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THE SHEPPARTON INTERNATIONAL BROADCASTING STATION, "RADIO AUSTRALIA"

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Introduction: A high power station was designed, constructed and operated during the war by the Australian Postmaster-General's Department for the purpose of broadcasting programmes associated with the conduct of psychological warfare by the United Nations in the Pacific theatres of operations. The programmes were prepared and presented by an organisation set up for the purpose, which worked in co-operation with a Committee representative of the United Nations. The station is situated near Shepparton, Victoria, and is equipped with two transmitters each of 140 kilowatts maximum power; one transmitter of 50 kilowatts, and a group of 19 directional aerials. The station transmits on several channels in the frequency band 6 to 22 megacycles per second.

Since the end of the war, the Shepparton station has been operated regularly as an international broadcasting station, with programmes in many languages. The programmes convey Australian news and information to most parts of the world. They are prepared from data supplied by several Departments of the Commonwealth Government of Australia, and are co-ordinated and presented by the Department of Information. The station has become well known by the name of "Radio Australia."

The intention of this article is to give an outline of the factors leading up to and involved in the establishment of the Shepparton International Broadcasting Station, "Radio Australia," together with a general description of the facilities provided and the results obtained. It is proposed that the more technical aspects of the design will be covered by further articles written by members of the group of engineers who brought the project into being during a period fraught with difficulties.

History of the Project: The value of high power radio stations having world range for the dissemination of news and information had been fully appreciated by Germany, Italy and Japan prior to the outbreak of the war, and those countries had spent large sums of money and much engineering effort in the provision of such stations. To achieve world coverage, these stations occupied many channels in the international high frequency broadcasting band of frequencies, namely, 6 to 22 megacycles per second. Further, those countries realised that transmitters having powers as high as the technical art permitted were necessary for the purpose.

When war commenced in Europe and North Africa, the enemy high power stations immediately became avenues of propaganda and weapons of psychological warfare.

Until the entry of Japan into the war, the only large scale countermeasures were those provided by stations operated in the United Kingdom by the British Broadcasting Corporation on behalf of the Allied Powers.

With the intensification of the war against Great Britain, there was a growing risk of damage to the B.B.C. stations; further, the situation in Asia and in the Pacific was steadily deteriorating. It seemed necessary in these circumstances that Australia should take responsibility for a substantial share in maintaining an Allied world-range broadcasting service and for countermeasures to enemy psychological warfare.

Accordingly, early in 1941 a proposal to establish a powerful high frequency transmitting centre in Australia was discussed between representatives of the British and Australian Governments. A plan that eventually became the Shepparton station was prepared by the writer, and was agreed to.

It was realised that transmissions from Australia would be particularly effective for technical reasons, because of the favourable geographical situation; and from the psychological aspect because it was felt that certain points of view pertaining to the Pacific Ocean environment could perhaps be more cogently presented from Australia than from elsewhere.

Technically, the main advantage is that service to the near and far north of Australia could be provided with fewer frequency changes than would be needed by broadcasting from either the U.S.A. or Great Britain. The ionospheric transmission path for the radiated energy in the latter cases would, in general, have to pass across the daylight-darkness transition zones, so suffering greater variation of attenuation than on north-south paths. Radio Tokio already had this advantage when transmitting southward; therefore the most effective countermeasure would be to transmit northward from Australia on at least equal power, so that troops and other listeners with inadequate receiving equipment would have a chance of receiving Allied transmissions at least equal to their chance of receiving enemy transmissions.

The Postmaster-General's Department at this time had high frequency broadcasting transmitters in operation; but these transmitters, while having an international range, were primarily designed as units of the National Broadcasting System for supplying a domestic service to remote areas of the Commonwealth outside the range of the medium frequency transmitters. Some of these transmitters had already been diverted from their normal peace-time use to provide a counter to enemy propaganda in the areas north of Australia; but their power, while sufficient for the purpose for which they were

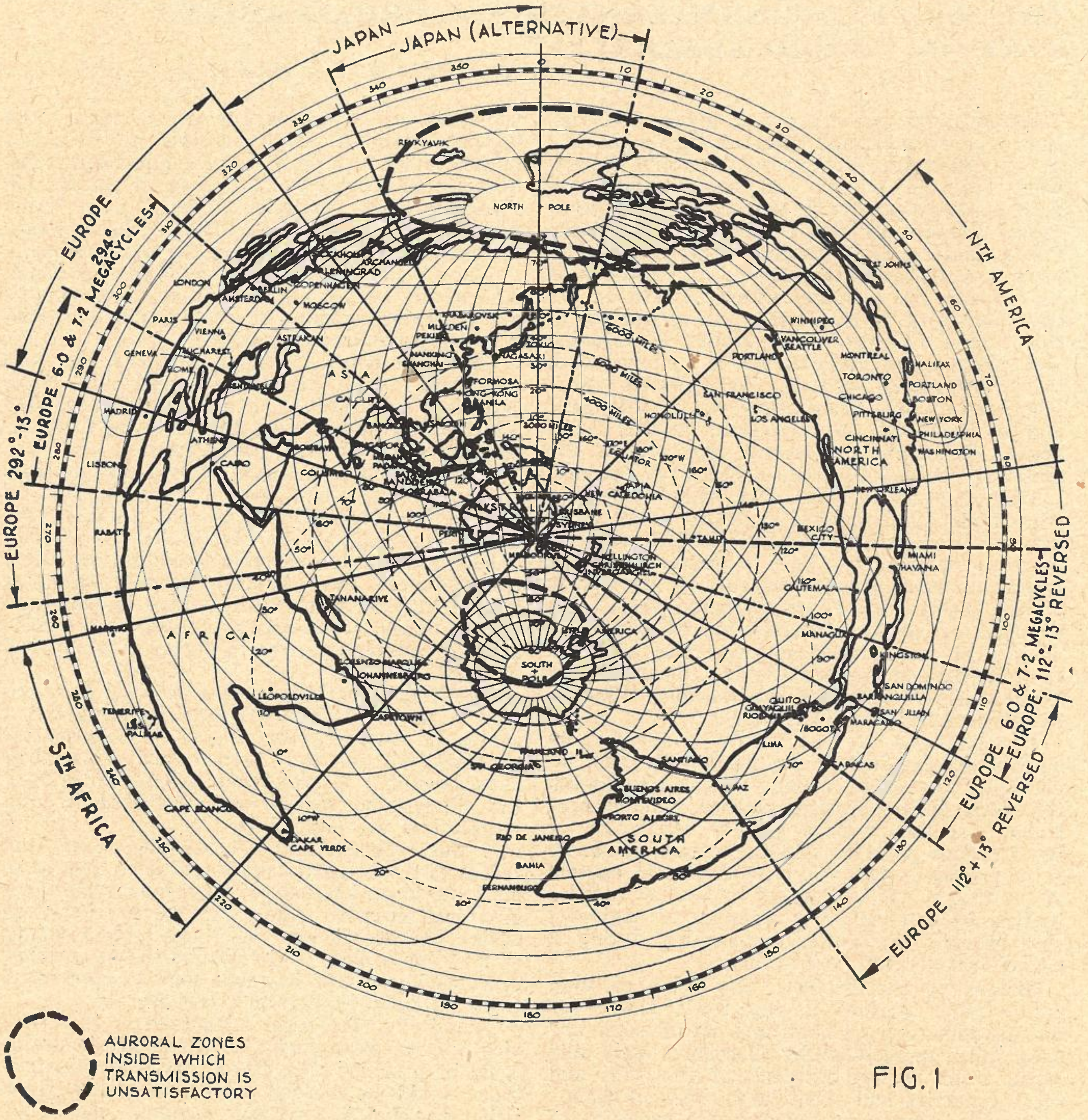


FIG. 1

installed, was not enough to compete successfully with enemy transmitters having power 10 to 50 times greater. The agreed plan therefore contemplated setting up an entirely new transmitting centre, with transmitting equipment comparable in power with the largest in use by any enemy country.

General Requirements for the Service: To cope with all likely requirements, it was desirable to provide for the following conditions:—

(a) The transmissions were to be capable of being directed to any country in the world. This necessitated the provision of a number of radiating systems in each direction in which it is desired to transmit, so that transmission can be made at any time on the optimum frequency for the particular time of day and season of the year.

(b) In each direction provision had to be made for transmission on two or more frequency channels simultaneously. This was desirable to ensure an adequate signal strength over as wide an area as possible. This set the lower limit to the number of transmitters required at two, but three would be preferable.

(c) Broadcasts must be carried out in a number of Asian languages such as Chinese, Burmese, Thai, Filipino, Indonesian and Japanese, in addition to English, Dutch, French, Spanish and the more important European languages.

(d) Any broadcast at any hour in any particular area or zone should be comparable in strength and reliability to that sent out by any other nation.

To meet all these requirements fully would have required a transmitting centre as large as any in the world, some of which had taken years to build up to their existing stage of completeness. Bearing in mind what could reasonably be expected to be done in Australia in the time available, and having regard to other war-time commitments, it was determined that the new station should be founded on three high power transmitters with nineteen directional aerials; and that for propagation, operational and defence reasons its site should be in the south-eastern part of Australia.

Fig. (1) shows an azimuthal map of the world with Melbourne as the centre, on which have been drawn sectors representing the beamed transmissions which have been provided for. From this map it will be apparent that all countries can be effectively covered, with the exception of certain portions of South America. Transmission toward portion of that continent suffers absorption due to the passage over the south polar auroral zone. Actually, by a reversal of the Japanese aerials, provision has been made for transmission to South America; but it is estimated that even with 100 kilowatts radiation, an effective service would be possible for only about 7% of the time.

The sectors shown on the map represent $\pm 18^\circ$ on each bearing, or a total angle of 36° for each transmitted beam, the outer limits being taken as the points where the field strength is 6 db lower than that on the centre line of maximum radiation.

General view of site showing main buildings.

Location of Station: The site was determined by a process of combining, with due weight given to each, the following factors: The aspect as to radio propagation; the degree of security from possible enemy attack; availability of electric power supply from a large system; suitability and adequacy of water supply; least obstruction to military and civil aviation; staffing and housing conditions; and reasonable nearness to the important centres of programme supply, namely, Sydney, Canberra and Melbourne. These considerations dictated a site in the south-eastern portion of the continent. In addition, due to the high power of the transmitters and the consequent strength of the radiated field which would be experienced by aircraft flying in the vicinity, it was necessary

General view of site with masts and transmission lines.

to consider an area sufficiently remote from Air Force training centres.

By a process of successive elimination, a site finally emerged that met the foregoing requirements to the best combined extent. The site chosen has an area of 567 acres and is situated approximately four miles north of the town of Shepparton, that town being approximately 113 miles by road north of Melbourne. The precise location is latitude 36° 19′ 50″ south, longitude 145° 25′ 20″ east.

The surrounding country is flat in all directions for many miles, and on the site itself the difference in level between opposite boundaries approximately 1 mile apart is less than four feet. No hill or mountain is so close that it subtends an angle greater than three degrees in the vertical plane passing through the centre of the site. An adequate water supply is available from an irrigation channel, and this channel is used to fill a reinforced concrete open tank 120′ x 120′ x 6′ deep holding sufficient water for engine cooling, for fire fighting purposes and for garden use. For other purposes requiring purer water, rainwater catchment and storage has been provided.

Buildings: The buildings consist of:—

(i) The main transmitter building, which accommodates the three transmitters and associated equipment such as air cooling systems, water cooling systems, programme control equipment, test rooms, monitoring room and emergency studios.

(ii) A power house for the diesel electric generating sets for use as reserve supply, and also providing for a workshop, stor-

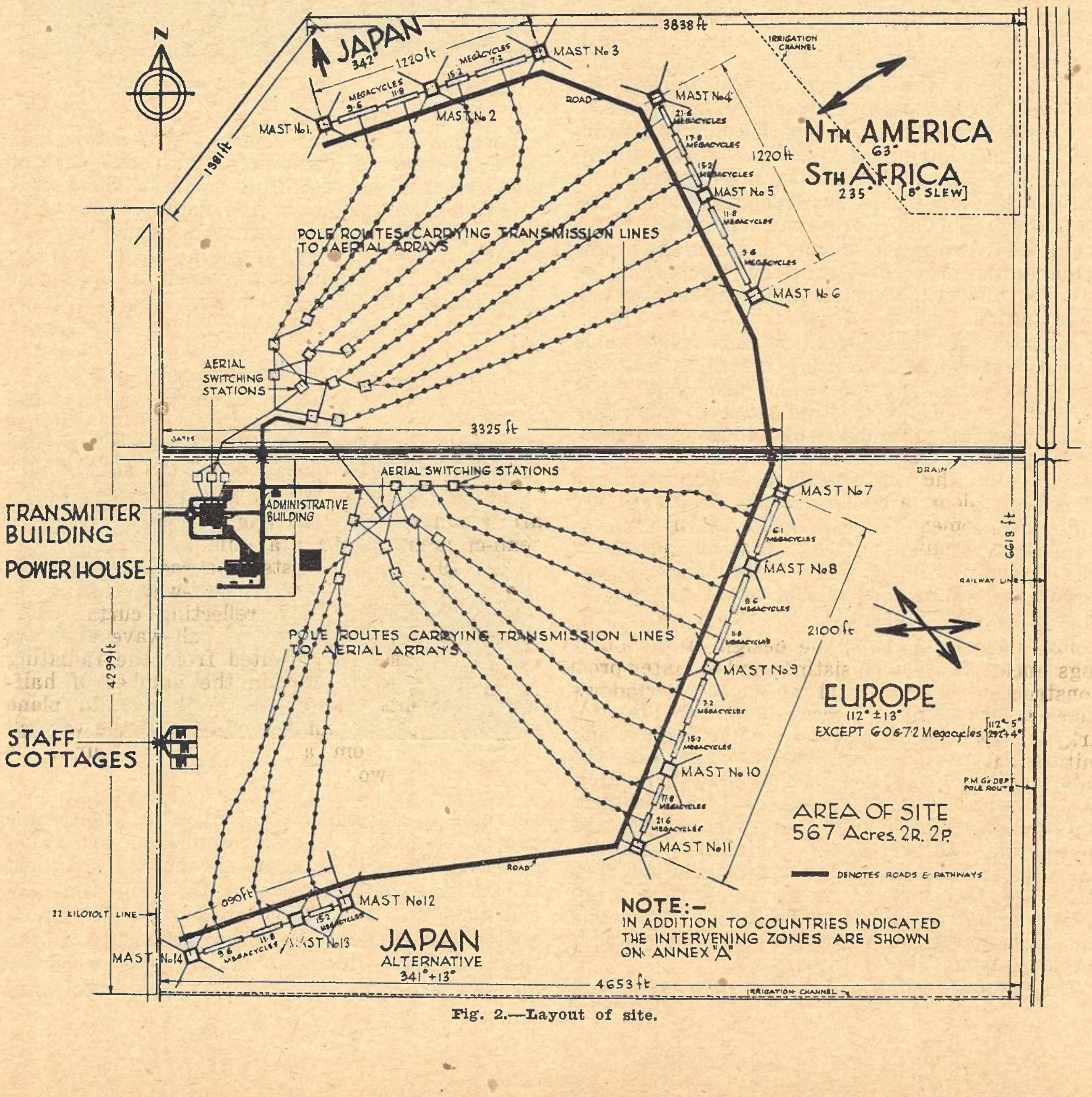


Fig. 2.—Layout of site.

age space, garages and the meal accommodation for outdoor staff.

(iii) Office building.

(iv) Three staff cottages.

Fig. (2) shows a layout of the buildings on the site in relation to radiating systems and radio frequency transmission lines. The erection of these buildings was itself a project of some magnitude in view of the short supply of all building materials and labour at the time; some delays occurred due to diversion of skilled manpower to certain defence works of pressing urgency.

Fig. (3) shows a ground floor and basement plan of the transmitter building, the overall dimensions being 155 feet long by 117 feet wide. A plan of the emergency power building is also included.

The radio frequency equipment is in the main transmitter hall, and all heavy equipment such as power transformers, modulation transformers, is in concrete cubicles provided with roller shutter doors opening on to the galleries on either side of the building. A travelling crane spans each gallery to enable the heavy equipment to be moved to loading docks from which it can be transported to the workshop in the power house. A basement, 135 feet long by 24 feet wide, underneath portion of the main floor, contains water cooling equipment, some transformers and auxiliary equipment such as power factor correcting condensers. Since the building had to be designed before details of the transmitting equipment were worked out, it was necessary to provide flexibility in the accommodation for cables. Therefore, cable tunnels approximately 8 feet high and 4 feet wide were provided, and these open into the basement and run the length of the building underneath the transmitting equipment. A mezzanine floor accommodates the programme control equipment for all three transmitters, two emergency studios and a monitoring room in which observations on the audio input and transmitter output may be made in quiet surroundings.

For security reasons, the design of the buildings included blast resisting and splinter-proof construction and a total absence of windows. Consequently, it was necessary to provide good artificial lighting, especially in the main transmitter hall. This was provided by fluorescent tubes, giving a quality of illumination approximating to natural light. This type of lighting has proved satisfactory; and, moreover, uses much less power than would be required by equivalent illumination with filament type lamps. With the latter, 32 kilowatts would be required in the main hall alone to provide an illumination of 15 foot-candles on the working plane. With fluorescent lighting the power consumption is 11 kilowatts. Further saving is reflected in the ventilating plant, which must remove the heat generated by the lighting system.

Underneath the basement, an earth system was put down consisting of $\frac{1}{2}$ inch copper rods, 6 feet long, driven into the ground every 8 feet in rows 8 feet apart and connected together to form a grid by 600 lb./mile copper wire. From this system risers were taken at intervals and terminated at convenient points within the building itself, thus providing a series of earthing points for the equipment. Care was taken to ensure that the earth system did not come in contact with the steel reinforcement in the concrete of the building, to avoid possibility of trouble due to electrolytic corrosion.

The power house was erected sufficiently far away from the main building to ensure freedom from earth-transmitted vibration arising from the generating equipment and to provide a measure of dispersal in the event of air raids. For the latter purpose also, the office quarters were separated from the main building. At a later date, it may be desirable to put the offices in the main building, and for this reason the present office building has been erected in the form of a cottage, which can then be used for staff accommodation in addition to the three cottages already provided.

Radiating Systems and Radio Frequency Transmission Lines: In order to meet the requirements of adequate transmission to any part of the world at any time of the day, 19 directive arrays have been erected, the supporting structures being 14 guyed lattice steel masts each 210 feet in height. Each mast is painted with colour bands for aircraft warning purposes, and, in addition, groups of masts are provided with aircraft warning lights. As a further safeguard to aircraft, a flashing beacon has been installed near the centre line of the site.

As will be evident from Fig. (2), these masts are arranged along a line forming roughly a semi-circular arc over a mile in length. Each of the 19 arrays consists of a radiating curtain comprising a number of half-wavelength elements, together with a reflecting curtain containing the same number of half-wave elements properly phased and excited from the radiating curtain. In every curtain the number of half-wave elements end-on in the horizontal plane is four, while the number of tiers in the vertical plane varies from a maximum of four to a minimum of two.

For broadcasting purposes, it is not desirable to concentrate the radiated energy into a very narrow beam in the horizontal plane. The Shepparton aerials have been designed so that the angle in the horizontal plane is $\pm 18^\circ$, wherein the boundary level of field strength is 6 decibels below the maximum value at the centre of the beam. The elevation of the centre line of the vertical radiation varies with the number of

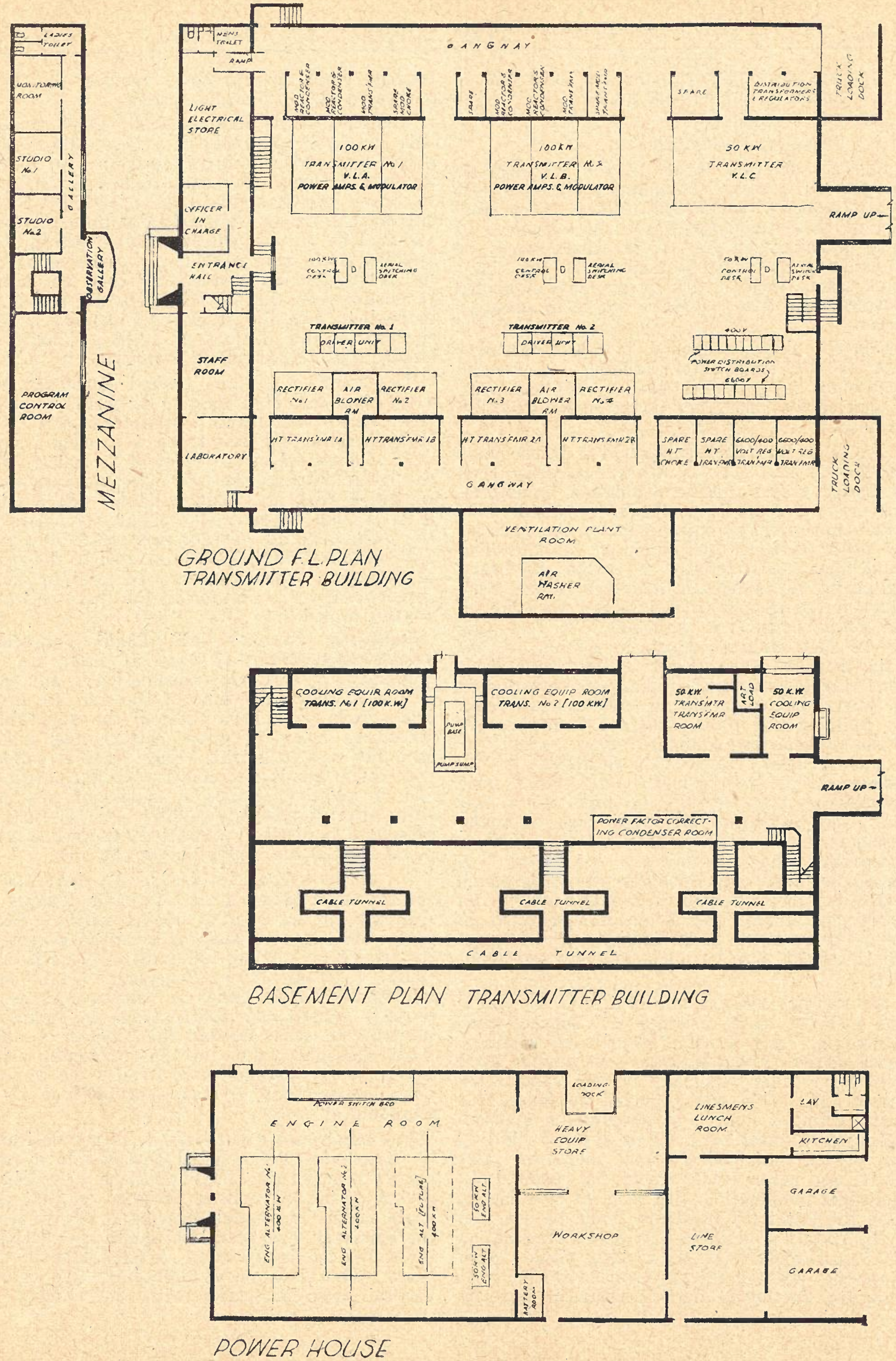
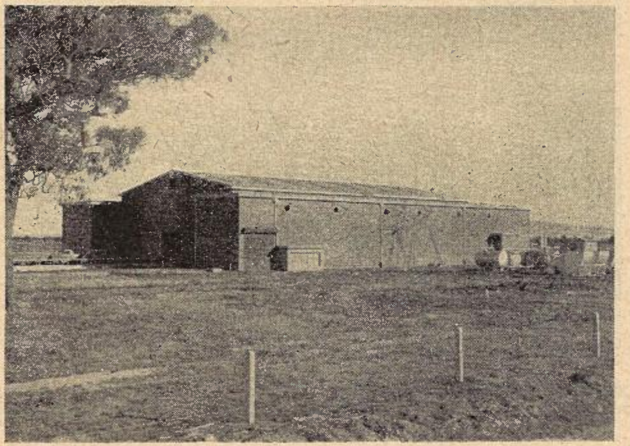


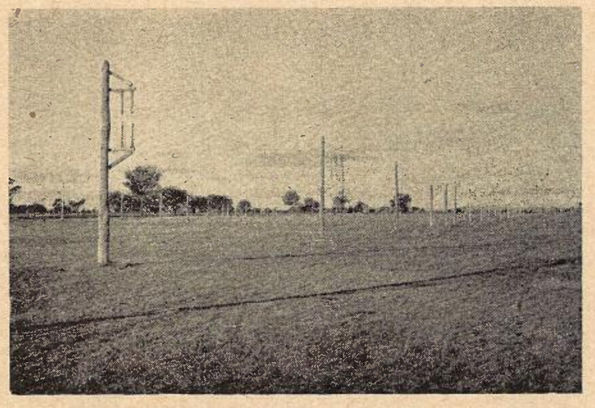
Fig. 3.—Floor plans of transmitter building and power house.

tiers of radiating elements and with the height of the bottom element above ground; in the Shepparton case, this elevation is 9° for the highest frequency and 18° for the lowest frequency. The switching system provides for reversing the direction of radiation of some of the aerials and also for slewing the direction of maximum radiation of some arrays by amounts of 8° to 13° in the horizontal plane.



Transmitter building.

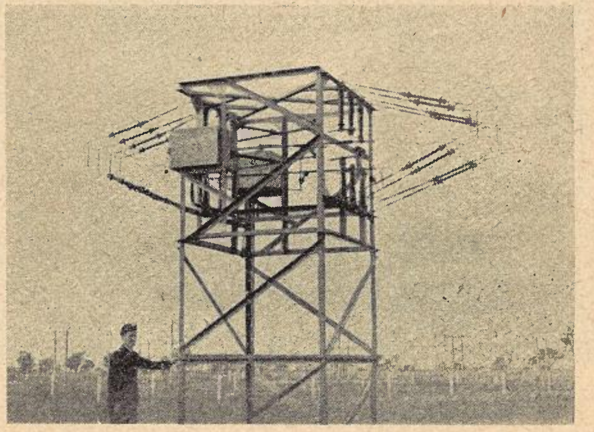
Each of the 19 aerial arrays is connected by radio frequency transmission lines to outdoor switching centres. The switches were designed and constructed to present to the radio frequency transmission lines an impedance not differing greatly from the characteristic impedance (Z_k) of the lines themselves, the nominal value of Z_k being 310 ohms; they have been found by measurement to present discontinuities either negligible or easily compensatable.



Details of transmission lines.

The whole of the switching system is controlled from the main transmitter hall by means of push buttons which cause the operation of ½ H.P. 3 phase motors within the switch boxes. The push buttons are grouped on an aerial control desk in the transmitter hall, one desk for each transmitter. By this means, transmitters or radiating systems can be switched within a period of minutes. The whole system is electrically interlocked for safety, and to prevent wrong combinations, such as a transmitter being excited without connection to its load, or power at a particular frequency being sent out to the wrong aerial, or two transmitters being fed into the same aerial. Indicating lamps on the switching desks show the state and course of every connection set up.

The radiating system and remotely operated switching system for a station as large as Shepparton presented problems new to radio engineering in Australia. On R.F. transmission lines of $Z_k = 310$ ohms carrying power up to 140 kilowatts, the peak voltage at 100 per cent. modulation is 18,000 volts when the standing wave ratio is unity. To provide for departures from unity s.w.r., the design peak voltage was set at 30,000 volts. Bearing in mind these values can occur at a frequency of 22 megacycles

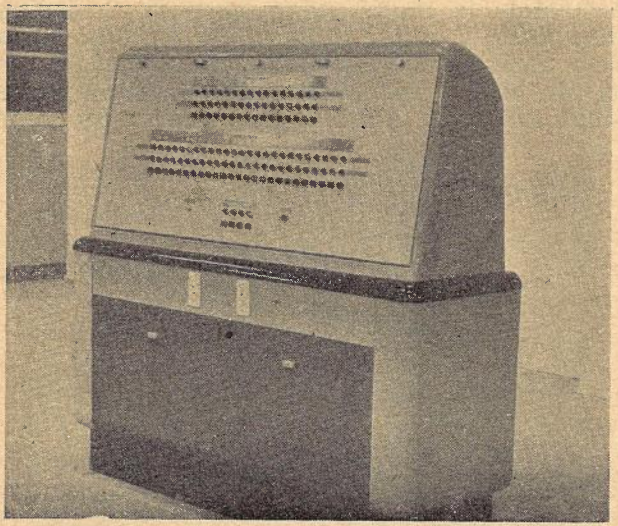


Aerial selector switch.

per second, it was necessary to guard against excessive heating of insulators due to dielectric hysteresis, loss of power in corona discharges, and damage due to arcing. This required the design and manufacture for the aerial arrays and for transmission lines of insulators with a long leakage path and a small cross-section, and with corona rings at the ends to prevent a concentration of the electric field. All metallic objects in intense radio-frequency fields or likely to be excited by them had to have physical contours which would not be likely to start a corona discharge. No insulators and hardware available in Australia met all the foregoing requirements; hence the necessity to design in detail and have manufactured nearly every item, and thousands were required.

Three types of radio frequency transmission lines are used to connect the output of each transmitter to the radiating systems via the switches. First there are 2-wire balanced shielded lines to lead the power from the transmitters out of the building; second, the main system of 4-wire lines for feeding the aerials; and, third, short 2-wire open lines joining the ends of the 4-wire system to the panels of the aerials. The shielded lead-out lines were necessary to prevent losses arising from the heavily steel reinforced concrete forming part of the blast-resistant building construction. These shielded lines have a diameter of 20 inches, and the conductors are supported within the shield by polystyrene rods, no ceramic then available having low enough losses.

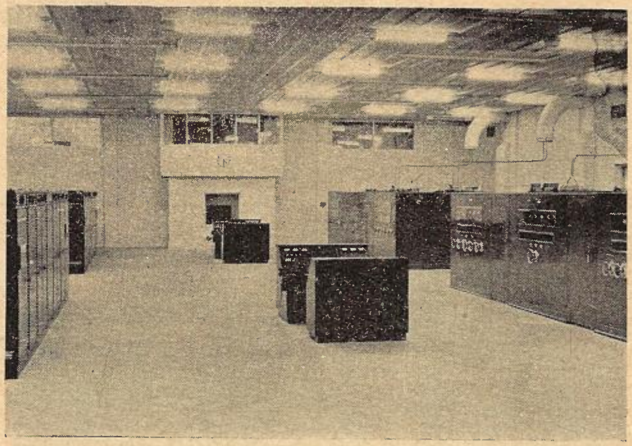
For the main R.F. distribution system, four-wire lines were used instead of two-wire lines to achieve the combined advantages of a convenient value of Z_k, low attenuation and a reasonable corona limit. The four wires are each of 600 lb. per mile copper and are connected two in parallel; as stated, the characteristic impedance Z_k is 310 ohms. The diameter of 600 lb. per mile copper wire is 0.194 inch, and when the wire is new and bright corona will occur at approximately 80,000 volts peak; but it falls to about 30,000 volts peak when the wire becomes oxidised. Since 0.194 inch copper wire was available and otherwise desirable, the adoption of 4-wire construction met the design requirement of 30,000 volts peak for the corona limit of oxidised wire.



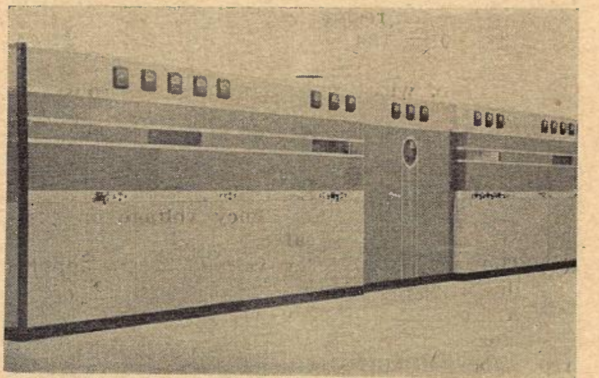
50 K.W. (R.C.A.) transmitter aerial switching desk.

The design of the switching and feeder system as a whole was intentionally made to permit quick changes and flexible operation, although this entailed considerable complexity in design and construction. It was not known at the outset what combinations may be required of programmes, directions and frequencies. If further transmitters and aerials are added to the station, there will be most likely less switching required, because the greater amount of plant available will permit stable group assignments to certain schedules. The existing switching system may not require any further extension, although possibly it may be rearranged.

Transmitting Equipment and Power Supply: Three transmitters are installed, one of 50 kilowatts carrier power output manufactured by the Radio Corporation of America, and two each of 100 to 140 kilowatts output manufactured in Australia by joint contractors, Messrs. Standard Telephones & Cables Pty. Ltd. and Amalgamated Wireless Ltd., to the general design and performance requirements of the Postmaster-General's Department. All transmitters can operate on any channel in the frequency bands allocated to international broadcasting, i.e., each transmitter is capable of operation on any one of a number of channels from 6 megacycles per second to 22 megacycles per second. Each transmitter has means for quickly changing over from telephone broadcasting to telegraph working. Programmes for all transmitters are fed over programme lines from Melbourne equalised to 10 kC/s; and, in addition, two studios have been provided within the transmitter building for use in the event of interruption to the programme lines. The programme lines pass through the main control centre at Melbourne,



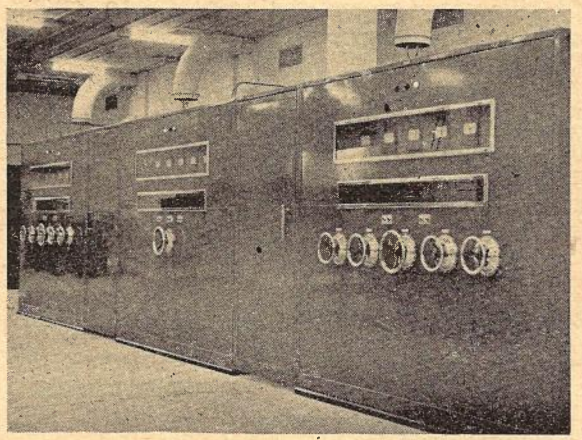
Transmitter hall, showing 100 K.W. transmitters, low power and high power stages, control and aerial switching desks.



50 K.W. (R.C.A.) transmitter—front panel.

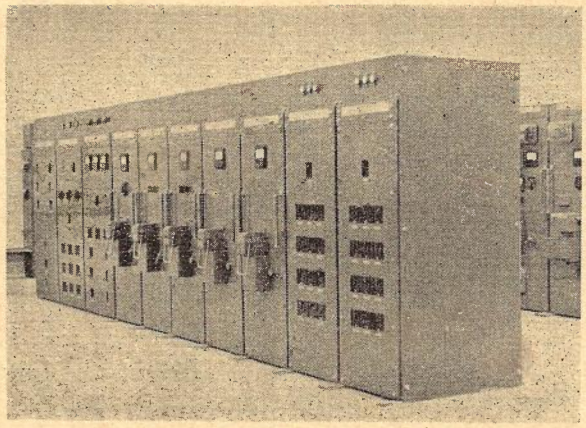
through which access can be given to the whole programme line network of Australia.

Each transmitter derives all its supplies (including filaments) directly from the alternating current mains. The total load drawn when all transmitters and auxiliary equipment are in operation is of the order of 1200 kilowatts. As



100 K.W. (STC and AWA) transmitter high power stage—front panel.

all three transmitters are modulated in their final stages by means of high level modulators operating as class "B" audio amplifiers, the load varies under modulation, and, in the event of a single programme modulating all transmitters simultaneously, there would be a change of some hundreds of kilowatts at speech-syllable frequency. The degree of power supply regulation, therefore, becomes an important factor.

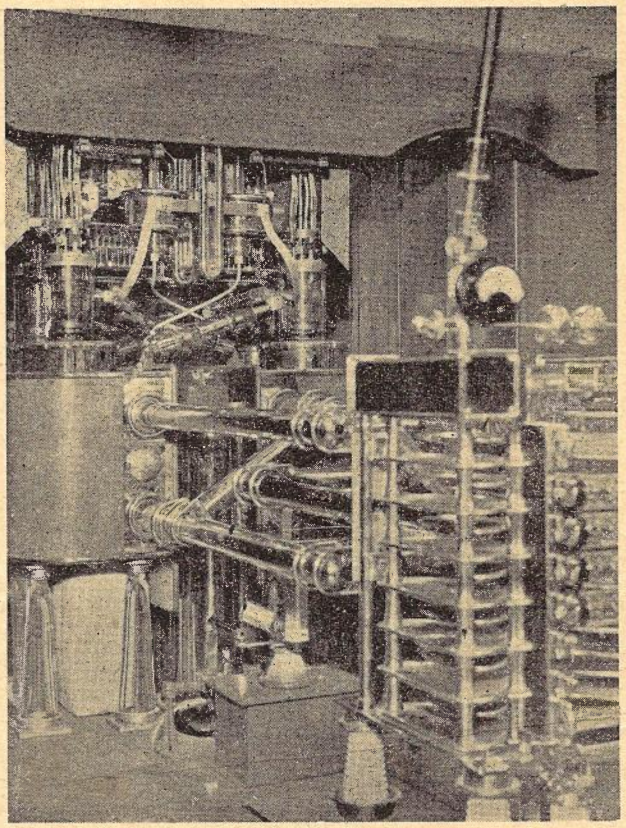


Power supply to transmitters.

