COURSE OF TECHNICAL INSTRUCTION

LONG LINE EQUIPMENT 3.

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

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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LONG LINE EQUIPMENT III.

Issue 1, 1950.

The subject of Long Line Equipment is presented in three books -

LONG LINE EQUIPMENT I includes the elementary theory of transmission, principles of carrier telephony and telegraphy, details of the apparatus used and information about crosstalk and power plant.

LONG LINE EQUIPMENT II includes voice frequency repeaters, signalling on trunk circuits, description of carrier telephone and telegraph systems and radio programme transmission over trunk lines.

LONG LINE EQUIPMENT III includes long line installation, maintenance and testing notes, line considerations, and transmission measurements.

LONG LINE EQUIPMENT III.

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NOTES.

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/Noise

/Tests

COMMONWEALTH OF AUSTRALIA.

Engineering Branch,
Postmaster-General's Department,
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Melbourne, C.2.

COURSE OF TECHNICAL INSTRUCTION.

INSTALLATION AND MAINTENANCE OF CARRIER EQUIPMENT.

CONTENTS:

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1. MOUNTING ARRANGEMENTS.

1.1 Racks. Carrier equipment is usually mounted on iron racks of over-all dimensions 1'8-1/4" wide and 10'6" high. Each main side member of the rack is made up of 3" x 1-1/2" x 4.6 lb. channel iron, and the rack is braced top and bottom with angle iron. The channel iron members are drilled to 19" centres at alternate 1-1/4" and 1/2" intervals on both sides to mount standard panels. Clearance of 2-5/8" from the bottom and 2-1/2" from the top of the rack is allowed for commencement and finish of panel mounting holes. The channel iron is also drilled with a number of 7/16" holes on the side to permit fixing to adjacent racks. (In some instances of low ceiling heights, 8'6" racks are used but 10'6" is the standard height and, as far as practicable, buildings are designed with ceiling clearance to suit 10'6" racks.)

1.2 Mounting Panels and Covers. Mounting Panels for the racks are 19" in length and are constructed from 14 or 15 B.G. mild steel. The width of the panel varies to suit particular equipment requirements and is in multiples of 1-3/4", commencing from panel size A (1-3/4") up to panel size J (17-1/2"). Between the rack, the panel edges are folded over at right angles for a width of 7/16" for strengthening purposes. To permit attachment to a

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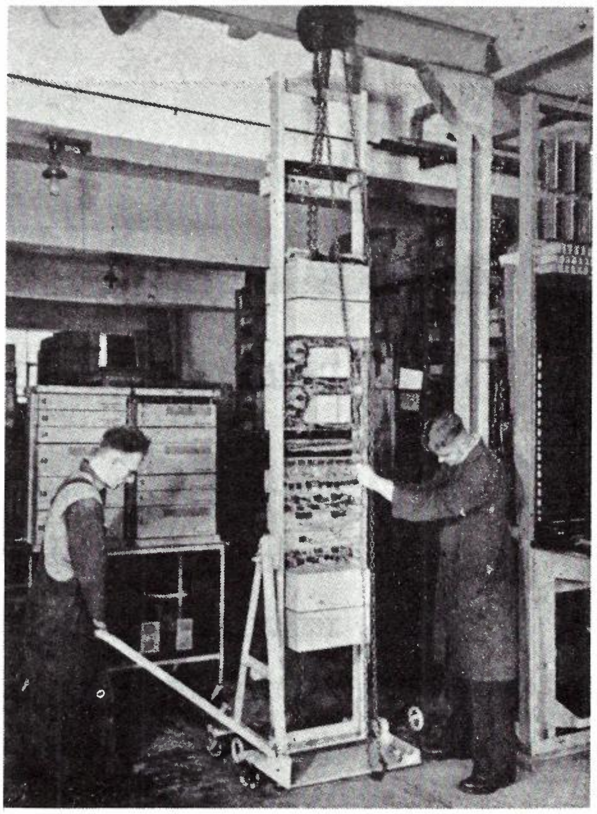
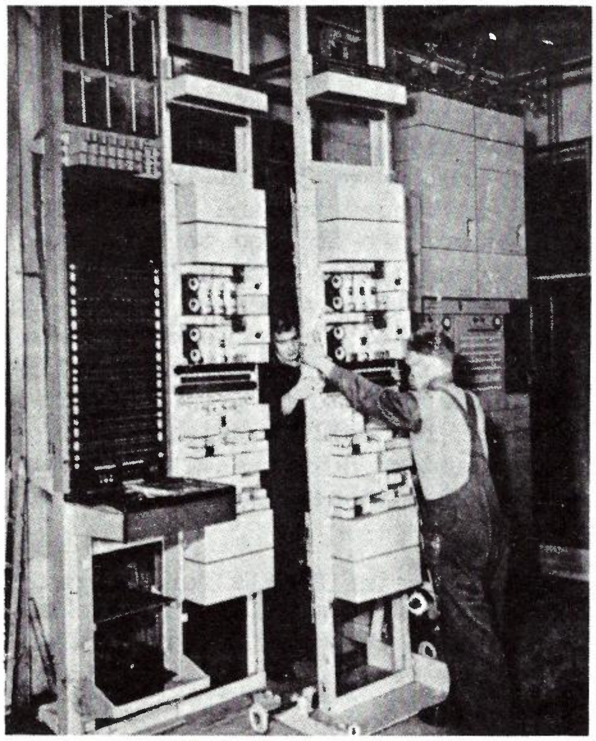


RACK PRIOR TO BEING WHEELED INTO POSITION.



"WALKING" A RACK TO THE FINAL POSITION.

rack, U shaped mounting slots to clear 5/32" screws are cut in the panels, the number of such slots varying with the size of the panel. On the left-hand end of the panel, a larger U shaped slot is cut in the centre of the panel as a wiring slot to permit entrance of the panel form from the main form. The edges of this slot are protected with a rubber grommet to avoid damage to form wiring. The panel corners are drilled to take corner brackets, which serve to locate the panel cover. The corner brackets carry a phosphor bronze spring, which is shaped to fit into indents in the cover to provide for centring and form location of the cover.

Covers are made from No. 20 B.G. mild steel plate box shaped to fit over panels. The over-all depth of covers is 6-1/4". This is now the standard depth, although earlier equipments employed covers with 4-3/4" depth. The covers are made in various sizes to suit the panels previously enumerated.

The standard method of mounting carrier equipment is to mount the apparatus single sided with respect to panels and double sided with respect to racks. In other words, all apparatus and wiring on a panel should be accessible from the front, and it should not be necessary to remove a panel from a rack in order to inspect the wiring or remove component parts.

1.3 The steel and ironwork is cleared of scale and blister in the factory, and either treated with an antirust compound or else cadmium plating to prevent rust. Racks, panels and covers are finished in aluminium paint, using super grade aluminium powder as a base for the paint. Alternatively, light battleship gray enamel is used.

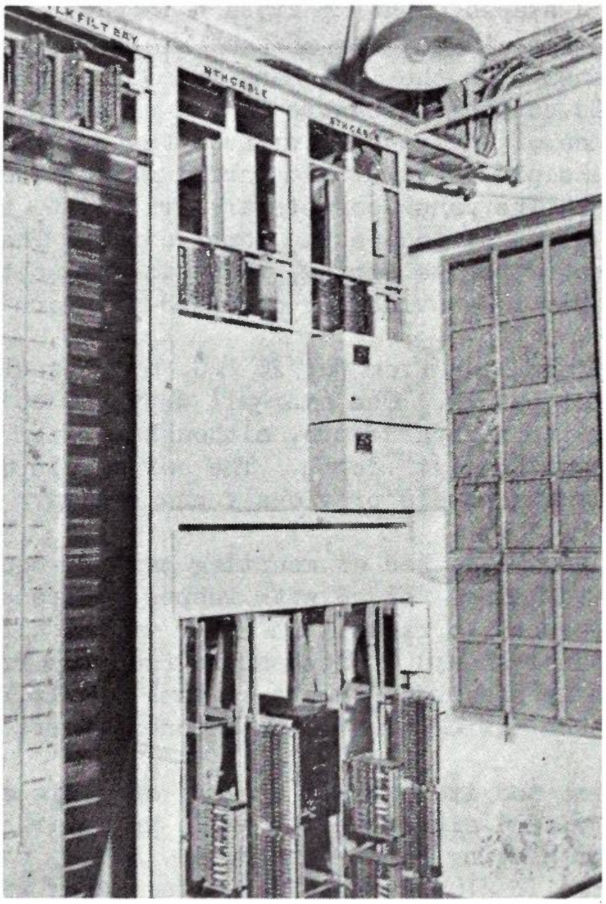
Controls used on the apparatus may be radial switch or continuously variable potentiometer type, or, alternatively, slotted screwdriver controls located under a panel cover.

Where possible, wiring is point to point, insulated and laid out for easy identification. Where necessary, as in jack and key panels, the wire is colour coded and made up in a properly supported laced form. The wire gauge is not less than 23 S.W.G. or its equivalent and the wire is flame proof. The insulation resistance between any two points not electrically connected is not less than 100 megohms when measured with a 250 volt megger.

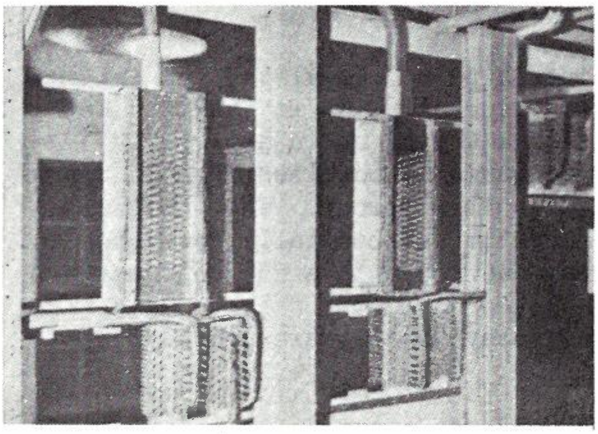
All jacks, keys, lamps, cords, relays, etc., are usually standard items.

1.4 Pictures of typical installation practice and equipment are shown on pages 2 and 4.

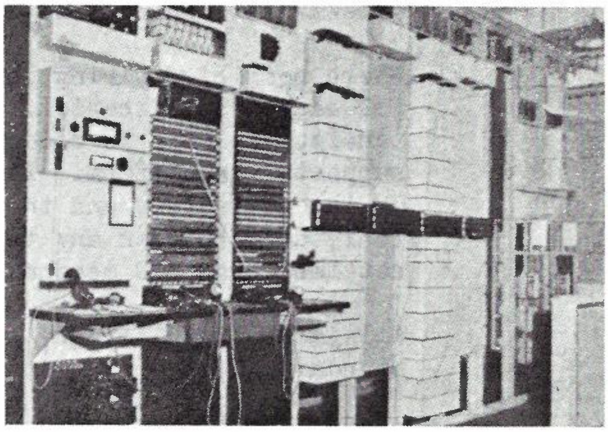
/ Cable



CABLE TERMINATING BAYS SHOWING CABLE TERMINATING CHAMBERS, TERMINAL LOAD UNITS, PROTECTIVE EQUIPMENT AND CROSSTALK FILTER BAY.



CABLE TERMINATING CHAMBERS.



CABLE TERMINATING BAYS, CROSSTALK SUPPRESSION FILTER BAY AND TEST BOARDS.

2. BUILDINGS AND LAYOUTS.

2.1 Buildings for long line equipment may be divided into two main groups -

(i) Buildings in which other equipment, that is, exchange equipment, is also located.

(ii) Buildings erected specially for long line equipment. These buildings are, in general, repeater stations, where telephone density is low or, alternatively, the site chosen is influenced by factors, such as correct repeater spacing and proximity to trunk route, and, therefore, is unsatisfactory for telephone exchange purposes.

Long line equipment buildings, in general, conform to Departmental requirements for equipment buildings, the type of construction depending on the locality in which it is erected. In effect, the building conforms to the standard of surrounding structures. In all closely settled areas, brick or concrete structures are employed. In very remote areas, where building costs are excessive due to long distances involved in transport of building materials, a prefabricated building has been employed and, from experience to date, appears very suitable for the particular conditions. The prefabricated buildings use galvanised iron walls and roofing over iron framework with internal timber and fibro cement lining and concrete foundations and floors. Prefabricated buildings are reasonable in cost and very easy to erect, and are preferable, from a heat dissipation point of view, to an equivalent brick or concrete structure.

The main requirements for a carrier equipment building are -

(a) Adequate space for 20-25 years' estimated development. For preference, the building should be capable of extension at a later date.

(b) Adequate ceiling clearance to suit 10'6" racks and overhead runways.

(c) Provision of suitable lighting - natural if practicable - also good artificial lighting and emergency lighting.

(d) Good ventilation.

(e) Adequate power points.

(f) Double doors to the equipment and power rooms to permit entrance and exit of heavy equipment. If the building is a two or more storey structure, provision of a cathead for lifting heavy equipment is required.

(g) Adequate staff accommodation.

/ 2.2

2.2 Layouts. The layout of long line equipment differs widely in various buildings, and is influenced, to a great extent, by space available and whether it is to be installed in a building already accommodating some other equipment.

The main points to be watched are -

(i) The I.D.F. should be located as close as possible to the trunk test boards.

(ii) Miscellaneous apparatus requiring heavy cabling, such as line filter groups, line transformers, composite sets and voice frequency repeaters, should be as close as possible to the I.D.F. (In small offices, the I.D.F., T.T.B. and miscellaneous line equipment are located in one row.)

(iii) Test equipment should be closely associated with T.T.B's.

(iv) Broadcast programme equipment, if installed, should be close to the T.T.B's.

(v) The main bulk of the carrier equipment can then be located in succeeding rows and, as far as practicable, equipment of a similar nature should be housed in the same row. It is generally desirable to keep carrier telegraph equipment closer to the T.T.B's. than carrier telephone systems, as they require more frequent maintenance attention.

The standard spacing between carrier equipment rows is 4 feet between centres. The main aisle space should be not less than 4 feet. The auxiliary aisle can be 2'3" to 4 feet, depending on the space available. (See Fig. 1.)

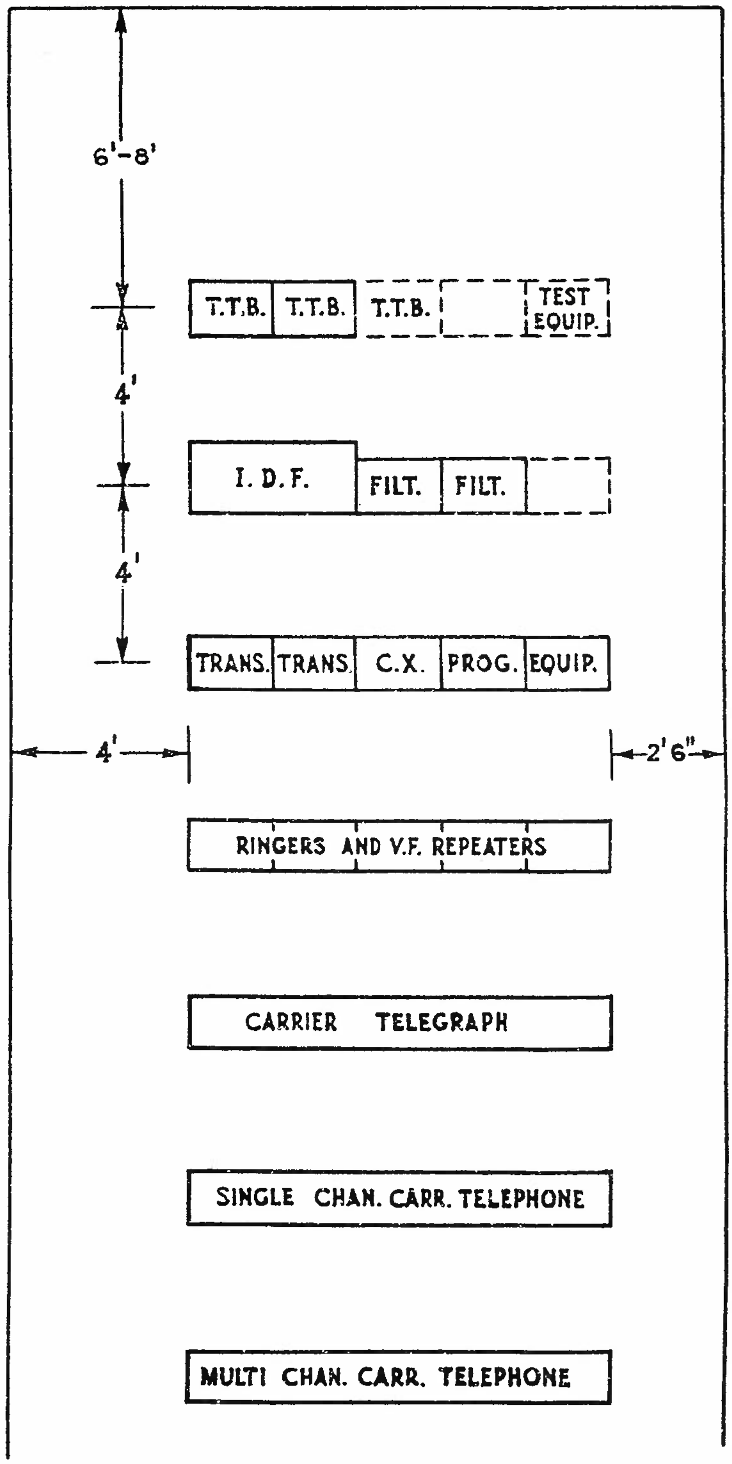
The equipment rows should not contain too many systems without resort to a centre aisle, as double sided mounting of equipment necessitates maintenance attention both sides of a rack, and such attention is rendered difficult in long unbroken rows.

The tendency is for test equipment in long line stations to be mounted on movable racks and brought up to systems as required. The adoption of 4 feet spacing assists in this respect.

The power and battery rooms should be arranged so that the charge and discharge leads from the battery to the power board are as short as possible. Likewise, the power room should be close to the equipment room to keep power leads to a minimum length.

In deciding the building space required, it is necessary to know the type of equipment likely to be installed.

/ Fig. 1



TYPICAL LAYOUT OF CARRIER APPARATUS.

FIG. 1.

Early three-channel systems were grouped in pairs on five 10'6" racks, the centre rack - battery supply bay - being common to both systems. Later three-channel systems were accommodated on two 10'6" racks and, more recently, on one 10'6" rack. Carrier Telegraph systems require five 10'6" racks per first-in installation and three 10'6" racks for second-in installations. More recent nine-channel systems require one 10'6" rack.

Figures for voice frequency repeaters, ringers, etc., have been stated previously.

In deciding space requirements, care should be taken to make one dimension a multiple of 4 feet to suit standard rack spacing.

A typical layout of a terminal station is shown in Fig. 1.

A diagram illustrating the interconnection of the various equipment bays and the type of cable is shown in Fig. 2.

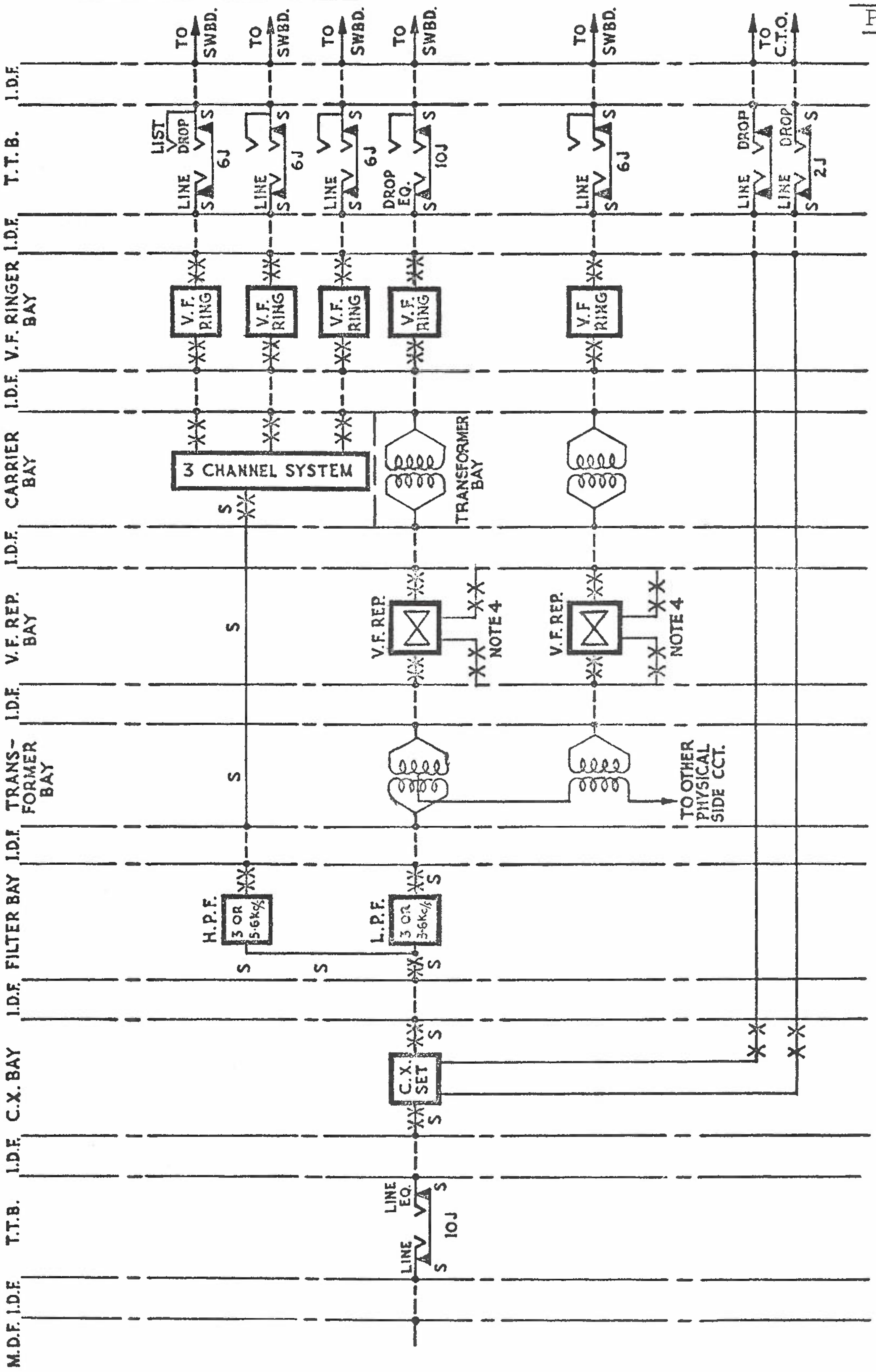
3. INSTALLATION TESTS ON A THREE-CHANNEL CARRIER SYSTEM.

3.1 When a three-channel carrier system has been installed, the following tests must be made -

(i) Check all power supplies.
(ii) Insert all fuses.
(iii) Insert all valves. (Allow warm up time.)
(iv) Adjust filament currents.
(v) Check anode currents.
(vi) Check alarm circuits.
(vii) Transmission Tests.
  (a) Terminate hybrids and line in 600 ohms, cut variable equalisers out of circuit.
  (b) Check modulator oscillator frequencies (by making a loss measurement of the modulator band filter using modulator oscillator as test tone).
  (c) Check modulator and demodulator oscillator supplies to modulators and demodulators. Adjust to correct value.
  (d) Adjust carrier leak, that is, balance of modulators and demodulators.
  (e) Check gains and losses in transmit direction. Send zero (1 milliwatt) at 800 c/s into Hyb. Line of each channel in turn. The loss or gain at each test point of the circuit should be within the limits stated in the manufacturer's handbook. The usual Test Points are -

Mod. In.
M.B.F's. Out.
Trans. Amp. In.
Trans. Amp. Out.
Dir. Filt. Out.
Line Filt. Out.

