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THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

Engineering Training Section, Headquarters, Postmaster-General's Department, Melbourne C.2.

LINE TRANSMISSION - EQUIPMENT APPLICATIONS

1. INTRODUCTION.

1.1 The Australian communication network is expanding rapidly and new types and styles of equipment are constantly being installed. Although some older equipment does not conform with required standards, for economic reasons it is retained in service. In most line transmission areas the equipment already installed and the equipment currently on order is from a number of manufacturers. For these reasons there are wide variations in circuitry and style for any one type of equipment.

1.2 Line transmission equipment is commonly referred to as Long Line Equipment and encompasses the equipment used to obtain trunk and junction circuits. It also embraces certain telegraph, audio and video programme, data and facsimile equipment.

1.3 The basic principles of line transmission equipment are outlined in the papers "Introduction to Line Transmission Equipment" and "Equipment Principles - Line Transmission." This paper shows the applications of these basic principles and also the relationship between line transmission equipment and other equipment in the communication network.

2. HISTORICAL DEVELOPMENT.

2.1 In 1858 the development of the trunk network commenced with the installation of an open wire telegraph line between Melbourne and Sydney. Trunk telephone circuits were provided by physical pairs over the same route in 1907, and in 1925 the first carrier system was brought into operation on the route.

This form of development for the Sydney-Melbourne route was typical of the general trunk circuit development throughout Australia. During the 1930's and 1940's trunk circuits were generally provided by open wire lines but with a gradual increase in the number of open wire carrier systems, mainly single and three circuit systems. In 1939 the first 12 circuit open wire system was installed and by the 1950's these systems were in common use. In most cases an upgrading of the open wire routes was required to allow the operation of 12 circuit systems in addition to three or single circuit systems.

During the 1940's and 1950's a large number of pair cable carrier systems were installed between capital cities and the larger provincial cities. These systems operate over distances up to about 150 miles.

In the late 1950's radio telephone systems were installed to provide trunk circuits. Some of these systems provided one trunk circuit and others provided bearers for multi-circuit systems. In the initial installations it was typical for three, four, twelve or twenty four circuit operation over these systems. During the 1960's microwave radio telephone systems were used as bearers for broadband carrier telephony and from 300 to 900 circuits were obtained on one system.

The installation of the first coaxial cable system was commenced in 1959 and this was followed by numerous installations until, at the time of writing, Australia is inter-laced with broadband systems using coaxial cable pairs or radio telephone systems as bearers.

Since about 1958, Rural Carrier Systems have been used to obtain up to 10 trunk circuits on relatively short trunk routes. These systems are used on open wire lines where it is not economically justified or practicable to upgrade a trunk route.

Fig. 1 shows the main open wire and cable trunk routes of Australia and Fig. 2 shows the broadband systems in service at the time of writing. The microwave radio routes are shown in greater detail in Fig. 3.

2.2 Although the initial development of the network was concerned primarily with telegraph and telephone working, the network, in addition, now embraces audio programme, video programme, facsimile and data transmission equipment.

2.3 Line transmission equipment is extended into the junction network with the limited use of four-wire repeaters, negative impedance repeaters and short haul coaxial and pair cable carrier telephone systems to upgrade and provide junction circuits.

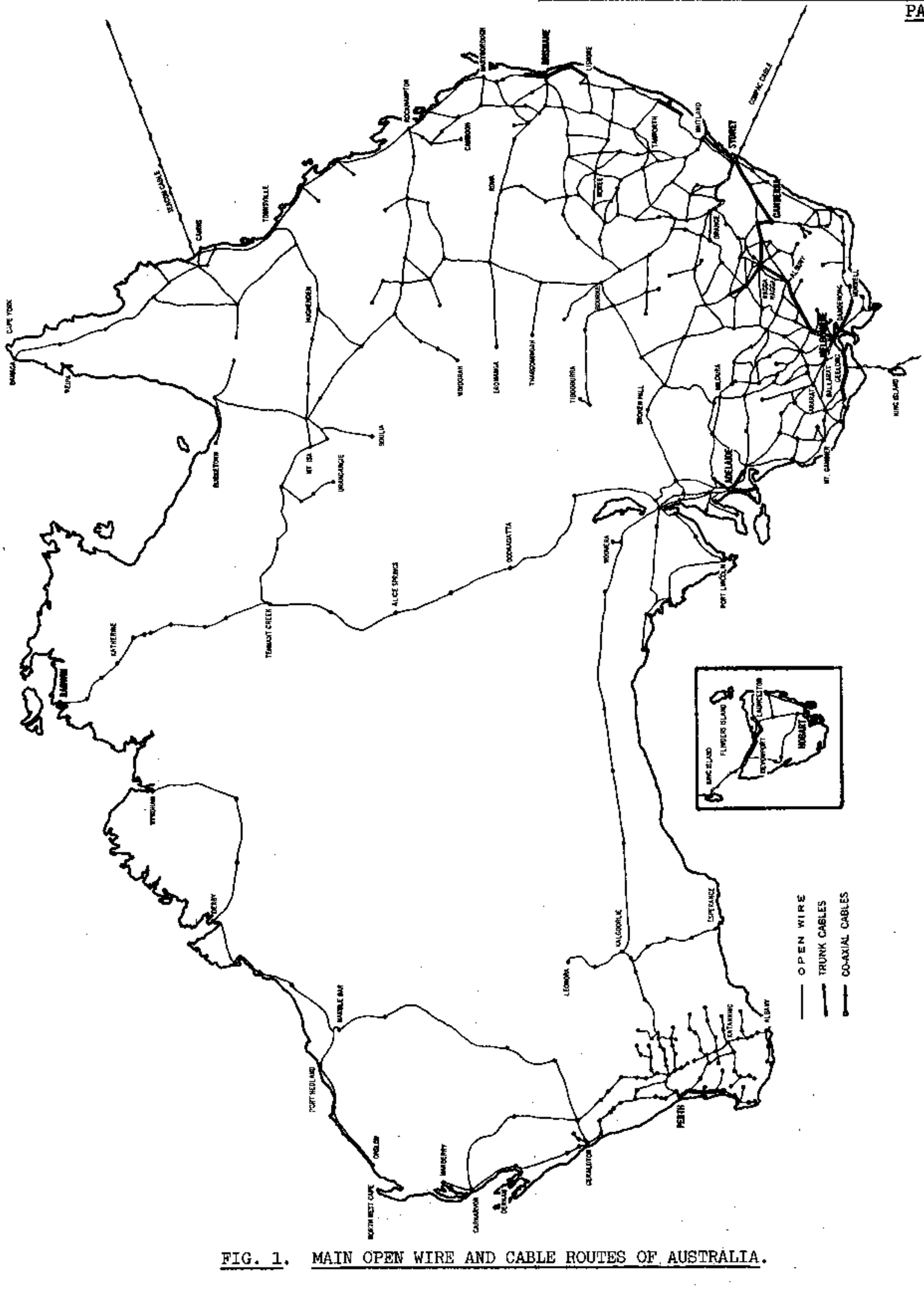


FIG. 1. MAIN OPEN WIRE AND CABLE ROUTES OF AUSTRALIA.

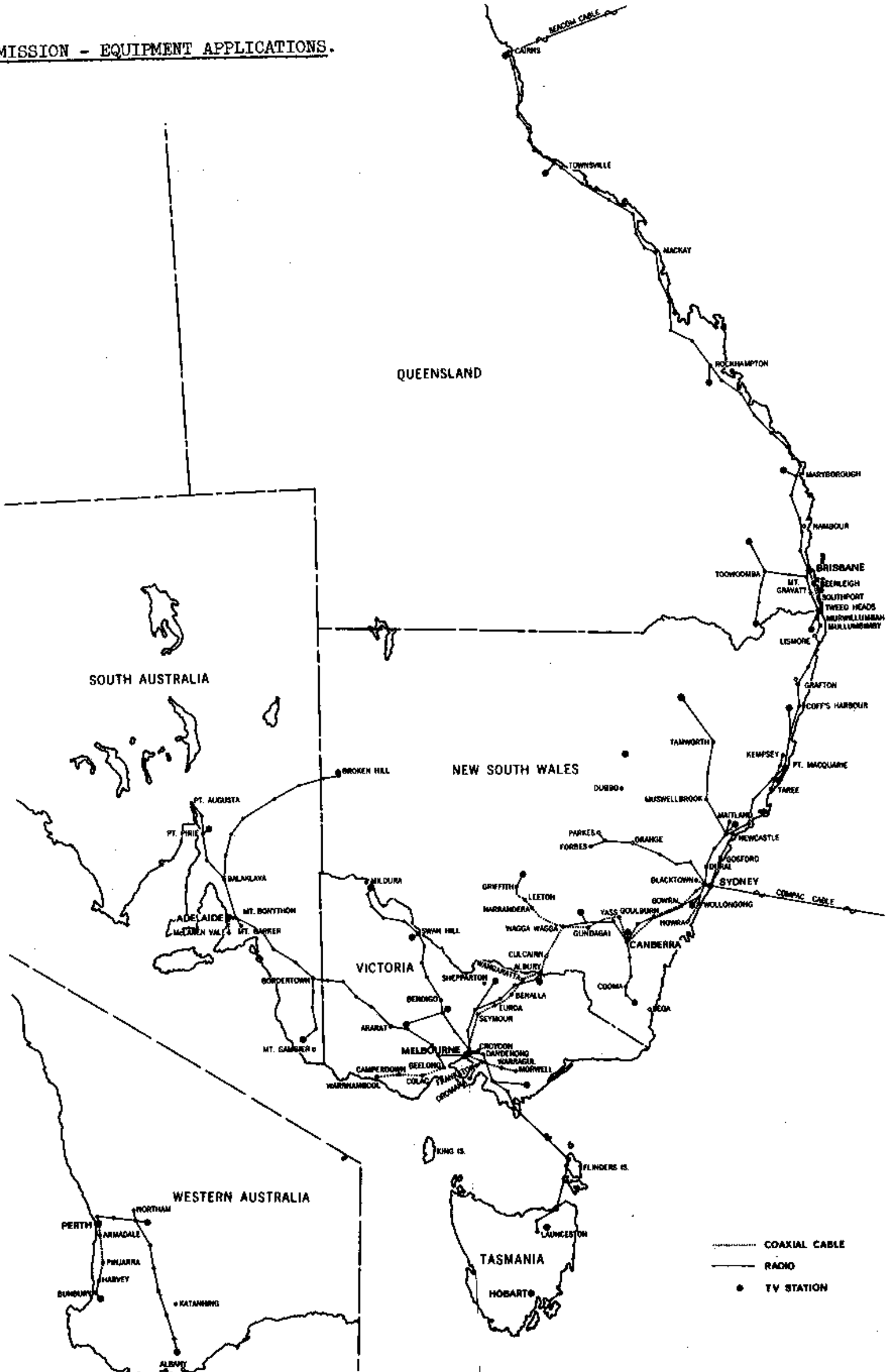


FIG. 2. BROADBAND SYSTEMS IN USE IN AUSTRALIA.

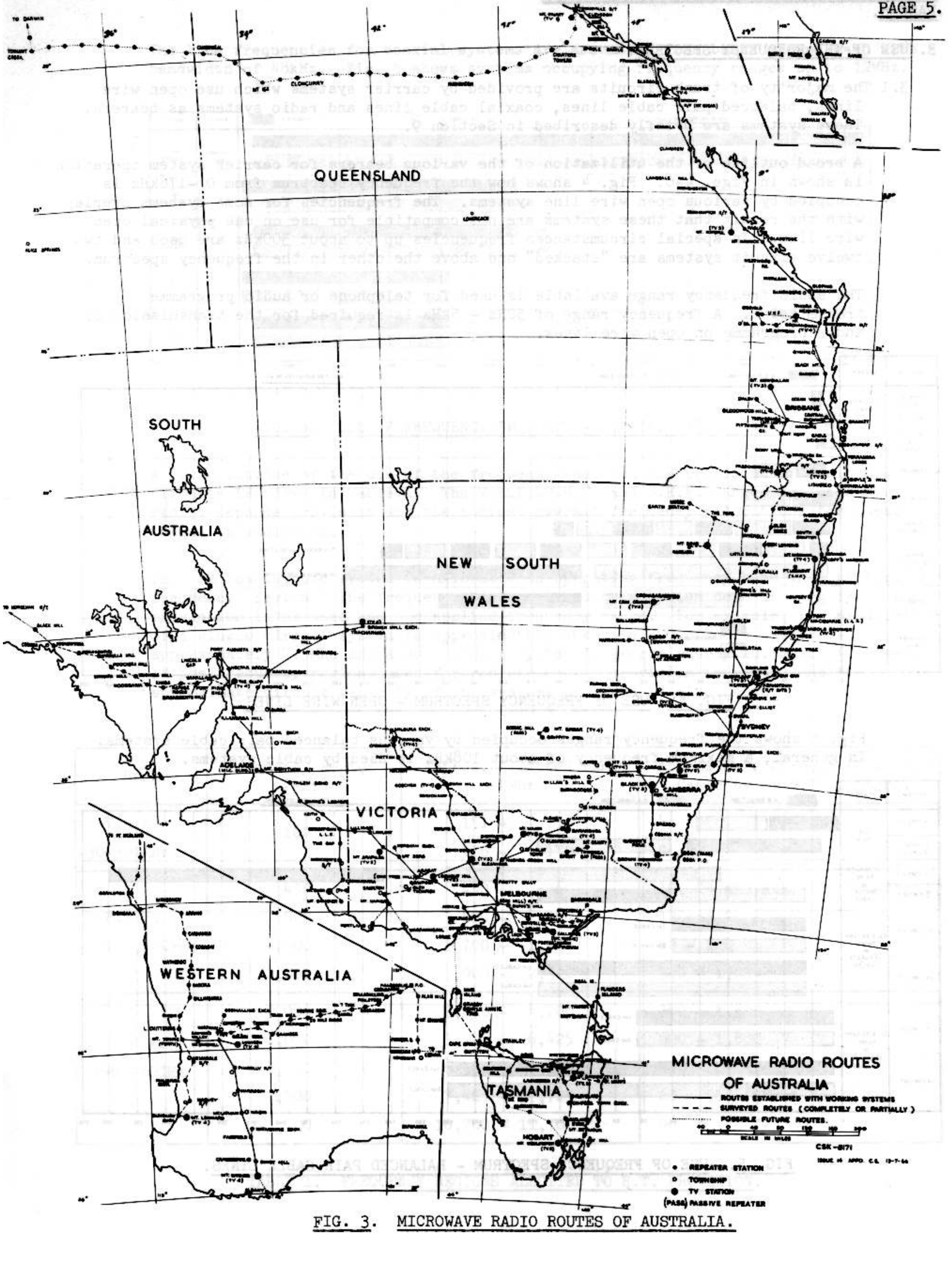


FIG. 3. MICROWAVE RADIO ROUTES OF AUSTRALIA.

3. USE OF THE FREQUENCY SPECTRUM.

3.1 The majority of trunk circuits are provided by carrier systems which use open wire lines, balanced pair cable lines, coaxial cable lines and radio systems as bearers. These systems are briefly described in Section 9.

A broad outline of the utilization of the various bearers for carrier system operation is shown in Figs. 4-6. Fig. 4 shows how the frequency spectrum from 0 -176kHz is occupied by various open wire line systems. The frequencies for some systems overlap with the result that these systems are not compatible for use on one physical open wire line. In special circumstances frequencies up to about 300kHz are used and two twelve circuit systems are "stacked" one above the other in the frequency spectrum.

The audio frequency range available is used for telephone or audio programme transmission. A frequency range of 50Hz - 5kHz is required for the transmission of audio programme on open wire lines.

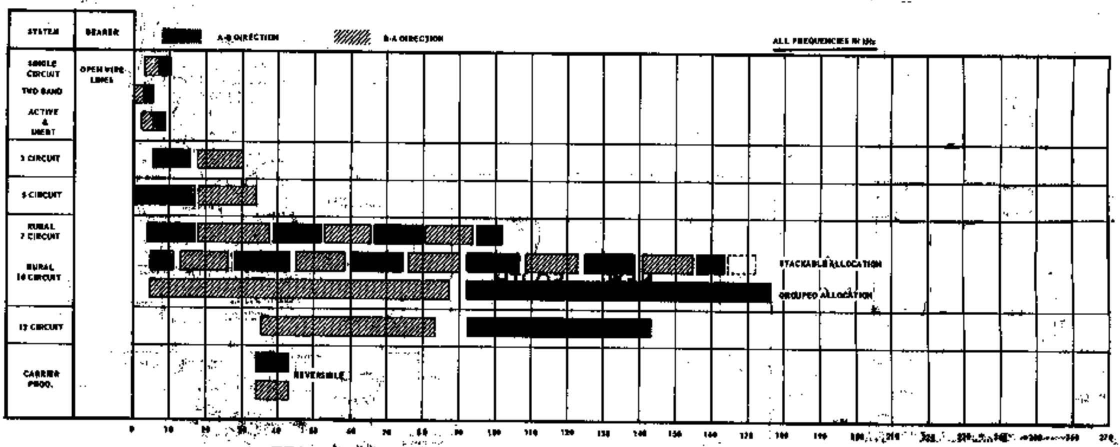


FIG. 4. USE OF FREQUENCY SPECTRUM - OPEN WIRE LINES.

Fig. 5 shows the frequency ranges occupied by various balanced pair cable systems. In general, a maximum frequency of about 108kHz is used by cable systems.

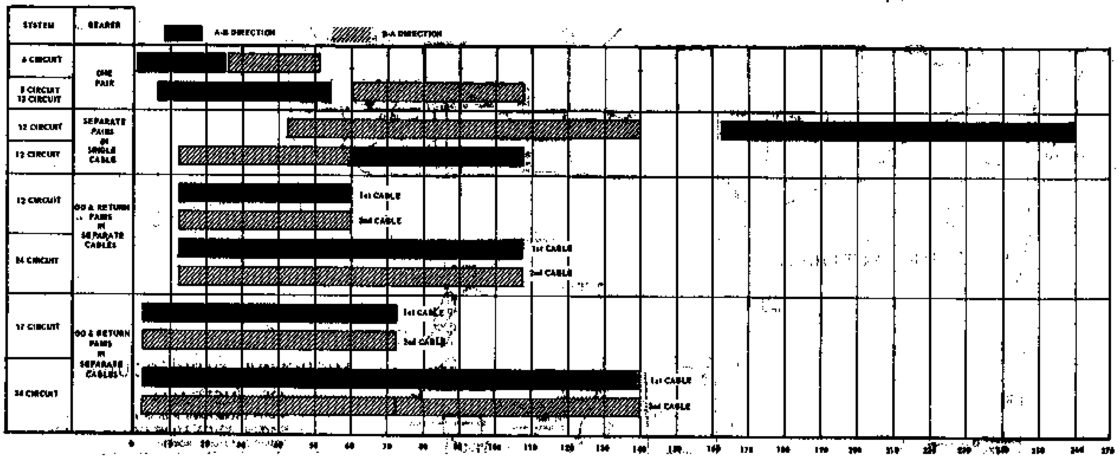


FIG. 5. USE OF FREQUENCY SPECTRUM - BALANCED PAIR CABLE LINES.

The line frequencies for coaxial systems are assembled from basic groups each with a bandwidth of 48kHz. Fig. 6 shows systems occupying frequency ranges up to 12MHz.

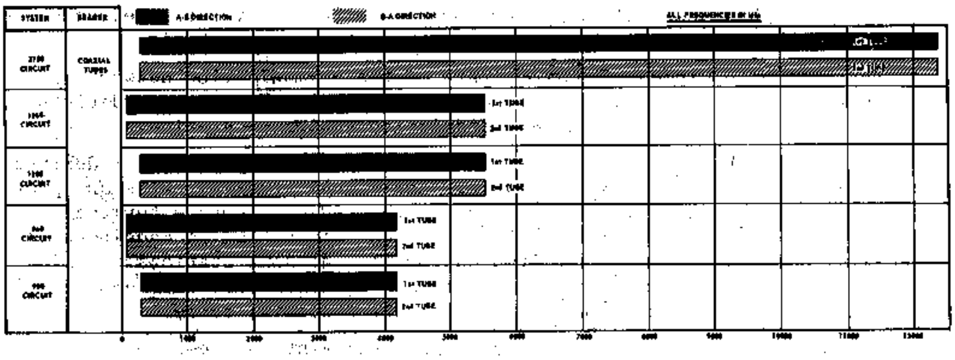


FIG. 6. USE OF FREQUENCY SPECTRUM - COAXIAL CABLE LINES.

A broad outline of the use of the frequency spectrum for provision of radiotelephone circuits is shown in Table 1. The V.H.F., U.H.F. and S.H.F. ranges are used for radiotelephone provision and the nominal overall frequency allocations for these ranges is indicated.

Each radiotelephone system is allocated an operating frequency band in a particular frequency region. The frequency band occurred by a system depends largely on the modulation index used and the applied frequency range. For example, the bandwidth of a single circuit system is approximately 16kHz, a 300 circuit system is approximately 7.5MHz and a 960 circuit system is approximately 10.5MHz. A summary of the frequency regions used for radiotelephone provision is given, and the approximate circuit capacity of the systems provided is also shown.

Range	Frequency Region (MHz)	Approx. Allotted Band (MHz)	Approximate Circuit (Channel) Capacity of R.T. Systems.
V.H.F. 30-300MHz	160	151 - 156	4
		156 - 170	Single
U.H.F. 300-3,000MHz	450	450 - 460	12, 24 and aux. for broadband.
	900	820 - 960	12 and 24
	2,000	1,700 - 1,900	60 - 120
	2,000	1,900 - 2,300	300 - 1,800
S.H.F. 3GHz-30GHz	4,000	3,770 - 4,200	300 - 1,800
	6,000	5,925 - 6,425	600 - 1,800
	7,000	6,425 - 7,250	960
	7,500	7,425 - 7,725	60 - 960 (Short Haul)
	11,000	10,700 - 11,700	960

TABLE 1. FREQUENCY REGIONS ALLOTTED TO R.T. PROVISION.

4. RELATIONSHIP BETWEEN MAJOR EQUIPMENT AREAS.

4.1 The Australian Post Office is responsible for a huge national communications network which provides telegraph, radio, television, data, facsimile, etc. circuits and channels throughout Australia. In conjunction with the Overseas Telecommunication Commission, the network can be extended on an international basis.

4.2 Line transmission equipment forms one part of the communication network. Fig. 7 shows the general relationship to other types of equipment. The diagram depicts conditions which are typical for a large line transmission equipment station.

The Physical Lines involved in providing trunk circuits (physical or derived) are open wire, pair cable and coaxial cable. Additional trunk circuits are provided using radio telephone bearers, and in the example the radio telephone terminal is remote from the line transmission equipment station and connection is made between the two by coaxial cable tubes and associated equipment. At some stations the line transmission equipment and the radio telephone equipment are in the same building; interconnection is then made with hard dielectric coaxial cable.

Repeater Equipment is installed, as required, to maintain the necessary noise and loss requirements for each circuit. This equipment is part of the line transmission equipment.

Audio Programme from National and Commercial broadcasting stations is relayed throughout Australia on audio programme channels provided by the Department. The majority of trunk programme channels are provided by programme carrier equipment and the remainder by physical pairs. Audio programme is switched to the programme transmission room in the line transmission equipment station, from the Australian Broadcasting Commission (National) and Commercial network switchrooms or studios. In the programme room connection is made to the appropriate relay channel.

Telegraph Equipment is connected to the line transmission station via a telegraph office. At some large centres, carrier telegraph equipment is situated in the telegraph office and connection is made from this equipment to the carrier telephone equipment. The telegraph subscribers equipment is connected to the carrier telegraph equipment via the carrier telegraph office. At most stations, the carrier telegraph equipment is situated at the line transmission terminal although at some large stations this equipment is at the telegraph office. Carrier telegraph equipment is included as line transmission equipment.

Telephone Exchange Equipment provides subscribers and trunk switching facilities. Trunk switching exchanges are associated directly with line transmission equipment and through this equipment trunk circuits are interconnected and subscribers are switched to trunk circuits. In a number of cases the trunk switching equipment is in the same building as the line transmission equipment. The present trend is to automatic trunk switching but manual switching is still in common use.

Television Programme is relayed locally and throughout Australia on video channels provided by transmission equipment on coaxial tubes and microwave radio bearers. The video switching and transmission equipment is included with the line transmission equipment.

Facsimile and Data Equipment. Facsimile equipment has been in use for many years for the transmission of photographs for newspapers (picturegrams), and more recently for transfer of written information within private business (business-fax) or of weather chart information (weather-fax). The picture information is transmitted on a voice frequency channel. In 1964 facsimile equipment capable of transmitting and receiving picture information to enable the printing of newspaper pages was introduced. This information is transmitted in the frequency range of one supergroup (240kHz). Data transmission has been in use in Australia for a number of years and consists of equipment which ranges in sending rates from 50 bauds to 1200 bauds. At the time of writing 2400 baud operation is being investigated. A standard telegraph channel is suitable for 50 baud operation and telephone channels are used for 600 and 1200 baud equipment. These telephone channels must conform to certain requirements as regards delay distortion and frequency deviation.