For this reason, arrangements were made with the State Electricity Commission of Victoria for a special supply. The Commission's 66,000 volt three-phase 50 C/s transmission line was brought straight to the site and terminated in an outdoor substation situated close to the station power house. The 66000/6600 volt transformers in the substation are in duplicate, each with a capacity of 2000 kVA. The 6600 volt supply passes through a voltage regulator capable of taking the whole load of the station, thence through underground cable to the transmitter building. By these means, a regulation better than 2% from full load to no load is obtained.

The power factor of the load drawn by each transmitter is between 0.85 and 0.9. A power factor correcting condenser installation brings the load of the whole station to a value approximating unity.

To provide a source of power to enable at least two of the transmitters to remain in operation in the event of interruption to the main supply, there has been provided a power



100 K.W. power amplifier.

house with a diesel engine generating installation. There are two generating sets (with space for a third), each consisting of a Crossley 800 B.H.P. solid-injection diesel engine direct-coupled to a 400 kVA 6600 volt 3-phase 50 cycle per second alternator with exciter. For auxiliary power and lighting there are two 84 H.P. 50 kVA 400 V 3-phase diesel engine sets, with relay control arranged to start up the sets automatically on failure of the main supply. In order to keep the regulation of the 6600 V engine-generated supply within the required limits under the varying load conditions imposed by the transmitters, the specified design for the engines required the provision of heavy flywheels. The kinetic energy released by each flywheel is 1,750,000 foot pounds. For regulation reasons also, the engines are larger than would be necessary for driving 400 kVA alternators in ordinary practice.

General: The Shepparton station represents an unusually large radio engineering work so far as Australia is concerned. Apart from the amount of specialised design and engineering effort required, its construction in war-time posed difficult problems of manpower and material. An idea of the work involved may be gained from Fig. (4), which shows the main quantities and costs for the principal sections of the project. A list of the major contracts is given in Appendix I.

No attempt has been made in this article to give more than a general description and to recount some of the main lines of approach to design questions. Detailed treatment of each section of the installation, it is hoped, will be the subject matter of separate articles.

Conclusion: In May, 1944, the first unit, the 50 kilowatt transmitter, came into operation, broadcasting programmes under the ægis of the Allied Political Warfare Committee. Reports which reached Australia soon after this showed that very strong reception was being provided in the required areas and that the station was an effective counter to Radio Tokio, whose transmissions had hitherto been the most effective in the islands north of Australia.

INTERNATIONAL HIGH FREQUENCY TRANSMITTING STATION, SHEPPARTON

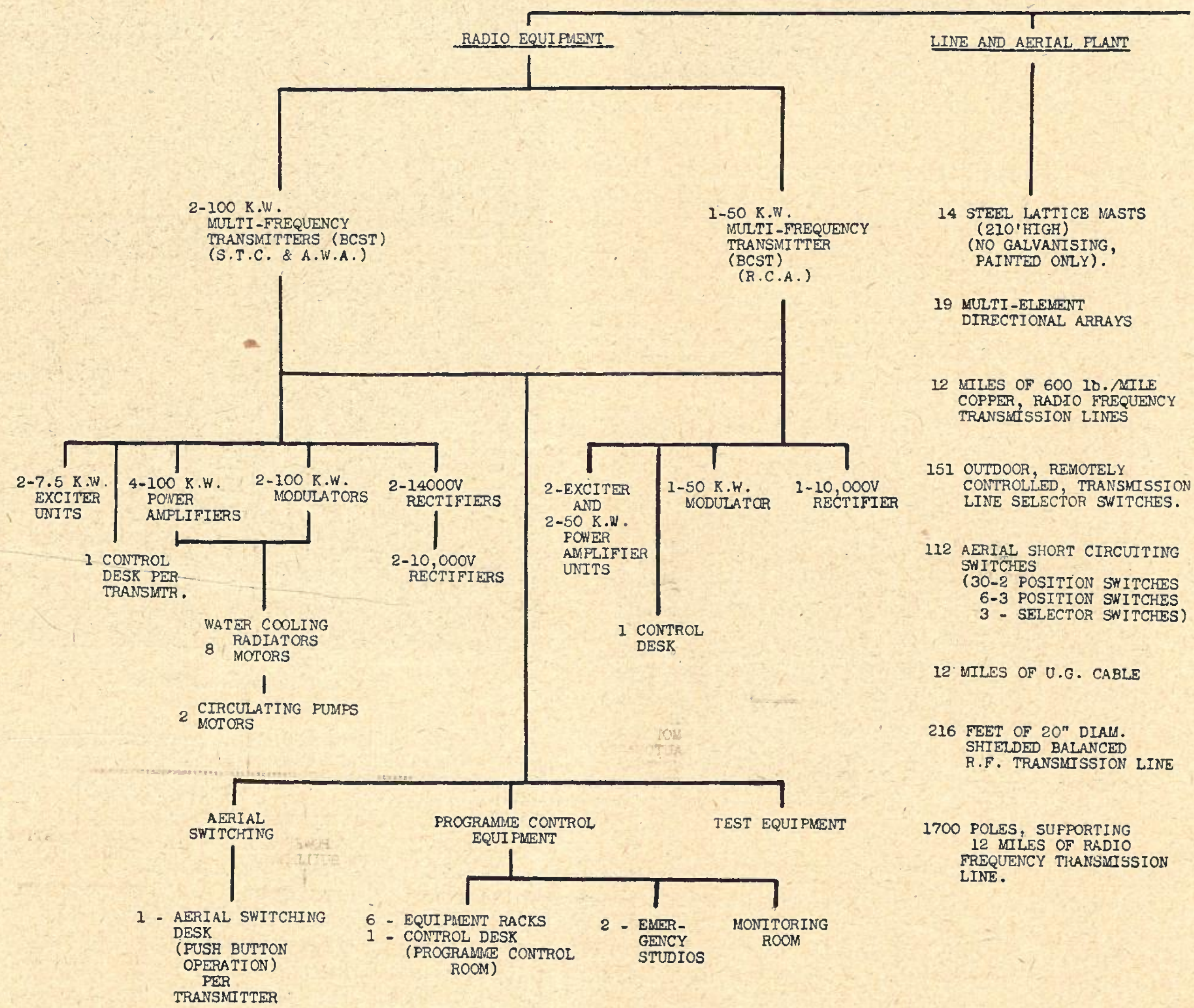


Fig. 4.

Prior to the invasion of the Philippines, a session directed on the Philippines and known as the Philippine Hour was regularly broadcast over Shepparton. After the successful re-occupation of those islands, the Department of External Affairs received a message from General MacArthur, which read as follows:—

"The Australian Postmaster-General, by supplying the technical facilities of the Shepparton Station, gave the shortwave broadcast to the Philippines, called the 'Philippine Hour,' a strong and constant signal which was audible in every part of the Philippines. As a result of excellent transmission, these broadcasts were heard, copied and distributed widely in occupied and unoccupied territory of the Philippines. The part they played in maintaining Filipino morale was a direct contribution to the military campaign which resulted in the liberation of the Philippines.

"In addition to this shortwave broadcasting being used as a weapon aimed directly at the enemy, it was successfully used to encourage resistance on the part of able people whose country had been occupied by the enemy.

"It has been definitely proven that shortwave radio broadcasting is an established arm of psychological warfare, and 'The Philippine Hour' was an excellent example,

DETAILS OF PROPERTY, PLANT AND EQUIPMENT

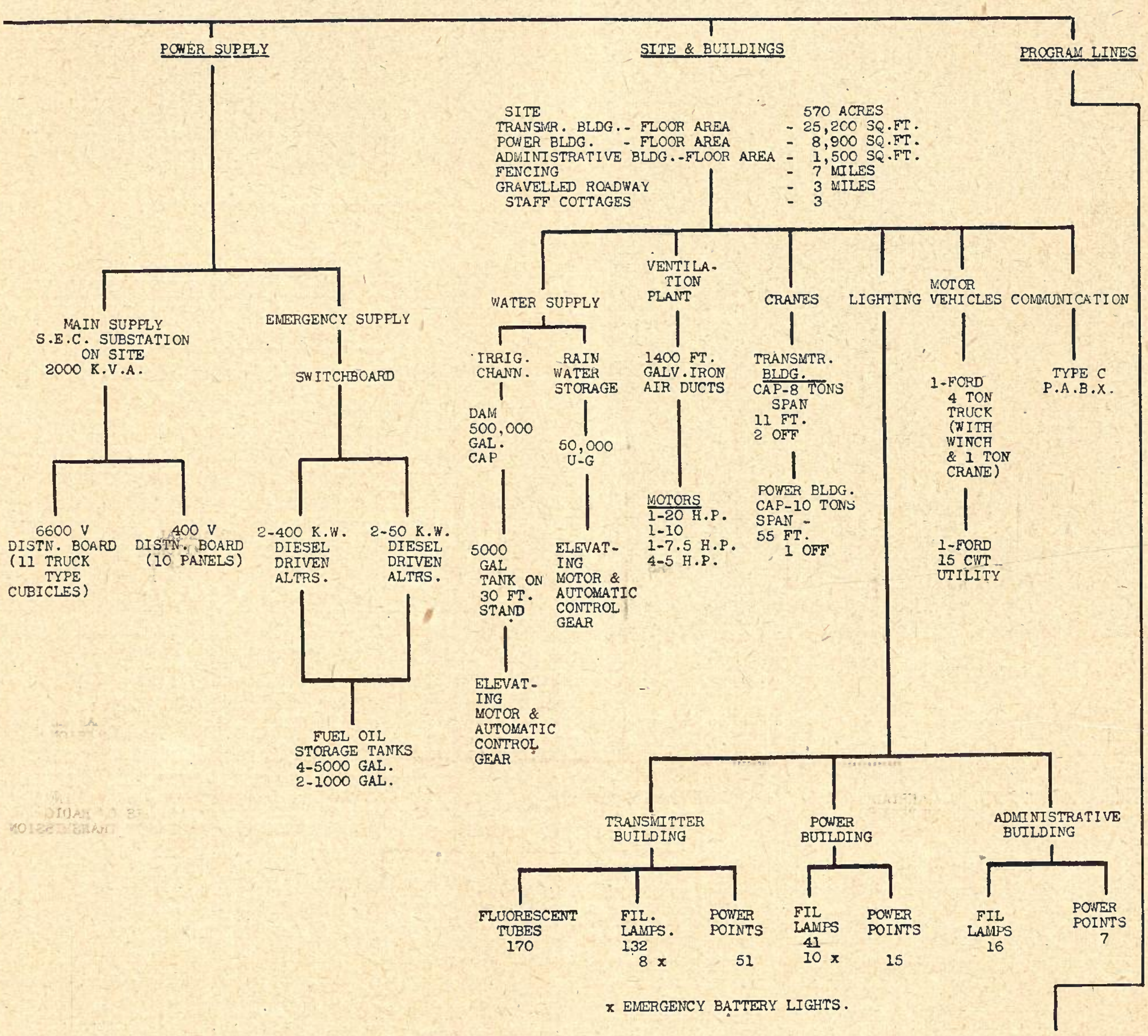
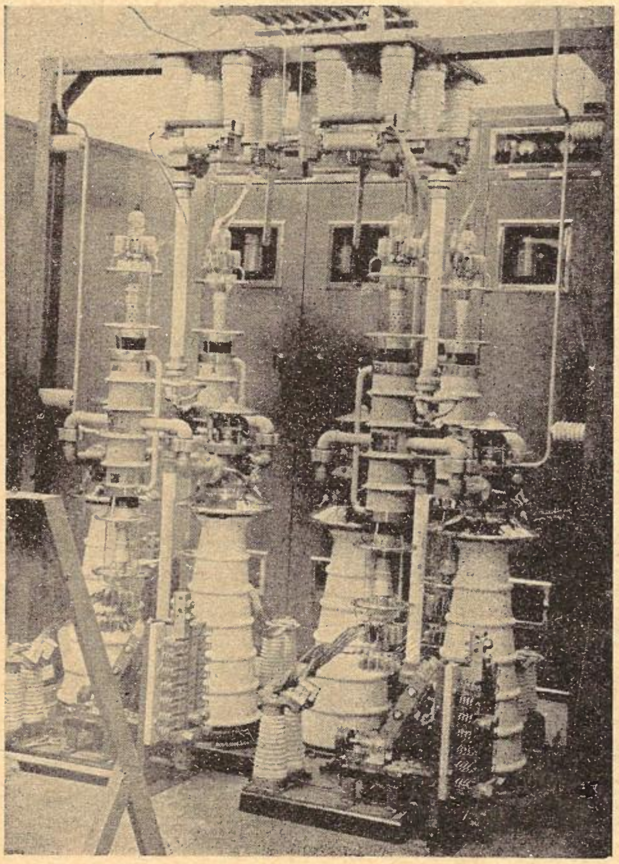


Fig. 4.

since it did encourage the resistance of those people."

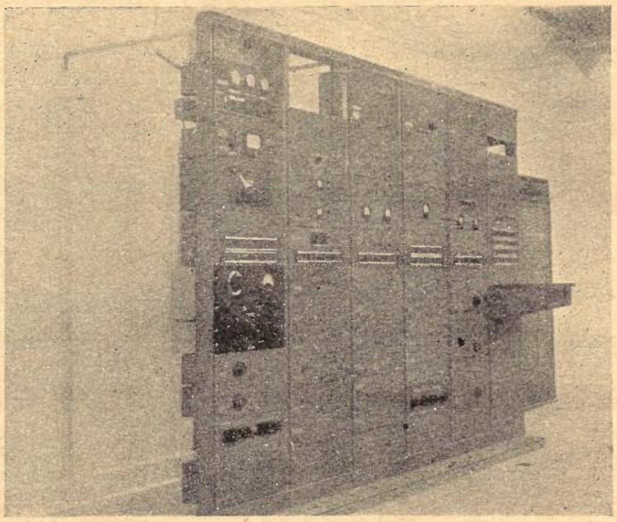
The Shepparton installation now known as "Radio Australia" has its use in peace as it had in war. Radio Australia is presenting to other nations news and information concerning the Australian viewpoint on international affairs. The programme matter broadcast is in the hands of the Department of Information, which uses data gathered by itself and several other Commonwealth Government Departments, while all technical services are provided by the Postmaster-General's Department.



100 K.W. transmitter modulator.

At the present time, the station is in operation for 20 hours per day, transmissions taking place in eight languages. Judging from the evidence in reports of trained observers in various countries and from hundreds of letters regularly received by the Department of Information from all parts of the world, the transmissions of Radio Australia are being well received.

The writer pays a tribute to the members of his staff, who contributed so much in ideas and long hours of labour during difficult times; to the staff engaged in actual installation work at Shepparton; to the staffs of the Research Laboratories Model Shop and the Postal Workshops, Melbourne, for the manufacture of special items; to the Contractors and their staffs for those large units of the installation which were provided under contract to unusual specifications; and, finally, to the staff of the Allied Works Council for the construction of the buildings, which must have presented some peculiar features, to say the least.



Programme control racks.

Appendix I.
INTERNATIONAL HIGH-FREQUENCY STATION, SHEPPARTON, "RADIO AUSTRALIA"

Main Groups of Work and Contractors

After design and developmental work by the Postmaster-General's Department, the supply and construction was divided into major groups. Specifications were issued, tenders called and contracts let in certain groups, while in others the work was carried out by the Department's staff. The main groups and contractors were as follow:—

Construction of the buildings and provision of building services.—Allied Works Council (now the Department of Works and Housing). Contractors: Prentice Builders Pty. Ltd. and J. R. & E. Seccull Pty. Ltd., of Melbourne.

Two radio transmitters each 100 to 140 kilowatts output and 6 to 22 megacycles per second. —Joint contract for manufacture in Australia and erection by Standard Telephones & Cables Pty. Ltd. and Amalgamated Wireless (A/asia.) Ltd., both of Sydney.

One radio transmitter, 50 kilowatts output, 6-22 megacycles per second.—Purchased from Radio Corporation of America Inc., and installed by P.M.G. staff.

Electric power supply at 66,000 volts 3-phase 50 cycles per second, with 2000 kVA substation on the site.—State Electricity Commission of Victoria.

Reserve electric power generating plant, consisting of two Crossley Co. diesel engines and Brush Co. alternators, 800 B.H.P., 400 kVA, 6600 volt, 3-phase, 50 C/s; and two diesel engine alternators, 84 H.P., 50 kVA, 400 volt, 3-phase, 50 C/s.—Supplied by the agents, William Adams & Co. Ltd., of Melbourne.

14 lattice steel guyed masts each 210 feet high.—Manufacture and erection by Sidney Williams & Co. Pty. Ltd., of Sydney.

19 directive aerial systems complete.—Construction and erection by P.M.G.'s staff.

12 miles radio-frequency transmission lines connecting aerial systems with transmitters.—Construction and erection by P.M.G.'s staff.

151 radio power switches for transmitter-aerial switching system. — Radio design by P.M.G.'s Department; manufacture by Australian General Electric Co. Ltd., of Melbourne; and erection by P.M.G.'s staff.

THE DESIGN AND CONSTRUCTION OF UNDERGROUND CONDUITS FOR TELEPHONE CABLES

A. N. Hoggart, B.Sc.

PART VII.: BURIED JOINT CONSTRUCTION, PRECAST JOINTING PITS AND MANHOLES
(Continued.)

Manhole Covers and Frames: The entrances to manholes are closed by means of manhole covers fitting into suitable frames. These are of two main types, namely, roadway manhole covers and frames which are specially designed to withstand heavy traffic loads, and footway types, which are lighter and not intended to support heavy loads.

The roadway type cover and frame at present in use are shown in Fig. 63. The single cover type provides an opening approximately 1' $8\frac{1}{2}$" square, while the double cover type gives a clear opening approximately 1' $8\frac{1}{2}$" x 3' $5\frac{1}{2}$". The double cover type uses two covers identical with that used for the single cover. In earlier roadway manhole construction it was usual to provide a small entrance using a single round or square cover. Nowadays the larger entrance provided by the double cover is preferred on account of the better working conditions provided in the manhole, particularly in relation to light and ventilation and ease of entry and exit. Both cover and frame are of cast iron suitably treated with a bituminous compound to reduce the incidence of corrosion.

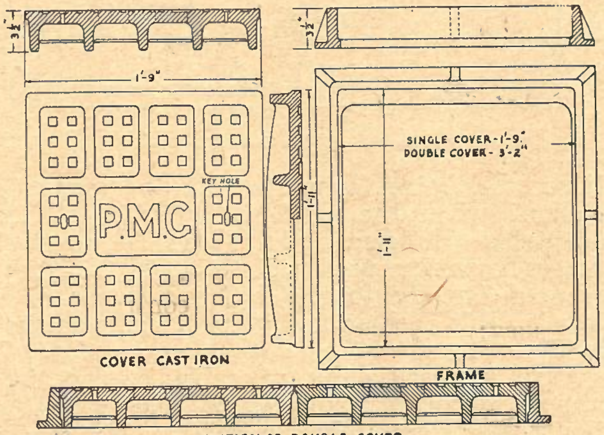


Fig. 63.—Roadway manhole cover and frame.

It will be noted that the cover is supported only on two opposite sides; this construction has been adopted to reduce the tendency of the cover to rock.

Footway type covers and frames are supplied in three sizes to suit various manhole and jointing chamber sizes. In this connection, see Figs. 55-59 inclusive in the previous issue of the Journal. The three sizes are:—

Single cover—Opening 2' 5" long, 1' $10\frac{1}{2}$" wide.
Small double cover—Opening 3' $11\frac{1}{2}$" long, 2' 5" wide.
Large double cover—Opening 4' square.

The usual construction has been cast iron, and this type of cover requires to be filled with concrete, which should be given a smooth finish flush with the cast iron. Fig. 64 is an illustration of the small double cover type; and it will be noted that a removable cross-bar is provided so that the cover is supported on all sides. The small single cover type uses the same cover in a small frame to suit, while the large double cover is of somewhat similar construction to the small double cover type, but of larger size.

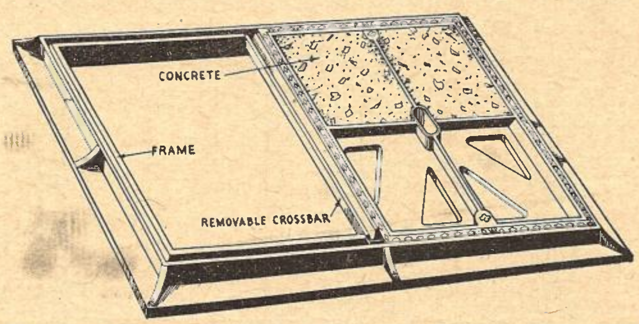


Fig. 64.—Footway manhole cover and frame. (One cover only shown, part of which is filled with concrete.)

An alternative type of footway cover and frame is shown in Fig. 65. This is fabricated from steel sections, the cover being essentially a sheet of chequer plate. A special locking device operated by a small manhole key is usually provided to prevent unauthorized opening of the cover. Although having the advantage of lower weight as compared with the concrete filled type (see page 33 of the previous issue of the Journal), experience has shown that this design is somewhat subject to warping of the cover and frame, resulting in the parts not fitting correctly together.

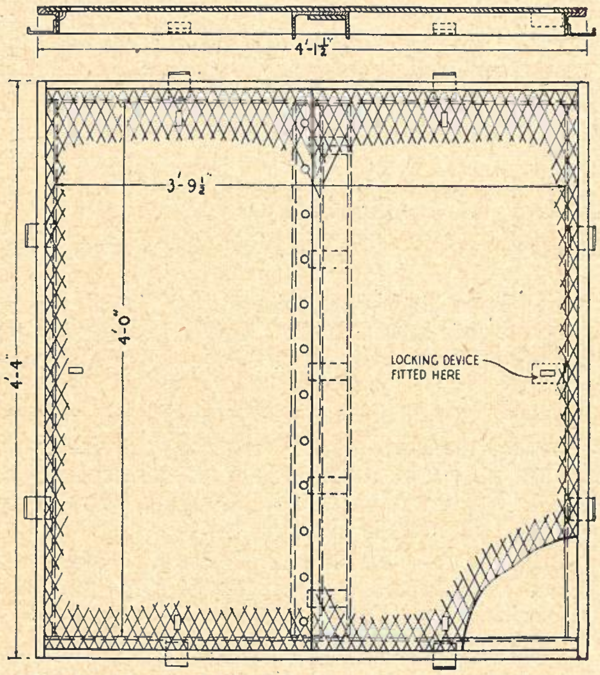


Fig. 65.—Footway manhole cover and frame, chequer plate type.

Cable Bearers: Where a manhole accommodates a number of cable joints, removable bearers are most suitable. The present standard type is shown in Fig. 66, and consists of a

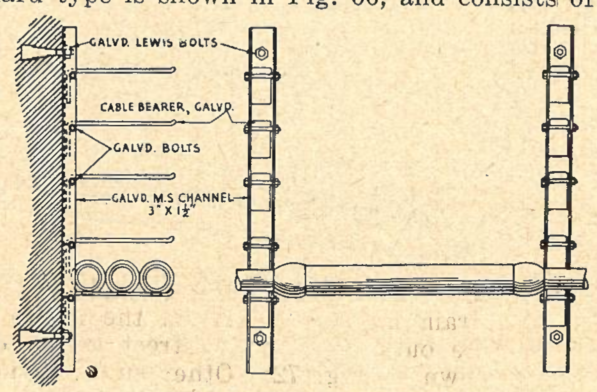


Fig. 66.—Cable bearer rack.

channel iron rack, which is secured to the manhole wall, and removable L-shaped bearers (Fig. 67), which fit into the rack in the manner shown. The bearers are available in varying lengths to suit different conditions. The channel iron rack may be secured to the wall by means of lewis bolts, which need to be installed in position during the construction of the manhole, which demands care in ensuring that the lewis bolts are correctly placed. Alternatively, expansion bolt anchors and ⅝" x 2" bolts can be used; these are suitable for installation after the manhole is constructed.

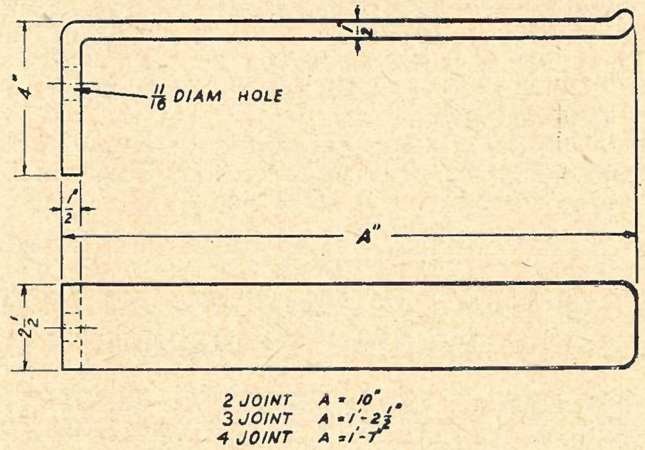


Fig. 67.—Cable bearer, movable.

Where only one or two cables are to be supported, fixed cable bearers as shown in Fig. 68 may be used. These require to be fitted during the construction of the manhole, and are therefore only suitable when the proper loca-

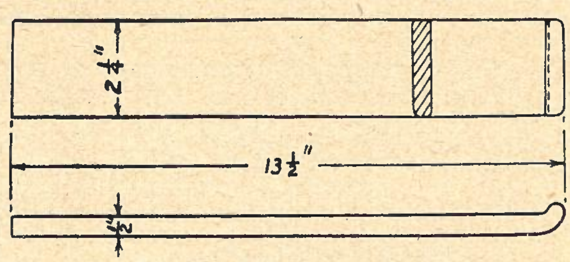


Fig. 68.—Cable bearer, fixed.

tions for cable supports can be accurately planned when the manhole is built. A more adaptable arrangement is to use the removable bearer normally used with channel iron racks, secured directly to the wall by means of expansion bolt anchors and ⅝" by 2" bolts as shown in Fig. 69.

Care in positioning of cable bearers is of utmost importance to ensure that cables and joints are adequately supported. Inadequately

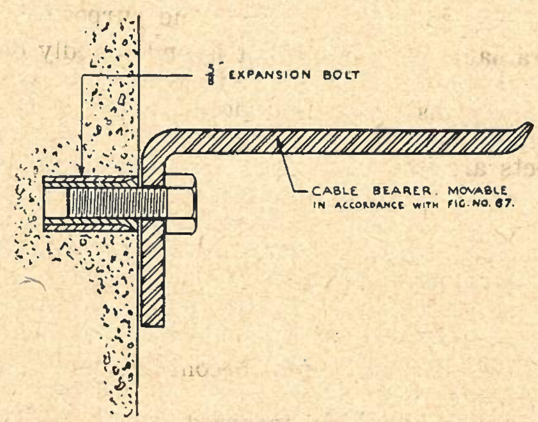


Fig. 69.—Method of using movable cable bearers without channel iron rack.

supported cables are liable to sag and are subject to fatigue failures of the cable sheath. Cables should be supported on either side close to the joint, but not under the joint itself. Elsewhere, it is desirable to support cables at no more than 2 feet intervals.

Manhole Steps: To provide means of access to manholes, steps may be set in the wall. The type of steps used in concrete manholes is shown in Fig. 70, and a similar step of flat sec-

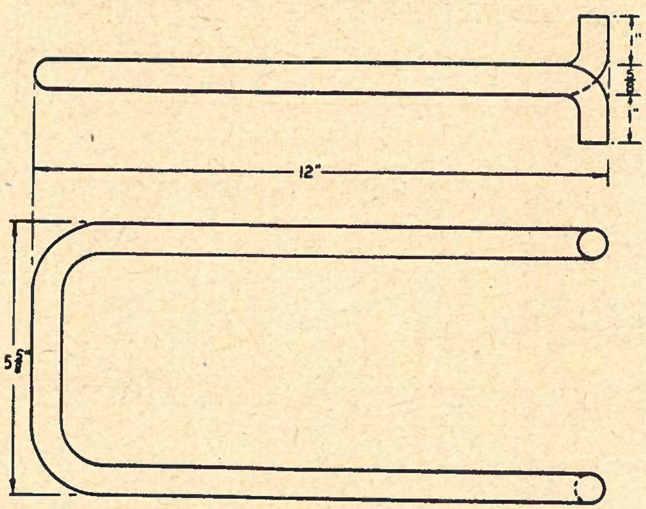


Fig. 70.—Manhole step for concrete manholes.

tion is available for brick manholes. Steps are normally fitted in two vertical rows, about 12 inches between centre lines of the rows, the steps being arranged alternately in each row with 12" vertical separation between steps. Steps should only be used on a wall against which not more than one or two small cables are run, otherwise cables will be damaged by workmen entering or leaving the manhole. If all walls are to be used for large sized cables, a removable steel ladder is preferred for access purposes.

Anchor Irons: These are as shown in Fig. 71, and are set in the manhole floor or walls to provide for attachment of cable hauling gear. Anchor irons are now used in lieu of ring bolts previously provided for the same purpose.

Drainage of Manholes: It is undoubtedly desirable that the whole of the conduit system should be as free from accumulated water as possible; and in this connection the following aspects are important:—

1. Risk of cable failure, particularly due to electrolysis or chemical corrosion, is considerably reduced if conduits are kept dry.
2. Working conditions in manholes are much better when these are dry, resulting in greater efficiency of the workmen and less liability of joints becoming damp when open.
3. Expenditure is incurred and much time lost in dewatering manholes in which water accumulates to any extent.

The theoretically ideal method of obtaining a dry conduit system would be to so construct it that water is prevented from entering the system at all times. This, however, is not economically practicable, and therefore current practice is to provide means for draining water away from the conduit system. At the same time, the entry of water into the system is prevented as far as is practicable with the type of construction in use.

The need for correct grading of conduits, to ensure that water will tend to flow along the conduits into the manholes, has been stressed in earlier sections. The removal of water from manholes can best be arranged by laying a drainpipe from a sump in the floor of the manhole to a suitable outlet. The choice of outlet will depend on local circumstances, such as depth of manhole, the natural fall of the ground and the relative levels of suitable outlets.

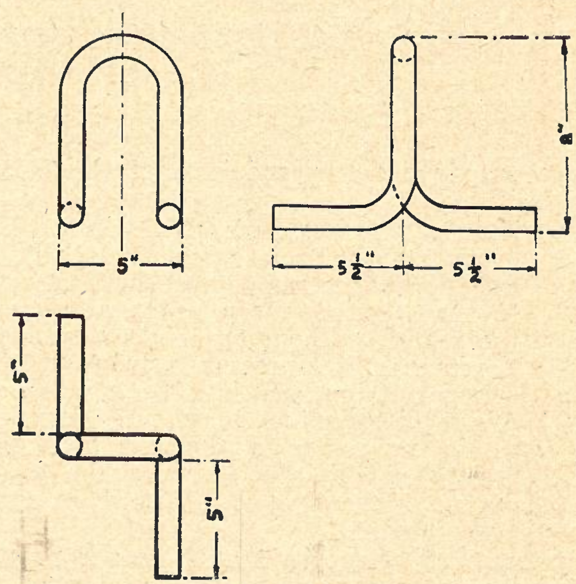


Fig. 71.—Anchor iron.

Where the natural fall of the ground is suitable, the drain may be laid from the manhole to a surface outlet, e.g., to a street gutter or kerb as shown in Fig. 72. Other suitable surface outlets are storm water channels, gulleys, etc. Frequently it is not practicable to provide a drain to a surface outlet, but an underground storm water drain may be available into which a suitable connection can be made. Where no other suitable outlet is available, it is sometimes practicable to make a drainage connection to a nearby sewer, subject, of course, to the agreement of the Sewerage Authority. Drainage to sewers can usually only be resorted to in special cases, where no alternative means of draining is available, as Sewerage Authorities are loth to grant permission for such drains to be connected to a sewer. It is also necessary to prevent sewage flowing back into the manhole, and also to permit the drain to be shut off if necessary, e.g., in the event of flooding of the manhole. Fig. 72 shows a drainage system for connecting to a sewer, and includes the following features:—

(a) A sluice valve to shut off the drain. The operating spindle is extended to just below the surface and a small cover provided so that the valve can be operated from the surface without opening the manhole.

(b) A reflux or back-pressure valve to prevent sewage flowing back into the manhole.

(c) A sump with outlet to drain so arranged as to reduce to a minimum the possibility of silt, etc., entering the sewer. As an alternative, a "P" trap is sometimes used.

It frequently happens that it is not practicable to provide a separate drainage outlet for each manhole; but one manhole can be drained to the next until a suitable outlet is obtained. In such cases the drainpipe is laid in the same trench as the conduits, the trench being made sufficiently deep to suit the drain. The drainpipe is, of course, laid under the conduits, the trench being refilled to the required level before the conduits are laid. Special care is necessary to ensure that the refilled soil is well consolidated so as to form a firm bed for the conduits. Fig. 74 shows a typical arrangement of a manhole when "through" drainage is in use.

For drainage purpose second-grade 4″ earthenware pipes ("untested" pipes) are favoured. These are not required to conform to the normal specification for earthenware pipes, and can usually be obtained at cheaper rates. They are, however, quite suitable for drainage purposes, and can be laid more economically than pipes used for conduits, in that the same care regarding alignment, etc., is not necessary, the main requirement being an even grade of not less than 1 in 200 so that water will drain away. Cement mortar is used for jointing.

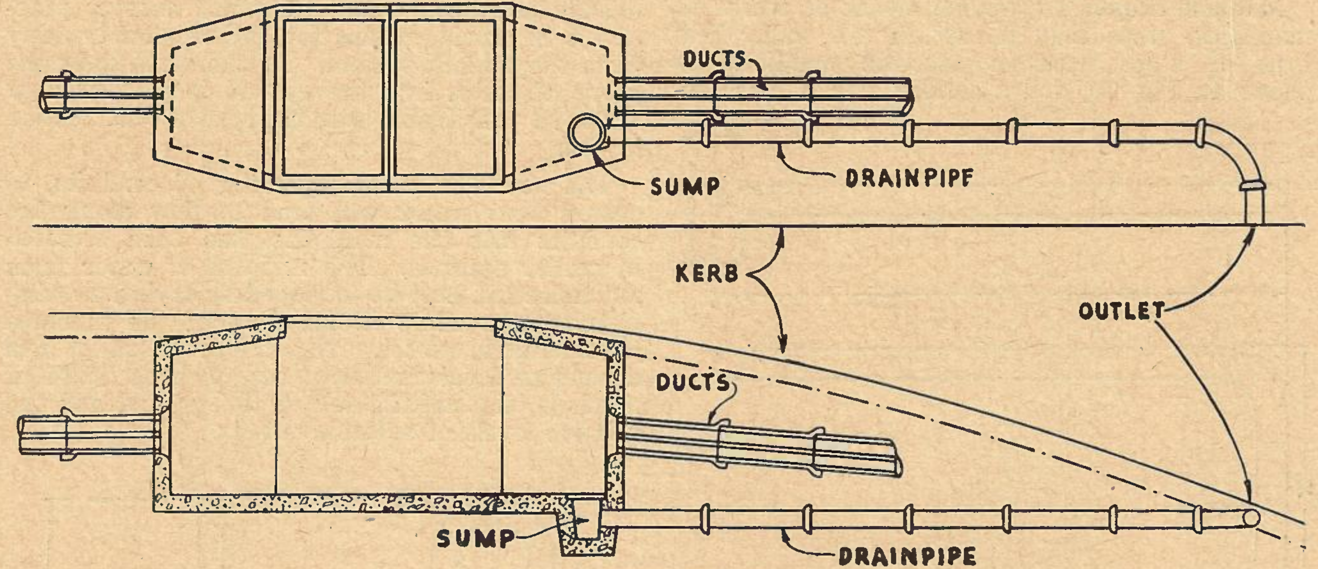


Fig. 72.—Drainage to kerb.

Where E.W. pipes are not available, other pipes such as concrete may be used. The fact that these are in six foot lengths is, however, a disadvantage if, as frequently occurs, curves are to be negotiated in the drainage run.

The actual arrangement of the drainage outlet from the manhole is important. In one method the drainpipe is laid through one wall of the manhole, the invert of the pipe being at or slightly below the level of the manhole floor. The mouth of the pipe is covered with a cast iron grating and the manhole floor is given a slight slope to the drain. With this arrangement there is a tendency for silt and rubbish to collect on the floor of the manhole, partially or completely blocking the drain.

A preferable arrangement is one which includes a silt trap, and this is best arranged by installing a sump in the floor of the manhole, the drainpipe being led into the sump, which is covered with a grating. In some cases it has been the practice to place the sump in the middle of the manhole, the floor having a slight fall from the walls to the sump. The floor is then likely to be continually wet if water is entering the manhole from the conduits. As cable jointers are called upon to work long periods in a manhole, it is desirable that the floor, particularly the centre portion, be dry. This can be arranged by placing the sump at one end of the manhole, with a shallow "gutter" in the floor around the walls draining into the sump; the floor is graded from the centre to the sides and ends of the manhole.