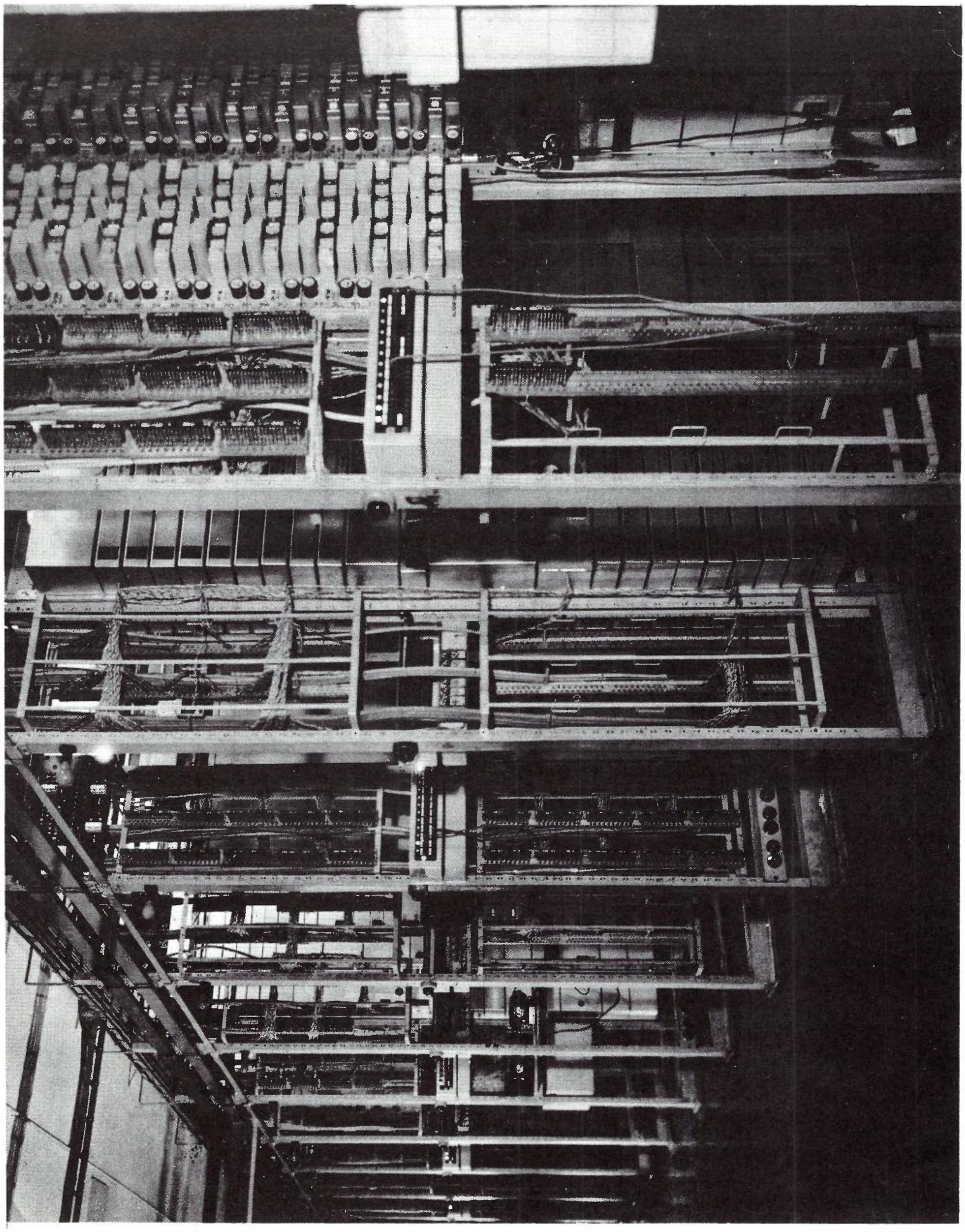
/ Fig. 2



Notes.

1. Screened wire marked "S". All other cabling is in multiple twin 20 lb. cable.
2. V.F. Repeater Networks not shown in this diagram.
3. X-X denotes jacks similar to those shown for T.T.B.
4. To networks (via balancing equipment).

FIG. 2 - TYPICAL INTERCONNECTION OF CARRIER APPARATUS.



LONG LINE EQUIPMENT LAYOUT.

(f) Receiving Circuit. This test is facilitated if a high frequency oscillator is available. By sending a level of zero (1 milliwatt) into the receiving side at a frequency which, when demodulated, will produce 800 c/s, the system may be checked at the various points. (If possible, the demodulator oscillators should be first synchronised with the modulator oscillators at the distant terminal.) If the distant terminal is not available, the demodulator oscillator's air condensers should be set to their mid position. The transmit side should be blocked out by inserting a 600 ohm plug at Trans. Amp. In. If no high frequency oscillator is available, both modulator and demodulator of the channel under test can be supplied from the demodulator oscillator. If 800 c/s is applied to Hyb. Line, the modulator will produce two sidebands, one of which is correct for the receiving circuit. (It is necessary to patch to replace the M.B.F. with the associated D.B.F.) Send 1 milliwatt zero into Line Filt. jacks. Check loss or gain at each part of the circuit to be within limits stated by the manufacturer.

Usual Test Points -

Dir. Filt.
Fixed Equaliser.
Rec. Amp. In.
Rec. Amp. Out (with and without variable equalisers).
Demod. Band Filter In.
Demod. Out.
Demod. Amp. Out.

(g) Over-all Line Up. Check that circuit is in good order. A-B Direction. The A terminal adjusts the transmitting levels on each channel in turn. The repeater nearest the A terminal measures the output level on each channel in turn (without variable line equalisers in circuit) and, from results, determines the A to B variable line equaliser settings and the A to B amplifier setting. The same procedure is adopted at each repeater in turn and, finally, the receiving levels of the B terminal are lined up. The procedure is the same for the B to A direction. If the pilot channel is equipped, it is necessary to make tests on this before over-all line up. Immediately after line up, set pilot levels and variable attenuators. When all levels are adjusted, the following tests are made -

Synchronisation.
Measurement of quality in each direction on each channel.

All measurements made must be properly recorded, so that the future performance of the system can be compared against the installation tests. This comparison serves as a reference standard.

/ Synchronisation

Synchronisation - Terminal Stations. The general procedure for synchronisation is to send simultaneously upper and lower sidebands of 800 c/s in one direction over the channel by patching out of circuit the modulator band filter at the transmitting terminal and the demodulator band filter at the receiving terminal, and to listen via the monitoring circuit on the channel at the receiving terminal to the demodulated sidebands. If there is any difference of frequency between the modulator and demodulator oscillators, the two sidebands received will audibly beat together. When making the test, the demodulator oscillator air condenser is adjusted until the beats are slower than one period per second.

When one direction of a channel has been synchronised by transmitting both sidebands, the band filters are reconnected into circuit, thus allowing a single 800 c/s tone to be sent over the channel in the direction already synchronised. The other direction of this channel is synchronised by looping this tone back to the transmitting terminal, by patching at the receiving terminal from the output at the receive side of the four-wire terminating set to the input of the transmit side of the channel. The transmitting terminal then listens via the monitoring circuit on the channel on which tone is being sent, when both transmitted and received tones are audible, and adjusts the demodulator oscillator condenser until the beats are slower than one period per second. It will be appreciated that any frequency difference in this case between the transmitted and received tones is due only to lack of synchronism in the receiving direction, since the other direction has already been synchronised by the double sideband method. For this reason, the double sideband method must be applied to one direction of a channel before the tone is looped back for synchronising the reverse direction.

From a study of drawing C1125 (at rear of Paper No.3, Long Line Equipment II), it will be appreciated that, even if the band filters are patched out, two sidebands cannot be sent on Channel 3 in the A to B direction of the SOT system if telegraph separating filters are equipped, or on channel 3 in the A to B direction of the SOS system if 5,000 c/s cut-off line filters are used. It will also be seen that two sidebands cannot be sent on Channel 2 in the B to A direction of the SOT system due to the directional filters.

In order to avoid these difficulties and to cause the minimum crosstalk interference into carrier or physical circuits operated on other open wire pairs on the same route, it is recommended that the channels be synchronised as follows -

Channel 2. Both sidebands A to B looped back B to A.

Channels 1 and 3. Both sidebands B to A looped back A to B.

/ 4.

4. MAINTENANCE OF CARRIER TELEPHONE SYSTEMS.

4.1 General. To ensure that the transmission qualities of channels provided by carrier telephone systems are maintained at the desired standard, a schedule of tests is carried out at various intervals. Details of these tests and their periodicity are contained in Transmission Engineering Instruction, Long Line Equipment T5310.

On systems which are not equipped with automatic pilot regulation, it is necessary for the channels to be lined up daily owing to changes which occur in "transmission equivalent" due to weather variations. This consists of checking the transmission levels at the terminal and repeater stations and adjusting them to their original value as necessary. The "transmission equivalent" of carrier channels is, as a general rule, 0 db from hybrid line to hybrid line.

Daily Line-up. This involves both the terminal and repeater stations, and it is necessary to employ a channel or channels for communication purposes between them during the test. The type of channel which is used for this purpose is governed by local conditions and is arranged in conjunction with the traffic section.

Having completed these preliminary arrangements, it is assumed that the A-B direction of transmission is to be lined-up first.

Line-up A-B Direction. The A terminal sends a test signal of frequency 800 cycles at the correct level at hybrid line on the channel occupying the mid-frequencies of the A-B Frequency Group (Channel 2). After checking the send level at Trans. Amp. out, the test current is allowed to pass to line. The repeater station adjacent to the A terminal checks the output of the A-B repeater and adjusts to normal. Each repeater station, in turn, follows the same procedure. At the B terminal, the test current is measured at hybrid line on Channel 2 with the demodulator gain control set at the centre of its range. Any necessary adjustment is made by altering the gain control on the Receive Amplifier.

The A terminal then transfers the test current to Channels 1 and 3 in turn, and the B terminal similarly checks and adjusts the demodulator gain controls of each channel as necessary; the repeater stations do not adjust for these channels.

/Line-up

Line-up B-A Direction. A similar procedure is carried out for the B-A direction with the exception that the mid-frequency channel is Channel 1 for this direction.

A speaking test is made on each channel and, if satisfactory, the system is restored to traffic. The settings of the controls at the various stations are recorded as required. If the speaking test is not satisfactory, the cause should be investigated, and it might indicate that synchronising is necessary.

Location of Faults. It is difficult to prescribe any hard and fast rules for the location of faults in carrier telephone systems. Faults can, however, be divided into two main categories, namely, common equipment faults which affect all channels in a system, such as a common transmitting or receiving amplifier at a terminal or in the amplifiers at a repeater station, and individual faults peculiar to one of the channels in a system, such as oscillator, modulator, demodulator or demodulator amplifier failure. The preliminary location of a fault can best be diagnosed by a knowledge of the block schematic diagram of a system. Having isolated the fault into a section or sections, the next step involves the use of testing instruments or test facilities provided on the system. Filament and anode currents are first checked and, if valves are satisfactory, alternating current tests are made, checking for correct levels at the various test jack points in the system. Experience leads to many quick test methods which cannot be detailed, and a knowledge of the circuit operation and layout disposition of the equipment on the racks is essential if faults are to be cleared in a minimum of time.

4.2 Battery Maintenance. The filament battery voltage should be maintained at -24 volts ± 2.4 volts.

The anode battery voltage should be maintained at +130 volts ± 10 volts.

The telegraph battery voltages should be maintained within 10% of their nominal value, and the difference between the positive and the negative battery potentials should not exceed 5%.

4.3 Maintenance of V.F. Carrier Telegraph Systems.

Line-up Tests - Daily. The following tests should follow on the regular daily line-up tests of the circuit over which the carrier telegraph system is being operated -

/Relay

Relay Neutrality Test. Reversals are sent on each channel and the receive circuit adjusted for neutrality by varying the bias current. The receive relay is changed where this adjustment does not produce satisfactory reversals. Except in cases for which special instructions have been issued, the speed of reversals is 25 bauds.

Relay Replacement. On systems employing P.R. 10 type relays, the receive relay of each channel is replaced with one previously adjusted in the relay test panel or relay test table.

Machine Generator Frequency Test. The speed of the machine generator is checked with the stroboscopic disc and associated test oscillator and adjusted to its correct value when necessary.

Weekly Tests. The following weekly tests are made -

Filament and Plate Currents. The filament and plate currents of all tubes are measured and recorded. Where plate current readings fall outside the limits specified for the equipment, and the battery and grid bias voltages are correct, the tubes are changed.

Amplifier Detector Gain Adjustment. The gain of each amplifier detector, with respect to its limiting point and the carrier input, is adjusted to the correct value by varying the input potentiometer as described in the relevant handbook.

Stroboscope Oscillator Frequency. The frequency of the test oscillator associated with the machine generator is checked against a test oscillator tuning fork and adjusted if necessary. Where a tuning fork is not available, a standard test frequency is used.

Relay Replacement. With the exception of P.R. 10 type relays, the receive relay of each channel is replaced with one previously adjusted in the relay test panel or relay test table.

Other tests are made at periods as shown in Transmission Engineering Instruction, Telegraphs T 5000. These tests include -

/Monthly

Monthly Tests -

(i) Channel Send Level.

(ii) Amplifier Detector Sensitivity.

(iii) Automatic Volume Control Range Check.

Quarterly Tests -

(i) Send and Receive Amplifier Gain.

(ii) Machine Frequency Generator Output Level.

(iii) Channel Oscillator Output Level.

Half-Yearly Tests -

(i) Static Modulator Discriminator.

Location of Faults. In operating telegraph circuits over a carrier telegraph system, the service may be interrupted by several different kinds of faults.

Line, Send and Receive Amplifiers. Faults in the above portions of the circuit are usually indicated by the abnormal behaviour of the detected current on all channels of the carrier telegraph system. The causes may be -

(i) Failure of battery supplies or incorrect voltages.

(ii) Intermittent or complete failure of bearer channel.

(iii) Faults in the common send and receive amplifiers, line equipment panel or main jack field.

In the case of a fault affecting all channels at each terminal, a check should be made to see if tone at the correct level is being received from the distant terminal. If tests show that correct currents are being transmitted from each terminal, but there is no received level or the level is incorrect, the circuit or line over which the system is operating should be tested.

/If

If the fault is confined to one terminal, the battery supplies may have failed or dropped to a low value, or a fault may have developed in the common equipment.

Alternating Current Circuit Faults on Terminal Apparatus of Individual Channels. Faults, as above, are indicated by abnormal behaviour of the received current in one or two channels only.

If the detected current under marking conditions from the distant terminal falls to zero or a low value, the cause may be -

(i) Faulty anode circuit due to valve failures, high resistance circuit or wiring faults.
(ii) Incorrect setting of an amplifier detector potentiometer.
(iii) Insufficient level being transmitted from the distant terminal due to wiring fault, faulty key contacts, static relay failure, send filter fault or oscillator drift.
(iv) Wiring troubles in amplifier detector circuit.
(v) Faulty receive filter.
(vi) Individual battery supply leads faulty.

Spasmodic kicks, which show in the "Obsvn. Receive" meter but not in the "Detected Current" meter, indicate a faulty receive relay. The receive relay should be replaced with a spare relay, which should be in perfect adjustment, and the faulty relay should be thoroughly checked for dirty contacts, adjustment, etc.

The faults which cause distortion and consequent poor operation are discussed in the section on Interference.

The use of a telegraph distortion measuring set for measurement of the over-all distortion from line to line compared against the figures recorded at time of installation is the most satisfactory means of ensuring that the performance of the equipment is satisfactory.

Faults in the various direct current circuits have to be traced out in each individual case, but a knowledge of the circuits should enable these to be located quickly.

Interference Tests. Carrier telegraph channels are designed for independent operation. If the current in one channel has any effect on the operation of the other channels, the effect is described as interference. When the system is operating normally, interference will be perceptible, but it will be of such low value that it will not affect the telegraph transmission. If the interference becomes abnormal, it will cause severe signal distortion or will result in chattering and false operation of the receiving relay in the channel concerned.

-3

/ Interference

Interference consisting of an alternating current applied to the amplifier detector, when no current is being sent from the associated channel at the distant terminal, is termed "spacing interference." Interference which appears as a change in the alternating current applied to the amplifier detector, when current is being sent from the associated channel at the distant terminal, is termed "marking interference." In general, interference is caused by intermodulation in common amplifiers and repeaters and in transformers and loading coils. Severe crosstalk from other circuits can also cause interference. The presence of excessive interference usually indicates that the level is too high in some portion of the circuit.

Spacing interference at a level of more than 26 db below the level of the signal incoming to a channel will not produce objectionable distortion. Similarly, marking interference, which causes a change of less than 1 db in the strength of the received signal, will not cause objectionable distortion.

Interference tests should be made whenever a carrier telegraph system is applied to a new circuit, or whenever it is suspected that the circuit levels previously in use have been altered.

Spacing Interference Test.

(i) The amplifier detector of the channel under test should previously be adjusted for correct operation in the midpoint of the A.V.C. range.

(ii) At the distant terminal, operate "Send Mark" keys on all channels except the one under test, which should be operated to "Send Space."

(iii) Increase the input potentiometer on the amplifier detector to maximum gain, and decrease the attenuation in the line pad until a reading is obtained on the detected current meter.

(iv) Obtain a mark on the channel under test, reduce the input potentiometer in the amplifier detector and increase the attenuation in the line pad until the same reading is obtained on the detected current meter. The difference in values inserted under the above conditions gives the level spacing interference expressed in db below the level of the required signal. Spacing interference less than 20 db below the required signal should not be tolerated.

Marking Interference Test.

(i) Obtain a mark from the distant terminal on all channels.

(ii) Set the rectified current on the channel under test to a convenient value (say 3-4 milliamperes). Note the potentiometer settings.

(iii) Obtain a space from the distant terminal on all channels except the one under test.

/ (iv)

(iv) Reset the rectified current to the same value obtained in (ii). Note the new potentiometer setting. The difference between the potentiometer settings expresses the marking interference in db.

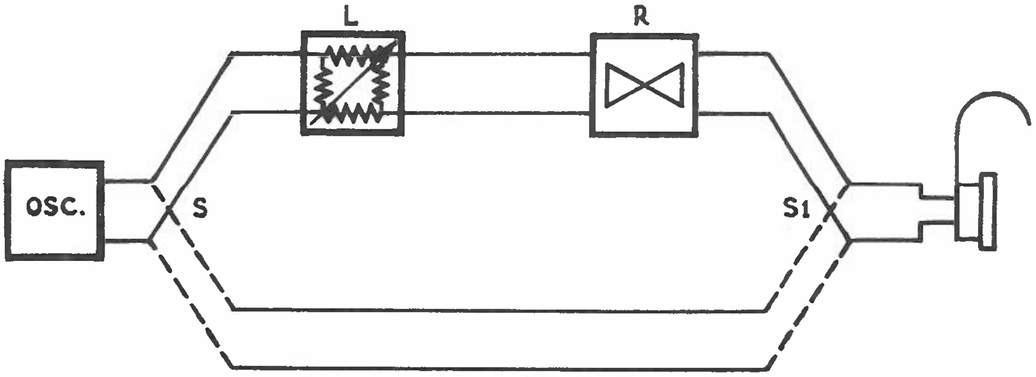
Marking interference exceeding 1.5 db should not be tolerated.

If a sensitive alternating current meter is available, the above interference tests can be made more readily by measuring the level differences at the respective channel "Rec. Filter Out" jacks.

5. MAINTENANCE OF TWO-WIRE VOICE FREQUENCY REPEATERS.

5.1 The purpose of this section is to give a technical description of the more important tests, which are conducted at various intervals upon the repeater equipment.

Gain Tests. At each station, a means of testing the gain of the repeater is provided. This test may be understood by reference to Fig. 3.



GAIN SET.

FIG. 3.

The gain set operates on the "substitution" principle. The oscillator supplies 1,000 c/s tone to the circuit. The two sets of key contacts, shown S and S_1, form portion of a two-way key. The operation of this key in one position places the oscillator in direct connection with the receiver. The tone in the receiver forms a standard of comparison.

The key is now operated to the second position, and places the oscillator tone through the variable attenuator or loss L to the input of the repeater R. The repeater amplifies the tone

/ which

which reaches the receiver. The loss L is adjusted until the tone heard in the receiver with the key S in either position is the same value. It follows that the loss introduced by L is then equal to the gain due to the repeater, and the value shown in L is the gain of the repeater. The loss L is arranged to give a direct dial reading.

In present day repeater equipment, the receiver is replaced by a Transmission Measuring Set giving a direct reading in db. The circuit on the repeater unit is suitably wired through jacks allowing the necessary patches to be put up when required.

Balance Test. It has been previously stated that the operation of a two-way repeater is dependent upon the arrangement of a balance network to match the line on either side of the repeater.

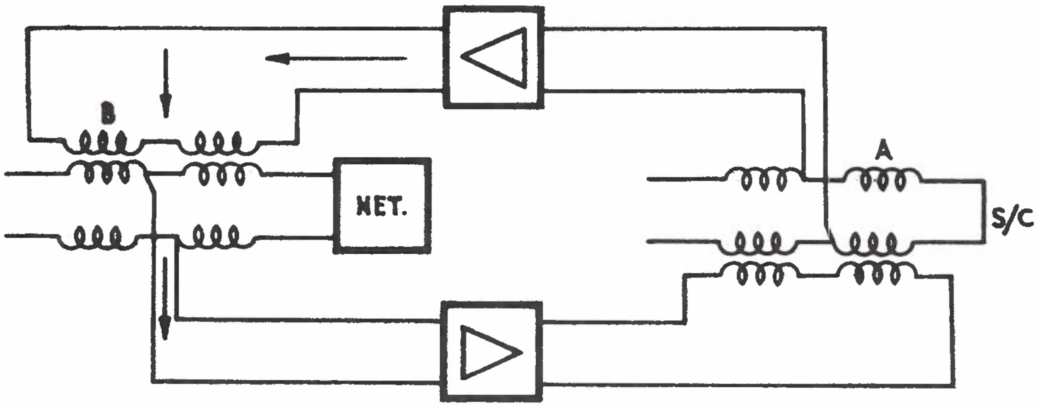
The accuracy with which this network matches the line influences the gain available from the repeater and also affects the frequency band or quality of the repeater. The effect of an unbalance between the network and the line of a repeater gives rise to "singing" or sustained oscillation around the repeater circuit. This effect can be observed as a continuous tone in the monitoring head-set. If a balance network could be designed as an ideal match for a line at all frequencies, the gain which could be used in the repeater would be infinite, assuming that the hybrid coil or three-way transformer was, itself, perfectly balanced.

However, this condition does not exist in practice, and the gain which can be utilised in a repeater is limited by the tendency of the repeater to sing. The singing point is an expression for the lowest gain in the circuit at which a repeater will sing. The maximum gain which can be utilised before "singing" commences is taken as a measure of the degree of balance between the network and the line.

The following simple test has been developed for determining the balancing conditions of a two-wire repeatered circuit. This test, although not giving such accurate results as may be obtained with other methods, such as the Impedance Unbalance Measuring Set, has the advantage that measurements may be made rapidly and that only standard two-wire repeaters are necessary.

/ Referring

Referring to Fig. 4, one hybrid coil A may be readily converted into a repeating coil by short-circuiting the line terminals and opening the network terminals.



