed in nepers, is known as the image attenuation constant. It is commonly referred to as the attenuation of the network, and may be conveniently expressed in decibels, or decinepers, since the neper is an inconveniently large unit.



Z_{01} : Image impedance of four terminal network at terminals 1 and 2.
Z_{02} : Image impedance of four terminal network at terminals 3 and 4.
For image operation:
$Z_{01} = Z_S$ and $Z_{02} = Z_L$.

Fig. 16.—Four terminal network operating between a source and a load.

To calculate the insertion factor of the network of Fig. 16 assuming now $Z_S \neq Z_{01}$ and $Z_L \neq Z_{02}$, it is firstly necessary to obtain the current that flows under conditions of direct connection of source to load. This current may be expressed as $I_1 = E/(Z_S + Z_L)$.

It can be shown that the four-terminal network of Fig. 16 may be completely represented, as far as all external effects are concerned, by the tandem connected arrangement of a symmetrical T network having elements which are a function of the image impedance Z_{01} and the image transfer constant θ, and an ideal transducer which impedance transforms Z_{01} to Z_{02}. By inserting this equivalent network between Z_S and Z_L it is possible to obtain an expression for I_2.

Thus $G = I_1/I_2$ may be obtained. The calculation is somewhat laborious, and the result only is stated here, expressed in decibels:

$$IL\ (db) = 20 \log_{10} |G| = -L_1 + L_2 + L_3 + L_4 + L_5$$

where

$$L_1 = 20 \log_{10} \left| \frac{Z_S + Z_L}{2\sqrt{Z_S \cdot Z_L}} \right|$$

$$L_2 = 20 \log_{10} \left| \frac{Z_S + Z_{01}}{2\sqrt{Z_S \cdot Z_{01}}} \right|$$

$$L_3 = 20 \log_{10} \left| \frac{Z_L + Z_{02}}{2\sqrt{Z_L \cdot Z_{02}}} \right|$$

$$L_4 = 20 \log_{10} \left| 1 - \frac{Z_S - Z_{01}}{Z_S + Z_{01}} \cdot \frac{Z_L - Z_{02}}{Z_L + Z_{02}}\ e^{-2\theta} \right|$$

L_5 = Image attenuation constant, db.

The physical significance of these terms has been explained in the main part of this article.

It is interesting to note that when $Z_S = Z_{01}$ and $Z_L = Z_{02}$, the terms L_2, L_3 and L_4 each become $20 \log_{10} 1$, or 0 db, and the insertion loss becomes equal to the real part of the image transfer constant, expressed in decibels, less the term L_1. These conditions of operation are referred to as image operating conditions, and the impedance junctions Z_S, Z_{01} and Z_L, Z_{02} are said to be image matched. From a transmission aspect this means that no reflections are occurring at these impedance junctions.

If $Z_L = Z_S = Z_{01} = Z_{02}$ the terms L_1, L_2, L_3 and L_4 each become $20 \log_{10} 1$, or 0 db, and under these symmetrical conditions of image operation, the insertion loss is simply the term L_5, the real part of the image transfer constant, expressed in decibels.

Considering Fig. 3, which shows a differential transformer performing the function of a four-wire terminating set, the term L_1 becomes:

$$L_1 = 20.\log_{10} \frac{600 + 300}{2\sqrt{600 \cdot 300}}$$

$$= 20.\log_{10} \frac{9}{2\sqrt{18}} = 0.51 \text{ db.}$$

APPENDIX II

Derivation of the Extrema of $|K|$ in terms of a_1 and a_2

It has been shown that K may be defined in terms of T, Z_1 and Z_2 by the expression:

$$K = \frac{2 \cdot T \cdot (Z_1 + Z_2)}{(T + Z_1)(T + Z_2)}$$

$$= 2 \cdot \frac{\frac{Z_1}{T} + \frac{Z_2}{T}}{\left(1 + \frac{Z_1}{T}\right)\left(1 + \frac{Z_2}{T}\right)} \quad (1)$$

Now Z_1 and Z_2 may be expressed implicitly in terms of the expressions $(Z_1 + T)/(Z_1 - T) = A_1$, where A_1 is a complex quantity of magnitude $|A_1| = a_1$, and angle $\propto_1$,
and $(Z_2 + T)/(Z_2 - T) = A_2$, where A_2 is a complex quantity of magnitude $|A_2| = a_2$, and angle $\propto_2$.

By rearranging these expressions, Z_1/T and Z_2/T may be expressed explicitly as:

$$\frac{Z_1}{T} = -\frac{1 + A_1}{1 - A_1}$$

$$\text{and } \frac{Z_2}{T} = -\frac{1 + A_2}{1 - A_2} \quad (2)$$

By inserting equations (2) into equation (1), K may be written:

$$K = 2 \cdot \frac{\left[-\frac{1 + A_1}{1 - A_1}\right] + \left[-\frac{1 + A_2}{1 - A_2}\right]}{\left[1 - \frac{1 + A_1}{1 - A_1}\right]\left[1 - \frac{1 + A_2}{1 - A_2}\right]}$$

$$= -\frac{2 \cdot (2 - 2 \cdot A_1 \cdot A_2)}{(-2 \cdot A_1)(-2 \cdot A_2)}$$

$$= 1 - \frac{1}{A_1 A_2}$$

It is required to examine

$$|K| = \left| 1 - \frac{1}{A_1 \cdot A_2} \right|$$

for extreme values. Considering the unit vector to lie on the real axis, then $|K|$ will have its maximum value when the angle $-(\propto_1 + \propto_2)$ of $1/A_1 \cdot A_2$ becomes $(2 \cdot n_1 + 1)\pi$, while the minimum value of $|K|$ occurs for $-(\propto_1 + \propto_2) = 2 \cdot n_2 \cdot \pi$, where n_1 and n_2 are integers.

$$\text{Thus, } |K|_{max} = \frac{|A_1| \cdot |A_2| + 1}{|A_1| \cdot |A_2|}$$

$$= \frac{a_1\ a_2 + 1}{a_1\ a_2}$$

$$\text{and } |K|_{min} = \frac{|A_1| \cdot |A_2| - 1}{|A_1| \cdot |A_2|}$$

$$= \frac{a_1\ a_2 - 1}{a_1\ a_2}$$

where $|K|_{max}$ and $|K|_{min}$ represent the extreme values of $|K|$.

Consequently the following relations obtain:

$$|K|_{min} = \frac{a_1 a_2 - 1}{a_1 a_2} \leq$$

$$|K| \leq \frac{a_1 a_2 + 1}{a_1 a_2} = |K|_{max}.$$

THE BULK MOVEMENT OF WORKING EQUIPMENT AND CABLE AT MAROUBRA EXCHANGE

K. G. HARDY, A.S.T.C.

Working trunk boards at Maroubra 4000-line pre-2000 type automatic exchange were shifted bodily about two feet, and at the same time the main runway carrying all the cables between the trunking equipment and the primary suites, were elevated eighteen inches. This operation was necessary to permit an area of 700 sq. ft. spanned by the runway to be equipped with 10 ft. 6 in. high, 2000-type racks. See Fig. 1, showing the exchange layout. At this time Maroubra was a pre-2000 type exchange laid out to develop to a capacity of 7000 lines, and with 4000 lines already installed. The trunking equipment was grouped at one end of the switchroom while the primary units and M.D.F. were located about forty feet away at the other end, the intervening space being reserved for additional primary equipment. A single twenty-four inch runway about ten feet high, carried the cables linking the switching equipment with the rest of the exchange.

As pre-2000 type primary units were not available to extend the exchange, it was necessary to install 2000 type equipment, which, it was assumed, would also be used eventually to replace the existing primary line switch boards. At the same time it was desirable to make provision for eventually increasing the capacity of the exchange to 10,000 lines. The obstructing runway and cable could have been replaced at a higher level, but this operation was estimated to require 5000 manhours and to cost about £5000, so a cheaper and more satisfactory alternative was sought. A detailed examination showed that a scheme for moving the switching equipment, as a whole, towards the primary equipment, and at the same time lifting the obstructing runway to a suitable height, was feasible and this was the method adopted. A description of the procedure is given in the following.

Each trunk board and also an I.D.F. and a T.D.F. were lifted a few inches by hydraulic jacks and continuous angle iron shoes fitted under the ends of each row of boards. They were then lowered on to one inch diameter pipe rollers which, in turn, moved on 1" x ⅜" mild steel tie bar used as rails to reduce friction, see Fig. 2. The boards were now braced to form a solid block, see Fig. 3, and their fuse panels loosened to prevent damage. Tubular scaffolding was then erected between the two blocks of equipment and around the runway to be lifted. This structure, see Fig. 4, was

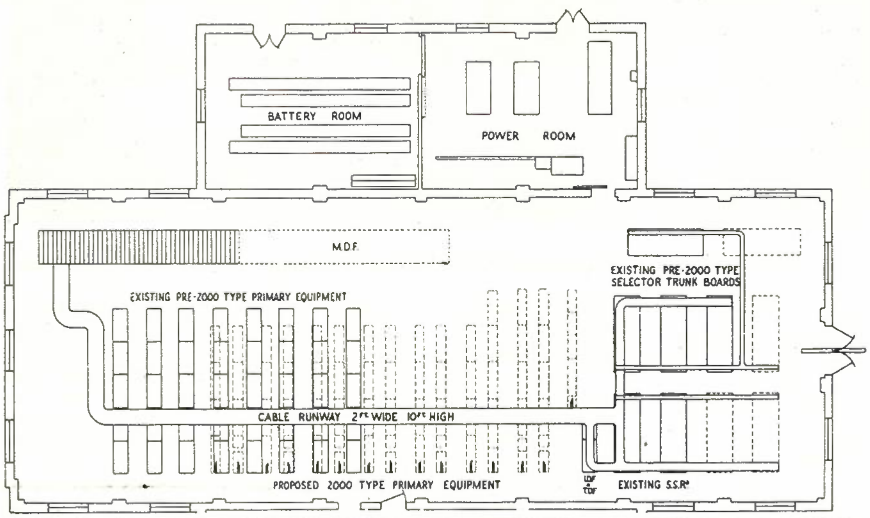


Fig. 1.—Disposition of existing primary and trunking equipment forty feet apart, bridged by one two feet wide, ten feet high runway. Ultimate 2000 type primary racks shown dotted.

Fig. 3.—Working trunk boards braced to form solid block.