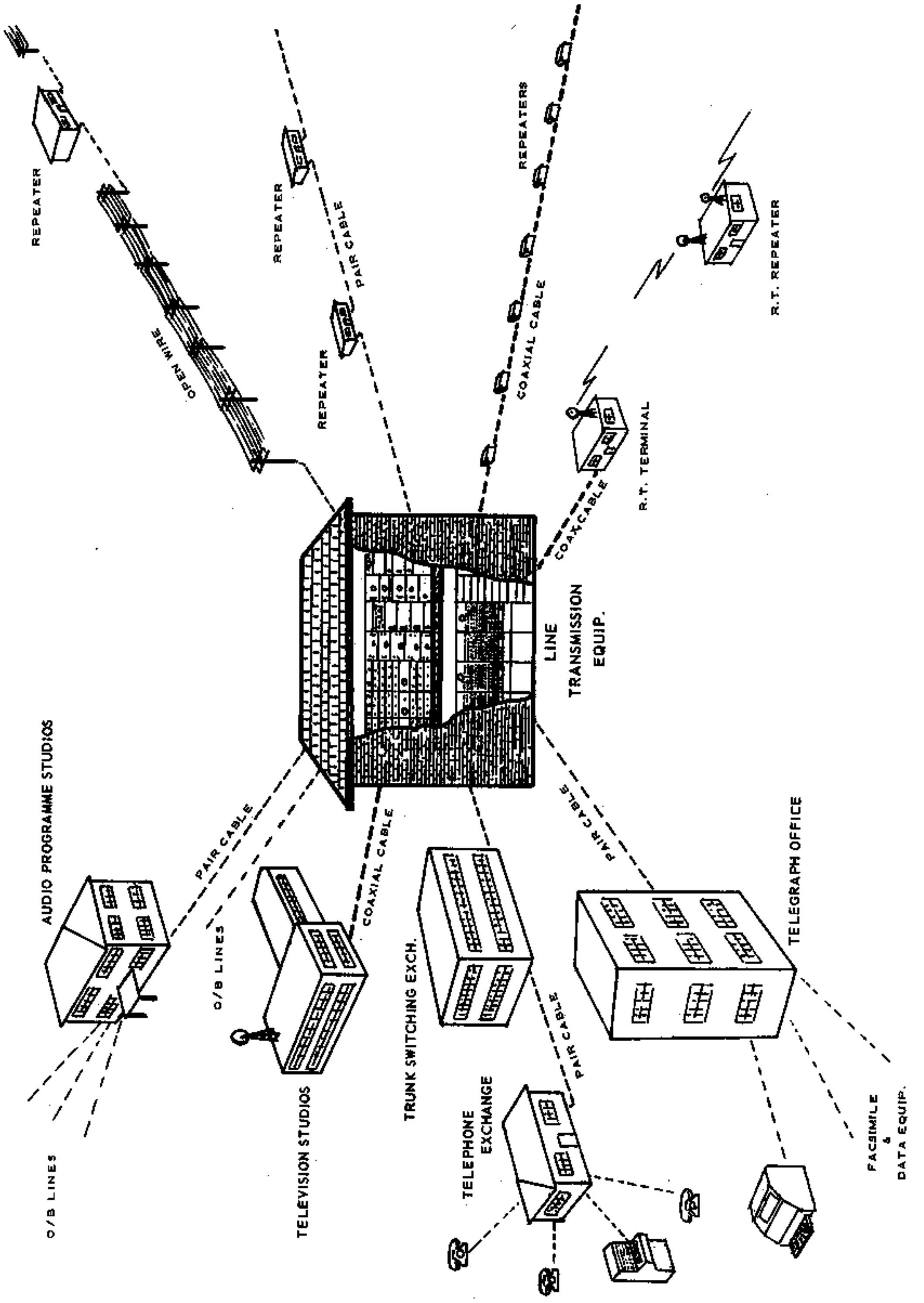


FIG. 7. PORTION OF THE COMMUNICATION NETWORK.

4.3 The equipment shown in Fig. 7 can be divided into major equipment areas. In Fig. 8 the main elements of line transmission equipment are outlined and their relationship to other major equipment areas is shown.

The major equipment areas are:

- Line Transmission Equipment (Long Line Equipment).
- External Plant.
- Telephone Exchange Equipment.
- Subscribers Equipment.
- Telegraph Equipment.
- T.V., Radio and Broadcasting Equipment.
- Power Plant.

In general, the Department divides the installation and maintenance of equipment into the areas shown, although the responsibilities of one sub-section or station may extend into a number or all of the areas.

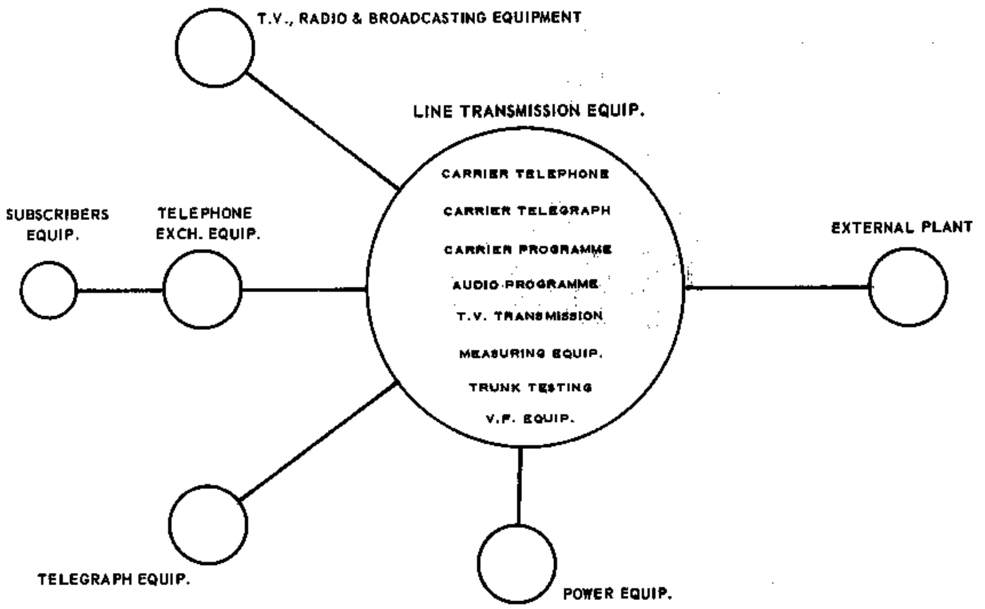


FIG. 8. RELATIONSHIP BETWEEN LINE TRANSMISSION EQUIPMENT AND OTHER MAJOR EQUIPMENT AREAS.

4.4 From Fig. 8 it can be seen that a technician involved with the installation or maintenance of line transmission equipment should have a knowledge of the associated equipment in the other areas. For example, the transmission lines, which play an important part in trunk circuit provision, are installed and maintained by the external plant section, but a knowledge of the make-up and characteristics of these lines is essential for a line transmission technician. Similar examples can be given for telephone equipment, telegraph equipment, T.V., radio and broadcasting equipment, and power equipment. There is no direct tie between subscribers equipment and line transmission equipment. Subscribers' equipment is switched to line transmission equipment via telephone exchange equipment. These relationships and certain equipment details are described more fully in sections 5-9. The line transmission equipment is divided into the equipment groups shown in Fig. 8.

5. EXTERNAL PLANT SECTION.

5.1 The External Plant Section is responsible for the provision and maintenance of all underground cables and aerial lines. Cables are subdivided into balanced pair cable and coaxial cable; each of these is further subdivided into various types. Aerial lines are divided into open wire and aerial cable; as regards trunk circuit provision open wire construction is normally used.

A technician involved with line transmission equipment installation or maintenance should have a knowledge of line characteristics, constructional details and associated line equipment. This information is necessary to enable a complete appreciation of line transmission equipment circuitry, and also to assist in diagnosis of trunk circuit faults and line fault location.

5.2 Balanced Pair Cable. Several types and sizes of cable are used in a cable scheme, because of the variety of conditions that have to be considered. All cables, regardless of type and size, have three basic parts:-

(i) The Wire. Soft copper wire is generally used and it is designated according to its weight per mile, for example "10 lb wire" means that one mile of this wire weighs 10 lbs. The wire weights in general use are 4 lb., 6½ lb., 10 lb., 20 lb. and 40 lb.; the latter three are commonly used for trunk circuit provision. The conductor weight is directly related to conductor resistance, and this information is important in line fault location.

(ii) The Insulating Material is used to insulate the wires from each other and the sheath. Various materials are used, the most common being paper (woodpulp and manilla), and plastic (polythene and polyvinyl chloride). The colours or coloured markings of the insulation are used to distinguish between the wires of the cable.

(iii) The Sheath is the outside covering which protects the wires from damage or moisture and is commonly made of lead, lead and antimony, or plastic. Additional protective armouring is sometimes added.

Rotation Counting of Pairs and Quads. The numbering of the pairs or quads in a cable commences from the "marker" in the core of the cable and continues in rotation throughout the various layers to the last pair or quad in the outer layer.

In all States except South Australia and Western Australia the rotation is clockwise looking towards the exchange and this is shown in Fig. 9.

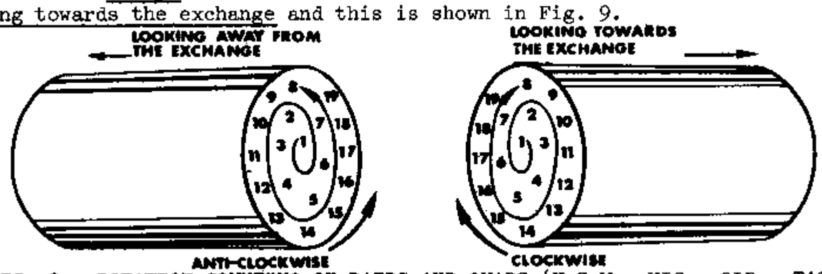


FIG. 9. ROTATION COUNTING OF PAIRS AND QUADS (N.S.W., VIC., QLD., TAS.).

In South Australia and Western Australia the direction of rotation is reversed and is shown in Fig. 10.

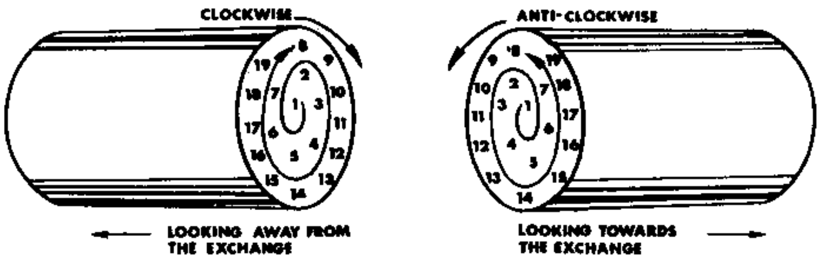


FIG. 10. ROTATION COUNTING OF PAIRS AND QUADS (S.A. AND W.A.).

Table 2, shows the main types of cable and their abbreviations, and gives an indication of their uses in the network.

TYPE	ABBREVIATIONS	USE
Paper Insulated, Lead Sheathed, Quad local. 6½lb, 10 lb, 20 lb.	P.I.Q.L.	Exclusive subscribers cables or combined trunk and subs. cables.
Paper Insulated, Lead Sheathed, Quad Junction. 10 lb, 20 lb.	P.I.Q.J.	Junction cables.
Paper Insulated, Lead Sheathed, Quad Trunk. 20 lb, 40 lb.	P.I.Q.T.	Trunk cables.
Paper Insulated, Lead Sheathed, Quad Carrier. 20 lb, 40 lb.	P.I.Q.C.	Carrier trunk cables.
Paper Insulated, Lead Sheathed, Unit Twin. 4 lb, 6½ lb.	P.I.U.T.	Subscriber cables.
Polythene Insulated, Polythene Sheathed, Unit Quad. 4 lb, 6½ lb, 10 lb, 20 lb.	POLYQUAD	Subscribers distribution and leading-in cables.
Polyvinyl Chloride Insulated, Lead Sheathed. 10 lb.	P.V.C.L.C.	Entrance cable to exchange and subscribers distribution frames.

TABLE 2. TYPES OF CABLE.

Specially designed quad cables are used for special purposes. A typical example is spiral four disc insulated, lead sheathed cable (SP.4 or D.I.S.Q.) used in older installations for carrier trunk entrance; this cable, although in common use, is now obsolete. Another example is a polythene quad, with a copper shield and lead sheathed, used for the transmission of frequencies in the range 60-552kHz; at the time of writing, this cable is in the experimental stage.

5.3 Gas Pressure Equipment is added on some main trunk cables to safeguard the cable against water damage. The system consists of making a cable network gas tight, by eliminating as many leaks as possible, and then installing contactors at intervals to short circuit an alarm pair or pairs when the gas pressure drops to a predetermined value. While the gas pressure remains within the cable it is difficult for water to penetrate the sheath.

Selected terminal or attended repeater stations are made Gas Pressure Alarm (G.P.A.) supervision stations and a line length up to about 50 miles can be supervised by these stations.

5.4 Characteristics (Cable Pairs). The characteristics of local type and unloaded carrier cables are described in detail in A.P.O. Engineering Instructions. Some of the main characteristics only are given in this paper.

Resistance. The resistance of a cable conductor varies slightly with changes in temperature but these changes have little effect on other characteristics. The values used for typical cable pairs are shown in Table 3.

Nominal Weight Per Mile	Resistance per Single Wire Mile (60°F)
6½ lb.	134.96 (135) ohms
10 lb.	87.72 (88) ohms
20 lb.	43.86 (44) ohms
40 lb.	21.93 (22) ohms

TABLE 3. CABLE RESISTANCE VALUES.

Attenuation. The attenuation constant (dB/mile) for 20 lb. and 40 lb. trunk cable pairs is shown in Fig. 11. The overall range 4 - 160kHz is shown in Fig. 11(a) and the range 200Hz - 4kHz is shown in Fig. 11(b).

(a) 0-160kHz

(b) 0-4kHz

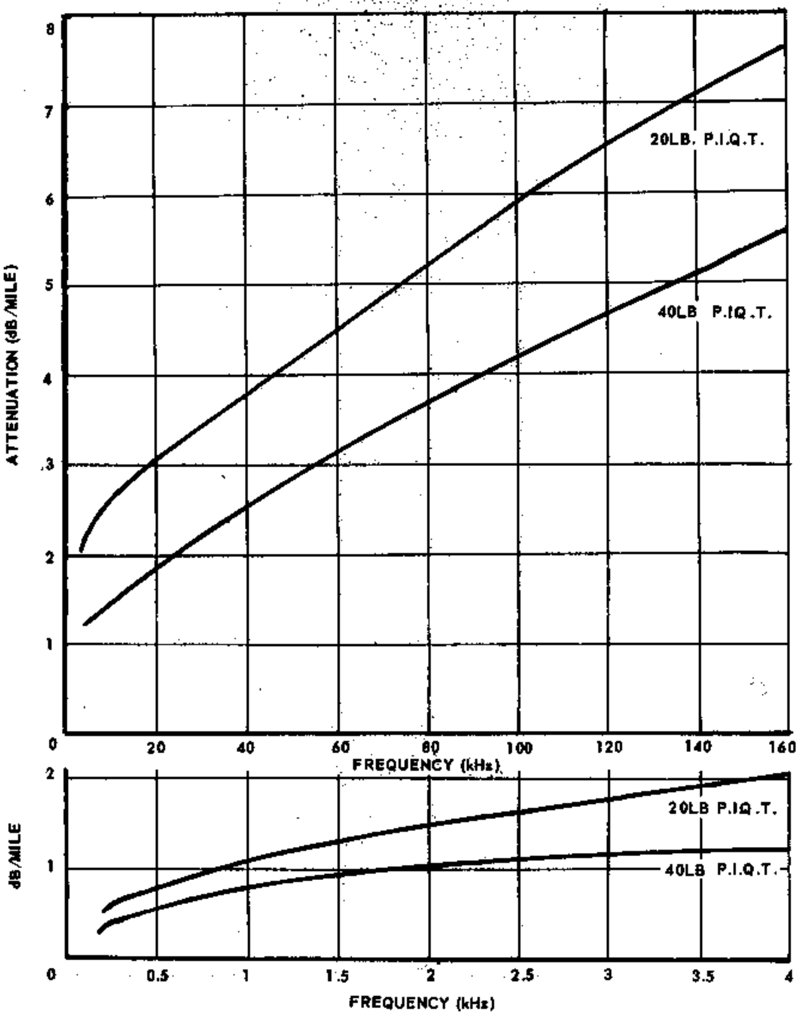
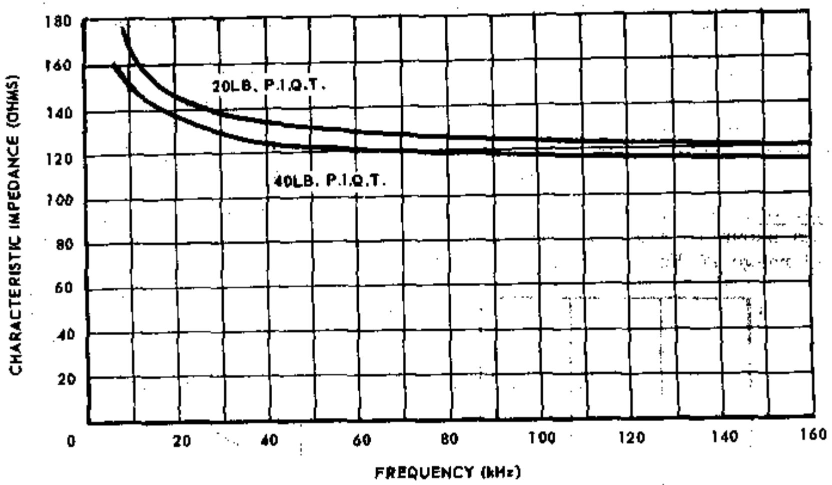
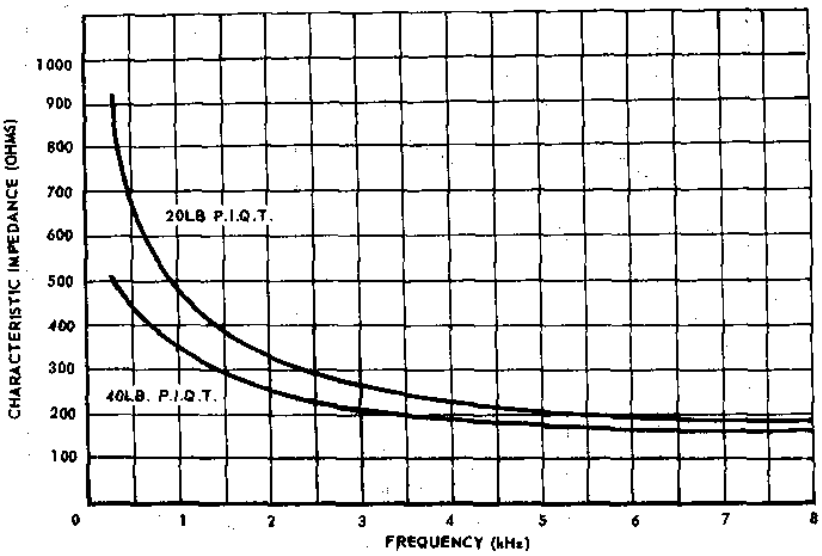


FIG. 11. ATTENUATION CONSTANT - 20 AND 40 lb. P.I.Q.T.

Impedance. The characteristic impedance (Zo) of a cable pair varies with frequency; the main variation taking place in the V.F. range. In the V.F. range, the characteristic impedance of cable pairs is broadly regarded as being 150 ohms and in the carrier frequency range it is regarded as being 135 ohms. Fig. 12 shows how the characteristic impedances of 20 lb. and 40 lb. trunk cable pairs vary with frequency. Fig. 12(a) shows this variation over the range 8 - 160kHz and Fig. 12(b) shows the 300Hz - 8kHz range in which the major changes occur.



(a) 0-160kHz



(b) 0-4kHz

FIG. 12. CHARACTERISTIC IMPEDANCE OF 20 lb. AND 40 lb. P.I.Q.T.

5.5 Crosstalk Considerations. (Cable Pairs). During the manufacture of quad cable, the quads are twisted so that the electromagnetic induction is effectively eliminated. The "twists" produce relative transpositions between the quads.

Electrostatic induction is due to deviation from geometric symmetry of the wires in the quad. These deviations cause capacitance unbalance between the pairs. These unbalances also exist between the wires of quads and earth.

Although close control is exercised during manufacture, the resultant unbalance is often large enough to produce severe crosstalk.

To offset crosstalk due to the inherent capacity unbalance of the cables, a number of capacity balancing methods are employed in trunk cables. Firstly a selective jointing scheme is used to obtain as good a balance as possible on a complete trunk cable. When additional balancing is required, special balancing capacitors are added between wires of the quads. For long distance trunk carrier cables the resistive unbalance between wires of quads is also a contributing factor to crosstalk. For these cables, "admittance unbalance", which incorporates both capacity and effective resistance unbalance, is determined and the cables terminated on special cable balancing racks where the required balancing capacitors and resistors are added.

5.6 Uses of Trunk Cables. A trunk cable is one which connects exchanges not in the same or adjoining charging zones. Trunk cables are also used for trunk entrance purposes. A trunk entrance cable is one which is used for connection from a line transmission equipment station to an open wire trunk pole route. This is necessary when it is physically impractible, or undersirable from a crosstalk and noise point of view to terminate the pole route at the line transmission station.

Trunk cable telephone circuits can be provided by either voice frequency or carrier frequency transmission. In general, carrier systems are used for distances greater than about 20 miles.

V.F. Transmission. Voice frequency working over trunk cables can be either on a "passive" or "active" basis. The passive circuits are suitable only over short distances, and heavy gauge conductors are required to meet transmission requirements. It is often necessary to employ V.F. loading (88mH coils at approx. 6000ft intervals) to obtain the required loss figures.

The active circuits are subdivided into:-

(i) Two-wire. V.F. working is improved by the use of negative impedance repeaters and two wire hybrid (type 22) repeaters. However, because of instability, these circuits are not normally operated over long distances.

(ii) Four-wire. Separate "Go" and "Return" pairs, including amplifiers, are used for each direction of transmission and the problem of instability is reduced.

Carrier Working. The majority of trunk cable carrier circuits are provided by 12 circuit systems operating over quad carrier (20 lb. or 40 lb.) cable bearers. Two types of systems are in use; one type uses separate "go" and "return" bearers and the other type uses one bearer pair and separates the directions of transmission by the use of different frequency ranges for each direction.

Special 14 or 24 pair cables are often provided for these systems and repeater stations are required at spacing ranging from about 12 miles to 22 miles depending on the conductor size and maximum frequency used. Twelve circuit systems are also used for junction circuit provision and, in these cases, repeater spacings of about six miles are sometimes necessary.

A single quad polythene insulated cable with a copper shield has been installed and is capable of providing 120 circuits with a single cable or 240 circuits using "go" and "return" cables. Frequencies up to 552kHz can be used and so two supergroups can be accommodated.

5.7 Coaxial Cables. Coaxial cables are capable of being used for the transmission of wide frequency bands and their main application is the transmission of television programmes or large groups of voice frequency circuits. Several types and sizes of coaxial cables are in service in Australia. The trunk network consists predominantly of four and six tubes cables, although eight and twelve tube cables are used for radio link and television connection and two tube cables are used for some subsidiary routes.

Construction. A coaxial tube consists of an inner copper wire conductor surrounded by an outer copper conductor formed into a cylindrical tube. Two layers of steel tape and two layers of paper complete the coaxial tube. This is shown in Fig. 13.

In the coaxial tube in general use, the diameter of the inner conductor is 0.104", and the inner diameter of the rube is 0.375". Polythene discs spaced at 1.3" intervals hold the inner conductor in place.

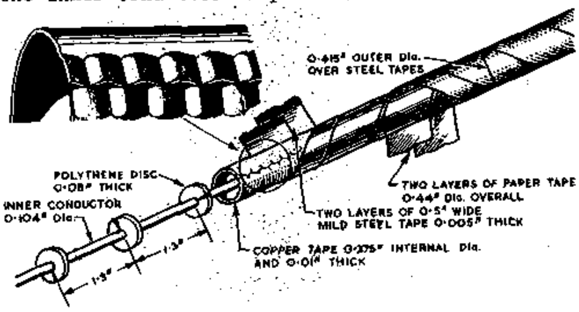


FIG. 13. BRITISH DIMENSIONED COAXIAL TUBE.

In general, more than one coaxial tube is included in the cable, and the tubes are laid-up around a core consisting of paper insulated 20 lb. pair or quad conductors which are used for control, supervisory and alarm circuits. A 20 lb. paper insulated carrier quad is placed in the space between each tube. A helical lapping of at least two thicknesses of paper is applied over the composite cable, and if required, one or more layers of 10 lb. or 20 lb. paper insulated quads can be made around the cable with a final double lapping of paper. The make-up of a typical 4 tube coaxial cable is shown in Fig. 14.

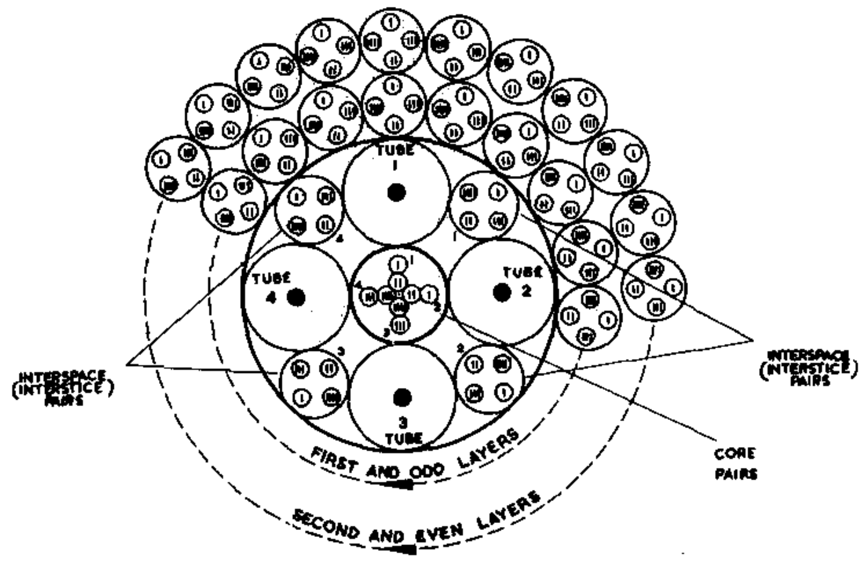


FIG. 14. MAKE UP OF 4 TUBE COAXIAL CABLE.

Typical cable lay-ups for 2, 4 and 6 tube coaxial cables are shown in Table 4.

Number of Tubes in Cables	Core Space			In each Outer Interspace Between Coaxial	Layers Pairs as Required - Local Type		
	Centre	1st Layer	2nd Layer		1st Layer	2nd Layer	3rd Layer
2	Nil	Nil	Nil	5-20lb Carr. &Junc. Quads	24-20 lb. Quads	30-20 lb. Quads	36-20 lb. Quads
4	4-20lb Twin Pairs	Nil	Nil	1-20lb Carrier Quad	40-10 lb. Quads 27-20 lb. Quads	46-10 lb. Quads 33-20 lb. Quads	52-10 lb. Quads 39-20 lb. Quads
6	2-20lb Trunk Quads	8-20lb Trunk Quads	Nil	1-20lb Carrier Quad	48-10 lb. Quads 34-20 lb. Quads	54-10 lb. Quads 40-20 lb. Quads	60-10 lb. Quads 46-20 lb. Quads

TABLE 4. TYPICAL CABLE LAY-UP 2, 4 AND 6 TUBE CABLES.

The complete coaxial cable is usually sheathed with lead alloy, but where the cable is subject to severe power induction an alternative sheath of aluminium alloy is used to increase the magnetic screening.

As the majority of faults are caused by mechanical damage, special precautions are taken to protect the cable. When the likelihood of damage is great the cable is armoured with steel tape or some form of outer wire protection. Most unarmoured cable is plastic covered to give a certain degree of protection. Fig. 15 shows standard "buried" cables with 4 and 6 coaxial tubes. The four tube cable has first layer pairs only and is plastic covered. The six tube cable has no layer pairs and has an aluminium sheath.