BALANCE TEST.

FIG. 4.

Alternately, the line terminals may be open-circuited and the network terminals short-circuited. These two methods of conversion are referred to arbitrarily as "Positive Poling" and "Negative Poling" respectively. The current transmitted through the hybrid coil with "Positive Poling" is in approximate phase opposition to that transmitted with "Negative Poling." (When making a test, both methods should be tried, as usually it is found that one phase relationship is more favourable to singing than the other.)

The balance of the second hybrid coil B is tested by increasing the gain in the amplifiers until "singing" is heard in the receiver. This singing occurs when the gain in the amplifiers is sufficient to equal or overcome the loss in coil B, due to the unbalance between the line and its network. The greater the unbalance between the line and the network, the smaller is the loss in the coil and the more easily can singing occur.

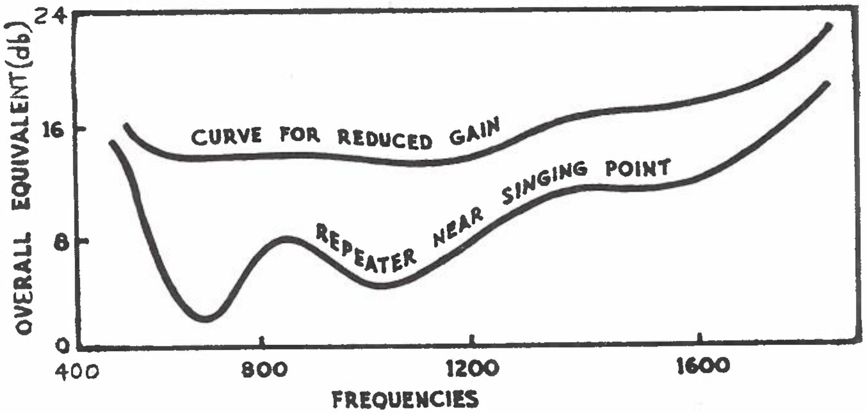
The short-circuit and open-circuit are now changed over to the opposite end of the hybrid coil A. The reason for this change can be explained as follows -

When the unbalance current, having travelled around the circuit, returns to the input of the hybrid, it may or may not be in phase with the original current at this point. If the return current is directly in phase, the singing point is lower than when the current is out of phase, that is, the circuit has a greater tendency to sing. Two readings are, therefore, taken to discover the condition which brings the currents more nearly in phase.

/ The

The phase difference or rotation is brought about by the filters, transformers, vacuum tubes and nature of the unbalance between the line and network. Should it happen that, owing to line troubles, the standard of balance between the line and network is lowered and the repeater gain is not reduced by a corresponding amount, the gain given by the repeater at different frequencies will depart from normal values, giving rise to distortion.

This effect is illustrated by Fig. 5, which indicates the advantage of reducing the gain when an out of balance exists between the line and the network.



GRAPHS SHOWING ADVANTAGE OF REDUCING GAIN WHEN OUT OF BALANCE EXISTS.

FIG. 5.

5.2 Maintenance. General. In order to make daily maintenance tests on repeaters, it is necessary to remove from service the circuits on which they operate. To reduce "lost circuit" time during daily tests, a procedure has been prepared which provides for co-operation between testing stations. A definite time is set aside for the periodical tests, to be made, if possible, when telephone traffic is light. All repeater stations and both terminal stations co-ordinate the work under the direction of the control station. The success of this system is dependent upon each station doing its part of the work correctly, punctually and within a specified time allowed for the tests.

For proper maintenance of telephone repeaters, it is necessary that a series of routine tests should be regularly carried out on the repeating equipment, as well as on the through circuit. The tests are divided into five groups, namely -

Daily, Weekly, Monthly, Quarterly and Yearly Tests.

These tests, listed below in order of performance, apply to the repeater equipment as well as the through circuit. The daily tests are described in paragraph 5.3 of this Paper.

/ Daily

Daily Tests.

(i) Repeater gain test to determine the amplification of the repeater (in db) on normal working stops.
(ii) Transmission equivalent test to determine the over-all transmission equivalent of the circuit.
(iii) Talking test made under normal talking conditions with two telephone sets to observe the voice quality and presence of crosstalk or noise on the circuit.
(iv) Signalling test made by signalling over the through circuit under normal conditions to ensure that the terminal ringing equipment is working satisfactorily and, in the case of 135 c/s ringing, to test the relay equipment at the repeater.
(v) Over-all Circuit Balance Test. A rapid means of checking up the balance conditions of the lines associated with each two-wire repeater without disconnecting lines or networks.

Weekly Tests.

(i) Test of fuse alarm.
(ii) Test of repeater alarms (filament fail alarm).

Monthly Tests.

(i) Vacuum Tube Rejection Test. Conducted to ascertain whether the emission of the tube is satisfactory.
(ii) Balance Test on Repeaters. Conducted to determine the degree of balance in the repeater unit.

Quarterly Tests.

(i) Circuit Test. A more complete form of the balance test described in Daily Tests (v). The test shall be made in period of light traffic.

Yearly Tests.

(i) Gain versus Potentiometer Stops. The gain shall be measured on each stop of both potentiometers of the repeater.
(ii) Gain versus Frequency. The gain through the repeater shall be measured over the frequency range.
(iii) Mechanical inspection of wiring forms and equipment.

5.3 Daily Tests on Repeaters. Details of the daily tests are as follows -

Roll Call - Daily Line-up. The Testing Officer at the Control Station "calls the Roll" at a fixed time each morning. This time is dependent upon the early traffic over the particular circuit. All stations answer the "roll call," commencing with the first station and proceeding through to the distant terminal, giving the name of station, temperature and weather conditions.

The Testing Officer at the Control Station arranges, prior to roll

/ call

call, for the circuit to be cut out of traffic for the period required for the testing purposes.

Prior to roll call, the technicians at the repeater stations check the A and B battery voltages on the repeaters and adjust the filament currents to their correct values. The Control Station Testing Officer advises the repeater attendants to proceed with the first test, that is, the repeater amplification or gain test.

Gain Tests. This test has already been described.

Transmission Equivalent. The transmission equivalent between terminals is measured daily in both directions with a Transmission Measuring Set and adjusted to the value prescribed. In cases where the repeated line forms a link between carrier channels or is joined to a carrier channel, the equivalent over the voice frequency line is measured, apart from the carrier channel, prior to an overall equivalent being measured.

Talking Tests. A talking test is carried out over the repeated line from standard telephones at each terminal. The circuits are observed for quality of speech, crosstalk from neighbouring circuits and noise.

Signalling. Signals are exchanged from the operating position at each terminal to test the operation of the ringing equipment.

Over-all Balance Test. In order to check the balance conditions of the lines associated with each two-wire repeater in traffic, without disconnecting either of the lines or networks from the repeater, an observation of the point at which the repeater sings when its gains are increased is made, all other conditions in circuit remaining normal, including the gain of other repeaters, if any, in tandem on either side of the station.

The results are compared with those obtained on previous occasions under similar conditions to ascertain whether any serious trouble has developed. It is not essential that the ends of the circuit be properly terminated for this test, that is, the test can be made in the interval between the two successive conversations, under which conditions the ends of the line will be terminated with the receiving signalling apparatus.

In this manner, the service need not be interrupted, patching is not required and co-operation from other stations is not necessary.

6. TEST QUESTIONS.

1. What tests are made on a three-channel carrier system following installation?
2. What is meant by "daily line-up" tests as applied to carrier systems?
3. What tests are made daily on repeaters?
4. Describe the Transmission Tests made on a three-channel carrier system after installation.

END OF PAPER.

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COURSE OF TECHNICAL INSTRUCTION.

LONG LINE EQUIPMENT III.

PAPER NO. 2.
PAGE 1.

TRUNK LINE TESTING.

CONTENTS:

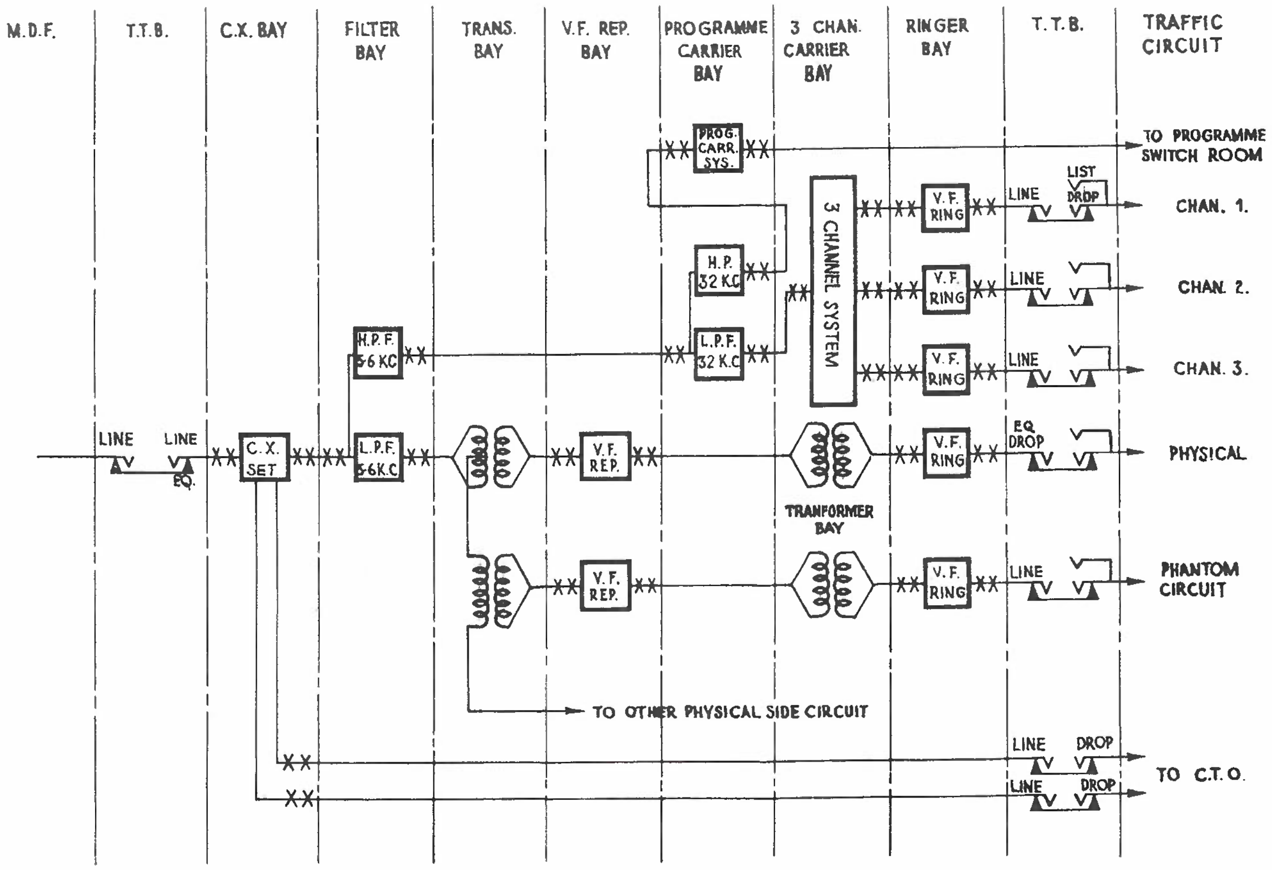
1. TEST BOARDS.

1.1 Trunk Test Boards. Trunk Test Boards are essential in maintaining high grade trunk line service. The facilities for trunk testing have undergone many changes in recent years, but certain principles and methods confirmed by long experience provide a basic technique which applies despite the wide variety of test equipment now in existence.

Two general types of testing are performed on trunk test boards. The first type of test verifies that a fault exists on a circuit and determines its general nature and approximate location. The second type of test locates the position of the fault with precise measuring apparatus, if the fault exists on the line rather than in the office equipment.

Another function of the trunk test boards, which is a necessary corollary of the presence of faults, consists of rearranging the lines and office equipment so that channels are made available to take the place of those temporarily out of service whilst faulty. In addition, any temporary regrouping of circuits required from time to time because of special circumstances can be readily taken care of.

The composition of a typical interstate trunk line is shown in Fig. 1. The crosses "X" indicate break jacks (3630 type), also, for simplicity, one line is shown instead of two per pair. Referring to Fig. 1, it will be seen that this line carries the following circuits -



TYPICAL CONNECTIONS OF INTERSTATE TRUNK LINE.

XX denotes jacks similar to those shown for T.T.B.

thus  , but designated according to their relative position in the circuit.

NOTE: V.F. repeater networks not shown in this diagram.

FIG. 1.

(i) One voice frequency physical circuit,
(ii) One voice frequency phantom circuit,
(iii) Three telephone carrier channels,
(iv) One programme carrier channel, and
(v) Two composite telegraph channels.

It will be appreciated that any line carrying such a large number of circuits (particularly if between Capital centres) plays an important part in the handling of traffic, and constant care during testing is necessary to avoid circuit interruption. If a faults develops, prompt arrangements must be made for a "patch" in the faulty section, either by utilising a spare patch line, if available, or some other working line which is not carrying traffic of the same volume or importance.

/ In

In view of the large amount of equipment involved, it is desirable to make a line patch on the T.T.B. If a phantom group is involved and another complete group is available, it is generally most satisfactory to patch in the complete group. Fig. 2 shows typical line patch arrangements.

It is assumed that a line fault has developed on line B, which may be an important interstate or intrastate trunk line carrying a number of derived channels. It may be seen that, provided similar line patches are inserted at each end of the faulty line section, all the derived channels on lines A and B, plus the phantom E, will be restored to the normal condition. Actually, new wires are substituted in this "patch" for the faulty lines A and B.

In some instances where it is only necessary to restore the superimposed carrier systems a high pass patch may be utilised providing the necessary line filters are in situ. This merely transfers the high frequency channels from one bearer circuit to another as shown in Fig. 3.

1.2 Typical Features of Trunk Test Boards. Trunk test boards provide for testing and patching facilities on the following types of circuit -

(i) Physical lines,

(ii) Phantom circuits,

(iii) Composite telegraph or dialling circuits,

(iv) Carrier telephone systems,

(v) Carrier telegraph systems, and

(vi) Four-wire circuits connected clear of hybrid coils.

1.3 Parts of Trunk Test Boards. The parts of typical trunk test boards are -

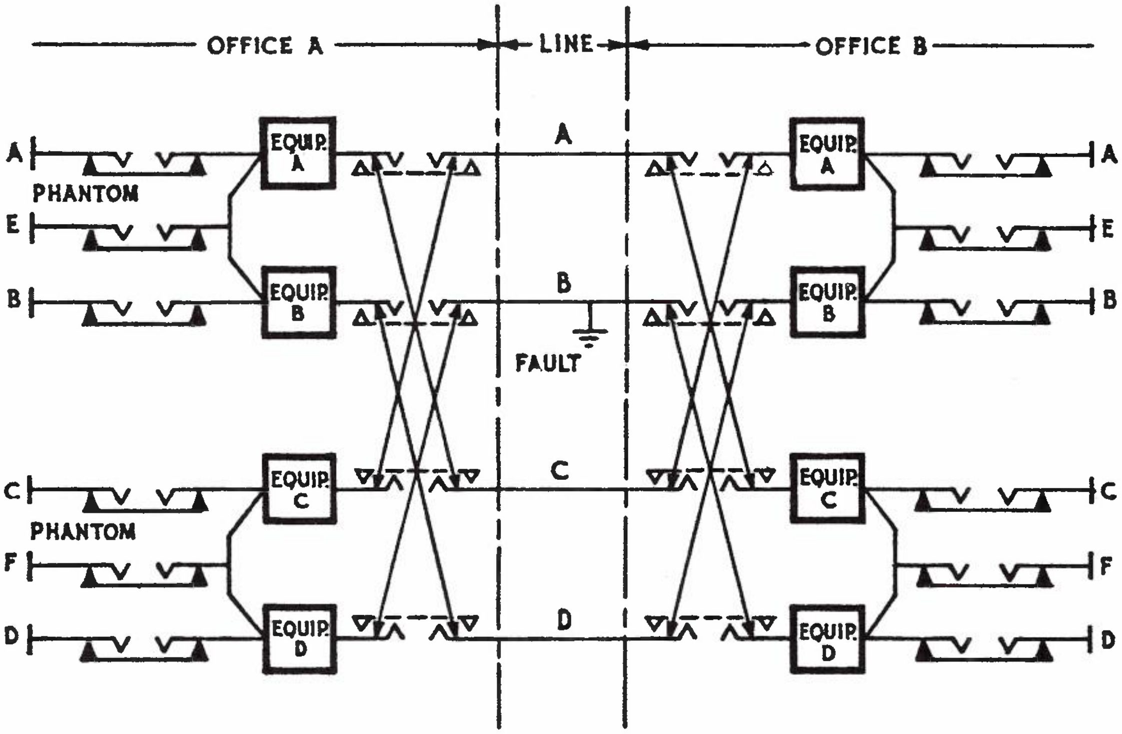
(i) Voltmeter position.

(ii) Wheatstone Bridge position.

(iii) Combined voltmeter and bridge position.

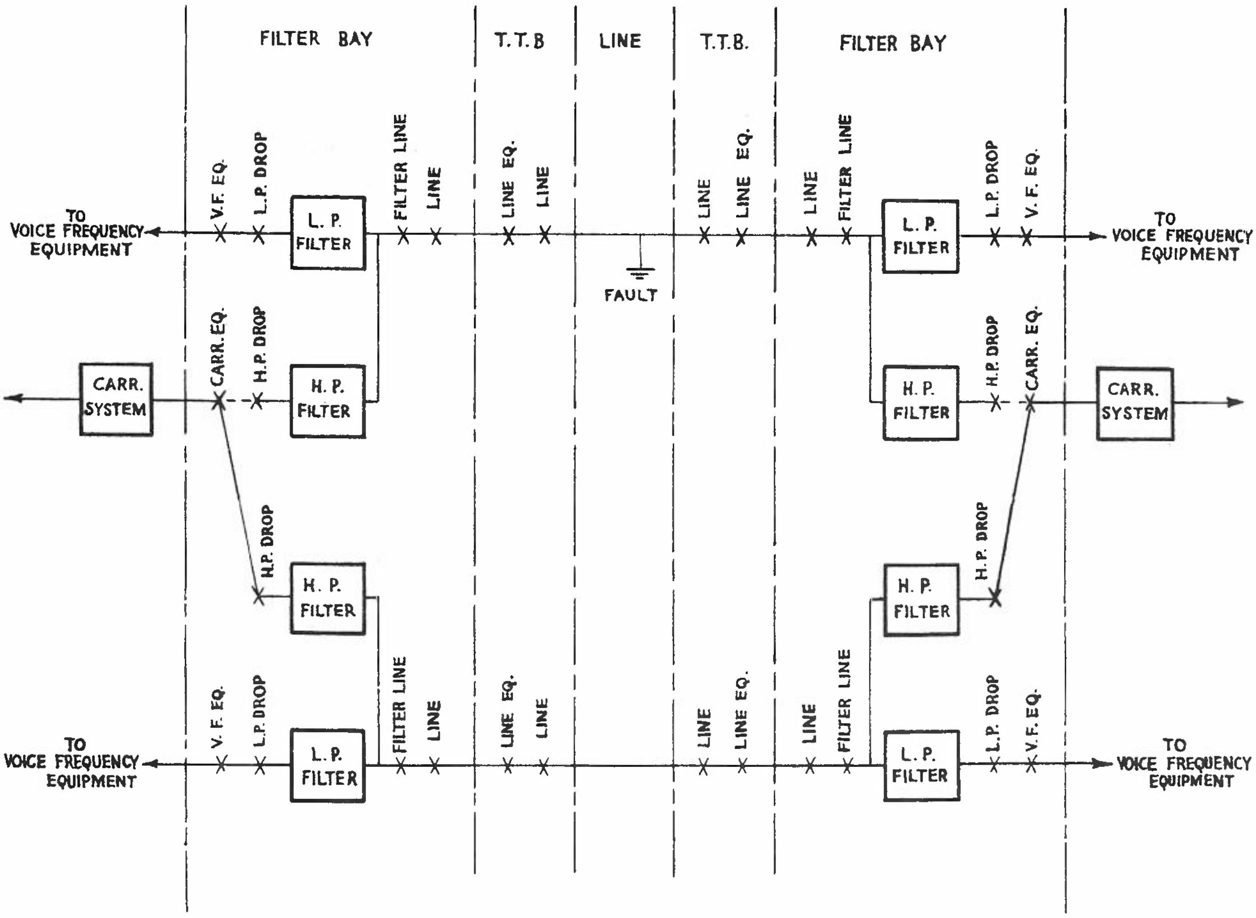
(iv) Writing shelf position.

/ Fig. 2.



PATCHING A FAULTY LINE.

FIG. 2.



HIGH-PASS PATCH.

FIG. 3.

(Continued from page 3.)

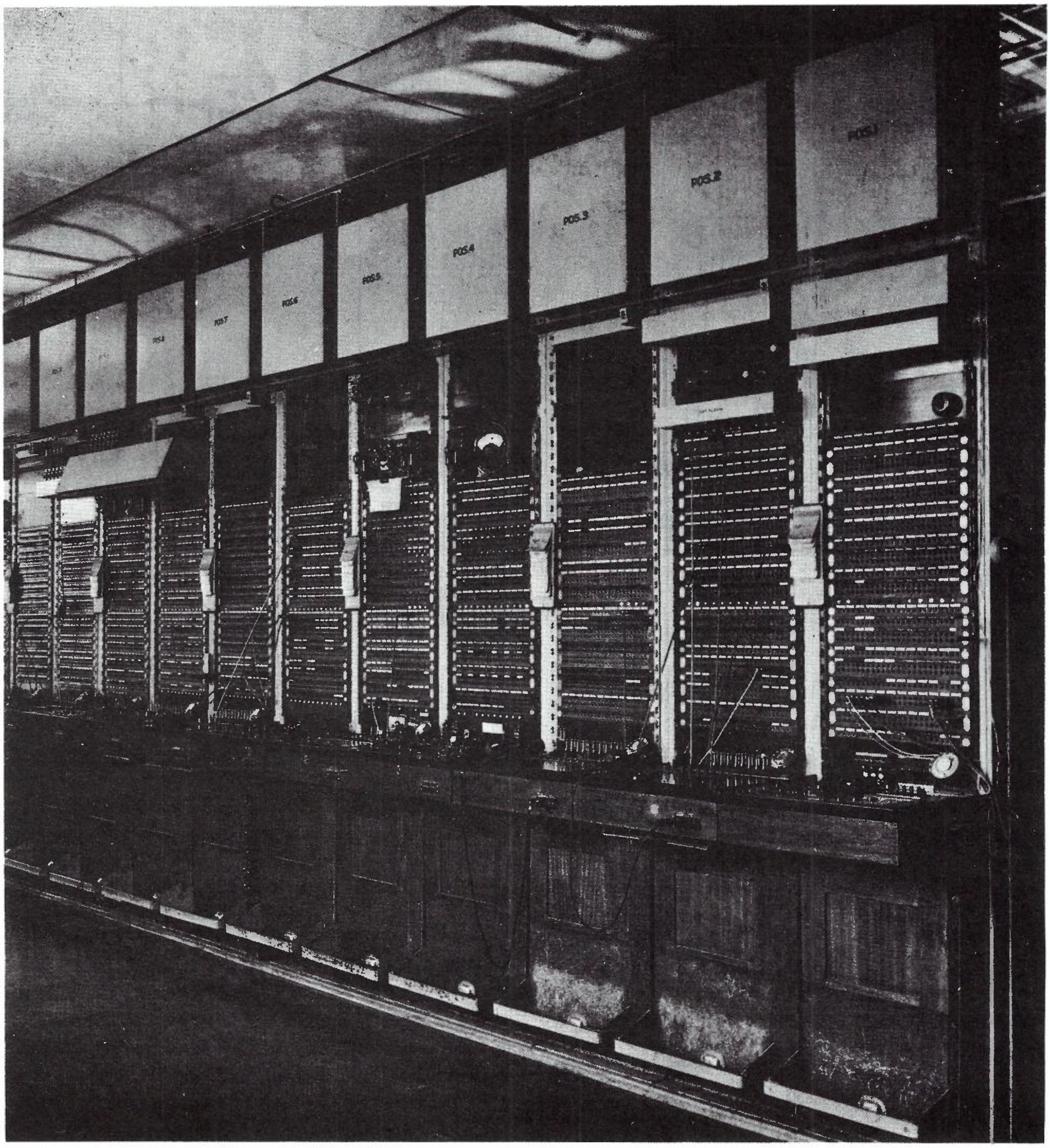
(v) Jack Field. A full jack field comprises -

36 - 10 jack circuits.
36 - 6 jack circuits.
29 - 2 jack circuits.
7 - 2 jack circuits provided with signalling facilities.