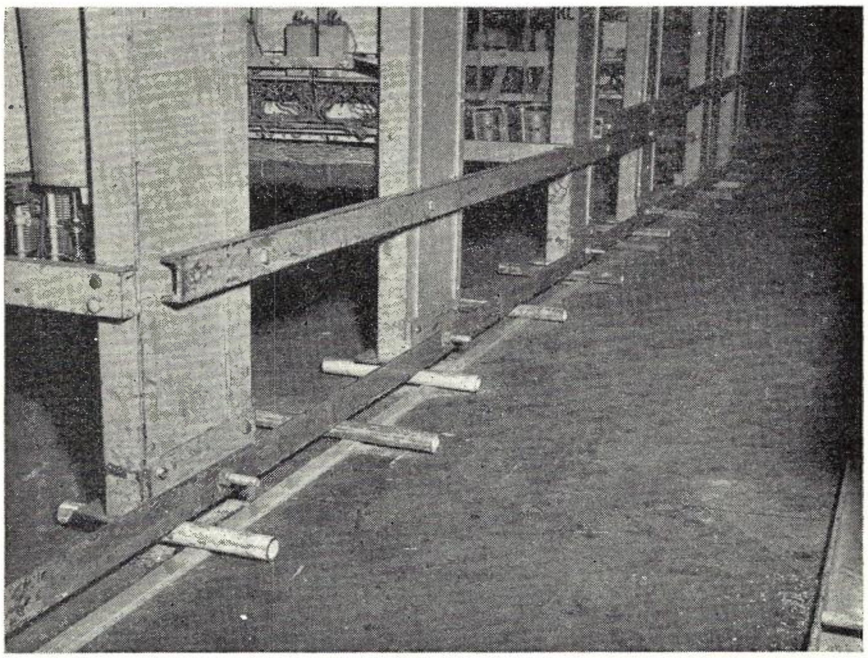


Fig. 2.—Trunk boards fitted with angle-iron shoes riding on 1" pope rollers using tie-bar rails to reduce friction.

extended to the 14 feet high ceiling by means of adjustable feet, and was arranged with a plank catwalk erected at a height of eight feet from the ground to form a working platform on which the men could manipulate the runway lifting devices.

Five "U" shaped channel iron supports were manufactured, see Fig. 5, each fitted across its open end with a removable one-inch pipe ferrule on a three quarter inch rod. The runway rested on the ferrules, and thus had freedom to move longitudinally in a horizontal plane. It was, of course, essential that the runway should have this freedom since, to gain the requisite additional height, part of it had to move lengthwise about two feet towards the primary boards. The supports were placed around the runway at intervals of about six feet, and were attached by means of three-quarter inch screwed mild steel rods to the upper structure of the scaffolding. An inherent advantage in these lifting devices was their safety and ability to remain as supports as long as was necessary.

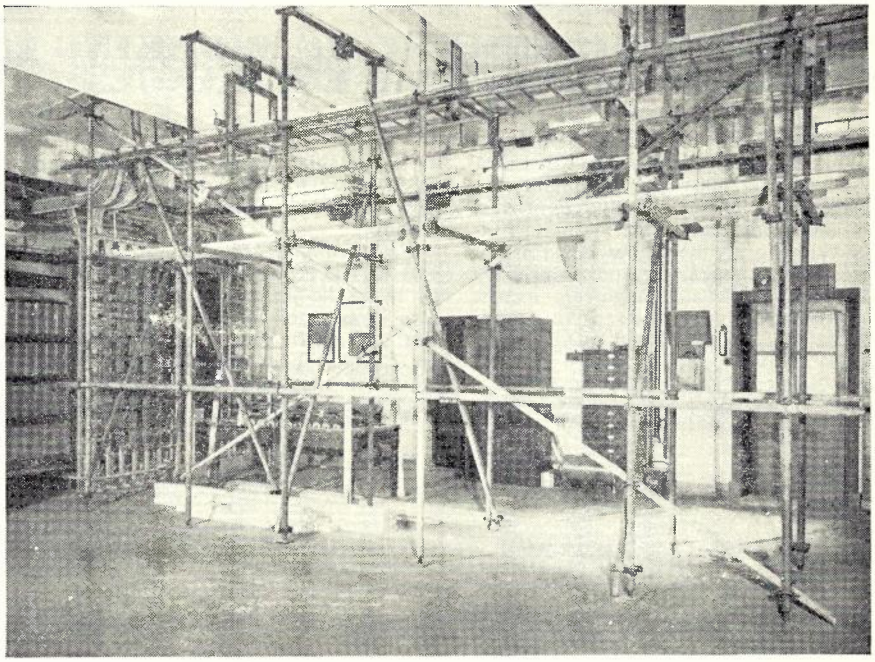


Fig. 6.—Runway after elevation, showing cables hanging loosely over one of the new bends.

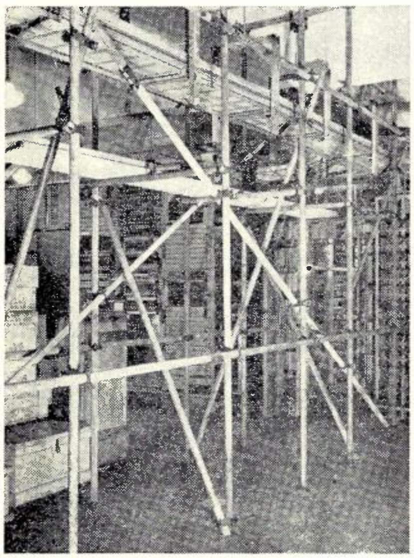


Fig. 4.—Tubular scaffolding and catwalk erected around the runway to be lifted.

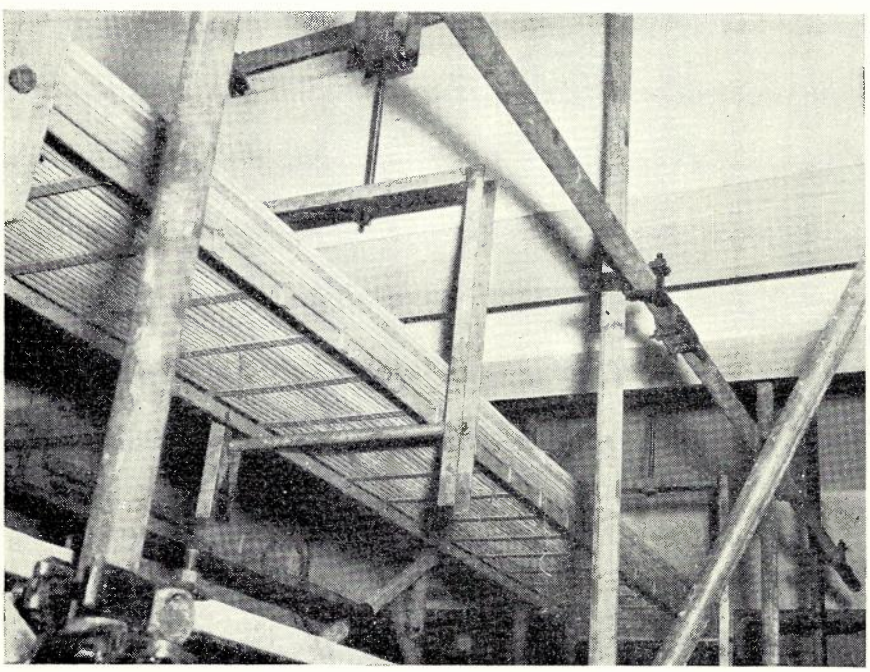


Fig. 5.—Runway resting on removable pipe ferrule and free to move longitudinally.

For a distance of about three feet at each end of the section to be raised, the sidebar and slats of the runway were removed, and the lacing cut away from the cables which were opened out. Of these two unlaced portions, one was almost immediately above the I.D.F. and the other above the nearest suite of primary boards. Here bends were to be formed to effect the requisite change in height. They were required to be reasonably sharp to ensure that the new equipment suites abutting these points had sufficient headroom. Before beginning the main operation two banks of infra red lamps were trained on the free cable in the area of the projected bends. Some of these cables are more than twenty years old, and it was desirable to have them as pliable as possible before any movement was attempted. They were heated by the lamps in the beginning for about 30 minutes and at various intervals throughout the job. This treatment proved to be quite effective, the cables being noticeably softer and easier to manage, and no damage was observed.

Five men controlled the movement of the trunk boards, two being stationed at the back of each of the two rows of boards, while the fifth guided the I.D.F. and T.D.F. Three men with baulks of timber and using the ceiling beams as fulcrums, exerted pressuse on the upper structure of the trunk boards. A man was also stationed at each of the five runway lifting supports. The move began slowly. As the main section of the runway rose, the block of trunk boards was eased forward towards the primary equipment. In about an hour the runway had been elevated approximately five inches, and at this stage the applied and resistive forces were in two different horizontal planes forming a couple which

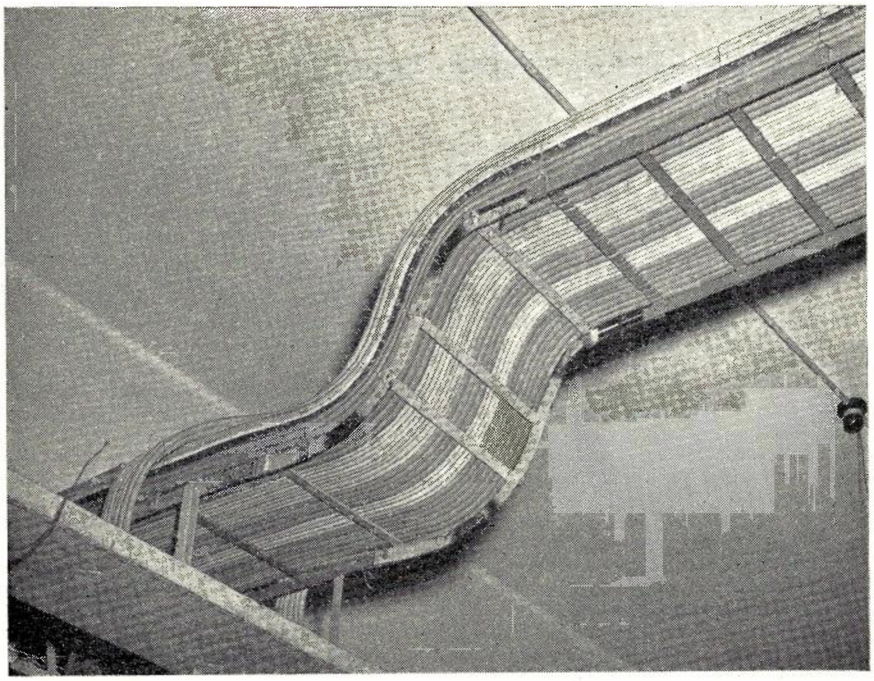


Fig. 7.—One bend newly finished.

aided the remainder of the move. This allowed the subsequent elevation of the runway to take place to within one inch of the required height with rapidity and comparative ease, see Fig. 6. While the move was in progress several men helped ease the cables into their new positions as the bends gradually formed, and also watched to see that no undue distortion or tension occurred in the cables, see Fig. 7. After attention to the shape of the bends, the runway was lifted into its final position.