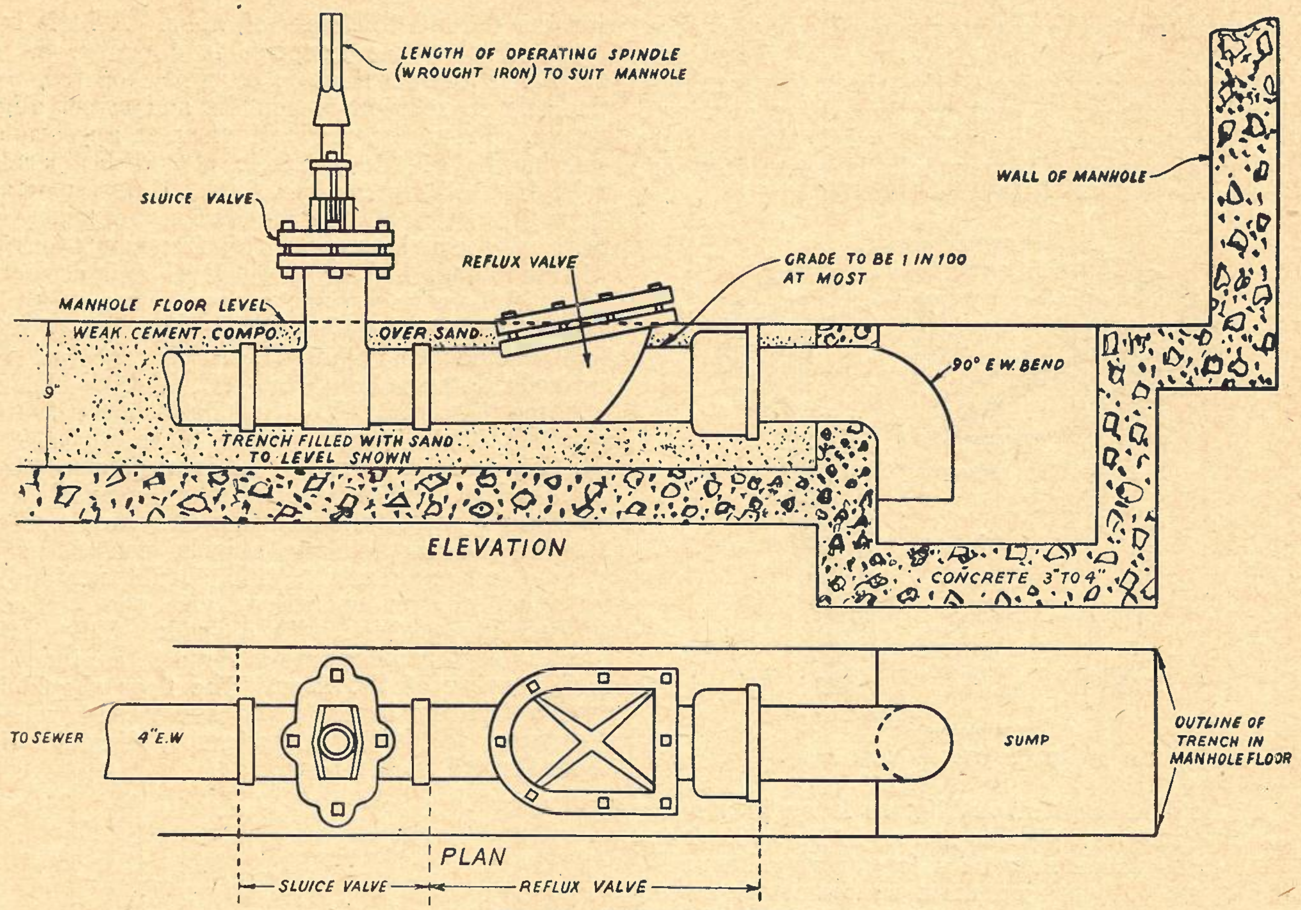


Fig. 73.—Drainage to sewer.

The sump can be conveniently formed in situ in concrete by the use of a mould such as shown in Fig. 75; the interior of the sump should be carefully finished smooth with a trowel. The drainpipe should enter the sump near the top, as this permits of conduit rods being pushed down the drain to clear a blockage. An alternative is to use a 9" earthenware drainpipe set in the floor of the manhole, a hole being cut in the side of this pipe for entry of the drainpipe.

Ventilation of Manholes: There is frequently a tendency for foul or poisonous gases, e.g., coal gas, to accumulate in underground structures, particularly manholes. Arising from the presence of such gases, there is a hazard to health or life of workmen, also a danger of explosions. In many cases a suitably designed ventilation system will materially improve the condition of the air in the manholes. Ventilation will also reduce the condensation of moisture in underground structures.

One method of ventilation is to use manhole covers provided with ventilation holes; at present these are only available in the case of roadway type covers, in which case covers similar to Fig. 63, but with a number of small

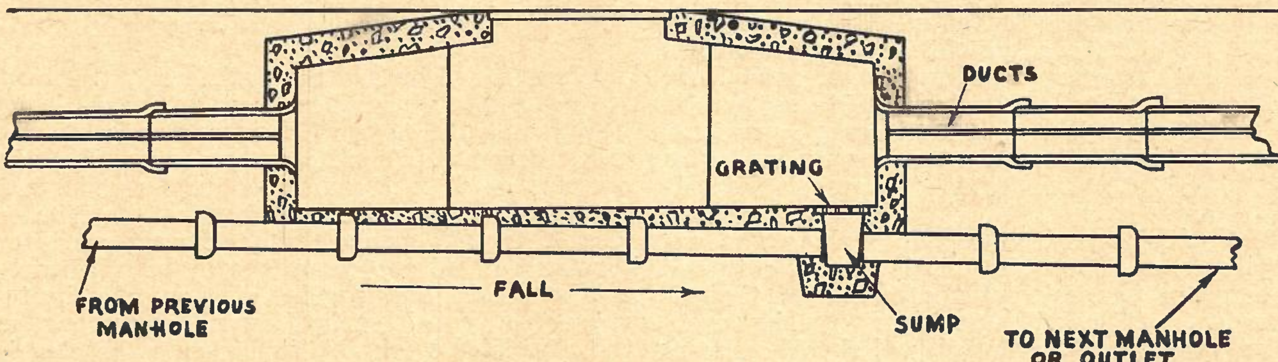


Fig. 74.—"Through" drainage.

holes through the cover, are used. In the case of footway manholes, the use of large-size covers usually permits of the air in the manhole being sweetened in a short time after opening, so that the need for special ventilation is not so great, unless the manhole is very deep or particularly liable to accumulate foul air.

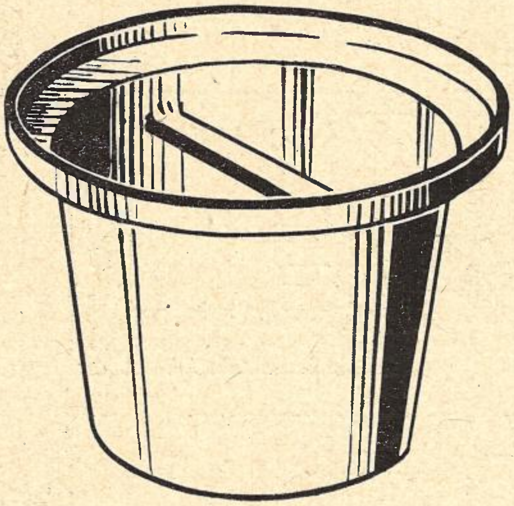


Fig. 75.—Mould for manhole sump.

A further form of ventilation is by means of an external vent pipe as shown in Fig. 76. The vent pipe, which may be a length of galvanized iron pipe 3 inches or more in diameter, fitted with a suitable cowl, should preferably be located in an open position, e.g., on the kerb line, where it is not shielded from the wind.

Tests have shown that for efficient ventilation of a manhole it is important that two openings to the open air be provided, one of which should enter near the top of the manhole and one near the bottom. These conditions can be realized by any of the following methods:—

(a) Vent pipe entering near bottom of manhole and ventilated cover.

(b) Vent pipe entering near top of manhole and drain to surface outlet from manhole sump.

(c) Adjacent or near adjacent manholes, each with ventilated cover or vent pipes, the conduits being used to circulate air from one manhole to the next. It has been found that a complete run of manholes can be ventilated by a few well-placed vent pipes, particularly if these are at different levels; in such cases, provision of ventilation at the lowest and the highest manholes in the run is important.

Method of Construction: In making the excavation for the manhole it is desirable to use a template to mark out the outline of the excavation. A suitable template can be made from, say, 3" x 1" hardwood, and should conform to the shape and size of the manhole, allowing for the desired thickness of walls. A little care in positioning the template is desirable to ensure that the manhole is correctly located, particularly in relation to conduit and street alignments. From the point of view of appearance, the length of the manhole should be parallel with the building or kerb line. It is important that the walls of the excavation be kept vertical; this can be ensured by frequent checking with a plumb bob or spirit level and straightedge. Where necessary, owing to the depth of excavation or condition of the soil, the excavation should be timbered, using one of the methods described in Part III. (Vol. 5, No. 2).

When the excavation has been made to the required depth, the drainage pipes are set in position, and, if a preformed sump is used, this is installed. The floor of the excavation is levelled off and any loose soil well rammed. The floor of the manhole can now be poured, using a 1-2-4 concrete mix. This should preferably be done in one operation, and the concrete worked into position with a spade. Where the sump is cast in situ, this is done in conjunction with pouring of the floor. The floor should be graded slightly towards the sump, and, where necessary, to drainage gutters leading to the sump formed in the floor.

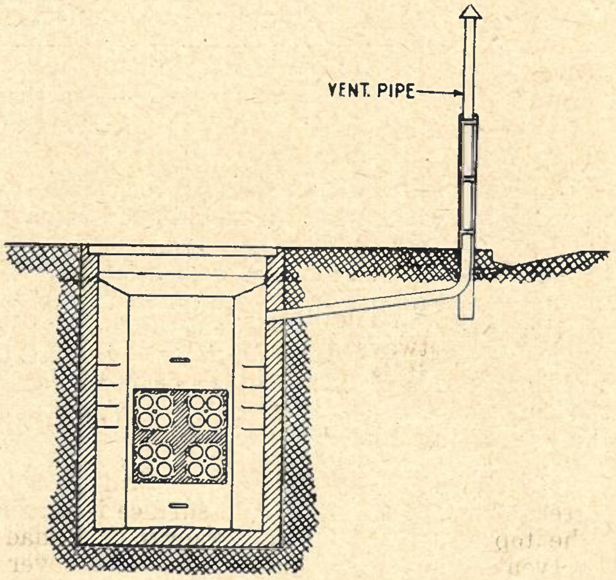


Fig. 76.—Ventilation of manhole.

When the floor has set sufficiently, the form for the walls is placed in position, boards being placed over the floor to prevent damage to the green concrete. The forms are normally constructed of 6" x 1" hardwood, and should conform to the exact size and shape of the interior of the finished manhole. The boards used for construction of the form should be accurately cut to length and square, also set closely together so that irregularities will not show on the completed work. Adequate cross bracing is essential to support the weight of the fluid concrete. The form will normally be built above ground and lowered into position.

To ensure a good bond between concrete previously laid in the floor and new concrete to be poured in the walls, the old concrete should be cleaned with a wire brush and a thin grouting of neat cement laid across the join. In pouring the concrete in the walls it should be well rodded and rammed with a narrow blade; this ensures that the concrete is worked well into position, and any air pockets forced out. It is particularly important that concrete should be worked well round reinforcing rods or wires. Immediately the walls are cast the roof, if any, should be poured; where practicable, this should be done in one operation so as to provide a strong structure and to avoid a seam. Items such as anchor irons, steps and lewis bolts for cable racks, should be set in the walls during the construction process, the forming boards being suitably notched to hold these fittings in position.

On completion of these operations the frame for the manhole cover can be set in position. Some care is necessary in this operation to ensure that the surface of the cover will be at the correct level. The top of the cover should not normally be below the level of the surrounding ground, so as to mitigate any tendency of water seeping into the manhole through the cover. In permanent pavements such as concrete or asphalt, the top of the cover should be set slightly (about $\frac{1}{8}''$) above pavement level, and the final reinstatement finished flush with the frame. In nature strips or unpaved footways, the frame should be set $\frac{1}{2}$ to 1 inch above the level of the surrounding ground; in such cases a concrete edging about 4" wide round the frame is desirable, the concrete graded up from the ground level to the top of frame. In unpaved footways which may be paved in the near future it is desirable to ascertain the proposed footpath levels and fit the manhole frames accordingly, if practicable. This may result in the cover being above or below the level of the surrounding ground; but usually will present no great difficulty providing the surface is graded to the top of the cover and arrangements made to prevent water accumulating above a cover set lower than the surrounding ground. This procedure obviates the necessity for resetting covers and frames when the footway is constructed.

When the concrete has set sufficiently, the forms are removed. To provide a clean surface to the manhole it is considered worth while to render the whole of the interior with cement mortar, which is trowelled to a smooth surface.

It is the practice with some administrations to use permanent forms for manhole construction, and this would appear to have advantage where a number of manholes of the same type is to be built. Such forms, if suitably designed so as to be easily assembled and dismantled, should effect savings in time as compared with the practice of constructing each individual form from timber. Permanent forms may be made either wholly of steel or of wood faced with steel or iron sheet; a sheet iron surface is an advantage, as this gives a sufficiently smooth surface to the concrete without final plastering.

When constructing manholes in brick, a concrete floor is laid in the normal way and the walls then built up on this foundation. Expert bricklayers only should be used to obtain a satisfactory job. In 9 and 14 inch work the method of laying known as "English Bond" is preferred; in this the length of the bricks runs at right angles in alternate layers. The joints in the brickwork should be pointed flush with the surface.

Acknowledgment: The writer wishes to acknowledge the assistance of various colleagues in the preparation and checking of these articles. In particular, the advice of Mr. C. B. Taylor on many practical aspects has been very helpful.

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PRACTICAL APPLICATIONS OF CATHODE RAY TUBES—FROM CROOKES' TUBE TO RADAR

J. H. T. Fisher, B.E., A.M.I.E.(Aust.)

1. INTRODUCTION

1.1. **Historical:** The cathode ray tube may be considered to have evolved from the experiments of Sir William Crookes about 1873. Experiments on electric "glow" discharges between metallic electrodes in sealed and evacuated glass tubes had already been carried out by others, and the dark space between the cathode (or negative electrode) and the first part of the discharge glow became known as the Crookes' dark space. Crookes found that when the pressure in the tube was reduced to the order of 0.01 mm. of mercury, this dark space extended to fill the whole of the tube, and the glass walls of the tube began to fluoresce. He also found that if an object was placed at the anode (or positive electrode), fluorescence ceased on the end of the glass tube beyond the object, as though a shadow of the object were being cast on the wall of the tube by rays moving in straight lines from the cathode (Fig. 1). The presence of some form of rays proceeding from the cathode had be discovered by Plücker as early as 1859, and it was subsequently shown by Johnstone Storey in 1890 that these "cathode rays" consist of particles of matter carrying unit negative charges of electricity, which we now call "electrons," and travelling at high velocities. In the same year, Hess suggested that these rays might be employed to trace curves, and in 1897 Braun developed a cathode ray tube in which the rays were deflected by the electro-magnetic field of coils round the neck of the tube, and Sir J. J. Thomson developed a tube in which deflection was accomplished by an electro-static field between two metal plates inside the tube.

In 1905, Wehnelt found that much stronger cathode rays could be produced with less than 1000 volts, instead of voltages of 50,000 or more as had been used previously, by having a cathode coated with alkaline earth material and heated by a current-carrying filament. He also suggested (1903) the concentration of the rays into a narrow beam by a small cylindrical electrode surrounding the cathode and having a negative potential with respect to it. These developments of Wehnelt may be considered as the birth of the cathode ray tube as we know it today. During the next 30 years, further important developments took place, but the cathode ray tube remained a laboratory curiosity. About 1935, commercially produced cathode ray tubes, and units containing them called cathode ray oscillographs, appeared on the market at comparatively low cost, and engineers and physicists began to appreciate the value of the cathode ray tube as a tool for the measurement and investigation of all kinds of electric phenomena. The object of this article is to discuss and describe some of the more important practical applications of the cathode ray tube.

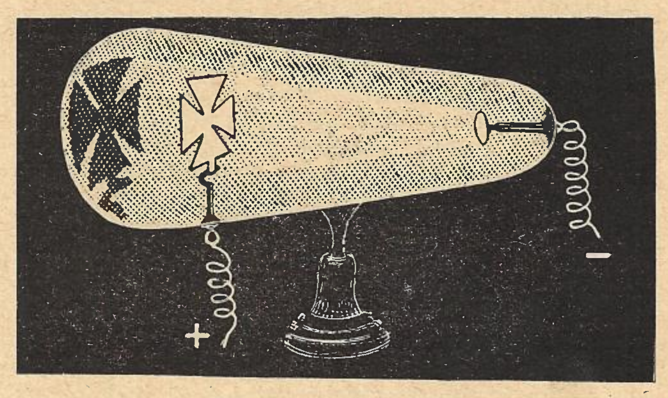


Fig. 1.—Crookes' Tube.

1.2. **The Construction of Cathode Ray Tubes:** Most cathode ray tubes have a glass envelope in the form of a narrow cylinder at one end, which broadens out into a cone, the base of which, forming the other end of the tube, is slightly dished. The smallest commercial cathode ray tubes have a maximum diameter of about 1" and the largest about 22". There are two main classes of tubes:—

(a) **Gas-filled type:** These contain a rare gas, usually Argon, at a pressure of the order of 5×10^{-3} mm. of mercury. The simplest type is shown in Fig. 2. It contains a number of metal electrodes connected to contacts in the base of the tube. The cathode K is usually coated with an oxide which, when heated by A.C. or D.C. flowing through the filament F, emits electrons copiously. Surrounding the cathode is the grid or Wehnelt cylinder C, having its axis coincident with that of the tube. It is given a negative potential with respect to the cathode, and its functions are:—

(i) to concentrate by repulsion the electrons emitted by the cathode K into a small region along the axis of the tube; and,

(ii) by adjustment of the potential applied to the cylinder, to regulate the number of electrons emitted by the cathode K and thus regulate the intensity of the electron stream. This function is analogous to that of the control grid in an ordinary radio valve.

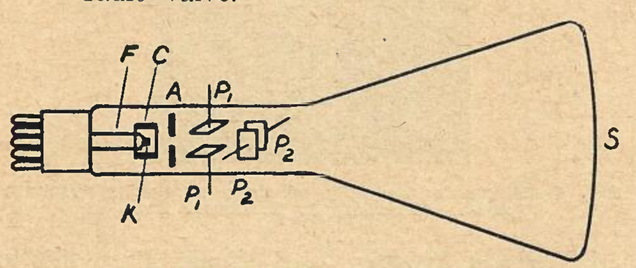


Fig. 2.—Gas-filled cathode ray tube.

Immediately in front of the Wehnelt cylinder is the anode A, which usually takes the form of a disc having a small hole in the centre at the axis of the tube. It is given a positive potential of several hundred volts with respect to the cathode, and its function is to attract towards it and accelerate the electrons emitted by the cathode K. Most of the electrons, having been concentrated along the tube axis by the negative cylinder C, pass right through the hole in A, and continue along the tube at high velocity until they strike the fluorescent screen S coating the inside of the large end of the tube. This coating is of a crystalline material, which fluoresces or emits light at points where it is bombarded by electrons. One of the most commonly used materials is zinc silicate, which gives a green fluorescence. Other materials give other colors of fluorescence, and have various degrees of afterglow when the electron bombardment ceases at any point. The brightness of the fluorescent spot depends on the intensity of the electron stream, which is controlled by the potential on the Wehnelt cylinder C. As the electrons travel toward the screen S at high velocity, some of them strike molecules of the gas contained in the tube and produce ionisation, i.e., they cause the molecules to break up into positive ions and further electrons. Now, these positive ions have a much greater mass and hence lower velocity than either the secondary electrons which are produced with them or the electrons in the main electron stream, and their comparatively slow movement away from this stream means that a positive charge is formed along the stream which tends to concentrate the electrons still more along its axis. This phenomenon is known as "gas-focussing," as it has the effect of reducing the area of cross section along the electron stream, and hence reduces the size of the fluorescent spot produced on the screen S. Just in front of the anode are two pairs of plates, P_1 and P_2. The plates of each pair are equidistant from and usually parallel to the tube axis, and the P_2 plates are perpendicular to the P_1 plates. If a voltage is applied across either pair of plates, electrons will be attracted toward the plate which is positive at any instant, and so the electron stream in passing between those plates will bend towards the positive one. Thus potential differences on these pairs of plates will deflect the electron stream, and hence the fluorescent spot on the screen S, in either of two directions at right angles. Therefore, if we imagine two intersecting diametral lines drawn across the screen S parallel to the deflecting plates P_1 and P_2 respectively, the co-ordinates of the position of the fluorescent spot on S with reference to these lines as axes, will depend on the potentials applied to P_1 and P_2. Hence P_1 and P_2 are often referred to as the X and Y plates or the horizontal and vertical deflecting plates respectively.

Deflection is sometimes performed by means of coils instead of plates. Two coils may be provided, mutually perpendicular, and each with the two halves of its winding on opposite sides of the cathode ray tube, so that their axes intersect that of the tube at right angles. The deflection of the spot will depend on the ampere-turns of the coils at any instant, and the sense of deflection will obey Fleming's left-hand rule, considering the electron stream as a wire carrying a current towards the cathode K. Electro-magnetic deflection makes a simpler cathode ray tube practicable, as the plates P_1 and P_2, used for electro-static deflection, may be omitted; but deflecting coils are useful over only a limited range of A.C. frequencies, and consume power, whereas deflecting plates can be used for all frequencies, and the power loss in them is negligible at all but ultra-high radio frequencies.

(b) **High vacuum type:** These are evacuated to a pressure of the order of 10^{-6} to 10^{-7} mm. of mercury. A typical high-vacuum cathode-ray tube is shown in Fig. 3. In such tubes the gas-focussing effect is, of course, absent, and some other means has to be provided to focus the electron stream to a fine spot on the fluorescent screen. The cathode K, filament, and Wehnelt Cylinder C are similar to, and perform the same functions as, those in the gas-filled tube; but, beyond the disc anode A_1, are two additional anodes, A_2 and A_3. A_1 is given a positive potential of several hundred volts with respect to K, and is usually a disc with a hole at the centre. A_2 may have a slightly lower positive potential (which is usually adjustable in the outside circuit), and is generally a partly-closed cylinder. A_3 has a positive potential of several thousand volts with respect to K, and may be a metallic coating on the inside of the glass tube. The higher the potential on A_3, the greater is the final velocity of the electrons, and the smaller the deflection sensitivity. With such an arrangement of anodes, the equipotential surfaces in the spaces between them may have convex or concave forms, depending on the shape of these electrodes and the potential differences between them. These curved equipotential surfaces cause the electrons to travel in converging or diverging paths, so that the anode assembly performs a function similar to that of a lens with light rays. Hence the assembly is known as an electron lens, and the theory of the geometrical behavior of streams of electrons passing through charged electrodes has become known as electron optics. The form of the equipotential surfaces may be varied by adjustment of the potential on A_2, and by such an adjustment the electron stream can be made to come to a focus on the fluorescent screen, giving a very small and sharply defined fluorescent spot.

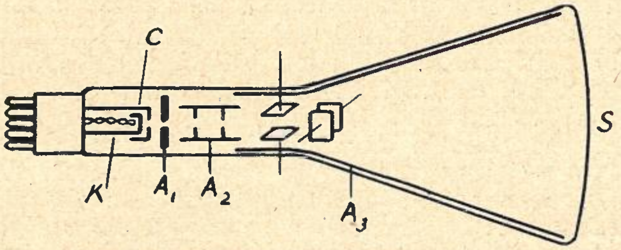


Fig. 3.—High-vacuum cathode ray tube.

Deflecting plates or coils can be used with high-vacuum cathode ray tubes in the same way as with gas-filled tubes. Some medium vacuum tubes have only two anodes, in which case the potential on the first of these is made adjustable for focussing.

At very high frequencies of deflection, gas-filled cathode ray tubes are subject to defocussing, as the heavy positive ions are left behind by the rapidly sweeping electron stream and the gas-focussing becomes inoperative. On the other hand, high vacuum cathode ray tubes are free from defocussing even at the highest deflection frequencies. Fig. 4 shows the electrode assembly or "electron gun," as it is sometimes called, of a three anode high vacuum tube. "Sh" in this diagram is the Wehnelt cylinder. The leads from the various electrodes are usually brought out to pins on a suitable contact base at the small end of the tube. Frequently, the last anode is commoned to one each of the P_1 and P_2 plates inside the tube, which reduces the number of leads coming out. It is usual, for safety and shielding considerations, to earth either the cathode K or the final anode.

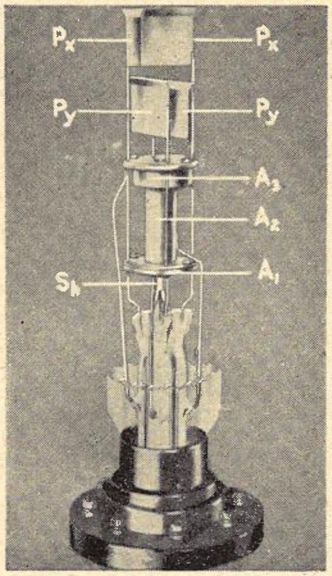


Fig. 4.—Electrode assembly of three anode high-vacuum tube. (Courtesy A. C. Cossor Ltd.)

1.3. **Power Supply to Cathode Ray Tubes:** Power for the tubes may be from batteries, but it is usual to employ a power transformer on the 230V A.C. mains feeding a rectifier valve with adequate smoothing on the output. The cathode ray tube filament is usually run on a separate transformer winding at voltages from 0.4 to 6.3V. A.C. The working potentials for the other electrodes are picked up from a high resistance potential divider placed across the rectifier output. Potentiometers forming part of this potential divider are used to make the necessary voltage adjustment for the cathode ray tube electrodes.

Fig. 5 shows a schematic representation of a cathode ray tube, with its associated potential divider, the adjustable controls being given their conventional designations. An adjustable bias potential is usually provided for each pair of deflecting plates, so that any deflection due to stray magnetic fields may be compensated for, and the spot either centred or moved to any desired point on the fluorescent screen before other deflecting voltages, which are to be investigated, are applied.

A resistance R_g, in series with the lead to the Wehnelt cylinder C, provides an input load for grid or "intensity" modulation; a similar resistance R_a, in series with the lead to the final anode A_3, provides an input load for anode or "sensitivity" modulation. These two functions will be described later.

The effect of potential variations on the electrodes which chiefly concern us may be summarised as follows. All potentials are with reference to that of the cathode:—

(i) **Grid, or Wehnelt cylinder C:** More negative potential decreases spot brightness. Less negative potential increases spot brightness. The bias potential on C may be modulated by A.C. voltages injected across the series resistance R_g.

(ii) **Focussing anode A_2:** An optimum potential will produce correct spot focus and, in general, this will be different for any change in potential of C or A_3.

(iii) **Final anode A_3:** More positive potential increases spot brightness and decreases deflection sensitivity. Less positive potential decreases spot brightness and increases deflection sensitivity. The potential of A_3 may be modulated by A.C. voltages injected across the series resistance R_a.

(iv) **Deflecting plates:** Voltages applied across either pair produce deflection of the spot parallel to the line joining the plates.

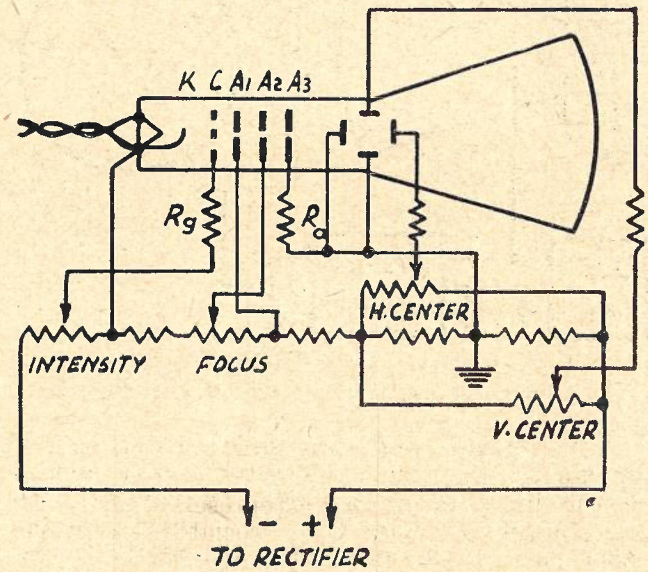


Fig. 5.—Typical potential divider for cathode ray tube.

2. PRACTICAL APPLICATIONS

2.1. **General:** In operating cathode-ray tubes, they should be kept well away from stray magnetic fields, which may deflect the electron stream and give misleading results. An efficient earth connection should always be provided, to minimise electrical pick-up effects, and as a safety precaution because of the high voltages used. The fluorescent screens of these tubes are subject to ageing or loss of their fluorescent property if subjected to too intense electron bombardment for any length of time; for this reason, the intensity of the fluorescent spot should never be made greater than is necessary for convenient observation, and the spot should never be allowed to remain stationary at a single point on the screen for longer than is essential. The high vacuum tubes, especially, should be handled with care, and should not be allowed to lie on gritty surfaces, which may scratch the glass; because of their peculiar shape and their high degree of vacuum, the glass of these tubes is subjected to considerable mechanical stress, which makes them more susceptible to implosion than most other types of vacuum tubes.

The most commonly used cathode ray tubes for oscillographic work are those having 3" or 5" diameter screens, which operate at about 1000 or 2000V. maximum plate potential for high vacuum types, and have a deflection sensitivity of about 0.3 to 0.8 mm. per volt D.C. (applied directly to the deflecting plates). Most commercial oscillograph units include one or more amplifiers to increase the deflection for small input voltages, but full consideration should be given to phase change and possible phase distortion or frequency distortion in such amplifiers in interpreting the trace on the cathode ray tube screen when they are used. We will now consider a number of useful applications of cathode ray tubes, and it will be convenient to classify these according to the number of variable quantities whose relationships are to be observed on the cathode ray tube screen. The illustrative circuits in Figs. 6 to 20 are given in a simplified form to show the underlying principle in each case, and are not intended to be complete. In each figure, the appearance of a typical fluorescent trace on the screen is shown in a circle to the right of the cathode ray tube.

2.2. **Applications Involving One Variable.—Measurement of D.C. or A.C. voltages and currents:** The cathode ray tube may be used to measure either D.C. or A.C. voltages by the spot deflection produced by direct application to the deflecting plates (which should be free of other circuit connections), and a high vacuum tube used in this way has the advantage of being quite independent of frequency, in the case of A.C., up to about 100 megacycles, when proper precautions are taken with the leads. The sensitivity in such measurements is small, and as this is dependent on anode voltages, which may vary, the tube requires calibration each time it is used for this purpose. While D.C. voltages merely deflect the spot, A.C. voltages (due to persistence of vision), at frequencies greater than 12½ cycles/sec., produce a line; the length of line represents the total peak-to-peak value of the voltage wave, and **not** the R.M.S. value. Amplifiers may be used to increase the sensitivity, but these limit the frequency range, and calibration is still necessary. Therefore, the cathode ray tube is not particularly suitable for this purpose, except in special cases, and the use of a valve voltmeter is generally preferable. The same applies to current measurements, which must be made by measuring the potential drop produced across a shunt of suitably low resistance value.

2.3. **Applications Involving Two Variables:** In the following applications, the variables are applied to the deflecting plates only:—

(a) **Comparison of frequencies:** It is sometimes necessary to compare electrical frequencies, as when synchronising two oscillators, when measuring an unknown frequency by comparing it with that of a standard oscillator, or when calibrating an oscillator against a standard. This may be done simply and with great accuracy by applying the two frequencies to be compared to the two pairs of deflecting plates respectively, of a cathode ray tube, as in Fig. 6. The resulting figures produced on the fluorescent screen are known as Lissajous figures, and a discussion of their interpretation will be found in any good textbook of Physics (under Simple Harmonic Motion). The form of the figures depends on both the frequency relationship and the phase relationship of the two inputs, and the figures for simple numerical frequency ratios up to 10: 1 are easily recognised after a little practice. With the simplest frequency ratios the following figures are obtained on the screen:—

Frequency Ratio of Inputs	Phase Difference of Inputs		
	0 or 180°	90° or 270°	Intermediate
1 : 1	straight line	circle (if amplitudes equal)	skew ellipse
2 : 1	parabola	figure eight	skew figure eight

The figures for higher and fractional frequency ratios are more complicated, but a general rule is, regarding the figure as enclosed in a rectangle, count the number of loops of the figure touching two adjacent sides of the rectangle. The ratio of the number of loops on these two sides is the inverse frequency ratio of the inputs producing deflection parallel to those sides.

When the phase relationship is exactly zero or 180° the loops will close so that half the figure is a retrace of the other half, making the pattern unsuitable for analysis. This is easily overcome by very slightly changing the frequency of one input so that a slight change in phase difference is produced, when the loops will slowly open out and ultimately close again. When the frequency ratio is greater than 10: 1, it becomes difficult to count the number of loops; but it is possible to calibrate an oscillator by this method at 25 points between 300 and 3000 cycles per second, by comparison with a single standard 1000 cycle source, without having to count more complicated frequency ratios than 11: 4. Two other methods of frequency comparison will be discussed later.

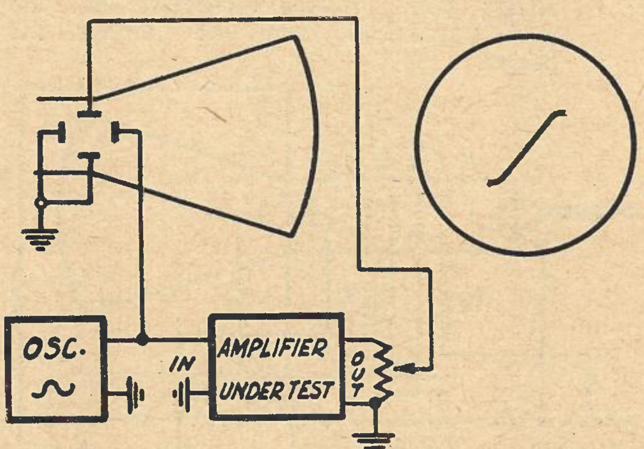


Fig. 7.—Overload and harmonic distortion of amplifiers.

(b) **Overload and harmonic distortion of amplifiers:** When an oscillator output is applied to the input of an amplifier in parallel with one pair of deflecting C.R. tube plates, and the other pair of plates is connected to the amplifier output, as in Fig. 7, the resulting screen figure will be a straight line if no overload or phase distortion occurs in the amplifier. If there is phase distortion, the figure will be an ellipse, and if overload occurs, the ends of the straight line will bend over in opposite directions. Overload and presence of phase distortion at any frequency are thus easily detected and, by measuring the voltage input to the amplifier while this is increased, the overload point may be determined.

(c) **Depth, and linearity, of modulation of radio transmitters:** When the carrier frequency in a radio transmitter is amplitude modulated by an audio frequency, the ratio of the amplitude of the undistorted audio frequency envelope of the modulated carrier wave to the normal unmodulated carrier frequency amplitude is known as the modulation depth, and is a measure

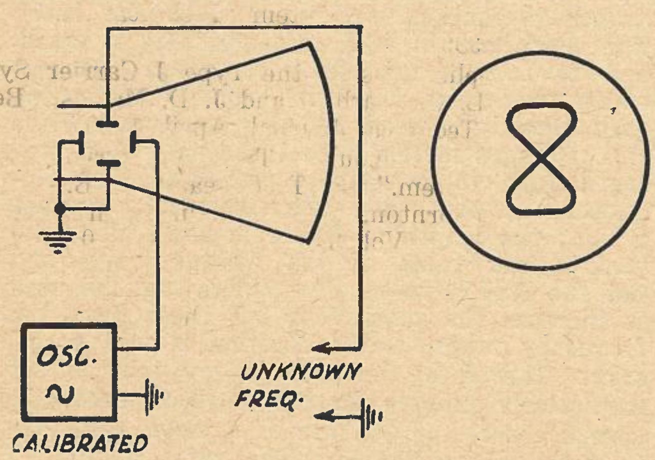


Fig. 6.—Comparison of frequencies (first method).

of the modulation efficiency of the transmitter. Measurement of this without a C.R. tube is somewhat difficult; but, by connecting the output of an audio frequency oscillator to the modulation input of the transmitter in parallel with one pair of C.R. tube deflecting plates, and connecting the other pair of plates to a pick-up coil in the R.F. field of the transmitter, as in Fig. 8, a figure is produced which gives an immediate indication of modulation depth.