Designation of Jacks.

6 jack circuits - Listen, Line, Drop.
10 jack circuits - Listen, Line, Line Equipment, Drop Equipment, Drop.

/ Trunk



TRUNK TEST BOARDS.

(vi) Cord Circuits. The cord circuits provided for each type of Trunk Test Board are -

Cord Circuit.	No. per Board.	Type of Board.
Connecting Cord.	1	All types.
Four-wire Monitor and Speak Circuit.	1	All types.
Telephone Trunk Test Cord.	2	Voltmeter, Bridge and Combined types.
Telegraph Test Cord.	2	Voltmeter, Bridge and Combined types.

In addition, double ended patching cords fitted with twin plugs are provided with each board.

(vii) Exchange Line Circuits. Calling lamps and jacks are provided for 10 and wired for 7 exchange line circuits. These circuits are suitable for calling in or out on any type of telephone exchange or trunk circuit.

(viii) Talking and Monitoring Facilities. All types of trunk test boards are equipped with an operator's telephone circuit. This circuit is equipped with facilities for ringing exchange or line with frequencies of 1,000 c/s, 135 c/s and 17 c/s. In addition, dialling facilities are provided on the exchange connecting cord circuit.

(ix) Operator's Set. An operator's set is associated with the key circuits, and it is possible to transfer the circuit via keys to the test cord circuit. The circuit includes a calling dial connected via keys.

A separate cord circuit is provided to enable the operator to monitor and speak both ways on any four-wire circuit (mod. to demod. or tail chasing connection). The circuit is jack ended and arranged so that the operator's handset can be transferred to it by means of keys. The input impedance of the circuit must be high to avoid any appreciable loss on a trunk circuit when.it is bridged across such circuit.

(x) Valve Monitoring Circuit. This circuit is supplied on all Voltmeter, Bridge and Combined boards, and consists of a high input impedance amplifier so that bridging losses

/ are

are negligible. The amplifier has a three-stage gain control calibrated to provide output levels of zero, +4 db and +10 db with respect to normal received input.

1.4 Testing Equipment. The testing equipment section is usually provided with a writing position and a voltmeter and bridge position.

A centre zero type voltmeter is provided. The voltmeter has two scales, namely, 150 - 0 - 150 volts and 3 - 0 - 3 volts. The meter is dead beat with an evenly divided scale. An external zero adjustment is provided.

The test keys associated with the test cord circuits permit the following tests -

Test for open circuit.
Test for short circuit.
Test for earth.
Test for foreign potential.
Conductor resistance.
Milliampere readings.

A Wheatstone Bridge and galvanometer are provided. The bridge is compact and the bridge arms are arranged to provide values of 1 to 10,110 ohms in 1 ohm steps. Ratio arms enable ratios of 10^{-3}, 10^{-2}, 10^{-1}, 1, 10^{1}, 10^{2} and 10^{3} to be obtained. The accuracy of all resistances is better than ± 1 per cent. The galvanometer is a moving coil, reflecting or shadow pointer type, with a horizontal scale.

By operating the associated keys, the following tests are possible -

Loop resistance measurements.
Single wire resistance measurements.
Insulation resistance measurements.
Varley loop measurements.
Murray loop measurements.
Open location measurements.

Figs. 4a and b are included to give some idea of the testing facilities provided on trunk test boards. Fig. 4a is the testing circuit of the combined voltmeter and Wheatstone Bridge position on a Siemens trunk test board, whilst Fig. 4b shows simplified circuits of the various voltmeter testing conditions brought about by operating the various keys. The Bridge tests are dealt with in Section 2 of this Paper.

/ Fig. 4a.

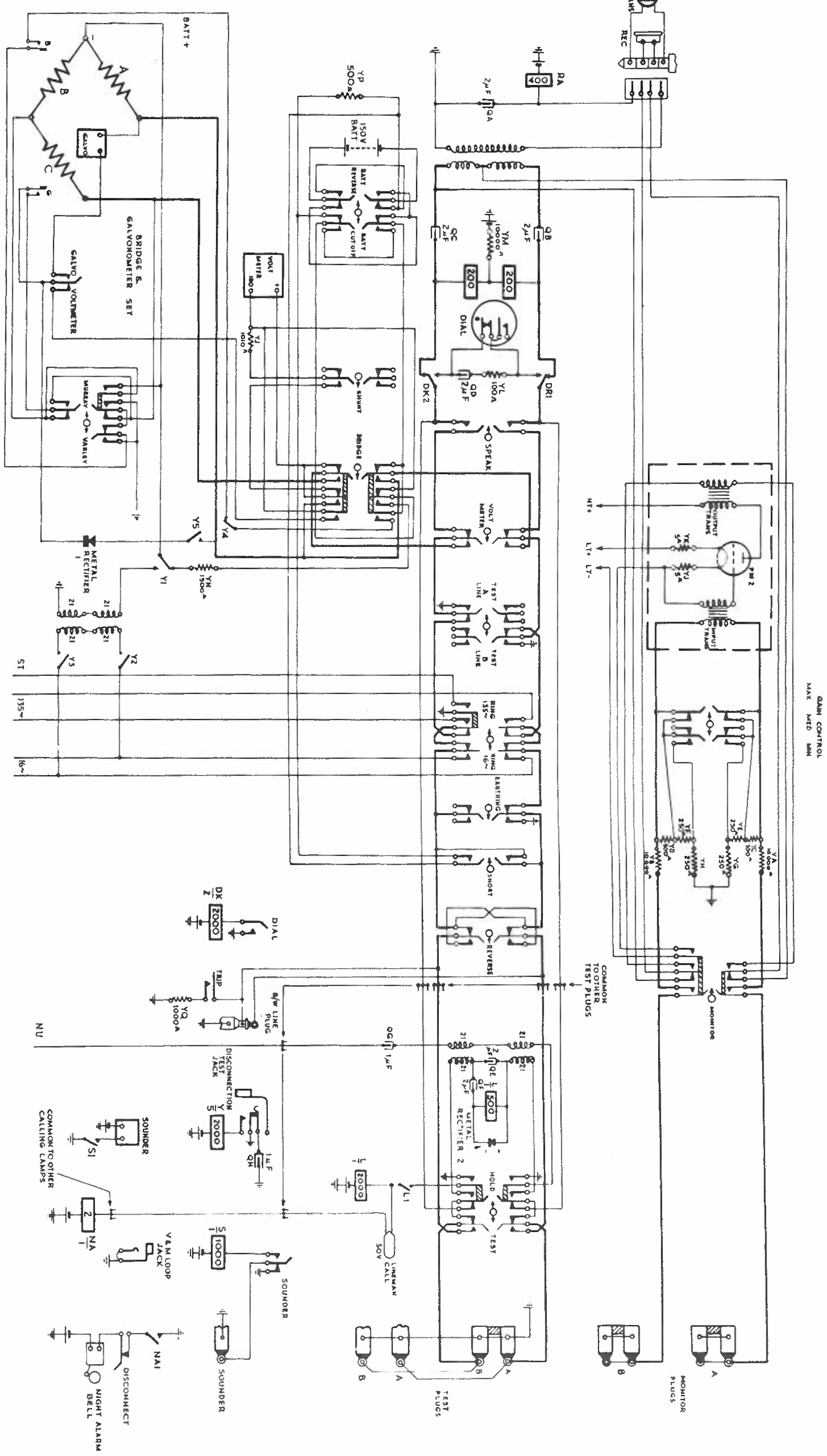
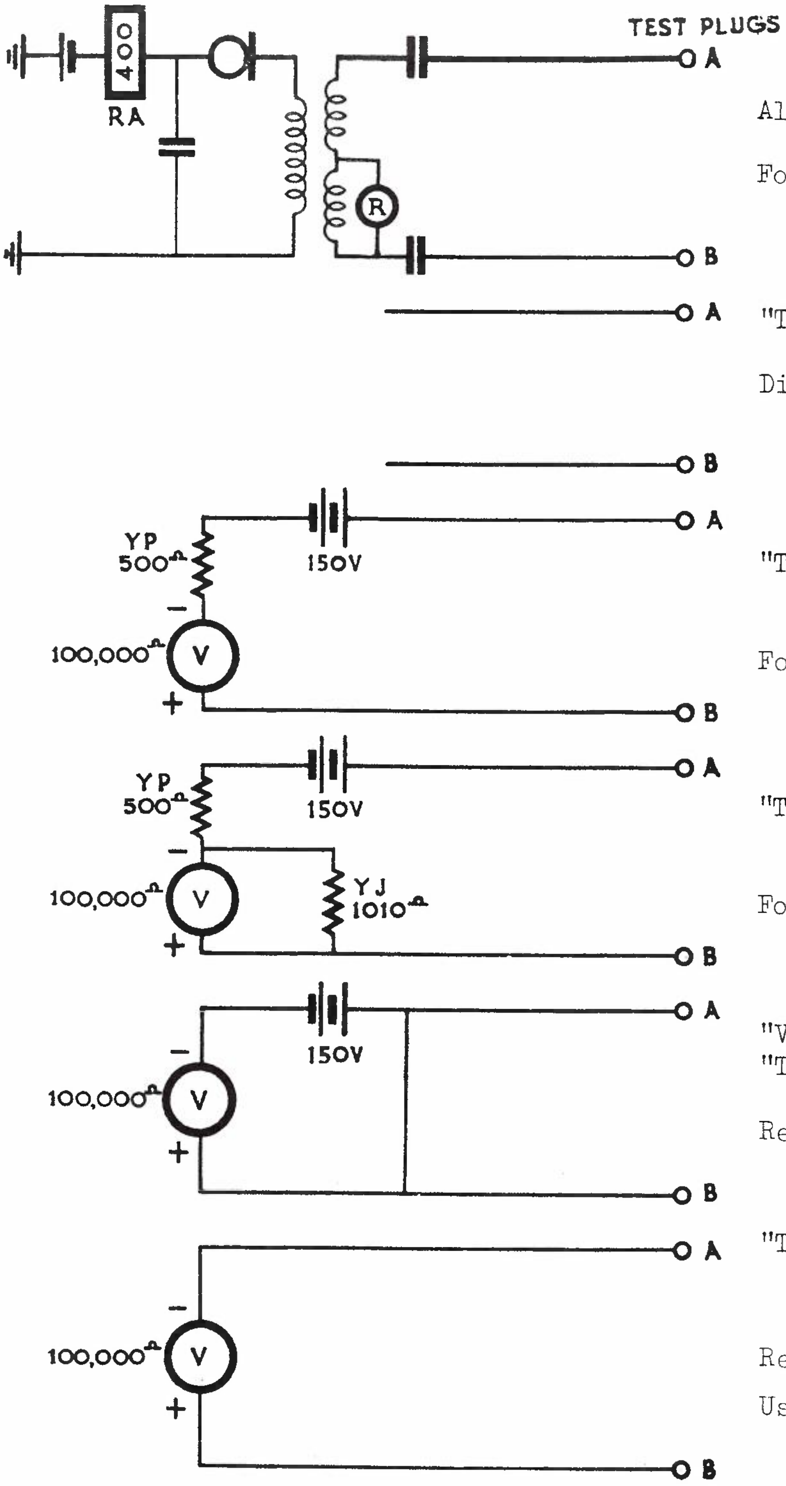


FIG. 4a - TRUNK TEST BOARD CIRCUIT.



All keys normal.

For speaking and listening on Test Cords.

"Test" key operated.

Disconnects Operator's Circuit preparatory to testing.

"Test" and "Voltmeter" keys operated.

For High Resistance Tests.

"Test," "Voltmeter" and "Shunt" keys operated.

For Low Resistance Tests.

"Voltmeter," "Short" and "Test" keys operated.

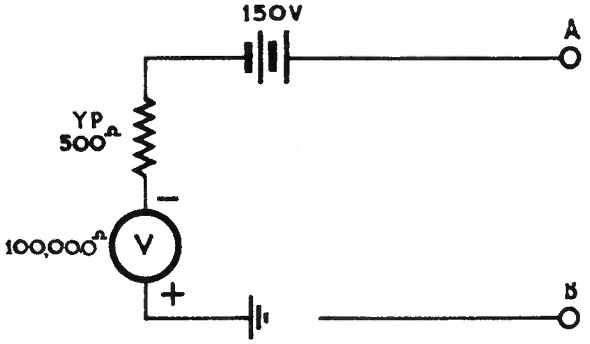
Reads battery voltage.

"Test," "Voltmeter" and "Batt. Cut-off" keys operated.

Reads battery across line.

Use "Reverse" key also when necessary.

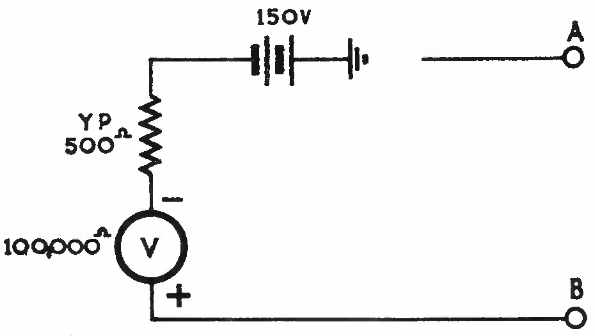
FIG. 4b. SCHEMATIC CIRCUITS OF VOLTMETER TESTS.
(For Bridge Tests, see Section 2.)



"Test," "Voltmeter" and "Test A Line" keys operated.

Tests for earth on A Line.

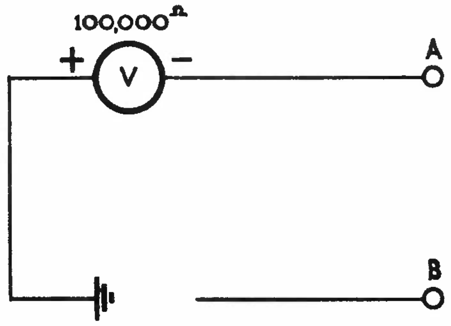
With "Batt. Reverse" key also operated, equal and opposite reading obtained.



"Test," "Voltmeter" and "Test B Line" keys operated.

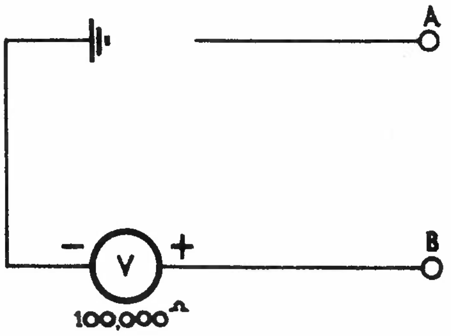
Tests for earth on B Line.

With "Batt. Reverse" key also operated, equal and opposite reading obtained.



"Test," "Voltmeter," "Test A Line" and "Batt. Cut-off" keys operated.

Tests for earthed battery on A Line.



"Test," "Voltmeter," "Test B Line" and "Batt. Cut-off" keys operated.

Tests for earthed battery on B Line.

FIG. 4b (Continued). SCHEMATIC CIRCUITS OF VOLTMETER TESTS.
(For Bridge Tests, see Section 2.)

2. TRUNK LINE TESTING.

2.1 When a trunk line is reported "out of order," the traffic staff prepare a fault docket. This is forwarded to the engineering staff and, in a large centre, the trunk line master card is attached to the fault docket and passed to the testing officer. The testing officer then proceeds to test the line, first making any preliminary patching arrangements which may be required because of the importance of the line.

If the trunk line is equipped with carrier systems, the derived channels are usually reported out of order at the same time by the traffic staff, a docket being prepared for each speech channel affected.

2.2 Trunk line faults may be broadly classified as follows -

(i) Contact between the two wires of a pair - usually termed a "short circuit."
(ii) Contact between a wire of one pair and another circuit - usually termed a "cross."
(iii) Contact between one wire of a pair and an earthed circuit or object - usually termed an "earth".
(iv) A high resistance contact or leakage to another conductor or earth and termed L.I.R. (low insulation resistance) between the pair, or to another circuit or earth as the case may be.
(v) An open circuit of one or both wires of a pair without contact with other pairs or earth - termed an "open circuit."
(vi) Noisy circuit - due usually to one or more of the previous faults.

Before an attempt is made to determine the location of a fault, reference is made to the trunk line master card, whereon is recorded the equipment in circuit, the gauge and type of wire, particulars of entrance and intermediate cables and other details relevant to the testing of the circuit.

If shunt or series equipment exists on the line, such as in intermediate offices, it is first necessary to clear the line by either opening the leg (if it is a leg station) or patching out the intermediate office if the line is looped in, as for example in divided working.

With regard to the line, it is generally sufficient to know the approximate resistance of the various sections, as the actual resistance values vary throughout the year due to temperature changes. It is not practicable to make complete corrections

/ for

for temperature variations when making fault location tests, as the temperature may vary considerably over the length of the trunk route.

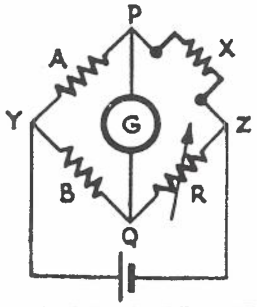
For practical purposes, the following values for loop mile resistance of the various gauges for wire are generally used -

600 lb. Copper	3 ohms per loop mile.
300 lb. Copper	6 ohms per loop mile.
200 lb. Copper	9 ohms per loop mile.
100 lb. Copper	18 ohms per loop mile.
100 lb. Bronze	40 ohms per loop mile.
70 lb. Bronze	58 ohms per loop mile.
70 lb. Cadmium Copper	30 ohms per loop mile.
400 lb. Galvanised Iron	27 ohms per loop mile.
200 lb. Galvanised Iron	54 ohms per loop mile.
100 lb. Galvanised Iron	108 ohms per loop mile.
40 lb. Trunk Type Cable	44 ohms per loop mile.
20 lb. Trunk Type Cable	88 ohms per loop mile.

It will be appreciated that preliminary location tests will be an approximation, and that the longer the section of line tested the greater will be the error. When dealing with faults on long circuits, a check test is made with the fault lineman in the vicinity of the advised location, and this enables the degree of error to be reduced and usually provides an accurate location.

Either the Varley or the Murray Loop Test may be used for fault location. The Varley Test is the most simple to apply and is the more convenient method, particularly if an elaborate switching arrangement is not a feature of the test set.

2.3 The Wheatstone Bridge. Before detailing Varley Loop methods, the well-known Wheatstone Bridge principle is restated. Referring to Fig. 5, if the resistance A is equal to resistance B, there will be no potential difference between points P Q, providing that resistance R is equal to resistance X.



WHEATSTONE BRIDGE.

FIG. 5.

$$\text{Thus } \frac{A}{B} = \frac{X}{R}$$

$$\therefore X = \frac{AR}{B}$$

$$\text{and as } A = B$$

$$\text{then } X = R.$$

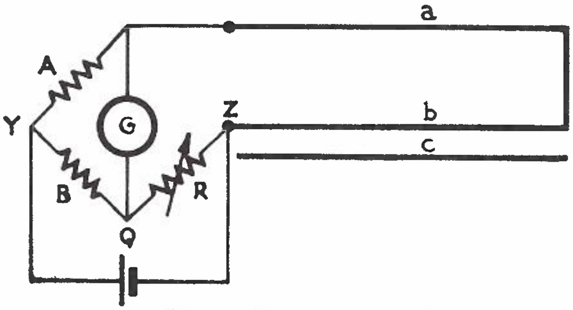
/ The

The two rules to remember are, therefore -

For equal ratio arms $X = R$

For unequal ratio arms $X = \frac{AR}{B}$.

The Wheatstone Bridge can be used to measure the resistance of a single wire by the "Three Wire Method." The connections are made as shown in Fig. 6. Three readings are taken with two wires looped in each case. The readings are the loop resistance of $a + b$, $a + c$ and $b + c$.



MEASURING THE RESISTANCE OF A SINGLE WIRE.

FIG. 6.

As each of these wires has been measured twice, then one half of the sum of the three loop resistances equals the sum of the resistance of the three wires. Thus -

$$\frac{(a + b) + (a + c) + (b + c)}{2} = \frac{2a + 2b + 2c}{2}$$

$$\therefore \frac{2a + 2b + 2c}{2} = a + b + c = X$$

Then $a = X - (b + c)$, that is, $a + b + c - b - c = a$

$b = X - (a + c)$

and $c = X - (a + b)$

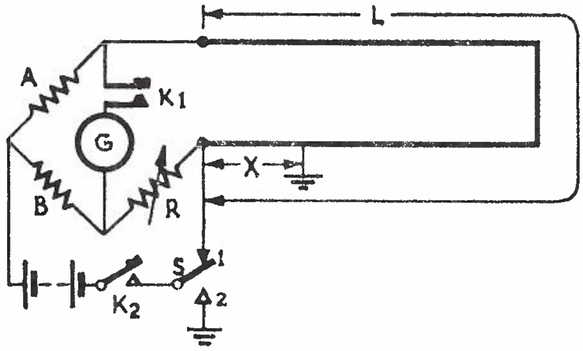
2.4 Varley Test for Earth Fault. To locate an earth fault on a line by this method, first determine between which offices the fault exists and which is the faulty wire. This test can be made with a voltmeter and battery.

The station immediately beyond the fault should be asked to loop the line by patching at the T.T.B. or section switches. (The location test could be made by looping at the distant terminal, but, as previously mentioned, the initial error is reduced by keeping the section under test as short as possible.)

When the line has been looped, the test circuit should be arranged as shown in Fig. 7. If a Wheatstone Bridge is not available, resistance boxes can be wired to serve the same purpose. A and B are the ratio arms of the bridge, R is the variable arm, G is a sensitive galvanometer, K1 and K2 are keys for closing the galvanometer and battery circuits respectively, and S is a change-over switch to disconnect one side of the battery from line and connect it to earth when required.

/ The

The line is connected, as shown in Fig. 7, with the faulty side wired to the R arm of the bridge and switch S in position 1. K2 and K1 are closed in that order. R is adjusted until the closing of the keys results in no deflection of the galvanometer needle, when the resistance R in the variable arm of the bridge will be equal to the resistance L of the line, provided that the resistance of ratio arms A and B is equal.



VARLEY LOOP TEST FOR EARTH FAULT.

FIG. 7.

Referring to Fig. 7, $BL = AR$

$\therefore$ as $A = B$

then $L = R$.