Since it was not known to what extent the cables would be affected by the process of bending, the final positions of the trunk boards could not be predetermined, thus preventing the floor being plugged in advance for anchoring purposes. However, the boards were securely fixed in their new position by the use of an explosive type fastening tool (Fig. 8) which fired steel pins through the angle iron bases of the boards direct into the concrete floor giving a solid connection.

The weight of cable and runway raised was estimated at 2000 lbs., while the total cost of the work done was about £300 consisting of the hire of tubular scaffolding £6, miscellaneous iron, fastenings, etc., about £15; together with 500 manhours. The actual movement required fifteen men for about four hours, commencing at 8.30 a.m. on a Sunday morning to ensure least serious interruption to service should any mishap occur. However, no faults attributable to these operations were found either during the move or afterwards.

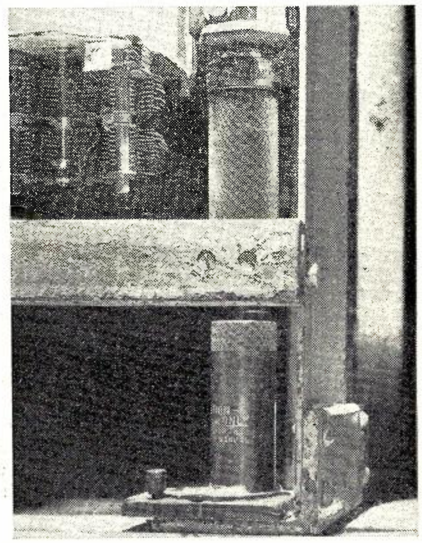


Fig. 8.—Fastening tool firing steel fixing pins through angle-iron into concrete floor.

DESIGN FEATURES OF THE 3000 TYPE RELAY

H. M. AITCHISON

Introduction: For some years, the 3000-type relay has been the standard all-purpose relay, and, while its general characteristics and adjustments may be well known, certain aspects concerning its design are not generally appreciated.

There is a very considerable number of conditions under which modern relays have to operate in modern circuit technique, and it would be impossible, therefore, to design one relay which would meet completely each separate condition. The main aim in evolving the 3000-type relay was to produce a relay fulfilling all requirements with a reasonable amount of efficiency, and the most important of these requirements are as follows:—

(i) It must meet a wide range of operating conditions which will affect the springset load, its energisation, (current values on which it must operate, release, etc.), and the operating time lag taken for these functions.

(ii) Consistent with satisfactory performance, its construction must be as simple as possible and the number of parts kept to a minimum. Furthermore, these parts must be easily replaceable.

(iii) The springsets must be interchangeable and they must also be arranged to permit easy examination of the contacts and adjustment of individual springs.

(iv) The dimensions of the magnetic circuit must be chosen so that it is capable of carrying the maximum flux required by the most heavily loaded relay. In conjunction with this requirement, however, it must be suitable for sensitive relays with closely controlled release conditions and also for high-impedance relays used for bridging and battery feeding.

(v) The adjustments must be simple, definite and permanent.

(vi) The mounting method must minimise the accumulation of dust on the contacts.

(vii) A relay made by one manufacturer must have the same operating characteristics as a similar relay made by another manufacturer.

The main features of the 3000-type relay are discussed in the following paragraphs.

The Magnetic Circuit: The proportions of the iron circuit have been very carefully established and air gaps have been avoided except at the essential point, that is, between the armature and the pole face. By good design of the magnetic joints between the core and yoke and the yoke and armature, the magnetic reluctance has been kept to a minimum. This helps to increase the operating efficiency of the relay when only weak energisation is available and effects an overall saving in current in an exchange since it permits the use of high resistance windings. It also ensures a minimum leakage even at high flux values thus reducing magnetic coupling between adjacent relays.

The Coil: The core is made from a special grade of soft iron carefully annealed and having high permeability and low retentivity. The core has a circular cross section of 0.098 sq. in. with an enlarged portion at the armature end to form a pole piece 0.273 sq. in. in area. This provides an air-gap of large area and consequent low reluctance, but ensures that the core diameter is the minimum to avoid saturation at the heavy current values necessary to provide the operating force under certain conditions.

The original design of this relay used a copper front core cheek. It was thought that this would provide a slight slugging effect and obviate contact bounce, but investigation showed that the gains were very limited. As the S.R.B.P. board cheeks are necessary on relays required to operate as fast as possible, the Australian specification does not cover the two types and copper is not called for on any relay other than those with an armature end slug. The complete coil assembly can be dismantled from a mounted relay without the relay being removed from the mounting. The wiring is disconnected from the coil tags, the armature removed, and then, when the core nut is taken off, the coil can be slipped out.

Rear coil cheeks are provided with two, four or five tags, depending on the number of windings. The inner end of each winding may be shown by a red enamel marking on the tag. All windings are wound anti-clockwise starting from the inner end, and when viewed from the rear end of the coil. Four types of coil are provided:—

(i) **Plain.** All general purpose relays.

(ii) **Nickel iron sleeved.** When relays are connected across speech paths or when they provide the feeding bridge for speech transmission, they are required to offer a high impedance to speech currents to avoid shunting the speech current while, at the same time, offering a low resistance to D.C. Relays used for this purpose have three cylindrical nickel iron split sleeves fitted over the core. The following figures indicate the result of impedance tests made on two 200 + 200 ohm coils, the windings of each being connected in series aiding. The frequency of the testing current was 796 c/s.

	Demagnetised (ohms)	With 60 mA D.C. (ohms)
Normal coil	7,783 /55.8°	5,405 /55.5°
With sleeves	19,290 /72.1°	15,607 /76.1°

(iii) **Slugged.** When a relay is required to have an appreciable operate or release lag, slugged coils are generally used. For an operate lag, the slug is at the front or armature end of the spool, while for a release lag, it is at the heel or rear end. Three lengths of slug are used —½ inch, 1 inch and 1½ inch—according to the spring load and the required time lag. These slugs are of pure copper and are, in effect, low resistance short-circuited windings of one turn. A relay with a front slug is slow to operate and also slow to release, but a relay with a rear slug may, for most purposes, be regarded as fast to operate but slow to release. The length of the residual gap is an important factor in the release lag of a slow release relay and for this reason most slugged relays are fitted with a screw residual with the correct gap marked in brackets, on the code label. Slow release relays must be saturated magnetically to ensure the constancy of the lag, for which a minimum of 450 ampere turns is required. As a rough working guide, the energising period should not be less than the specified release period. With a small load, a release lag of 500 milliseconds is obtainable; while with the maximum load, a lag of 200 milliseconds can be obtained.

In the case of slow operate relays, the lag is dependent on the circuit factor of safety of the relay and on the "turns squared/resistance ratio" (T^2/R). With a factor of safety sufficient to ensure reliable operation, operating lags of 50-75 milliseconds may be obtained.

Unless considerable experience is available slow operate relays are difficult to design where stable timing is important, since the delay in operation is dependent on changes in the supply voltage, and where long delays are required, the use of a low circuit factor of safety also introduces wide timing variations.

(iv) **Nickel iron cores.** The speed of operation of a plain unslugged relay may be increased by the use of the following methods:—

(a) By excess of current received over that just required for operation.

(b) By decrease of the ratio of the circuit inductance to the circuit resistance.

(c) By decrease of the slugging effect of the magnetic path.

In general, use is made of methods (a) and (b) but when operate times of the order of five milliseconds or less are required, it is necessary to employ method (c) in addition. The slugging effect is decreased by using a nickel iron core instead of ordinary soft iron. Due to its high electrical resistance, eddy current losses, and therefore the slugging effect, are then much reduced. By attention to a similar set of conditions, fast release times can be obtained.

The Armature: There are two types of armature—

(i) **Ordinary.** This is made in four patterns—three have fixed residual studs of 4, 12 or 20 mils, of which the 12 mil is most commonly used. The other pattern is fitted with a screw and lock nut. This screw residual is used to meet timing or other tests which require a variation of the residual value given by the three standard studs.

(ii) **Isthmus:** This type is used on relays which are required to respond to impulse trains. Those with square slots are the general type used but, when the relay is of low resistance in series with a barretter, armatures with "V" slots are used. The use of the isthmus is threefold:—

(a) As the cut-away armature becomes saturated at a much lower value of ampere turns, the relay gives a more uniform performance over a wide range of energisation imposed by varying conditions.

(b) The moment of inertia of the armature is reduced.

(c) The flux in the circuit for a given current is reduced, and prompt release is ensured.

Isthmus armatures may be obtained with fixed residual studs but the screw type of adjustable residual is more common.

Springsets: Four kinds of contact action are provided, namely: make, break, changeover and make-before-break changeover, known briefly as M, B, C and K units respectively.

The relay will hold a maximum of eighteen springs in two piles of nine. This permits six units without restriction; seven units, provided not more than four are C or K units; and eight units, provided not more than two are C or K units. The two piles of springs are mounted one on either side of the buffer block except when only one unit is provided, when it is mounted on the left of the block viewed from the armature end with the springset uppermost. In all references to springsets the terms "left" and "right" are referred to in this sense. Where two or more contact units are provided they are divided into two sets with approximately equal loads. If the loads are not identical, the left should be the heavier. In the majority of cases, the units are arranged in M B C K sequence from the yoke. The springs are numbered from "1 to 9" on the left side and "21 to 29" on the right side, and this numbering appears on circuit diagrams. For any spring combination, there is one, and only one correct method of arranging the springs.