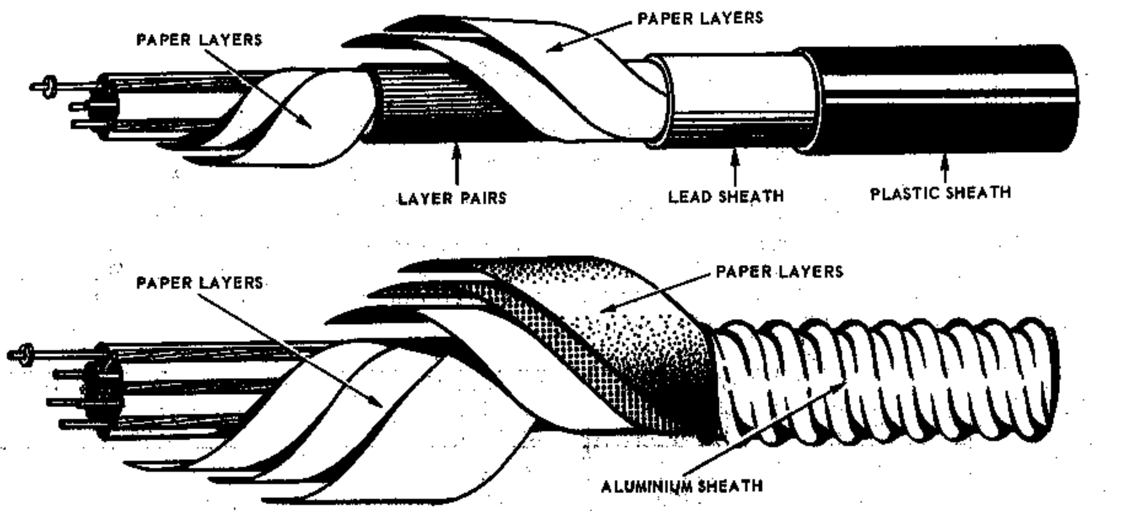


FIG. 15. TYPICAL 4 AND 6 TUBE COAXIAL CABLES.

Coaxial cables are laid four feet down, and after back-filling, the route is marked by tall posts bearing warning notices drawing attention to the hazard of high voltage distribution on the cable.

5.8 Characterisitcs. The tube characteristic which has the greatest effect on the quality of the broadband frequencies transmitted on a coaxial tube is impedance. Regularity of impedance is an essential feature of a coaxial tube to avoid reflection. Although irregularities may be due to variations in the dielectric or conductivity of the conductors, it is more usual to be caused by changes in the tube dimensions due to mechanical damage. An impedance versus frequency response for a typical coaxial tube is shown in Fig. 16. The tube has a nominal characteristic impedance of 75 ohms, but below about 1MHz the impedance rises above this nominal value.

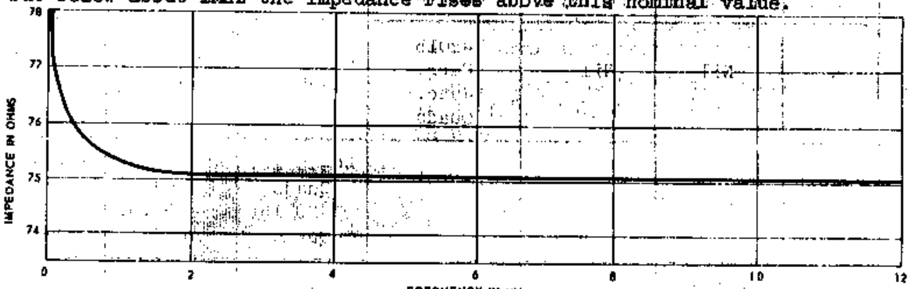


FIG. 16. IMPEDANCE - FREQUENCY RESPONSE FOR TYPICAL COAXIAL TUBE.

The attenuation constant of the coaxial tube rises sharply with increasing frequency Fig. 17 shows an attenuation versus frequency response for a typical coaxial tube having a cable temperature of 50°F.

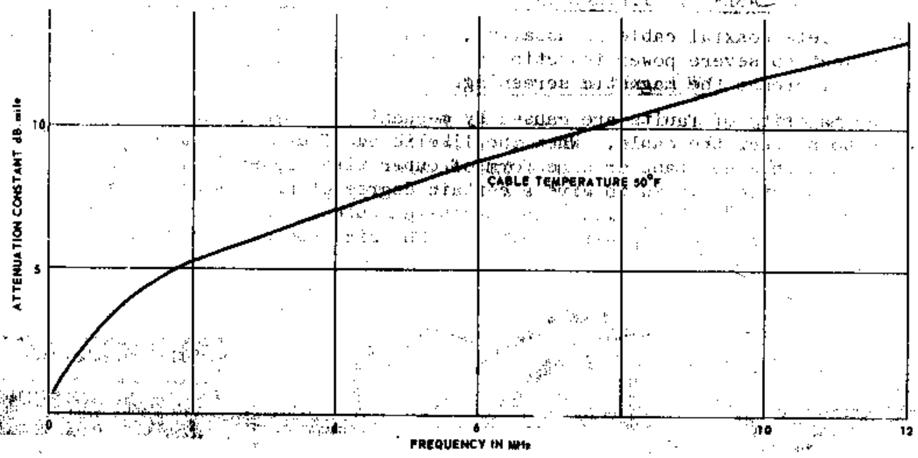


FIG. 17. ATTENUATION - FREQUENCY RESPONSE FOR TYPICAL COAXIAL TUBE.

Table 5 shows the effect of temperature on attenuation constant of a coaxial tube, at frequencies of 0.06, 1, 2, 10 and 12MHz. The attenuation constant is shown for temperatures of 50°F, 59°F and 68°F and the differences in attenuation constant between 50°F and 68°F are indicated.

FREQUENCY MHz	ATTENUATION dB/mile at 50°F	ATTENUATION dB/mile at 59°F	ATTENUATION dB/mile at 68°F	DIFFERENCE IN ATT. CONSTANT dB/mile 50°F - 68°F
0.06	0.918	0.928	0.938	0.020
1	3.755	3.795	3.840	0.085
2	5.315	5.360	5.430	0.115
10	11.840	11.950	12.100	0.260
12	13.000	13.207	13.340	0.340

TABLE 5. EFFECT OF TEMPERATURE ON ATTENUATION CONSTANT.

5.9 Cable Terminals. At the coaxial cable terminals, the equipment associated with power feeding and gas pressure alarms is added. Fig. 18 shows the cable pothead frames, power feeding rack, cable terminal rack and gas pressure alarm equipment at a typical repeater station. The four tube coaxial cable is terminated at the cable pothead frame, and the tubes are extended with single lead covered air spaced coaxial tubes to gas tight terminations. Connection is made from these terminations to the power feeding rack with connectors and semi-flexible solid dielectric coaxial cable.

The paper insulated pairs required at the station are extended with a cable tail to a cable terminal rack. At this point they can be distributed for use as supervisory and alarm pairs, minor trunk cables, or bearers for pair cable carrier systems. At some older installations all paper insulated pairs are taken to the cable terminal rack, and through connected or distributed locally at this point.

Typical gas pressure alarm equipment is shown at the right of the illustration. At later installations this equipment is situated in an entrance porch; this enables the lines staff to perform normal maintenance inspections etc. without entering the equipment room.

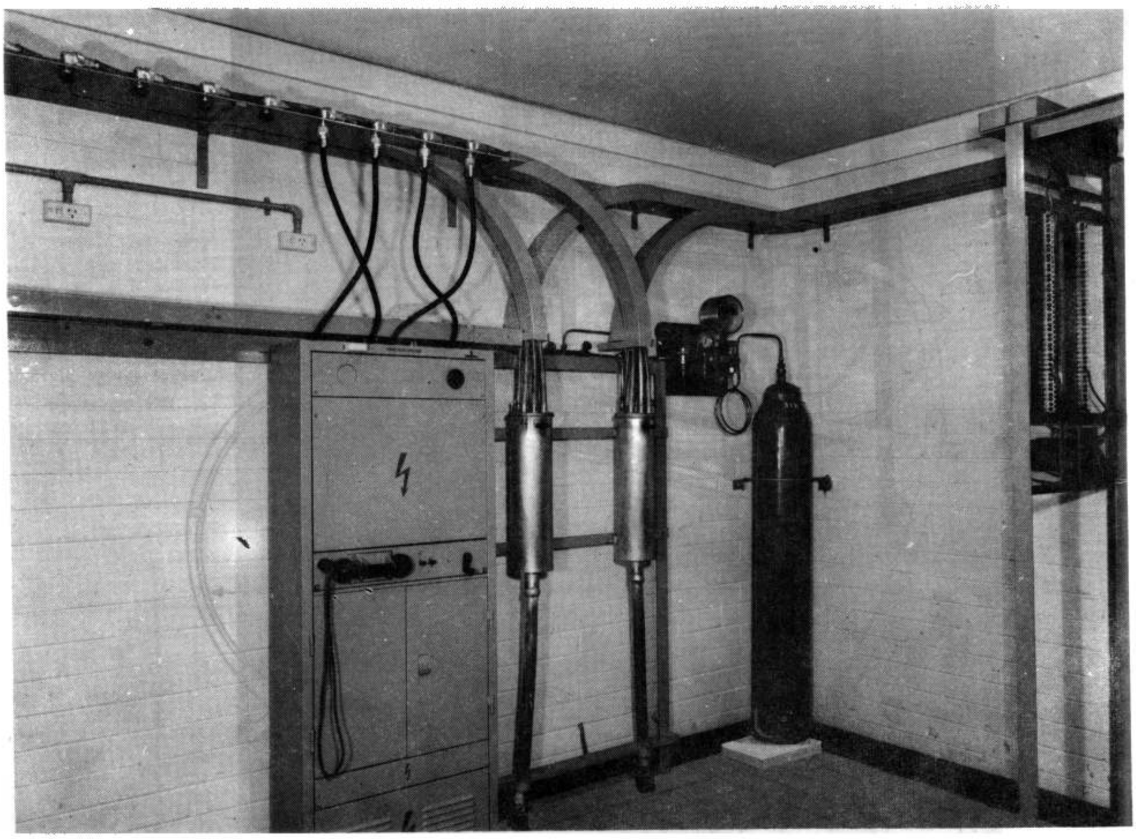


FIG. 18. CABLE TERMINATION AND POWER FEEDING RACK AT REPEATER STATION.

When transistor type line equipment is used, underground repeaters are installed, and the repeater buildings associated with valve type equipment are replaced by manholes. In the manhole a metal housing, maintained under gas pressure, accommodates both the coaxial tube terminations and the transmission equipment (two repeaters). The manhole also accommodates cable joints, gas pressure control and order wire equipment.

The typical layout for a manhole with a coaxial repeater is shown in Fig. 19. The coaxial cables for each direction are shown connected to standard coaxial cable tails which lead to the repeater housing. Air feeds are taken from the coaxial tubes, and the enclosed repeater housing, to gas pressure alarm equipment; contactor, manifold and bypass valves. Alarm and order wire pairs are brought out to terminal points. At intervals not greater than about 20,000 yards (two 4MHz repeater sections) gas cylinders are provided to inject gas to ensure a flow sufficient to prevent entry of water at any leak point. At a gas injection manhole the fourth bypass valve (stopped with a plug in Fig. 19) is used to feed gas from a high pressure cylinder and regulating valve.

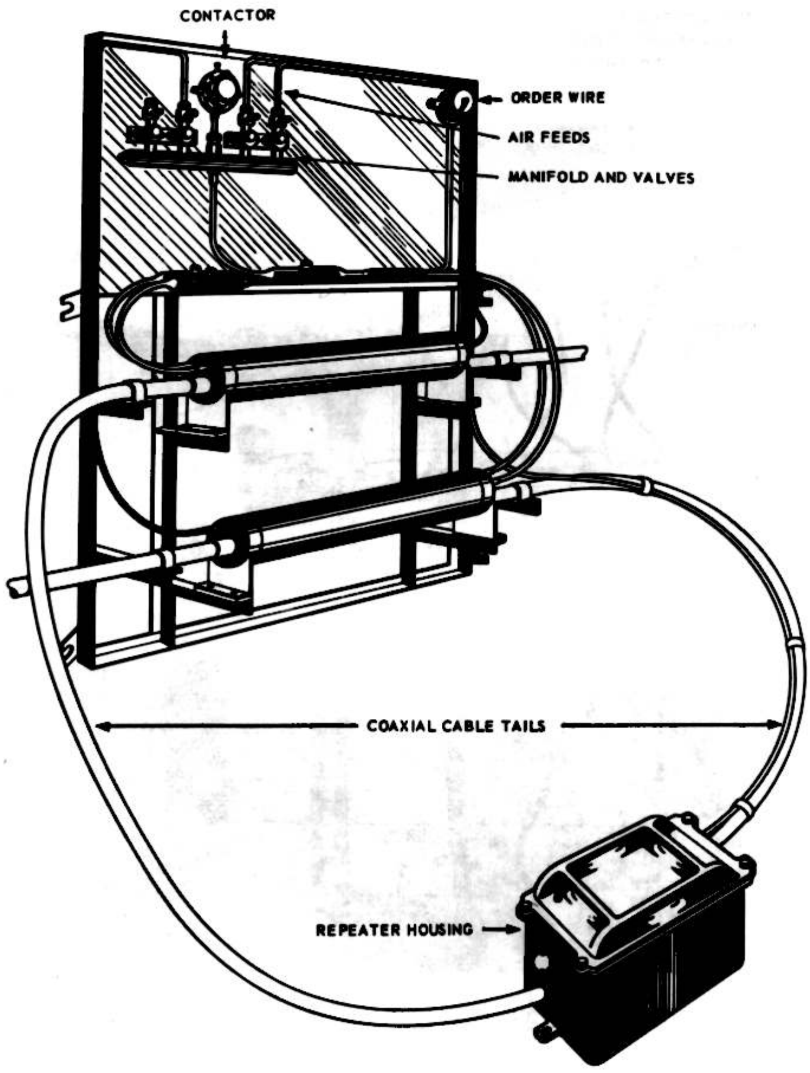


FIG. 19. TYPICAL LAYOUT IN MANHOLE WITH COAXIAL REPEATER.

Fig. 20 shows a partly equipped housing. The housing is approximately 22 inches long, 13 inches wide and 16 inches high and has been designed to accommodate two repeaters of either U.K. or German design. The housing is connected to the main coaxial cable by means of two coaxial tube tails. The four tubes, for each direction, appear in the housing as individual flexible cables which can be taken to the inputs and outputs of repeaters. In the example, only two tubes are equipped and the spare tubes are fitted to a mounting plate and patched through with short coaxial cable patching links. The repeater in Fig. 20 is of German design; the U.K. repeater is of slightly different design and minor changes are made to the connections within the housing.

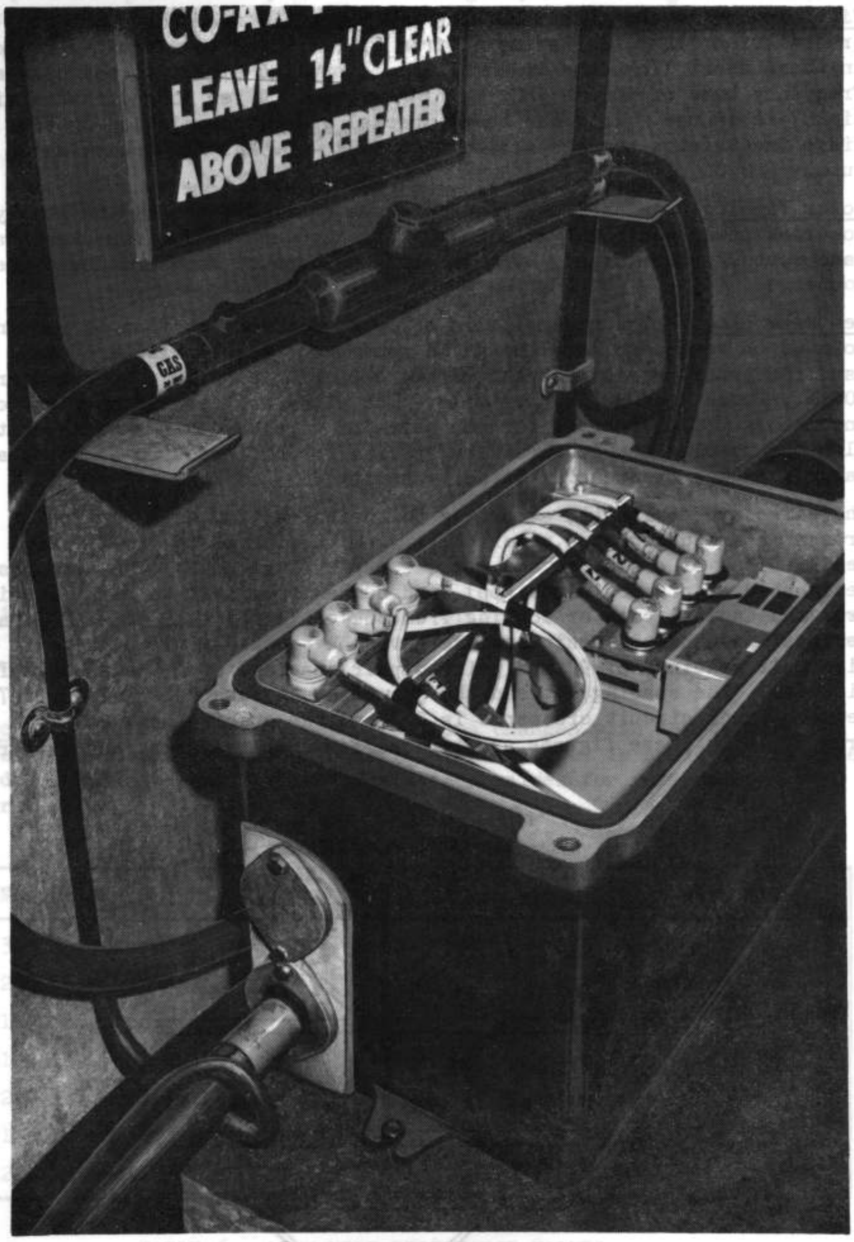


FIG. 20. TYPICAL COAXIAL SYSTEM BURIED REPEATER.

5.10 Use of Coaxial Tubes. The prime use of coaxial tubes is for broadband carrier telephony and television programme transmission. In many cases, power for certain repeater stations is fed from no-break power equipment at main repeater or terminal stations over inner conductors of coaxial tubes. The paper insulated pairs and quads, which are sometimes included with the coaxial tubes, are used for minor trunk provision and supervisory facilities.

Broadband Carrier Telephony. One coaxial tube is used for each direction of transmission and with repeaters spaced at about 5.75 miles intervals, frequencies up to 4MHz or 6MHz are used. With 4MHz working 900 or 960 speech circuits are obtained. At the time of writing, the installation of 12MHz systems providing up to 2700 speech circuits is planned.

Video Transmission. Coaxial tubes are generally used for short haul video transmission links, for example, from T.V. studios to microwave radio relay stations. In these short links the video signal is applied direct to the coaxial tube and a frequency band of 30Hz - 5MHz is transmitted. A few long distance video transmission links are in use. In these cases special video transmission systems are used and the video frequencies are translated to 0.5MHz - 5.5MHz for transmission on a coaxial tube.

Power Feeding. An ancillary use for some coaxial tubes is the supply of power from no-break power equipment at a main station to unattended repeater stations on the same route. Power supply by this means is used on most broadband coaxial equipment routes.

5.11 Open Wire Lines. The general form of open wire construction is wooden crossarms mounted on wooden poles although in some cases steel poles are used. The wire pairs used for trunk provision are normally copper or cadmium copper and are typically 100lb., 200lb. and 300lb. per mile. The wires are carried on glass or porcelain insulators. The spacings between pairs of wires and wires of separate pairs, and also the spacing between crossarms varies for different pole routes and depends largely on the frequencies to be transmitted.

The wires are designated according to their position on a particular crossarm; the crossarms are designated numerically from the top of the pole. Fig. 21 shows the designations of crossarms and wires for a typical pole. The wire positions are designated as pin positions (pp), and number from left to right looking at the pole from the Capital city or looking from the cable terminal pole. (Details of the wire designations and pin positions are given on trunk circuit maps). In the example, wire pair spacings of 9" and pair to pair spacings of 19" are shown for the trunk circuits. The spacing between the junction and subscriber wires is 7". The spacing between trunk circuit crossarms is 28" and the spacing between trunk and subscribers arms is 14". These figures are typical for combined trunk and subscriber poles.

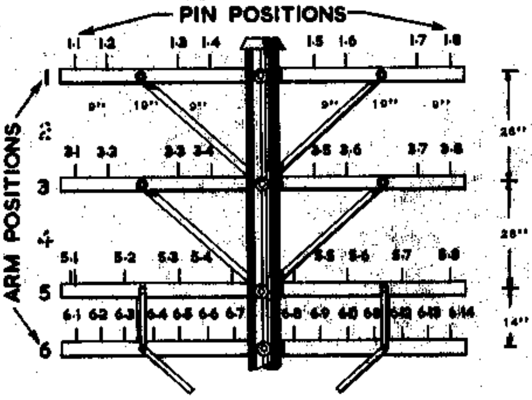


FIG. 21. NUMBERING OF ARM AND WIRE POSITIONS - LOOKING FROM CAPITAL CITY.

On cable terminal poles the trunk circuit numbers and wire type and size are indicated on pole plans. Fig. 22 shows a typical example. Trunk circuit number 2167 occupies pin positions 1.1 and 1.2; trunk circuit 495 occupies pin positions 1.3 and 1.4 and so on. Crossarms 5 and 6 are used for junction and subscribers lines and details are not given.

C2 indicates 200lb. copper conductor and C1 indicates 100lb. copper conductor. Cadmium copper conductors are indicated with the prefix CC. The designation F4 indicates 400lb. galvanised iron conductor.

The transposition pole number, E36 in the diagram, is shown against the pole and indicates the pole position with respect to a transposition scheme (para. 5.13).

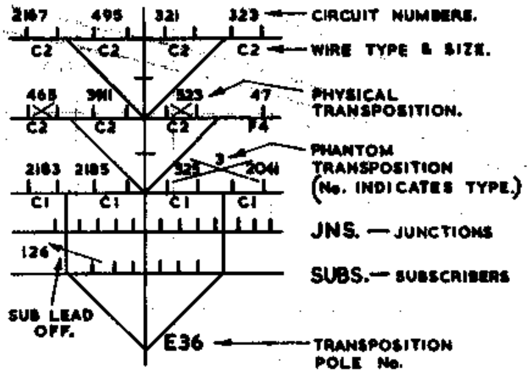


FIG. 22. CABLE TERMINAL POLE PLAN.

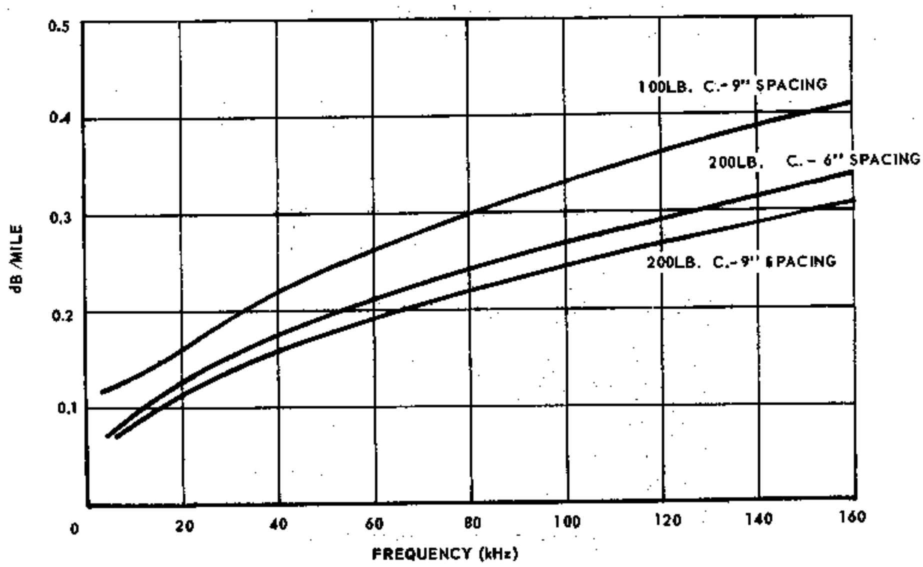
5.12 Characteristics (Open wire lines). Details of open wire line characteristics are given in A.P.O. Engineering Instructions. This paper includes some of the main characteristics only.

Resistance. The resistance of open wire lines changes with temperature but the effects of these small changes on other characteristics is small and is generally disregarded. Table 6 shows typical resistance values for various open wire conductors.

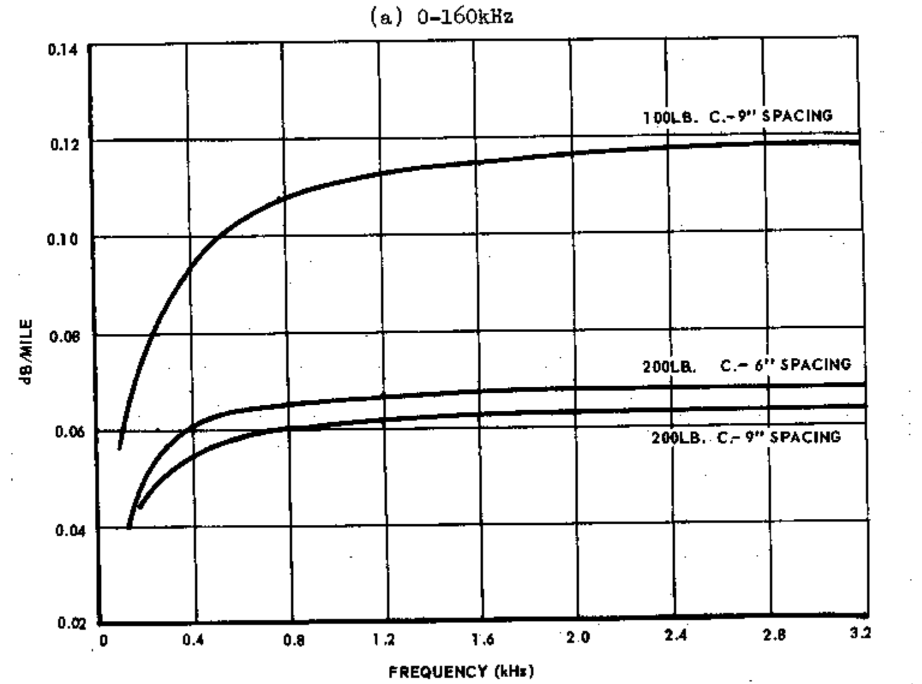
Nominal Weight per Mile	Resistance per Single Wire Mile
300 lb. (copper)	2.9 ohms
200 lb. (copper)	4.4 ohms
150 lb. (copper)	5.8 ohms
100 lb. (copper)	8.8 ohms
237 lb. (cadmium copper)	4.5 ohms
118 lb. (cadmium copper)	9.0 ohms
200 lb. (galv. iron)	26.6 ohms

TABLE 6. OPEN WIRE RESISTANCE VALUES.