(K2 should always be closed before K1, so that the line will be charged before the galvanometer circuit is closed. Similarly, K1 should be released before K2.)

When the loop resistance L is determined, the switch S is moved to position 2 and R is varied until a second balance is obtained.

The condition then is $B(L - X) = A(R + X)$

$$\text{and } X = \frac{BL - AR}{A + B}$$

But the ratio arms A and B are equal -

$$\text{and thus } X = \frac{L - R}{2}$$

(The resistance of the fault forms part of the battery circuit and, therefore, does not affect the location test, provided that the resistance is low compared with the normal I.R. of the line.)

Having obtained a resistance value for X, which is the resistance of the faulty wire from the testing office to the fault, the distance to the fault can then be computed from the line data recorded on the trunk line master card.

Basic Varley Formula. The formula $X = \frac{L - R}{2}$ is the basic Varley formula for equal ratio arms, and can be applied to a circuit even though the two wires of a pair are of unequal resistance.

Where it can be safely assumed that the two wires of a pair are of equal resistance, a simplification is possible and the formula reduces to -

/ X

$$X = L - R.$$

In order to obtain the distance to the fault in this case, it is necessary to divide the loop resistance to the fault by the loop resistance per mile of the wire gauge concerned.

In the former case, where $X = \frac{L - R}{2}$, it is necessary to divide the single wire resistance to the fault by the single wire resistance per mile of the wire gauge concerned.

Distance of Fault from Far End. It is often desirable to determine the distance of a fault from the far end of a looped line, particularly when the fault is nearer that end. If, as is usually the case, both wires of the pair under test are of similar gauge, it is possible to determine this distance from the results of the Varley Loop test already made -

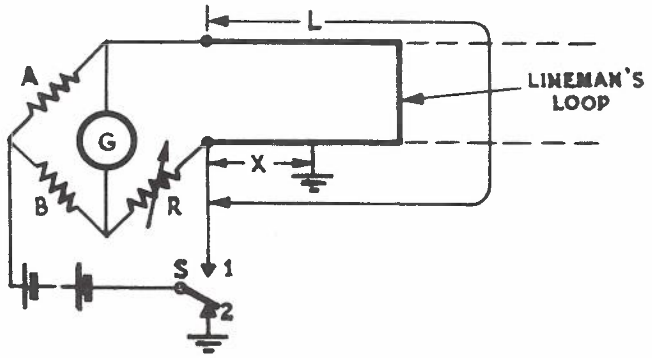
$$X = \frac{L - R}{2}$$

$$\therefore 2X = L - R$$

$$\therefore R = L - 2X$$

Referring to Fig. 7, it will be seen that, if 2X is deducted from the loop resistance L, then R equals the resistance of all the wire remaining in circuit between the fault and the far end. In other words, 2X represents the loop resistance of the faulty pair between the testing station and the fault, whilst R equals the loop resistance between the fault and the far end.

This simplification provides a ready means of carrying out a check test with a lineman. Assume the line has been examined in the vicinity of the location without locating the fault. The testing officer requests the lineman to loop the faulty line, the condition then being as shown in Fig. 8.



VARLEY LOOP TEST FOR LOCATING DISTANCE OF FAULT FROM DISTANT STATION.

FIG. 8.

With the switch S in No. 2 position, R is adjusted to obtain a balance. If the lineman's loop is beyond the fault, the resistance R will indicate the loop resistance of the section of line between the lineman's loop and the fault looking towards the testing station.

/ If

If a balance is obtained with R = 0, then the line has been looped between the testing station and the fault for, in this case, referring to Fig. 9, it will be seen that -

$$Ba = A(R + b)$$

and, if A = B

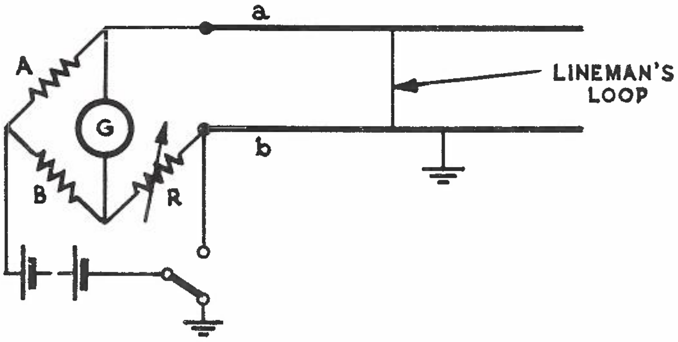
this reduces to -

$$a = R + b$$

but a and b are also equal, so that -

$$R = 0.$$

Note. This result only holds when both sides of the line have equal resistance per mile, and quite a small resistance unbalance will affect it.



CHECK TESTING WITH A LINEMAN.

FIG. 9.

In any case, when making a location test to the lineman's loop, it is possibly more desirable to check the loop resistance and compare it with the original Varley result -

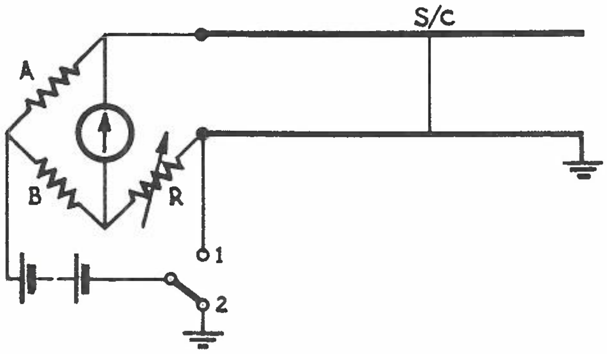
$$X = \frac{L - R}{2}$$

where X equals the resistance to the fault.

2.5 Short-Circuit Tests. The usual test for a short-circuit fault is made by measuring the resistance of the circuit through the fault and calculating the distance represented by the resistance obtained from the details on the trunk line master card. Generally, this method is reasonably accurate, but it includes the resistance of the fault.

In some instances, the resistance of the fault may be considerable, and it is preferable to make a Varley test by earthing one side of the line beyond the fault as shown in Fig. 10.

The loop through the fault is measured and a second reading made with switch S in position 2. If R = 0, then L = the loop resistance to the fault.



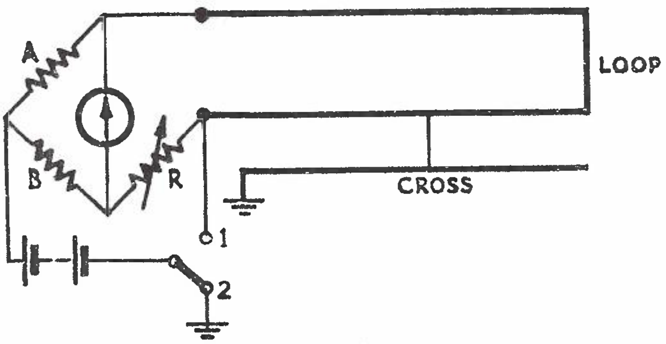
TESTING FOR A SHORT CIRCUIT.

FIG. 10.

/ If

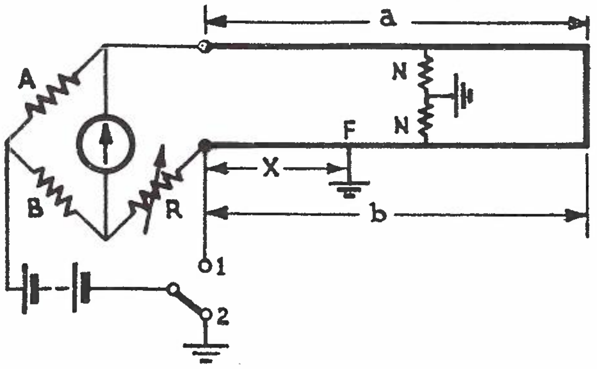
If there is any resistance in the R arm when the second balance is obtained, it will indicate the resistance of the fault itself if the line is balanced. An unbalanced line will result in either some resistance in R at balance or else inability to obtain a balance, even though there may be no measurable resistance in the fault itself. The degree of unbalance is usually small, and an R reading of 2 or 3 ohms may be neglected when making a short-circuit test, except in the case of 400 or 600 lb. copper circuits. If the R reading is appreciable, it should be deducted from the loop resistance before calculating the distance to the fault.

Cross. To locate a "cross" fault, it is first necessary to determine the lines in contact. One circuit should then be looped at a station beyond the fault, and the faulty wire of the other circuit earthed either at the distant station or at the testing station. See Fig. 11. The conditions are then equivalent to an earth fault, and the same Varley tests can be made to determine the distance to the fault.



TESTING FOR A "CROSS" FROM ONE WIRE OF A PAIR TO ONE WIRE OF ANOTHER PAIR.
FIG. 11.

2.6 Low Insulation Resistance. The previous tests apply where the fault resistance is very low compared with the Insulation Resistance of the line. If the fault resistance approaches the insulation resistance of the line, the location tests will not be accurate.



LOW INSULATION TESTING.

FIG. 12.

Referring to Fig. 12, the normal distributed insulation resistance of each wire may be regarded as a high resistance contact to earth located at the mid-point of the line as represented by N.

If a fault to earth develops and the resistance of the fault is low, the effect of the normal insulation resistance of the line will not affect the accuracy of the location test. If, however, the fault resistance is appreciable in relation to the insulation resistance, the

/ normal

normal test, $X = \frac{L - R}{2}$, will indicate that the fault is between the actual point of contact and the centre of the line, and the higher the fault resistance the greater will be the error.

For the condition shown in Fig. 12 and with equal ratio arms, when a balance is obtained -

$$X = \frac{a + b - R}{2} - \frac{F}{N}\left(\frac{b - a}{2} + R\right)$$

If both wires a and b are of equal resistance, then a + b = L, and the equation may be simplified to -

$$X = \frac{L - R}{2} - \frac{F}{N} R$$

where $\frac{F}{N}$ is the ratio of the fault resistance to the normal insulation resistance of the circuit.

In practice, the ratio $\frac{F}{N}$ is not known, and it may be eliminated from the calculations by making a test from each end of the line and combining the results. This is sometimes referred to as a double Varley Test.

If a = Resistance of good wire,
b = Resistance of faulty wire,
R = Balancing resistance at Main station,
R1 = Balancing resistance at Distant station, and
X = Resistance to the fault of the faulty wire from the main station,

$$\text{then } X = \frac{a + b - R}{2} - \frac{a - \left(\frac{R + R1}{2}\right)}{b - a + R + R1}\left(\frac{b - a}{2} + R\right)$$

and as a = b and a + b = L then -

$$X = \frac{L - R}{2} - \frac{\frac{L}{2} - \left(\frac{R + R1}{2}\right)}{R + R1} R$$

which may be reduced to -

$$X = \frac{L}{2}\left(\frac{R1}{R + R1}\right)$$

To take an example, let L = 600 ohms,
R = 300 ohms, and
R1 = 200 ohms,

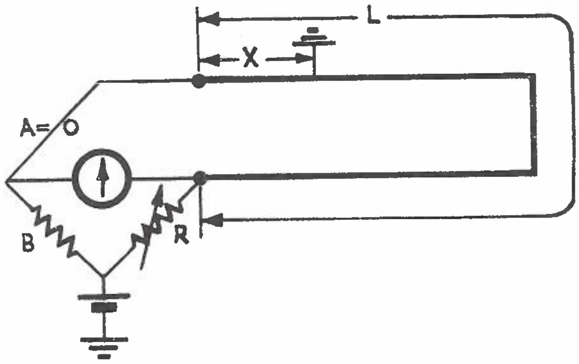
$$\text{then } X = \frac{L}{2}\left(\frac{R1}{R + R1}\right)$$

$$= 300 \times \frac{200}{500} = 120 \text{ ohms.}$$

/ If

If the test had not been made from both ends and the correction formula neglected, the normal Varley test, $X = \frac{L - R}{2}$, would give X = 150 ohms, which would have introduced an error of 25 per cent. for the case concerned.

2.7 Murray Loop Tests. The bridge connections for locating an earth fault by the Murray method are shown in Fig. 13.



MURRAY TEST, LOCATING AN EARTH.

FIG. 13.

The loop resistance must first be determined, then the bridge connections altered to the Murray arrangement as shown, with the A ratio arm plugged out and the B arm set at 100 or 1,000 ohms for convenience of calculation. The faulty wire is connected to the A arm terminal, and, when a balance is obtained-

$$RX = B(L - X)$$

$$\text{or } RX + BX = BL$$

$$\therefore X = \frac{BL}{R + B}$$

The value of X is the single wire resistance of the faulty wire from the testing station to the fault.

The Varley and Murray tests are complementary in their functions, the Varley test being the most suitable for location tests on open wire lines and long lengths of cable. The comparatively high resistance value of the loop L allows a similar fairly high resistance value for R, in order to obtain the difference (L - R) which is a measure of the resistance to the fault. As these measurements and their difference are all comparatively large, small inaccuracies in measurement will not seriously affect the value of X.

The Murray test is particularly useful for making final locations in short lengths of cable, as, for example, after a Varley test has determined that the fault lies between two adjacent man-holes. Small errors in measurement cannot then be tolerated, and the condition of balance in the Murray test does not involve any differences and, consequently, any measurement inaccuracies remain in their correct proportion.

2.8 Open Locations. Measurement of Capacity of Condensers, etc., by an A.C. bridge, S.T.C. Type. Refer to Fig. 14.

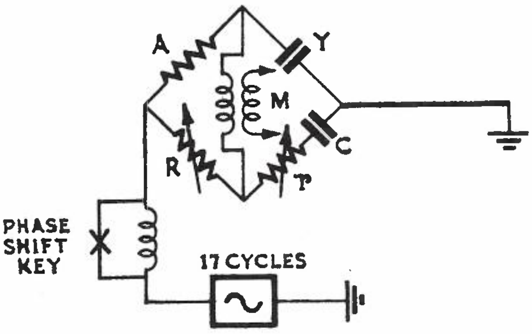
$$\text{Reactance of condenser } Y = \frac{1}{j\omega Y}$$

$$\text{Reactance of condenser } C = \frac{1}{j\omega C}$$

$$\text{Condition of balance} = A\left(\frac{1}{j\omega C}\right) = R\left(\frac{1}{j\omega Y}\right)$$

$$\text{that is, } \frac{A}{j\omega C} = \frac{R}{j\omega Y}$$

j and ω are common to both sides of the equation as the frequency is the same. Therefore, the equation becomes -



MEASURING CAPACITY.

FIG. 14.

$$\frac{A}{C} = \frac{R}{Y}$$

$$\text{that is, } AY = RC$$

$$\text{Therefore, } Y = \frac{RC}{A}$$

$$\text{If } A = 1{,}000 \text{ ohms}$$

$$\text{and } C = 1\ \mu F$$

$$Y = \frac{R}{1{,}000}\ \mu F.$$

Note. r serves to balance out any resistance component in condenser Y and cancels out, as it would appear on both sides of the equation.

This formula, $Y = \frac{R}{1{,}000}$, is made use of in the open location test. In this test, two capacities are measured, Y and Y1; where reactances correspond to readings R and R1 on bridge.

R = Reading on the R rheostat when the faulty wire is connected to the bridge.

R1 = Reading on the R rheostat when the good wire connected to the bridge.

The capacity reactance of the faulty wire will be a proportion of the capacity reactance of the good wire, therefore -

$$\frac{Y}{Y1} = \frac{\frac{R}{1{,}000}}{\frac{R1}{1{,}000}} = \frac{R}{1{,}000} \times \frac{1{,}000}{R1} = \frac{R}{R1}$$

/ If

If D equals distance between Testing Stations, then -

$$X = \frac{RD}{R1}$$

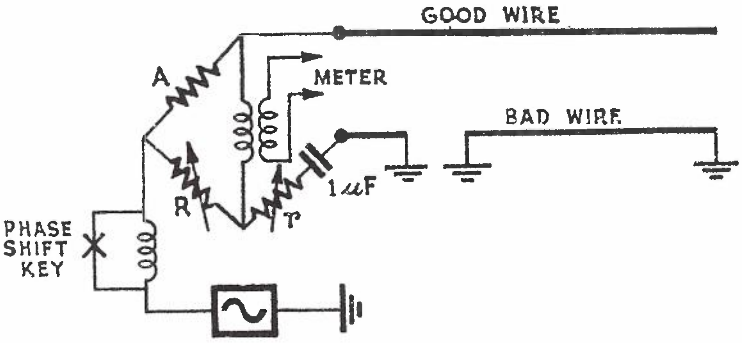
2.9 Open Location Test. In Fig. 15,R is approximately proportional to capacity of wire under test to earth. r serves to balance out the resistance component of the line and, therefore, does not enter into calculations. Distance to the fault is given by -

$$X = \frac{RD}{R1}$$

Where X = Distance from the testing station to the fault,
D = Distance between the two testing stations,
R = Reading of the R rheostat when the faulty wire is connected to the bridge, and
R1 = Reading of the R rheostat when the good wire is connected to the bridge.

Actually, the open location test is simply a comparison between the capacity reactance of the faulty wire divided by the capacity reactance of the good wire. This is multiplied by the distance between the testing stations, in order to determine the distance to the fault.

Note. r merely serves to balance out the resistance component of the good and bad wires.



LOCATING "OPENS." (S.T.C. BRIDGE.)

FIG. 15.

The open location test was designed initially for uniform lines or cables, and, when lines of mixed construction exist (which is the most common), errors will occur unless capacity to earth measurements have been taken and recorded of all entrance and intermediate cables.

As an example, a trunk line from A to C (70 miles) is routed via 10 miles of cable to an intermediate station B and from B via 60 miles of aerial line to C. Asssume the capacity to earth from A to B is 2 µF, also the capacity between B and C is 2 µF. If a fault occurred at the cable head at B, the formula would indicate the fault half-way between A and C (35 miles), but actually the fault is only 10 miles out.

$$\left.\begin{array}{r}\text{Reactance of a } 1\ \mu F \\ \text{condenser at } 20\ c/s\end{array}\right) = \frac{10^6}{6.28 \times 20 \times 1}$$

$$= 8{,}000 \text{ ohms approximately.}$$

/ C

$$\therefore \; C = 8{,}000 \text{ ohms},$$
$$X = 4{,}000 \text{ ohms Bad wire } (2\ \mu F),$$
$$\text{and } X1 = 2{,}000 \text{ ohms Good wire } (4\ \mu F).$$

Condition of balance with bad wire -

$$1{,}000 \times 8{,}000 = R \times 4{,}000$$

$$R = \frac{8{,}000{,}000}{4{,}000} = 2{,}000 \text{ ohms} \; \ldots\ldots\ldots\ldots \; (1)$$

Condition of balance with good wire -

$$1{,}000 \times 8{,}000 = R1 \times 2{,}000$$

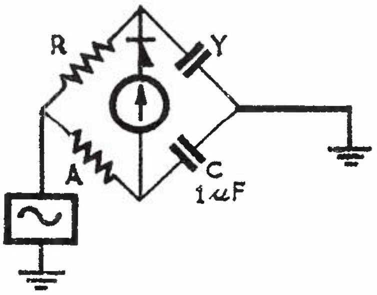
$$R1 = \frac{8{,}000{,}000}{2{,}000} = 4{,}000 \text{ ohms} \; \ldots\ldots\ldots\ldots \; (2)$$

Distance to the fault -

$$X = \frac{R}{R1} D = \frac{2{,}000}{4{,}000} \times 70 = 35 \text{ miles.}$$

The above example shows the method and also indicates the possibility of error, as the line is of mixed construction and the capacity per mile is different at one end to the other. The actual fault was 10 miles out.

2.10 Open Location, Siemens Trunk Test Board. (See Fig. 16.)



LOCATING "OPENS."
(SIEMENS TRUNK TEST BOARD.)

FIG. 16.

$$A \left(\frac{1}{j\omega Y}\right) = R \left(\frac{1}{j\omega C}\right)$$

$$\frac{A}{j\omega Y} = \frac{R}{j\omega C}$$

Since j and ω are common, the equation becomes -

$$\frac{A}{Y} = \frac{R}{C}$$

$$\therefore YR = AC$$

$$\text{and } Y = \frac{AC}{R}$$

$$\text{If } A = 1{,}000 \text{ ohms}$$
$$C = 1\ \mu F$$

$$\text{and } Y = \frac{1{,}000}{R}.$$

This formula is similar to the formula for the S.T.C. bridge, but the bridge does not use a resistance to balance out the resistance component of the open wire. It also does not employ a method to shift the phase to check the balance.

/ 3.

3. TEST QUESTIONS.

1. What are the functions of a Trunk Test Board at a long line equipment station?

2. Draw a block schematic diagram showing the arrangements of the line equipment necessary at a terminal station to provide the following circuits on an open wire line -

   (i) Voice frequency physical circuit with terminal amplifier and 1,000 c/s signalling. (This circuit frequently used to relay broadcast programmes.)

   (ii) Cailho Telegraph.

   (iii) Three Carrier Channels with 1,000 c/s signalling.

   The diagram should include Trunk Test Board Jacks and the arrangement of the V.F. networks. Blocks will be sufficient to indicate V.F. repeater and carrier system.

3. If an open wire line carrying important interstate carrier circuits suddenly becomes noisy, rendering the channels unworkable, what preliminary test would be necessary, assuming that there were two attended repeater stations en route, and what arrangements would you make to restore the service pending the location and repairing of the fault?

4. (i) Explain, with the aid of diagrams, the method you would adopt to locate the position of an earth fault in a 100 mile section of open wire line.

   (ii) Having satisfied yourself that the location is correct, what arrangements would you make for the fault to be cleared?

5. What tests and precautions are necessary in making a location for a short circuit or loop on a line?

6. What factors would influence you in the choice of either the Murray or Varley method of locating faults?

END OF PAPER.

COMMONWEALTH OF AUSTRALIA.

Chief Engineer's Branch,
Postmaster-General's Department,
Treasury Gardens,
Melbourne, C.2.

COURSE OF TECHNICAL INSTRUCTION.

LONG LINE EQUIPMENT III.

PAPER NO. 3.
PAGE 1.

LINE CONSIDERATIONS.

CONTENTS:

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1. INTRODUCTION.

1.1 The application of Long Line Equipment produces several types of communication channels. Such channels may be broadly classified into two groups - channels that operate at voice frequencies and channels that operate at carrier frequencies. In the first group are the ordinary two-wire circuits, which employ a single pair of open wire or cable wire as the transmitting medium. This voice frequency group also includes the four-wire circuits, in which a separate pair of wires is employed for each direction of transmission. If lines are of considerable length, both the two-wire and four-wire circuits require the insertion of repeaters at regular intervals, in order to maintain the overall transmission equivalent at a satisfactory figure.

Except for special applications (for example, coaxial cables, radio links and channels provided on high tension power lines), carrier systems also employ two-wire or four-wire circuits for transmission purposes, and they also require the use of repeaters at regular intervals.

It is not possible to state qualitatively the particular situation to which each particular type of circuit is applicable. In general terms, the two-wire circuits are used for relatively short distances - approximately 1,000 miles maximum for open wire circuits and 150 miles for cable. Four-wire cable circuits can be used for longer distances, but their application in Australian practice is limited to fairly short distances at the moment.

Carrier circuits are, in general, used for distances over which it is not economical to provide the required number of voice frequency circuits.

The different classes of lines employed display a wide diversity in their relative transmission efficiencies. Thus, at voice frequency, say, 1,000 c/s, for example, a 20 lb. cable conductor has a transmission loss of 1.01 db per mile, whereas a 200 lb. aerial conductor has a loss of 0.064 db per mile at the same frequency.