The tags of the springs are staggered, the lever spring tags being innermost and the buffer springs outermost. The contact springs are fitted with twin dome contacts and the spring tips are split, thus enabling the two contacts to function almost independently. The springs are made of a special alloy of nickel silver and for general purposes are of two thicknesses, 14 and 12 mils. 14 mil springs are used for the initial design of any general purpose relay, but if the resultant loading is too great for satisfactory operation, 12 mil springs may be used. In certain cases, thicker springs are used, such as on impulsing relays where a heavy load and a short travel are desirable. A stiff break buffer spring is usually provided in these cases and buffer block clearance is then absent.

The standard contact material is pure silver which has been shown to be the most suitable, having consideration for fault liability, longevity and capital cost. Silver contacts may be used to carry and break currents up to 300 mA with 50 volt working. Platinum contacts may be specified to carry, make and break currents up to 1.25 amps, suitable quenches being fitted when required. Platinum is often used for currents under 300 mA where heavy service is required, such as time-pulse relays.

Contacts controlling lamp circuits are a special case as the load, although non-inductive, has a high initial "surge" value at the instant of make. The number of lamps which may be operated on a single silver contact, for a contact life of 10^6 operations is based on a loading of 40 watts under steady-state conditions or a maximum initial "surge" current of two amps. On this basis, silver contacts may be used to control 50 lamps No. 2 (6V.), 17 lamps No. 2 (12V.) or 8 lamps No. 2 (50V.). Platinum contacts are less efficient than silver for this type of load. For controlling circuits other than lamp circuits with current greater than 1.25 amps or for voltages greater than normal exchange voltages, mercury contact tubes may be fitted to the relay. In some cases, single tungsten contacts may be fitted to the springs.

Springs with platinum contacts are identified by a notch cut in the tip of the springs. When it is necessary to have more than one contact material in a relay, the first appropriate contact unit from spring "1" is selected as platinum. No mixture of contact materials is permitted in a single contact unit. On circuit diagrams, platinum, mercury or tungsten contacts are indicated by the use of letters "Pt," "Hg" or "W" respectively placed alongside the contact code letter as a suffix.

In all normal actions during operation, the "break" contacts open before the "make" contacts close. A changeover for this purpose may be regarded as a break and a make. In a K unit, however, the reverse sequence takes place.

Circuit conditions sometimes require that one unit should operate earlier than the remainder. This is then termed an X-action. On the other hand, it may be necessary that one unit shall operate later than the rest and this is known as a Y-action. Only one X or Y action is permitted on a given relay and in no case can a relay have both types of action. Furthermore, only M or B units may be X or Y action. These actions are always accommodated in the right hand springset; in the case of the X action in the unit nearest the armature and in the case of the Y action in the unit remote from the armature. The left springset in these cases is normal and the lifting pin lengths of the right hand springset are modified to produce the action required. For an X action a packing piece is introduced under the buffer block and each springset. A longer armature travel is required, it being increased from 31 to 43 mils.

Buffer Blocks. Buffer blocks are made from a white synthetic moulding material and are secured to the yoke by two screws and a clamping plate. A recent development in the United Kingdom is the use of a ceramic for these blocks. They are closely dimensioned, each significant dimension being governed by a very fine tolerance. This is necessary because the adjustments of the relay springs depend on the buffer block for spacing and tensioning. Five different types of buffer blocks are available.

Mounting. For mounting, each relay is provided with a bakelite insulating plate and two screws with ebonite insulating bushes. The relay is mounted with the springsets on the side to reduce dust trouble. Horizontal flanged type strips have been developed on which the relays are mounted with the springsets to the right. A vertical flanged type mounting is made but is not commonly used. A double drilling is provided for relay sets and selector mountings which are jacked in, and in these cases the relays are mounted with their springsets outermost. Another type of mounting is used for accommodating relays on the right hand vertical of 2000 type automatic equipment racks.

On flanged type mountings, the relays are mounted at $1\frac{1}{8}''$ vertical and $2^7/_{16}''$ horizontal centres. If, however, the fitting of individual covers is required, it is necessary to space them $1^5/_{16}''$ vertically. On relay set and selector bases, the drillings are spaced at $1^3/_{16}''$ centres vertically. There are four types of cover, for a single relay, for two relays and a series of covers for each of the flanged and jacked-in mountings. The single and two relay covers are fitted with a tray to retain the cover by friction, whereas the common covers are supported by guide details fixed to the mounting.

Special types of 3000 type relay. In addition to the normal relay, there are several other special types which have been developed to employ the same mounting arrangements and which use most of the 3000 type piece parts. The shunt field relay was developed to perform functions under the control of a current reversal in the operating circuit. This relay consisted of a line coil and a polarising coil mounted on two cores on one yoke. As this relay occupies more coil space than the normal type it can only be fitted with a one-step buffer block unless special mounting arrangements are made. It provides "operate", "non-operate" and "release" functions, as follows:—

(a) **Operate:** This requires both coils to be energised in assisting directions.

(b) **Non-Operate:** This can be arranged in three ways:

(i) line coil energised only;

(ii) the polarizing coil energised only;

(iii) both coils energised in opposing directions.

(c) **Release:** Four conditions can control the release:

(i) reversal of the line coil current;
(ii) disconnection of both coils;
(iii) disconnection of line coil only;
(iv) disconnection of polarizing coil only.

Generally, owing to the light contact load and to the fact that, with one winding energised, a certain proportion of the magnetic flux leaks into the armature circuit, the relay is extremely sensitive and is prone to operate under surge conditions, for example, when used as a relay in a transmission bridge. The relay is also subject to greater variation in a batch during production than is the normal 3000 type. For these reasons, its use has been restricted in this country and it has been replaced in circuits by a 3000 type relay connected to a suitable arrangement of rectifiers.

A.C. Switching Relays. For switching mains supply voltages and also for D.C. circuits passing more than 1.25 amps, attachments are made which mount mercury tubes, operated by an armature extension. One or two tubes may be fitted and M B or C actions obtained, but the complete arrangement takes the space of two relays vertically.

Polarized Relays. In general appearance the polarized relay is similar to the shunt field relay, except that the polarizing coil is replaced by a permanent magnet of rectangular cross section. This magnet is made of 36 per cent. cobalt steel, having a flux of opproximately 3000 lines per sq. cm. on open circuits. When the winding is not energised, or when it is energised to produce flux in the magnetic circuit aiding that due to the magnet, the relay will remain unoperated, but when energised in the reverse direction, corresponding poles will be produced in the links and the relay will operate.

Thermal Relays. There are several applications of relays in which they are required to have an operating or releasing lag much in excess of that to be obtained by electromagnetic means, and for these cases a thermal relay is used, which makes use of the heating effect of a current. Two main types have been designed:—

(a) The thermostat type with flick or normal action.
(b) The thermal element type.

Under the influence of the heat produced by the current in a winding around a bimetallic strip and the consequent unequal expansion of the two sides of the composite strip, the flick action type bends until a point is reached when a contact on a bowed spring is caused to change over from the heated strip to make a buffer spring. A similar, but unheated strip, is mechanically connected to the thermal strip to compensate the effects of normal changes in the ambient temperature surrounding the relay. The essential feature of the flick action is the instantaneous changeover, the transit time being less than eight milliseconds, which is effective after the pre-arranged time interval.

In the normal action thermostat type, the heated strip is equivalent to the lever spring of an ordinary C action and changes over between two buffer springs. A transit clearance must be provided to prevent contact between all three springs during the operation, and there is consequently a period of disconnection. This type is compensated for ambient temperature in a manner similar to that described above.

Thermostat relays must be designed to give operate lags of the order of 10 to 60 seconds, while the release time is usually about 15 seconds. Both operate and release lags can be adjusted to reasonably close limits but not simultaneously. The actual operate time depends mainly on the wattage of the relay and since this is affected by the variation in the operating voltage precise timing cannot be effected. A further factor of uncertainty arises when the thermostat is re-operated before being completely cooled, but with intervals of, say, half a minute or more, the variation due to this is small. The total variation due to all undesired effects can be expected to be of the order of $\pm$ 20 per cent. If actions other than a single M B or C are required, the thermostat relay is used to operate a relief relay. Single dome silver contacts are used on the springs.

LAYING OF OXLEY-DARRA CABLES

D. C. CRAIG

Darra is a rapidly growing suburb situated approximately 8½ miles radially from the Brisbane G.P.O., and 3¼ miles from the nearest telephone exchange at Sherwood, as shown on the locality plan on Fig. 1. Existing services in this suburb were connected to the exchange either by means of aerial wires erected on one of two main trunk pole routes, or by a 54-pair buried cable, all following the railway line. Numerous applications for telephone services from residents and business premises in the area, including some urgent lines for defence services, could not be satisfied as the plant was fully occupied.

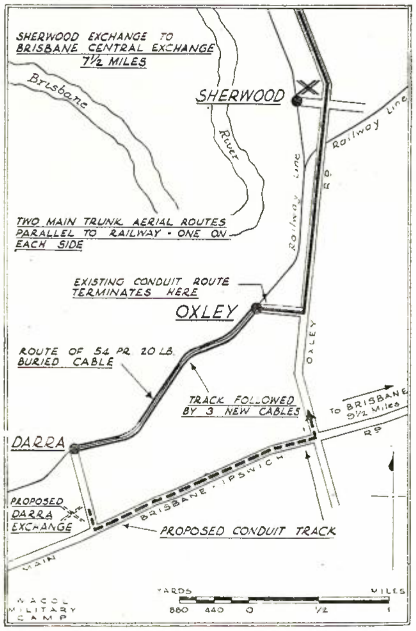


Fig. 1.

Future plans provided for the establishment of an automatic exchange to serve the Darra area. However, it was estimated that it would be at least two to three years before the exchange would be provided, and it was necessary to adopt temporary relief measures to satisfy the demand for telephone services in the meantime. This was achieved by laying a buried cable by mole plough between Oxley and Darra. At Oxley, the new cable was jointed into existing spare subscribers' cables from the Sherwood Exchange. The new cable is used initially to connect new services to the Sherwood Exchange until the Darra Exchange has been established, when it will be used for junction circuits between the new exchange and the Toowong main exchange.

150 pairs were required for interim subscriber development and for ultimate junction services, but due to this size of cable being unavailable, three 54-pair tape armoured cables from existing stocks were used. A survey of the area indicated that the most suitable location for laying the buried cable was inside the railway enclosure between Oxley and Darra, a distance of approximately two miles. Inside this enclosure, the buried cable would be protected from most of the hazards normally associated with cables buried along footpaths or roadways, that is, excavation work by authorities for water, gas or electric light mains, and road or footpath reconstruction works.