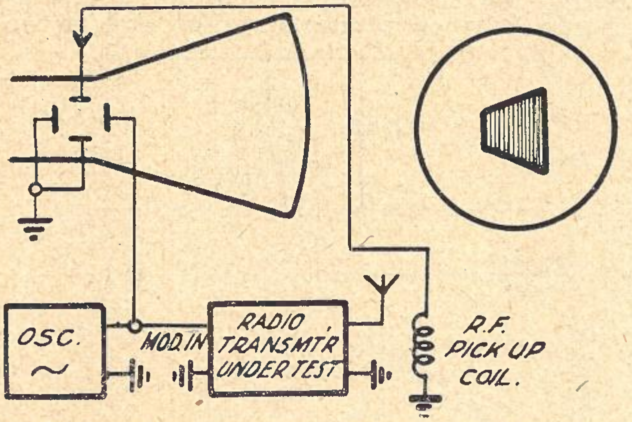


Fig. 8.—Depth and linearity of modulation of transmitters.

If modulation is linear, and less than 100%, the figure is a trapezium, and the ratio of the sum and the difference of the lengths of the two parallel sides (expressed as a percentage) is the modulation depth. In the case of 100% modulation, the figure becomes a triangle and, with greater than 100% modulation, it resembles a triangle with a tail. If the modulation is non-linear, the sloping sides of the figure are curved instead of straight; if the modulated envelope of the carrier wave is not in phase with the modulation input, the sloping sides of the figure become loops, and the figure has the appearance of being double. These effects are somewhat difficult to describe, and they must be seen to be appreciated.

(d) **Valve characteristics:** The grid voltage-plate current characteristic of a radio tube is generally plotted from a series of successive readings when the grid voltage is varied in steps. With a cathode ray tube, the dynamic characteristic may be shown on the screen instantly by connecting the radio tube with an oscillator, in a manner such as that shown in Fig. 9. The C.R. tube horizontal deflection then indicates grid voltage; and, as the vertical deflection depends on the drop across a fixed resistance in the radio tube plate circuit, this indicates plate current. The grid swing provided by the oscillator, of course, must cover the range required for the characteristic. The effect of changes of grid bias, plate battery voltage or filament current, on the characteristic, may be determined immediately. If it is desired to know the horizontal and vertical voltage and current scale of the figure, the deflection sensitivity of the C.R. tube must be determined.

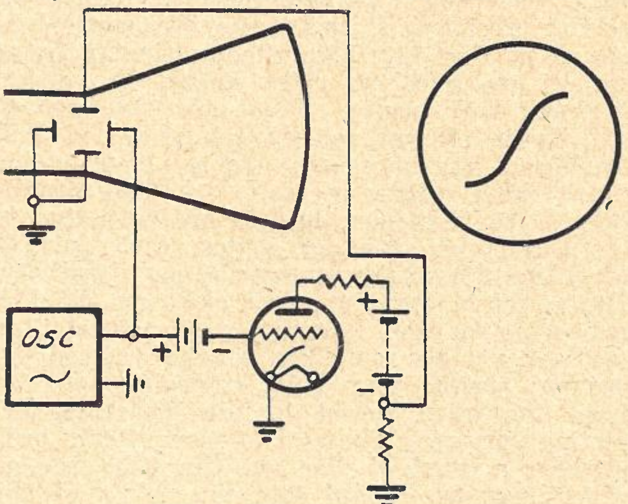


Fig. 9.—Valve characteristics.

(e) **Hysteresis loss of magnetic material:** Fig. 10 shows a method of qualitative (rather than quantitative) examination of magnetic materials from their B—H curves. The oscillator output provides horizontal deflection, from the potential drop in the series resistor, and as this output also passes through a coil of wire round the specimen of magnetic material, the horizontal deflection represents the magnetising field H. The magnetism induced in the specimen deflects the stream of electrons vertically (the specimen being placed horizontal, close to the neck of the tube and pointing radially). Thus, the vertical deflection represents the magnetic flux density B.

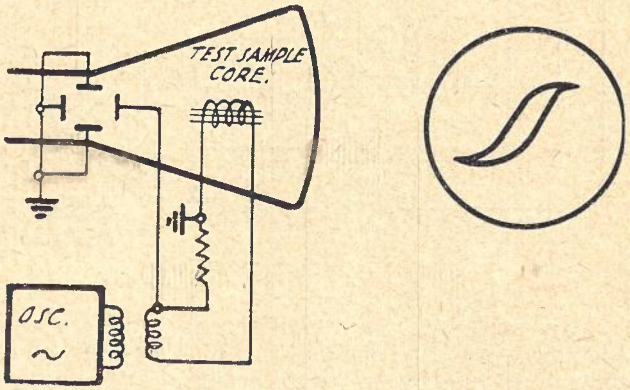


Fig. 10.—Hysteresis loss of magnetic material.

When specimens of various magnetic materials, having similar dimensions, are placed successively in the magnetising coil, their B—H curves may be compared rapidly and simply on the screen. The method is of little use quantitatively, however, because of the difficulties in accurately calibrating the deflections in terms of B and H.

(f) **Direction finding:** The application of cathode ray tubes to radio wave direction finding was developed by Watson Watt about 1929, who used it to determine the location of distant electrical storms. His arrangement is shown in Fig. 11. Two exactly similar frame aerials are fixed at right angles in vertical N-S and E-W planes. These are connected to the inputs of two exactly similar tuned R.F. amplifiers, having exactly similar amplification at all radio frequencies to which they can be tuned. The amplifier outputs are connected to the C.R. tube deflecting plates, each pair of which must have the same deflection sensitivity. The aerial in the N-S plane picks up the N-S component of the incoming radio signal, and feeds it via the amplifier to the vertical deflecting plates. The E-W component is fed from the other aerial to the horizontal deflecting plates. These two components will produce a straight line on the tube screen, which may be divided into the points of the compass, with North at the top. If the overall sensitivity from each aerial to its associated pair of plates is the same, the orientation of the line of light on the screen gives the line of direction of the incoming signal directly. The fluorescent spot, of course, must be at the centre of the screen when there is no incoming signal.

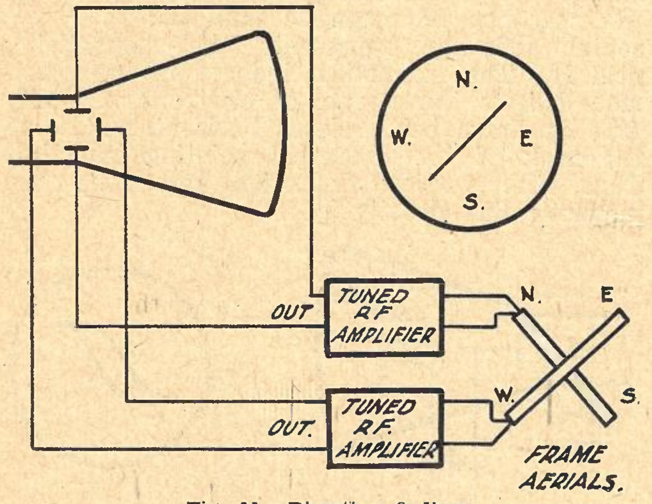


Fig. 11.—Direction finding.

Two such set-ups at different locations will give two lines of direction which, when drawn on a map should, by their point of intersection, give the location of the transmitter or storm producing the signals. The method obviously requires great accuracy in the matching of the circuits associated with each aerial at a given location, as any difference in characteristics of these may mean a comparatively large error in indicated direction. The set-up may be calibrated by a small local transmitter, at some distance from the frame aerials, modulated by timed impulses.

2.4. The C.R. Tube with Linear Time Base.—(a) Linear time bases, or Sweep circuits: These circuits are used with cathode ray tubes to produce periodic deflections in which the spot displacement is linear with respect to time. One such circuit is included in nearly every commercial cathode ray oscillograph, and a brief description of their principle of operation would not be out of place here. In their simplest form (Fig. 12a), they consist of a condenser C, which is charged through a series resistance R from a high-tension D.C. supply. Across the condenser is connected a gas discharge tube or thyratron. The striking voltage of the thyratron is well below the voltage of the H.T. supply charging the condenser. When the voltage of the charge on the condenser rises to the striking voltage of the thyratron, the latter strikes, discharging the condenser. When the discharge is almost complete, the thyratron ceases to conduct at the reduced condenser charge voltage, and the condenser then immediately commences to recharge. The output of the circuit is taken from the terminals of the condenser. Now, the curve of voltage-rise against time of a condenser being charged through a resistance, is almost linear over the greater initial portion of the charging process, and the circuit is designed so that the discharge occurs before the voltage rise passes this linear portion of the curve (Fig. 12b). The discharge through the thyratron occurs extremely rapidly, compared with the rate of charge, and so the voltage-time curve of output is a periodic wave of sawtooth shape. This output is generally applied to the horizontal deflecting plates of a C.R. tube. The frequency of these sawtooth oscillations may be varied by adjusting the value of the series charging resistance or of the condenser capacity.

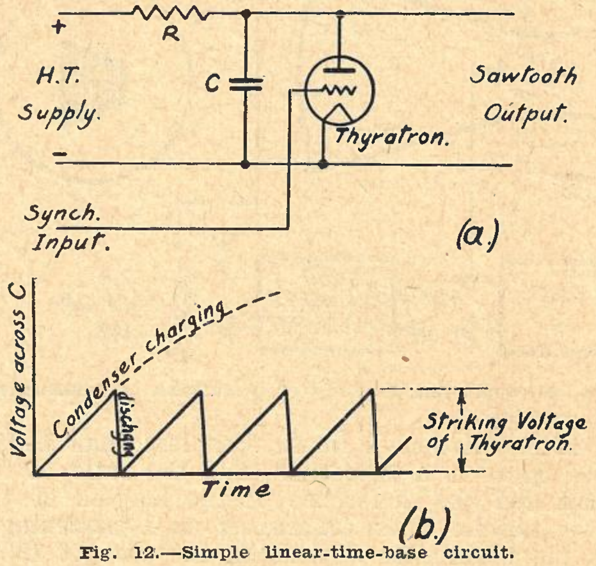


Fig. 12.—Simple linear-time-base circuit.

The frequency may also be synchronised or "locked" with other frequency sources. The thyratron has a control or "trigger" grid (Fig. 12a). The frequency of the sawtooth output is first adjusted to a value just below the synchronising frequency or just below a sub-multiple of it. The synchronising frequency is then applied to the thyratron grid, and a positive half-cycle of this frequency, occurring just before the normal striking time of the thyratron, will cause it to strike immediately. This will be repeated just before the next normal striking time, so that the sweep circuit is forced to operate at the frequency of the synchronising source, or a sub-multiple of it. Sweep circuits for very high frequencies are more complicated, and employ only high vacuum radio tubes.

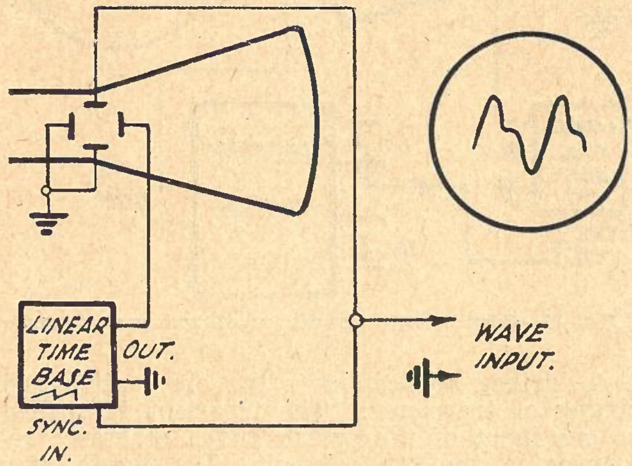


Fig. 13.—Wave form examination.

(b) **Applications with Linear Time Base and one other variable:** These are the most common applications of cathode ray tubes or oscillographs, and include examination of all kinds of wave forms. Any signal whose wave form it is desired to examine is connected to the vertical deflecting plates, while the output of a linear time base is connected to the other pair of plates, as in Fig. 13. If the signal has a periodic wave form, then part of this signal is fed to the synchronising input of the time base, and the latter may then be synchronised or "locked" in step with the signal so that one or more waves (depending on the ratio of signal to sweep frequency) remain stationary on the screen.

Examination of signal wave form may thus reveal the presence of harmonics, overloading in an amplifier through which the signal has passed, wave assymmetry, etc. With a slow sweep, the operation of relays may be examined, and in the examination of voltage transients a special sweep circuit which gives a single stroke may be used; the speed of the single sweep is controlled by the usual sweep frequency adjustments, and it may be initiated either manually or automatically (by the arrival of the transient itself). This single stroke on the screen may be photographed, or with transients of not excessively short duration, a C.R. tube with a long persistence fluorescent screen may be used, which allows the trace of the fluorescent spot to glow for a few seconds after its occurrence.

2.5. **The C.R. Tube with Linear Frequency Base.**—(a) **Linear frequency bases, or wobbulator circuits:** These circuits are used with cathode ray tubes to produce periodic deflections in which the spot displacement is linear with respect to frequency. The circuit includes an oscillator, whose frequency is "wobbled" or caused to vary periodically up and down over a given range by some device which is also causing a periodic movement of the cathode ray tube spot. If the spot displacement during any cycle of movement is directly proportional to the change in oscillator frequency, we have a linear frequency base. The "wobbling" device may be mechanical, such as a variable air condenser with motor-driven rotating plates in parallel with the tuning condenser of the oscillator; on the same rotating shaft is the moving arm of a potentiometer whose ends are connected across a battery, and the periodic voltage variation from this moving arm is used to provide the horizontal spot displacement on the C.R. tube. Completely electronic wobbulators have also been developed. In one of these the frequency wobble is produced by a varying impedance in series with the tuning condenser of the oscillator; the impedance consists of a resistance and the plate impedance of a pentode tube in parallel, and the pentode plate impedance is varied by applying a periodic voltage to its grid. Thus, a periodic voltage is applied to this grid and the C.R. tube horizontal deflecting plates in parallel, and as it moves the C.R. tube spot horizontally, so it also varies the oscillator frequency, the relationship of spot displacement and frequency change being linear independently of the wave form of the periodic voltage used as a control.

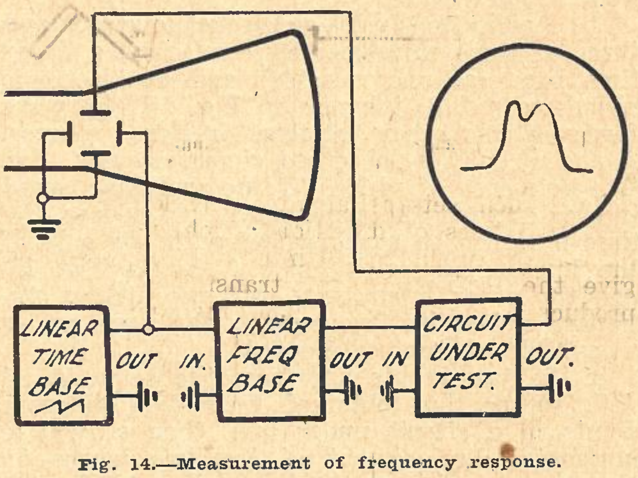


Fig. 14.—Measurement of frequency response.

(b) **Applications with linear frequency base and one other variable:** Linear frequency bases are used for the examination of the frequency response of circuits. With the electronic type of frequency base, an ordinary sweep circuit is a convenient source of controlling voltage, and is connected to the C.R. tube horizontal deflecting plates and to the frequency base, as in Fig. 14. The wobbling frequency output of the frequency base is connected to the input of the test circuit, whose output is connected to the C.R. tube vertical deflecting plates. The figure produced on the C.R. tube screen then represents the frequency response of the test circuit over the frequency band covered by the wobble of the frequency base. The vertical scale is, of course, a linear voltage scale, and not the logarithmic or decibel scale used conventionally for response curves. This set-up is very useful in the adjustment of band pass filters, as in the lining-up of R.F. and I.F. amplifying stages in a radio receiver. In lining-up the R.F. stages of a receiver, the tuning controls of the frequency base and of the receiver may be rotated simultaneously, so as to observe the R.F. response on the screen over the whole of the tuning range, instead of checking the line-up at two or three radio frequencies only, as is done in ordinary line-up procedure.

2.6. **The C.R. Tube with Electronic Switch.—(a) Electronic switch circuits:** These circuits have two or more signal inlets and one common signal outlet, and their function is to switch the various signal inputs to the common output in rotation, at any desired rate, generally providing some amplification in the process. The switching may be performed by gas discharge tubes, which are made to oscillate and to produce a periodic blocking action in the several amplifying tubes of the circuit in rotation. When the switching rate is sufficiently high, such a circuit may also be used to amplify D.C. voltages, as by the periodic chopping action it virtually converts the D.C. voltage into a square-topped wave.

(b) **Applications with an electronic switch and three or more variables:** By connecting a linear time base (as one variable) and an electronic switch to a C.R. tube, as in Fig. 15, the wave forms of two other variables or signal sources, A and B, may be observed simultaneously, due to persistence of vision (if the switching speed is greater than 12½ times/sec.). Of course, the time base can be synchronised with one only of the inputs, e.g., with input A, as in Fig. 15, and the other input wave will not appear stationary unless its frequency is the same as, or a multiple of, that of input A.

If the two inputs are from the same initial A.C. source, but obtained from two different points in a circuit under test, then a relative horizontal displacement of the two waves on the screen indicates a voltage phase difference at these two points in the test circuit, or a difference in shape of the two waves indicates a difference in harmonic content at these two points.

In lining-up two tuned circuits by means of a linear frequency base, as in section 2.5.(b), an electronic switch may be used to show the response curves of both circuits on the screen simultaneously, so that both circuits may be given the same tuning adjustment.

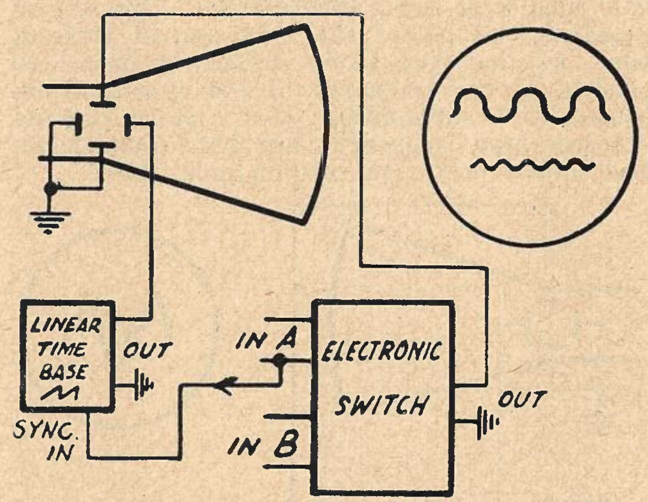


Fig. 15.—Simultaneous observation of two wave forms.

A further application is the observation and timing of transients. The transient is applied to one input of the switch and a constant frequency to the other input. The figure may then by photographed, or observed on a long persistence C.R. tube screen, and the duration of the transient is given by the number of cycles of the constant frequency appearing on the screen with it.

Other variables than a time base output may, of course, be used on the horizontal plates, together with an electronic switch, and electronic switches may be made with capacity for more than two inputs; alternatively, several two-input switches may be used, in tandem, to produce more than two traces on the screen.

Electronic switches usually have provision for biassing the various signals as they pass through, so as to deflect one trace upwards and the other trace downwards on the C.R. tube screen, when it is desired to separate the traces for greater clarity.

2.7. **Applications with Three Variables Only.—(a) Anode modulation:** So far, we have dealt only with voltage variables applied to the deflecting plates of C.R. tubes. If we apply a varying voltage to the final anode, it has the effect of varying the deflection sensitivity. (This is not practicable with tubes in which the anode is commoned to one vertical and one horizontal deflecting plate inside the tube). Thus, we may obtain polar deflection in the following way: To the horizontal and vertical plates, respectively, two voltages of the same amplitude and frequency, but differing in phase by 90°, are applied. These may be obtained from a phase-splitting circuit, such as that shown in Fig. 16, and the Lissajous figure produced is a circle. If, now, voltages are applied to the final anode of the C.R. tube, they will produce radial deflections from this circle. The circumference of this circle is, of course, greater than the longest linear sweep that the tube screen can accommodate. Therefore, such a circular time base is longer for a given frequency of recurrence, and is quite continuous, whereas, with a linear sweep, some time is lost when the spot flies back to its starting position at the end of each sweep.

Polar deflection in this way is useful in recording any transient voltages whose time of occurrence cannot be predetermined, and also in the comparison of frequencies by a second method. If a frequency greater than that of the rotating spot is applied to the anode, as in Fig. 16, a "gear wheel" pattern is produced, and the number of teeth is equal to the ratio of the anode frequency to that of the spot rotation.

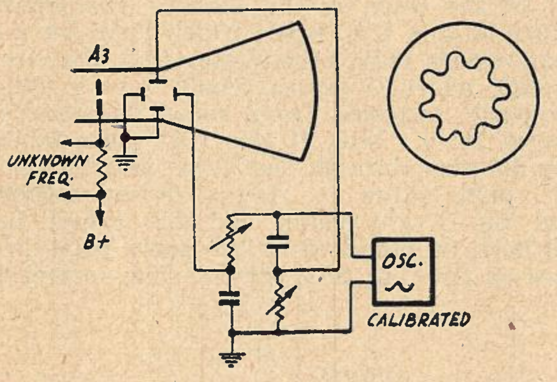


Fig. 16.—Comparison of frequencies (second method).

The advantage of such a pattern is that, if the anode frequency is not quite equal to some multiple of the circle frequency, the teeth of the figure will rotate, and the direction of rotation indicates whether the anode frequency is above or below that multiple of the circle frequency. Thus, the sense of the ratio discrepancy is indicated, while the method of frequency comparison shown in Fig. 6 gives no such indication.

(b) **Grid modulation:** If we apply a varying voltage to the grid or Wehnelt cylinder of the C.R. tube, it has the effect of modulating the brightness of the spot or spot intensity, and sufficient grid voltage swing will vary the spot from brightness to complete extinction. This provides a third method of frequency comparison, as in Fig. 17. A circular spot movement is produced by one frequency, as in Fig. 16, but the other frequency is used to modulate the grid and, instead of "gear wheel" teeth, alternate bright and dark streaks are produced round the circle. When the frequencies are almost equal, a single streak rotates round the circle, and the direction of its rotation is here also an indication of the sense of frequency discrepancy. As movement of such streak is easily detected, the sense and magnitude of frequency differences as small as 1 cycle in ten minutes, or smaller, are measurable, even in comparing frequencies of the order of some hundreds of megacycles.

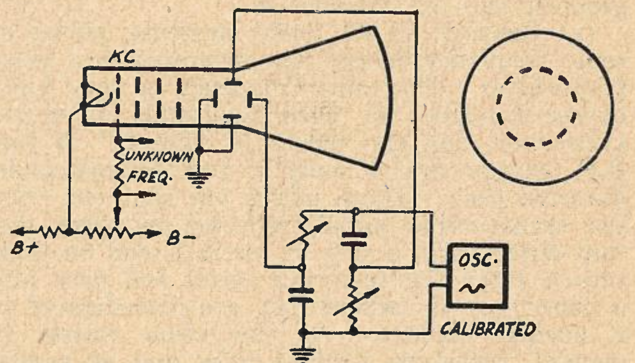


Fig. 17.—Comparison of frequencies (third method).

A second application of grid modulation is the marking of time intervals as alternate bright and dark dots or streaks in any wave form under examination with a normal linear time base. A third application of grid modulation is in television reception. Here a picture frame or "raster" is built up of scanning lines produced by a comparatively low frequency sweep applied to the vertical deflecting plates of a C.R. tube, and a much higher frequency sweep applied to the horizontal deflecting plates, as in Fig. 18. The picture signals are then applied to the grid, and by variation of spot brightness along these scanning lines, a picture is built up on the screen.

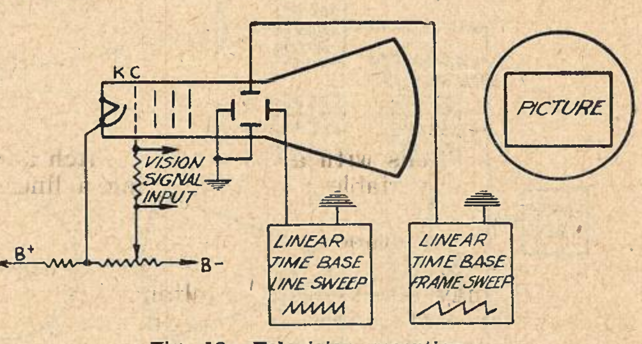
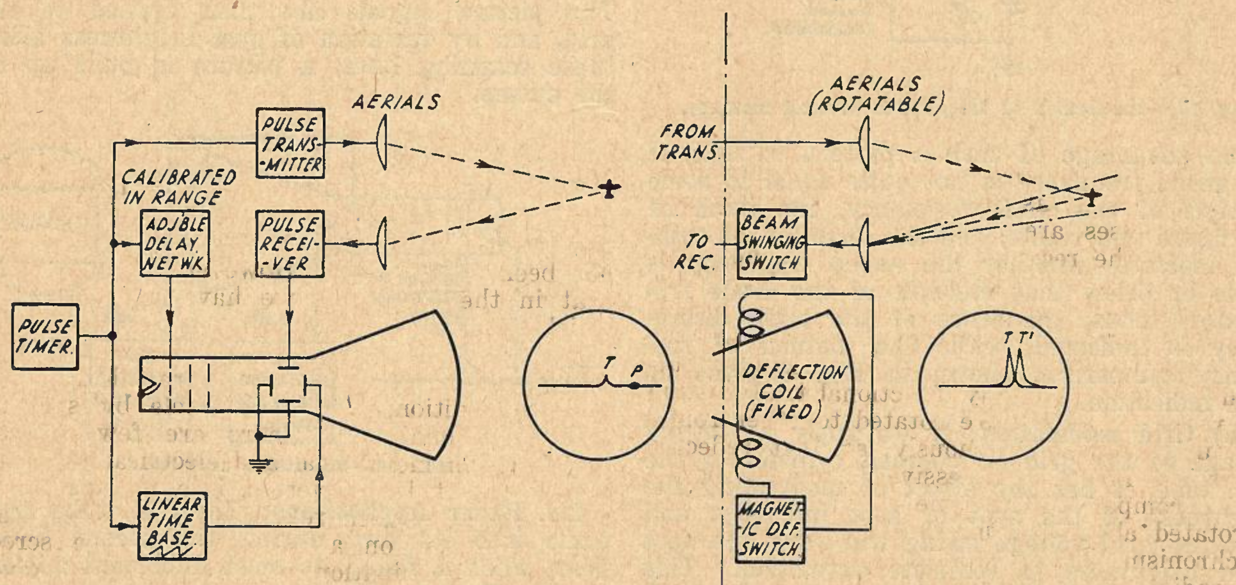


Fig. 18.—Television reception.

2.8. **Radar Applications:** The C.R. tube truly came into its own during the second World War, when it found its most important application in Radar. The many thousands of such tubes required for this work resulted in standardisation of manufacture and a considerable reduction in tube cost, which will have obvious post-war advantages. The most important Radar applications are shown in Figs. 19 and 20. These have been simplified, as far as possible, and single line circuits are shown where the return side has no special significance. In these applications, the fundamental functions of the C.R. tube itself do not differ from those described in the sections above, and the ingenuity of the Radar System lies in the external circuits. Other methods may also be used to obtain similar results, but those shown in the accompanying figures have been selected for greatest ease of explanation.

(a) **General:** In all Radar systems, pulses of radio frequency energy are generated in a pulse transmitter. The radio frequency is very high, maybe hundreds or even thousands of megacycles/sec., and the pulses or "bursts" of this R.F. energy are of only a few microseconds' duration each. These pulses are sent out from the transmitting aerial, reflected by some distant object, say, a ship or aircraft, and on their return enter the receiving aerial and pass into a pulse receiver, where they are demodulated in a normal manner. As the radio waves, in general, travel in straight lines and at a constant velocity equal to that of light (approximately 186,000 miles per second), the time taken for any given pulse to return after transmission is a measure of the distance to the reflecting object, and the direction of the returning pulse is an indication of the bearing of that object. Thus, if a Radar system measures the returning time and returning direction of pulses, the range and bearing of the reflecting object may be determined, even though the object itself may be out of visual range at the Radar station, or hidden by darkness, smoke or fog.



(a) RADAR - RANGE MEASUREMENT (b) RADAR - BEARING MEASUREMENT

Fig. 19.

(b) **Range Measurement:** As in Fig. 19a, the generation of pulses in the transmitter is controlled by a pulse timer, which also controls the time base for the C.R. tube. Thus, each time an R.F. pulse leaves the transmitting aerial, the time base commences to sweep the spot across the C.R. tube screen. The R.F. pulse travels out till it meets, say, an aircraft, is reflected, enters the receiving aerial on its return, and, after demodulation in the receiver, produces a sharp vertical deflection of the C.R. tube trace, known as the Target Break (T). The interval between successively generated pulses must be sufficient to allow all reflections of one pulse (from objects within a desired maximum range) to return and register Target Breaks on the trace before the next pulse leaves the transmitter and the next sweep commences on the C.R. tube screen.

The time between sweep commencement and break T is to be measured, as an indication of target range. Each time the pulse timer causes an R.F. pulse to leave the transmitter, it also passes a transient D.C. pulse into an adjustable delay network, which will ultimately apply the D.C. pulse (positively) to the grid of the C.R. tube and cause a brightening over a short patch (P) of the trace on the screen. The transient nature of this D.C. pulse, which lasts for a few microseconds only, necessitates that the circuits through which it passes should have a uniform frequency response from audio frequencies to several Mc/s. Now, if this D.C. pulse takes as long to pass through the delay network as the R.F. pulse takes to return (when reflected), then the bright patch and the target break will both be produced at the same point in the trace on the C.R. tube screen. The control dials of the adjustable delay network are calibrated in terms of range (say, thousands of yards). These dials are adjusted to move P into coincidence with T, and the range of the target is then read directly from the dials.

(c) **Bearing measurement:** The system used may be similar to that shown in Fig. 19a, with the addition of the equipment shown in Fig. 19b. Both receiving and transmitting aerials must be capable of being rotated together, and must be sharply directional. A device called a Beam Swinging Switch is interposed between the receiver and its aerial. This is driven by a small motor, and has the effect of swinging the direction of maximum sensitivity of the receiving aerial over a small deviation in a horizontal plane to the left and right of the transmitting aerial direction, alternately. The same motor alternately opens and closes the circuit of a C.R. tube deflection coil by the magnetic deflection switch, in synchronism with the receiving aerial "swing." This has the effect of slightly displacing the whole C.R. tube trace to the left and right, alternately. The "swinging" rate is greater than $12\frac{1}{2}$ times per second, so that, due to persistence of vision, the trace appears to be in both left and right positions simultaneously, and thus each target break appears "double" (T and T^1). When the target is truly in line with the transmitting aerial direction, the received strength of the reflected pulse will be the same for both "swung" positions of the receiving aerial sensitivity, and, consequently, the breaks T and T^1 on the C.R. tube screen will be of equal height, or amplitude. The aerials are therefore rotated together until this equality of T and T^1 is obtained, and the bearing of the target is then read directly from a dial which indicates bearing of the aerials.

(d) **Plan position indication:** This system (P.P.I.) gives a diagrammatic representation of the position of target objects on a plan of the surrounding country, coastline, etc. In Fig. 20 the pulse timer controls the pulse transmitter and a time base, as described for Fig. 19a, and reflected pulses are passed from the receiving aerial into the receiver. In this case, however, the time base employs magnetic deflection of the C.R. tube electron stream, and this is arranged so that the spot commences at the centre of the screen and sweeps radially outwards. Now, the highly directional transmitting and receiving aerials are rotated together round 360° in bearing, continuously, so that reflected pulses are received successively from all points of the compass. The time base deflection coil is rotated about the neck of the C.R. tube, in synchronism with the rotating aerials, so that the radial sweep moves round the screen like the hand of a clock, and its direction on the screen at any instant corresponds to a definite bearing of the aerials.

The reflected pulses received are demodulated in the receiver and applied (positively) to the grid of the C.R. tube, producing a momentary brightening of the trace. The radius of this bright spot from the tube centre will depend on the range of the reflecting object. Thus, as the radial sweep trace moves round the screen, it virtually plots, by means of bright spots, the positions of reflecting objects as they would appear on a polar map diagram, with the Radar station as centre. The C.R. tube used has a long persistence fluorescent screen, and the rate of rotation of the aerials and the radial sweep is such that all bright spots plotted are still glowing on the screen when a full rotation is complete. The R.F. pulses are reflected not only by aircraft and ships, but also by buildings, mountains, coastlines and other solid objects, and the rotating trace therefore "paints" a bright outline-in-plan of such objects within effective range of the Radar station. Thus, on the C.R. tube screen, appears a brightly fluorescent map of the surrounding coastline, etc., with ships or aircraft appearing in their true relative positions as bright spots which move across this map as they change their position. This is indeed a crowning achievement in the application of the cathode ray tube.

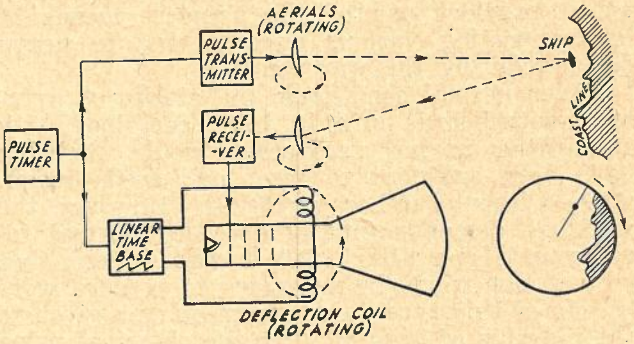


Fig. 20.—Radar—P.P.I.

3. CONCLUSION

Space has not permitted a detailed discussion of all the applications of cathode ray tubes mentioned, and there are many others which have not been referred to. However, we have seen that in the C.R. tube we have an instrument which can show graphically on a screen the relationship of quantities in two directions at right angles, as well as in a radial direction, and, in addition, another variable by spot intensity modulation. There are few variable quantities in mechanical and electrical machines which cannot be converted into voltage variations, and shown in relationship to other variable quantities on a cathode ray tube screen by some combination of the features given above.

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THE MAGNETO CORDLESS SWITCHBOARD— PYRAMID TYPE

A. W. McPherson

Readers will no doubt be interested to learn of a recent development in connection with 4-line, 6-line and 10-line magneto switchboards of the pyramid type. This type of switchboard, which provides one of the simplest means of interconnecting various circuits, was in heavy demand during the war years.

Under normal conditions, the stocks of pyramid switchboards held in 1939, combined with anticipated annual recoveries, would probably have been sufficient to meet our needs indefinitely without further purchases. However, the war-time demands greatly exceeded normal requirements and after 1942 it was evident that some action would be necessary to procure more boards of this type. Consideration was given to the redesign of the unit with the object of using standard component parts for which manufacturers in Australia were already tooled.

At the same time, an alternative design using key switching was being considered, and, to this end, a pilot model was completed in 1944. This model incorporated a number of interesting features, which included the following:—

(1) Indicator strip and sloping key panel mounted on steel frame chassis fixed to base board.
(2) Sides, top and rear of board made in form of removable cover to permit ready accessibility.
(3) Handset mounted horizontally on cradle switch on front of board.
(4) Method of operation similar in principle to standard C.B. cordless P.B.X.

Concurrently with the development of this model, the Superintending Engineer, Sydney, had been conducting investigations with a view to modifying the existing design to suit local manufacture, and, as a result, suggested a circuit modification which permitted the use of standard jacks and plugs.

A study was made of the relative merits of the pyramid type and the key type, and it was considered that any advantages possessed by the latter are outweighed by the following features of the pyramid board:—

(i) Simplicity in manufacture and operation;
(ii) lower fault liability;
(iii) relatively low cost.

The fault liability aspect is probably the most important consideration in this case, as the majority of small magneto switchboards are situated in remote country areas where serious delays may occur in the restoration of service in the event of a breakdown. Furthermore, cost is a factor which cannot be ignored, and the pyramid switchboard offers the same switching and supervisory facilities as a key type, but at a much lower cost.

It was decided, therefore, to continue with switchboards of the pyramid type in general principle, but with suitable modifications as suggested by the Superintending Engineer, Sydney.

Fig. 1 shows the circuit arrangement of the modified board, which includes standard magneto plugs, type 2037, strapped internally, and standard jacks, type 7424. The latter is a jack No. 5424 with an additional pair of make springs. The open end of each plug is filled with a black phenol formaldehyde stop. The indicators are ironclad type, as manufactured in the Melbourne Workshops and described in Vol. 4, No. 3, page 163. The telephonist's circuit includes an A.S.T.I.C. No. 21A and a moulded handset type 184.