At carrier frequencies, a 40 lb. cable conductor has a loss of 2.0 db per mile at 30 kc/s, a loss of 3.0 db per mile at 72 kc/s and a loss of 4.3 db per mile at 140 kc/s, whilst a 200 lb. aerial conductor has losses of 0.16 db per mile and 0.3 db per mile at frequencies of 30 kc/s and 140 kc/s respectively.

Prior to the introduction of the two-wire repeater, it was necessary to employ large gauge open wires for all long distance circuits, but, even with these, the distance over which good transmission was possible was severely limited. The application of repeaters had two far reaching effects - firstly, it made possible an indefinite extension of the range of telephone communication and, secondly, it permitted smaller gauge wires for long distance circuits, thus allowing the economic derivation of long distance circuits.

Repeaters are now used in practically all long distance open wire and cable routes. Since open wire facilities must, for mechanical reasons, be of relatively large gauge and suspended with considerable separation between conductors, their resistance and capacitance values are relatively low. As a result, voice frequency repeaters need only be spaced at intervals of approximately 100 to 200 miles to compensate for the attenuation caused by the conductors. This means that, even in the longest circuits, the number of repeaters in tandem is small. On the other hand, in cables the conductors are usually of 20 lb. or 40 lb. per mile and, even with the use of loading, repeaters must be inserted at 40-50 mile intervals depending on the gauge employed, whilst without loading the spacing is reduced to approximately 20 miles. It follows that a long

/ cable

cable circuit must include a large number of repeaters in tandem.

2. REPEATER GAINS AND TRANSMISSION LEVELS.

2.1 The location of repeater stations depends on a number of factors both economic and electrical. Most trunk routes include a number of differing gauge wires, and the attenuation of the lesser gauge wires is one determining factor. The suitability of a town in respect to power supplies and the building space available also plays a part. Obviously, the circuit attenuation is the controlling factor, as it is not practical to exceed a certain distance if over-all transmission standards are to be maintained. The spacing between repeater stations may be decreased somewhat to suit economic requirements, but it cannot be increased beyond certain limits.

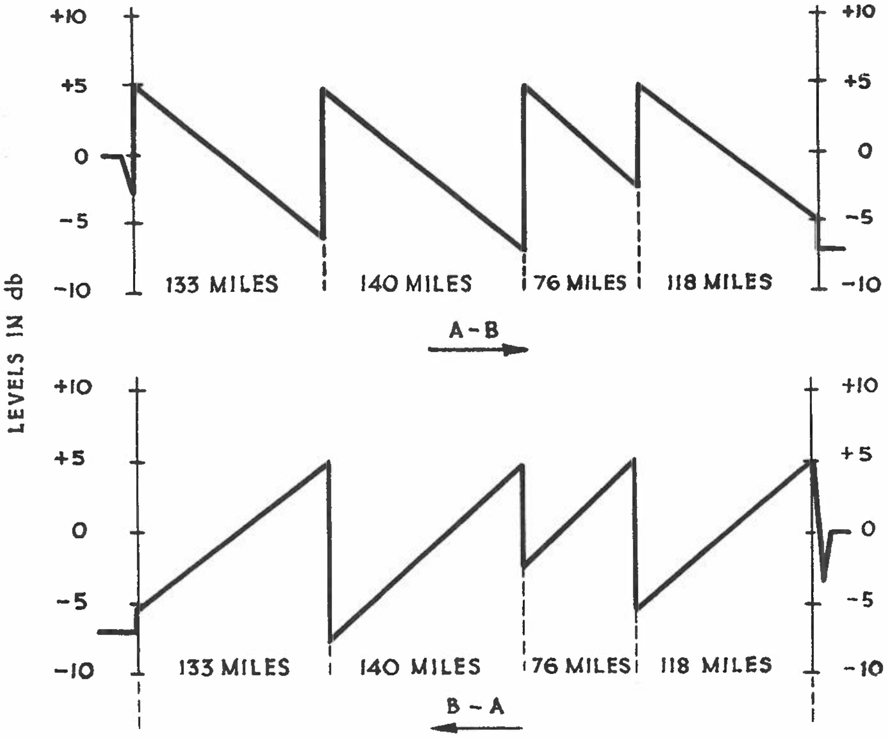
As the location of individual repeater stations has been determined, it is necessary to decide the gain to be inserted in each circuit at each repeater point. It is generally desirable to keep the energy of the speech currents traversing a circuit at the highest possible level, in order to reduce the possibility of noise interference. If the transmission level is too low, any small noise currents, which may be introduced into the circuit from extraneous sources, may be enough to cause excessive interference when amplified by the repeaters. On the other hand, by keeping the circuit transmission levels high with respect to interference currents, the effect of the latter is minimised. (Signal to noise ratio should not be worse than 45 db.)

It should be remembered that there is a limit to the amount of energy that any particular amplifying circuit can handle without introducing distortion, and this, in itself, limits the transmission level. Crosstalk considerations also determine the magnitude of transmitted levels. Regardless of spacing, no 22 Type repeater, for example, should be expected to give a gain of more than +18 db.

In four-wire repeaters, higher gains are permissible, but again crosstalk considerations place a limit on the gain possible. Consider the case where an incoming pair is adjacent to an outgoing cable pair of any other four-wire circuit, and assume that a small crosstalk unbalance exists between the pairs. The high energy circuit will transfer a small fraction of its energy to the other circuit, and this transferred energy may be appreciable when compared with that existing in the other circuit. This crosstalk energy is applied to the repeater in conjunction with the incoming circuit energy and is amplified to the same degree, so that, unless the incoming signal to crosstalk ratio is great enough, audible crosstalk will result./ In

In laying out long circuits containing a number of repeaters in tandem, use is made of a power level diagram which shows the loss in each section, the gain at each repeater and the level of the voice energy at each point of the circuit as compared with the energy applied at the terminal.

Fig. 1 is a diagram for a typical long two-wire circuit on open wires. The ordinates represent energy levels in db above and below zero level, losses being measured downwards and gains upwards. The gains of the repeaters are represented by straight vertical lines, whilst the line attenuation losses are indicated by lines between repeater stations sloping downwards in the direction of transmission. A separate set of zigzag lines shows the transmission in each direction.



POWER LEVEL DIAGRAM.

FIG. 1.

Whilst it is usual to describe the gain of a repeater by a single value in db, this should be understood to mean the gain of the repeater at a single frequency (usually 1,000 c/s). At any other frequency, the gain of the repeater may or may not be

/ the

the same value. In order to describe completely the characteristics, it is necessary to know the gain at all frequencies in the effective voice range as typified by the gain versus frequency characteristic of the repeater and circuit. Other factors that determine the gains at which it is possible to operate repeaters are the "return loss" and "singing points," which were dealt with in previous Papers. It should be remembered that two-wire repeatered circuits are concerned as much with the impedance of the line (absence of irregularities) as with the attenuation.

The extent to which a repeater may be used to improve transmission depends, firstly, on the "smoothness" of the line impedance throughout the working range and, secondly, on the adjustments that it is possible to make to reduce the effect of terminating conditions on this impedance.

3. CHARACTERISTICS OF OPEN WIRE CIRCUITS.

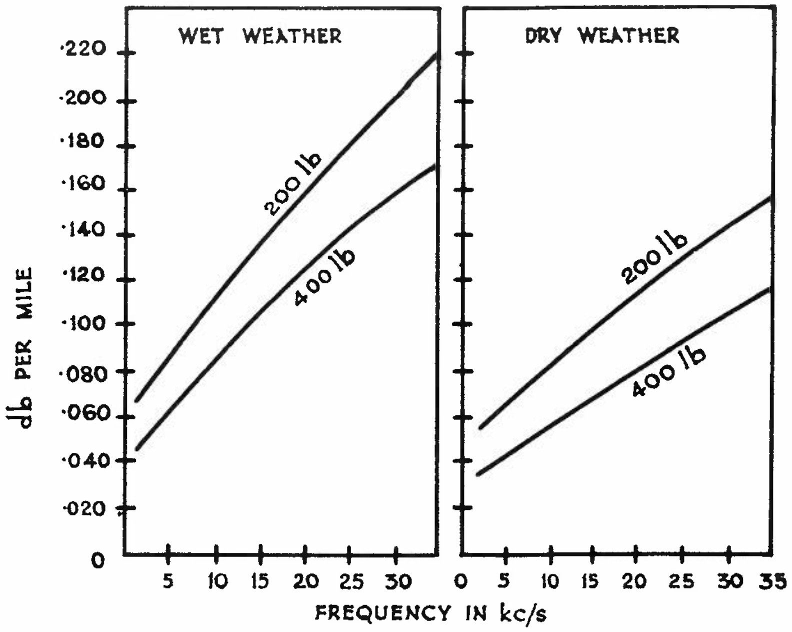
3.1 One and Three-Channel Systems. In the following section, the attenuation, impedance, crosstalk and noise of open wire lines and associated cables over the frequency range employed by three-channel carrier systems is briefly discussed. Reflection effects, resulting from impedance mismatch, are considered, together with loading arrangements and other methods which can be employed to minimise these effects.

3.2 Attenuation. As mentioned earlier, the attenuation of open wire lines in the carrier frequency range is considerably greater than at voice frequencies, since the attenuation increases with frequency. Also, crosstalk between one pair and other pairs on the route may result in the absorption of energy and cause large losses over one or more bands of frequencies in the carrier range, producing what are known as "absorption peaks." When these peaks occur, they can usually be eliminated by a correct choice of carrier transpositions.

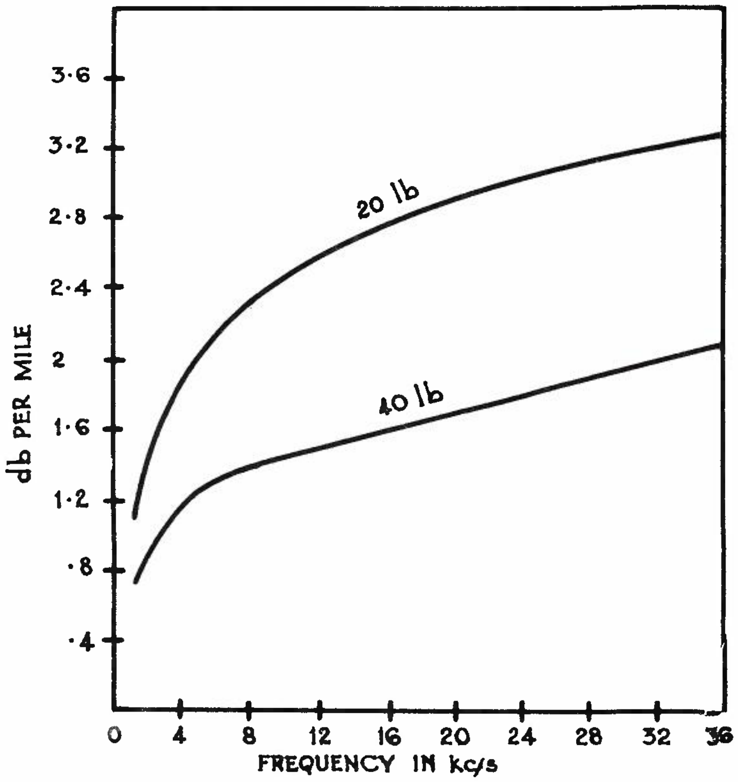
Fig. 2a shows approximate attenuation versus frequency curves for 200 lb. and 400 lb. open wire circuits at a temperature of 68°F. Curves are shown for both wet and dry weather. These curves assume absorption peaks are not present and are 12" spaced pairs equipped with trunk insulators. Because of the increase in the leakance in wet weather, the attenuation at such times is considerably greater than the dry weather value and is assumed to be the maximum likely to be experienced. Consequently, the wet weather attenuation figure is generally employed when engineering carrier systems.

Where conditions of sleet or frost on the wires are encountered, the maximum attenuation is greatly increased. Under such conditions, attenuations three to four times as great as the wet

/ Fig. 2.



(a) Attenuation of Open Wire Side Circuits.



(b) Attenuation of Non-loaded Cable Circuits.

ATTENUATION VERSUS FREQUENCY CURVES.

FIG. 2.

weather values have been measured, but such conditions are rarely encountered in Australian practice.

As is well known, the carrier frequency attenuation of cable circuits is much greater per unit length than that of open wire lines. Hence, the losses introduced by cables, which are often employed at entrance and intermediate points, are of considerable importance. Fig. 2b shows the variation of attenuation with frequency of several gauges of unloaded cable. These curves apply only when reflection losses (discussed later) are not involved.

3.3 Characteristic Impedance. The characteristic impedance of open wire lines and associated cables is also of interest, as it is desirable to avoid circuit irregularities and to match the impedance of the line to that of the carrier equipment. In the frequency range employed by three-channel systems, the characteristic impedance of open wire lines is very nearly a pure resistance of approximately constant value, and is substantially independent of weather conditions. The approximate characteristic impedance of a 200 lb. open wire circuit is shown in Fig. 3.

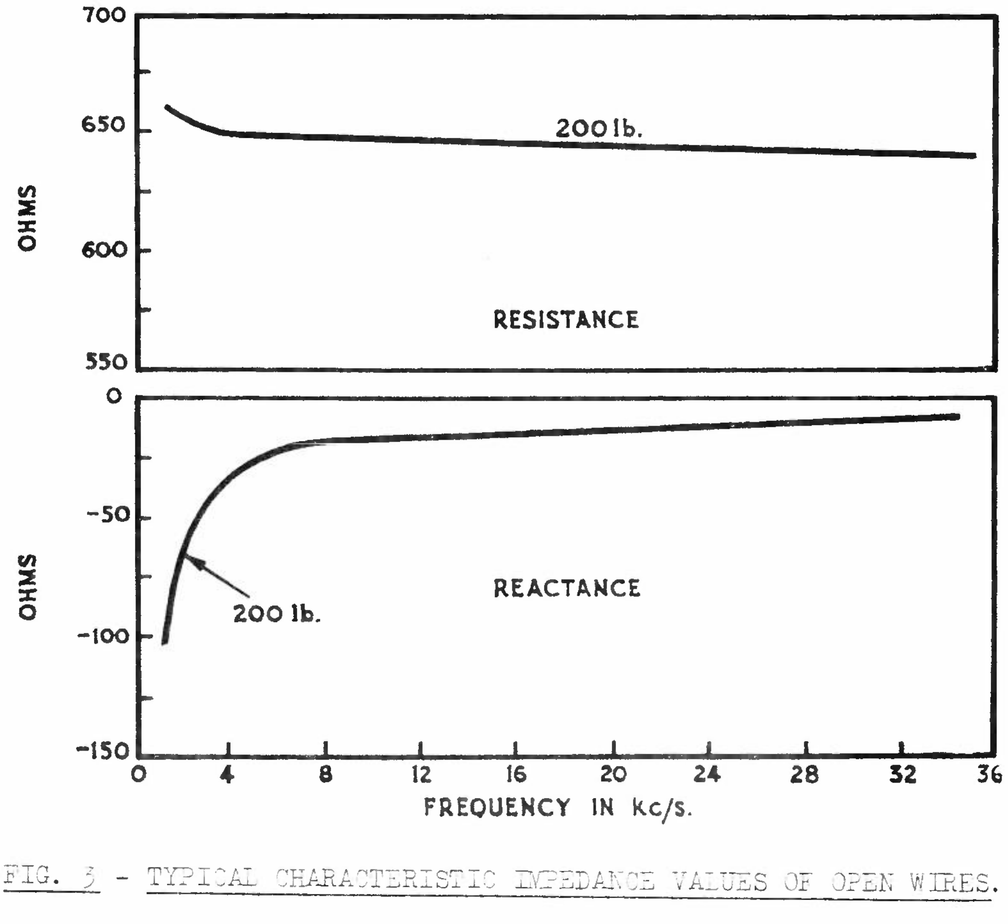
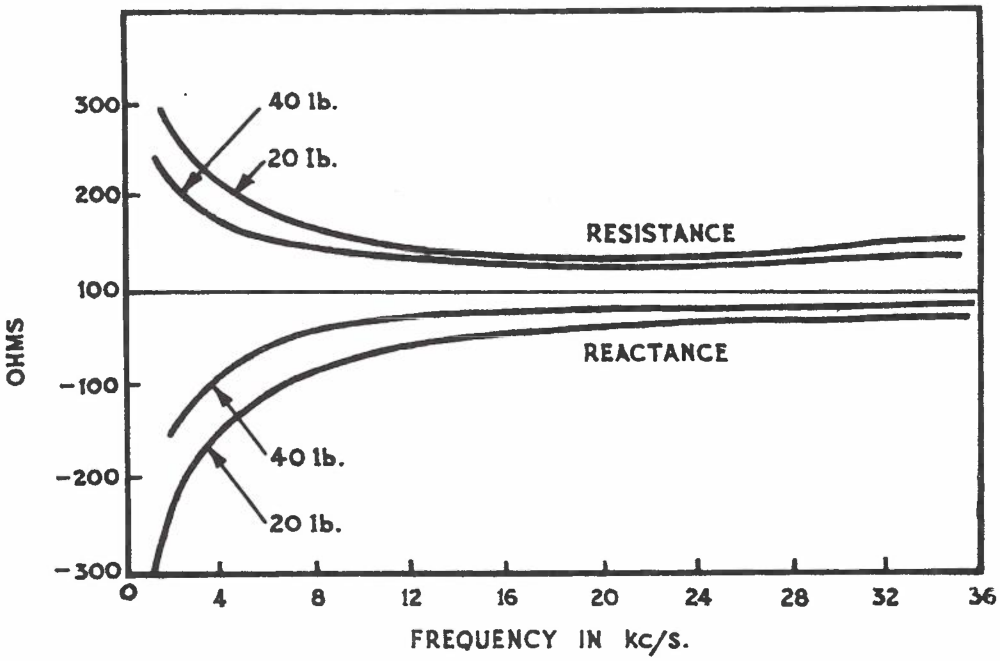


FIG. 3 - TYPICAL CHARACTERISTIC IMPEDANCE VALUES OF OPEN WIRES.

The characteristic impedance of non-loaded cable circuits is larger than that of open wire lines. Over the frequency range up to the highest transmitted frequency of a three-channel system, the characteristic impedance is not as constant with frequency as the open wire impedance and, in addition, has a much larger reactive component. The characteristic impedance of some unloaded cable circuits is shown in Fig. 4. By the use of loading, the impedance of these cable circuits can be increased, so that it closely matches that of the open wire lines and carrier equipment.



CHARACTERISTIC IMPEDANCE OF NON-LOADED CABLE WIRES.

FIG. 4.

3.4 Crosstalk and Noise. The crosstalk between pairs in open wire lines and also in cables is considerably higher at carrier frequencies, as crosstalk increases approximately in direct proportion to frequency. Consequently, crosstalk difficulties are likely to be experienced where more than one three-channel system is operated over the same route, if the pairs are transposed for voice frequency operation only. Since the lower portion of the three-channel frequency range overlaps the range employed by some single channel systems, there is the possibility of crosstalk between the single channel system and the lower channel of the three-channel system, unless the pairs over which they operate are widely separated. Carrier

/ transposition

transposition arrangements can be and are provided, which permit the operation of a number of three-channel and single channel systems over the same route.

Excessive crosstalk at carrier frequencies is also likely to be experienced in entrance or intermediate cables of any substantial length. This can usually be minimised by providing a large number of pairs in such cables, as the crosstalk is likely to vary considerably between various pair combinations, and combinations having low crosstalk coupling can then be selected.

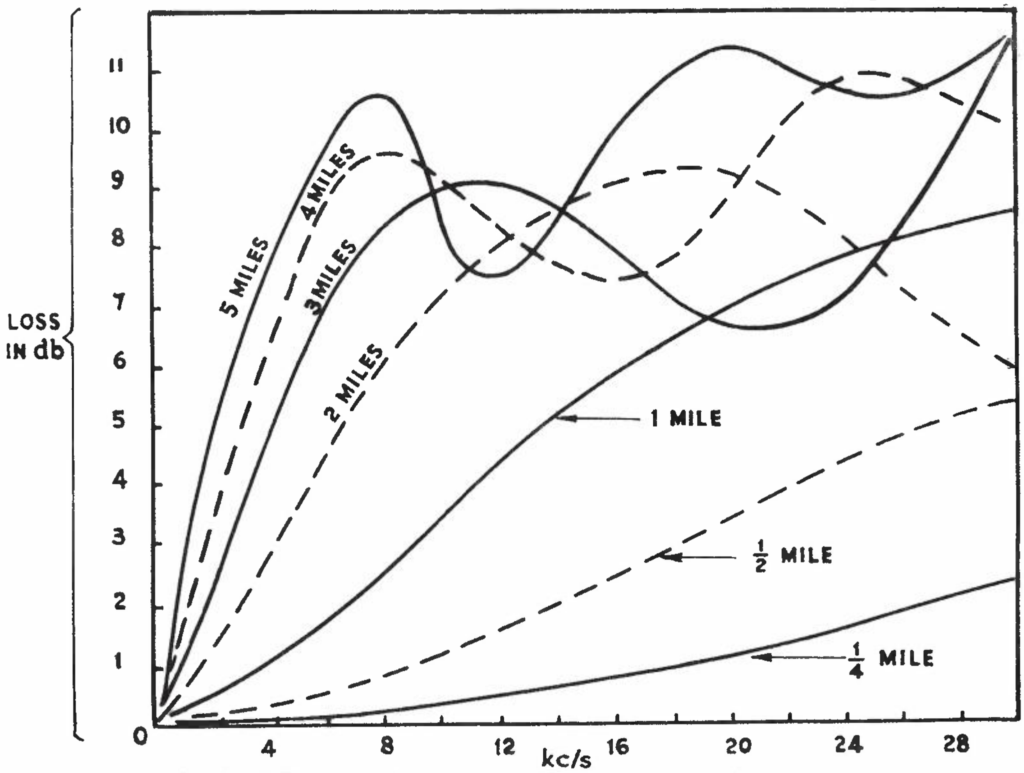
In addition to the absorption effects previously mentioned, crosstalk from a pair on which a carrier system is operating to the surrounding wires on the route may, if the crosstalk is severe enough, provide a feedback path around a repeater and cause the repeater to sing. For most transposition schemes used, this type of crosstalk is rarely great enough to cause trouble of this nature but, in long repeater sections employing high repeater gains, this trouble can be experienced. Since the gain of the repeater does not decrease very rapidly above the effective transmission range, singing can occur at frequencies above the working range of the repeater. When trouble of this type is experienced, a low-pass filter (roof filter) with a cut-off slightly above the three-channel frequency range can be provided at the repeater to prevent singing. The cost of such filters is considerably less than the cost of additional transpositions required to accomplish the same result.

Line noise normally present on open wire lines is, in general, somewhat lower at carrier frequencies than at voice frequencies, and, in addition, the use of carrier transpositions tends to reduce it to negligible proportions.

3.5 Reflection Effects. Due to the large difference in the impedance of open wire and non-loaded cable circuits, the introduction of cable into open wire circuits utilised for carrier transmission will result in reflections at the junction points unless suitable arrangements are employed to match the impedances. Since the carrier terminal equipment is designed to match open wire side circuit impedance, reflections will also occur between the carrier equipment and non-loaded entrance cable unless impedance matching arrangements are provided. Among other effects, these reflections produce irregularities in the attenuation versus frequency characteristic of the circuit and cause reflection losses, which raise the total insertion loss due to the cables. The reflections also tend to increase crosstalk when more than one system is operated over the same route.

/ The

The total loss, including cable plus reflection losses at each end, introduced by inserting given short lengths of non-loaded cable between two 600 ohm resistances is shown in Fig. 5.