The most economical method of laying buried cable over long distances is by means of a mole plough. This type of plough closely resembles a heavy road ripper plough with a single blade attached to the centre. Cable feed-in tubes are welded to the rear of the blade. Cable is then fed through these tubes into the ground at the bottom of a narrow cutting made by the blade, see Fig. 2. As three cables were being laid simultaneously, it was necessary to fit three separate tubes to the plough, one being used for each cable.

The cable laying train consisted of a TD. 18 Caterpillar type tractor. Coupled to the rear draw-bar was a mole plough which, in turn, was followed by three cable trailers each loaded with a drum of 54-pair 20 lb. tape armoured cable. The two leading trailers were fitted with overhead free-running pulleys to give support to the cable from the rear trailers. See Fig. 3.

Cable trailers have a very low-slung axle in order to provide clearance for the large drums of cable they are required to carry. As the front draw-bar of the trailer is higher than the rear axle, it was necessary to design a special universal type, flexible, two-level coupling for coupling up the two rear trailers. When travelling over rough, uneven or sloping ground, the varying levels cause the trailers to twist and tilt. It was, therefore, necessary to use flexible couplings as rigid couplings would quickly break under the very heavy strain imposed upon them.

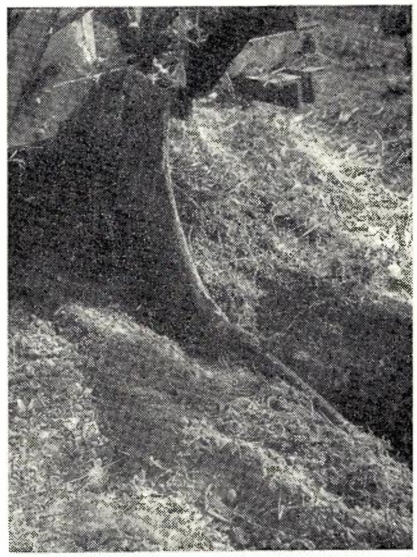


Fig. 2.—Mole plough cable guide tubes.

A preliminary survey was made of the track and, following this survey, long

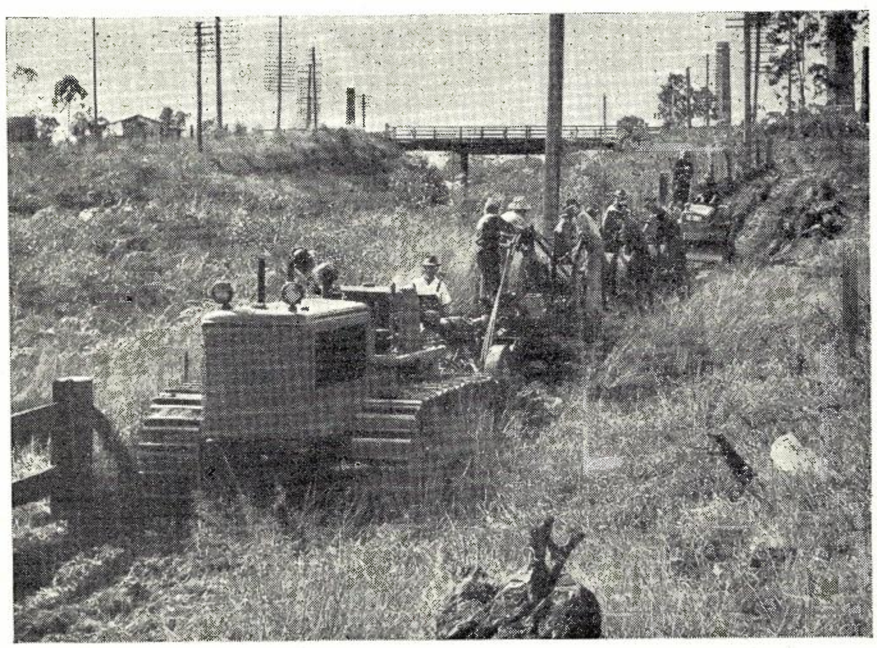


Fig. 3.—Mole plough in operation.

grass and undergrowth was cleared by a small bulldozer fitted with a hydraulically operated blade. The dozer was also used to roughly level-up severe slopes or rough spots which could not be traversed easily by the cable-laying train. It was also necessary to take down fences in many places to provide clearance for the tractor, as a line of telephone poles existed within a few feet of the railway fence and approval to lay cable in the railway enclosure had only been given, conditionally upon the cable being laid close to the fence alignment.

After all preliminary work had been completed, an exploratory run was made with the mole plough without the cable trailers. This preliminary run loosened the ground and located any tree roots, stumps, boulders or other obstructions which would interfere with the laying of the cable. These obstructions were cleared off by hand or with the assistance of the bulldozer. Having completed the preliminary steps, the complete cable-laying train was set in motion and cable laying proceeded steadily without any undue difficulty. When in motion, the train proceeded at a speed of approximately half a mile per hour, laying the three cables simultaneously, the time taken to lay the three cables for the full distance of two miles being approximately four days. The chief delays that occurred were due to the need to redrum most of the cable from large drums on to smaller ones, to load cable trailers with cable, and to overcome various minor difficulties encountered along the track.

Over one section of approximately 400 yards on a gradual uphill slope, the ground was too boggy to support the heavy tractor. This sodden ground was caused by years of drainage from a nearby brickworks running down the slope of the ground. When this section was reached, the tractor was uncoupled from the remainder of the train and taken to firm ground at the top of the slope. It was then firmly anchored and an extended steel wire rope from the tractor's logging winch was taken down the slope and attached to the plough coupling. The plough and trailers were then gradually drawn up the slope by means of the tractor's logging winch.

FAULT REPORT DISTRIBUTION

J. HARDIE

In the city area of Melbourne metropolitan network there is a staff of approximately fifty faultsmen engaged on the maintenance of subscribers' equipment. These men are required to call the fault desk officer at least once each half-hour to receive reports of faults in their particular areas.

It was observed that, after waiting for some time because the desk officer was engaged with other calls, an area faultsman would be answered and sometimes advised that there were no faults for his area. Such calls wasted a considerable amount of the time and effort of all concerned, and seriously retarded the speed of distribution. To minimise this, a circuit arrangement was installed that provided an exchange line number for each area faultsman. Each of these lines is terminated at the desk officer's position by means of a call lamp and switchboard key.

When calling the desk, the faultsman dials the number associated with his area. If the desk officer has fault reports for an area, the key in the termination of that area line is depressed, and in this position an incoming call will light the line lamp and be answered accordingly. If no faults are in hand for an area, then the key is left in the normal position and a faultsman calling in will receive a "no reports" signal of continuous ring tone. The circuit arrangement is shown in Fig. 1.

P.A.B.X's in the city are grouped into convenient areas and are maintained by a separate staff. Each P.A.B.X. is normally provided with an extended alarm wire back to the exchange and a paging signal arrangement has now been superimposed on this wire to notify the maintenance man that he is required to call the fault desk. If a fault is reported at a P.A.B.X. the desk officer at the exchange operates a key that sends "pulse signals" over the alarm wires of all P.A.B.X's in the maintenance group in which the fault exists. These pulses operate an audible alarm in or near the P.A.B.X. equipment and flash a lamp on the manual switchboards. The circuit of this arrangement is shown in Fig. 2. The signal continues to operate until the faultsman calls the desk officer, who then restores the key.

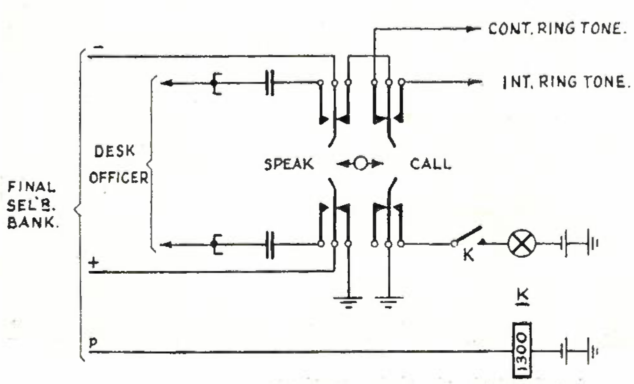


Fig. 1.

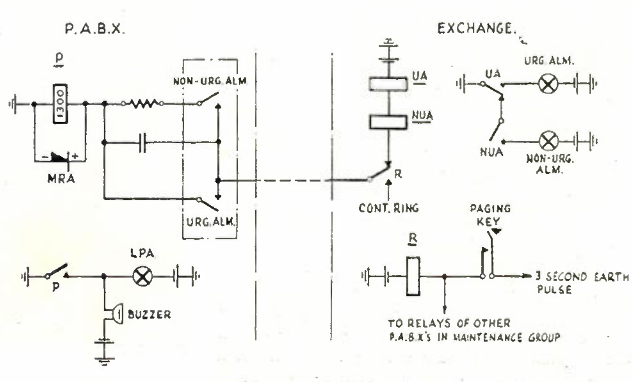


Fig. 2.

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. 3407—ENGINEER, LINE CONSTRUCTION.

Q. 2.—(a) List the main purposes for which tractors are used by the Department. Briefly specify the principal features of a machine and associated equipment which you would recommend for each of these purposes.

(b) List the factors which could influence (i) the general provision, and (ii) the use for a particular task, of trench excavating machines.

(c) Name three types of trenching machines in use in the Department and give mechanical particulars and average performance figures of one type.

A.—(a) Tractors are used by the Department for:
(i) Hauling cable-laying or ripper plough.
(ii) Clearing.
(iii) Backfilling.
(iv) Shovel loading.
(v) General purposes.

Principal features and equipment required for—

(i) Adequate draw-bar horse-power. Crawler-tracked machine. Logging winch and double drum power control unit, or either of these, preferably the former. Suitable towing attachment for cable drum trailers in use.

(ii) Dozer blade, cable or hydraulically operated, suitable for angling and tilting if possible. Logging winch. Tree-dozing attachment desirable.

(iii) Wheeled (farm) type tractor preferable. Blade for backfilling.

(iv) Wheeled (farm) type tractor preferable. Cable or hydraulically operated shovel, approx. ½ cu. yd., adequate height and clearance from tractor, for loading tip truck. Sufficient width to clear path for tractor front wheels.