The operation of the pyramid switchboard is probably familiar to most readers; but, in view of the circuit modifications, the operation for a typical call is given as follows:—

An incoming ring is received on line No. 1, the associated indicator being operated via (a) side of line, break springs of bottom jack, indicator, tip and ring springs of jack (through s/c plug) to the (b) side of line. The telephonist removes the plug from indicator jack No. 1 and places it in line jack No. 1 and removes the handset from the switch hook. This places the telephonist's circuit across line No. 1 for answering the calling subscriber. Assuming the party to be called is line No. 2, the telephonist replaces No. 1 plug into indicator jack and removes plug No. 2 from the indicator jack to line jack No. 2. This connects the tele-

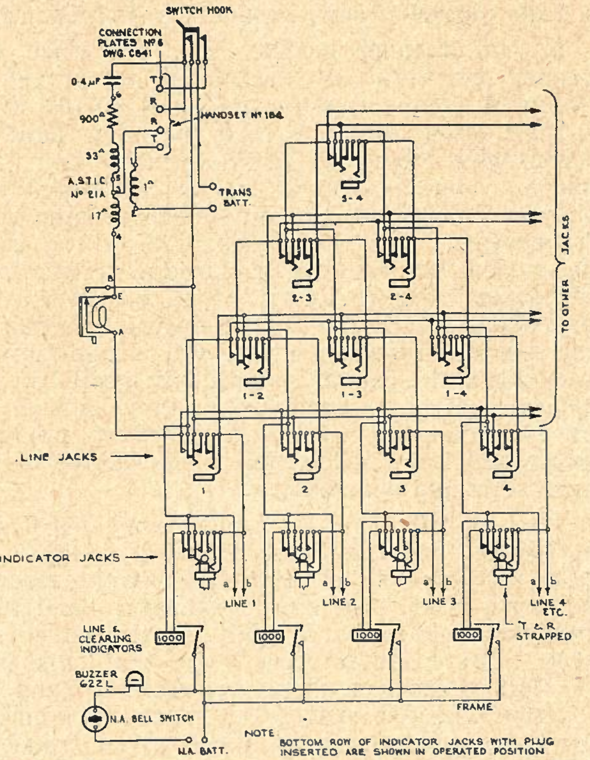

Fig. 1.—Circuit arrangement of modified pyramid switchboard.

phonist's circuit to line No. 2. The telephonist then replaces the handset on the switch hook and operates the generator to transmit $16^2/_3$ C/s ringing current to line No. 2. When the required subscriber answers, the telephonist connects lines Nos. 1 and 2 together by the insertion of plug No. 2 into jack designated 1-2. In this condition the telephonist's circuit is disconnected and indicator No. 1 is bridged across the connection for supervisory purposes. If the telephonist desires to monitor the connection, it is necessary to insert a plug into line jack No. 1 or No. 2. A spare jack is provided for this purpose. When the call is completed, indicator No. 1 will operate, and the telephonist restores the switchboard to normal by transferring the plug from jack 1-2 to the indicator jack associated with line No. 2.

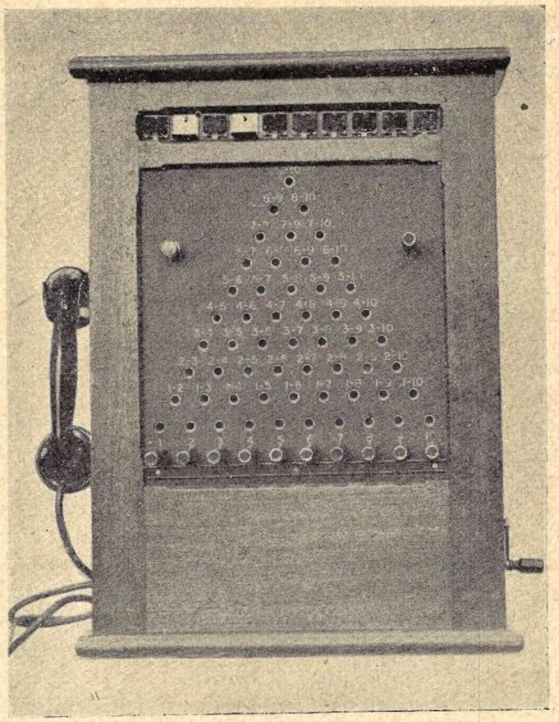

Fig. 2.—10-line pyramid switchboard.

Consideration was given to the inclusion of a non-locking key for the purposes of code ringing; but, in view of the localities in which the boards are installed, it was decided that this feature is unnecessary except in special cases, which can be individually treated as circumstances demand.

A complete 10-line switchboard is shown in Fig. 2.

R. M. OSBORNE, M.E.E., A.M.I.E.E., A.M.I.E.(Aust.)

Since the issue of the June number of the Journal, Mr. R. M. Osborne has resigned from the Board of Editors. It is with considerable regret that the Postal Electrical Society received the resignation of Mr. Osborne, who has transferred from Engineering to another Branch of the Department's activities. We wish Mr. Osborne every success in his new work and take this opportunity of recording his outstanding contribution to the "Telecommunication Journal" as an Editor from its inception in 1935. As some token of its appreciation of Mr. Osborne's work, both as an Editor and Honorary Treasurer of the Society (1932-1944), the Committee unanimously elected him a life member of the Postal Electrical Society of Victoria.

We welcome Mr. S. Webster, of the Telegraph Section of the Chief Engineer's Office, to the Editorial Board.

THE TYPE J 2 TWELVE CHANNEL CARRIER TELEPHONE SYSTEM

J. E. Freeman, B.Sc., A.I.R.E.(U.S.A.)

Introduction: The first type J twelve channel system in Australia was installed between Melbourne and Sydney in 1939. This system was known as the Type J1 system, and the installation is described in Vol. 3, No. 1 of this Journal. Modifications were made to the Type J1 system, and later systems were known as the Type J2, a number of which have been or are being installed in Australia in the following locations:—

Adelaide-Melbourne—Two systems.
Melbourne-Sydney—Three systems.
Sydney-Brisbane—Two systems.
Brisbane-Townsville—One system.
Sydney-Dubbo—One system.

The line equipment and a large part of the miscellaneous equipment are essentially the same as that employed on the J1 system; but the following are the more important improvements included in the later system.

(a) Four frequency allocations, which permit more liberal crosstalk coupling requirements on open wire lines than would be permissible for like systems. The systems are designated NA, NB, SA and SB.

(b) A maximum repeater and normal terminal gain at 140 kC/s of 77 db., compared with 45 db. available on J1 equipment. At terminals an additional gain of 36 db. is available by the insertion of an auxiliary amplifier.

(c) Regulation by means of two pilot frequencies in each direction of transmission, and automatic adjustment of equalisation and gain for a wide range of line attenuation changes, including those due to quite severe ice accumulations. The J1 system used only one pilot frequency in each direction.

Terminal Equipment: An overall schematic circuit of the type J2 terminal is given in Fig. 1.

In addition to block indications of the major components, the normal operating levels and the impedances at successive points in the circuit are shown. Gains and losses of individual components are also given. Four wire terminating sets are normally mounted on a bay associated with the 4-wire V.F. patching bay. Throughout this description, it will be assumed that a voice frequency tone at a level of 1 milliwatt is being applied to the transmitting trunk switchboard, and the term dbm will be used to indicate levels with respect to this reference level.

The incoming tone is padded to provide a level of —13 dbm, and this tone is taken to the channel modem bay by means of shielded cable. In the other direction, voice frequency current at a nominal level of +4 dbm is received from the channel modem bay, and after passing through testing jacks the current is padded in the four-wire terminating set to give a 6 db overall circuit, including switching pads.

In the channel modem bay, the voice frequency currents are modulated to provide a group of frequencies in the band 60-108 kC/s. In the other direction, the incoming band of frequencies from the group terminal bay (frequency range 60-108 kC/s) are separated into channel bands and demodulated to provide voice frequencies. The modulator used in the channel modem bay consists of a bridge arrangement of copper oxide rectifiers, which provides a low impedance across the circuit during one half of the carrier frequency cycle, and a high impedance when the carrier potential is applied in the opposite direction during the other half of the carrier frequency cycle. This effect produces upper and lower sidebands in the output of the modulator and demodulator.

Tone at a level of —13 dbm is applied to the modulator, and the lower sideband is separated from the products of modulation by the modulator band filter. Both the modulator band filter and demodulator band filter are of the crystal type. The manufacturers claim that this class of filter permits a wider transmitted band for a given channel spacing, a more uniform attenuation over the band for a given transmission loss, and a smaller and more compact assembly than could be obtained with the coil and condenser type of filter. However, the most suitable frequency range for the crystal type of filter is above 50 kC/s, and for this reason the primary modulation is carried out in the frequency range 60 to 108 kC/s. Additional steps of modulation are provided to translate the carrier channel bands to the line frequency range used for the various systems. The common side of the modulator band filters (in parallel with a compensating network) is connected to a hybrid coil. This arrangement provides two outputs of 135 ohms impedance, and facilitates patching if a spare group terminal and high frequency line are available.

In the receiving direction, a band of frequencies in the range 60 to 108 kC/s is passed from the output of the group terminal bay to an input transformer in the channel modem bay. This transformer is followed by a group of 12 demodulator band filters, which are identical with the modulator band filters previously mentioned. The individual channel bands are demodulated and the voice frequencies from the demodulator are amplified in the demodulator amplifier to a level of +4 dbm. This level can be adjusted over a range of approximately 10 db by means of a potentiometer connected in the

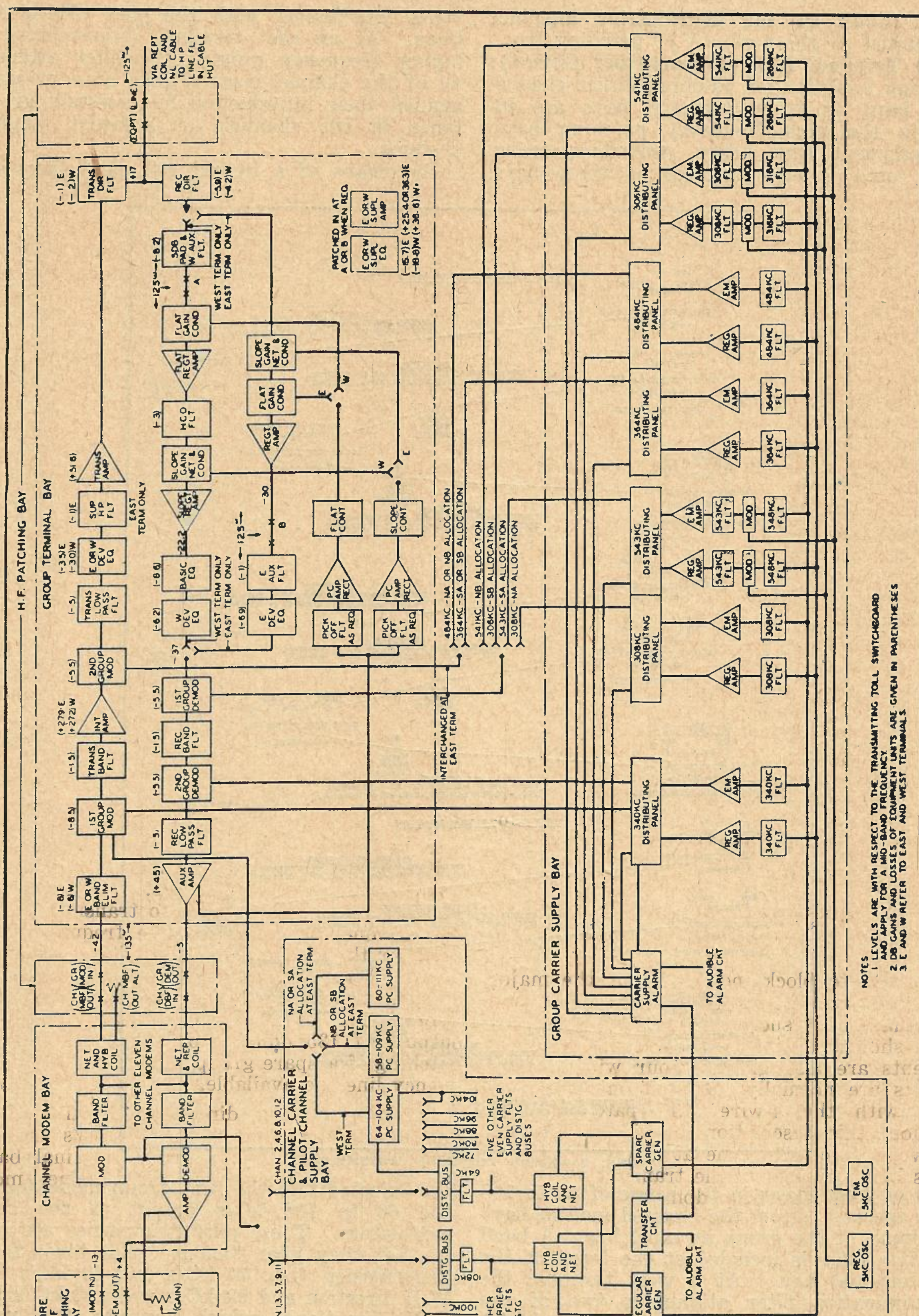

Fig. 1.—Block schematic of Type J2 terminal.

cathode circuit of the demodulator amplifier and mounted on the 4-wire V.F. patching bay.

Group Terminal Bay (Transmitting Circuit): All jacking facilities for patching either channel modem bays or group terminal bays are included in the high frequency patching bays. Line equipment (line filters, protectors, transformers, etc.) is also mounted on these bays. A band of frequencies in the range of 60 to 108 kC/s is received (from the channel modem bay) at the input of the group terminal bay. A band elimination filter is included at the input of the group terminal bay. At a west terminal the band elimination filter attenuates two of the channel carrier leaks (64 kC/s and 104 kC/s) which are of the same frequencies as the pilots which are also introduced at the input of the first group modulator. This precaution prevents interference with the pilot control functions. At an east terminal (transmitting the higher frequency group), the filter attenuates all of the channel carrier leaks as a precaution against their introduction by crosstalk as fixed tones in the channels of adjacent staggered systems.

By means of a hybrid coil, pilot frequencies are injected into the first group modulator with the 60 to 108 kC/s output of the channel modulators. These pilot frequencies are chosen so that they give standard pilot tones for line transmission (i.e., 40 kC/s and 80 kC/s in the W-E direction and 92 kC/s and 143 kC/s in the E-W direction), which permits the use of identical repeaters for each of the four frequency allocations.

In the first group modulator, the frequencies

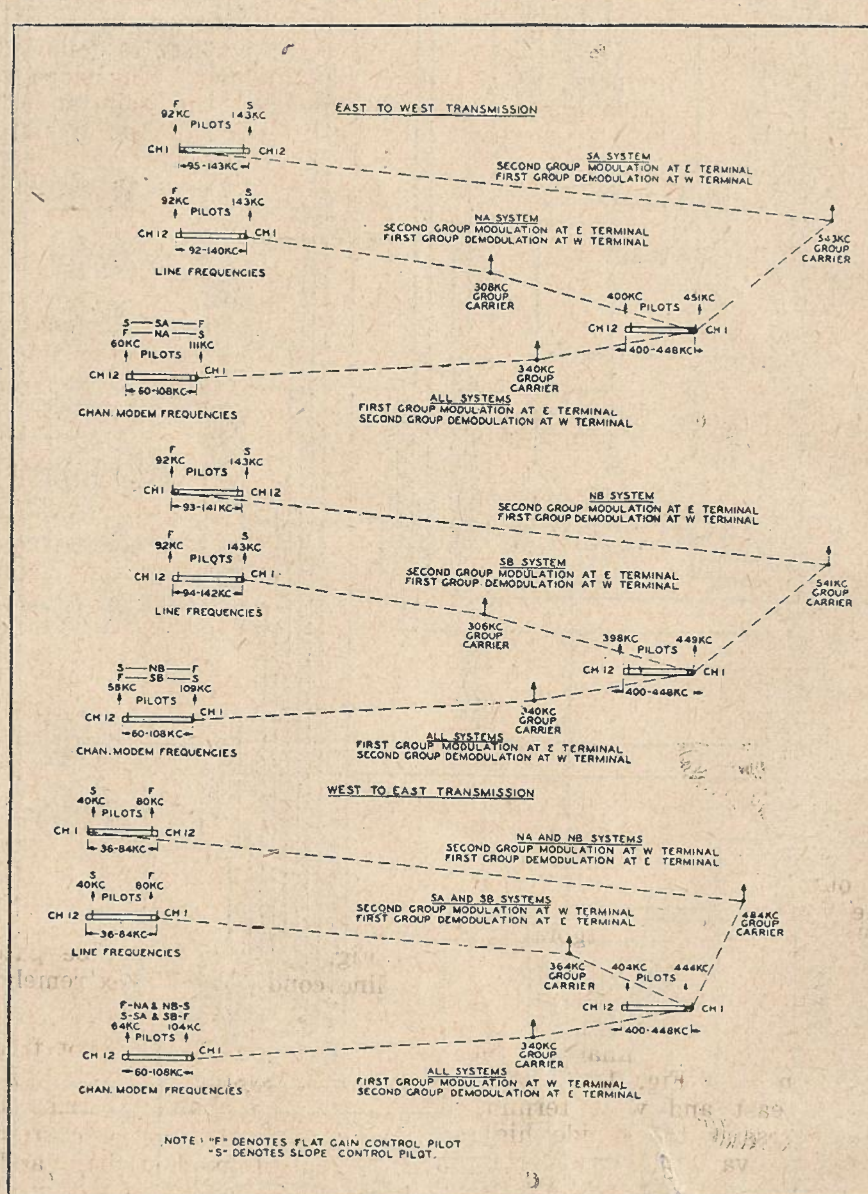

Fig. 2.—Group frequency translations.

of the 12 telephone channels and the two pilots are shifted as shown in Fig. 2 to positions in the frequency range of 400 to 448 kC/s, appearing as an upper sideband of a 340 kC/s carrier frequency. Both group modulators employ copper oxide rectifiers in a double-balanced bridge arrangement requiring centre-tapped input and output transformers. Both the carrier itself and the original frequency band are balanced out with this modulator arrangement, as are some of the unwanted products of the modulation process. The lower sideband of the group modulation is eliminated by the succeeding transmitting band pass filter.

Amplification of the 400 to 448 kC/s band is accomplished by an intermediate amplifier, and the band is then applied to the second group modulator. The carrier frequency used in this modulator depends on the type of system and the terminal concerned. The inversion of the band (where necessary) and frequency staggering for various system types are achieved in this modulator, and the frequencies used are indicated in Fig. 2. This modulator is similar in type to that used for the first group modulator, and is followed by a transmitting low pass filter to eliminate the higher products of modulation.

The deviation equaliser corrects for distortions introduced by the various filters in the transmitting terminal, and, at east terminals only, a supplementary high pass filter is included to eliminate near-end crosstalk due to unwanted low frequency products of the second group modulator. The line frequencies are amplified by a transmitting amplifier which has a flat gain over the frequency range from 36 to 143 kC/s. This amplifier is a three-stage feedback type in which four tubes are operated in parallel in the output stage to deliver a level of +17 dbm. The output is passed to the line equipment via the transmitting side of a directional filter which separates the outgoing and incoming frequency groups.

Group Terminal Bay (Receiving Circuit): The receiving path of a west group terminal bay only will be described, as the east terminal can then be followed by reference to Fig. 1. The differences between the east and west terminals are caused by the necessity to provide higher gain and greater slope variation in the high frequency direction (i.e., at a west terminal). The incoming line frequencies are separated from the outgoing frequencies by the receiving directional filter, and the west auxiliary filter provides additional discrimination in the range of the transmitting branch of the circuit and thus prevents possible overloading by these frequencies.

The flat gain condenser is driven by means of a motor, and, in association with the flat regulating amplifier, a variation in gain of 45 db can be obtained. The high cut-off filter following the flat regulating portion of the circuit prevents noise interference or possible overloading effects at frequencies above the type J range. In the slope regulating circuit a series of equalisers is provided to compensate for the higher line attenuation at 143 kC/s. Each equaliser is connected to a fixed set of vanes on the slope regulating condenser, and the correct network is chosen by means of a moving set of vanes driven by a motor. The slope regulating condenser is followed by a slope regulating amplifier. The slope regulating circuit does not vary the gain at 92 kC/s, but provides a variation of approximately 32 db at 143 kC/s. Thus, in the west terminal, the automatic level control features will compensate for line losses which vary from 0 to 45 db at 92 kC/s, and from 0 to 77 db at 143 kC/s.

The control equipment is followed by a basic equaliser, which, together with the regulating amplifier, provides the necessary line equalisation. The west deviation equaliser compensates for the distortions introduced by the several filters in the receiving group terminal. Thence the received band is passed to the first group demodulator, a receiving band filter, the second group demodulator and a receiving low pass filter. This equipment performs a similar function to the group modulating equipment (as illustrated in Fig. 2), and a band of frequencies from 60 kC/s to 108 kC/s is obtained from the receiving low pass filter. These frequencies are amplified by the auxiliary amplifier, and leave the group terminal bay at a level of —5 db. The auxiliary amplifier has a hybrid type output transformer, and pilot pick-off filters are connected across one side of this transformer. The pilot frequencies from these filters are amplified and rectified to operate "Sensitrol" relays. These relays in turn control the motors which drive the regulating equipment. A fixed auxiliary equaliser and an auxiliary amplifier are also provided on the group terminal bay (as indicated in Fig. 1). These can be patched into circuit if line conditions are extremely severe.

Channel Carrier and Pilot Channel Supply: Carrier frequency and pilot frequencies required in the J2 system are supplied from a common source. The channel carrier and pilot channel supply bay provide the carrier frequencies for the channel modem bay and the pilot frequencies necessary for automatic regulation. The group carrier supply bay provides the carrier frequencies for group modulation and demodulation in the group terminal bay. These two bays can supply up to 10 J2 terminals. Both regular and emergency carrier supplies are included, and, should any failure occur in the regular supply, the emergency equipment is automatically switched into circuit by means of the carrier supply alarm and transfer circuit panels. An audible alarm is also provided.

The regular carrier generator includes a 4 kC/s tuning fork type frequency generator, and this tone is applied to a non-linear coil at a high level to generate a large number of odd harmonics. In later systems, the tuning fork is replaced by a quartz crystal. A rectifier bridge included in the circuit provides the even harmonics of 4 kC/s distinct from the odd harmonics. These frequencies pass through hybrid coils (so that the emergency supply can be switched when necessary) and the individual carrier supply frequencies are separated by means of crystal filters and applied to the channel carrier supply busbars. The channel modem bay connections are wired direct to resistances connected across these busbars.

64 kC/s and 104 kC/s pilot supplies are amplified from the common supply generator, but 58, 109, 60 and 111 kC/s are supplied by separate crystal oscillators. The pilot channel supply panels include busbars so that a number of systems can be provided with pilot frequencies. The channel carrier supply bay also includes 5 kC/s regular and emergency oscillators which are used to derive certain of the group carrier supplies.

Group Carrier Supply Bay: A separate branch of the odd harmonic output from the 4 kC/s carrier generator is applied to the group carrier supply filters, which are of the crystal type. The 308 kC/s frequency is then amplified and applied to a distributing busbar. 340, 346 and 484 kC/s supplies are derived in the same manner. In the case of the 543 kC/s supply, 548 kC/s is first selected by a crystal filter and then modulated with 5 kC/s to produce 543 kC/s with other products. The 543 kC/s is selected by means of another crystal filter, amplified, and applied to distributing busbars. 306 kC/s and 541 kC/s supplies are also derived in this manner.

Repeater Equipment: A block schematic of the J2 Repeater is given in Fig. 3, and the operation of the repeater can be followed by referring to the description of the group terminal bay given above. The same repeater can be used for either an NA, NB, SA or SB system; but repeater stations are divided into three different types, as follow:—

(a) **Main Repeater Station:**
Operates from 24 and 130 volt battery supplies. Usually contains three channel and other carrier equipment in addition to type J2 equipment.

(b) **Auxiliary Repeater Station (A.C. power available):**
Operates from 152 volt battery, which provides plate supply and 21.7 volt sections for filament supply. These stations are normally unattended, and alarms are extended back to a main station by means of an alarm trunk control system. Battery is continuously floated by a regulated rectifier.

(c) **Auxiliary Repeater Station (no A.C. power available):**
These stations are similar to (b), except that battery charging is accomplished by means of petrol engine generators.

Line and Crosstalk Suppression Equipment: A description of the installation of outside plant associated with Type J Systems is given in another article in this Journal. Due to the problems introduced by the extension of the carrier frequency range from 30 kC/s to 150

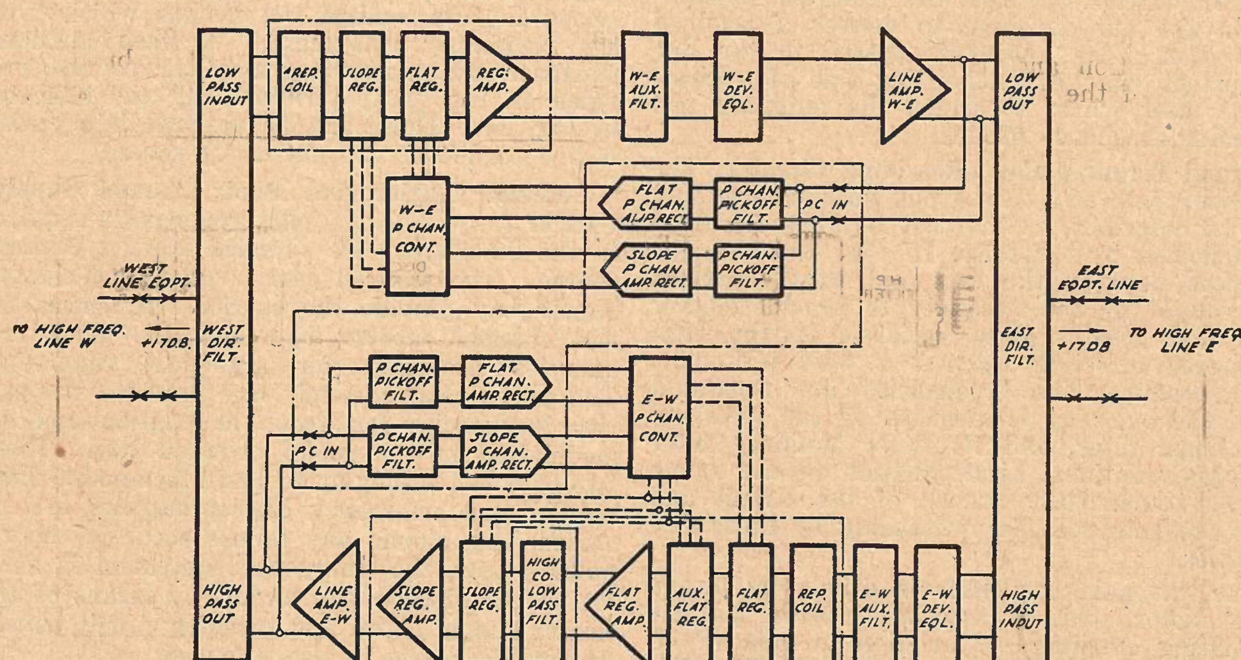

Fig. 3.—Block schematic of Type J2 repeater.

kC/s, a number of new items has been introduced. The J line filters separate the circuits working below 30 kC/s from the band of frequencies above about 35 kC/s. The line filters have a characteristic impedance of 560 ohms, but shunt and series resistances on the common side of the filters permit them to be used in circuits of impedance 520 ohms to 600 ohms. The line filter groups used in Australia are coded 102A type, and they include a transformer after the high pass filter to match the equipment impedance (125 ohms).

Crosstalk coupling paths involving non-J circuits which act as tertiary paths may exist at auxiliary repeater stations, and it is possible for these paths to give rise to serious crosstalk between J systems. To reduce this coupling, crosstalk suppression filters are installed in each non-J pair. As the coupling may result from either metallic or longitudinal circuit currents, the necessary suppression must be introduced in both types of circuits.

Two types of crosstalk suppression filters are used as explained below:—

(a) The 105A filter is used on pairs carrying voice frequency, d.c. telegraph and a single channel carrier system, such as the type D and type H.

(b) The 99A filter is used on pairs carrying voice frequency, d.c. telegraph and a three channel carrier system.

The 99A filter is mounted on a standard $5\frac{1}{4}$ in. mounting plate, and two 105A filters can be mounted on a standard $3\frac{1}{2}$ in. mounting plate.

At main repeater stations a roof filter is required in the west-east side (high frequency) direction of the type C repeater on type J pairs under any of the following conditions:—

(a) When a type C system and a type J system are on the same pair on one side of the repeater station and on different pairs on the other side of the repeater station;

(b) when the type C system is repeatered while two type J systems on the type C pair terminate from both directions; and,

(c) where interaction crosstalk paths between type J systems via the type C repeater exist.

The 106A type C roof filter is used for this purpose, and it attenuates frequencies above 33 kC/s.

Cable Entrance Methods: In order that the reflected near-end components of far-end crosstalk between type J systems may be kept within reasonable limits, it is important that the reflection coefficients at the junctions of the open wire, the loaded lead-in cables, the line filter equipment, trunk entrance cable (where used) and the carrier equipment be kept at low values. Under normal circumstances, a return loss of the order of 26 db should be obtained in the frequency range from 94 to 140 kC/s, and 20 db over the frequency range from 36 to 82 kC/s, when measuring at the junction point of the open wire line and the equipment terminating the entrance cable. The important requirement is that the sum of the return loss and the near-end crosstalk attenuation between the disturbing and the disturbed circuits shall be greater than the far-end crosstalk between them. Loaded disc insulated cable and unloaded paper insulated trunk cable have both been used in Australia for type J entrance facilities. Fig. 4 illustrates typical line arrangements when a filter hut is not used. The loading arrangement indicated in the figure (type E-1 or H-1 unit) is used for short lengths up to 330 ft. Where the length exceeds 330 ft. other terminal loading units are required, an intermediate loading coil being introduced at 600 ft. intervals.

For long lengths of entrance cable a filter hut is established at the open wire end of the cable, and unloaded paper insulated cable pairs in normal trunk cables are used to bring the J frequencies in to the office. The line arrange-

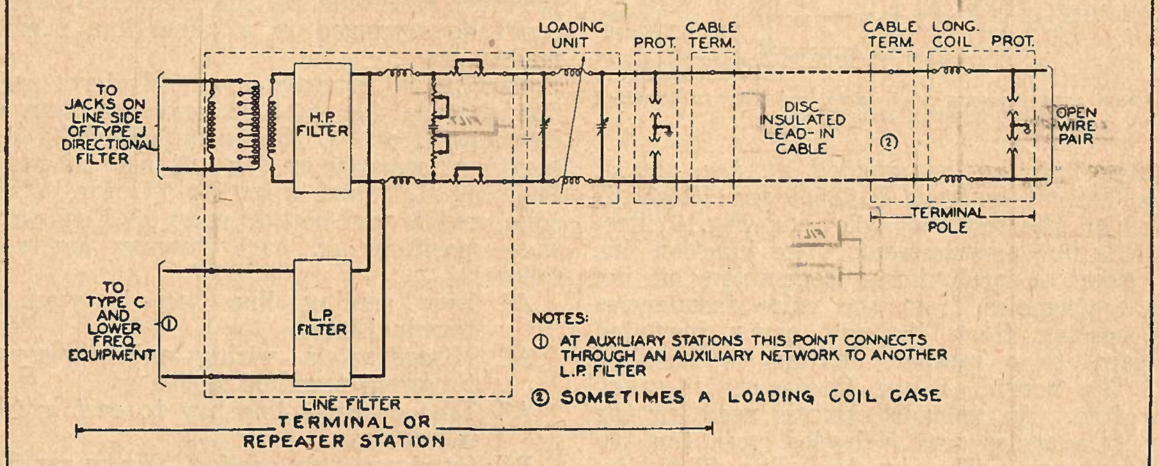

Fig. 4.—Typical line arrangements where filter huts are not used.

ments under these circumstances are illustrated in Fig. 5.

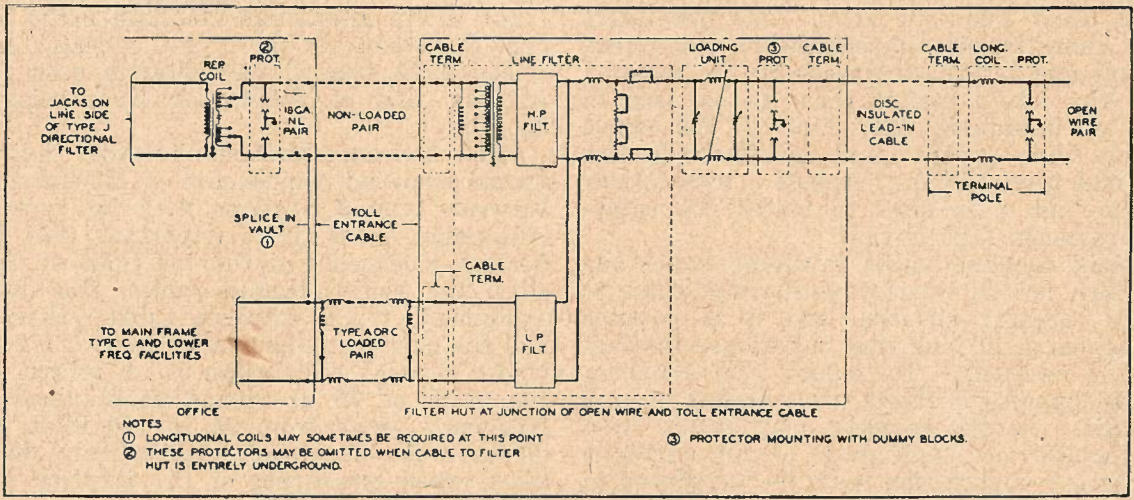

Fig. 5.—Line arrangements using a filter hut.

Up to the present, 40 lb. star quad trunk type cable has generally been used to provide the non-loaded pair between the filter hut and the terminal office, and loaded pairs in the same cable provide for the three channel facilities. Where a large number of J systems is operated in the same cable, it is sometimes difficult to select sufficient pairs with satisfactory cross-talk characteristics. The use of 40 lb. star quad carrier type cable may be necessary in the future to overcome this difficulty, and this cable may prove to be more economical than the installation of trunk quad cable with a cross-talk balancing frame.

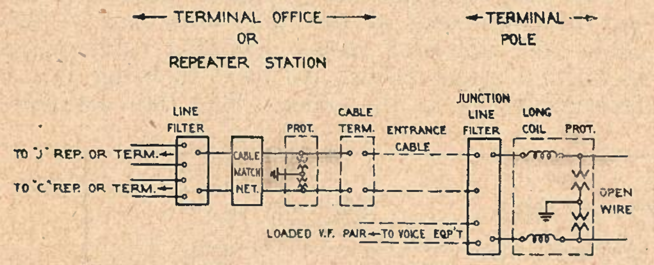

Fig. 6.—Line arrangements at a main repeater or terminal with junction line filters.

A filter hut can be avoided by the use of junction line filters (type D158535 and D158536) mounted on the terminal pole, and Fig. 6 illustrates this line arrangement. The junction line filters effect a preliminary separation of the carrier frequencies from the voice frequencies before passing them through paper insulated cable pairs to a repeater station or terminal office. The normal J line filters are mounted in the office. An unloaded pair is used for the carrier frequencies and a loaded pair for the voice frequency. The junction line filters include an impedance matching network, and in the carrier branch the loss in the transmitting range varies from about 5 db at 6 kC/s, to 2 db at 30 kC/s. When added to the loss in three miles of non-loaded entrance cable, this results in a flat loss of about 8 db over the three channel range.

Installation: A typical layout for a type J terminal is shown in Fig. 7, and this layout

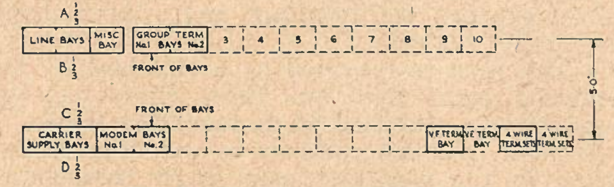

Fig. 7.—J2 system terminal layout.

would provide for an ultimate development of 10 systems. Four systems to three bays have been allowed for on the channel modem bay line, although later systems may permit two systems on a single bay. If it is desired to restrict the number of bays in a single line to facilitate maintenance, the voice frequency bays could be arranged in a third line behind the modem bays.

Two 10 in. runways mounted above each bay line provide for cabling, and the runways in positions B and C should be joined by a short length of runway on the left side of the suite. Positions 1, 2 and 3 in Fig 7 refer to the top edge, middle and bottom edge of A runway, and these positions on each runway are used as follow:—

A1 Line cabling—line bay to west group terminal bays.

A2 Miscellaneous wiring—miscellaneous bay to group terminal bays.

A3 Line cabling—line bay to east group terminal bays.

B1 Carrier supply cabling—group carrier supply bay and channel carrier supply bay to group terminal bays.

B2 Group modulator cabling—channel modem bay to line bay to group terminal bays.

B3 Group demodulator cabling — channel modem bay to line bay to group terminal bays.

C1 Group demodulator cabling—see B3.

C2 Group modulator cabling—see B2.

C3 Carrier supply cabling—see B1.

D1 Carrier supply wiring — channel carrier supply bays to channel modem bays.

D2 Mod. and demod. wiring—channel modem bays to voice frequency bay.

The "cabling" mentioned above is type 720 cable (rubber covered and shielded). The cable types used for the remaining connections are described on the appropriate installation drawings. The entrance cables from the open wire lines terminate on the line bays.