INSERTION LOSS DUE TO SHORT LENGTHS OF CABLE BETWEEN 600 OHM RESISTANCES.

FIG. 5.

These curves may be considered as representative for all normally used gauges of cable. Since the impedance of the open wire lines and the terminal equipment is approximately 600 ohms, the curves represent the approximate losses which will be experienced in a carrier circuit when such a length of non-loaded cable pair is inserted in an open wire side circuit.

3.6 Loading of Incidental Cables. The undesirable effects of intermediate and entrance cables can be minimised by the use of coil loading specially developed for such purpose. This loading not only raises the cable impedance to approximately that of the open wire line, so as to minimise reflection, but it also greatly reduces the cable attenuation over the carrier and voice frequency range. Details of standard carrier loading practice were given in earlier Papers. Terminal loading units must, of necessity, be installed at both ends of incidental cable pairs to enable them to present an impedance which is constant over the carrier frequency range.

/ 3.7

3.7 Impedance Matching Transformers. Although carrier loading is the best solution for the incidental problem, it is expensive, especially on long cable lengths, due to the relatively high installation costs involved in the small amount of loading required. When favourable transmission margins exist in the voice frequency attenuation, and impedance matching requirements in the voice range are not stringent, considerations of economy will frequently justify the use of impedance matching transformer networks at cable junctions as a substitute for carrier loading. Such arrangements are not as satisfactory as carrier loading.

At the present stage of development, matching transformers are less effective in the voice frequency range than in the carrier range, and, where earthed composite telegraph operation is used, serious restrictions may be imposed. Certain inherent limitations in transformer design result from the fact that the ratio of the non-loaded cable impedance to that of the open-wire impedance varies widely over the frequency range, and thus the impedance ratio that is optimum at carrier frequencies is disadvantageous in the voice frequency range. An additional complication (important when voice frequency repeaters with high gains are used) results from the fact that the difference between the ratio of the reactive and resistance components of the cable characteristic impedance and the corresponding ratios of the open wire impedance is much greater at low frequencies than at the upper voice and carrier frequencies, and thus a transformer suitable for matching at carrier frequencies may cause considerable impairment to the voice frequency circuits.

Auto transformers (rather than the repeating coil type transformer) with condensers located at the electrical centre of their bridged windings are more suitable for impedance matching, as they permit through direct current testing, facilitate the use of superposed earthed direct current telegraph circuits and can, in general, be arranged to accept 17 c/s ringing.

3.8 Bridged Telephone Sets. Where intermediate stations have telephone sets bridged directly across the line, the carrier frequency attenuation and impedance characteristics of the line are likely to be adversely affected. In addition, mutual interference can be experienced between a voice frequency circuit and the lower channels of a three-channel system on such a circuit. In general, only a few such bridged sets are permissible on a line equipped with a three-channel system, and then only provided special arrangements, such as suitable filters, are inserted at the bridging points.

3.9 Additional information on the transmission characteristics of open wire lines is contained in the Transmission Engineering Instruction, General CO 2011.

/ 4.

4. CROSSTALK.

4.1 In considering practical methods for keeping the crosstalk in long trunk circuits at a reasonable minimum, it is desirable first to consider the effects of certain basic design features of long circuits with respect to crosstalk. In general, these will apply equally to both open wire and cable circuits, and at either voice or carrier frequencies. One such important feature is the effect of the location of telephone repeaters on crosstalk. Thus, it is obvious that, if two circuits are in close proximity at a point near a repeater station, and one circuit is carrying the high current levels coming from the output of a repeater while the other circuit is carrying the low current levels approaching the input of a repeater, the tendency of the first circuit to interfere with the second circuit is very great. The very small percentage of the current in the first circuit, which may be induced into the second circuit, will be amplified by the repeater on that circuit along with, and to the same degree as, the normal transmission. The best practical remedy for this condition, of course, is to avoid such situations by keeping circuits carrying high levels of energy away from low level circuits as much as possible. Where such physical separation between circuits is not feasible, differences in energy level between adjacent circuits can frequently be minimised by proper adjustment of repeater gains when the circuit is designed.

4.2 Another basic element of circuit design is that, in most of the longer voice-frequency cable circuits and in all carrier circuits, the effect of near-end crosstalk is minimised by the use of separate paths for transmission in the two directions. In cable circuits, the wires carrying the transmission in the two directions are physically separated as much as possible by placing them in different layers or segments of the cable, or, in the special case of cable carrier circuits, in different cables. An equally effective separation is obtained in open wire carrier circuits by using entirely different bands of frequencies for transmission in the two directions.

Furthermore, any near-end crosstalk occurring in spite of these physical separations is returned on the disturbed circuit to the output of an amplifier. Since the amplifier is a one-way device, the crosstalk can proceed no farther and does not reach the terminal of the circuit. Near-end crosstalk in such circuits is, therefore, of little importance, except insofar as it may be converted into far-end crosstalk by reflection from an impedance irregularity. To avoid this latter effect, it is essential that all circuit impedances be so matched as to eliminate important reflection possibilities.

/ Apart

Apart from the above techniques for avoiding crosstalk through circuit design methods, practical procedures differ considerably depending upon the type of circuit. It is desirable, accordingly, to analyse separately the problems for open wire and cable facilities.

4.3 In the case of open wire lines, crosstalk reduction depends upon three principal factors, namely, wire configuration on the poles, transpositions and resistance balance. Resistance balance is primarily a question of maintenance and ordinarily presents no great difficulty. The use of high frequency carrier systems, with their much greater crosstalk possibilities, has led to the development of new configurations of open wire lines in which the wires of individual pairs are closer together and the pairs are spaced farther apart. The separation of the wires of each pair is 6 inches, the horizontal separation on the cross-arm between any two wires of different pairs is at least 22 inches, whilst the vertical separation between cross-arms is 42 inches.

The basic principle of transpositions was outlined in a previous Paper. It was noted there that a large number of transpositions was needed in any long section of line to reduce crosstalk to the desired extent. In the entire discussion, moreover, only two pairs were considered. In practice, an open wire line usually carries many more wires than this, and obviously there are crosstalk possibilities between any two pairs on such a line. These possibilities are greater between the pairs that are adjacent to each other, but all of the other possibilities are sufficiently large that they must be taken into consideration in designing a transposition system for the line. A practical system must also guard against crosstalk between side and phantom circuits, and between the phantoms themselves when such circuits are used.

There is still another extremely important factor which has not been considered up to this time. This is the possibility of crosstalk from one circuit to another via a third circuit. In a line carrying many circuits, there is a large number of these tertiary circuits via which crosstalk might be carried from any one pair to any other pair. Even the hypothetical line (which was considered in the first place), carrying only four wires, has two such tertiary circuits. These are the phantom circuit, made up of the two wires of one pair transmitting in one direction and the two wires of the other pair transmitting in the opposite direction, and the "ghost" circuit, made up of the four wires acting as one side of a circuit with an earth return. (Note that these circuits exist as tertiary crosstalk paths regardless of whether a working

/ phantom

phantom circuit is actually applied to the four wires.) Needless to say, the presence of these tertiary circuits in a line complicates the problem of designing effective transposition systems, so much so, indeed, that no attempt can be made here to analyse this problem in detail.

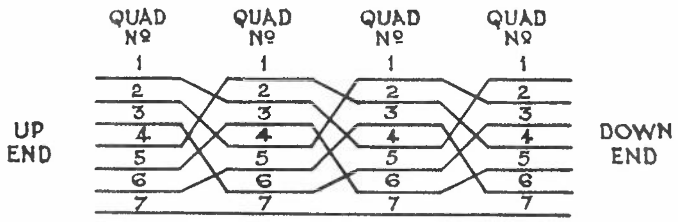
Transposition systems for open wire lines are designed for unit lengths ranging from half a mile (X sections) to eight miles (E sections). The purpose of the design is to approach as closely as possible to a complete crosstalk balance in each such unit section. Any number of sections can be connected in tandem. The non-uniformity in the length of sections is required because of discontinuities in the line, such as junctions with other lines, wires dropped off or added, etc. It is naturally desirable that such points of discontinuity coincide with junctions between transposition sections where the crosstalk is balanced out.

4.4 Turning now to cable, the most striking feature with respect to crosstalk is that the conductors are "crowded" close together. This close spacing of the two wires of a pair, in which equal and opposite currents are flowing, tends to minimise the external effect of the electromagnetic field of the pair. Moreover, in the process of manufacture, each two pairs of wires are so disposed that the capacity unbalance between the four wires of each individual quad so formed is reduced to a minimum. This aspect has already been dealt with in Long Line Equipment I, Paper No. 4. In Multiple Twin type cables, the two wires of each pair are twisted together producing the effect of close transpositions, and each two pairs are then twisted together producing the effect of phantom transpositions. This twisting together of wires and pairs further reduces crosstalk. A still further reduction is brought about by spiralling the quads in opposite directions about the core. In Star Quad cable, the twisting together of the wires and pairs is not resorted to - the four wires of each quad are "rolled," this roll producing much the same results as does the twisting. As with multiple twin type cable, the quads are spiralled in opposite directions about the core.

At voice frequencies, inductive coupling between circuits in a cable is normally so small as to be of relatively little importance in creating crosstalk. The same cannot be said of capacitive coupling. Despite the most careful manufacturing methods (there being limits economically in any case), the capacity unbalances are great enough to cause objectionable crosstalk in long circuits. This crosstalk is minimised in practice by special balancing methods to be described later.

/ These

These balancing methods reduce the "within" quad unbalances and, therefore, the "within" quad crosstalk. Where crosstalk in adjacent quads is likely to be excessive if quads are "straight" jointed, that is, the same quads in each length of cable jointed together throughout the full length of cable, systematic jointing of quads may be applied. This scheme results in quads which are adjacent in any length being jointed to non-adjacent quads in the next length in a definite order. Fig. 6 illustrates the systematic jointing of quads as applied to a 14 pair (7 quad) cable.



SYSTEMATIC JOINTING OF QUADS TO OBTAIN QUAD SEPARATION.

FIG. 6.

In this case, adjacent quads in any length resume adjacency only once in every four lengths.

4.5 The above capacity balancing methods have been found adequate in practice for voice frequency cable circuits. When carrier systems are applied to cable circuits, the crosstalk problem becomes much more severe. In fact, whilst capacitive coupling is still of consequence, inductive coupling also becomes important as a cause of crosstalk.

The crosstalk problems at the relatively high frequencies of the 17-channel and Type K systems require special treatment. The transmitting paths in the two directions of transmission are separated by using separate cables for transmission A-B and B-A. (Alternatively, a special cable with a shield between pairs transmitting in opposite directions can be used.) The circuits in the two directions are likewise kept separated in terminal offices and repeater stations, and shielded office wiring is used in all cases. This ensures that the energy levels of the carrier currents are approximately the same in all physically adjacent conductors, and that near-end crosstalk possibilities are eliminated (assuming that reflection effects have been guarded against).

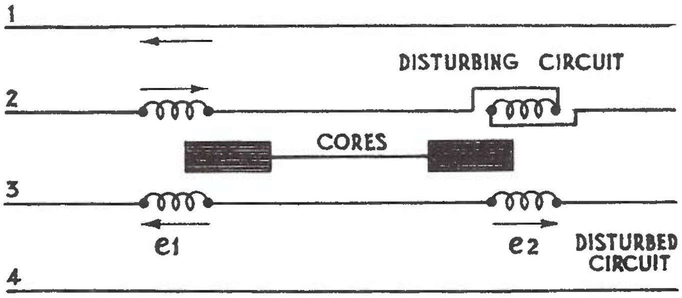
Far-end crosstalk is reduced by taking special precautions. In the first place, cable which is to transmit carrier frequencies is manufactured to produce a much smaller capacity unbalance, mutual capacity deviation, and resistance unbalance than is

/ the

the case with cables intended for V.F. circuits only. As in the V.F. case described above, the factory lengths are jointed together in such a manner that the capacity unbalance and mutual capacity deviation are reduced below specified limits over predetermined lengths, these limits being much lower than those for V.F. cables. Also, the quads are transposed from outer to inner layers throughout those predetermined lengths, as in the V.F. case. These precautions take care of "within" quad crosstalk and also of crosstalk between quads to some extent, and aim at reducing far-end crosstalk due to capacity unbalances. It is now necessary to reduce the far-end crosstalk produced by the inductive coupling which exists between the pairs.

The basic problem is to balance every carrier pair against every other carrier pair in the same cable in each repeater section. The method employed counteracts the crosstalk currents with equal currents flowing in the opposite direction. Thus, if in a given distributed circuit a crosstalk current is flowing in a clockwise direction, it is desired to set up an equal current in the circuit flowing in a counter-clockwise direction. This result can be obtained by connecting small transformers between each carrier pair and every other carrier pair, but, since it is necessary to control the magnitude of the induced currents and also cause them to flow in either direction as might be required, depending on the direction of the actual crosstalk current, the transformers must be designed so that the coupling between circuits can be adjusted and so that they can be "poled" in either direction.

The method used is shown schematically in Fig. 7. It will be noted that there are two separate transformers, one having a reversed winding in the disturbing circuit, so that a current I flowing in the disturbing circuits will induce oppositely poled voltages in the disturbed circuits. If the cores of the two transformers are centred as shown in the sketch, the induced voltages will be equal and the net effect on the disturbed circuit will be nil. By moving the two cores as a unit in either direction, one or other of the induced voltages can be made to



PRINCIPLE OF CROSSTALK BALANCING COIL.

FIG. 7.

/ predominate

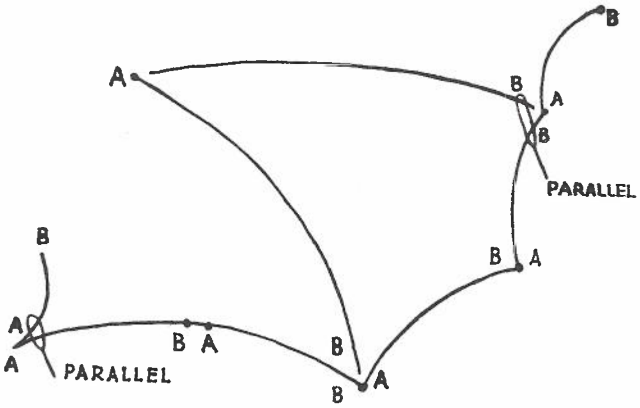
predominate. Thus, if the cores are moved to the left, e_1 will be increased, whilst e_2 will be decreased a like amount. This will result in a current flowing in a counter-clockwise direction in the disturbed circuit. On the other hand, moving the cores to the right will result in a clockwise current in the disturbed circuit.

The method of balancing out the crosstalk due to inductive coupling, as described above, is not used in Australia. It is included here to show how a voltage deliberately introduced from one circuit to another can eliminate the crosstalk voltage induced between the same circuits by arranging for the deliberately introduced voltage to be 180° out of phase with the induced voltage. Australian practice uses a parallel resistance capacity network to introduce deliberately the required voltage, the amount of the voltage deliberately introduced being determined by the value of capacity and resistance used. The measurement to ascertain the required amount of resistance and capacity is called an "admittance unbalance" measurement, and involves measuring the impedance unbalance between each pair and every other pair in the cable and correcting that unbalance.

The capacity balancing precautions discussed above assume that only capacity exists between the wires of a cable. This is not quite so, as some leakance is usually present because it is not possible to achieve perfect insulation. This insulation resistance paralleling the capacity between the wires forms a parallel impedance, the reciprocal of which is the admittance. The measurements undertaken to ascertain the extent of this unbalance with a view to its correction are termed "admittance unbalance" measurements, because the equipment used gives the amount of capacity and leakance required to correct that unbalance. The required capacity and resistance network would, when connected, deliberately introduce a voltage from one circuit to the other which would be 180° out of phase with any crosstalk due to inductive coupling. Admittance unbalance measurements are made over predetermined lengths of cable, these lengths then being jointed together in such a manner that the over-all admittance unbalance is reduced to a minimum. Any residual unbalance can then be corrected at the far end of each repeater section by small variable condensers and suitable parallel resistors where necessary.

/ 4.6

4.6 Poling of Systems. In general, and to avoid the possibility of near-end crosstalk conditions, single and three-channel carrier telephone systems in use in the Commonwealth are installed so that the A-B direction is counter-clockwise, taking Perth as a starting point. For frequency allocations in different directions, see Drawing No. C.1125 at rear of Paper No. 3, Long Line Equipment II.



POLING OF CARRIER SYSTEMS.

FIG. 8.

There are exceptions to this rule, such exceptions being dictated by trunk route parallels. The usual poling and necessity for exceptions are shown in Fig. 8.

4.7 Staggering. In order to assist transposition problems, which are particularly severe if identical systems are employed on adjacent pairs, several systems with slightly differing frequency allocations are used. These are applied in pairs known as normal and staggered systems, for example, C2N, C2S, SOS, SOT, T1 and T2.

The staggering advantage or effective crosstalk reduction between systems is obtained because -

(i) The inversion or displacement of channels in the different systems with respect to each other makes the crosstalk unintelligible.

(ii) The reduction of the overlap between channels results in less energy being transferred between them by crosstalk.

Staggering Advantages.

6 db for inversion.
10 db for normal staggering.
SOS-SOT approaches infinity.

Repeater Spacing and Level Adjustments.

Latest systems high frequency gain 50 db.
Earlier systems high frequency gain 35-40 db.

Later systems are, therefore, capable of operating over distances of 200 miles and, in entirely new routes, advantage is

/ taken

taken of this fact. In old established trunk routes, repeater sites were determined by earlier systems and are approximately 140 miles.

Type J repeater spacings average 60 miles.

In order to assist in limiting crosstalk between circuits, it is important that the transmitting levels of the systems on the same route are uniform at terminal and repeater points. The maximum output level is +18 db, referred to 1 milliwatt. Normal output levels are approximately +10 db and +14 db, and are adjusted to be as uniform as possible between adjacent systems.

Other factors influencing repeater spacing are -

Atmospheric noise.
Crosstalk (60 db far end on repeater sections is aim, measured with equal level on both circuits. 45 db is the irreducible limit.)

4.8 Connecting Systems Together. It is often necessary to connect systems in tandem to provide traffic facilities between remote points. Where circuits are required on a permanent basis between the two centres, the systems may be permanently connected four-wire from modulator to demodulator in each direction of transmission, with suitable pads inserted to limit modulator input levels to the correct value.

Where circuits are switched through as required, it is necessary to reduce the normal over-all additive equivalent. This is achieved either by the use of tail eating or pad switching connections.

If hybrids are connected directly together without tail eating, the loss is 6 db. When the tail eating connection is made, the loss is reduced to zero if transformer losses are neglected.

Pad Switching. The systems are normally lined up to their equivalent with 3 db pads in circuit. When two systems are connected together, these pads are switched out of circuit, thus leaving the over-all equivalent unchanged.

/ 5.

5. CIRCUIT CONSIDERATIONS FOR TYPE J SYSTEMS.

5.1 The introduction of the Type J systems brought about an increase of approximately 5 : 1 in the transmitted frequency range of open wire lines, and thereby greatly intensified the problems connected with attenuation variations, crosstalk and reflection.

5.2 Line Attenuation. Due to the large and often rapid attenuation variations brought about by weather changes, it is essential that Type J systems include automatic gain regulation. (As stated earlier, automatic gain regulation is desirable with three-channel systems operating over long distances.)

5.3 Crosstalk. Crosstalk is mainly controlled by use of suitable transposition schemes. As grouped frequency working is employed, transposition design is capable of giving the required results. The crosstalk between systems, which is of direct importance, is the "far-end," that is, between the speaker at one end and a listener on another circuit at the other end. "Near-end" crosstalk, that is, between a speaker and listener at the same end, becomes a source of interference only when portion of it appears as "far-end" crosstalk because of reflection at points of impedance irregularity.

5.4 Absorption Effects. Absorption effects are usually eliminated by transpositions but, if only portion of the pairs on a route are transposed for J working, absorption in a J pair can be caused by a nearby non J pair.

5.5 Construction Irregularities. Unequal sags of pair wires, variation in transposition pole spacings, pin and arm spacings, in fact, any constructional irregularities must be eliminated if satisfactory J pairs are to be obtained.

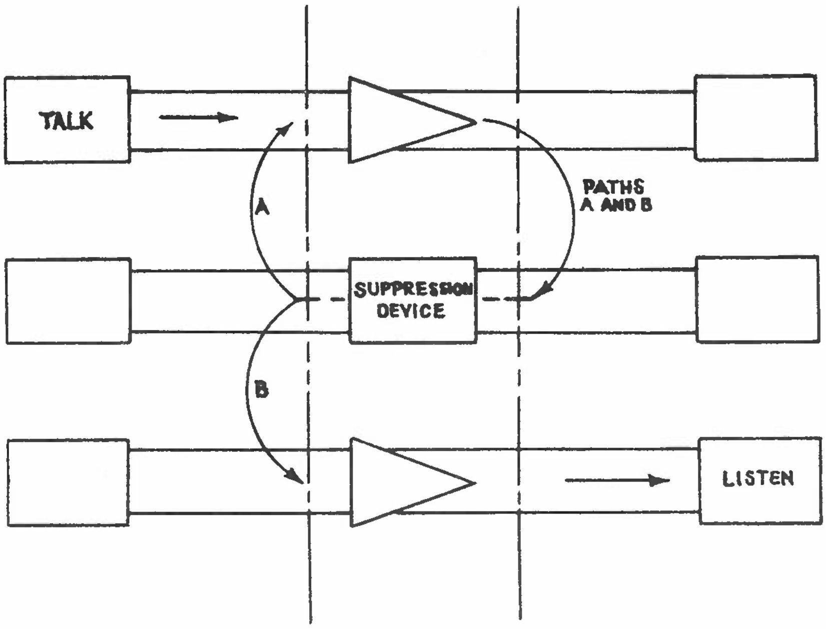
5.6 Interaction Crosstalk at Repeaters. This is crosstalk which occurs from one side to the other of a J repeater. (See Fig. 9.)

Path A shows the crosstalk from a system to itself; this can cause distortion and singing.

Path B shows the crosstalk between different J circuits. The important feature of this crosstalk is that it passes through a J repeater and is thereby amplified by the repeater gain.

In applying J systems, the consequent larger magnitude crosstalk at higher frequencies, the increased repeater gains and the greater number of repeaters per unit length all contribute to increase the interaction crosstalk problems.

/ Fig. 9.



CROSSTALK SUPPRESSION FILTER.

FIG. 9.

Several methods are used to reduce this crosstalk. Firstly, to prevent direct coupling between wires on both sides of a repeater, it was found necessary to create a gap in the line by leading into the repeater about 80 to 100 ft. from terminal poles using special lead-in cables. Secondly, to block crosstalk paths, special crosstalk suppression filters are installed in non J circuits. (These filters introduce a loss of 70 db at 140 kc/s.) In addition, to provide an extra margin of safety against interaction crosstalk currents which might find their way through the repeater station by various stray paths, longitudinal choke coils are connected in the J pairs between junctions of open wire lines and lead-in cables. These coils do not affect ordinary transmission but add high impedance in longitudinal circuits.

5.7 Staggered Systems. Transposition arrangements possible on existing open wire lines do not permit the operation of identical J systems on all pairs - therefore, four types with differing channel frequency allocations are used. The staggering advantages range from 6 to 16 db.

5.8 Line Impedance. It is important that impedances be closely matched and large irregularities avoided.

/ Special

Special construction and lead-in arrangements make it possible to obtain a reflection coefficient of 5 per cent. at the highest frequency transmitted.

The accuracy of the wire spacing, transposition arrangements, etc., affect the smoothness of the impedance versus frequency curve.