(b) (i) Availability of suitable machine. Distance to be transported. Expected savings by use. Absence of better alternative method, e.g., using cable laying plough.

(ii) Nature of soil. Suitability of terrain. Absence of obstructions. Adequate space for use of machine along route. Depth and width of trench required. Presence of rocks.

(c) Barber-Green 44C; Jeep-A-Trench; Aveling Barford.

The Aveling-Barford trench cutting machine is powered by an 8 h.p. one-cylinder radiator (formerly water-hopper) cooled petrol engine. It is hauled forward by cable anchored ahead of machine, a forward mounted ratchet driven winch winding in cable at adjustable speed. Rear wheels are adjustable for height to enable a vertical trench to be cut in sloping ground. Cutting chains are provided for excavating trench either 11″ or 18″ wide. Maximum trench depth 3′ 6″. Spoil banking chain is operable either side. Automatic safety clutch to protect engine and transmission when obstructions encountered. Steers by worm and handwheel. Weight about 3 tons. Formerly fitted with steel rimmed wheels, but pneumatics now procurable.

Capable of excavating at a minimum rate of 25 feet/hour at maximum depth in heavy ground, and up to 175 feet/hour for shallow trenches in light ground.

Q. 3.—(a) Give an account of the procedure adopted in excavating for and laying a nest of self-aligning ducts.

(b) List the fundamental principles which you would apply to the design of manholes for such a route.

A.—(a) Before excavating the trench, enquiries should be made from municipal authorities and the ground should be inspected to locate obstructions. Pilot holes should be sunk along the route where there is any possibility of unmarked obstructions necessitating an alteration of the intended location of the conduits. The pilot holes should be at least 6 inches deeper than the proposed trench and the bottom and sides should be well probed for foreign bodies. Having fixed the location of the trench, the sides should be marked out, allowing a minimum width which will be wide enough for men to work, generally not less than 3 inches wider than the conduits. A suitable method of marking each side of the trench is to drive a peg at each end of the section with intermediate pegs at 30 feet intervals and then draw a line tight along the outside of the pegs.

The line is then marked on the ground by means of the sharp point of a pick on the outside of the line. To facilitate repair to the pavement surface care should be exercised in cutting the surface in the first instance. Asphalt cutters or a mattock should be used for cutting asphalt. Stone or concrete slabs may be lifted with care, and reset in position after reinstatement of the trench. In the case of concrete cast in situ which has to be cut, special care is necessary as satisfactory reinstatement cannot be made if an irregularly shaped opening is made. The concrete should be cut so as to provide straight edges. Pneumatic concrete breakers, operated by air compressors should preferably be used. Where this equipment is not available medium or large cold chisels and a 2 lb. hammer can be used.

If the trench is excavated in grass the turf should be cut in rectangular sods and laid aside for replacement later. The top soil should be kept separate from the subsoil so that it can be reinstated on top. The depth of the trench should be such that the minimum cover over the top of the conduits will be 18″ on footpaths and 2 feet under roadways. Where obstructions such as other mains which were not anticipated are encountered during the excavation, it may be more economical to arrange for the removal of the obstruction than to alter the trench. Where other mains are exposed by the trench these should be adequately supported. Where the nature of the soil is such that the walls of the trench are not self-supporting, the trench should be timbered.

Suitable guards such as ropes or barrier posts and rails should be placed around excavation and lights provided at night. In all cases the whole of the trench between manhole locations should be opened up in one operation. At road crossings this will entail the provision of a temporary bridge for traffic. The bottom of the trench should be made straight between manholes with a grade of not less than 1 in 200 to ensure good drainage and boning rods should be used to ensure a uniformly graded trench. Pegs should be driven every 9 feet approximately and these pegs are levelled, using the boning rods. The bottom of the trench should then be filled to the top of the pegs with fine loose earth and levelled between pegs. Where the trench is excavated in rock, a bed of at least 3 inches of fine earth should be rammed into position.

In laying conduits care should be taken to keep the bores, spigots and sockets free of dust. A line should run along the centre of the trench and the conduits adjusted to this line. Each conduit should be laid in turn and jointed to the one previously laid. Generally conduits should be laid with sockets facing away from the point of commencement, and it is usually easier to lay with sockets facing uphill. There are a number of methods of jointing. In the case of the E.W. conduits two methods are:—

(i) The spigot and socket should be coated with hot molten compound and after the conduits have been pressed home the seam of the joint should be again coated with compound.

(ii) The bitumastic linings of the spigot and the socket should be heated until the compound begins to melt and then the joint should be made. Two air acetylene torches with fish-tail burners should be used to heat the two conduits simultaneously. After jointing, the exposed surface of the linings should be heated again.

In the case of concrete conduits with rubber rings, the rubber ring should be placed over the spigot of the second pipe close to the end, and then the spigot end should be pushed right home into the socket of the first pipe using, if necessary, a bar levering against a block of wood held across the socket of the second pipe. In some cases a mandrel should be used to ensure correct alignment.

If a nest of conduits is being laid the joints should be staggered.

In backfilling the trench first fine earth free of stones should be placed in the bottom of the trench and under and around the conduits to a depth of a few inches over the conduits. The backfilling should then be tamped and then the remainder of the spoil replaced in the trench in layers, each layer being well tamped. The trench should be overfilled and left to settle before the surface is reinstated.

Design of Manholes.—The following fundamental principles should be considered in the design of the manholes for such a route.

(i) Adequate provision should be made for housing every cable satisfactorily. This requires that cables are supported at least every 3 feet.

(ii) All joints should be readily accessible for opening and inspection and the sheath of the whole length of the cable in the manhole should be capable of being examined.

(iii) Sufficient room should be available for workmen to work in the manhole drawing in cable and jointing, etc.

(iv) Adequate space for pulling in or withdrawing cable, and rodding ducts.

(v) Manhole should provide good working conditions in relation to lighting, ventilation and freedom from moisture.

(vi) Ready means of entrance and exit should be available which do not entail standing on cables.

(vii) The construction should be of adequate strength to meet all loads.

(viii) Maintenance costs should be a minimum, for example, fittings should be galvanised.

(ix) The construction should be as economical as possible, consistent with these requirements.

Q. 4.—A 1,200 pairs 6½ lb. conductor star quad subscribers' cable is to be provided between an exchange and a manhole ¾ mile distant in order to relieve a congested area. Spare ducts are available and manholes are about 90 yards apart.

(a) List the items of material required to provide and connect up the cable from the line fuse strips on the main distributing frame to the manhole ¾ mile from the exchange.

(b) Describe in detail, making mention of the tools and equipment required, the operations including testing, involved in carrying out the work up to the stage where the new cable is ready to connect to the existing cables which are to be relieved.

A.—(a) Material items: Cable, P.I.L.C. 1200 pair; Cable, E. & S.C., 100 pair; Cable pulling compound; Gas CO_2 or dry air; Lead sheet, 5 lb.; Lead sheet, 7 lb.; Solder wiping; Solder, soft; Solder, R.C.; Sleeves, paper 6½ lb.; Sleeves, paper butt, 6½ lb.; Paper, cable jointing, 4 in.; Stearine; Tags, linen identification; Linen tape; Kerosene; Gas, acetylene; Cotton waste; Cable supports.

(b) The drawing in of the cable should be carried out according to the following procedure:—

(i) The duct is first rodded, using conduits rods, and a wire with a brush, a short length of 1200 pair cable and a further draw wire is pulled through the duct. Any obstructions are investigated and cleared.

(ii) Set up the first drum ready for drawing in so that the cable can enter the duct in a smooth curve. Make sure from the marking on the sheathing at the end of the cable that the cable will be laid in the correct direction. Set up the cable hauling winch at the next manhole and pull the flexible steel rope back through the duct with the draw wire previously inserted, passing it over guide pulleys in the manhole at the winch end. Attach the steel rope to the cable by means of the cable grip, swivel and steel link after dressing down the sheathing on the end of the cable using a lead dresser.

(iii) Draw the cable carefully into the duct completely covering the cable with cable pulling compound, until sufficient cable has been drawn into the far manhole to allow for the setting up of the cable for jointing. Cut the cable with a hacksaw at the first manhole, and seal both cut ends immediately, the tools required for the operation being a shave hook, lead dresser, wiping pad and air acetylene outfit. A party of six or seven men would normally be required for this operation, two men attending to the drum, one guiding the cable to avoid kinks and abrasions, one applying cable pulling compound, one or two on the winch, depending on whether it is motorised or not, and one supervising.

(iv) Pressure test the length of cable drawn in with CO_2 or dry air.

(v) Repeat this procedure with each length of cable.

The E. & S.C. cables at the exchange are fanned out, placed in position and terminated on the M.D.F. terminals. The joint between the P.I.L.C. and the E. & S.C. cables will be completed next, each wire joint being soldered with resin-cored solder, using an electric soldering iron. The joints in the P.I.L.C. cable will then be made, working from the exchange. The jointing operation should be carried out to the following procedure:

(i) Dry out the manhole and take action to ensure that there is no likelihood of moisture coming into contact with exposed conductors.

(ii) Set up the ends of the cable in the manholes, placing each in its final position.

(iii) Cut off approximately 2 feet of sheathing from each cable end, using a hack knife, so that there is 28 inches between the ends of the sheathings, and lay back the quads in layers for jointing.

(iv) Joint the pairs by rotation in each joint, using side-cutting pliers to cut the wires.

(v) On completion of each joint the conductors will be wrapped with brown paper and the lead sleeve will be fitted over the conductors and wiped to the cable sheath. The tools used to prepare the lead sleeve and wipe it to the cables are lead dresser, plumber's snips, shave hook, wire brush, wiping pad, mirror, air acetylene equipment. As it would be impossible to complete one joint in a day, temporary sleeves or rubber bandage should be fitted to the unfinished joints overnight.

(vi) As each lead sleeve is completed, it is pressure tested with CO_2 or dry air and soap suds before being left.

(vii) Leave the joint at the first and eighth manholes from the MDF till last, and before making these joints, test each length for insulation resistance with a megger and then identify pairs with cable identification sets. Attach tags to all identified pairs.

(viii) On completion of the last joint all pairs should be tested with a megger and identified from MDF to end of cable preparatory to cut over to existing cable.

(ix) Finally, prepare a plan showing the actual cable lengths between manholes and the position of the identified joints.