<u>Attenuation</u>. The attenuation constant characteristics of 100 lb. and 200 lb. copper conductor open wire lines are shown in Fig. 23. The characteristics from about 4-160kHz are shown in Fig. 23(a) and the characteristics from about 0.05kHz - 3.2kHz in Fig. 23(b).



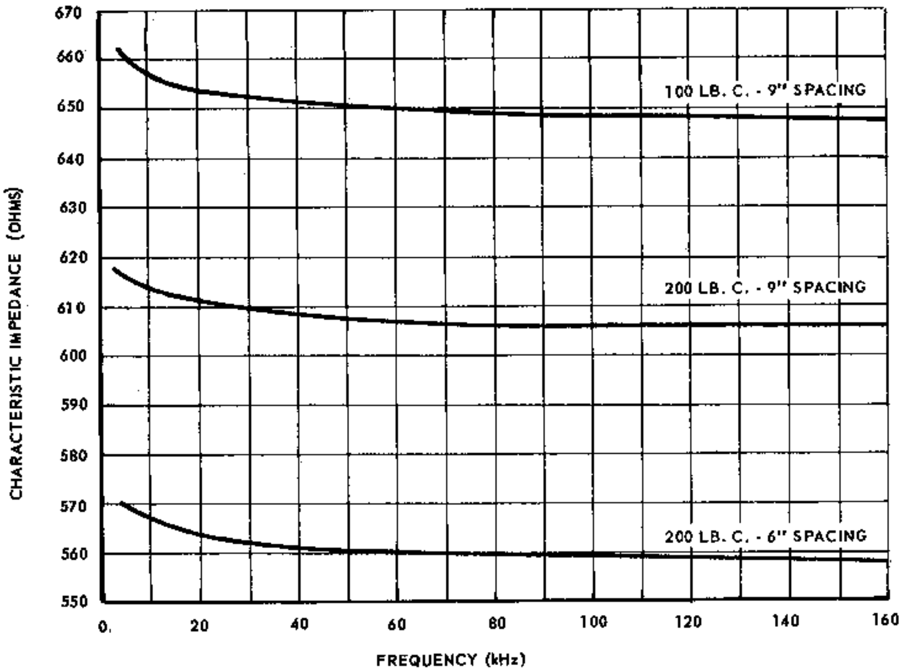
(a) 0-160kHz



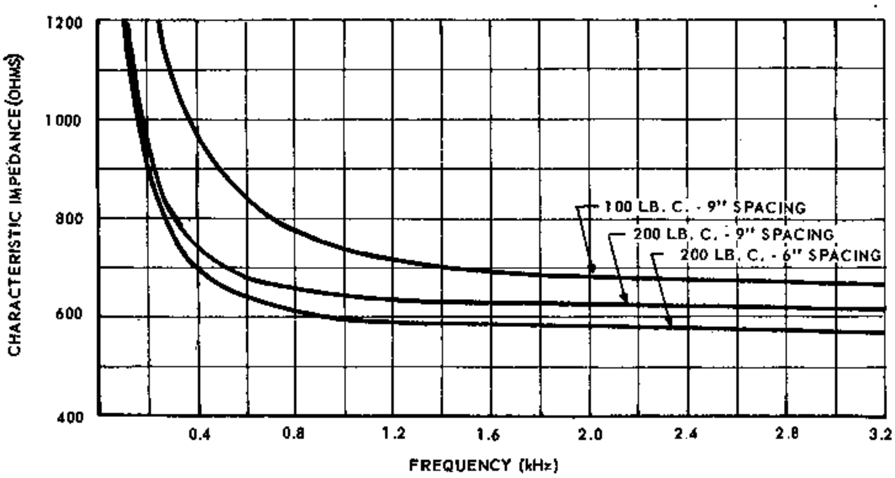
(b) 0-3.2kHz

<u>FIG. 23.</u> <u>ATTENUATION CONSTANT OPEN WIRE LINES.</u>

Impedance. The characteristic impedance of open wire lines varies with frequency and, as for cable pairs, the majority of change takes place in the V.F. range; that is in the range up to about 3kHz. Open wire lines are regarded as having a nominal characteristic impedance of 600 ohms and beyond about 3kHz this is the approximate value for most lines. Fig. 24 shows the charateristic impedance versus frequency for three types of open wire lines. The 100 lb. and 200 lb. copper conductor with 9" spacing having a general characteristic impedance slightly greater than 600 ohms and the 200 lb. copper conductor with 6" spacing has an impedance slightly less then 600 ohms.



(a) 0-160kHz



(b) 0-3.2kHz

FIG. 24. CHARACTERISTIC IMPEDANCE - OPEN WIRE LINES.

5.13 Crosstalk Consideration (Open wire Lines). In open wire lines the crosstalk coupling between pairs is affected by various features of the pole configuration. These are:-

- The distance between the wires comprising each pair.
- The distance between the wires of adjacent pairs.
- The spacing of the crossarms.

By crossing the wires of the pairs to a definite pattern (a transposition scheme) it is possible to control crosstalk over a certain frequency range. Each transposition scheme has a definite bandwidth and once the frequency limit is exceeded the quality of crosstalk reduction performance drops off sharply.

The three transposition schemes in common use are for three circuit, twelve circuit, and rural carrier system bearers. As the frequency range of the bearer is increased, the number of transposition per unit length is increased.

5.14 Uses of Open Wire Lines. Open wire trunk lines provide a number of trunk telephone circuits by either voice frequency or carrier frequency transmission.

V.F. Working. Voice Frequency transmission over physical lines can be on a "passive" or "active" basis. The passive circuits are generally only suitable for short trunk circuit provision. Reduction of circuit loss can be obtained by the use of two-wire hybrid repeaters or two-band systems. Neither method is used extensively as circuit performance is degraded because of the limited frequency range (maximum frequency about 2.6kHz) transmitted. Because of the problem of instability V.F. repeatered circuits operate with some finite loss and are normally only suitable for short trunk circuit provision.

Carrier Working. Open wire lines can be designed to allow transmission of frequencies up to about 170kHz under normal conditions, and frequencies up to about 300kHz with spacial transposition schemes.

Trunk open wire carrier circuits are provided by carrier systems which range from one circuit to twelve circuits per system. In many cases more than one system can share an open wire bearer and this increases the total number of circuits obtained per bearer. Rural carrier systems are designed for use on relatively low grade bearers and provide up to twelve circuits per system. Using a special transposition design it is possible to operate a three circuit system and two twelve circuit systems (one above the other in the frequency spectrum) on the one bearer. Frequencies up to about 300kHz are used and 27 circuits are obtained on one open wire bearer. At the time of writing this is considered a maximum for open wire working.

On the longer trunk routes, carrier system repeaters are required at intervals to maintain the required loss and noise figures. The spacing of repeaters varies considerably because of the geographical situation of towns and cities on the various routes. As a general rule the maximum repeater spacing for twelve circuit systems (maximum frequency 143kHz) is 90 miles. Three circuit system repeaters can be spaced up to about 200 miles apart; when they are on the same route as twelve circuit systems it is normal practice to locate them at each alternate twelve circuit repeater station. In practice, because of the geographical location of suitable repeater stations, maximum repeater spacings are rarely used.

5.15 Trunk Entrance Arrangements. Terminal and repeater line transmission stations are often situated in towns and cities in such a place that direct connection of the open wire lines to the equipment is not physically practicable. In some cases it is practicable, but because of the possibility of noise and crosstalk from adjacent subscribers circuits, power lines and traction systems, it is not desirable.

Fig. 25 shows simply the trunk entrance arrangements at a typical terminal station. The open wire line terminates on a "cable terminal pole". The trunk entrance cable pairs terminate in a cable jointing pit and are connected to the open wire pairs by a "riser" cable, a terminal box and "bridle" wire. Additional equipment, such as protectors, filters, etc. are added at the cable terminal pole.

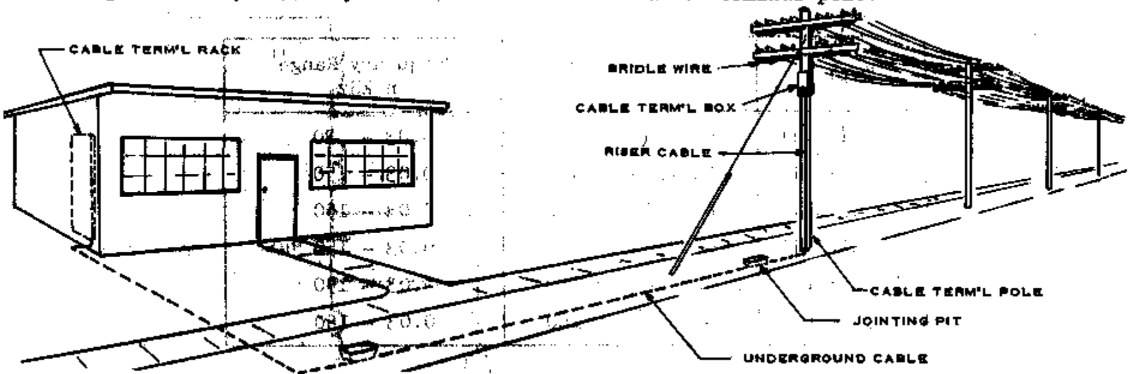


FIG. 25. SIMPLE TRUNK ENTRANCE ARRANGEMENTS.

The basic functions of the equipment associated with an open wire to cable, trunk entrance arrangement are to provide impedance matching and electrical protection. In trunk circuit provision it is unusual for open wire lines to be used only for voice frequency transmission. A large number of open wire trunk lines are used as bearers for carrier systems so in this paper the subject of trunk entrance for composite V.F. and carrier transmission is covered.

The trunk entrance equipment is situated at the junction of the open wire route and the cable. Most of the equipment is situated in weather proof boxes mounted on the pole; in some cases special filter huts or filter cabinets are installed to house some of the equipment.

5.16 Methods of Impedance Matching. Two basic methods of impedance matching are used. These are:-

(i) Matching transformers. The different impedances of a cable pair and an open wire line can be matched using a transformer with a suitable turns ratio between windings.

(ii) Cable loading. The addition of loading coils increases the Zo of a cable pair and this method can be applied to make the impedance of a cable pair equal to that of an open wire pair.

Use of Transformers. Except in special cases auto transformers are used for cable to open wire matching. This method has the advantage over normal transformer connection in that D.C. testing is not precluded.

Transformer matching has the disadvantage that it is difficult to obtain correct matching over a wide range of frequencies. This is brought about by the fact that the impedance versus frequency characteristics of open wire and cable pairs varies considerably in the V.F. range, and as shown in Fig. 26 this variation is such that a transformer with a fixed turns ratio cannot achieve efficient matching in this range. It can be seen that beyond about 10kHz the impedances for both lines become stable and transformer matching is practicable.

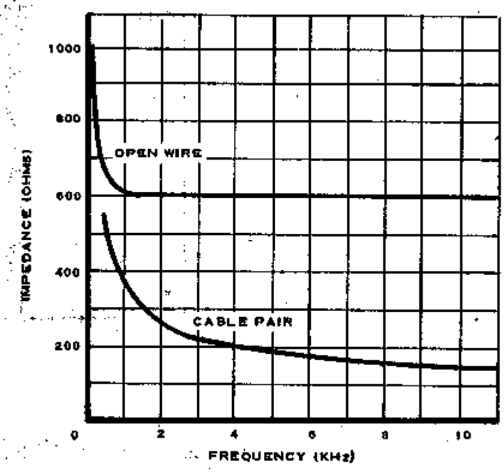


FIG. 26. IMPEDANCE VERSUS FREQUENCY CHARACTERISTICS OF OPEN WIRE AND CABLE PAIRS.

Although transformer matching is not entirely satisfactory it is used in many cases and the two main features to be considered for matching transformers are frequency range and impedance matching. Table 7 shows the impedance matching and frequency range of typical transformers. Different types of transformers are available in the twelve circuit system range to enable matching to different types of cable pairs.

Type	Matching Range in ohms	Frequency Range in kHz
3 Circuit	600/136	0.03 - 30
12 Circuit	600/115 or 120	0.03 - 150
12 Circuit	600/125 or 130	0.03 - 150
12 Circuit	600/135 or 140	0.03 - 150
12 Circuit	600/145 or 150	0.03 - 150
12 Circuit	600/155 or 160	0.03 - 150

TABLE 7. MATCHING AND FREQUENCY RANGE FOR TYPICAL TRANSFORMERS.

The connection for a typical transformer is shown in Fig. 27. The connection shown is for 600 ohm: 125 ohm conditions. The dotted connection is suitable for 600 ohm: 115 ohm conditions. The inbuilt 4μF capacitor prevents a permanent D.C. loop across the line.

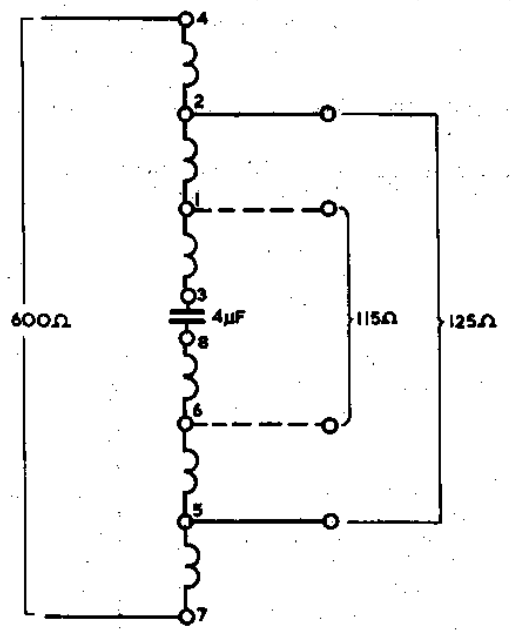


FIG. 27. TYPICAL TRANSFORMER CONNECTIONS.

In some cases double pair matching is used. Fig. 28 shows a typical example in which two cable pairs are connected to two secondary coils of transformer T1 and an open wire pair is connected to the primary. This method of matching is sometimes used when 17Hz signalling or audio programme is provided on the physical. A 2μF capacitor gives a satisfactory response down to 50Hz.

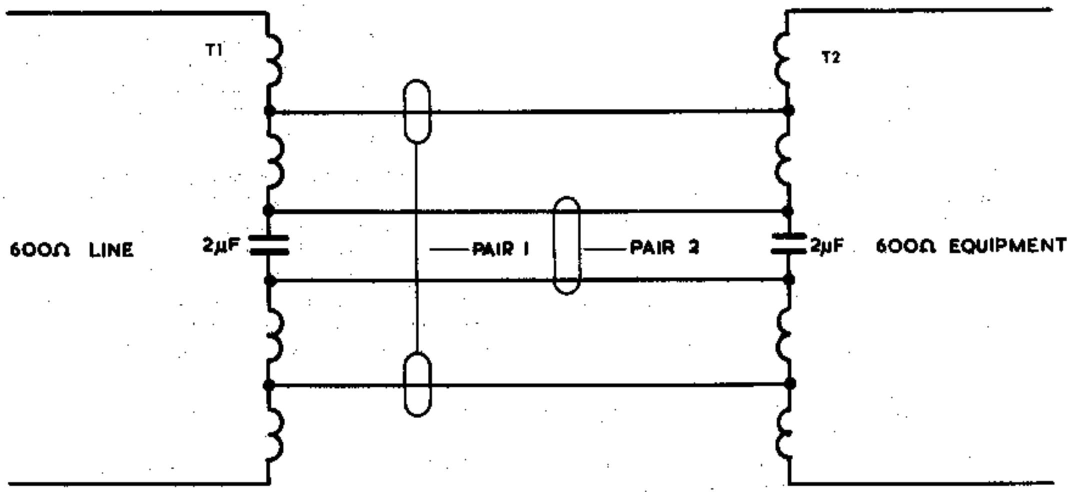


FIG. 28. TYPICAL "DOUBLE PAIR" MATCHING.

Cable Loading. The addition of series inductors at fixed and equal intervals along a cable pair is known as loading. Loading is used for a number of reasons and introduces certain advantages, and also the disadvantage of a restricted frequency range. Additional information is given in the paper "Transmission Line Characteristics."

The standard form of carrier loading uses 2.44mH coils at intervals of approximately 600 feet. This results in a cut-off frequency of about 40kHz to 50kHz so that carrier system working beyond this frequency is prevented. The impedance versus frequency characteristics of carrier loaded cable pairs are almost identical to those of open wire pairs and efficient matching is obtained over the frequency range.

In some special circumstances loading is added at 150 feet intervals and a frequency pass range up to about 150kHz is obtained. This type of loading is too expensive for large scale use and when used is confined to short cable lengths.

Fig. 29 shows the entrance arrangements for V.F. and three channel working using a carrier loaded entrance cable pair.

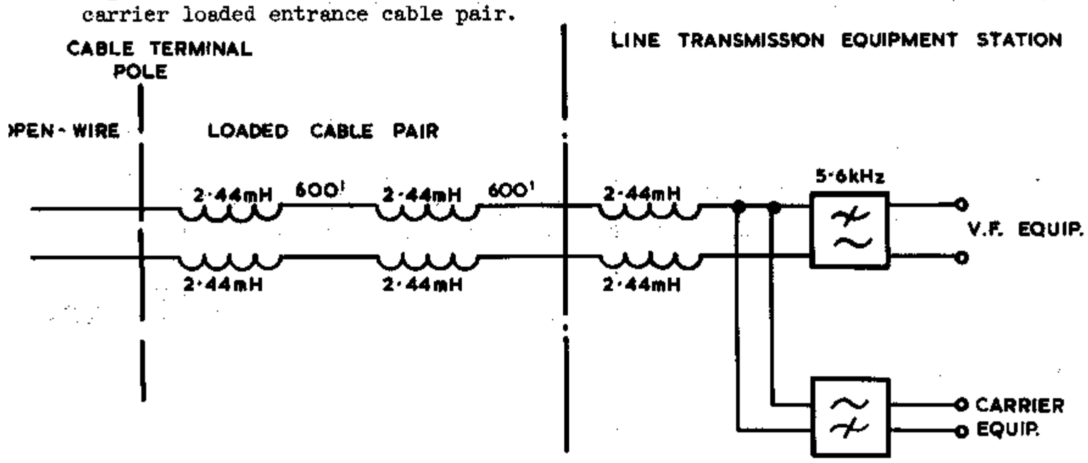


FIG. 29. TRUNK ENTRANCE ARRANGEMENTS USING A CARRIER LOADED PAIR.

5.17 Frequency Splitting. Transformer matching is not always entirely satisfactory because of the variation in line impedance with frequency, and cable pair loading to obtain a frequency pass range beyond about 50kHz is too expensive for general use. For these reasons an alternative method of trunk entrance used on twelve circuit bearers is to split the voice frequencies and three circuit system frequencies from the twelve circuit system frequencies at the open wire to cable junction. To do this a 32kHz line filter group is situated at the cable terminal pole. These filters may be on the pole, in a filter cabinet at the base of the pole, or in a filter hut in the vicinity of the pole. The entrance arrangements for a rural carrier system, where the entrance cable is longer than 100 feet, is similar to that for the twelve circuit system but a 4kHz filter group is used at the cable terminal pole.

Fig. 30 shows simply typical entrance arrangements using frequency splitting at the cable terminal pole. In this example the open wire pair is connected to the filter by means of a special disc insulated star quad cable (D.I.S.Q.) or S.P.4. This cable is loaded to achieve an impedance characteristic similar to that of the open wire; on short lengths (below about 330 feet), one terminal load unit is required but on lengths greater than 330 feet load units are used at each end of the cable and in some cases intermediate load units are required. When pole mounted filters are used D.I.S.Q. is not required for the short connection from the open wire pair to the filter.

The 32kHz filter group has an impedance of 600 ohms so it is necessary to match this impedance to that of the unloaded cable pair used for transmission of the twelve circuit system frequencies to the line transmission station. The impedances of unloaded trunk cable pairs range from about 110 ohms to 140 ohms and the matching transformer turns ratio is variable to enable correct matching for any condition. At the terminal or repeater station it is normal to match the equipment to the cable pair. A typical line impedance for twelve circuit equipment is 125 ohms and a suitable matching transformer is used to connect the cable pair to the equipment.

The low pass section of the filter is connected to a carrier loaded cable pair and so matched conditions exist through to the equipment in the line transmission station where connection is made to a 3, 4 or 5.6kHz line filter group for separation of the voice frequencies and three circuit frequencies.

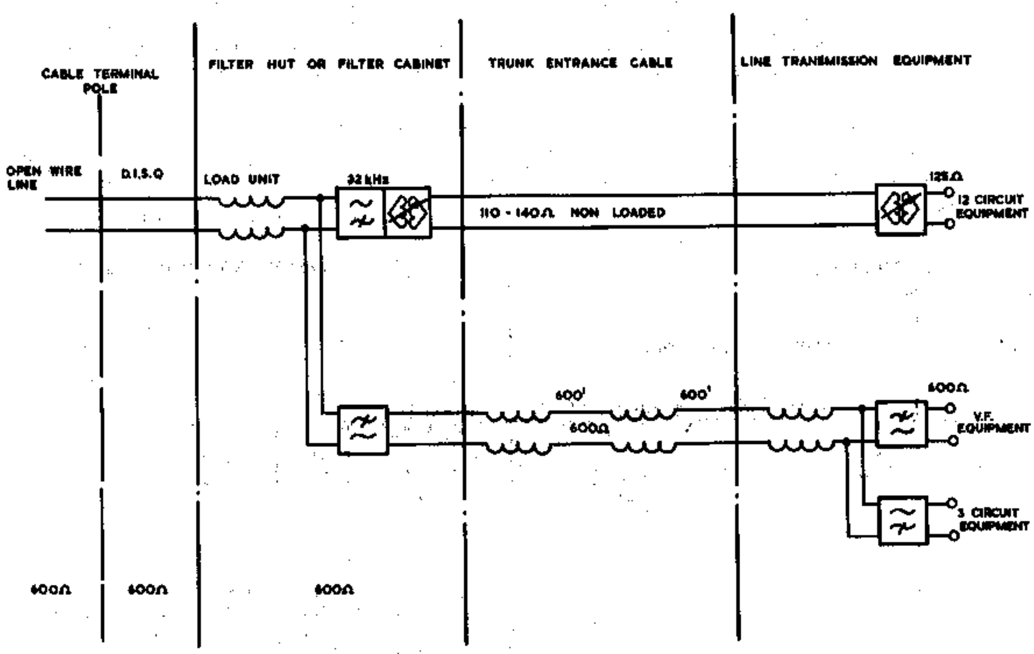


FIG. 30. TRUNK ENTRANCE ARRANGEMENTS USING FREQUENCY SPLITTING.

The filter and matching transformer arrangement for a rural carrier system bearer with entrance cable in excess of 100 feet is shown in Fig. 31. A 4kHz filter group is mounted on the cable terminal pole; the low pass side (voice frequency) is extended to the station by an unloaded cable pair and the high pass side (rural carrier system) is matched with an auto matching transformer to an unloaded cable pair which makes the connection with the equipment via an auto matching transformer at the station.

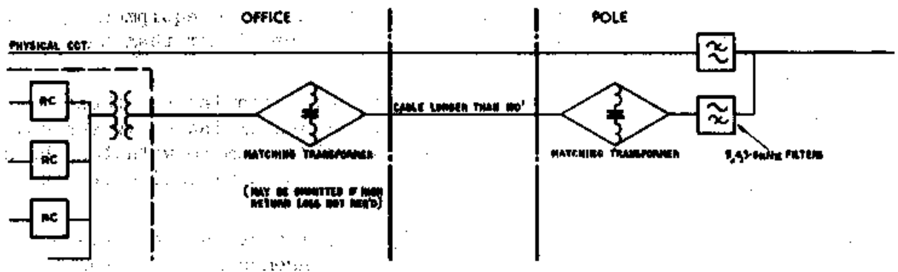


FIG. 31. SIMPLE TRUNK ENTRANCE ARRANGEMENT FOR RURAL CARRIER SYSTEM.

Charge over trunk facilities are sometimes provided over bearers for rural carrier systems. Because line filters are limited in current carrying capacity it is necessary to keep any charging current out of the filter and this is usually achieved by installing chokes on the line side of the filters and extracting the charge current from the centre tap of the choke. These features are shown in Fig. 32. Where necessary a number of pairs in parallel may be used to reduce the resistance of the charge over trunk control circuit. When the legs of the pair are to be kept separate for D.C. loop dialling or similar purposes, it is necessary to put a 1 or 2μF capacitor across the centre tap of the choke. The resonant frequency of the choke, considered in conjunction with the entrance cable capacity, is then lowered below the V.F. range.

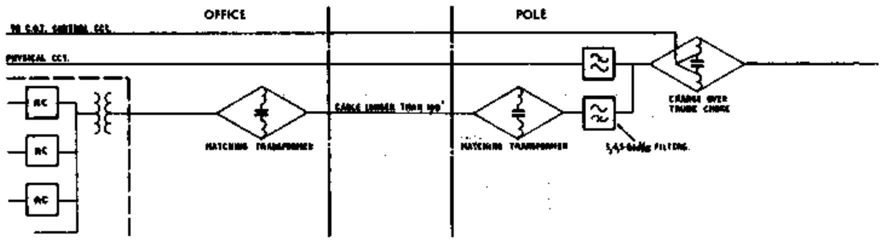


FIG. 32. CHARGE OVER TRUNK ARRANGEMENTS AND FREQUENCY SPLITTING.

5.18 Bridging Filters. At intermediate stations on multi-office trunk lines which are also bearers for single or three circuit systems, bridging filters are used to tee local telephone equipment across the line. The filter is designed to minimise the losses at carrier frequencies caused by bridging the telephone equipment across the line, and to reduce crosstalk between the carrier and the voice frequency circuits. Fig. 33 shows a typical arrangement.

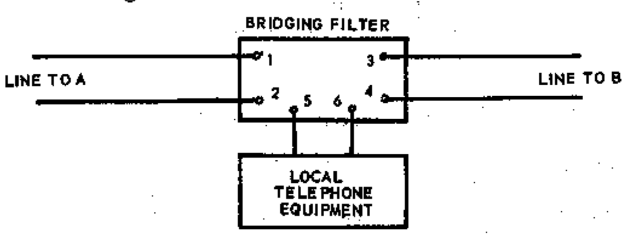


FIG. 33. TYPICAL BRIDGING ARRANGEMENT.