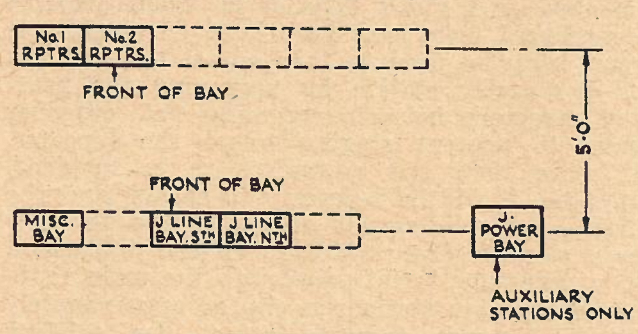

Fig. 8.—J2 system repeater layout.

A typical layout for a type J Repeater is shown in Fig. 8. In addition to the equipment shown, provision must be made for a crosstalk suppression filter bay. If all incoming lines from one direction (except type J lines) terminate on a cable head bay, the crosstalk suppression filter bay should be mounted as close to this bay as possible. In this way, unwanted crosstalk paths can be suppressed as soon as the lines enter the office, and coupling in the office wiring is not of importance.

At auxiliary stations, the power bay should be arranged as close to the tapped battery as possible in order to reduce the length of battery leads. A separate "rack" earth and "battery" earth should be provided, and these should only be joined at the power board in the power room. By the use of two separate runways as described for the terminal, cabling and wiring for the repeater can be run without risk of interference from noise or coupling between the east and west type 720 cables of the repeaters.

Special earthing arrangements at auxiliary repeater stations are employed for the purpose of improving the effectiveness of crosstalk suppression filters and type J line filters in reducing interaction crosstalk around type J repeater points. If a perfect earth could be obtained, the filters would operate with no impairment; but, because of the nature of the electrical circuit of the filters, a small amount of resistance or reactance in such a single earth connection acts as a mutual impedance between the two halves of the crosstalk suppression filter, or between the east and west line filters, and may seriously impair their effectiveness. This effect can be overcome by the use of the so-called 3-ground arrangement, i.e., two terminal pole earths in addition to the normal station earth. Under these circumstances the incoming line cables are insulated from the station runways by means of wooden slats.

Future Developments

Auto-Transformer: As an alternative to the use of J line filters installed in filter huts, or junction line filters mounted on the cable terminal pole, an attempt has been made to develop an auto-transformer to match the open wire line to the carrier cable. Trial transformers have been installed at Glen Innes and Tenterfield on the Sydney-Brisbane route, and two J2 systems are at present operating over this section.

Multi-Channel System in Frequency Range 148 to 260 kC/s: The new transposition types now being introduced were designed for frequencies up to 150 kC/s. It is possible that on a few selected pairs the transmission characteristics may be satisfactory for an additional 12-channel system in the frequency band 148 kC/s to 260 kC/s, above the existing J2 system. Measurements are proposed to check the possibilities in this direction.

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THE TYPE J 12-CHANNEL CARRIER TELEPHONE SYSTEM — OUTSIDE PLANT

D. F. Styles, B.Sc.

A general description of the 12-channel open wire carrier system used in Australia has been given in Vol. 2, No. 2, October, 1938, and Vol. 3, No. 1, June, 1940; and a description of the type J2 system, which incorporates a number of improvements to the earlier J1 system, is included in this Journal. The present article will deal mainly with modifications to line plant required for the operation of such a system, with particular reference to the lead-in arrangements at repeater and terminal stations.

Line Requirements: The operation of type J frequencies to 150 kC/s requires appreciably more rigid limits in the design of pole routes than is involved with 3-channel operation to 30 kC/s. New routes for type J operation are designed to accommodate a three and 12-channel system on each pair. For this purpose wires are spaced 6″-22″-6″-34″-6″-22″-6″ and arms are spaced 42″ apart. Poles are spaced 40 to the mile, giving a 256 span "E" section of maximum length 6.4 miles.

Because of the existence of very considerable mileages of pole route designed primarily for operation to 30 kC/s, the use of such routes for a limited number of 12-channel systems is desirable. These existing routes designed for 3-channel carrier operation are laid out on the basis of 9″-19″-9″-28″-9″-19″-9″ wire spacing, with 28″ between arms. Poles are usually spaced 32 to the mile, giving a 256 span "E" section 8 miles in length. On account of the relatively high coupling coefficients between the majority of pair combinations, it is practicable to use only a few selected pair combinations with low coupling coefficients for 12-channel carrier operation. Apart from the more intensive transposing of the pairs required for 12-channel carrier purposes, it is necessary to apply appreciably closer tolerances to sag differences between the two wires of a pair and to the accuracy of the pole spacing.

Spacing of Repeaters: Under wet weather conditions the attenuation of a well transposed 200 lb. H.D.C. pair is approximately 0.385 db per mile at 150 kC/s. The normal transmitting level of a type J system is 17 db, and the normal practice is to work on the basis of 28 db line attenuation per repeater section. This corresponds to approximately 73 miles of open wire under wet weather conditions. If this is exceeded there is, under severe conditions of atmospheric or other external interference, a danger of channels being affected by noise. Where it is known that external noise conditions are favourable, these figures may be increased.

Apart from the open wire line, allowance must be made for the attenuation of lead-in cables which may be considerable where P.I.L.C. cable is used. For example, star quad trunk type cable with 40 lb. per mile conductors has an attenuation of 5.3 db per mile at 150 kC/s. Repeater stations have usually been established at distances of 50 to 70 miles apart. Under these conditions, the gain of the amplifiers in adjacent stations is sufficient to allow a repeater to be patched out for maintenance, except during extreme weather, without causing any serious deterioration in the speech channels.

Loop Conditions: When only one J system is installed on a route, little or no trouble will be experienced from loop conditions. A single pole route may be used to take wires into and out of a repeater station by upgrading the near-end crosstalk between incoming and outgoing pairs to prevent singing round the repeater. If more than one system is to be installed, however, it will be necessary to ensure that the high level side cannot crosstalk into the low level side of other systems. In the first place, it is necessary to introduce into the main route at all repeater stations a gap of approximately 80 ft. between terminal poles. On existing routes it is generally found convenient to introduce this or a larger gap when the route is being respaced and retransposed in readiness for the installation of J systems. In addition, complete separation of incoming and outgoing circuits in the loop is essential. This may involve separate open wire routes, separate in and out cable systems, or a cable in one direction and an open wire route in the other direction.

To reduce still further the danger of crosstalk from the high level side of one system to the low level side of another, where "in" and "out" cables are used these are placed in separate ducts, and as far as possible, in separate duct routes. At terminal stations, systems feeding separate aerial routes usually have quite distinct conduit routes, and there is a large gap between terminal poles; but where these conditions do not apply for all systems, the same precautions will have to be taken as at repeaters.

In a number of cases repeaters are installed at towns where the main open wire route is remote from the office and loop circuits are led in by means of relatively long trunk cables, usually loaded for 3-channel carrier operation. The four methods of leading J systems into repeater stations which normally require consideration are:—

(a) Place the repeater station at or between the trunk cable terminal poles. The objection to this arrangement is that it often involves the establishment of a repeater station separated from an existing V.F. or 3-channel repeater station where power, batteries and staff are already available.

(b) Build open wire routes to lead the J circuits in close to the repeater station. This is frequently the most economical and satisfactory method, but at times is regarded as a retrograde step by local authorities, who have been pleased to see the earlier open wire construction disappear, especially where the streets have been planted with ornamental trees.

(c) Instal long loaded disc insulated cables; but this method is expensive.

(d) Where it is impracticable to have the terminal pole within reasonable access from the office by disc cable, provide a filter hut close to the terminal pole. Filters separating the frequencies above and below 35 kC/s are installed in this hut, the lower frequencies being transmitted to the repeater or terminal via loaded cable, and the higher frequencies via unloaded cable. The exact distance at which it becomes economical to adopt this method will depend largely on the most variable factor, namely, the cost of erecting a building suitable to that particular locality. The establishment of a filter hut introduces additional maintenance problems, and this has a considerable bearing on the method chosen.

In some cases the most suitable method to adopt may be a combination of two of the methods outlined in the foregoing. In addition to line modifications, further measures to reduce crosstalk include the careful screening of all office wiring and the fitting of crosstalk suppression filters to non-J pairs at auxiliary (i.e., non-3-channel) repeater stations, and, in some circumstances, to pairs at main repeater stations.

Details of Leading-In Equipment: J pairs usually enter a station in a disc insulated star quad cable, suitably loaded to give the correct impedance characteristics. This D.I.S.Q. cable has been specially designed for the purpose, having a low capacity which reduces the high frequency attenuation and lends itself to a practicable loading scheme. It consists of four wires in spiral formation separated by disc insulators. Diagonally opposite wires of the quad are 0.32″ apart, and constitute a pair. Multi-disc cables, containing up to seven quads, have been manufactured in U.S.A., but have not yet been used in Australia. Characteristics of the cable are:—

Gauge of conductor: 16 A.W.G., approximately 40 lb. per mile copper wire.

Wire separation: 0.32″ between diagonally opposite wires of a pair.

Length of spiral: Approximately 10 inches.

Discs: Commercial rubberoid compound or hard rubber $^1/_{16}$″ thick, 1″ apart.

Paper insulation: One layer covers discs, another the shields.

Shields: One copper covered by two steel tapes, wound spirally.

Sheath: Thickness, 0.085″; external diameter, 0.94″.

Cable weight: 1.2 lb. per ft.

Dielectric strength: 1200 volts A.C. for two seconds.

Capacity: 4.7$\mu\mu$f. per foot.

Effective resistance: 109 ohms per loop mile at 140 kC/s.

Impedance: 240 ohms at 140 kC/s.

Non-loaded attenuation: 2 db per mile at 140 kC/s.

Loaded attenuation: 1.2 db per mile at 140 kC/s.

The cable is terminated in an office in a 28A cable terminal, which consists essentially of a gas-tight plug fitted with terminals for drop wiring and a U-shaped support for rack mounting. The corresponding outdoor terminal for use when the entrance cable is so short as not to require a pole loading unit is a 29A, which is virtually a 28A unit enclosed in a weatherproof metal cover and provided with a support to allow it to be attached to the woodwork of a pole.

To give additional protection from crosstalk, and, incidentally, to protect J line filters against excess voltages, longitudinal retard coils are fitted to all non-J lines on one side of a repeater station, and to all J lines on both sides of repeater and at terminal stations. The coils used with physical pairs are designated "D157639" units, and those used with phantom groups are "262A" units. The former are protected by standard carbon arresters included in the unit, but the latter are protected by carbon arresters mounted in a separate unit known as the "83A" protector. The coils are designed to give high impedance above 30 kC/s in the respective longitudinal paths, and to have small effect in the metallic circuit paths (including both side and phantom circuits where the 262A is concerned). Telephone and telegraph channels below 30 kC/s thus remain unaffected by the installation of the protectors and retards.

In areas subject to severe lightning damage, it may be necessary to apply electrical drainage to J and non-J pairs. This requires the fitting to each pair of a retard coil, with the mid-point earthed and the ends separated from the line wires by carbon block arresters. Carbon blocks are also connected across the halves of the retard coil from the line wires to earth. These auxiliary fittings may be installed both at the pole and in the office.

Three different loading systems are used, depending upon the impedance of the circuit involved. The J-0.94 loading system has a nominal impedance of 600 ohms; the J-0.85 system has a nominal impedance of 575 ohms, and the J-0.72 system has a nominal impedance of 542 ohms. Up to the present, the Department has only used the J-0.94 system. The J-0.85 system will be required for new 6" spaced J routes. These routes (with 200 lb. copper pairs) have a characteristic impedance of approximately 560 ohms. The various types of loading equipment required for the J-0.94 systems are shown in the following list:—

a total capacity of 3105 $\mu\mu$f. from the centre of one coil to the centre of the next. If a fractional (0.8 of the full weight) loading coil RF30 or F30 is used, the section capacity becomes 2500 $\mu\mu$f. from centre to centre of coils. If the two coils in sequence are RF30 and F30, the figure is reduced to 1892 $\mu\mu$f. These total capacities comprise the individual capacities of—

(i) half the loading coil at each end;

Cable Length in Feet	Loading Unit at Terminal Office	Loading Unit at O.W. Terminal Pole		Loading Unit at Intermediate Point		
	Type of Coil	Type of Coil	Type of Case	No. of Coils per Pair	Type of Coil	Type of Case
0-130	H1 or E1	—	—	—	—	—
130-330	H1 or E1	G2	144B	—	—	—
330-360	RF30	F30	143B	—	—	—
360-480	RF30	A30	143B	—	—	—
	or	or				
	RA30	F30	143B	—	—	—
480-600	RA30	A30	143B	—	—	—
600-960	RF30	F30	143B	1	730	D157642
960-1200	RA30	A30	143B	1	730	D157642
1200-1560	RF30	F30	143B	2	730	D157642
1560-1800	RA30	A30	143B	2	730	D157642
etc.						

For normal lengths of disc cable up to 180 feet, E1 or H1 office units are used without any loading at the terminal pole. In practice, owing to the additional capacity introduced by retard coils, etc., it is usually desirable to reduce the length of 180 ft. to 130 ft. For lengths of cable between 130 ft. and 330 ft. the E1 or H1 unit is used in the office, but a G2 fixed type loading coil is installed on the terminal pole.

For lengths of cable exceeding 330 ft. it will be seen that to some extent the choice of type of coil will depend on the physical position of the intermediate loading points. The full loading section length is 600 ft; but it is desirable to plan for a maximum of 580 ft. to allow a small additional margin for unforeseen capacity variations. The H1 and E1 office loading units have variable condensers and inductances. The former is the war-time modification of the latter, differing from it in having multi-unit fixed mica condensers instead of continuously variable air condensers, and is more economical of rack space. The loading section for which the full weight coils, A, RA and 730, were designed has

(ii) the stub cables of the loading coils;
(iii) the D.I.S.Q. cable itself; and,
(iv) any additional capacity which may be inserted.

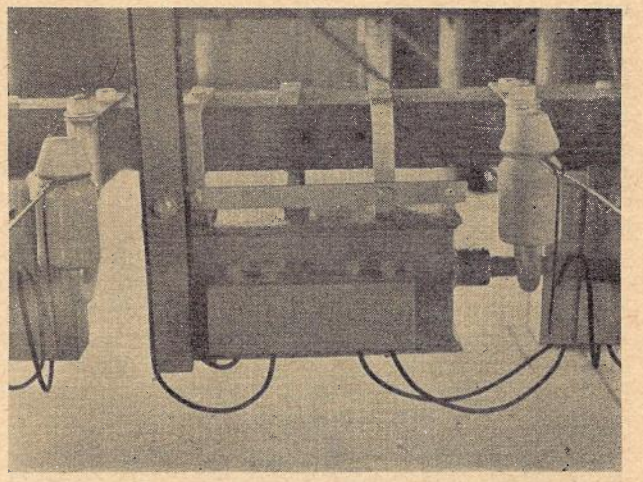
That portion of the capacity between two loading coils contributed by the D.I.S.Q. cable depends upon the geography of the layout, and is very seldom such as to give the exact total capacity desired between the two loading points. For this reason, building out units usually have to be inserted in each loading section. The types used are tabulated below. Where an H1 or E1 unit is used, for cable lengths less than 330 ft., the variable components of the unit are adjusted, and no special building out units are required:—

Code No. of Building Out Unit	Type	Capacity ($\mu\mu$f)	Where Inserted
51A	Fixed	1000 ± 2%	In pole loading coil case or in office loading coil case.
51B	Fixed	500 ± 2.5%	Do.
51C	Fixed	254 ± 3%	Do.
50C	Variable	0-275	Do.
209F	Variable	0-500	In pole loading coil case or in office loading coil case or in sheath sleeve at intermediate loading point.

A 209 unit (in which other ranges than that shown are available) is usually installed only when it is necessary to build out at an intermediate point where a D157642 type loading coil case is used. If there are only one or two loading sections, the building out units can all be accommodated in the special compartments provided in the pole mounted or rack mounted cases. The 50C and 209 units are varied by removing windings during the actual building out adjustments. The inductance of the windings is such that no special compensation for that component is necessary.

Filter Huts: At a filter hut, the J pairs enter the building from the open wire terminal in D.I.S.Q. cable as described in foregoing paragraphs. The J line filters separate the frequencies above and below 35 kC/s, and the higher frequencies are taken from the filter hut to the repeater station in specially selected and balanced unloaded pairs in a P.I.L.C. trunk entrance cable, while the frequencies below 35 kC/s occupy 3.5 m.H. loaded pairs in the same cable. The pairs in the P.I.L.C. trunk cable selected for J working are taken in a special 8-pair screened cable from the nearest convenient jointing point on the trunk cable to a 2A binding post chamber mounted on a rack in the filter hut. The tags of the 2A binding post chamber are connected to the tags on the drop side of the filters by the screened office wiring.

At a repeater or terminal station recent practice has been to terminate the P.I.L.C. trunk entrance cable in a compound filled cable terminal, thus superseding the S.I.L.C. termination, which has been found unsatisfactory at high frequencies. In some cases the J pairs are taken direct from the cable terminal to the drop side of the filters via screened office wiring.



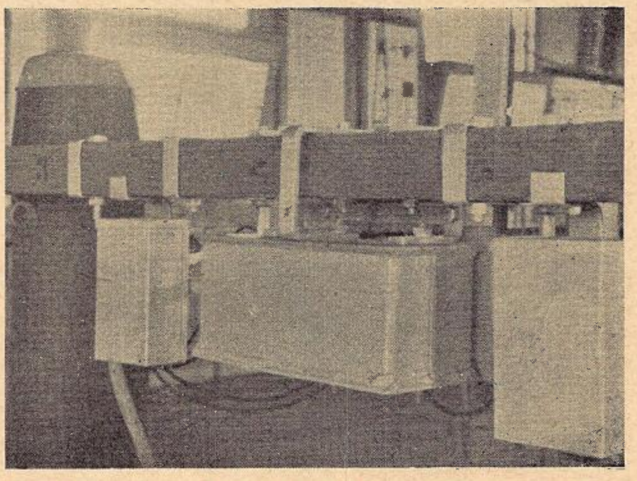
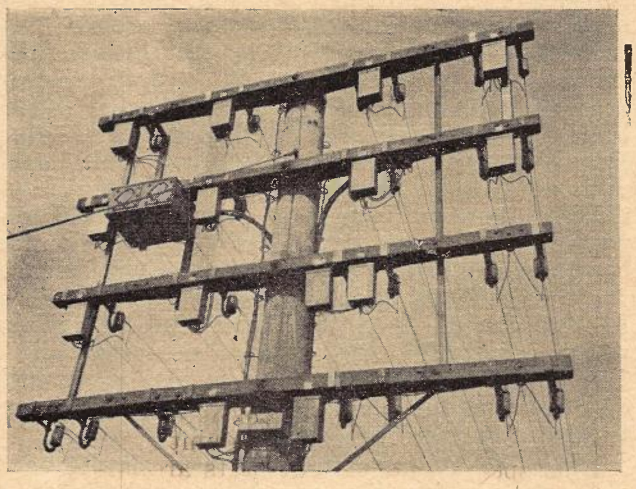


Fig. 2.—Front and rear views of mounting for 144B type loading coil.



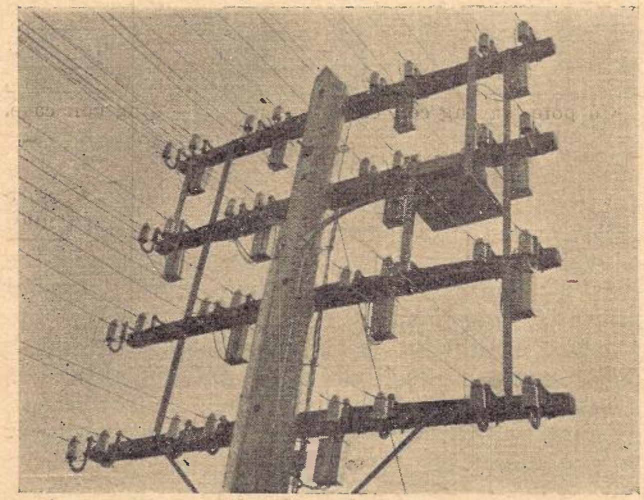


Fig. 1.—Front and rear views of prototype pole, showing methods of mounting equipment.

Mechanical Considerations

Terminal Poles: It will be evident from the foregoing discussion that many terminal poles on a J route will have to carry a considerable amount of new apparatus, and some attention to detail is necessary to plan a satisfactory terminal pole layout. A number of desirable features appear in designs for terminal poles developed in different States, and some layouts incorporate what appear to be the best points of earlier designs. Fig. 1 illustrates a prototype terminal pole, showing the method of incorporating the various components. As an alternative to this arrangement, the cable riser pipe itself has been used to form the quadrant support for the D.I.S.Q. cable stub of the loading unit or 29A terminal. The D157639 units (protectors and retards) are mounted as close as practicable to the corresponding open wire pair. The 143B or 144B loading unit, or the 29A cable terminal, is mounted beneath the arm (see Fig. 2). When selecting the position on the arm at which the D.I.S.Q. cable is to terminate, due regard should be paid to the ultimate layout of J pairs on the pole. The 262A phantom retard coils are located beneath the arm near the pole for simplicity in wiring. The 83A protector can accommodate 10 pairs of carbon blocks, and is sufficient for two phantom groups (see Fig. 3). It is convenient to mount one on the pole four inches below each arm carrying phantom groups. In this position it is sheltered to some extent by the arm, and the cover can be opened fully.

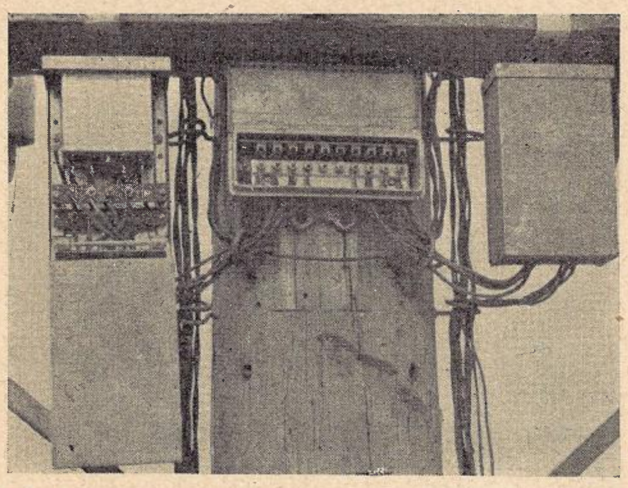


Fig. 3.—Mounting arrangements for retard coils and 83A protector box.

All pole work must be robust and durable. The 143B loading unit, including stub cable, weighs 125 lbs., and the 144B unit weighs 90 lbs., so that block and tackle have to be used to raise them to the crossarms. Care must be taken to provide firm supports capable of withstanding exposure to weather for a long period, and special protection must be given the vulnerable point where the D.I.S.Q. cable stub leaves the iron loading coil case. The steel supports required for the various items of J equipment shown in Fig. 1 are of four types:—

- (i) quadrant bracket, to support the stub of the 29A, 144B or 143B unit;
- (ii) loading coil support to carry the 144B or 143B case;
- (iii) batten brackets to support the hardwood battens to protect V.I.R. leads between arms;
- (iv) protector brackets to support D157639 type or 262A protector and retard units.

All iron and steel should be given some rustproof coating. Galvanising tends to flake off the threads of nuts and bolts, and for these an electrolytic deposit such as "oxoseal" (a cadmium alloy) is preferred. When the installation is complete the loading coil cases should be repainted.

The D.I.S.Q. cable stub is firmly tied to the quadrant bracket by means of straps packed with lead to protect the sheath from abrasion. The quadrant has an L-shaped extension to attach the top to the arm with a coach screw, and coach screws secure the lower end to the pole. The loading coil cases are each provided with four bolts projecting from top and bottom to allow them to be mounted on either side of the pole—they are not weatherproof if mounted vertically. The weight is taken by the shearing strength of the threads of the bolts and nuts; but since there are four of them and regular inspections would reveal incipient weaknesses, no danger is anticipated from this cause. For transmission reasons it is necessary to lead some wires directly from one arm to another and to give them uniform spacing. In the pole illustrated this is done by clipping the insulated wires to 2″ x 1″ hardwood battens attached to a simple metal bracket projecting from the arm, and to a bracket forming part of the loading coil support. The combiner could be used in place of the batten in some instances where no loading coil with its terminals several inches from the arm is involved. But it is preferable to separate the insulated wires with wood rather than metal in case the insulation deteriorates. Heavy gauge insulated wire has been used without battens, but it is more liable to accidental damage than if it were supported and protected by battens. The galvanised iron brackets supplied by the manufacturing company for the D157639 and 262A cases are bent at a line $9\frac{1}{4}$ inches from the lower end in such a manner that the case may be supported about 1 inch below the arm; there is also a one-inch gap between the loading coil case and the arm to give clearance for the wiring.

Unless particular care is taken to simplify and order the wiring the appearance will be most unsatisfactory, fault liability will increase and maintenance will be more difficult. The fundamental wiring rules to be observed are that all J leads must be as short as practicable, and, for as great a length of their path as possible, wires of a J pair should be at a uniform separation of 2 inches or more. J pairs should be at least 6 inches apart. Wiring between protectors and retards and the open wire pairs they serve should be short, and all non-J leads should be twisted pairs. After fitting the terminal brackets, and before mounting any other apparatus on the arms, it is necessary to mark out the work, drill all holes and fit all bridle rings, cleat insulators and attach neutral roses, as direct access to some of these points will not be available later.

A neutral rose screwed to the pole immediately beneath the level of each arm is a convenient terminal to which may be connected earth wires from each unit on the arm and the main terminal pole earth. In cases where the soil conductivity is good, and a long underground cable, say, from filter hut to repeater station, is available, a low effective resistance to ground can be obtained by using the cable sheath, and this is sufficient for both pole and office earths. A three-point earth arrangement is recommended, however, where these conditions do not hold, a pole earth for each side of the station and a station earth for the apparatus between the J line filters. The J line filters and the halves of the crosstalk suppression filters are connected to the respective pole earths. This practice improves the effectiveness of the filters in reducing interaction crosstalk around the repeater.

Ducts and Manholes: The usual problems encountered when planning an ideal layout of cables in ducts entering repeater stations are complicated by the desirability of having opposite directional D.I.S.Q. cables in ducts with the maximum separation in the common path, with due regard for the ultimate development. A good scheme with no cables crossing in manholes is often possible only if the layout of racks in the office is made to conform with that of the cables.

The placing of loading units in manholes also requires some consideration. The intermediate 730 type coils in the D157642 type case have only a single stub, to which the D.I.S.Q. cables leaving opposite ends of the manhole must be connected. The several obvious modified jointing methods have disadvantages; for example, to loop back the stub cable pairs is a strain on the insulation, the paper sleeve may slip off, while a T-shaped sleeve is mechanically weak. The only satisfactory solution is to prepare an orthodox three-way joint in which the two D.I.S.Q. cables enter the sleeve from one end and the stub from the other, and, if necessary, to vary the manhole design to suit the cable layout. This means that one D.I.S.Q. cable must sweep through a half-circle. A safe radius of curvature is 12 inches, so that it is usually possible to support a vertical sweep on one wall of the manhole. If a horizontal sweep is preferred, it is good practice to have the cables enter the manhole in ducts near opposite corners. The D157642 type loading unit has an overall height of 28 inches, and, allowing a 12 inch radius for bending the stub, the minimum dimension required for its accommodation is about 3 feet 6 inches. If the manhole is not large, it may be housed in a recess in the floor or wall.

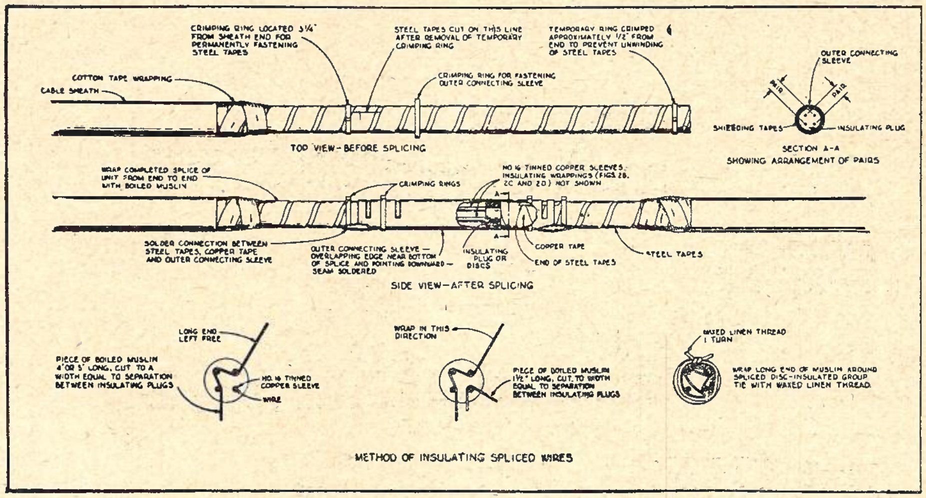


Fig. 4.—Method of jointing spiral—four disc-insulated cable.

Jointing: The jointing operations are novel, and will be unfamiliar to those who have not yet been engaged on type J installations. The make-up of a D.I.S.Q. cable has been described previously. Special tools and material are used to make the joint, and the actual jointing operation is simple if the cable is set up firmly and cut accurately. The cable is placed in position without bending at any point to a radius less than 12 inches. A few inches of sheath and outer paper covering are first removed, and three crimping rings are slipped on each end to be jointed. The external ring is crimped to prevent the steel shielding tapes from unwinding. The sheaths are then cleaned, waxed and cut to give a 12 inch opening; the neck is taped and the heavy paper insulation is removed. Reference to Fig. 4 will simplify the following description.

The first ring is permanently crimped $3\frac{1}{4}$ inches from the end of the sheath and the steel tapes are thoroughly cleaned. The temporary external crimping ring is then released, the second ring is located against the first and the steel tapes cut at a point just beyond the crimping rings. The copper tape which is now revealed is cleaned and cut at 5¼ inches from the sheath with a pair of shield cutting pliers. It may be necessary to tack the copper tape with solder to prevent it unwinding. The inner paper insulation is removed up to the same mark, and several discs are pushed back under the paper. The conductors are now cut ¾ inch from the copper shield and jointed to their opposite wires by means of a soldered metal sleeve. The wires at the joint are then insulated from each other, and the shield, with muslin, boiled in paraffin. A flat copper sheet known as an outer connecting sleeve is then cleaned and formed into a cylindrical shape on a mandrel, fitted over the joint, crimped into position with the loose ring at each end, and solder is applied to its seam and slots, giving electrical continuity to the shields. The whole joint is then insulated and sleeved.

of the cable conductors and shields should be insulated from each other, and from earth, so that insulation resistance tests may be applied to the conductors and sheaths when they have been prepared for jointing. Using a 500 volt megger, the insulation is tested, firstly, between each wire and the remaining three bunched to the shields and sheath, and, secondly, between the shields and the sheath. Tests should be made for open circuits and split pairs after several joints have been made. Before the last joint in a cable is made, it is as well to identify individual wires, and joint so that T_1 at the 28A corresponds to T_1 at the 29A, etc.

Cable Faults: Although the sheath is rather hard, the D.I.S.Q. cable must be handled with care, for there is no solid body of wire within the sheath to help resist bending. A minimum radius of bend for safety is 12 inches. It is

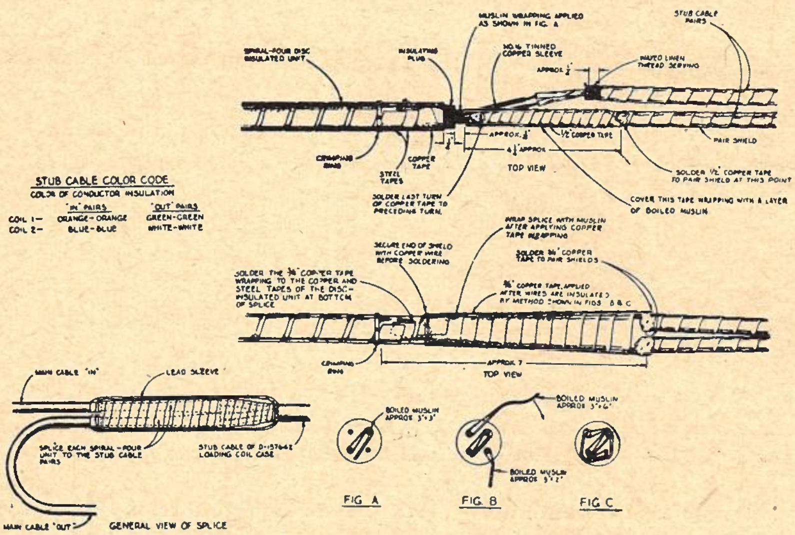


Fig. 5.—Method of jointing intermediate loading pot into disc-insulated cable.

The D157642 loading pot stub consists of four paper insulated shielded pairs. When set up for jointing the sheath opening is 17 inches. The D.I.S.Q. cable is prepared as in the foregoing, except that the only ring is crimped at 5¼ inches and the copper tape is cut at 7¼ inches. See Fig. 5.

The shielded pairs of the stub are cut at 9 and 9½ inches, and the shielding tapes at 6½ inches from the sheath. The latter are tacked with solder. Beyond the shielding tapes the tinsel braid is allowed to project ¼ inch, and beyond that there is about one inch of paper insulation. The first pair is jointed with a soldered metal sleeve, insulated with muslin and wrapped with a copper shield. The second pair is next jointed, insulated and wrapped with copper tape. Finally, the whole quad is wrapped with copper, insulated with muslin and sleeved.

During jointing operations, the distant ends

perhaps even more important not to twist the cable, as to do so will cause it to collapse between discs very readily. The cable should never be flattened at one end when being pulled in, as unsuspected damage may be caused several feet away. If water should enter the sheath it may penetrate a considerable length of cable in a short time. In that event it would be difficult to dry out, and the wet section would have to be replaced. It is safe to draw in 100 yard lengths of D.I.S.Q. cable in level 4 inch conduits, with no more than one other similar cable in situ, if due care is taken to clean the ducts and use a lubricant.

Measurements and Adjustments: Certain line tests are usually made prior to installation of the equipment to ascertain if the outdoor plant is suitable for J operation. Where only one system is contemplated, impedance and attenuation measurements suffice; but where more than one system is involved far-end crosstalk must also be measured. Where the normal P.I.L.C. trunk entrance cable is used to lead J systems into an office, pairs having the smoothest impedance characteristics must be selected from those previously found satisfactory from the crosstalk standpoint. To do this, return loss measurements are made every 10 kC/s from 40-140 kC/s on each pair, and those which give the smoothest curves are selected.

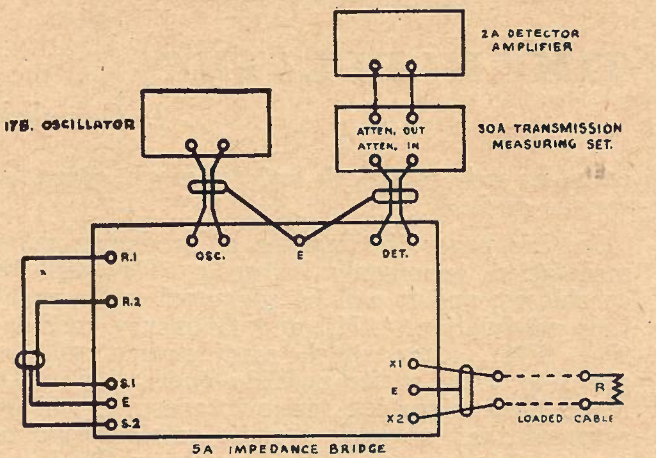


Fig. 6.—Method of making return loss of loaded cable versus a fixed resistance representing the open wire line.

Notes:

1. Use shielded cable for connecting leads, which should be as short as practicable.
2. The loaded cable is terminated at its far end in a resistance representing the nominal impedance of the open wire line.
3. The resistance dials of the impedance bridge are set to the same value as R.
4. The value measured is the return loss between the loaded cable and the resistance R in the impedance bridge.

Further measurements are necessary in connection with the adjusting of the loading equipment of the D.I.S.Q. cable. These measurements vary somewhat for the different loading arrangements involved. Since the primary purpose of the loading is to make the impedance of the loaded cable the same as the nominal impedance of the associated open wire line, a return loss measurement is made to determine whether the impedance matching results are satisfactory. The return loss expressed in db is a convenient method of indicating the degree of mismatch between two impedances, and is comparatively simple to measure.