Q. 5.—Detail the action which should be taken before, during and after the laying of a major trunk cable between two towns 100 miles apart to reduce the possibility of corrosion to the cable. Assume one town has an electric traction system extending approximately 10 miles along the route of the cable.

A.—Before laying a major trunk cable the route has to be selected. Many factors influence the selection, such as ease of laying a cable, overall length which governs repeater station spacing, accessibility of power for operation of repeaters, freedom from damage due to roadway operations and many others. One of these is the precautions taken to minimise the possibility of corrosion damaging the cable and causing interruption. The action can be divided into three stages, before, during and after laying the cable.

In most cases selection of a route through a town is limited, but as far as practicable low-lying, marshy areas and areas in which chemical corrosion is likely to occur should be avoided. Discussions with the local staff will often indicate areas where corrosion has been known to occur previously. All conduit work should be adequately drained and the duct in which the trunk cable will be laid selected so that possible interference would be reduced to a minimum during later work on junction and subscribers' cables. In the area where the electric traction system is in operation, electrolysis surveys will probably have been carried out previously, but if these results are not available the area should be surveyed.

In the country area, tape armoured cable would be generally laid, the use of wire armoured cable being restricted to areas where additional mechanical strength to that provided by tape armoured cable, is required. A soil resistivity survey is carried out along the route of the cable, the areas of low resistivity generally indicating the localities where corrosion is likely to occur and remedial action will be necessary.

All conduits should be free from any obstruction and be carefully laid to prevent leakage of water into the ducts. If necessary a brush should be pulled through to remove any loose material which would cause abrasions on the sheath, as scratches and scour marks are the starting points of corrosive attacks. Cable pulling compound should be used on all cables laid in ducts.

When laying cable by mole plough, excessive stresses must be avoided. Any filling used must be free from corrosive materials, cinders and slag from furnaces, being generally particularly bad in this respect. Drainage from heavily fertilised land, stables or sewers, should be diverted from the route of the cable. In all cases where armoured cable is used the armouring should be bonded to the lead sheath at all jointing points and all cables must be adequately supported at all points. Where more than one cable is laid, all cables must be bonded together at frequent intervals to prevent interchange of any currents flowing in the sheath.

When the cable has been laid a maintenance routine is introduced which provides for a frequent inspection of the whole cable. This routine covers the visual inspection of all manholes to see if the cables are adequately bonded and supported. In the country the route is patrolled, to ascertain if the ground has been disturbed at any point and damage likely to occur in the cable. River and creek crossings are regularly inspected, especially the banks where the cable is landed and erosion is possible. The maintenance routine is closely associated with the maintenance of the gas pressure alarm system which is installed on the cable, and although it may not appear to be very effective in reducing damage due to corrosion, will often reveal incipient faults which would develop at a later date.

After the cable sheath has been jointed through from end to end, an electrolysis survey is undertaken, the main measurement being potential difference between the cable sheath and a buried lead plate. On some occasions the current flowing in the sheath is measured. In the town, where the traction system is in operation, any remedial action would be undertaken in conjunction with the electrolysis committee which is formed by representatives of the traction authority and other interested bodies, such as gas, water, electric power and telephone, who maintain buried pipes and cables. Electric drainage bonds would be installed where necessary, after tests into the effectiveness of any bond had been carried out by the interested authorities. If not already in operation, a maintenance routine to check the operation of all bonds and also the electrical condition of the cable, should be instituted.

In the country areas where the survey has indicated that some form of remedial action is necessary, natural earth currents are generally the cause, although the possibility of a D.C. power supply, earthed telegraph circuits, operation of rural automatic exchanges, etc., causing the electrical condition of the cable, must not be overlooked. All possible sources of current must be investigated, but in many cases the use of sacrificial anodes will be necessary.

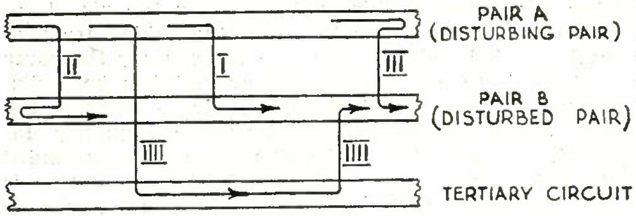
Q. 6.—(a) Explain why it is the practice to use two separate cables for the operation of multi-channel cable carrier systems.

(b) Describe the major crosstalk couplings which exist in a cable operated at carrier frequencies. Illustrate by means of a diagram. Describe by what means each of the crosstalk couplings is reduced during the balancing.

(c) For what purpose is the factory allocation of drum lengths of cable to particular sections within a repeater section arranged?

A.—(a) When two separate cables are used, one for each direction of transmission, the same group of carrier frequencies can be used in each cable, because the near-end crosstalk between pairs in cables laid side by side is not worse than about 130 db at a frequency of 60 kc/s. Hence, with a repeater section that has a circuit attenuation of 60 db, the near-end crosstalk between pairs in each cable is not more than 70 db below the received signal and can be regarded as having practically no influence on the total interference due to crosstalk. The main factor governing interference is, therefore, the far-end carrier frequency crosstalk within the cable.

(b) The more important types of far-end crosstalk couplings are shown in the following sketch.



Q.6, Fig. 1.

Path (I) is one of those followed by the direct crosstalk component. As the path followed from the near to the far end of each of the components is the same, they arrive at the receiving end of the disturbed pair in approximately equal phase for all frequencies.

Paths (II) and (III) represent two of the many reflected near-end crosstalk components. As these crosstalk currents generally traverse different lengths of cable, they differ in phase from each other and from the direct crosstalk currents (I), and the phase relations vary with frequency. Path (IIII) represents the crosstalk coupling, via a tertiary circuit, such as a phantom circuit or the cable sheath. The propagation characteristics of these circuits differ from those of a normal cable pair, and therefore the crosstalk currents from these sources are generally not in phase with the direct crosstalk.

The final crosstalk balancing of a carrier cable is carried out by means of variable condensers (and occasionally resistors) generally installed at the receiving end of each cable and connected between all pair combinations. The crosstalk can only be reduced to a satisfactory value if the currents to be balanced have the same phase relationship to each other at all frequencies. It is therefore essential to reduce, by controlled jointing of the cable, the crosstalk components represented by paths (II), (III) and (IIII).

In reducing direct far-end crosstalk due to capacity unbalance, the control of "side to side" capacity unbalance between adjacent cable lengths is important. These measurements are made at a frequency of 1 kc/s as the capacity unbalance does not vary appreciably with frequency. Reduction to the specified limits is obtained by selection of quads and cross splicing within a quad. The reduction of the other capacity unbalances, namely, Phantom to Side and Side to Earth, and resistance unbalance, necessarily affect the selection and a compromise to obtain the best overall result is adopted.

The reflected near-end crosstalk can be considerably reduced by—

(i) close matching of impedances, particularly at the higher frequencies where the near-end crosstalk is greatest;

(ii) reducing the near-end crosstalk as fas as practicable.

The terminal apparatus can be matched to the cable impedance, provided the cable impedance is constant and substantially non-reactive at the highest frequency in use. This requires close matching of the impedance of adjacent groups of cable lengths by selection and jointing of pairs based on their mutual capacity characteristics.

It is not practicable to reduce appreciably the carrier frequency near-end crosstalk between cable pairs by capacity balancing between manufactured drum lengths. This is due to the large phase change, over the normal drum length of 200 yards and is about 19° at a frequency of 60 kc/s. Improvement of this near-end crosstalk must, therefore, be achieved mainly by attention to control during manufacture.

Reduction of far-end crosstalk due to third circuit effects

This crosstalk occurs via two tertiary crosstalk paths in series, and it can therefore be controlled by the reduction of "side-to-phantom" and "side-to-earth" capacity unbalances between adjacent lengths during jointing.

(c) The factory allocation provides for the drum lengths of manufactured cable to be disposed to such positions in each repeater section as will ensure a minimum deviation of average mutual capacity from length to length. Where practicable, consideration is also given to other electrical characteristics which influence the overall crosstalk limits of the cable. By this means uniform propagation characteristics are obtained, balancing is simplified, and better electrical conditions within the cable are obtained.

Q. 7.—List the modifications which you consider would be necessary to upgrade a T. & T. route, constructed for voice frequency operation, to permit the operation of 3-channel carrier systems on all pairs and 12-channel carrier systems on selected pairs. Concise notes of the reasons for each alteration should be given.

A.—The modifications necessary are as follows:—

(1) As all pairs are to be retransposed, review the layout of transposition sections to obtain a layout which will ensure—

(a) All transposition sections are within the maximum allowable lengths of 8.0 miles for E Sections, 4.0 miles for L Sections, etc.

(b) Consecutive E sections are provided as far as practicable with shorter types of transposition sections confined as far as possible to the ends of repeater sections. An "S" pole should be provided at terminal poles at repeater stations or where a 12-channel system leaves the route.

(c) Consistent with (a) and (b) the minimum of poles required to reduce the value of the pole spacing irregularity factor to less than 3.0 on a 128 transposition interval basis for E sections and 256 interval basis for shorter sections.

(d) Some consideration should be given to co-ordination with parallel power lines subject to (a), (b) and (c) being met.

These modifications are required to provide a layout of transposition sections which will meet the requirements of the carrier transposition scheme both for individual transposition sections and for the series of transposition sections between repeater stations. The value of less than 3.0 for the pole spacing irregularity factor will ensure that the irregular spacing of transposition poles will not control the crosstalk.

(2) Replace all crossarms less than 108″ in length with 108″ crossarms bored to 9″-19″-9″ wire spacing and rebore all existing 108″ crossarms to this spacing. Respace crossarms to provide 28″ vertical spacing between consecutive crossarms. This wire and arm spacing is necessary to provide the values of the Coupling Soefficients on which the carrier transposition scheme is based.

(3) Replace any 100 lb. H.D.C. wires which may exist with 200 lb. H.D.C. wires. 200 lb. H.D.C. wire is the standard gauge of wire for carrier bearers and calculated attenuation between repeaters is normally based on its use.

(4) Rearrange pairs where necessary to fill the pin positions on the top arm first and then those on the lower arms and, as far as practicable, provide for the same number of pairs on each side of the pole. Ensure uniform pole configurations over repeater sections.

This will reduce interference with existing carrier bearers if additional carrier pairs are erected at a later stage and balance the pull of the wires on each side of the poles.

(5) Improve the stability of the route if necessary by fitting additional stays, erection of stouter poles, alterations to angles and desirable deviations.