5.19 Protection. The majority of pole mounted equipment has provision for fitting protectors. Three types of protectors are in common use; a gas arrestor, an atmite arrestor, a carbon arrestor. As a general rule arrestors are fitted at the termination of the open wire line; one each side of the wire to earth and one across the pair. Arrestors are also fitted to protect equipment not adjacent to the open wire line.

The operate voltages and operate lags of arrestors on a trunk line should be co-ordinated so that normally the only arrrestors to operate are those nearest to the open wire line. The striking voltage of arrestors in the equipment station, and between the station and the line arrestors should be higher than that of the line arrestors.

It is common practice to fit fuses in the equipment station but these fuses should play no part in protection against lightning strikes or inductive surges. The fuses should have anti-surge characteristics which enable them to withstand high current for short periods but should operate when subjected to excessive current for prolonged periods.

In some special circumstances, particularly in areas subject to severe lightning damage, it is necessary to add drainage coil arrangements with arrestors included in the connection between the retard coils and each wire and also in the centre tapped earth connection. With this arrangement the discharge current to earth from one side of the line induces a voltage in the other coil which hastens the discharge to earth for the other side of the line. The drainage coil and arrestors are normally the items of protection equipment nearest to the open wire line.

The functions of drainage coils are:-

(i) To ensure that longitudinal surges of high voltage, due to lightning or power induction, cause practically simultaneous operation of the arrestors in each leg. (The operation of one arrestor before the other could cause transverse voltages which could damage equipment).

(ii) To prevent a short circuit between the line conductors when both arrestors are operated. (The coils are wound so that a high impedance is presented to transverse voltages).

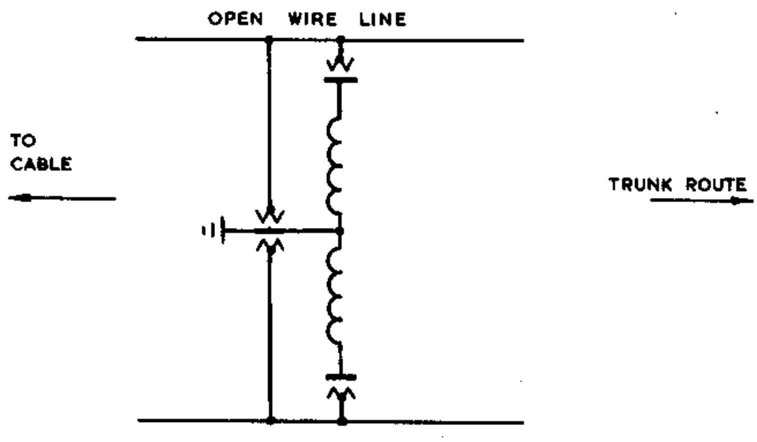


FIG. 34. USE OF DRAINAGE COILS.

Longitudinal retards are added on some lines to help reduce crosstalk. They also give a degree of protection against excessive voltages. The longitudinal retard consists of double wound inductors; one winding is inserted in each side of the open wire pair to cause a high impedance to longitudinal currents but negligible effects on transverse current (para. 5.21).

Fig. 35 shows a typical line protector unit associated with a pole mounted filter. This unit includes a drainage coil and longitudinal retards in addition to the arrestors.

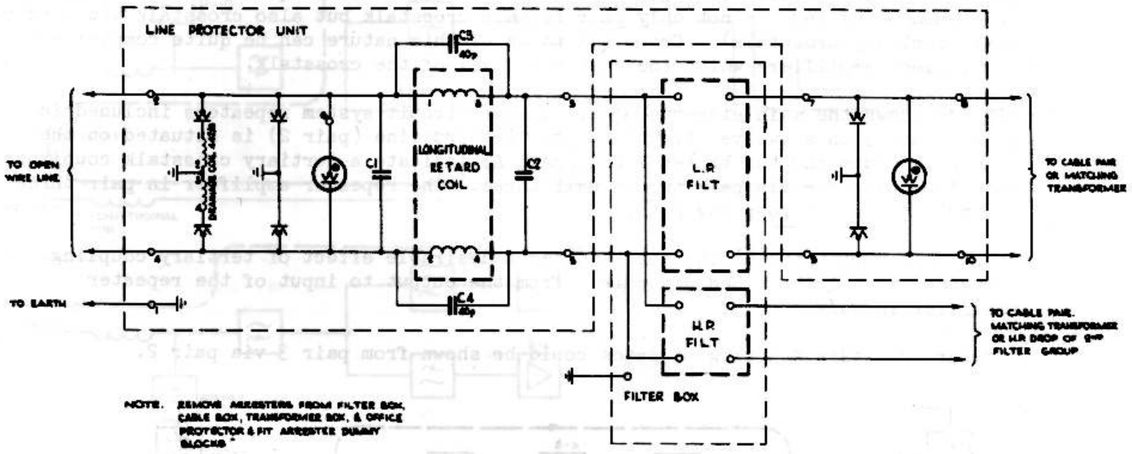


FIG. 35. TYPICAL LINE PROTECTION UNIT.

Some transistor operated line transmission equipment incorporates additional protective equipment to ensure that no damage can occur due to high voltage surges. These limiting circuits are normally included with a line transformer unit and employ zener diodes as voltage reference devices.

A typical limiting circuit for a rural carrier system is shown in Fig. 36. Zener diodes SC1 and SC2, with a nominal breakdown voltage of about 35-40 volts are connected across the equipment side of the transformer. Large voltage surges cause these diodes to conduct and pass a large current pulse, up to 3 ampers, for a few microseconds. In turn, a voltage is developed across R1 and R2 which is sufficient to cause the operation of conventional line protectors mounted external to the equipment. The neon lamp LP1 gives a degree of protection to the silicon diodes during high voltage surges.

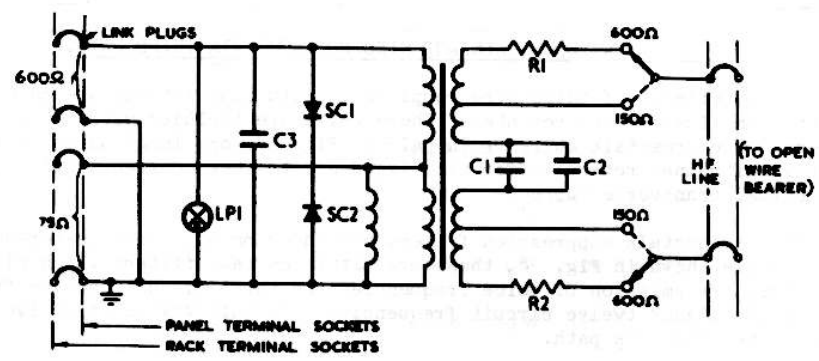


FIG. 36. PROTECTION INCORPORATED IN LINE TRANSMISSION EQUIPMENT.

5.20 Crosstalk Suppression Equipment. The crosstalk reduction techniques employed in line construction do not completely eliminate crosstalk between pairs. The high line frequencies used by twelve circuit and rural systems, together with the greater attenuation offered to these frequencies, accentuate the effects of certain crosstalk paths which are usually of small consequence in the lower frequency ranges. These crosstalk paths involve not only pair to pair crosstalk but also crosstalk via a third pair (tertiary crosstalk). Crosstalk paths of this nature can be quite complex and can include amplifiers which increase the level of the crosstalk.

Fig. 37 shows the main elements of two twelve circuit system repeaters included in pairs 1 and 3 on a twelve circuit route. A third line (pair 2) is situated on the same pole route and the broken lines (path A) indicate a tertiary crosstalk coupling path from pair one via pair two to pair three. The repeater amplifier in pair three is included in the coupling path.

The broken lines (path B) indicate another undesirable effect of tertiary coupling. A "singing" path is provided via pair 2 from the output to input of the repeater amplifier in pair 1.

Similar crosstalk and singing paths could be shown from pair 3 via pair 2.

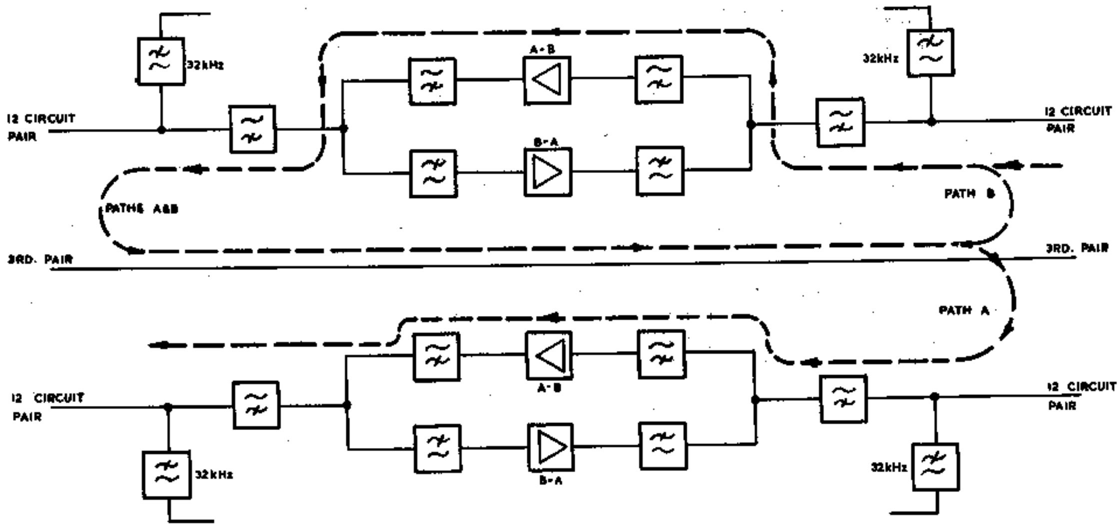


FIG. 37. CROSSTALK AND SINGING PATHS VIA THIRD PAIR.

To reduce the effects of third wire coupling longitudinal retards are added on pairs on both sides of the repeater. These coils are included with the pole mounted equipment. The crosstalk currents in pair 2 (Fig. 38) are longitudinal currents and the longitudinal retards offer high impedance to these currents but low impedance to the normal transverse currents.

In addition, crosstalk suppression filters are added on all non-repeatered circuits. In the example shown in Fig. 38, these are 32kHz low pass filters which allow satisfactory transmission of voice frequencies and three circuit carrier frequencies but block the higher twelve circuit frequencies. In this way an effective block is placed in the crosstalk path.

The crosstalk paths shown in Fig. 37 are relatively simple. In practice complex paths involving office wiring and equipment exist and crosstalk reduction methods must take these into consideration.

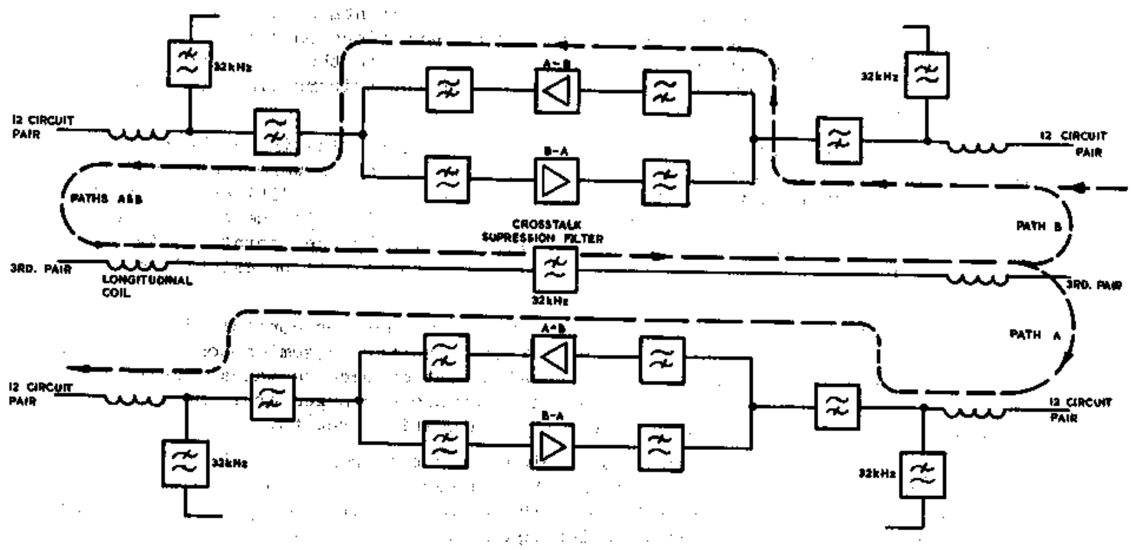


FIG. 38. USE OF LONGITUDINAL RETARDS AND CROSSTALK SUPPRESSION FILTERS.

5.21 Longitudinal Retards. These coils are added essentially to reduce crosstalk effects but they also provide a degree of protection against longitudinal current surges. The coils are wound in such a manner that high impedance is offered to longitudinal currents (indicated by dotted lines in Fig. 39) and negligible impedance is offered to transverse currents (full lines in Fig. 39).

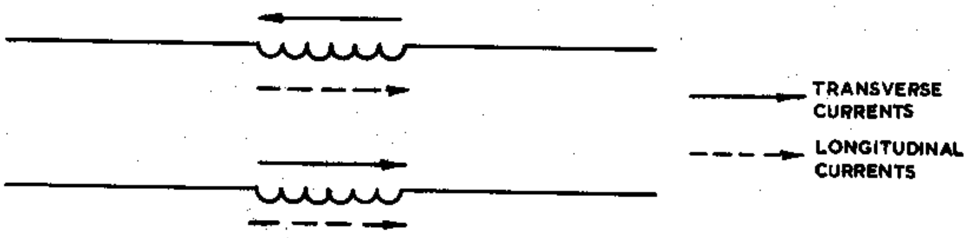


FIG. 39. OPERATION OF LONGITUDINAL RETARD.

Longitudinal coils should be fitted, on twelve circuit and rural carrier bearers:-

(i) At terminals where more than one circuit is on the route.

(ii) At twelve circuit repeaters on the twelve circuit pairs on one side and all pairs on the other side.

(iii) On any pairs on a twelve circuit route where it is necessary to isolate a condition of unbalance.

6. TELEPHONE EXCHANGE EQUIPMENT.

6.1 The telephone exchange equipment section provides and maintains the switching equipment required for subscriber to subscriber connections on a local or trunk call basis. The term trunk line switching generally refers to the interconnection of trunk lines but also embraces the switching of the subscribers lines to the trunk lines.

Until about 1940 all trunk traffic was on trunk lines terminating at both ends on manual switchboards. This meant that at least two operators were required for each call, and when intermediate switching centres were involved additional operators were required. Since 1940 automatic equipment has been provided in the trunk network and by 1960 the majority of trunk traffic was handled by only one operator. As S.T.D. facilities are increased in the trunk network more calls will be established without involving switchboard operators.

This means that the network is being converted from operator controlled to automatic operation. The operator controlled network is often termed semi-automatic. Complete S.T.D. working will not dispense with manual operation because manual assistance centres are associated with S.T.D., and until complete changeover is made these centres will perform some switching for semi-automatic circuits.

The function of the line transmission equipment in the trunk network is to provide trunk circuits which meet specified speech requirements and also allow the accurate transmission of signalling information. The main consideration between telephone exchange equipment and line transmission equipment is the switching and signalling equipment.

A number of trunk circuits can be used for any trunk call and details of allowable trunk circuit losses and definitions of trunk switching terms are included in the paper "Requirements for Trunk Circuits".

6.2 Trunk Line Switching. Trunk switching is performed by operators at manual switchboards, by step-by-step auto equipment under the control of an operator, and by common control crossbar equipment under the control of an operator or a subscriber.

Trunk line switching can be subdivided into the following categories:

(i) Two-wire switching.
(ii) Four-wire switching (Tail-eating).
(iii) Four-wire switching (Dem. Out - Mod. In).

6.3 Two-wire Switching. At step-by-step automatic and manual switchboard exchanges, subscribers circuits are switched to trunk circuits on a two-wire basis. Fig. 40 shows the main elements of the switching arrangements. The hybrids, and level adjusting pads which are included to ensure that the losses between the exchange reference points and the channel modems give the required levels, are situated with the long line equipment.

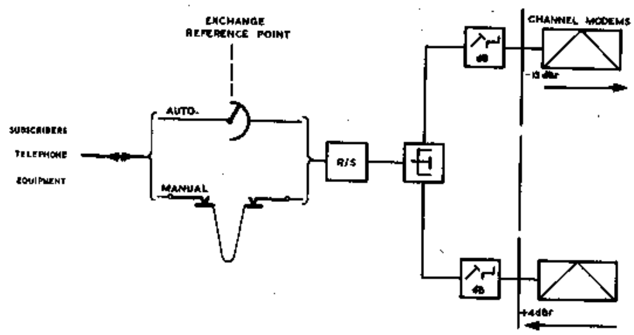


FIG. 40. SIMPLE TWO-WIRE SWITCHING AT TERMINAL EXCHANGE.

At ARM exchanges the hybrids and level adjusting pads are situated with the switching equipment. Details of subscriber to trunk switching for crossbar trunk exchanges are given in para. 6.5.

Some trunk circuits are interconnected on a two-wire basis, although from a transmission viewpoint this is not always desirable because of the possibility of circuit instability. Fig. 41 shows simply the two-wire interconnection of trunk circuits. Switching is made either manually (switchboards) or automatically (step-by-step), and level adjusting pads are included in the four-wire circuits to ensure that the losses between the exchange reference points and the channel modems give the correct levels.

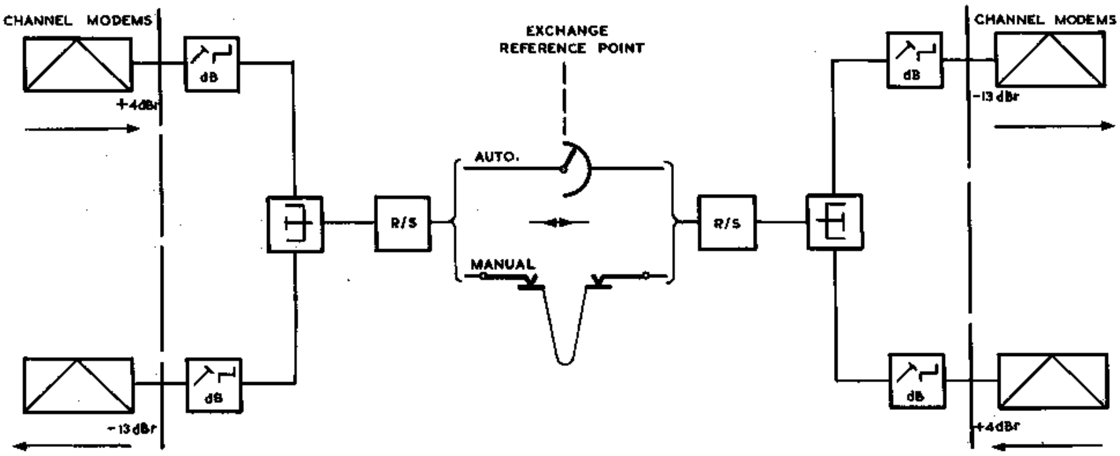


FIG. 41. SIMPLE TWO-WIRE TRUNK SWITCHING ARRANGEMENTS.

6.4 Four-wire Switching (Tail-eating). To avoid the possibility of circuit instability, four-wire switching is used in preference to two-wire switching. A number of sleeve control trunk switchboards are designed for four-wire, tail-eating switching but because of operating problems this facility is rarely used. At step-by-step automatic switching centres the tail-eating method is sometimes used and a simple interconnection arrangement is shown in Fig. 42. Level adjusting pads are included in the four-wire circuits to ensure that the losses between the exchange reference points and the channel modems give the correct levels. A tail-eating connection effectively removes the hybrid losses from the overall circuit and for this reason 3dB pads are added in the line and network connections of each trunk circuit. These pads introduce a total loss of 6dB to the overall circuit and so re-establish the required circuit loss figure.

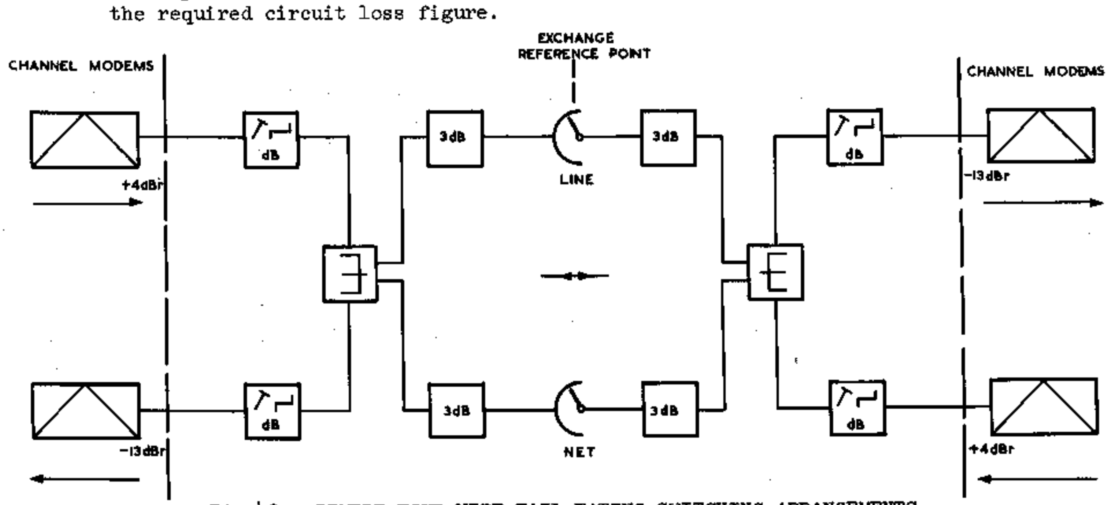


FIG. 42. SIMPLE FOUR-WIRE TAIL-EATING SWITCHING ARRANGEMENTS.

6.5 Four-wire Switching (Dem. Out - Mod. In). At crossbar trunk exchanges through connection of trunk circuits is made on a true four-wire basis; that is, a connection is made from Dem. Out of one channel to Mod. In of the other channel for both directions of transmission. Fig. 43 shows the main elements of a four-wire connection at a crossbar exchange. Preset variable pads are included in the four-wire circuits to ensure that the losses between the exchange reference points and the channel modems give the correct levels. An additional 8dB pad is required in the connection to the channel modulators to obtain the required level of -13dBr. This 8dB pad is switched out of the circuit when connecting to a trunk circuit which is not amplified.

At crossbar exchanges the hybrid coils associated with the trunk circuits are situated in relay sets in the crossbar exchange.

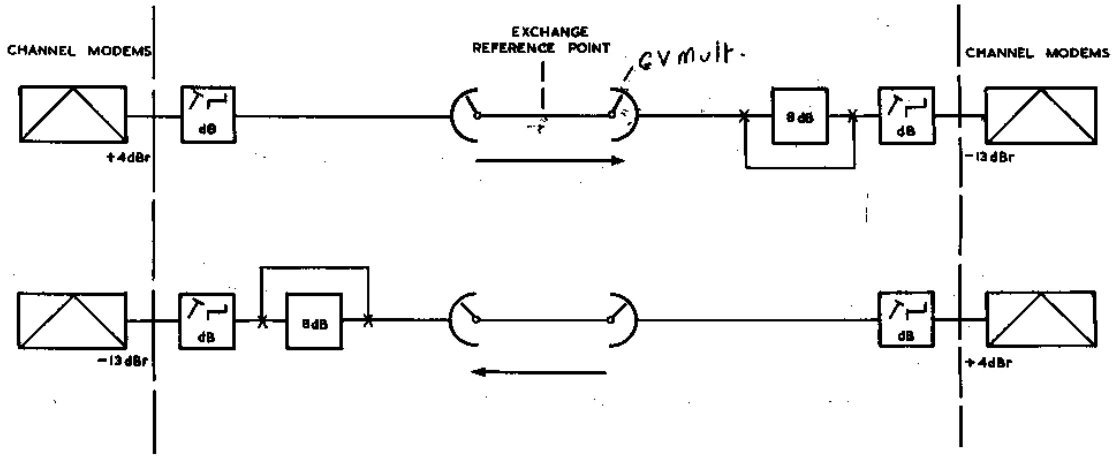


FIG. 43. SIMPLE FOUR-WIRE TRUNK SWITCHING ARRANGEMENT (CROSSBAR EXCHANGE).

At crossbar trunk exchanges switching from subscribers to trunk circuits is also made on a four-wire basis. The junctions from the local exchange network terminate on relay sets in the trunk exchange. Each relay set includes a hybrid and level adjusting pads and is switched, as shown in Fig. 44, to a trunk circuit on a four-wire basis.

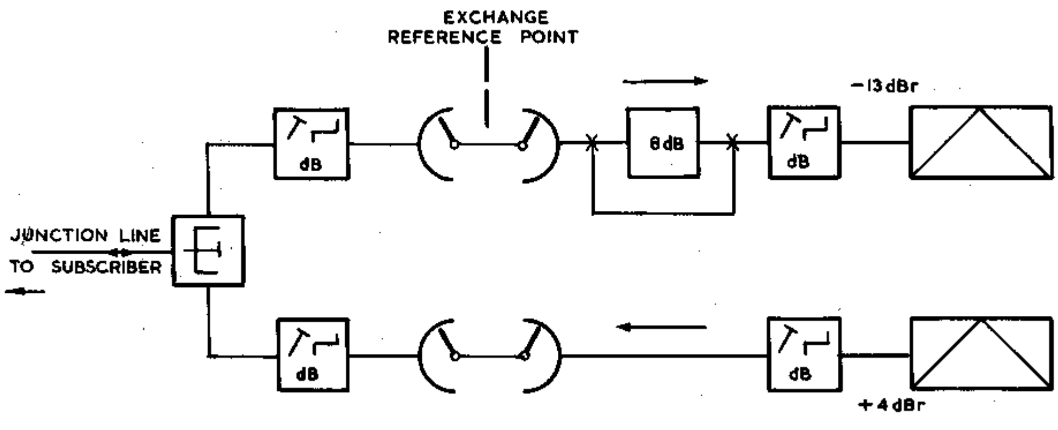


FIG. 44. SIMPLE FOUR-WIRE SWITCHING - SUBSCRIBER TO TRUNK.

6.6 Trunk Line Signalling. A number of signalling systems are used in the trunk network. Some of these are suitable for the S.T.D. and the semi-automatic network but others are suitable for the semi-automatic network only.

It is not possible to use conventional signalling systems (17Hz and D.C. loop) with the majority of trunk circuits, which provide a voice frequency range of about 300 - 3,400Hz. For this reason these conventional signalling systems are associated with either "in-band" or "out-of-band" systems to provide trunk line signalling. The in-band systems are those in which the signalling information is transmitted as a frequency or frequencies in the trunk circuit frequency range. The out-of-band systems are those in which a separate signalling channel is associated with the trunk circuit. In most out-of-band systems a signalling frequency beyond the speech range but within the channel frequency allocation is used; this is known as inbuilt out-of-band signalling.