A typical set-up for a return loss measurement on a loaded D.I.S.Q. cable is shown in Fig. 6. Normal type J line testing equipment is used, consisting of 5A impedance bridge, 17B oscillator, 30A transmission measuring set, 2A detector amplifier and type 720 screened cable test leads. The value to be measured is the return loss between the loaded cable (terminated at its distant end in a resistance representing the nominal impedance of the open wire pair) and a fixed resistance (provided by the resistance standards in the 5A bridge) of the same value as that used to terminate the distant end of the cable. The leads from the X_1, X_2 and S_1, S_2 bridge terminals must be carefully matched, and when the measurement is made at the terminal pole they will need to be about 45 feet long. Before these leads are connected, a calibration is made by throwing keys on the bridge, which put a resistance across each side of such a value as to give a known return loss of 25 db. The attenuator is set to 25 db and the gain of the detector amplifier adjusted so that it reads zero on the dial. The test leads are then connected and the bridge keys are set to measure the return loss of the loaded cable against the fixed resistance mentioned above. The oscillator output and the gain of the detector amplifier remain unaltered throughout the measurement, the attenuator being adjusted in each case to bring the detector amplifier as near as possible to zero. The return loss in db is given by 50 minus the attenuator reading. This might be clearer if the bridge is considered as a hybrid, the return loss being the loss between the oscillator and detector terminals minus the inherent hybrid losses. Since the output of the oscillator, the input to the detector amplifier and the inherent hybrid losses are fixed, it will be seen that the return loss plus the attenuator loss (RL + P) must be constant, i.e.:—

$$RL_1 + P_1 = RL_2 + P_2. \quad \text{(1)}$$

It will be remembered that for calibration—

$$RL_1 = P_1 = 25 \text{ db.}$$

Therefore from equation (1)—

$$25 + 25 = RL_2 + P_2$$

and $RL_2 = 50 - P_2$.

The return loss may be calculated for two unknown impedances from the formula—

$$RL = 20 \log_{10} (Z_1 + Z_2)/(Z_1 - Z_2). \quad \text{(2)}$$

The return loss for the J outside plant should not be less than 26 db for frequencies above 100 kC/s, and not less than 20 db for frequencies below 100 kC/s. This corresponds to a voltage reflection of 5% and 10% respectively. Methods of measuring crosstalk, attenuation and impedance at J frequencies have been described in a previous article in this Journal ("Transmission Measurements to 500 kC/s," by J. D. Uffindell; Vol. 4, Nos. 4 and 5.)

Future Development: Routes are already being constructed to carry ultimately ten or twelve J systems. Up to date, outside plant for J systems has been supplied from overseas sources; but the tendency will be to reduce this dependence by adaptation of locally manufactured equipment. For example, the P.M.G. workshops are manufacturing cable terminals to Australian designs, and pole mounting equipment is being produced locally. If a practicable auto-transformer can be designed, it may be possible to dispense in most cases with filter huts and long lengths of D.I.S.Q. cable.

Several items of material not previously mentioned in this article may become familiar. Multi-disc cables associated with 152 type pole-mounted and 252 type intermediate multi-quad loading units may be necessary on the more important routes. Protectors 101A, which include 263A drainage coils, or 264A coils and associated 102 type and 103 type protectors, will probably be required in districts subject to severe lightning trouble. As the systems are extended to more remote localities armoured D.I.S.Q. cables may be laid directly in the ground or may be required at creek crossings.

Bibliography

See page 105 of this Journal.

THE ELEMENTS OF PULSE-TIME MODULATION

J. Campbell

Introduction: Recently a new method of modulation has been introduced to the communication art which is known as pulse-time modulation, pulse modulation or time modulation, usually denoted by TM. It gives a new way of deriving communication circuits such as telegraph channels and voice frequency channels. Pulse modulation consists essentially of imparting to a pulse the intelligence which is to be conveyed. For example, the width of a pulse can be caused to vary in accordance with the amplitude of the modulating signal, the rate at which the width varies being determined by the frequency of the modulating signal. Alternatively, the pulse can be made to change its position in relation to a datum point, the amount of change being governed by the amplitude of the modulating signal, and the rate at which it changes by the frequency of modulation. Pulse modulation possesses one outstanding feature which makes it a competitor in some applications with the other types of modulation (amplitude and frequency modulation) used on carrier systems. This feature is that a number of channels may be derived without the use of frequency band filters. In the systems in which the channels are derived on a "frequency division" basis, the necessary filters may be both costly and bulky.

Pulse modulation derives the channels on a "time division" basis in a similar way to that used in the Murray Multiplex telegraph system. In the Murray system a rotating arm moves over a commutator, the contacts of which are connected to a number of telegraph circuits. The rotating arm is connected to the telegraph line, and so serves to connect the line to each circuit in turn. Each circuit uses the line for a small portion of the total line time, and because of the definite limit to the speed of the rotating arm only telegraph channels of limited band width can be derived. In the pulse modulated system, electron tubes are used instead of the commutator and rotating arm, and the switching process is speeded up to such an extent that the highest quality programme circuits, as well as speech and telegraph channels, can be derived.

In this paper the manner of producing pulse modulation (commonly known as TM) will be considered, and it will be compared with amplitude modulation (AM) and frequency modulation (FM), after which consideration will be given to some of its possible applications. To make the explanation easier to grasp, it will be assumed that we have a radio carrier wave to be modulated by an audio tone using the three forms of modulation, AM, FM and TM.

Types of Modulation; The modulation terms AM and FM describe briefly the way in which the radio carrier wave is altered or varied in accordance with the variations of the modulating tone, and so these two forms of modulation are easily understood. For instance, in Fig. 1, (A) shows the unmodulated radio wave, (B) the modulating audio tone and (C) the two combined to show the radio wave modulated 100% in amplitude by the audio tone. In frequency modulation (FM), the amplitude of the radio wave is left unchanged, but the frequency is varied in accordance with the audio wave. This is shown in Fig. 1 (D), where the carrier wave frequency is increased as the audio tone goes positive, and is decreased when the tone is negative.

Now, in pulse modulation another link is introduced in the modulation process, besides the carrier wave and the audio tone. This new element is a chain of direct current pulses which occur at a rate higher than the highest modulating frequency (at least twice and usually $2\frac{1}{2}$ times) and lower than the radio carrier wave frequency (usually less than $^1/_{100}$th of the carrier frequency). These pulses may be represented as in Fig. 2 (B). In Fig. 2, (A) represents the unmodulated carrier wave, as before, and (C) the audio tone.

To modulate the radio carrier, the modulating tone is applied to the train of pulses so as to alter one of the characteristics of the pulse train in the following ways:—

Pulse amplitude modulation, P.A.M.—The pulse amplitude is varied in accordance with the audio tone as in Fig. 2 (D).

Pulse frequency modulation, P.F.M.—The pulse frequency is varied in accordance with the audio tone as in Fig. 2 (E).

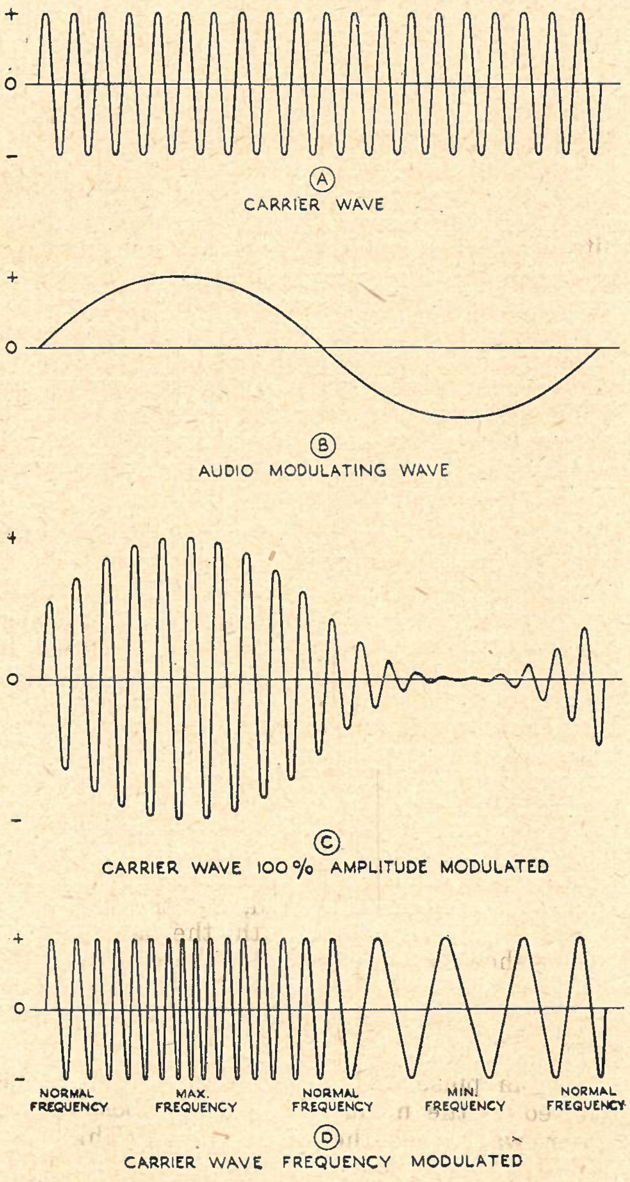
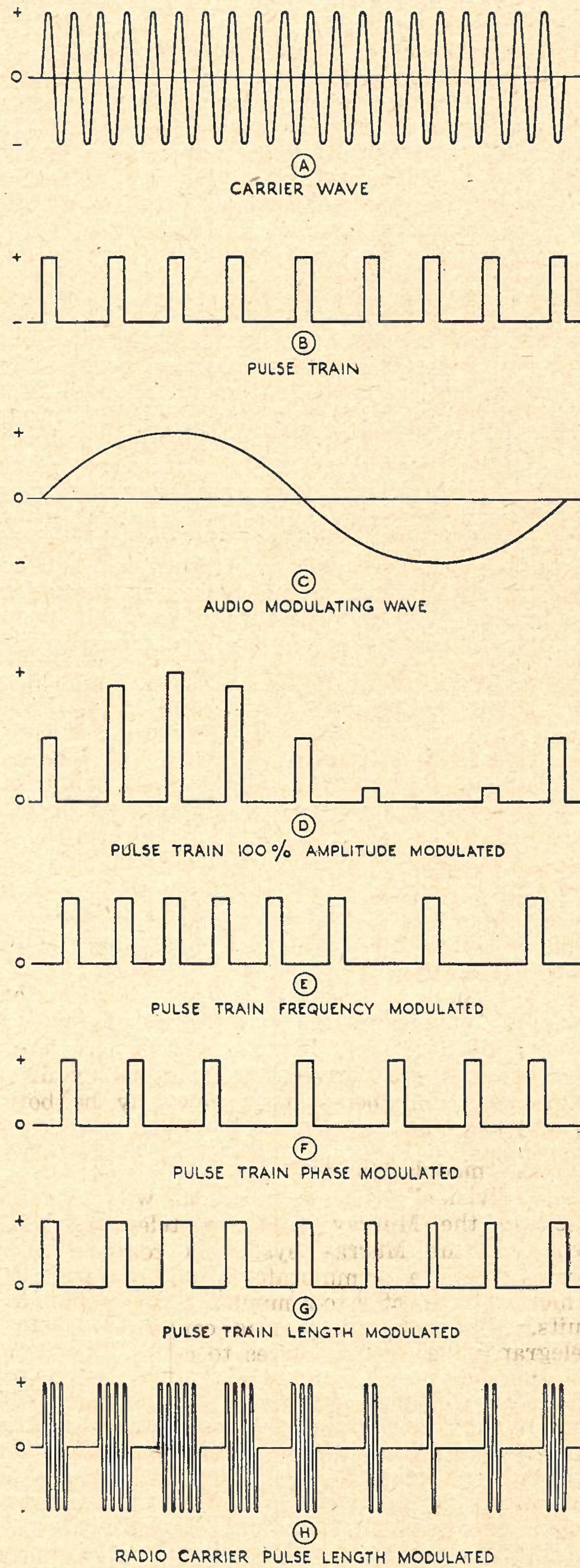


Fig. 1.

Pulse phase modulation (sometimes called Pulse Position Modulation), P.P.M.—The phase relation between the pulses is varied in accordance with the audio tone as in Fig. 2 (F). The difference between pulse frequency modulation and pulse phase modulation is not easily shown in such simple diagrams as these.

Pulse length (or width) modulation, P.L.M.—The length of the individual pulses is



varied in accordance with the audio tone as in Fig. 2 (G).

The radio carrier is then suppressed completely and the DC pulses are used to trigger off the radio oscillator or amplifier to produce pulses of RF energy, as shown in Fig. 2 (H). In this figure, the RF pulses are shown length modulated. The outline of the RF pulses is a replica of the DC pulses because of the trigger action occurring, the RF oscillator or amplifier being switched on and off by the DC pulses.

It will be appreciated that the modulated pulses may be applied to a radio channel or to a suitably designed line such as a coaxial cable. Carrier equipment with the filters associated with line transmission of AM and FM is not required for TM, pulse modulation and demodulation equipment taking its place. This applies for multi-channel carrier equipment also, as it is possible to obtain multi-channel operation by the pulse method. This is achieved by interlacing other pulses in between original pulses, using all but one pulse for the other channels (see Fig. 3). The pulse which is not allocated to a channel is used for synchronising the system.

3 CHANNEL SYSTEM PULSE TRAIN (UNMODULATED)

Fig. 3.

The four types of pulse modulation which were described are the four simple, basic types, but there are also some complex forms, which will now be described.

The Complex Forms of Pulse Modulation

(a) **Multi-channel Operation:** This is achieved by generating a train of pulses followed by a synchronising pulse. Each pulse in the train is allocated to a particular channel. A typical arrangement for a three-channel system is as shown in Fig. 3. It can be seen that, if pulse width modulation is used, each pulse can be allowed to expand to the point where it begins to encroach upon the time allocated for the next pulse. To prevent crosstalk due to what may be a large excursion, a suitable "guard" time is usually allowed between pulses. Any of the types of modulation—P.A.M., P.P.M., etc. —can be used for multi-channel operation. Besides obtaining telephone channels by this means, a multi-channel broadcasting system can be visualised giving a different broadcast programme on each channel. The listener's receiver would be tuned to a fixed radio or carrier frequency, the "station selector" becoming a "programme selector" by choosing the appropriate pulse in the train. In this case, one station would transmit a large number of programmes simultaneously.

(b) **Single Channel Operation with Secrecy:** To provide added secrecy, apart from that already inherent in pulse modulation, one or more pulses may be generated in addition to the pulse being modulated, so that some sort of selection device has to be added to the receiver demodulator to pick out the particular pulse required.

(c) **A Television Sound Channel:** A television signal usually consists of a complex amplitude modulated wave form representing a picture element or line followed by a synchronising pulse, the two parts being repeated at a high repetition frequency. The sound accompanying the picture transmission may be transmitted on another radio frequency, necessitating a separate transmitter and receiver. It can be seen from our analysis of pulse modulation that a sound channel can be obtained by splitting the television synchronising pulse into two parts and, while keeping one part for synchronising the picture, the other part can be varied in accordance with the audio frequencies being transmitted on the sound channel.

All of these types of pulse modulation can be used on radio equipment or on lines. No attempt will be made to describe in this paper the equipment which will provide pulse modulation; but a number of references is given at the conclusion in which both the theory and the applications are described in detail. The Laboratory Reports whose numbers are quoted describe some of the equipment which has been developed in the P.M.G.'s Research Laboratories, where all the types of pulse modulation have been studied. At present a three-channel radio link is being tested using pulse phase modulation in one direction of transmission, and pulse length modulation in the other.

The Reasons for Using Pulse Modulation: Having found out what pulse modulation is, it may be asked: "What are the advantages of using pulse modulation? Why do things in a complicated way when apparently there are simple and well-tried ways of obtaining the same result?" The answer is that pulse modulation will provide facilities and advantages which cannot be provided by the other forms of modulation in the present state of the art. Some of the advantages and disadvantages are as follow:—

(a) The transmission of pulses requires a wide frequency band—a disadvantage; but by making use of the very high frequency radio bands (above 1000 mC/s.), where there is plenty of frequency space, this disadvantage is offset. The frequency space required is about five times that required for AM and twice as much as for FM. In addition, these are the very bands where the pulse technique (due to radar develepment) has advanced much further than the continuous wave technique.

(b) The noise level on channels derived by pulse modulation is lower than on channels derived by AM and approximately the same as that on wide band FM. A further reduction in noise results from working in the very high radio frequency band. Other things being equal, however, FM is superior in this regard to either AM or TM.

(c) Multi-channel operation is possible without the use of the elaborate frequency separation filters used in line carrier equipment. Twenty-four-channel pulse modulation systems have been described which can be used on coaxial cable circuits or on radio circuits. Theoretically, over 100 channels could be obtained by pulse modulation in the band occupied by this system.

(d) In the television application, a separate transmitter and receiver for the sound channel are no longer required, which means a big economy for the listener.

(e) If repeaters are used in a P.F.M., P.P.M. or P.L.M. system, the repeaters do not introduce any distortion in the transmission, as it is the pulse train which is amplified, and the amplitude of the pulses does not have any effect on the modulation. Limiters may therefore be used to get rid of the noise in the top and the bottom of the pulse train. The resultant clear pulse train can then be applied to a trigger circuit, which produces a pulse train of much greater amplitude than the original, the process being similar to a relay in a telegraph system.

In both the radio and communication fields there is a pressing need for more channels of all kinds, and so all methods of obtaining more circuits should be explored to the fullest extent. It is not yet clear, however, just where the pulse modulation technique will fit into the communication systems, as equipment using these principles is not yet in common use, and until sufficient experience is gained in the operation and maintenance of such equipment, it is unwise to forecast the limits of the possible applications.

References: The following references are given so that the reader may go further into the theory of pulse modulation or read the descriptions of some of the equipment which has been produced:—

1. E. M. Deloraine and E. Labin:

Pulse Time Modulation—Electronics, Jan. 1945. Deals with the fundamentals of pulse modulation, giving the relations between pulse length, band-width, repetition frequency, etc. The historical development is also given.

2. D. Philips:

Nov., 1945. A description is given of Federal Telephone and Radio Corporation's 24-channel link, the Bell Telephone System's 8-channel system, type AN/TRC6, and the R.C.A. type AN/TRC5 equipment, with an account of some of the demonstrations given in America.

3. **P.T. Modulation for Multiple Transmission**—Electronic Industries, Nov., 1945:

Describes the 24-channel P.P.M. radio link equipment developed by Federal Telephone and Radio Corporation in America.

4. **AN/TRC6—A Microwave Relay System**—Bell Laboratories Record, Dec., 1945:

Deals with a demonstration of the equipment and outlines the technical details of the 8-channel system developed for the American Army by Bell Telephone Laboratories.

5. **Pulse Position Modulation Technics**—Electronic Industries, Dec., 1945:

Gives a detailed circuit description of the Bell Telephone Laboratories System, type AN/TRC6.

6. J. C. Simmonds:

Multi-Channel Communication Systems—Wireless Engineer, Nov. and Dec., 1945. Describes an 8-channel microwave radio link using P.A.M. which was investigated by the British Post Office.

7. **British Army Set, type No. 10**—Wireless World, Dec., 1945:

Describes microwave radio link equipment used by the British Army during the war. The equipment provides eight telephone channels and uses P.L.M.

8. **Television Developments** — Wireless World, Dec., 1945:

Describes the Pye application of pulse modulation to television, which produces a sound channel by splitting the synchronising pulse.

9. **P.M.G.'s Department Research Laboratory Reports:**

No. 2221—Multi-channel Pulse-length Modulated Equipment.

No. 2318—Modulation Equipment for a Single-channel, Pulse-frequency Modulated System.

No. 2360—Comparison of Various U.H.F. Radio Systems for Point-to-Point Communication.

No. 2562—Ultra High Frequency Multiplex Radio Systems for Point-to-Point Communication.

No. 2576—Basic Considerations in the Design of Pulse Modulated Systems.

No. 2626—Modulation Equipment for a Pulse-Phase Modulated V.H.F. Radio System.

10. D. D. Greig:

Multiplex Broadcasting—Electrical Communication, March, 1946. Describes a proposed system of broadcasting using pulse time modulation.

ANSWERS TO EXAMINATION PAPERS

The answers to examination papers are not claimed to be thoroughly exhaustive and complete. They are, however, accurate so far as they go and give information which a candidate should have to enable him to give answers which would secure high marks.

EXAMINATION No. 2585 SENIOR TECHNICIAN (BROADCASTING)

F. O. Viol and N. S. Smith

PAPER I.—SECTION A

Q. 1.—Define resonance; mutual inductance; self-inductance. A resonant circuit consists of a coil having an inductance of 100 microhenries and a high frequency resistance of 10 ohms in series with a variable condenser assumed to have zero loss. An e.m.f. of 100 volts at a frequency of 750 kilocycles per second is induced into the coil from a nearby circuit. What will be the value of capacitance to produce resonance with the induced e.m.f. and what will be the potential difference across the condenser at resonance?

A.—(a) Resonance is that condition of an A.C. circuit when the inductive and capacitive reactances are equal. In this condition the voltages developed across the reactances are equal, but since they are fundamentally 180 degrees out of phase their net result is zero. Resonance occurs at a frequency determined by the values of the circuit elements in accordance with the formula:—

$$f = 1/2\pi\sqrt{LC}$$

where f = frequency in cycles/second.
L = inductance in henries.
C = capacity in farads.

There are two particular cases:—

(i) **Series resonance:** The elements L, C and R are in series, and at resonance the impedance is a minimum and equal to R. Thus the current is a maximum when voltage at the resonant frequency is applied.

The impedance of a series circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

where R = effective resistance of circuit.
Y_L = inductive reactance.
X_C = capacitive reactance.
(at resonance $X_L = X_C$).

(ii) **Parallel resonance:** The usual assumption in this case is that L and C are in parallel and the resistance R in series with the combination. At resonance the impedance is a maximum and the current a minimum.
The resonant impedance approximates L/CR ohms.

(b) Mutual induction is produced when the lines of force, due to current in one circuit, cut a neighbouring circuit. If the current in the first circuit is varied, the lines of force also vary, and as they cut the second circuit an E.M.F. will be set up in the second circuit, which will be proportional to the rate of change of flux. The Mutual Inductance between two such circuits is defined as the E.M.F. induced in the second circuit when the current in the first circuit varies at the rate of one ampere per second.

(c) Self-induction is produced when the flux linked with a conductor varies, due to a change in the current flowing in the conductor. According to the laws of electro-magnetics, whenever the flux linked with a conductor is varied, an E.M.F. is set up in the conductor, the direction of which is such as to oppose the change. If, therefore, the current in the conductor is varied, there is a corresponding change in the number of lines of force linked with the conductor, and an E.M.F. will be set up in the conductor, whose direction will be opposite to the applied E.M.F. The Self-Inductance of a circuit (in henries) is the value of the back E.M.F. produced when the current varies at the rate of one ampere per second.

At resonance $f = 1/2\pi\sqrt{LC}$ and

$$C = 1/4\pi^2 f^2 L \text{ farads}$$

$$C = 1/4 \times 1/(3.14 \times 3.14) \times 1/(750{,}000 \times 750{,}000) \times 10^6/100 \text{ farads}$$
$$= 10^6/(225 \times 3.14 \times 3.14)$$
$$= 449 \text{ micro micro-farads.}$$

Voltage across condenser equals voltage across coil and at resonance this equals QE, where E is applied voltage and Q =

$$\omega L/R = 2\pi f L/R$$
i.e., $V_c = 2\pi f L E/R$
$$\therefore V_c = 2 \times 3.14 \times 750{,}000 \times 100/10^6 \times 100/10 = 4710 \text{ volts.}$$

ANS.: $C = 449\ \mu\mu f$
$V_c = 4710$ volts.

Q. 2.—What is meant by "skin effect"? Why does the resistance of a resistor at radio frequency differ from its D.C. value and how does the radio frequency resistance vary with frequency?

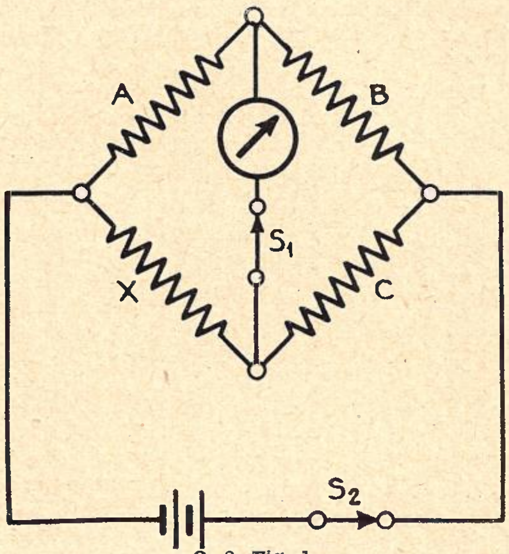
It is desired to measure accurately the D.C. resistance of a resistor of the order of 20,000 ohms. Show how this can be done by means of a bridge method. Give diagram of the connections of the circuit you would use.

A.—Skin Effect is a phenomenon which causes high frequency current flowing in a conductor to be concentrated in the outer part of the conductor. If a current flows in a round wire, then the magnetic flux caused by the current is in the form of concentric circles. Some of this flux is within the conductor, and therefore encircles the current near the centre of the conductor, but does not link with current flowing near the surface. The result is that the inductance of the central part of the conductor is greater than the inductance of that part of the conductor near the surface, because of the greater number of flux linkages. At high frequencies the reactance of the central part of the condctor, due to this extra inductance, is considerably greater than that of the surface of the conductor, and as a result the greater part of the current will flow on the surface where the impedance is low.

The effective resistance of a resistor will increase with increasing frequency, due to the fact that the higher frequency causes the extra inductance at the centre of the resistor to have a higher reactance, and hence the effective area carrying the current is smaller.

A Wheatstone bridge would be suitable for measuring a resistance of the given value.

To obtain greater accuracy it would be advisable to make the ratio of the ratio arms 10,000 to 1 so that the balance may be obtained by variation of balancing resistance between 1 and 3 ohms.



Q. 2, Fig. 1.

AB = ratio arms
X = unknown res.
S1, S2 switches.
S2 closed first to minimise surge effect from battery on meter.

Suppose A = 100,000 ohms
B = 10 ohm.
C balanced at 2.005 ohms.

Balance Condition AC = BX or X = AC/B.

$$\text{then } X = \frac{100{,}000 \times 2.005}{10} = 20{,}050 \text{ ohms.}$$

Q. 3.—What do you understand by "hysteresis losses" and "eddy current losses" in the iron core of a transformer? State what are the effects of these losses and describe how the losses can be kept low.

A.—Hysteresis: When iron is magnetized by a force F1 to a certain degree the application of a force F2 equal to F1 but opposite in direction will not completely de-magnetize the iron. It requires a greater force than the initial magnetizing force to do this. Magnetism of a core may be regarded as a rearrangement of molecules. When this has to take place a large number of times per second a certain amount of molecular friction takes place, and this gives rise to heat in the material.

This heating of the material abstracts energy and thus causes a loss of efficiency. The loss of energy is proportional to the frequency and the strength of the magnetic field.

The losses due to hysteresis may be kept low by using core material having a high permeability (that is, low retentivity), material in which the molecular friction is reduced, and also by constructing the core of laminations.

Eddy Currents: If a coil of wire is placed in a varying magnetic field, an e.m.f. will be induced therein. If the coil is short-circuited, current will flow due to this e.m.f., its value depending on the resistance of the coil. If the coil is replaced by a solid piece of metal, such as the core of a transformer, the metal may be considered as an infinite number of short-circuited coils. Thus circulating currents will be set up throughout the whole of the material. These currents are known as "eddy currents" and abstract energy from the circuit. The value of the current depends on the resistance of the eddy-current path and by making this high the eddy losses are reduced.

The losses take the form of heating of the transformer and according to the laws of induced e.m.f. the currents will be proportional to the frequency. The loss of energy therefore is proportional to the square of the frequency, and is thus greater than hysteresis losses.

The effect may be minimized by dividing the core into laminations, strips, wires or particles and insulating the individual laminations, etc. The addition of a small percentage of silicon also increases the resistance of the eddy current path.

Most of the measures taken to minimize the effects of hysteresis or eddy-current losses are effective for both cases.

Q. 4.—What do you understand by the terms coulomb; farad; dielectric; capacitance? A simple condenser consists of two insulated parallel plates and has a capacitance of 0.0005 microfarads. If the condenser receives a charge of 2 micro-coulombs, what is the potential difference between the plates?

What would be the capacitance of the condenser if the area of the plates were trebled and the spacing halved?

A.—Coulomb is the unit used to define the quantity of electrical energy in a circuit, and is equal to one ampere flowing for one second.

Farad is the unit of capacity. A condenser has a capacity of one farad when one volt applied across it will cause it to acquire a charge of one coulomb. This unit is too large for practical use and submultiples are used. One microfarad equals 10^{-6} farad and one micro-micro-farad equals 10^{-12} farad.

Dielectric is the name given to the insulating medium separating the plates of a condenser. It is often applied to all materials which possess insulating properties.

Capacitance: Any pair of electrical conductors that will store electrical charge when a difference of potential is applied to them constitute a condenser or capacitor, and such an element is said to possess capacitance. Capacitance may thus be regarded as a term indicating the presence of condenser characteristics in a circuit or circuit elements, the actual degree being expressed quantitatively in terms of the capacity units defined above.

A common application of the term is to express the ratio of the charge on a capacitor, i.e., the total electric flux between its electrodes, to the potential difference between them.

$C = Q/V$
where C = Capacitance in farads
Q = Charge in coulombs
V = Potential difference in volts.
when C = 0.0005 microfarads and
$Q = 2 \times 10^{-6}$ coulombs
Then $V = Q/C = 2/10^{6} \times 10^{10}/5 = 4000$ volts.

The capacity of a condenser is directly proportional to the area of the plates and indirectly proportional to the distance between them.

∴ Capacity would be $.0005 \times 3 \times 2 =$ **0.003 μf.**

SECTION B

Q. 5.—What is meant by the gain of an amplifier and how can it be measured?

The gain of an amplifier is usually expressed in decibels. Define decibel.

An audio frequency amplifier has a gain of 40

decibels. The input circuit impedance is 600 ohms and the output is arranged for a load of 5 ohms. What will be the current in the load when an A.C. potential of 1.5 volts is applied to the input?

A.—An amplifier is said to have gain when the ratio of its output power to its input power is greater than unity. This ratio when expressed logarithmically (common logs) is known as the gain of the amplifier.

A typical circuit for measuring gain is shown in Fig. 1.

Procedure: The output of the oscillator is fed through a variable pad having an attenuation greater than the gain expected from the amplifier. Care must be taken that the impedances are all matched, and if matching units are used due allowance must be made for their insertion loss.

With the amplifier out of circuit and minimum attenuation in the pad the oscillator is adjusted to give a convenient reading on the output meter, first ensuring that the amplifier will not be overloaded by the input level chosen.

The attenuator is then placed in position of maximum attenuation and the amplifier switched into the circuit. The attenuator is then adjusted until the output meter reads the same as before.

The gain of the amplifier is then the difference between the attenuator readings in the first case and the last. If in the first case the attenuator was at zero, then the reading of the pad in the second case is the gain of the amplifier.

It is preferable to place the attenuator in the input circuit as the amplifier output might be greater than the power capability of the attenuator.

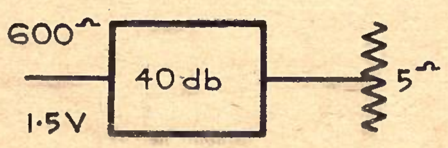
The decibel is derived from the fundamental unit called the "Bel" and is $^1/_{10}$th of this unit, the "Bel" being too large for practical use.

The Bel $= \log_{10} P_1/P_2$

where P_1 = the greater power

P_2 = the lesser power.

From this, gain in decibels (db) $= 10 \log_{10} P_1/P_2$.



Q. 5, Fig. 2.

Input power $= E^2/R = 2.25/600$ watts.

40 db. gain = power ratio 10000 : 1

$\therefore$ output power $= 10{,}000 \times 2.25/600$

$= 225/6$ watts.

$I = \sqrt{W/R} = \sqrt{225/30} = 2.74$ amps.

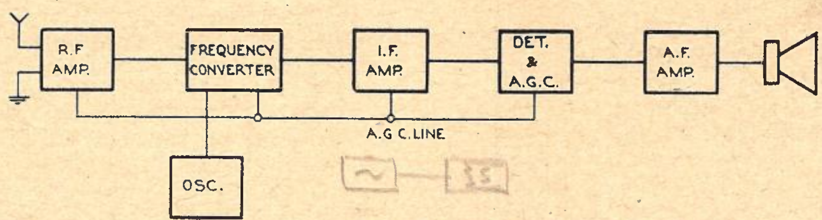
Q. 6.—Explain what is meant by mutual conductance of an electron tube, and indicate how its value can be determined.

What is its significance in relation to the operation of the tube?

If an electron tube has an amplification factor of 3 and an impedance of 2000 ohms, what is its mutual conductance?

A.—Mutual conductance of an electron tube is a measure of the mutual effect of the grid and plate on the performance of the tube. It indicates the control on the plate current of potentials on the grid.

It may be determined by measuring the variation of plate current for a small variation of grid voltage, all other potentials remaining constant. Its value is found from the formula:—



Q. 5, Fig. 1. (See page 132)

$Gm = \Delta Ep / \Delta Eg$

where Gm = mutual conductance in mhos

ΔEp = small change in plate current in amps.

ΔEg = small change in grid voltage producing Ep.

It is commonly expressed in micromhos but a more useful form is milliamps per volt, which indicates the plate current change in milliamperes per volt change of grid potential.

The significance in relation to the operation of the tube is that mutual conductance is the tube characteristic which determines stage amplification and power output in transmitting and receiving operation. It takes into account both the amplification factor and the dynamic plate resistance of the tube. Since a low plate resistance and a high amplification factor are desirable features in a tube, a tube with a high value of mutual conductance will give better performance than one with a low value. This will be seen from the following relationship:—

$Gm = u/Rp$

u = amplification factor of tube.

Rp = dynamic plate resistance of tube.

Given $u = 3$

$Rp = 2000$, find Gm

$Gm = 3 \times 10^6/2000$ micromhos

$= 1500$ micromhos

or 1.5 ma/V. ANS.

Q. 7.—Define reactance; impedance; power factor.

The operating coil of a contactor has an inductance of 1 henry and a resistance of 300 ohms. It is connected across a 240 volt 50 cycle supply. What is the current through the coil and the phase angle of the current relative to the applied voltage?

What value of capacity and resistance should be placed in series with the coil to reduce the phase angle to zero without altering the value of current through the coil?

A.—Reactance is the opposition to the flow of alternating current by a condenser or inductance, due to the back E.M.F. of self-induction in the case of an inductance, or the back E.M.F. of self-capacity in the case of a condenser.

Impedance is the total opposition offered to the flow of alternating current by a circuit containing resistance and reactance. It is equal to the vector sum of the resistance and effective reactance of the circuit.

Power factor is the ratio $\frac{\text{actual power}}{\text{apparent power}}$ in an A.C. circuit. The actual power may differ from the apparent power (volts x amps) because the circuit may be such that the current and voltage waves do not reach their peak values at the same instant, i.e., there is a phase difference between them. This phase difference causes a loss of efficiency in the A.C. circuit, and the power factor is an indication of the magnitude of this loss.

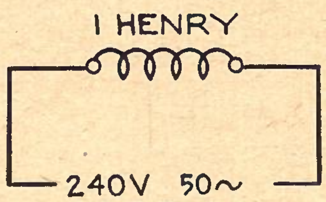
Numerically power factor is equal to Cos θ

where θ = phase angle between current and voltage.

$\tan\theta = X/R$

where X = reactance of circuit.
R = resistance of circuit.

$$\text{Reactance} = 2\pi fL$$
$$= 2 \times 3.14 \times 50 \times 1 = 314 \text{ ohms.}$$
$$\text{Impedance } Z = \sqrt{R^2 + X^2}$$
$$= \sqrt{9 \times 10^4 + 314^2}$$
$$= \sqrt{188700}$$
$$= 434 \text{ ohms (appr.)}$$
$$I = E/Z = 240/434$$
$$= .553 \text{ amps.}$$
$$C = 1/4\pi^2f^2L \text{ farads}$$
$$= 10^6/(4 \times 9.87 \times 50 \times 50)$$
$$= 10.15\ \mu f.$$



Q. 7, Fig. 1.

At resonance the reactances cancel out, therefore an additional resistance equal to Z — R must be inserted to reduce the current to required value (i.e., bring the circuit resistance to 434 ohms): Z — R = 434 — 300 = 134 ohms additional resistance.

Q. 8.—State, with reasons, what you consider the most suitable type of meter for the following measurements:—

(a) A radio frequency current of approximately 10 amperes.
(b) The peak radio frequency voltage on the grid of an amplifying valve.
(c) The audio frequency voltage at the input of a line amplifier.
(d) An audio frequency voltage of the order of 7000 volts R.M.S.
(e) Anode current and grid current of an oscillator tube.

Describe in detail the principle of operation and the general design of one of the instruments. Illustrate with sketches.

A.—(a) Thermo couple ammeter:—
(i) Sensitive.
(ii) Accurate.
(iii) Independent of frequency over a wide range.

(b) Peak-reading diode (or triode) vacuum-tube-voltmeter, in which the voltage to be measured is rectified and applied to a condenser. This voltage is measured by one of several methods.
(i) Imposes negligible load on source.
(ii) Condenser cannot readily discharge and is kept charged to the peak value of the voltage being measured.
(iii) Possesses reasonably good accuracy.