This work will ensure that the correct wire sags provided during the subsequent re-regulating are retained.

(6) Retranspose all pairs to the standard transposition scheme for 12-channel carrier operation on selected pairs, which is covered by Dwg. CL.324 sheets 3-8.

This will ensure that suitable transposition types are provided to meet the carrier crosstalk requirements for the arrangement of carrier systems specified.

(7) In conjunction with the re-transposing, re-regulate the wires to the sags and tensions laid down in the standard sag tables for 200 lb. H.D.C. wire and keep the difference in sag between the two wires of any pair as small as possible with a maximum of 1″. The accurate sagging of the wires is essential to ensure that the wire spacing irregularities will not control the crosstalk.

(8) Provide suitable trunk entrance arrangements at repeater stations. This will be provided with 24 pr. 40 lb. P.I.Q.C. cable loaded with 2.44mH coils for carrier bearers used for 3-channel carrier operation only. For 12-channel carrier bearers the type of entrance cable will depend on the length of cable and local conditions. For very short entrance cables up to 220 yards in length disc insulated SP4 cable would normally be used with suitable loading for the length of cable provided.

For longer lengths of cable 24 pr. 40 lb. P.I.Q.C. cable would be used with filters housed in a filter hut near the terminal pole. The 12-channel systems would be operated over non-loaded pairs and the 3-channel systems on 2.44 mH loaded pairs in the carrier type cable. Disc insulated cables would be provided between the terminal pole and the filter hut for the 12-channel bearers.

The terminal poles would be fitted with suitable protection apparatus.

These cable entrance arrangements are necessary to ensure that the cable does not introduce an excessive impedance mismatch which could result in reflected near-end crosstalk becoming the controlling factor in the far-end crosstalk over the repeater section.

(9) Any intermediate cables will be treated in a similar manner to the entrance cables, but in some cases where it is impracticable to provide the necessary loading, such as at wide river crossings, suitable matching transformers can be installed on each bearer at both ends of the cable to provide the necessary impedance matching, between the cable and open wire route.

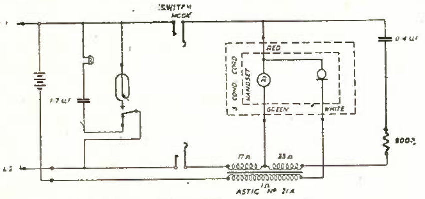
EXAMINATION No. 3701—SENIOR TECHNICIAN, TELEPHONE.

L. W. Wadsworth

Q.1.—(a) Draw the circuit of a 300-type magneto handset telephone and state the functions of—
(i) The 0.4 microfarad condenser;
(ii) The 900 ohms non-inductive resistance winding on the induction coil.

A.1.—(i) The 0.4 μF condenser is part of the anti-sidetone balance circuit and is designed to balance the capacitive component of the impedance of the subscriber's line.

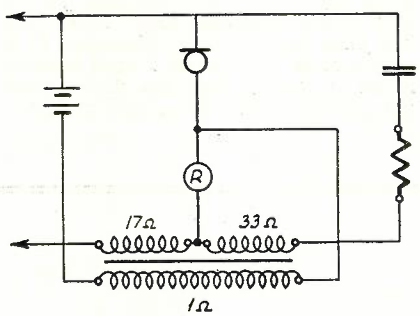
(ii) The 900 ohm resistor shown in the above circuit is actually wound on the induction coil. It is also part of the anti-sidetone balance circuit and is designed to balance the resistive component of the impedance of the subscriber's line.



Q.1—Fig. 1.

Q.1.—(b) What would be the result if the conductors carrying the transmitter current in the handset cord were reversed inadvertently at the terminal block in the instrument?

A.—If the "red" and "white" conductors of the handset cord were reversed the speech circuit would become as shown in Fig 2:—



Q.1—Fig. 2.

As the transmitter is now in series with the receiver so far as speech reception is concerned, losses due to its resistance will reduce the sensitivity of the receiver circuit. During conversations, D.C. will flow from + battery through the line and distant subscriber's telephone, 17 ohm winding of the induction coil, receiver, and 1 ohm winding of the induction coil to − battery, as well as that normally flowing in the transmitter circuit. This current will further decrease the efficiency of the receiver due to its magnetising effect. This current will also constitute a small added load on the battery, slightly reducing its life.

Q.2.—(a) Two lamp signalling private branch exchanges are to be installed in the same building. A 50V battery supply is available from an automatic exchange over a 10-lb. conductor cable 1,000 yards long. The full load currents for the P.B.X's are 800 m.A. and 1,200 m.A. respectively at the minimum busbar voltage of 40V. Calculate the number of cable conductors needed to supply "battery" to the two P.B.X's and state what fusing arrangements should be made in connection with the battery supply. The resistance of a 10-lb. cable pair is 176 ohms per loop mile.

A.—Figure 1 shows the proposed arrangement.

Total power lead load $+ I + I_1 + I_2$
$I + (1200 + 800)/100 = 2$ amps.

Max. permissible voltage drop over power lead (E_{pl})

$E_{pl} + E_{ex} - E_{pbx} = (50 - 40)$ V $= 10$ Volts.

Max. resistance of power lead $= R_{pl} = E_{pl}/I$

$R_{pl} = 10/2 = 5$ Ohms.

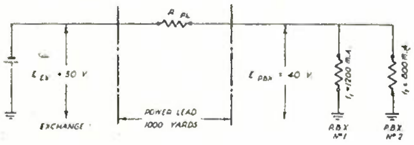
Resistance of 1 conductor = Res/loop mile ÷ 2 × length in miles.

= (176/2) × 1000/1760 = 50 Ohms.

Number of parallel conductors required

= Res/conductor ÷ R_{pl} = 50/5 conductors.

Ans. = 10 Conductors.



Q.2—Fig. 1.

However, as the total load of 2 amps. in this case exceeds the standard carrying capacity (1.5 Amp) of the exchange power lead fuses, these conductors would be paralleled in two separate groups supplying the two PBX's separately in proportion to their loads thus:—

No. of conductors for PBX No. 1 = (1200/2000) × 10 = 6 conductors.

No. of conductors for PBX No. 2 = (800/2000) × 10 = 4 conductors.

Q.2.—(b) What purpose is served by the following components in the operator's circuit of a lamp signalling P.B.X.:

(i) The 17/26 ohm induction coil;

(ii) The 2/2A rectifier.

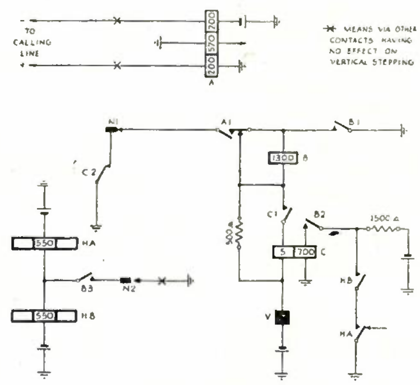
Why does the rectifier not short circuit the receiver so far as speech currents are concerned.

A.—(1) The purpose of the 17/26 ohm induction coil in the operator's circuit of the lamp signalling PBX is to enable the telephonist to hear the dial tone and other service tones between impulse trains. She can thus supervise the progress of a call whilst dialling, without having to restore the dialling key.

(ii) The 2/2A rectifier connected across the operator's receiver, acts as an acoustic shock absorber to protect the telephonist from any high level "clicks" encountered during switching or particularly from dialled impulses if she happens to supervise an extension to exchange call whilst the former is dialling. The rectifier does not short circuit the receiver because at the normal level of speech currents, its impedance is high compared with that of the receiver. However, as the resistance of a metal rectifier in the conducting direction, decreases with increase of applied EMF, the combination of the 2 rectifiers in this case will have a much lower impedance at the level of signals likely to cause acoustic shock. It will, therefore, act as a low resistance shunt across the receiver to these signals.

Q.3—(a) Explain with reference to a simple diagram of the relevant circuit elements the vertical stepping function of a 2,000 type group selector.

A.—A simplified vertical stepping circuit is shown in Fig. 1 Prior to vertical



Q.3—Fig. 1.

stepping, the A, B and C relays are operated. The vertical magnet is energised via C1, 1300 ohm winding of B, to earth at B1, but will not operate in series with the 1300 ohm winding of B relay,

When the first impulse is received A releases and A1 contacts short circuit B relay. making it slow to release, so that it holds during this and subsequent break periods of the dial. The short circuit on B relay causes the vertical magnet to operate and steps the wipers to the first level. The "N" springs operate mechanically and N2 operates HA and HB relays, whose contacts short circuit the 700 ohm winding of C. However, C is at this stage held on its 5 ohm winding in series with V, and the short circuit only makes it slow to release so that it will hold during the make periods of the dialled impulses, when its 5 ohm winding is in series with the 1300 ohm winding of B relay. Thus B and C relays hold during impulsing and the train of impulses only cause the vertical magnet to step the switch to the required level.

After the impulse train, A relay is held and C releases to complete the circuit (not shown in Fig. 1) for rotary stepping.

Q.3—(b) In what respects, other than in the circuit arrangements does the 2,000 type group selector differ from the pre-2,000 type?

A.—The 2000 type switch differs from the pre-2,000 type in the following respects:—

1. It has no release magnet. Release is achieved by continuing the rotary movement until the wipers leave the level, when the carriage drops vertically and restores to normal under spring control.
2. Vertical and rotary magnets have single coils with iron cores, polepieces and coil cheeks.
3. The wipers are not connected to a moving shaft as on the pre-2000 type switch, but are fastened to a tubular carriage which slides on a shaft fixed at both ends.
4. Because of 3 above, more than 3 sets of banks may be used.
5. Vertical and rotary interrupter springs have a special toggle action which allows the contacts to open at the end of the magnet stroke, and not close again until the end of the return stroke. This allows a rapid drive without an interacting relay.
6. The switch frame is die-cast from a light aluminium alloy instead of the heavier cast iron of the pre-2000 type frame.
7. The banks are supported from the switch cradle, allowing the switch to be jacked out and in without affecting wiper adjustment.
8. The vertical and rotary teeth occupy the same vertical section of the carriage and the weight during rotary motion is taken by the rotary disc resting on the teeth of the comb plate.
9. A helical restore spring is used instead of the clock type cup spring of the pre-2000 type switch.
10. Mechanically operated springsets are operated by means of cams.
11. Mechanically operated springsets are provided with twin contacts.

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