Table 8 shows the signalling systems used in the trunk network and indicates the types of trunk circuit with which they are associated.

SIGNALLING SYSTEM	MAIN FEATURES	TRUNK CIRCUIT ON WHICH USED.
D.C.	Loop-disconnect and current unbalance.	Physical lines.
17Hz	Standard ringing.	Physical lines.
Out-of-Band	Generally 3825Hz - Suitable for dialling and pulse signalling.	Standard carrier circuits.
Carrier and 83Hz.	Suitable for dialling and pulse signalling.	Rural carrier circuits.
1VF	Generally 2,280Hz. Suitable for dialling and pulse signalling.	Carrier circuits not using out-of-band signalling.
2VF	750Hz and 600Hz. Suitable for calling and dialling.	Physical lines and carrier circuits not using out-of-band signalling.
1000Hz ringing.	Suitable for ringdown operation.	Carrier circuits not using out-of-band signalling and V.F. repeatered circuits.
M.F.C.	(540),660,780,900,1020,1140, 1380,1500,1600,1740,1860, 1980Hz. Used for end-to-end signalling on trunk circuits terminating at common control crossbar exchange.	All trunk circuits.

TABLE 8. SIGNALLING SYSTEMS IN THE TRUNK NETWORK.

The signals transmitted during the establishment, progress and at the completion of a call can be divided into:-

(i) Line Signals. These signals can be termed "Supervisory" signals; they indicate the progress of a call and initiate seizure and release, etc. The line signalling code in the S.T.D. network is composed of two signal elements, one short and one long, with nominal lengths of 150mS and 600mS respectively.

(ii) Information Signals. These signals provide the routing information for a call. The information is established initially as dialled pulses or key sender pulses. With common control crossbar equipment, an end-to-end signalling system is used, and the transfer of information through the network is made by means of M.F.C. signalling. Standard decadic pulsing is used on routes to and from step-by-step equipment.

7. TELEGRAPH EQUIPMENT.

7.1 The general function of the telegraph section is to provide and maintain the equipment used for transferring written, rather than verbal information, from one point to another. The "written" information can be transmitted and received by many different types of machines and equipment ranging from telegraph page printing machines to data and facsimile equipment. On all long distance telegraph connections within Australia the bearer is provided by the line transmission section.

7.2 Telegraph Offices have been established to handle the telegraph traffic of the Public Telegraph Service of Australia. The size of the office depends on the volume of traffic; small telegraph offices have links to larger telegraph offices and these in turn have links to the Chief Telegraph Office (C.T.O.) within the State concerned. The larger telegraph offices are equipped with telegraph machines and connection to the minor telegraph office is made by telephone. The main features of the Public Telegraph Service are shown in Fig. 45.

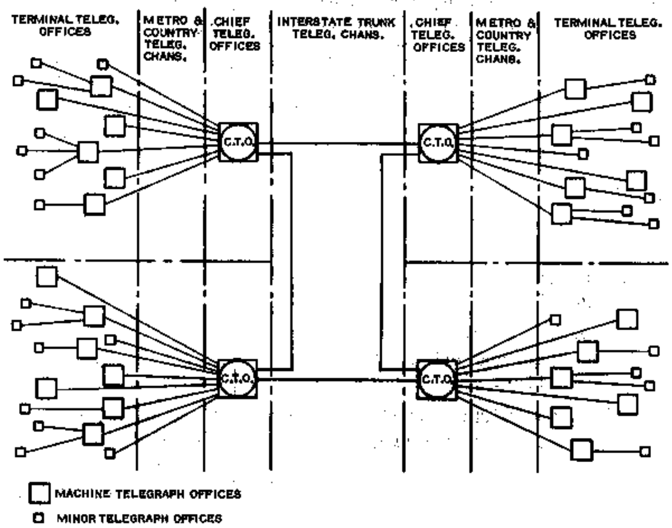


FIG. 45. LAYOUT OF PUBLIC TELEGRAPH SERVICE.

7.3 Telegraph Channels. Many telegraph channels are provided by Voice Frequency Telegraph Systems. These systems may use either amplitude modulation (A.M.) or frequency modulation (F.M.) and operate with a voice frequency channel as a bearer. In practice 6, 9, 18 or 24 telegraph channels are provided per system; the number of channels that can be provided depends on the frequency bandwidth allotted to each telegraph channel and the frequency bandwidth of the voice frequency. Most V.F. telegraph systems have carrier frequency spacings of 120Hz which allows a channel bandwidth suitable for 50 or 75 baud working. In some cases carrier frequency spacings of 240Hz are used and this allows for telegraph working to a speed of 75 or 100 bauds. Table 9 shows the main V.F. telegraph systems in common use and indicates the number of channels provided, the bandwidth of the bearer and the approximate maximum speed of telegraph working for each channel.

TYPE OF TELEGRAPH SYSTEM	FREQUENCY BAND OF BEARER	NOMINAL SPEED OF TELEGRAPH WORKING
9 CHANNEL (A.M.)	300Hz - 2.6kHz	75 bauds
18 CHANNEL (A.M. and F.M.)	300Hz - 2.6kHz	50 bauds
24 CHANNEL (A.M. and F.M.)	300Hz - 3.4kHz	50 bauds

TABLE 9. TYPICAL V.F.T. SYSTEMS.

7.4 Connection to V.F.T. Bearers. From Table 9 it can be seen that voice frequency circuits are suitable as telegraph system bearers. At same stations the V.F. telegraph systems are situated with the line transmission equipment and the telegraph channels are connected to the V.F.T. system via the telegraph office as shown in Fig. 46. The main function of the telegraph repeating equipment is to convert the single current output of telegraph machines to double current working suitable for application to the V.F.T. systems. At small stations the repeating equipment may be situated with the line transmission equipment.

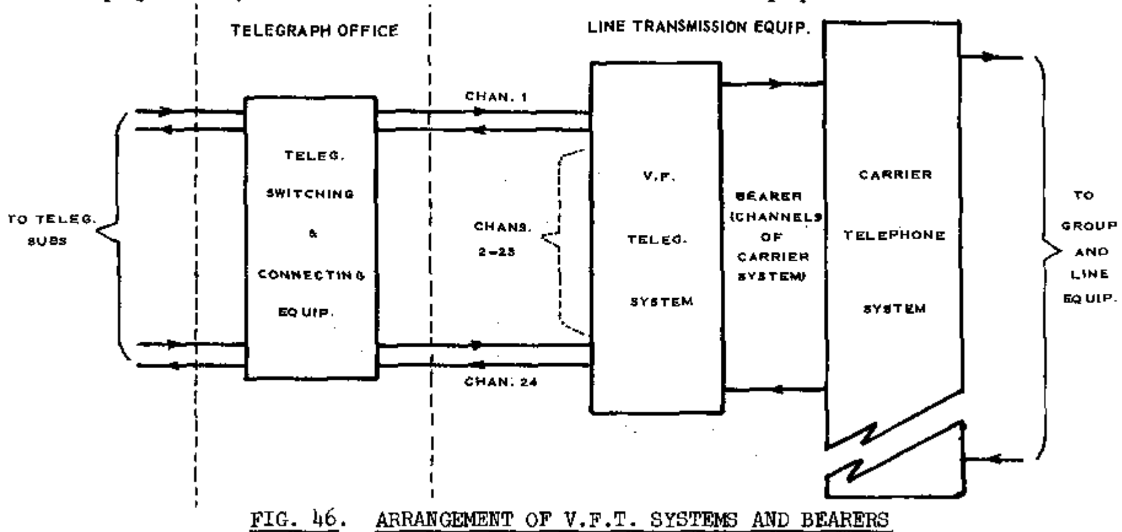


FIG. 46. ARRANGEMENT OF V.F.T. SYSTEMS AND BEARERS (V.F.T. WITH LINE TRANSMISSION EQUIPMENT).

At some stations the V.F. telegraph systems are situated at the telegraph office as shown in Fig. 47. Only the V.F.T. system bearer is extended to the line transmission equipment station.

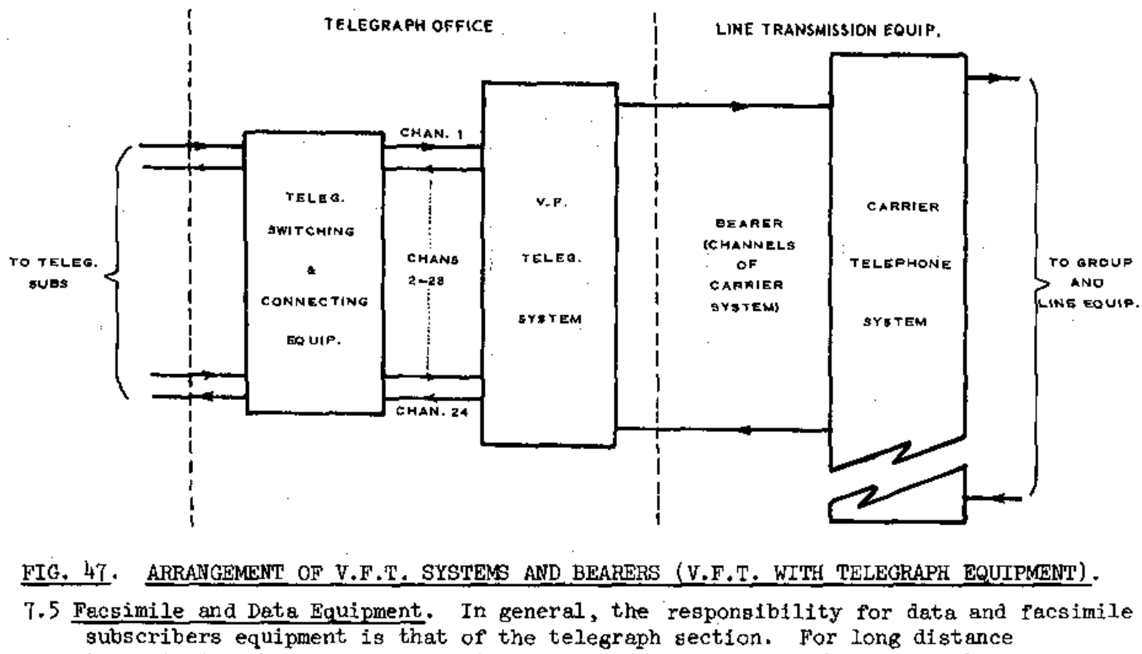


FIG. 47. ARRANGEMENT OF V.F.T. SYSTEMS AND BEARERS (V.F.T. WITH TELEGRAPH EQUIPMENT).

7.5 Facsimile and Data Equipment. In general, the responsibility for data and facsimile subscribers equipment is that of the telegraph section. For long distance transmission the bearers for this equipment are telegraph channels, telephone channels and groups or supergroups. The equipment is normally connected to the bearer via the telegraph office, and where a telegraph channel is used as a bearer the connection is made in a similar manner to that for a telegraph machine.

8. T.V., RADIO AND BROADCASTING EQUIPMENT.

8.1 Radio services provided by the Department are in three main categories:-

(i) National and Overseas Broadcasting Service.

(ii) Radio Telegraph and Telephone Service.

(iii) National Television Service.

The line transmission equipment section is involved in some way with the provision of each of these services.

8.2 National and Overseas Broadcasting Service. The programme channels used to relay audio programme throughout Australia are provided and maintained by the line transmission equipment section. Fig. 48 shows the functions of line transmission equipment in audio programme transmission from local studios. In the station a programme room or programme rack contains the equipment necessary to switch, amplify, test and monitor programme incoming and outgoing from the station. The incoming and outgoing interstate and intrastate programme channels are either physical lines (50Hz - 5kHz) or carrier programme channels (50Hz - 7kHz or 50Hz - 10kHz). Programme channels are divided into permanent and temporary types. Permanent channels are used only for programme transmission temporary channels are normally used for telephone traffic but when required are removed from service and used for programme transmission.

Outside broadcast lines (O.B. lines) are brought to the programme room or to the switch rooms; in general, the permanent O.B. lines are taken to the switchroom and temporary O.B. lines to the programme room.

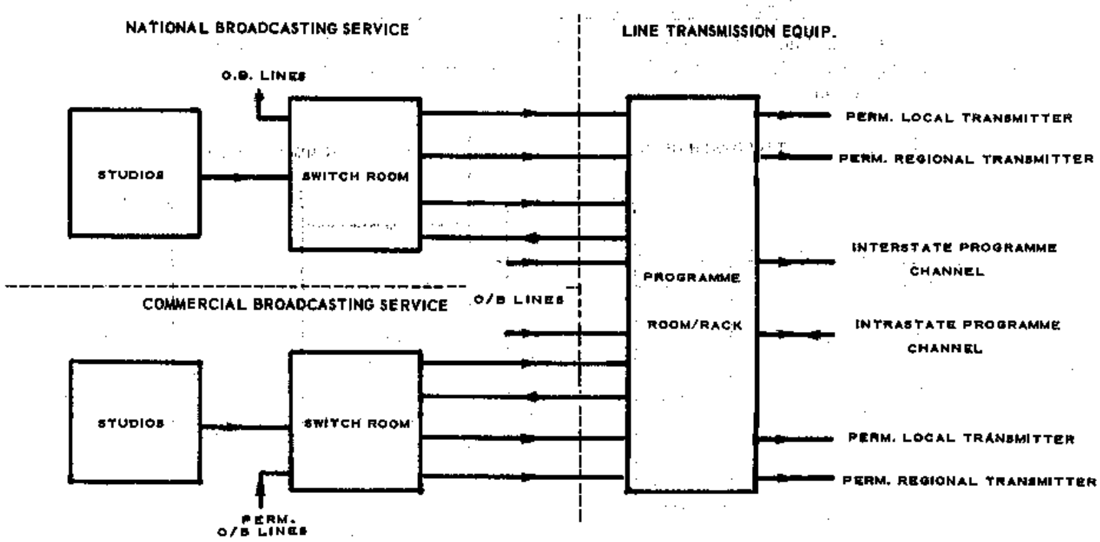


FIG. 48. PROGRAMME FACILITIES AT LINE TRANSMISSION EQUIPMENT STATION.

At programme stations without local studios, programme equipment is carried on a programme rack. This equipment may cater for amplifying, equalising, monitoring, testing, splitting and/or switching of the audio programme.

8.3 Radiotelegraph and Radiotelephone Services. Trunk telegraph and trunk telephone circuits derived on radio bearers are connected into the general telegraph and telephone network. The use of the frequency spectrum for radiotelephone provision is shown in Table 1. The majority of radiotelephone services are in the microwave range and these services are shown in Fig. 3. Radiotelegraph communications are sometimes provided by the frequency shift keying (F.S.K.) method. The principle of operation is to radiate two separate radio frequencies; one for mark condition and one for space condition. This type of system is used to provide an emergency radiotelegraph service between Melbourne and Perth and Brisbane and Townsville.

In general, the installation of radiotelephone systems is a function of the radio section. Terminal and repeater equipment situated in the main metropolitan areas is also maintained by the radio section but terminal and repeater equipment in country areas is maintained by the line transmission section.

8.4 Australian Television Service. Fig. 49 shows the main features of typical National and Commercial television services at a main metropolitan centre. From the studios, video and audio links are taken direct to the local transmitters. When the studios and transmitters are located together, the video connections are made with coaxial tubes and the audio connections with equalised cable pairs (interstice pairs of the coaxial cable). When the studios and transmitters are remote from each other the video and audio links are made with separate microwave radio systems. Outside broadcasting (O.B.) links to the studios are also normally made with microwave radio systems although cable pairs may be used for the audio links.

The video connections to and from the studios and the Television Operating Centre (T.O.C.) are normally made with coaxial video (C.V.) systems which transmit the video signal direct on the coaxial cable tubes. Repeaters are required at about 3 mile intervals over the routes. The audio connections are made with equalised interstice pairs of the coaxial cables.

The majority of T.V. links to national regional transmitters and to other T.O.Cs. are made with microwave radio systems. The video links to and from the T.O.C. and the local radiotelephone terminal are made with C.V. systems and the audio links with equalised interstice pairs.

Coaxial video systems are only suitable for operation over short distance (up to about 12 miles). Video transmission on coaxial tubes over long distances is achieved by the use of a vestigial sideband (V.S.B.) system. In these systems the video signal is shifted, by two stages of modulation, from 25Hz - 5MHz to 556kHz-6.05MHz and then transmitted on the coaxial tube. At the distant terminal the received frequencies are converted back to the normal video range. A limited number of these systems are in use.

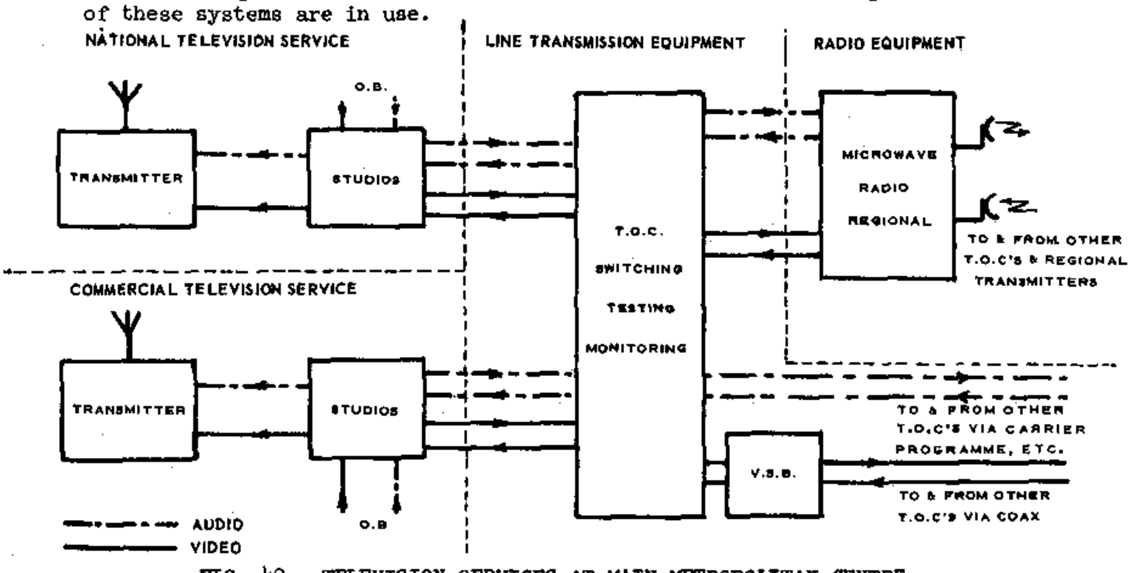


FIG. 49. TELEVISION SERVICES AT MAIN METROPOLITAN CENTRE.

9. LINE TRANSMISSION EQUIPMENT.

9.1 In Section 4 the relationship of line transmission equipment to the other major equipment areas is described. A summary is also made of the equipment in the line transmission area. It is convenient to divide the information on line transmission equipment, and its principles into four sections:-

(i) Basic Principles. In this section, line transmission (long line) equipment is defined, and the principles of transmission lines and equipment components are given.

(ii) Miscellaneous V.F. and Carrier Equipment, which includes carrier telephone, carrier telegraph (A.M. and F.M.), carrier programme, voice frequency repeaters, and signalling equipment. (Twelve circuit and broadband equipment is not included).

(iii) Twelve Circuit and Broadband Equipment. This section includes the channelling, group, supergroup and mastergroup equipment for twelve circuit and broadband systems. The coaxial line and microwave radio equipment used as bearers for broadband telephony and television systems are also described.

(iv) Installation and Maintenance Procedures. In this section the measuring, testing and recording procedures associated with equipment maintenance are included. The general principles of installation are also given.

These main categories are shown in Fig. 50, and each is further subdivided. The course papers and notes for line transmission equipment are presented in a similar manner to the breakdown shown in Fig. 50 and are listed in the Engineering Instruction GENERAL Publications C 0100.

9.2 The basic principles of line transmission equipment are described in the papers "Introduction to Line Transmission" and "Equipment Principles - Line Transmission". These papers introduce voice frequency, carrier telephone, carrier telegraph and carrier programme equipment. Equipment details and frequency allocations and modulation plan information are included in other papers.

9.3 Carrier telephone systems with circuit capacities ranging from one circuit to 1200 circuits are in use in the communication network. The majority of these systems employ frequency division multiplexing (F.D.M.), but at the time of writing, time division multiplexing (T.D.M.) systems are being introduced for short haul telephone circuit provision. T.D.M. systems employ pulse code modulation and provide 24 circuits per system.

Most F.D.M. systems in use in the communication network use single sideband suppressed carrier operation but Rural Carrier Systems, which are used for trunk circuit provision, use double sideband, controlled carrier operation. These systems provide up to 10 circuits per system.

Although the circuit details and line frequencies for the various F.D.M. systems differ, a number of common factors exist. These are:-

(i) Standardisation of frequencies.

(ii) Level regulation.

(iii) Crosstalk and noise reduction methods.

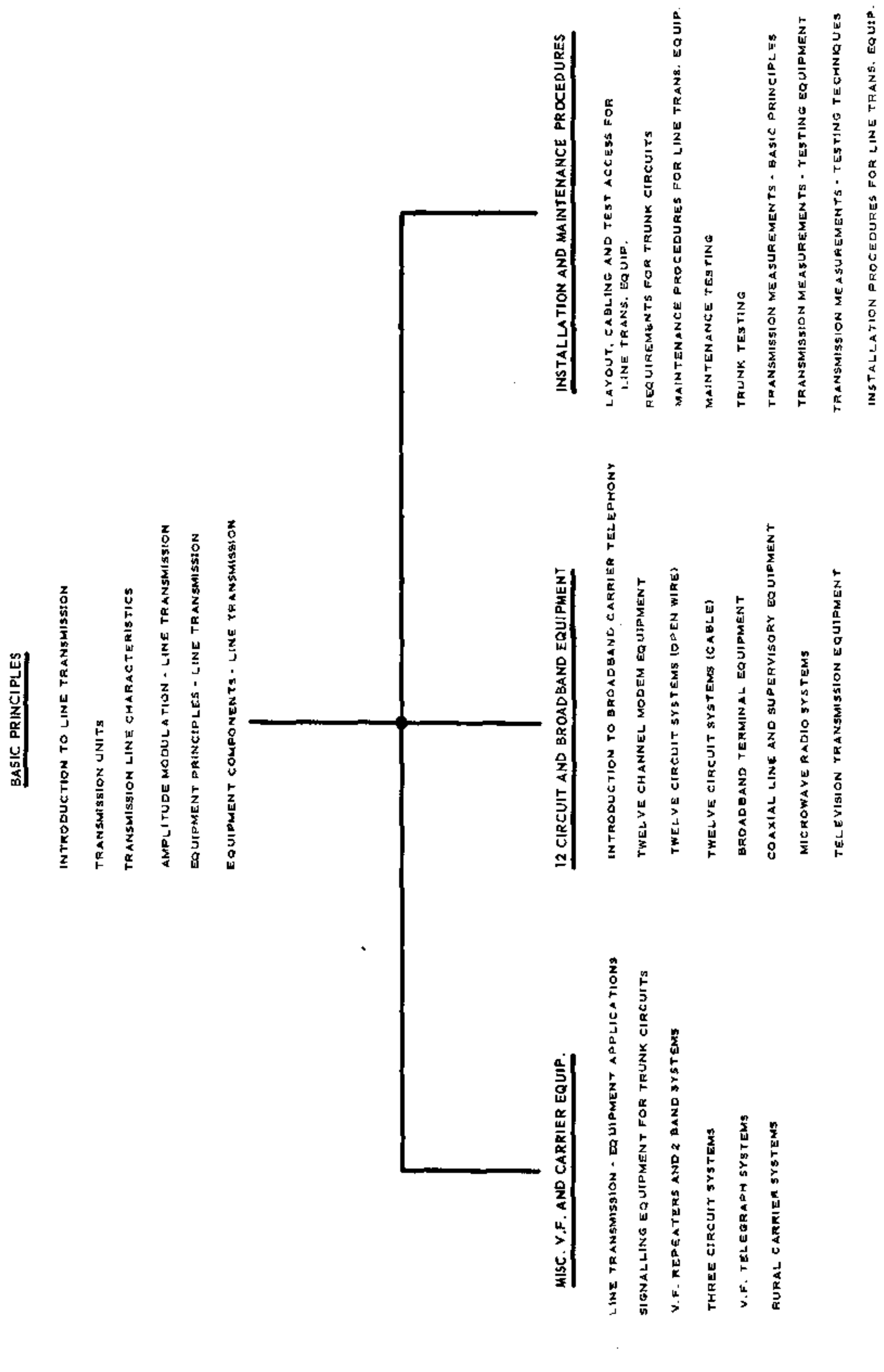


FIG. 47. OUTLINE OF LINE TRANSMISSION EQUIPMENT.

9.4 Standardisation of Frequencies. In F.D.M. carrier systems the channels are stacked one above the other in the frequency spectrum and transmitted to line in a frequency range to suit the particular transmission medium. The translation from voice frequencies to the line frequency range can be made in one translation stage, and for some low capacity systems (some three circuit and twelve circuit systems) this is done. However, multistage translation from voice frequencies to line frequencies offers many advantages over a single translation stage, and is employed by all broadband and many low capacity systems.

The voice frequency band of a standard carrier telephone channel is 3,100Hz from 300Hz to 3,400Hz. A frequency separation of 4kHz exists between adjacent carrier frequencies. This leaves a band of 300Hz below the speech band and 600Hz above the speech band and in the latter space a signalling channel with a mid-frequency of 3,825Hz is provided.

The first modulation stage requires a band pass filter in its output with characteristics sufficient to select the required channel band but reject all unwanted frequencies. Filters consisting of inductors and capacitors can be economically designed to meet these demands in the frequency range up to about 30kHz, but beyond this range and up to about 108kHz, crystal filters are used to meet the requirements. In systems employing multistage translation from voice frequencies to line frequencies, it is common for the first stage of modulation (channel modulation) to be made in the frequency range below about 30kHz and the line frequency range is achieved by one or more subsequent stage or stages of modulation. This introduces an economy of manufacture because more units of the same type are produced, but the greatest advantage lies in the flexibility gained by assembling the channels in standard blocks of 12, 60, 300 and 900.

The frequencies and input and output levels of these standard channel blocks are standardised to allow simple interconnection from one system to another. In addition, the various blocks of channels can be used to provide circuits between terminals and intermediate stations, and between one intermediate station and another, on a broadband route. Interconnection is made at distributing frames which are designated according to their function. For example, interconnection of groups is made at the Group Distribution Frame (G.D.F.).