(c) Rectifier type meter, thermo-couple meter or vacuum-tube-voltmeter. Main requirement is that it possesses a high resistance that will introduce negligible shunting effect on the input.

The three meters mentioned have satisfactory frequency characteristics. The first meter would be satisfactory from the point of view of cost.

(d) Electrostatic voltmeter:—
(i) Imposes negligible load on circuit.
(ii) Reasonably accurate.
(iii) Would introduce no frequency error, due to its capacity over the audio frequency range.
(iv) Reads R.M.S. values.

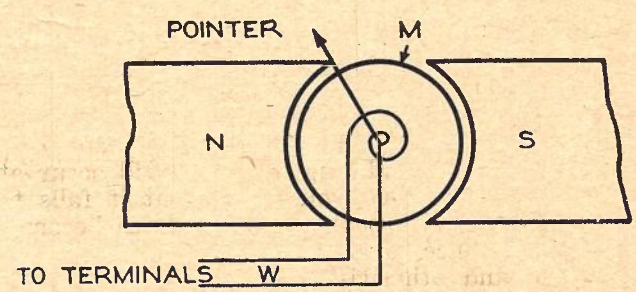
(e) **Anode current:** Moving-Coil D.C. milliammeter:
(i) Sensitive.
(ii) Accurate.
(iii) Linear scale.

Grid Current: Moving Coil D.C. micro-ammeter:
(i) Sensitive.
(ii) Accurate.
(iii) Scale linear.
(iv) Low resistance (will affect oscillator performance).

Fig. 1 illustrates the main design principles of a moving coil meter, which type has a wide application.

It consists of a pivoted soft-iron movement "M" on which is wound the moving coil consisting of a number of turns of fine wire, the number of turns depending on the sensitivity and range of the instrument.

The current is led to and from the coil by the wires W. The springs serve to carry the current to the coil and to provide a restoring torque for the movement.



Q. 8, Fig. 1.

The movement is placed in the field of a permanent magnet N-S with the pole-pieces so shaped as to provide a minimum clearance to air-gap between the coil and the magnet poles. This improves sensitivity. When a current is passed through the moving coil a magnetic field is generated which reacts with the field due to the permanent magnet. The result is a torque which tends to rotate the moving coil unit it attains a mutual position in the field. The torque is directly proportional to the current through the coil and the scale is therefore linear.

The sensitivity and accuracy of this type of meter have led to its use in A.C. and R.F. measurements by associating it with rectifiers and thermo-couples, and thus its application is extensive.

EXAMINATION No. 2473—ENGINEER, LINE CONSTRUCTION

J. W. Pollard, B.Sc., A.M.I.E. (Aust.)

GROUP 2—CABLES AND CONDUITS

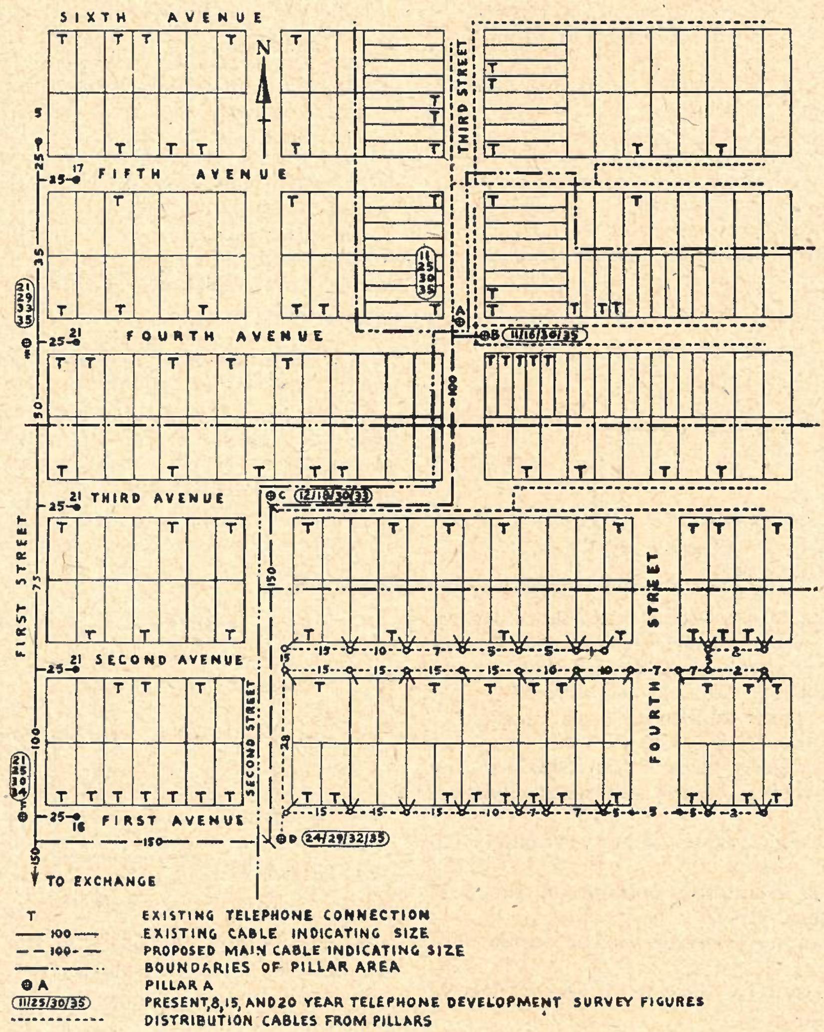
Q. 1.—Illustrate by means of a rough plan a suburban area approximately one-quarter mile square and plot thereon in any order preferred 100 subscribers.

Assume a direction for the feed to the main exchange and prepare a development plan for the area covering present, 8, 15 and 20-year periods.

A.—The area shown is at present served by a main cable running from south to north in First Street with cable heads having pairs connected in multiple, in each of the Avenues, and thence aerial construction in an easterly direction to each subscriber. The figures beside the cable heads indicate the number of subscribers connected to each head. Each head is served by a 25-pair cable and, therefore, it will be seen that most of the boxes are nearly full and relief measures are immediately necessary. The aerial routes at the western ends of the Avenues are also heavily loaded and the poles are nearing the end of their life and will require renewal at an early date. Development is taking place in the eastern half of the area and it is evident that additional plant will soon be required in this section.

A telephone survey of the area is therefore carried out, and from the expected development the number of telephones that it is anticipated will be connected at the end of the 8, 15 and 20-year periods is then calculated. The area is suitable for dividing into smaller subdivisions, each served from a cable terminal pillar. The 20-year development figures are used in fixing the boundaries of these areas, each area being chosen so that not more than 35 working lines will be connected to a pillar. As the cable terminal pillar has provision for connecting 40 exchange pairs, a small margin for unforeseen development is provided.

Plans showing the location and size of all cable and conduit in each pillar area for the ultimate or 20-year figure are prepared, and installation of plant in accordance with this plan is then carried out as new telephone connections are required. Iron pipe and precast jointing pits are generally provided, but in some instances it may be preferable to use aerial construction from cable heads. A typical layout for a pillar area, showing distribution pairs only, is shown for pillar D.



Q. 1, Fig. 1.

TABLE 1
Analysis of Expected Development

	Present	8 yr.	15 yr.	20 yr.
Pillar A	11	25	30	35
Pillar B	11	16	30	35
A & B	22	41	60	70
Pillar C	12	18	30	33
A, B & C	34	59	90	103
Pillar D	24	29	32	35
A, B, C & D	58	88	122	138
Pillar E	21	29	33	35
Pillar F	21	25	30	34
A, B, C, D, E & F	100	142	185	207

In order to provide for any unforeseen development in the area, a 4" E.W. conduit should be laid from First Street, along First Avenue, thence in Second Street, Third Avenue, Third Street to Fourth Avenue. As seen from Table 1, the cable in First Avenue, taking the main pairs which will be required in 20 years for pillars A, B, C & D, should be of 150 pairs capacity. It is preferable to lay this cable initially rather than to lay a 100-pair cable now and a 54-pair cable in eight years' time. The same remarks apply to the sizes of cable leading to pillars C, B & A so that all the cable required for main exchange pairs will be laid in the initial stage of the work.

As there is a 150-pair cable leading into the area from the exchange and the eight-year figure is 142 connections, no further cable to the exchange will be required until the latter part of this period. The method of obtaining relief will then depend on action being taken for providing relief in other areas, but approximately 70 additional pairs will be required to cover the 20-year period.

The layout of the distribution pairs for pillars E & F has not been shown, as this is similar to that indicated for the other areas. Only distribution cables are required in this area, as the existing cables are large enough to provide exchange pairs for the 20-year period.

Q. 2.—It is desired to lay a trunk underground cable between two exchanges 30 miles apart.

Detail a proposal for the installation of armoured cable for a distance of 25 miles, assuming good sinking ground and few obstructions. Assume also the use of unarmoured cable in existing conduits for a distance of 5 miles or 2½ miles out from each exchange.

Describe the plant you would prefer for the installation of both types of cable.

A.—A decision having been made to lay a trunk underground cable between the two exchanges, much preparatory work has to be carried out before the actual laying is commenced. As a conduit run is available for a distance of 2½ miles from each exchange, all that is necessary in this section is to ascertain that a suitable duct is available for the trunk cable and that when the cable has been pulled in at least one spare duct for emergency purposes will still be left.

For the section where armoured cable is to be laid, the country has to be examined and the route selected. Points to be watched are to select a route where damage to the cable is unlikely to occur from such sources as erosion of the soil, road deviations, etc. The route should be direct as possible, thus saving cable and reducing attenuation, but it is preferable to follow defined roads if possible rather than to divert through long sections of private property. If the latter is necessary, permission to obtain way-leaves must be obtained from the owners and access to the cable must be free at all times. Local and road authorities must be consulted and any plans for deviating roads or carrying out other works should be ascertained.

Having decided on the route, it must be accurately surveyed from exchange to exchange, and on the armoured section of the route, the positions of the manholes or jointing pits fixed. These will depend on the type of loading to be employed, and having decided on the loading coil spacing the positions of the loading coil manholes are determined. The contactors and terminal boxes of the gas-pressure alarm system are also generally installed in these manholes. It may be necessary to provide new manholes or enlarge existing ones on the conduit runs for installation of the loading coils. A cable address schedule giving drum lengths of cable and position in the route is prepared for the information of the contractor. A soil resistivity survey is carried out along the route to ascertain any areas where current discharge may take place and remedial action would be necessary.

Prior to delivery of the cable, arrangements for pulling in the unarmoured cable and laying the armoured section have to be made. For pulling in the unarmoured cable, apart from cable grip, etc., and some means of applying the cable-pulling compound, the main requirements are suitable cable trailers for both transporting the cable drums and holding it in position whilst pulling-in operations are in progress, and a power winch.

For laying the armoured cable, the main requirements are tractor, cable trailers and mole plough. It is also desirable to pull a ripper plough along the line of the cable before laying any cable, and thus determine the position of any obstruction. When the cable is finally pulled in there is less likelihood of it being damaged due to frequent stopping of the mole plough for removing buried obstacles.

The jointing procedure adopted will vary for different types of cable and be largely governed by the intended use of the cable and the crosstalk values required. The procedure and capacity unbalance limits having been determined, the jointing is completed, loading coils (if required) connected and then overall measurements carried out. Again these will depend on the intended use of the cable, but will generally be crosstalk, attenuation and impedance in the required frequency range. Finally, a gas-pressure alarm system is installed, and any sheath faults located and removed.

Q. 3.—Prepare a quantitative estimate of material, labour and incidentals for the installation of 1 mile of 4-way conduit to be laid in the footpath of an average suburban area, fairly free from ornamental trees.

Describe the necessary field survey work and show by means of sketch plans the type of drainage you would recommend.

A.—It is assumed that the pipes will be laid in the nature strip, where 12" cover will be allowed. Eight road crossings where 24" cover is allowed are included in the estimate. A manhole is allowed on each side of a road crossing, and with twelve intermediate manholes makes a total of 28.

Material:	Quantity
Conduit, E.W. 4″ self-aligning (2′ 6″ long)	2056
Conduit, Pipe E.W. 4″ untested (drains)	600
Acetylene (cub. ft.)	4000
Cement (bags)	190
Sand (cub. yds.)	27
Screenings (cub. yds.)	38
Manhole cover and frame (4′ x 4′)	28
Channel Iron support for cable bearer—2-way	56
Bearer, Cable, movable 2 joint	112
Bolts, lewis G.I. ¾″ x 6″	112
Grating for manhole sump	28
Iron Anchor	56
Sundries—Kerosene, etc.	

Labour:

Description	Qty.	Rate	Man-hours
Conduit—			
Excavating, hand (c. yds.) ..	390	2.5	975
Excavating, machine (c. yds.)	600	1.5	900
Filling-in, hand (c. yds.)	230	1.0	230
Filling-in, machine (c. yds.)	400	0.6	240
Conduit laying (ft.)	5112	0.15	766
Building Manholes	28	40	1120
Drainage—			
Excavating (c. yds.)	180	2.5	450
Filling-in (c. yds.)	120	1.0	120
Conduit laying (ft.)	1500	0.08	120
Recording — Includes supervision, ineffective time due to wet weather, clerical duties, driving motor vehicles, handling material, etc.		20%	979
		Total	5900

Incidentals:

Under this heading allowance must be made for cartage of spoil, plant upkeep, truck hire, reinstatement of pavement by local authority, fares.

After it has been decided to lay the conduit, a suitable route has to be selected. A general examination of the district is carried out and inquiries made from other authorities regarding the presence of underground construction. Where necessary, plans are prepared of cross sections of the streets indicating all underground obstructions. A route is finally selected and then surveyed to obtain the overall length, and to locate the position of the manholes. Levels are also taken and the system of drainage decided upon. The method to be adopted depends on the contour of the ground, and the presence or absence of watercourses, channels, underground drains, etc. As far as possible all manholes should be drained and methods of drainage are indicated on page 79 of this Journal in the article on "The Design and Construction of Underground Conduits for Telephone Cables," by A. N. Hoggart, B.Sc.

GROUP 3.—OPEN WIRE LINES

Q. 1.—Prepare a quantitative estimate of material, labour and incidentals for 100 miles pole line over average Australian plain country; the poles to carry 8/200 lb. H.D.C. wires, carrier spaced at 9″, 19″, 9″, etc., horizontally, and 42″ vertically.

Assume average clearing and poles spaced 40 per mile along a travelling stock route which is unfenced for 50 per cent. of the distance; the pole being erected along fences for the remainder of the distance. Gateways occur at one mile intervals along the fence section of the route.

A.—In this type of question it is not sufficient to give a list of material without indicating the basis for the various quantities shown and therefore the stages in the calculations are tabulated.

It is assumed that no intermediate offices are connected to the route, and that the four pairs are bearer circuits for carrier systems.

The economics of wooden poles versus steel beams or rails should be worked out, taking into account availability of supplies, freight, maintenance, etc. Steel beams have been allowed in this estimate for the whole length of the route.

Poles and arms: A second carrier arm will ultimately be required 42″ below arm 1 (position 4) and a minor trunk arm 28″ below the second carrier arm (position 6). No provision has been made for subscribers' arms, but if these are required sufficient additional pole height must be allowed for. Basic pole heights are calculated as follows:—

(a) Open stock route (50 miles)—

Space occupied by arms (5 x 14″)	= 5′ 10″
Clearance above ground	= 12′
Depth in ground	= 4′
Total	= 21′ 10″
	Say 24′

(b) Along fence line (50 miles)—

Space occupied by arms (5 x 14″)	= 5′ 10″
Clearance above ground	= 8′
Depth in ground	= 4′
Total	= 17′ 10″
	Say 20′

Where gates occur in the fence adjacent to the route, a clearance of 18′ over the gateway is required. This necessitates 30′ poles on each side of the gateway with a 24′ and a 28′ grading pole between them and the basic poles. A total of 50 gateways has been allowed for. Grading of the basic poles will be necessary and provision has been made for some longer poles.

Transpositions: The route is divided into 16 "E" sections each 6.25 miles in length, the number of transpositions per circuit per section being:—

Pin positions 1.1—1.2	32
Pin positions 1.3—1.4	48
Pin positions 1.5—1.6	48
Pin positions 1.7—1.8	64
	192

This gives a total of 16 x 192 = 3072, and allowing for junction transpositions, the total has been taken as 3100. Installation of plate type transpositions is allowed in the estimate.

Staying: Longitudinal stays are to be fitted every 16th pole (total 249 poles) and transverse or wind stays every 8th pole (total 499 poles). A terminal stay is required at each end of the route and 100 additional stays have been allowed for angles in the route. A total of 50 overhead stays and stay poles has also been allowed for. Excluding the terminal stays the total number of ground stays is therefore 498 + 998 + 100 + 50 = 1646, with 50 overhead stays.

Material:

(**Note:** For clarity the actual quantity of each item required has been listed. In certain cases, such as wire, spindles, insulators, etc., a small additional quantity would be included for wastage.)

Pole, Steel Beam—	Quantity
7″ x 3½″ x 20′ (basic)	1,401
7″ x 3½″ x 22′ (grading)	100
7″ x 3½″ x 24′ (grading)	100
7″ x 3½″ x 26′ (grading)	100
6″ x 5″ x 30′ (gateways)	100
6″ x 5″ x 28′ (gateways)	100
7″ x 3½″ x 24′ (gateways)	100
7″ x 3½″ x 24′ (basic)	1,600
7″ x 3½″ x 26′ (grading)	200
6″ x 5″ x 28′ (grading)	200
7″ x 3½″ x 24′ (overhead stay poles)	50
Total	4,051 poles

Plate, Foot, Steel (base) 12″ x 8″	4,051
Bolt U-shape (square end) ½″ x 3⅝″ x 8″	3,651
Bolt U-shape (square end) ⅝″ x 5⅛″ x 7″	400
Plate, Foot, Steel (surface) 18″ x 9″ (excludes poles fitted with angle or transverse stays)	3,352
Bolt U-shape (square end) ½″ x 3⅝″ x 8″	3,352
Plate, Foot, Steel (surface) 24″ x 12″	100
Bolt U-shape (square end) ⅝″ x 5⅛″ x 7″	100
Stay Rod 1″ x 8′ (terminal poles)	2
Stay Rod ⅝″ x 6′	1,646
Plate, Stay, Steel, 12″ x 12″	1,648
Wire S.S. gal. 7/14	5,500
Band, Transposition, Bent (attaching transverse, angle and overhead stays)	1,148
Thimble, ⅝″	1,148
Bolt G.I. ⅝″ x 2″	649
Washer, Spring ⅝″	649
Eyebolt lug ⅝″	550
Bolt G.I. ⅝″ x 2″	251
Eyebolt, Straight ⅝″ x 9″	50
Washer, Spring ⅝″	251
Plate, transposition PL 9″	3,100
Spindle, transposition	12,400
Insulator, TK P.LS	12,400
Tape, copper 100/237	12,400
Arm, wood, terminal 108″	2
Bolt G.I. ⅝″ x 9″	2
Bracket, terminal	16
Spindle TK. ⅝″ J.S.L.	16
Bolt G.I. ⅝″ x 4½″	16
Arm, wood, 108″/8-9″ W.S.	3,400
Arm, wood, 108″/8-9″ S.S.	599
Bolt G.I. ⅝″ x 6″	3,599
Bolt G.I. ⅝″ x 7″	400
Washer, Flat ⅝″	4,001
Brace, Arm long	8,002
Block Steel 1¼″	3,601
Block Steel 2″	400
Block Steel ⅜″	4,001
Bolt G.I. ⅝″ x 3½″	4,001
Washer, spring ⅝″	4,001
Bolt G.I. ⅜″ x 4″	8,002
Insulator, TK P.LS	23,516
Insulator, TL GLS	2,276
Spindle, TK Wood LS	23,516
Spindle, TK ⅝″ LS	2,276
Wire, copper H.D. 200 lb.	160,000 lbs.
Sleeves, wire jointing (Press type) C.200	3,200
Tape, copper 100/237	25,792
Wire, copper, soft 50	1,530 lbs.

Sundries—Stay guards, paint, etc.

Labour:

Description	Qty.	Rate	Man-hours
Erect poles—			
Soil (under 28 ft.)	3251	4	13,004
Rock (under 28 ft.)	700	7	4,900
Soil (over 28 ft.)	80	6	480
Rock (over 28 ft.)	20	9	180
Lay out poles	4051	1	4,051
Fit poles and arms	4001	1	4,001
Fit braces	4001	0.25	1,000
Fit terminal bands	16	0.22	4
Ground Stays—			
Soil	1318	4	5,272
Rock	330	7	2,310
Head Stays	50	2	100
Marking poles	1000	0.15	150
Erecting wire	800	15	1,200
Fitting transpositions	3100	1	3,100
Clearing trees (mile)	100	30	3,000
Loading poles at depot	4051	0.2	2,025
Recording — Includes supervision, ineffective time due to wet weather, clerical duties, driving motor vehicle, handling material, etc.		24%	10,823
		Total	55,600

Incidentals:

Incidentals will include allowance for the following:—Cartage, freight, truck hire, local purchases.

Q. 2.—Define the following generally accepted terms as applied to long line plant:—

(i) **Direct crosstalk.**
(ii) **Interaction crosstalk.**
(iii) **Near end crosstalk.**
(iv) **Far end crosstalk.**
(v) **Crosstalk coupling coefficient.**
(vi) **Inductive interference.**
(vii) **Type unbalance.**
(viii) **Absorption.**
(ix) **Reflection.**
(x) **Irregularity factor or "K" factor.**

A.—(i) **Direct Crosstalk:** Direct crosstalk is the crosstalk induced by either electrostatic or electromagnetic induction direct from one telephone circuit to another telephone circuit and excludes that caused by any other couplings via other circuits.

(ii) **Interaction Crosstalk:** The interaction crosstalk between two circuits "A" and "B" is the crosstalk due to the current in circuit "A" causing an induced current in a third circuit "C" and this current then induces a current into circuit "B." On a pole route with many pairs of wires there are many "third circuit" induction paths between the two circuits "A" and "B" and the total current induced with circuit "B" from circuit "A" via all these paths causes the crosstalk known as interaction crosstalk or third circuit effects.

(iii) **Near End Crosstalk:** This is the crosstalk heard at the end of the disturbed circuit adjacent to the input end of the disturbing circuit.

(iv) **Far End Crosstalk:** This is the crosstalk heard at the end of the disturbed circuit furthest from the input end of the disturbing circuit.

(v) **Crosstalk Coupling Coefficient:** This is the crosstalk per mile which would be obtained between two circuits occupying the same relative positions on a pole route for one mile and having no relative transpositions, but being frequently similarly transposed. It is a function of the mutual inductance and capacitance coupling between the circuits being considered and will, therefore, differ for different combinations of circuits depending on their relative positions on the poles.

(vi) **Inductive Interference:** Inductive interference is caused by induction from a power line to an adjacent telephone line. The effect is to cause noise or a "power hum" in the telephone circuit.

(vii) **Type Unbalance:** Any two open wire circuits tend to crosstalk into each other due to the coupling between them. By transposing the circuits, the coupling in any short length of line is nearly balanced in another short length by a second coupling of about the same size, but about opposite in phase. For this balance to be perfect it would be necessary to divide the circuits into infinitesimal sections. This cannot be obtained in practice and, therefore, there is a residual unbalanced coupling due to attenuation and the change in phase of the disturbing current and resultant crosstalk currents as they are propagated along the circuits. Owing to the short sections involved, the attenuation can be neglected and phase change only considered. This residual unbalance is called the type unbalance.

(viii) **Absorption:** The attenuation at certain frequencies may be greatly increased owing to the loss of energy due to induction into other circuits. It is mainly due to the high crosstalk coupling between a pair of wires and each of its wires and the earth return. This absorption effect can be minimized by suitable transposition design.

(ix) **Reflection:** In practice impedance mismatches may occur at junctions between equipment, open wire, and non-loaded entrance or section cables. Due to the impedance mismatches at these points, portion of the energy is reflected back along the circuit. This is known as reflection.

(x) **Irregularity Factor or "K" Factor:** A transposition section is divided into transposition intervals or segments of equal length, but owing to natural obstructions the transposition poles cannot always be placed in their correct positions. This means that some of the intervals are too long while others are too short and when these irregularities occur in a random manner, a probability factor can be determined indicating the accuracy of the transposition pole spacing. The factor is known as "k" and is expressed as the sum of the squares of the irregularities in feet divided by the length of the transposition section in feet.

Q. 3.—An open wire route consisting of 32/200 lb. H.D.C. wires erected on 4 arms at 14" vertical spacing changes direction by 15 degrees at an angle pole which has a supporting stay inclined at 30 degrees to the pole to which it is attached at the centre of the load.

Calculate the compressive load on the pole and the tension in the stay wire assuming span lengths of 60 yards and a line wire tension of 200 lb. per wire.

A.—The pull of the wires on an angle pole is given by:—

$$P = 2T \cos. \theta/2.$$

where P = pull of wires in lbs.

T = maximum aggregate tension (in lbs.) of all the wires being considered.

θ = angle subtended by the wires.

Substituting given values, and assuming that the given tension of the line wire includes the effect of wind pressure—

$$P = 2(32 \times 200) \cos 82\tfrac{1}{2}^\circ$$
$$= 2 \times 32 \times 200 \times 0.1305$$
$$= 1670.4 \text{ lbs.}$$

The pull (S) on the stay wire is such that when when resolved along the line of the resultant force due to the wires, it will be equal (but opposite) to that force. It is assumed that the stay bisects the angle of the wires.

$$S \cos. 60^\circ = \text{Resultant pull (P)}$$
$$S = 1670.4/\cos. 60^\circ$$
$$= 1670.4 \times 2$$
$$= 3340.8 \text{ lbs.}$$

The compressive load (CL) on the pole is the downward component of the stress in the stay wire plus the weight of the arms, bolts, combiners, arm braces, spindles and insulators mounted on the pole, together with half the weight of the wire in each span.

Downward component of stress in the stay—	
= 3340.8 cos 30°	
= 3340.8 × 0.866	= 2893 lbs.
Approx. weight of arms	= 152 lbs.
Approx. weight of bolts	= 5 lbs.
Approx. weight of spindles and insulators	= 128 lbs.
Approx. weight of combiners and arm braces	= 25 lbs.
Approx. weight of wire— 32 × 2 × 200 × 30/1760	= 218 lbs.
Compressive load	= 3421 lbs.

EXAMINATINO No. 2582—SENIOR TECHNICIAN—TELEGRAPHS

R. D. Kerr

Q. 1.—Show the connections between the plateau of a double arm Murray multiplex set and the printer and transmitter of one arm. Include the connections to the relay and battery leads. Referring to your diagram, describe how a "local run" is obtained.

A.—The connections between the plateau of a double arm multiplex set and the printer and transmitter of one arm are shown on Fig. 1.

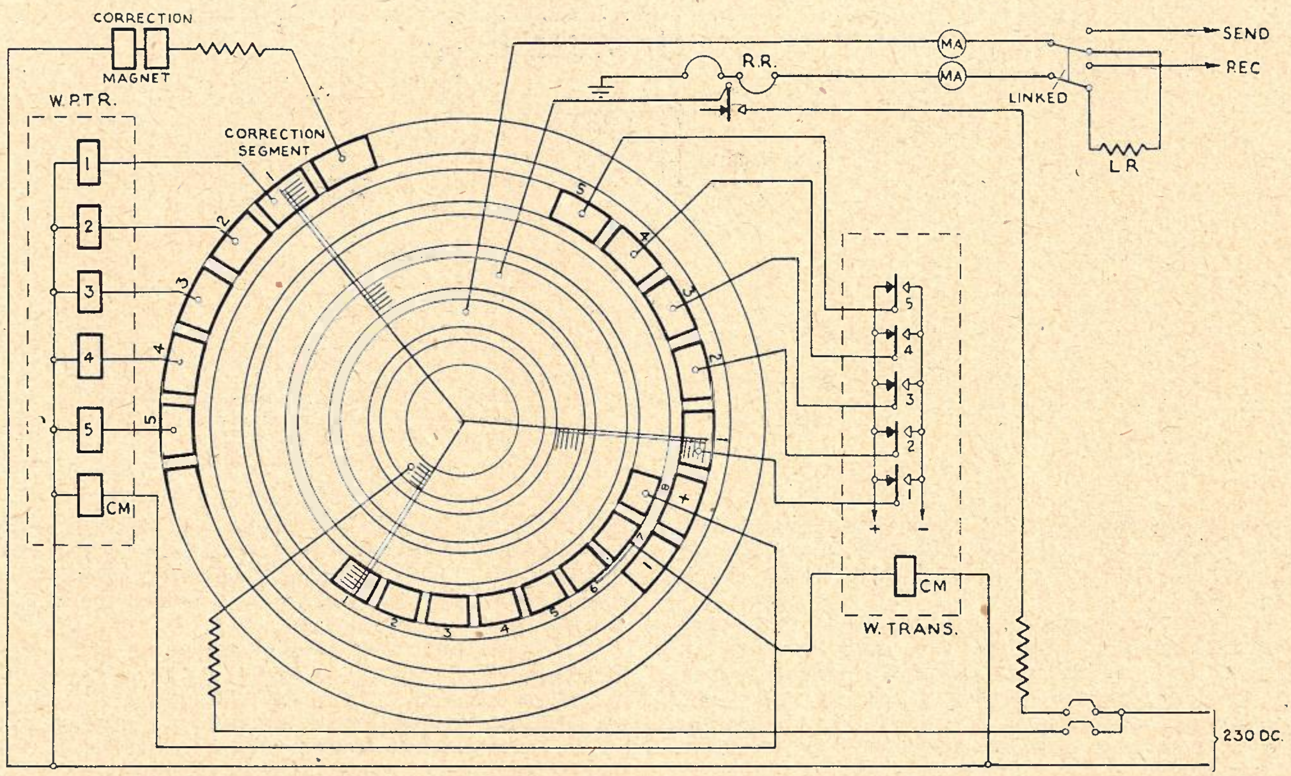
A local run on the multiplex set is obtained by throwing the local run switch, which disconnects the multiplex equipment from the external circuit and connects the send (solid) ring of the plateau to the receive relay of the set. The sending contacts (1-5) of the W tape transmitter are connected to five corresponding segments of the send (segmented) ring of the plateau and similarly the receive magnets (1-5) of the W printer are connected to five corresponding segments of the receive (segmented) ring of the plateau.

Should a tape be run through W transmitter, its five sending contacts will be positioned to mark (— battery) or space (+ battery), depending on the perforations of the tape. The revolution of the send brush will connect each of the five send segments and thus each of the five transmitter sending contacts to the send solid ring in turn and thence to the receive relay, positioning it to mark or space as it picks up — and + batteries respectively from the transmitter contacts.

As the send brush connects each of the transmitter contacts to the receive relay, the receive brush will connect the corresponding receive magnet of the printer to the tongue of the receive relay. The receive segmented ring is so oriented that the angle between the No. 1 printer segment and No. 1 send segment will be 120°, corresponding to the fixed angle between the receive and send brush arms. In this position as No. 1 send contact is connected to the receive relay, the No. 1 printer magnet will be connected to its contacts. If the relay is marking, the 230V D.C. will be connected through a limiting resistance to the receive magnet, thus operating it. If the relay is spacing, the circuit is not completed and the magnet remains unoperated.

After the five send contacts have been connected in turn to the five receive magnets and the code combination set up, the cadence magnets of the transmitter and printer are connected to the 230V D.C. through the local segmented and solid rings of the plateau.

The transmitter cadence magnet steps the next character perforated in the tape into position for transmission, whilst the printer cadence magnet engages the clutch between the printer mechanism and its driving motor, thus printing a character determined by the combinations set up on the five receive magnets.



Q. 1, Fig. 1.

Q. 2.—Draw a schematic circuit of a set which could be used for repeating signals between a carrier channel and a physical closed circuit simplex Morse line, showing the carrier loop arrangements. Describe the operation of the circuit shown.

A.—The circuit is given in the Journal, Feb., 1945, Examn. No. 2473, Ques. 3, Part (a), page 179.

The circuit shown is of the half duplex type, with a dry metal rectifier in the morse line circuit. The relay A is operated direct from the carrier receive relay tongue. When this relay is on the marking contact, the morse physical line current of 30 milliamps operates the relay B to marking against the 15mA current through the bias winding, which tends to operate the relay to spacing.

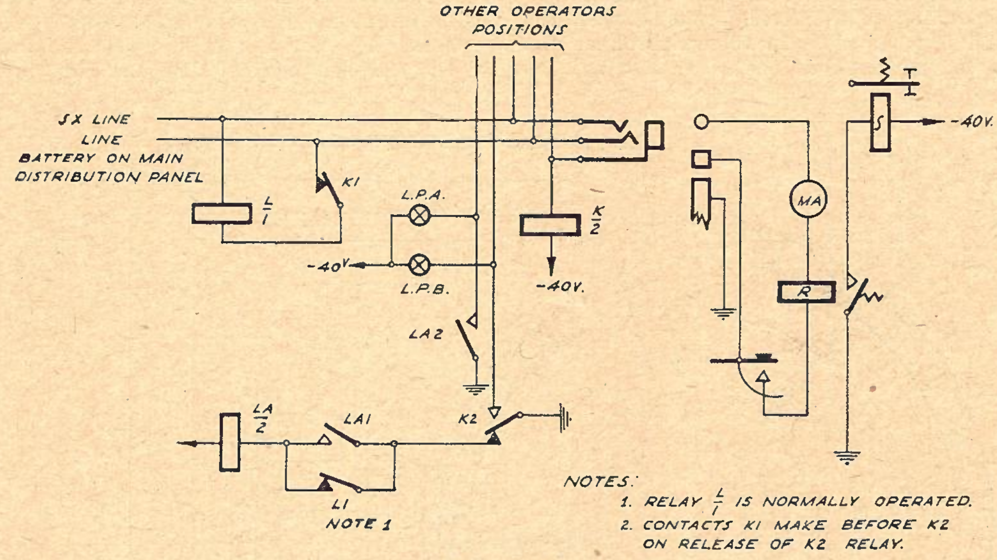
When the morse key is opened at the distant end of the simplex physical line, the bias current operates the relay B to spacing, passing the signals to the static modulator of the V.F. channel.

With the physical line closed, when the carrier receive relay is operated to spacing under the control of the operator at the distant V.F. terminal, the rectifier in the physical line prevents the flow of current in the physical line. The current through the bias winding is now reversed, and as Relay B is of the polarized type this relay is retained on the marking contact. By this means the morse signals are repeated from the simplex line to the V.F. channel, and in the reverse direction.

Q. 3.—Describe, with the aid of sketches, the circuit of a concentrator for terminating a number of closed circuit simplex Morse lines in a Chief Telegraph Office and explain its operation.

A.—The concentrator is used for terminating a number of lightly loaded simplex morse lines in a C.T.O. so that they may be operated by a smaller number of Telegraphists than would be the case if each line were terminated on a morse set and individually manned.

The circuit of such a unit is indicated in Fig. 1. With each line circuit there are associated three relays—L/1, LA/2, K/2, a line jack, a calling lamp LPA, and busy lamp LPB. Where the circuits are multipled over several operators' positions, the LPA, LPB lamps and the line jacks are multipled at each concentrator turret on the operating tables.



Q. 3, Fig. 1.

Circuit Operation: The L/1 relay is normally operated by the line battery fed through contacts K1 making, winding of L/1 relay and closed circuit simplex line.

When a morse station calls he opens the simplex line with his key and the L/1 relay releases. L1 contacts close circuit from earth, K2 contacts normal, L1 contacts restored, to relay LA/2, which operates. LA1 contacts operate and lock the LA/2 relay so that it does not release if L/1 is re-operated by the closing of the morse line. LA2 contacts close circuit to the LPA (calling) lamps on the multipled turrets.

An operator answers by plugging the cord and plug on his position into the line jack associated with the calling line. The earth on the sleeve of the plug operates the K/2 relay. K1 contacts open and remove the L/1 relay from the line. K2 contacts operate, opening the circuit to relay LA/2, which releases, extinguishing the LPA lamp. The operation of K2 contacts also closes circuit to the LPB (busy) lamps of the multipled turrets.

The lighting of the LPB lamps associated with any one line indicates at all turrets that a connection has been made to the line by one operator.

The circuit is established from the simplex line battery through the ring connections of jack and plug, the morse relay, key and meter on the operator's position, the tip connections of plug and jack to the simplex line. In this way a closed circuit simplex morse connection is established between the C.T.O. operator and the external line.

When the traffic has been handled, the connection is broken by the C.T.O. operator pulling out his plug, permitting relay K/2 to release. Contacts K1, which are adjusted to make before contacts K2, change over on the release of the relay, connect relay L/1 to the simplex line. L/1 relay re-operates, opening circuit to relay LA/2 before contacts K2 restore to normal.

Since the success of the calling-in circuit depends on the ability of relay L/1 to operate and release under the condition of varying leakage on the simplex line, it is generally a special type of telephone relay with a micrometer adjustment of spring tension so that it can be made to operate and release under the varying marginal conditions.

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