The standards for typical channels and channel blocks are shown in Fig. 51 and are summarised as follows:-

(i) Channels which conform to an international standard have a frequency band of 3,100Hz, from 300Hz to 3,400Hz, and a carrier frequency separation of 4kHz between adjacent carriers. An inbuilt out-of-band signalling facility using a frequency of 3,825Hz is normally provided. Most three circuit systems do not conform to this standard and provide a more restricted channel bandwidth. For example, with carrier frequencies spaced at 3.6kHz, a channel band of 2,700Hz, from 300Hz to 3,000Hz, is obtained and the inbuilt out-of-band signalling facility is provided at 3,425Hz.

(ii) Blocks of 12 channels in the frequency range 60-108kHz constitute basic groups and facilitate interconnection with similar basic groups from other systems. The 60-108kHz range can be produced by one or two stages of modulation; Fig. 51 shows two stages (4 x 3). Additional information is given in the paper "Twelve Channel Modem Equipment".

(iii) Blocks of 60 channels in the frequency range 312-552kHz constitute basic supergroups and facilitate interconnection with similar basic supergroups from other systems. Additional information is given in the paper "Broadband Terminal Equipment".

(iv) Blocks of 300 channels in the frequency range 812-2,044kHz constitute basic mastergroups and facilitate interconnection with similar basic mastergroups from other systems. Additional information is given in the paper "Broadband Terminal Equipment".

(v) Blocks of 900 channels in the frequency range 8,516-12,388kHz constitute basic supermastergroups and facilitate interconnection with similar basic supermastergroups from other systems. At the time of writing supermastergroups are not in use in the Australian communication network.

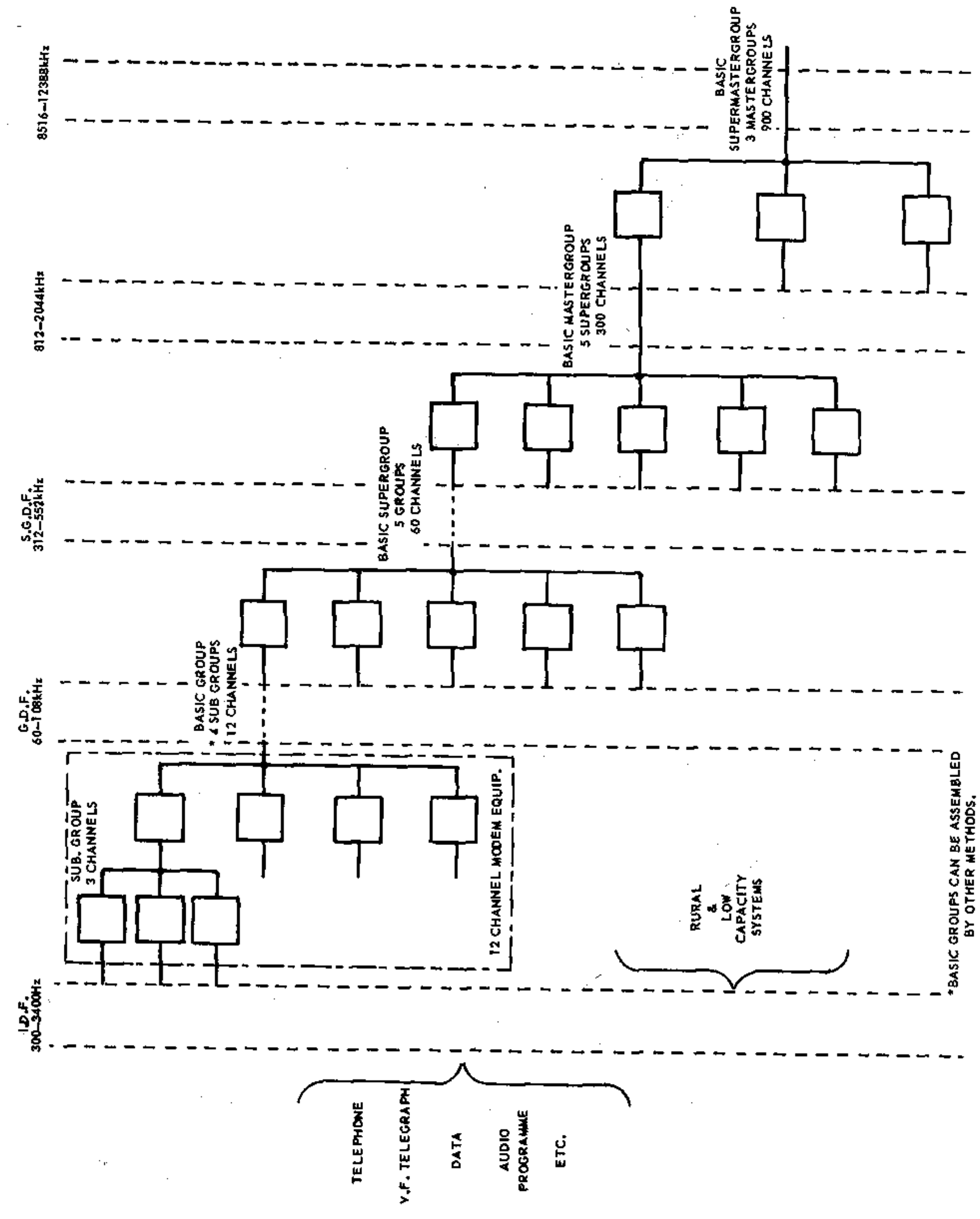


FIG. 51. STANDARDS FOR TYPICAL CHANNELS AND BLOCKS OF CHANNELS.

9.5 Level Regulation. To ensure satisfactory transmission performance on telephone circuits, it is necessary to keep level variations to a minimum. Short term level variations are normally caused by fault conditions, but long term level variations can be caused by a number of factors. These are:

- The effects of changing weather conditions on open wire lines.
- The effects of changing temperature on underground cable pairs and coaxial tubes.
- The effects of changing temperature on, and ageing of, equipment components.

Variations in level should not be such that the input level to repeater or receive terminal equipment is too low, allowing an unsatisfactory signal to noise ratio, or too high, causing non-linear distortion. When sudden or marked changes in level occur it is desirable that an alarm to indicate a possible fault condition should be given.

Level regulation of carrier telephone systems is achieved by using a pilot regulation system. Two types of pilot regulation are used; manual regulation which provides an indication of received level, and automatic regulation which provides an indication of the received level plus automatic adjustment of the level, provided the deviation from normal is not beyond prescribed limits. The reasons for the use of a pilot regulation system are:

- To maintain correct levels over a long period of time.
- To reduce the time out of traffic for maintenance purposes.
- To give an alarm when the degree of level variation indicates a possible fault condition.

Pilot regulation can be applied to:

- Line Equipment. Line regulation compensates for changes in line and line equipment characteristics which may effect all the channels of a system.
- Group and Supergroup Equipment. Group and supergroup regulation compensates for changes in level which may occur in a particular block of channels. Group and supergroup regulation are not applied to all broadband systems, and, in general, are not used jointly. That is, when supergroup pilot regulation is used, the associated groups are not regulated. Group and supergroup regulation are generally not used on the shorter broadband systems.

The principle of pilot regulation is to inject a pilot frequency at the input of the line and/or equipment to be regulated. This pilot frequency is low in level compared to the normal signal. In the receiving direction, at each repeater, and at the receive terminal, a pilot pick-off filter is bridged across the output of the line and/or equipment to be regulated. The pilot frequency is applied to a pilot indicator which is calibrated in dB and gives an indication of the degree of level variation from normal.

Where manual regulation is used, the indicator is followed by an alarm which, at a receive terminal, causes a visual and audible alarm when the level variation is beyond predetermined limits. At repeater stations with manual control, an audible alarm is not normally incorporated, and adjustments of level are only made at these stations under direction from the control station.

When automatic regulation is used, the pilot indicator is incorporated in a control circuit which controls the flat gain and/or slope gain amplifiers to maintain correct levels at all times. When the variation is beyond predetermined limits a visual and audible alarm is given. Attention is drawn to the regulating circuit and investigations are made to locate the problem. Once again, manual adjustments of level at repeaters are made only under direction from the control station.

9.6 A simple automatic pilot regulating circuit is shown in Fig. 52. In this example, line and line equipment regulation is obtained. The main items of pilot regulation equipment are the pilot frequency generating equipment and the pilot receiving and regulating equipment. The main requirements and features of the equipment are:-

(i) Pilot Frequency Generating Equipment. The pilot frequency can be supplied by a local oscillator or from a carrier frequency generating rack. The pilot frequency generator should be:-

(a) Stable in output level.

(b) Stable in output frequency.

(c) Applied to the circuit to be regulated in such a manner that loading of that circuit is negligible.

(ii) Pilot Frequency. Pilot frequencies chosen for regulation systems should give suitable regulation for the normal signal frequencies. To do this the pilot frequency should:-

(a) Be near the middle of the transmitted range when only one pilot is used and at the extremities of, or spaced through the frequency range, when more than one pilot frequency is used.

(b) Not interfere with speech or signalling channels derived in the transmitted frequency range.

(c) Be injected at a much lower level than the normal signal level.

(iii) Pilot Receiving and Regulating Equipment. The pilot receiving equipment, (pilot receiver) is often inbuilt in the receive circuit of the system but can be situated on a special regulating equipment rack. The pilot receive equipment must:-

(a) Be stable in gain and tuning.

(b) Give control for small changes in received level.

(c) Bring in an alarm for large changes in received level.

(d) Be applied to the circuit to be regulated in such a manner that loading of that circuit is negligible.

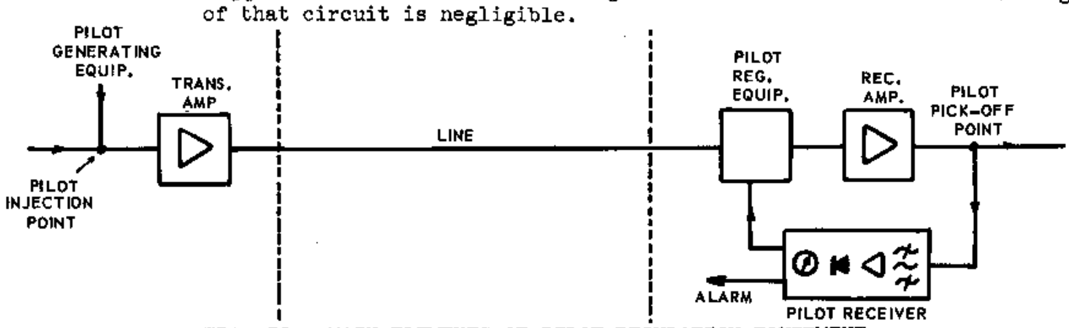


FIG. 52. MAIN ELEMENTS OF PILOT REGULATION EQUIPMENT.

Fig. 52 shows that the main function of the pilot regulating equipment is to monitor the incoming pilot frequency level and automatically adjust the amplifier gain to maintain a reasonably constant output. A regulating device which, under the control of pilot receiver, affects the gain of all the transmitted frequencies by the same amount is called a 'flat regulator' and the pilot frequency is termed the 'flat pilot'.

The transmission line bearers used by carrier telephone systems produce a loss to all frequencies transmitted. This loss increases with an increase in frequency and, on a graph showing loss versus frequency, appears as a slope. Attenuation equalisers are used to offset this slope, but with changes in temperature and weather conditions the slope can change. Pilot controlled regulating circuits may be provided to correct for this change. These regulators are known as 'slope regulators' and are controlled variable passive equalisers or equalising amplifiers. The controlling pilot frequency is termed the 'slope pilot'.

Fig. 53 shows the regulation available for a typical 12 circuit carrier telephone system. The flat and slope regulators have dial settings from 0-100 to indicate the degree of regulation applied. Two sets of graphs are shown. One set represents the regulator gain, for various settings of the slope regulator, with the flat regulator set at low gain (5). The other set represents the regulator gain, for various settings of the slope regulator, with the flat regulator set at maximum gain (100). It should be noted that the changes in flat regulation affect all frequencies to the same extent. Changes in slope regulation affect the higher frequencies to a greater extent than the lower frequencies. The flat and slope regulators jointly provide the required gain to maintain an overall flat frequency response and the correct level, for various line attenuation conditions.

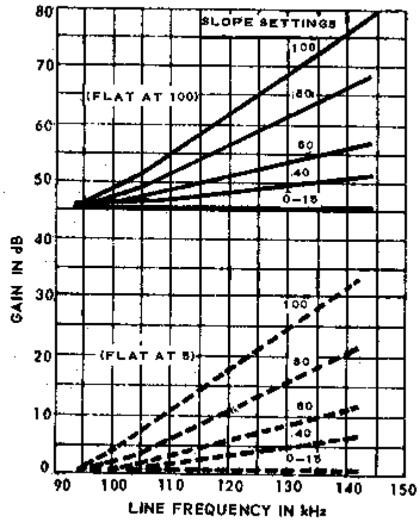
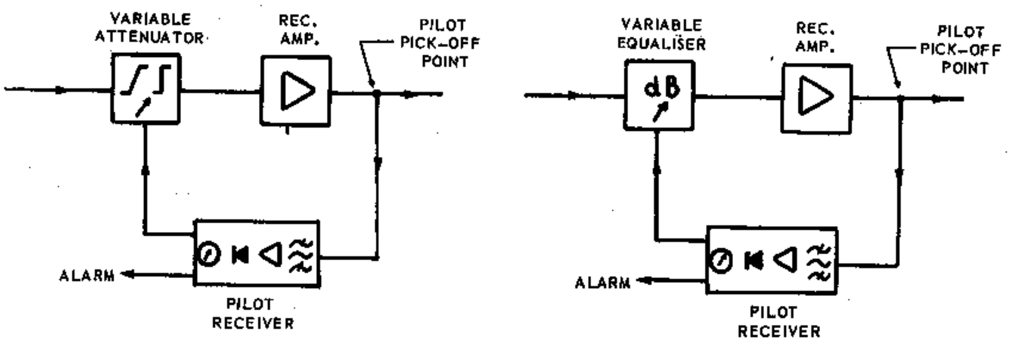


FIG. 53. FLAT AND SLOPE REGULATION.

9.7 Pilot Regulators. Details of pilot regulation equipment are given in the appropriate equipment papers. Figs. 54 and 55 show the principles only of typical regulator circuits. Flat and slope regulator circuits are shown separately, but both can be used in a practical circuit, and their circuitry is then arranged to prevent undesirable interaction, that is, hunting of the two pilot regulating circuits.

Alarm facilities differ for various regulators but, in general, an alarm is given when the pilot level deviation is beyond predetermined limits, and when a regulating circuit is driven to the end of its regulating range in either direction. The latter is termed an end alarm. The degree of allowable level variation differs with systems but typical values are from about -5dB to +3dB from normal.

Fig. 54(a) shows a flat regulator which consists of a motor driven, variable attenuator under the control of the pilot frequency. A decrease in pilot level causes the motor to drive in a direction to remove attenuation from the circuit; the motor drive ceases when the pilot level is restored to its normal value. An increase in level causes the motor to drive in the reverse direction and increase attenuation until the nominal level is attained. Fig. 54(b) shows a slope regulating circuit in which a motor driven, variable equaliser is under the control of a pilot frequency. A change in pilot level causes the motor to drive in a direction to increase or decrease the equaliser slope to compensate for the indicated line condition. The motor drive ceases when the pilot is restored to its nominal value.

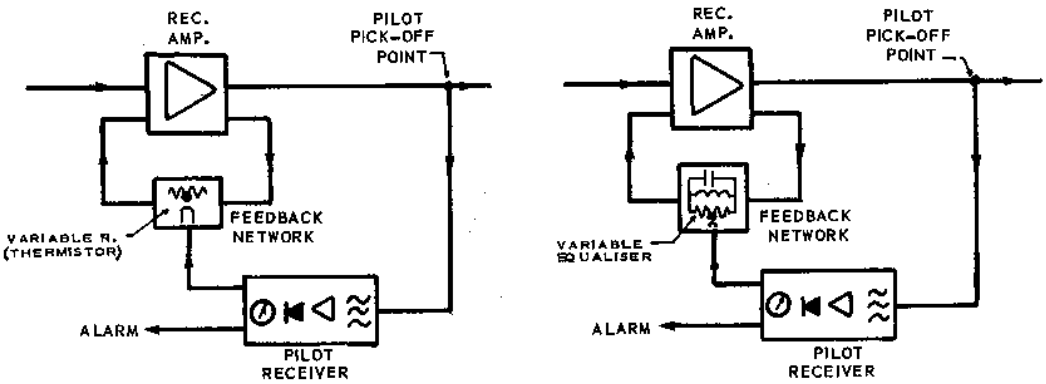


(a) Flat Regulator (Variable Attenuator). (b) Slope Regulator (Variable Equaliser).

FIG. 54. SIMPLE FLAT AND SLOPE REGULATORS.

Fig. 55(a) shows a flat regulator circuit with a variable resistor included in the amplifier feedback circuit. In the example shown, a thermistor is used as the variable resistor; the heater current of the thermistor (and the thermistor resistance) are determined by the pilot frequency level. Deviations of pilot frequency level cause appropriate changes in thermistor resistance to restore the pilot to its nominal value.

Fig. 55(b) shows a slope regulator circuit in which a variable equaliser is included in the amplifier feedback circuit. A thermistor is included in the equaliser network and the heater current of the thermistor is controlled by the pilot frequency level. Deviations of pilot frequency level cause appropriate changes in thermistor resistance to restore the pilot to its nominal value.



(a) Flat Regulator (Feedback Control). (b) Slope Regulator (Feedback Control).

FIG. 55. SIMPLE FLAT AND SLOPE REGULATORS USING THERMISTORS.

Details of the pilot control section of the pilot receivers are not shown in Figs.54 and 55. Typical methods of determining the degree of control required are:

- To compare the rectified pilot frequency with an extremely stable D.C. voltage. The rectified pilot and the stabilised D.C. voltage are equal to each other when correct level conditions exist. Variations of the rectified pilot in either direction from its nominal value cause the regulating action to begin. Relays are associated with the control circuit to introduce alarms for set variations.

- To apply the rectified pilot frequency to recording meters. Two meters are normally used; a control meter and an alarm meter. These meters are similar to contact voltmeters, and any variation beyond a predetermined amount, for example ±.5dB, causes the control meter to apply a drive to the regulator circuit. When the deviation is beyond the predetermined alarm range, for example -5dB to +3dB, the alarm meter completes the alarm circuit and disables the control circuit.

It is important that the level control of the regulator circuit is as uniform as possible to prevent introduction of noise, or sudden changes in level, by the regulating equipment. Because the equipment is involved with all the channels, or a block of channels, of a system, it is also important that interruptions to servic are avoided in the regulating equipment.

9.8 Crosstalk Considerations. Crosstalk reduction methods employed with external plant reduce, but do not eliminate crosstalk. To ensure that overall crosstalk and noise figures are satisfactory, additional features are applied to line transmission equipment. These features are:-

- Poling of Carrier Systems.
- Co-ordination of Transmission Levels.
- Separation of 'Go' and 'Return' Bearers.
- Frequency Frogging.
- Staggering and Inversion of Sidebands.

9.9 Poling of Carrier Systems. In general, carrier systems in use in Australia are installed so that the A-B direction of transmission is anti-clockwise, taking Perth as a starting point. Because of trunk route parallels there are exceptions to the rule. Fig. 56 shows typical poling arrangements. The broad frequency allocations for both directions of transmission for various types of carrier systems are given in Figs. 4, 5 and 6.

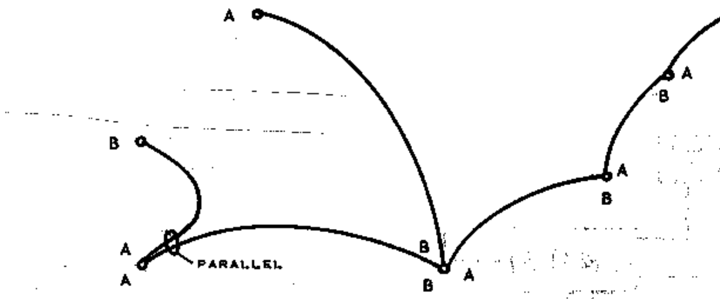


FIG. 56. TYPICAL POLING ARRANGEMENTS.

Poling of carrier systems prevents near-end crosstalk, which generally is greater in amplitude than far-end crosstalk. Fig. 57 shows the principle of near-end crosstalk prevention for typical 12 circuit open wire system operation. It can be seen that any crosstalk of the A-B direction frequencies, from system 1 to system 2, can produce far-end crosstalk, but near-end crosstalk is prevented because the receive filters of system 2 are designed to reject the A-B direction frequencies. Although these frequencies can be received by the transmit filters, they cannot cause interference because they are blocked by the undirectional transmit amplifier. The same reasoning can be applied for transmission from either system in both directions.

The value of far-end crosstalk is largely dependent on the effectiveness of the bearer crosstalk reduction methods, such as transpositions of open wire lines, balancing of cable pairs, etc. Impedance mismatches, which can increase the value of far-end crosstalk because of reflection effects, should be avoided.

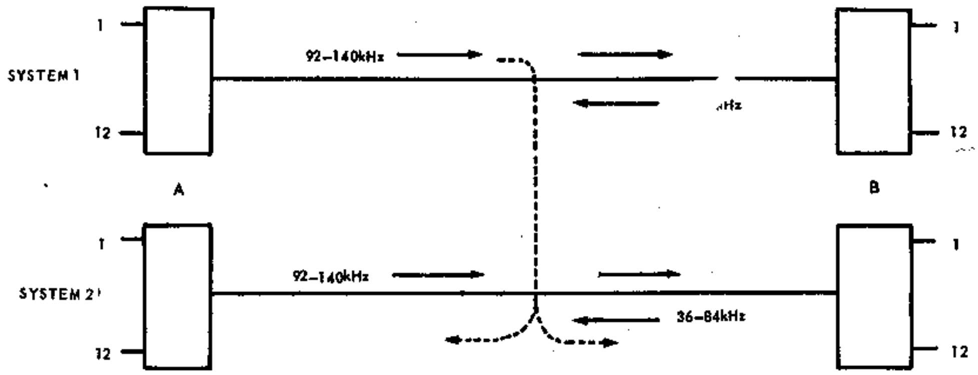


FIG. 57. REDUCTION OF NEAR-END CROSSTALK BY POLING.

9.10 Co-ordination of Transmission Levels. An important factor in the control of crosstalk is the relative levels of two or more circuits operating in the same frequency range on the same route. When a circuit carrying high level currents is close to a circuit carrying low level currents, crosstalk from the high level circuit to the low level circuit has a severe interfering effect. This is illustrated in Fig. 58. At a point in the circuit a crosstalk path of 45dB is assumed between bearers 1 and 2. At this point the transmission levels are assumed to be +17dBm for system 1, and 0dBm for system 2. The signal to crosstalk ratio in system 2 is 28dB which is unsatisfactory. The crosstalk in system 1 (62dB signal to crosstalk ratio) should not cause obvious interference.

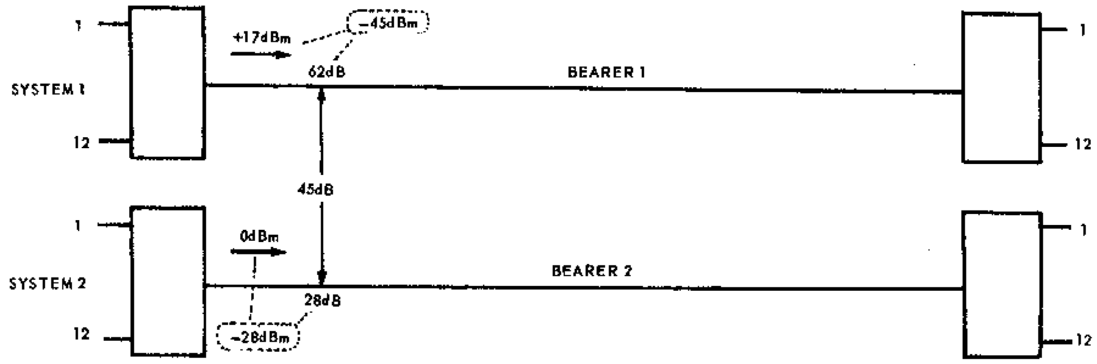


FIG. 58. EFFECT OF HIGH AND LOW LEVELS ON ADJACENT CIRCUITS.

The practical method to reduce the effect of crosstalk between neighbouring circuits is to maintain comparable levels at all points along the circuit. When the signal level in adjacent circuits is the same, the crosstalk to signal ratio is equal to the crosstalk path attenuation. If this figure is satisfactory then the crosstalk to signal ratio is satisfactory for both circuits.

At intermediate stations and junction points transmission levels must be compatible with those of the through route. For example in Fig. 59, an intermediate station B is shown on the route A to C. Similar carrier systems are installed from A-B and A-C. If the nominal maximum line-up level is used for both systems the relative levels at B are such that crosstalk interference from system 1 to system 2 is unsatisfactory. A nominal line-up of +17dBm is assumed and under these conditions the relative levels at B could +5dBm and +17dBm for one direction.

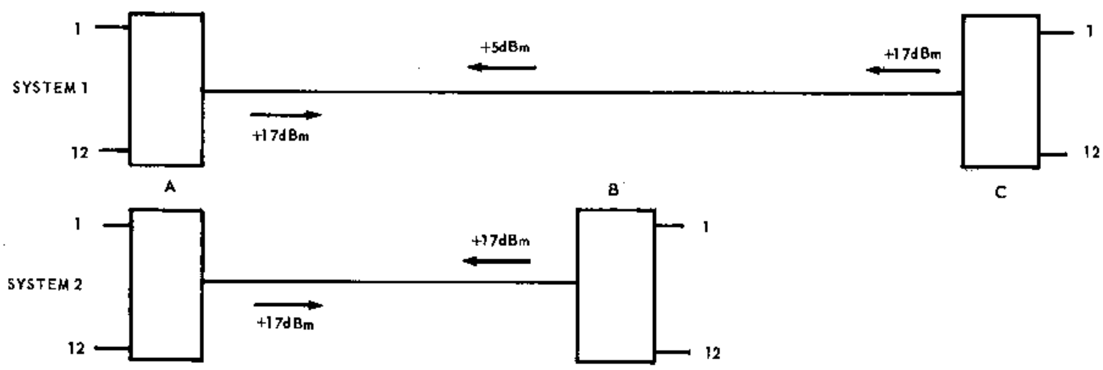


FIG. 59. INCORRECT LEVELS AT INTERMEDIATE STATION.

The problem shown in Fig. 59 can be overcome by either of two methods. The first is illustrated in Fig. 60, where the transmission level for system 2 at B is changed to +5dBm to be comparable with the transmission level of system 1 at this point.

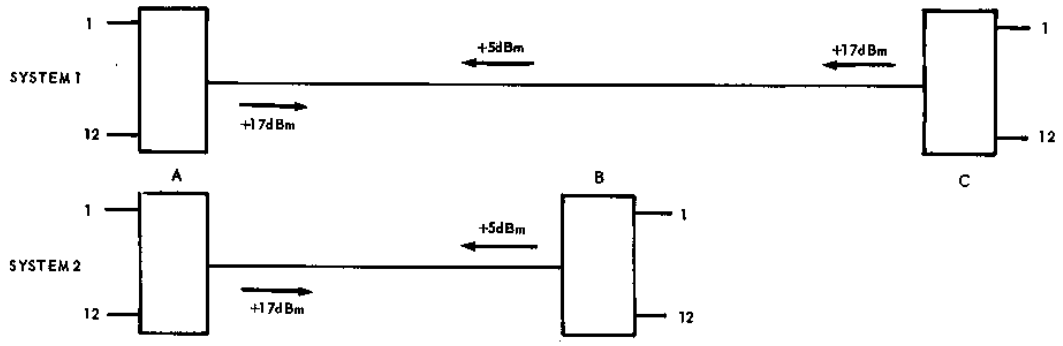


FIG. 60. CORRECT LEVELS AT INTERMEDIATE STATION (WITHOUT REPEATER).

The second method is shown in Fig. 61. A repeater installed on the A-C system at B ensures that all systems at that point transmit comparable levels.

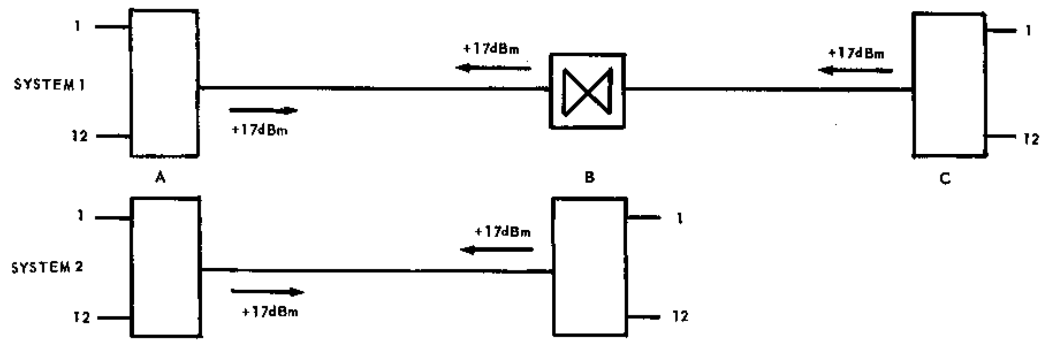


FIG. 61. CORRECT LEVELS AT INTERMEDIATE STATION (WITH REPEATER).

When bearers with different gauge conductors are used, some compromise of transmission levels may be necessary to maintain suitable crosstalk figures for the systems and circuits concerned.

There is a limit to the amount of energy that any circuit can handle without introducing distortion and this is a factor which limits the maximum transmission level of any circuit or system. Crosstalk considerations also determine the maximum transmission levels. Arbitrary nominal maximum levels are specified for all types of systems and circuits.

In line transmission equipment stations, frequency groups at different levels are physically separated by the use of cable ducts or high and low level runways. This is explained in the paper, "Layout, Cabling and Test Access for Line Transmission Equipment".

9.11 Separation of 'Go' and 'Return' Bearers. In pair cable system operation it is common to use separate pairs as bearers for each direction of transmission. When these pairs are in the same cable, different frequency ranges are used for each direction of transmission. The frequency allocation for a typical 12 circuit system is shown in Fig. 62. Crosstalk frequencies are shown with dotted lines. Crosstalk from the A-B bearer to the B-A bearer, or vice versa cannot cause ill effects because it is rejected by the receive filters at the receive terminals, and blocked by the terminal transmit amplifiers or repeater amplifiers. Provided that the cable is satisfactorily balanced, a number of systems can operate on pairs in the one cable. Transmission levels must be co-ordinated for all systems as explained in para. 9.10.

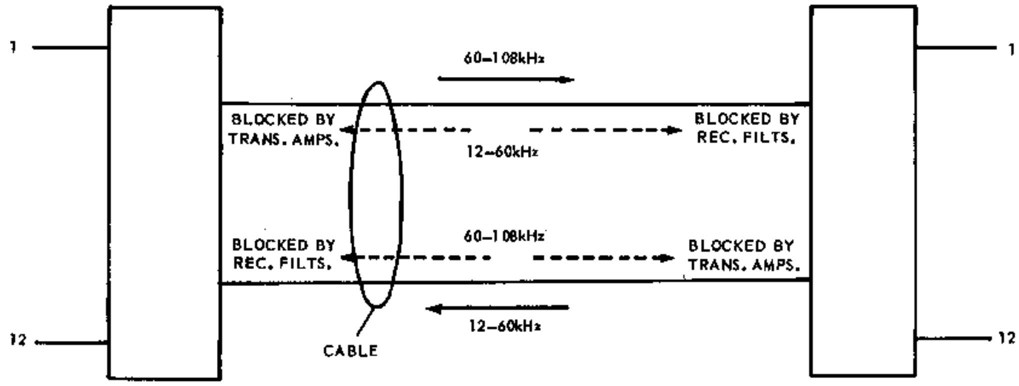


FIG. 62. USE OF SEPARATE PAIRS IN ONE CABLE.

When separate 'go' and 'return' cables are used, the same frequency range can be transmitted for each direction of transmission. This is illustrated in Fig. 63 which shows the frequency and pair arrangements for a typical 12 circuit system. The possibility of crosstalk between the two directions of transmission is prevented by physical separation of the bearers. A number of systems can operate within each cable provided that satisfactory balancing exists and that the transmission levels for all systems are co-ordinated.

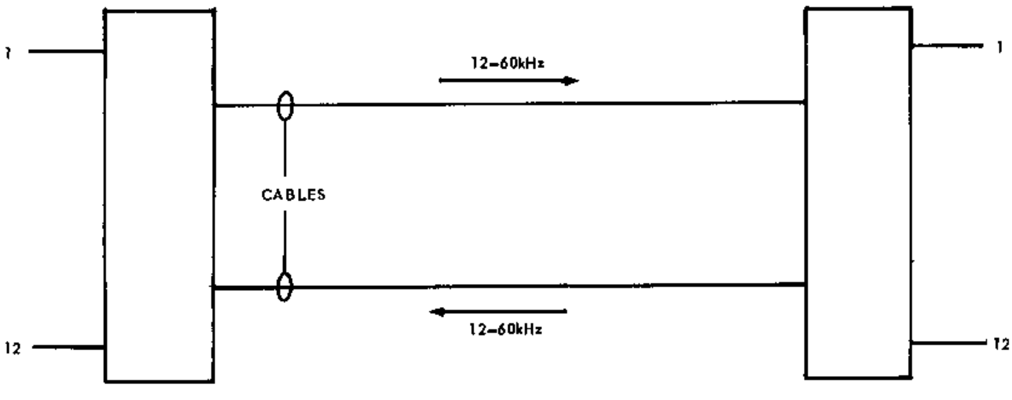


FIG. 63. USE OF PAIRS IN SEPARATE CABLES.

9.12 Frequency Frogging. In para. 5.19 the problem of tertiary crosstalk is described together with methods to reduce its effect for open wire working. Some pair cable carrier telephone systems use one cable pair as a bearer, and separate the directions of transmission by using separate portions of the frequency spectrum for each direction. These systems are often employed for junction circuit provision and use junction cable pairs as bearers. Although satisfactory crosstalk figures may be achieved between the individual bearers, by capacity-balancing, it is possible that crosstalk on a tertiary basis (that is, via pairs other than system bearers) may not be suitable. Fig. 64 shows tertiary crosstalk paths which exist between two pair cable carrier systems with repeaters. Crosstalk path A shows coupling between system 1 and system 2. The repeater amplifier of system 2 is included in the path so that crosstalk takes place at the low level input to the amplifier. A 'singing' path (path B) is provided from output to input of the system repeater. Similar crosstalk paths could be shown from system 2 to system 1 at each repeater.

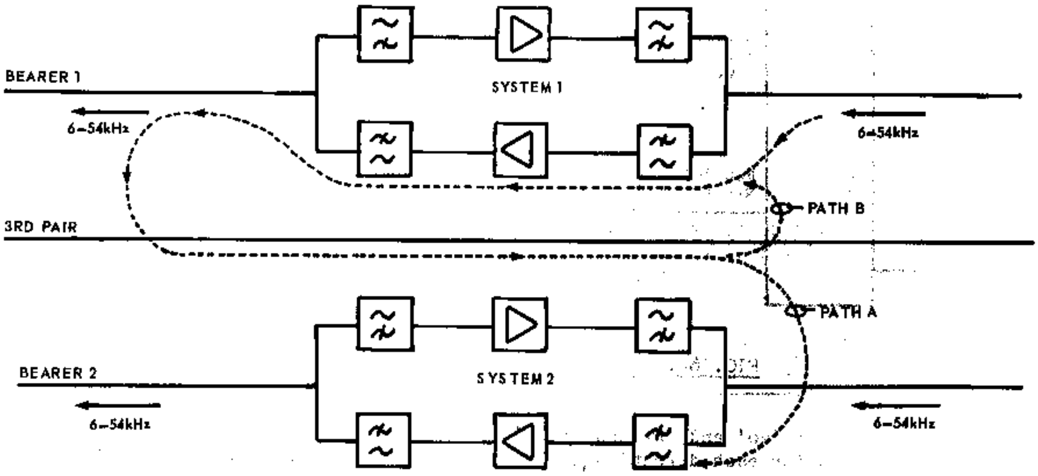


FIG. 64. TERTIARY CROSSTALK AND SINGING PATHS.

Frequency frogging can be used to offset this tertiary crosstalk effect. Fig. 65 shows a typical frequency frogging arrangement. At a terminal, 6-54kHz is transmitted and 60-108kHz is received; these two frequency groups are used for transmission on the entire route but at each repeater station, by modulation, the groups are changed as shown.

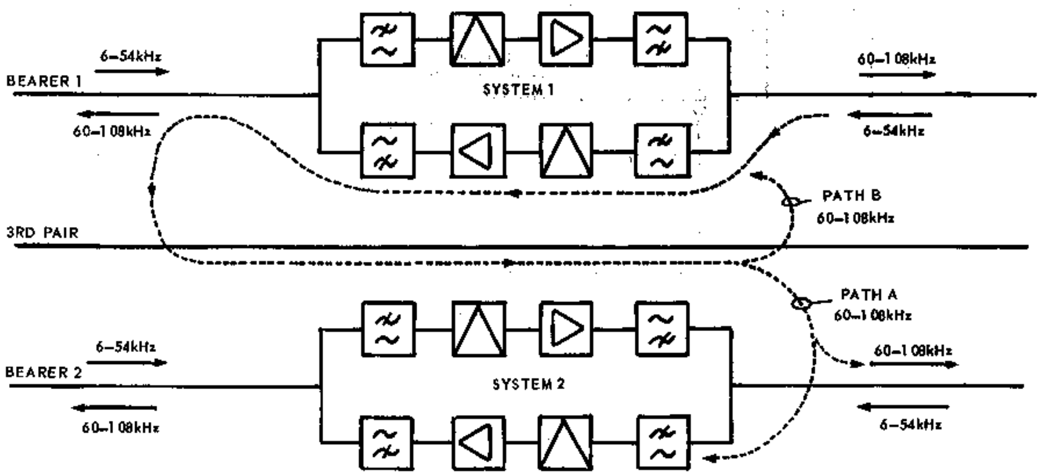
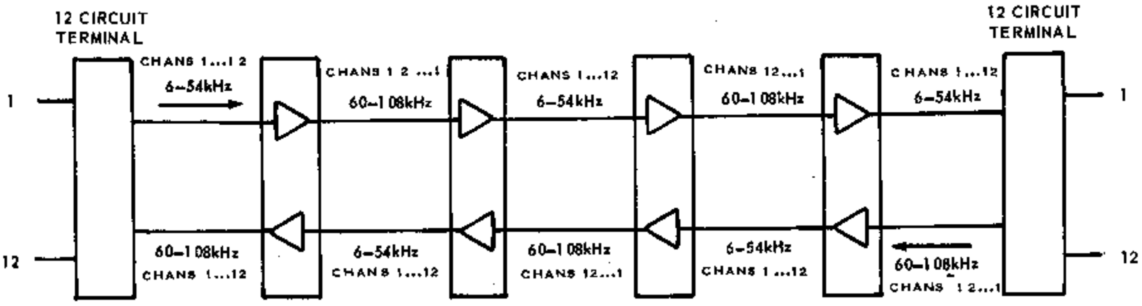


FIG. 65. TYPICAL FREQUENCY FROGGING AT A REPEATER.

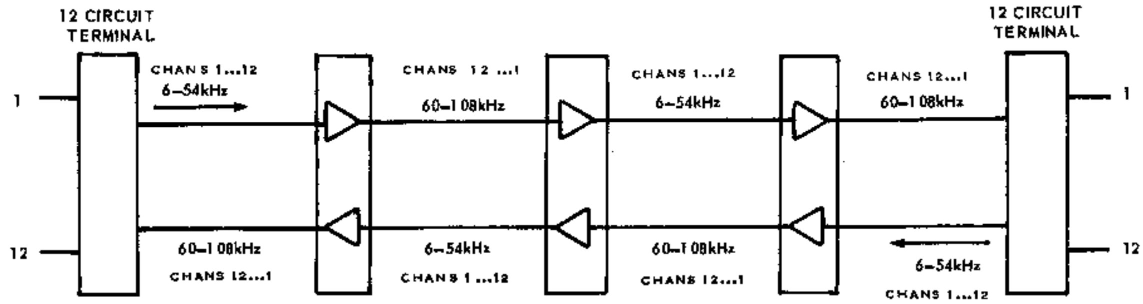
A crosstalk path from the system 1 bearer, via a third V.F. pair, to the system 2 bearer, is shown as path A in Fig. 65. The group of frequencies (60-108kHz) cannot be received by the repeater and are low level signals compared with the high level 60-108kHz group transmitted from the repeater.

At the output of repeater 1, a second crosstalk path (path B), via the third pair back to the input of repeater 1, cannot cause 'singing' because the repeater cannot accept 60-108kHz. Once again the crosstalk frequencies are low level compared to the high level 60-108kHz group transmitted from the repeater.

Fig. 66 shows the frequencies transmitted and received by terminals and repeaters in a typical frogging arrangement. At each repeater the frequency ranges for each direction of transmission are changed. When an odd number of repeaters exist, both the A and B terminals transmit the same group of frequencies. In addition to reducing the effect of tertiary crosstalk, frogging also improves system equalisation and regulation. The diagrams show that with 6-54kHz transmitted from a terminal, channel 1 occupies the low frequency slot and channel 12 the high frequency slot. However, in the next repeater section this condition is reversed; channel 1 occupies the high frequency slot and channel 12 the low frequency slot. This change continues for each repeater section. It should be noted that channel 1 receives the greatest change in frequency, from 6-10kHz to 104-108kHz. Channel 12 makes the smallest change, from 50-54kHz to 60-64kHz. The intermediate channels receive relative changes and an overall improvement in frequency response for each channel is obtained. Changes in temperature and weather conditions, which affect the higher frequencies to a greater extent than the lower frequencies, have less affect on the system as a whole because the higher frequencies are shared by various channels.



(a) Frogging with even number of Repeaters.



(b) Frogging with odd number of Repeaters.

FIG. 66. TYPICAL FROGGING ARRANGEMENT.

9.13 Staggering and Inversion of Sidebands. Two important techniques that successfully reduce interference, or the effects of interference, between systems operating in the same general frequency range, and sharing a common route, are the use of staggering and inversion of transmitted sideband frequencies. Staggering and inversion are used on the assumption that, although bearer crosstalk reduction features are employed, some crosstalk frequencies exist at the input to the carrier terminal.

Since each carrier channel occupies its own small frequency band (3100Hz for a standard channel), it is only affected by interference frequencies that fall within that band; other interference frequencies are rejected by the channel filters. Furthermore, the degree of affect of interfering frequencies that are selected by the channel filters depends on the following factors:-

(i) Intelligibility. The interfering affect of intelligible crosstalk is greater than unintelligible interference; that is, its annoyance value is greater because of the tendency to follow the background conversation.

(ii) Weighting Characteristics. Within the frequency range 300-3400Hz, the average human ear is more sensitive to frequencies in the range about 800-1500Hz, than to frequencies above and below this range. In addition the bulk of the power in the transmitted sidebands is contained in the low to mid-frequencies. When interfering frequencies in this range are reduced or eliminated the interference effect on the listener is considerably reduced.

(iii) Level. The signal to interfering frequency ratio is an important factor in determining the effect of interference on a listener. The ratio must be kept within prescribed limits but when related to (i) it can be seen that interfering effects can be reduced by rendering crosstalk unintelligible. Although the same amount of interfering energy is present, subjective tests show that unintelligible crosstalk can be 3dB higher than intelligible crosstalk to produce the same disturbing effect.

Staggering and inversion are described separately, and can be applied separately to frequency allocations. In many cases, however, staggering and inversion are applied jointly to frequency allocations, to gain additional crosstalk interference reduction.

9.14 Staggering of Sidebands. When staggering of sidebands is used, the sideband frequencies of one system are staggered with respect to those of another similar system, to minimise interference. Ideally this staggering should be such that the channels of each system occupy different portions of the frequency spectrum. Under these conditions the channel filters would reject the unwanted frequencies of the adjacent system. However, within the limited frequency spectrum available this degree of staggering is not economical and it has been found that a frequency shift of about 1000Hz to 3000Hz is sufficient to considerably reduce crosstalk and also the effect of crosstalk.

Fig. 67 shows sideband staggering arrangements for two typical three circuit systems. The B-A line frequency ranges for the three channels are indicated. The channels provide a limited speech bandwidth of 2300Hz from 300-2600Hz. The frequency range from about 800-1500Hz, which represents the range with greatest interfering effect, is shown shaded, and it can be seen that interference of these frequencies from one system to the other is generally eliminated because the frequencies are rejected by the channel demodulator band pass filters. Other frequencies are also rejected and because the "cut-off" of the filters is not perfect some interfering frequencies are attenuated. The actual group of crosstalk frequencies that are rejected depends on the degree of staggering employed. In general, the mid-channel frequencies are rejected.

In addition to the reduction in crosstalk level, the effect of crosstalk is also reduced because when voice frequencies are shifted in frequency by 1000Hz or more, they become unintelligible. This is equivalent to about a 3dB decrease in level.

The overall crosstalk advantage gained by using staggering is about 10dB.

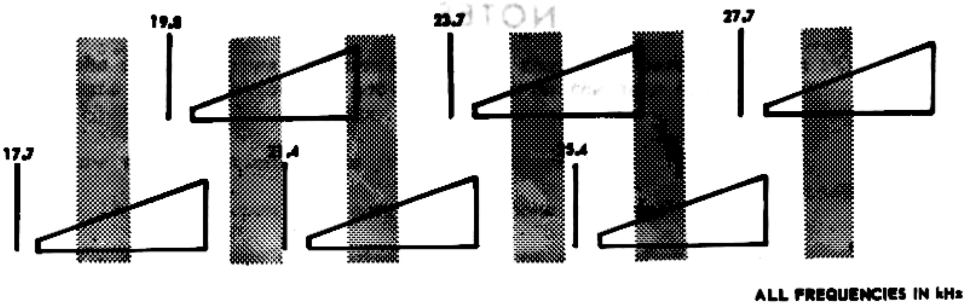


FIG. 67. STAGGERING ARRANGEMENTS FOR TWO THREE CHANNEL SYSTEMS.

9.15 Inversion of Sidebands. This technique relies largely upon the fact that crosstalk frequencies from one system to another are rendered unintelligible after demodulation. To achieve this the systems concerned transmit the same, or similar ranges of frequencies to line for each channel, but for one system an upper sideband is transmitted and for the other lower sideband. This is illustrated in Fig. 68 where the sideband frequencies for the two systems are almost the same. However, for system 1 these are upper sideband products and for system 2 they are lower sideband products. Crosstalk frequencies from one system to the other are accepted by the channel demodulator band pass filters but after demodulation these frequencies are unintelligible. In addition to becoming unintelligible the energy peaks of the crosstalk signals are shifted to new locations in the affected channel and have less effect upon the listener. Inversion of sidebands is said to achieve about 6dB crosstalk advantage.

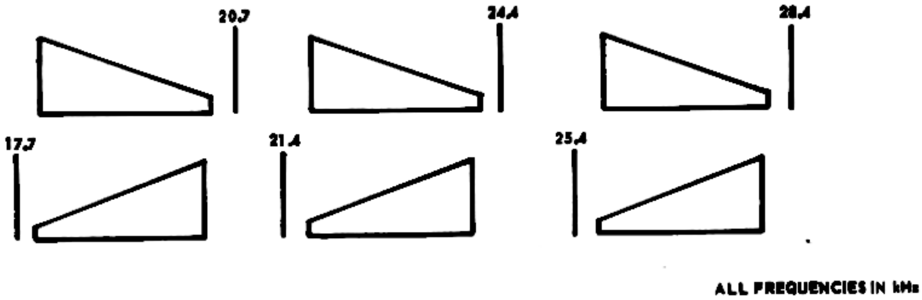


FIG. 68. TYPICAL FREQUENCY INVERSION ARRANGEMENT.

9.16 Typical staggering and inversion arrangements for twelve circuit open wire carrier systems are shown in Fig. 69. Frequency allocations are made for four system types and in the A-B direction only inversion is employed and in the B-A direction both staggering and inversion are used.

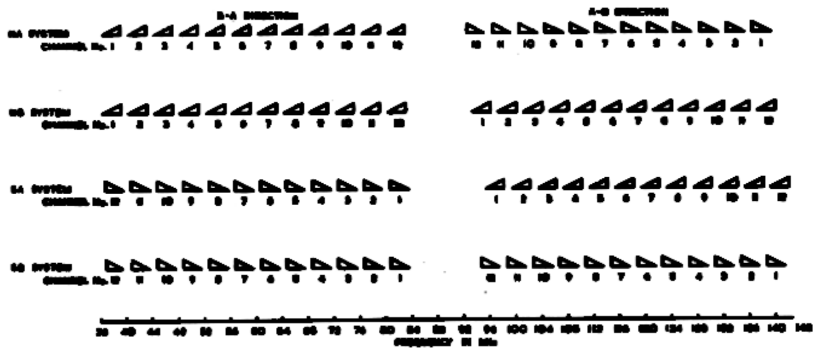


FIG. 69. FREQUENCY ALLOCATIONS FOR TWELVE CIRCUIT OPEN WIRE SYSTEMS.

10. *TEST QUESTIONS.*

1. List the various types of carrier systems that can operate on open wire lines. Indicate systems which are not compatible on the same bearer.

2. What are the approximate line frequency ranges for:-

(i) 12 circuit open wire carrier telephone systems?

(ii) 3 circuit open wire carrier telephone systems?

(iii) Rural carrier systems?

3. List the various types of carrier systems that can operate on pair cable bearers.

4. What are the approximate line frequency ranges for:-

(i) 12 circuit carrier telephone systems using one pair?

(ii) 12 circuit carrier telephone systems using pairs in separate cables?

5. What is the approximate line frequency range for a 960 circuit coaxial cable system?

6. State the nominal frequency bands allotted for:-

(i) The V.H.F. range.

(ii) The S.H.F. range.

(iii) The U.H.F. range.

7. State the approximate circuit capacities of radiotelephone systems in use in the communication network, and indicate the broad frequency band in which the various systems operate.

8. List the major equipment areas which comprise the communication network.

9. Why is gas pressure equipment fitted to most trunk and junction cables?

10. What is the approximate impedance of a 20lb. P.I.Q.T. pair in the carrier frequency range?

11. State the methods used to reduce crosstalk between P.I.Q.T. pairs.

12. Briefly define a trunk cable.

13. What are the main uses of trunk cables?

10. *TEST QUESTIONS. (Cont'd).*

14. *Briefly describe the construction of typical air core coaxial cable and state the main uses of this type of cable.*

15. *What is the approximate impedance of a coaxial tube in the frequency range above 1MHz?*

16. *Briefly describe the general form of open wire construction, and with the aid of a sketch show how the wires are designated on a typical cable pole.*

17. *What is the approximate impedance of an open wire pair in the carrier frequency range?*

18. *What method is used to reduce crosstalk between open wire pairs on the same pole route?*

19. *Why is impedance matching necessary at the junction of open wire and cable pairs?*

20. *What methods of impedance matching are used at the junction of open wire and cable pairs? State any limitation associated with the various methods.*

21. *State the various forms of protection used on open wire lines, and briefly describe each type.*

22. *What pole mounted equipment is used to reduce crosstalk between pairs?*

23. *With the aid of simple sketches show typical trunk entrance arrangements for twelve circuit open wire systems.*

24. *Draw a simple diagram showing the main features of double pair matching.*

25. *Briefly define longitudinal and transverse currents.*

26. *With the aid of simple sketches show the trunk switching arrangements for:-*

   (i) Two wire circuits.

   (ii) Four wire circuits.

27. *List the various signalling systems in use in the trunk network and state the type of trunk circuit on which each system could be used.*

28. *How are the majority of telegraph channels obtained in the trunk network?*

10. *TEST QUESTIONS. (Cont'd).*

29. *With the aid of a simple diagram, show the relationship between line transmission and telegraph equipment.*

30. *What is the nominal speed of telegraph working of a telegraph channel of a 24 channel F.M. V.F. telegraph system?*

31. *With the aid of simple diagrams show the relationship between:-*

    (i) *Line transmission equipment and audio programme equipment.*

    (ii) *Line transmission equipment and video programme equipment.*

32. *What advantages are gained by standardising frequency ranges for channels, and blocks of channels, of carrier telephone systems?*

33. *State the frequency ranges for:-*

    (i) *A basic group.*

    (ii) *A basic supergroup.*

    (iii) *A basic mastergroup.*

34. *Draw a simple sketch to illustrate the principles of pilot regulation as applied to carrier telephone systems.*

35. *Briefly define 'flat' regulation and 'slope' regulation.*

36. *With the aid of simple diagrams show how 'flat' and 'slope' regulation can be obtained.*

37. *Briefly describe how pair cable carrier telephone systems operate using:-*

    (i) *One cable pair as a bearer.*

    (ii) *Two cable pairs in the same cable as bearers.*

    (iii) *Two cable pairs in separate cables as bearers.*

38. *Why is it necessary for the transmission levels of similar frequency ranges on the same routes to be comparable at all points along the route?*

39. *What is meant by the term 'poling' of carrier systems and what advantages are gained by poling?*

40. *With the aid of a diagram explain what is meant by staggering of sidebands. State the advantage of employing staggering.*

41. *What is meant by inversion of sideband frequencies?*

END OF PAPER.