5.9 Intermediate and Entrance Cables. As previously indicated for three-channel systems, loaded cable or matching transformers are used for impedance matching between junctions of open wire lines and cables.

To load up to 150 kc/s would require very close spacing (200 ft.) - this would be expensive. Also, regarding the use of impedance matching transformers, the design would be too difficult over the wide frequency range concerned.

As a result, special disc cable, which can be loaded at normal spacing to match the open wire impedance, was developed for J installations. Loading coils for differing open wire gauges are available.

The disc cable uses 40 lb conductors in a spiral four arrangement supported by hard rubber disc spacers 0.6" diameter. These are surrounded by copper and iron tapes for purposes of shielding and strengthening.

Cables may be assembled in single units under a lead sheath or in multiples up to seven. Outside armouring is available for submarine cable.

5.10 Entrance Cable. When a new station is established at a point on a line route, it is usually located close to the line in order that the lead-in cable will be short. Lengths up to 175 ft. can be loaded with adjustable loading units located in the repeater station, and lengths up to 300 ft. can be loaded with adjustable loading units located both on the terminal pole and in the repeater station.

When, for particular reasons, greater lengths are necessary, disc loading can still be used, but, because of cost, it is sometimes more economical to construct a special filter hut near the open wire terminal pole and separate the J system from the three-channel system by line filters. Connection from the line to the filter hut is by means of a disc cable. From the filter hut to the repeater station, ordinary trunk entrance cable is used, the J being led in on unloaded pairs and the three-channel usually on loaded pairs. By thus limiting frequencies over the non-loaded pairs to the J group, it is possible to design and use suitable impedance matching transformers. The line filter sets

/ are

are designed for average open wire line impedance and, where necessary, building out networks are used to obtain close matching.

For office wiring, J systems use rubber covered shielded pairs. (Impedance at 140 kc/s = 125 ohms.) The repeater and terminal high frequency equipment impedances are designed to match this value very closely.

6. SUMMARY.

6.1 The successful transmission of frequencies up to 140 kc/s over open wire lines, as compared with transmission up to 30 kc/s, involves modification of open wire construction, new transposition design, new lead-in arrangements involving special cable and loading, improvement of impedance matching at junction points, closer repeater spacings and auto gain regulation.

6.2 Noise. Circuit noise can be divided into two types -

(i) Preventable noise, that is, that noise which, by careful design and maintenance, can be eliminated.
(ii) Unpreventable noise due to the basic nature of matter and electricity.

Of these, (i) is of importance in voice frequency circuits, but both (i) and (ii) are of importance in carrier circuits.

6.3 Preventable Noise may consist of -

(i) "Babble" due to direct crosstalk from many different circuits simultaneously. This may occur in cables themselves, in office wiring, or by couplings via common power supplies to repeater equipment.
(ii) Crossfire from telegraph circuits.
(iii) Noise from battery charging plant, either commutator ripple or alternating current hum. This may occur due to float charging, interference from a reserve battery on charge or mains operated equipment.
(iv) Induction from nearby power lines.
(v) Radio pick up. This is of importance only in carrier circuits, where the radio signal may be translated to speech frequencies in the frequency changing equipment. Open wire lines are most troublesome in this respect, but trouble can be experienced on cable circuits as crosstalk from other pairs which have open wire extensions.
(vi) Noise due to microphonic values, that is, due to electrode vibrations.
(vii) Noise due to line contacts - intermittent "opens," lines and apparatus.
(viii) Noise due to earth and intermittent earth faults.
(ix) In carrier circuits, noise due to intermodulation in repeaters and other non-linear circuit elements, such as loading coils.

/ (x)

(x) In carrier circuits, noise due to inadequate filtering in terminal equipment.

6.4 Unpreventable Noise is of Two Sources -

(i) Thermal Noise. Apparently inert matter has its ultimate constituents in a state of ceaseless motion, giving rise to random electric currents of calculable value. Thermal noise, resistance noise or Johnson noise has an average electrical energy, which is independent of the nature or magnitude of the resistance across which it is measured. It is proportional to the absolute temperature and the frequency band-width. For a speech band-width at atmospheric temperature, thermal noise is about 133 db below 1 milliwatt. The important noise usually arises in the grid circuit resistance of the 1st stage amplifier valve, where the signal energy is lowest.

(ii) Shot Noise. The electron stream in a valve is also particulate in nature and in the limit is not uniform. It, therefore, gives rise to a noise similar in character to thermal noise. This noise is known as shot or "Schrott" noise. With valves associated with grid circuit impedances of about 5,000 ohms, shot noise is comparable in magnitude to thermal noise.

If the noise or crosstalk level at a given point is known, the permissible signal level at that point can be deduced from a knowledge of the sending level, number of repeaters and required over-all signal/noise ratio. In most cases, crosstalk is the decisive factor, but, where this is effectively eliminated as in four-wire cable schemes, the circuit noise sets the limit to the repeater spacings.

7. TEST QUESTIONS.

1. State the causes and discuss the effects of Reflection.

2. State the principles of transposition design.

3. Why, and how, are crosstalk balancing coils used?

4. How are carrier systems connected in "tandem"?

5. What is "circuit noise"?

6. What are the main advantages of the use of repeaters?

END OF PAPER.

COMMONWEALTH OF AUSTRALIA.

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COURSE OF TECHNICAL INSTRUCTION.

LONG LINE EQUIPMENT III.

PAPER NO. 4.

TRANSMISSION MEASUREMENTS AND MEASURING EQUIPMENT.

CONTENTS:

1. INTRODUCTION.

1.1 Electrical measurements in Long Line Transmission involve the application of many types of measuring apparatus to determine the suitability of circuits and apparatus and to detect any variation in their performance.

1.2 Transmission measurements may be broadly divided into two categories -

(i) Measurements on open wire and underground or submarine cables to determine their suitability for the application of specific types of long line equipment.

(ii) Measurements on apparatus to ensure that it operates as required and will, in conjunction with a suitable transmitting channel, conform to over-all transmission standards.

1.3 These measurements involve both D.C. tests and A.C. tests or measurements.

2. D.C. TESTS.

2.1 It is important to make certain D.C. tests before proceeding with A.C. measurements. The D.C. tests to be made are as follows -

(i) Insulation Resistance. This test must be made between each wire of the circuit on which measurements are to be made, and between each wire and earth. Any abnormal behaviour, such as low and/or varying insulation resistance or unequal insulation resistance between each wire and earth, should be investigated. This test is made because any low insulation resistance can affect A.C. tests, for example, crosstalk will be more severe on circuits with low insulation resistances so that, by clearing up insulation troubles prior to A.C. tests, the results gained from the subsequent A.C. tests are a true indication of the performance of the circuit to alternating currents.

(ii) Conductor Resistance and Conductor Resistance Unbalance. The two wires of the circuit on which measurements are to be made are looped and earthed at the distant end, and the loop resistance and resistance unbalance of each wire are checked by a Wheatstone Bridge. From a foreknowledge of the make-up of the circuit to be measured, it is possible to check the loop resistance. Abnormal behaviour, such as high and/or varying loop resistance and resistance unbalance, should be investigated and cleared up for the reasons outlined above.

2.2 The methods of making D.C. measurements have been dealt with previously, and reference should be made to Paper No. 2 of this book for Bridge Measurements, and to Applied Electricity I, Paper No. 5, for the use of the Megger and Bridge Megger, should the trainee require information on these measurements.

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3. A.C. MEASUREMENTS.

3.1 Whilst many different circuit arrangements are used to make A.C. measurements, a particular arrangement is merely a method of making one of a relatively small number of measurements, the particular circuit arrangement used being dictated by the circumstances involved. For example, there are many methods of measuring the loss produced by a line, the particular method used being determined by the equipment available and the loss expected. This can be estimated from a knowledge of the make-up of the line and its primary and secondary constants.

3.2 The principal A.C. measurements made, together with some reasons for making them, are as follows -

(i) Characteristic Impedance versus Frequency of Circuits. This measurement is made to check that the practices employed in the erection of an aerial line, or the jointing or loading of a cable, produce a characteristic impedance which does not depart widely from the value calculated from the primary constants of the circuit concerned. The measurement also checks that no irregularities are present due to such features as the absence of aerial to cable matching transformers, terminal loading units, loading coils, etc. Also, from the measurement of the characteristic impedance of a line, the primary constants of the line can be calculated, thus enabling these constants to be determined from practical cases rather than purely theoretical considerations.

(ii) Insertion Loss or Gain versus Frequency. This measurement checks that alterations to the make-up of a circuit, the addition of such items of equipment as repeaters, etc., to a circuit, and so on, do not produce losses which would place the grade of the circuit outside the standard grade of over-all transmission. This measurement also includes the gains of amplifiers and the losses produced by individual items of equipment.

(iii) Crosstalk versus Frequency. This measurement checks an aerial route after retransposition, is used as a basis for selecting cable pairs for loading, and generally indicates the extent to which circuits will crosstalk between one another when in use.

/ (iv)

(iv) Noise and the Harmonic Analysis of Noise. Noise measurements are made either as the result of a complaint or where high level wide band equipment is to be used. When noise is present, its harmonic analysis is of great assistance in determining the source of the noise, from which steps can be taken to eliminate it.

(v) Return Loss. This measurement is made to determine the extent of an impedance mismatch, for example, at the junction of cable and open wire circuits, or when a circuit is terminated in some specific impedance.

(vi) Capacity Unbalance. This test measures the extent of the capacity unbalance between the four wires of a cable quad, with a view to its reduction or elimination by a jointing scheme or by the use of balancing condensers.

(vii) Admittance Unbalance. The capacity unbalance measurements dealt with above take into account only the capacity unbalances existing between the four wires of each quad, and the correction of this capacity unbalance eliminates crosstalk from one pair to the other in the same quad. Within quad balancing is sufficient to eliminate or reduce below an audible level any crosstalk at audio frequencies. At carrier frequencies, however, it is necessary to consider not only within quad crosstalk due to within quad capacity unbalance, but also crosstalk from quad to quad brought about not only by capacity unbalance but also by insulation resistance unbalance. The capacity and insulation resistance between each pair of wires in a cable forms an impedance, the reciprocal of which is the admittance. Admittance unbalance measurements estimate the degree of admittance unbalance between every combination of pairs in a cable in terms of the amount of capacity and resistance required to correct the unbalance. The amount of capacity and resistance required is provided in the form of variable condensers and resistors of the required value. The added resistance and capacity reduce crosstalk, because they provide a network through which one circuit deliberately crosstalks into another. This deliberately introduced crosstalk, however, is 180° out of phase with that due to the unbalances existing along the length of the cable, so that the resultant far end crosstalk is zero. Admittance balancing is, therefore, a means of reducing far end crosstalk, and is resorted to for this purpose.

(viii) Mutual Capacity Deviation. Carrier type cable, that is, cable designed and manufactured specifically for operating carrier systems over its pairs, must be manufactured and jointed in such a manner that the mutual capacity of each pair does not vary too much over the entire length of the cable. Any

/ variation

variation in the mutual capacity of a pair over the length of the cable will cause impedance changes which, at carrier frequencies, cause reflection and so increase crosstalk. The mutual capacity of each pair in predetermined short lengths of the cable, therefore, is measured, and these lengths are jointed in such a manner that little variation or deviation of the mutual capacity of each pair takes place over this entire length of the cable.

4. A.C. TESTING EQUIPMENT.

4.1 The various items of testing equipment necessary for carrying out the A.C. tests on lines and equipment listed in the preceding section are special applications of circuit principles already studied. The remainder of this Paper, therefore, will be devoted to brief descriptions of some items of testing equipment, and a subsequent Paper will deal with the method of carrying out individual tests with this equipment. Because of the large variety of tests made, testing gear used, and circuit arrangements devised to meet different sets of circumstances, it is not possible in a course of this nature to cover the whole field of testing equipment and testing methods. These Papers, therefore aim at providing the trainee with general principles only and should not be regarded as a comprehensive treatment of the subject.

5. OSCILLATORS.

5.1 Oscillators are the source from which A.C. testing power is drawn. The different A.C. measurements made on lines and equipment involve frequencies as low as 35 c/s (the lowest frequency of importance in music) and as high as 143 kc/s (the highest carrier frequency used in Australia at the moment).

5.2 The most important features of an oscillator required for testing purposes are -

(i) The harmonic content in the output should be small at all frequencies. The total amount of power delivered by an oscillator to a circuit under test and from that circuit to the measuring equipment, for example, an ammeter, will be the sum of the power in the fundamental frequency and that in the harmonics. Where tests at single frequencies are necessary (and this is generally the case) and untuned measuring equipment is used, the results obtained indicate the performance of the circuit over the single frequencies plus their harmonics rather than at the single frequencies concerned.

/ (ii)

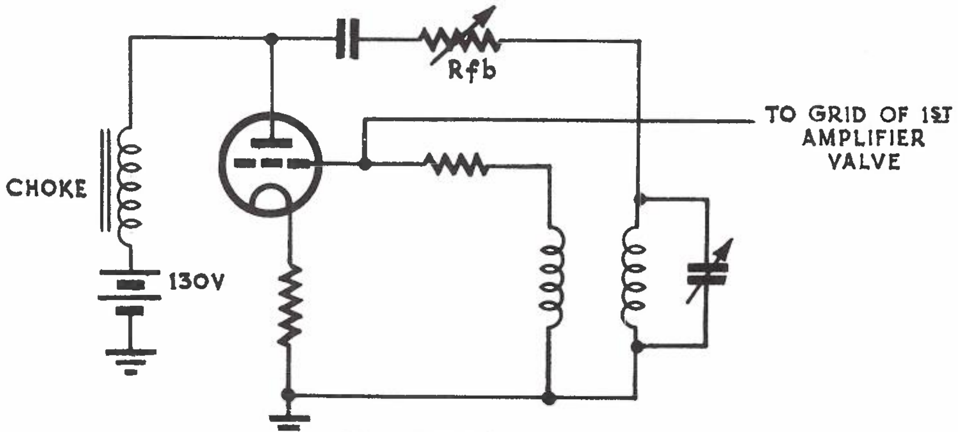
(ii) The output should be constant over the whole frequency range of the oscillator for any required output. This eliminates checking the output of the oscillator each time the frequency is changed when measurements are being made over a wide frequency range.

(iii) The frequency and output power should not vary with normal changes in temperature or electrode voltages.

5.3 Because of the difficulties encountered in providing these features on oscillators which have to cover a band-width extending from 35 c/s to 150 c/s, the oscillators used in practice only cover portions of this band. For example, oscillators for audio frequency measurements cover a range up to about 15 kc/s, oscillators for carrying out measurements on 3-channel systems cover a range up to about 50 kc/s, whilst oscillators for carrying out measurements on 3-channel and 12-channel systems are designed to provide their most satisfactory performance between about 3 kc/s and 150 kc/s. Some of these oscillators will now be described.

5.4 The 8A Oscillator. This is a portable oscillator covering the frequency range 100 c/s to 50 kc/s and operating from battery supplies of 24 and 130 volts.

The oscillator is of the tuned anode type and is followed by a two-stage amplifier, the second stage employing two valves in parallel arranged to provide a 600 ohms output. Fig. 1 shows a circuit of the oscillator unit alone.



8A OSCILLATOR.

FIG. 1.

A shunt feed arrangement is used to keep the anode D.C. out of the anode tuning coils. Five sets of inductance coils are used in the tuned circuit; these, together with a variable capacity, cover the required frequency band. The coils are switched in

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and out as required by a ten point switch which, besides carrying out this coil switching function, also provides two values of feedback resistance per coil. This feedback resistance, designated R_{fb} in Fig. 1, performs two functions -

(i) It prevents the output of the oscillator from varying excessively as the values of the tuning capacity and inductance are varied to vary the frequency. As the values of the tuning capacity and inductance change, the impedance offered by the tuned circuit at resonance ($Z = \frac{L}{CR}$) also changes, so that the amplitude of the tuned circuit current and, therefore, the voltage across the tuned circuit, which will mean the output power from the oscillator, will vary correspondingly. By varying the amount of the amplified oscillations returned from the valve to the tuned circuit by means of a variable resistance between them, variations in the power output from the oscillator can be checked. As there are only two values of feedback resistor for each coil, the power output from the 8A oscillator cannot be regarded as constant.

(ii) Changes in such factors as load impedance and anode and cathode supply voltages can cause variation in the frequency of the oscillator by causing changes in the impedance of the tuned circuit or the valve respectively. By employing a feedback resistor, the total impedance of the anode circuit can be increased to a value such that the factors mentioned produce little change in the total impedance of the anode circuit.

The output of the oscillator can be controlled by a potentiometer, which varies the voltage applied to the grids of the two paralleled valves in the output stage. The maximum output is from about 25 to 35 milliamperes into 600 ohms, which corresponds to about 25 to 28 db above one milliwatt into 600 ohms.

The proportion of harmonics present in the output varies with the magnitude of the output, the minimum amount being present when the output is small. When greater purity of output is required, provision has been made for the use of an external 9 volt battery for biasing the output valves.

A calibration chart is provided from which the settings of the coils and condensers can be ascertained for any frequency required.

5.5 The 10B Oscillator. This is a rack mounted oscillator, also of the tuned anode type, designed to cover the frequency range 35 c/s to 50 kc/s. The output impedance is 600 ohms and the output is from 6 to 10 milliamperes into 600 ohms, corresponding to between about13 and18 db above one milliwatt into 600 ohms.

Three sets of tuning coils are provided which, with a variable capacitance, cover the required frequency range. The feedback resistor is adjustable for each frequency setting, and a chart is provided from which the settings of the coils, condensers and feedback resistors can be ascertained for any required frequency. This provides a constant output as the frequency is changed.

The13 to18 db output mentioned above is provided by the oscillator valve followed by one stage of amplification - a single valve. When greater outputs are required, an additional stage of amplification is provided in the form of two valves in push-pull, the output of this stage being designed to work into 600 ohms. The maximum output from the amplifier is from 25 to 40 milliamperes into 600 ohms, corresponding to from about 26 to 30 db above one milliwatt into 600 ohms. This output can be reduced in 20 steps of approximately 1 db each.

5.6 The 17B Oscillator. (See Fig. 2.) A source of frequency covering the range to 150 kc/s has been provided by the Western Electric Company in the 17B oscillator. This oscillator is a development of the Bell Laboratories, and represents a departure from the resistance stabilised oscillators discussed above. This is a beat-frequency or heterodyne oscillator and, with careful design, qualities latent in this type have been developed to an exceptional degree. In consequence, the 17B oscillator has certain desirable attributes not possessed by earlier types; notably, a substantially flat output-frequency characteristic, and a single frequency control covering the whole range.

The frequency range of the 17B oscillator is 50 c/s to 150 kc/s indicated on a film scale some 25 feet in length and calibrated at 50 c/s intervals. The scale accuracy is within ±25 c/s at any point, and the long-time frequency stability is within ±20 c/s for any particular setting.

Of considerable practical value, from the viewpoint of testing technique, is the exceptional output-frequency characteristic which, for representative oscillators, is close to ±0.2 db for the range 3-150 kc/s, independent of the output level. The output stability is approximately ±0.5 db for a given output setting over long periods, provided the power supply voltage is stable to within ±10 volts. The output is adjustable in steps of less than 0.1 db from approximately 1 mW to 1,000 mW or from zero to +30 db referred to 1 mW. The output control is roughly calibrated in 1 db steps above the minimum of 1 mW. (Below 3 kc/s, the output falls, being about 7 db less at 200 c/s than at 3 kc/s for maximum output.) Because of this falling off in the output and an increase in the harmonic distortion below about 3 kc/s, this oscillator is not used for precise measurements below 3 kc/s.

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The principal circuit features are as shown in Fig. 2.

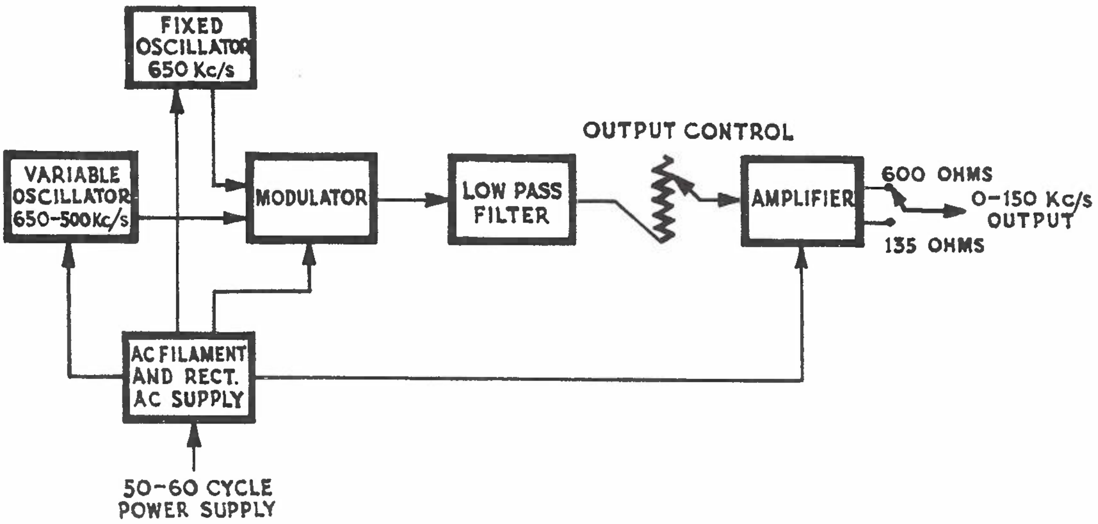

FIG. 2 - BLOCK SCHEMATIC OF 17B OSCILLATOR.

Two oscillators of high stability are incorporated, the first fixed at a frequency of about 650 kc/s and the second variable between 650-500 kc/s. The outputs are fed to a balanced valve modulator and then to a low-pass filter. The filter passes the difference frequency, but suppresses the fundamental component frequencies along with the higher order modulation products. The filter output passes via an output control to the main push-pull amplifier, appearing at the output jacks through an output transformer. The transformer provides output impedance of 600 ohms or 135 ohms, selected by a key. The variation in frequency of the variable oscillator from 650 kc/s to 500 kc/s, which provides the output frequencies from 0-150 kc/s, is only some 20% of the maximum frequency of 650 kc/s. Frequency variation over such a narrow band as this satisfies requirements for enabling a single coil and variable condenser to be used and makes possible a substantially flat output-frequency characteristic. This is distinct from the single valve oscillator, which would require a number of coils to cover the range to 150 kc/s along with the necessity for wide variation in tuning condenser capacity. Considerable change in output for differing frequencies is inherent under such conditions.

Heater and anode supply currents are provided through the medium of an A.C. power supply unit. Particular attention has been paid to regulation of the anode voltage to obtain output stability of a high order.

Facilities for calibrating the oscillator are provided. The two frequency points selected are 50 c/s (power supply frequency) and 100 kc/s.

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To satisfy the 50 c/s requirement, the fixed frequency oscillator only is adjusted by a trimmer condenser to bring about a frequency 50 c/s higher than that of the variable oscillator. At 100 kc/s, the tuning condenser capacity of both the fixed and variable oscillators is changed by identical amounts, but, since the variable oscillator tuning capacity is greater at 100 kc/s on account of its lower frequency, the relative change for the two oscillators will be different and, consequently, the difference or output frequency will be varied. At 50 c/s, the adjustment effected at the 100 kc/s point will have no effect, since the capacity of both condensers was changed by an identical amount at that point.

The 50 c/s calibration is brought about by beating the oscillator output against the 50 c/s power supply frequency, which is generally held within close limits. The film scale is set to 50 c/s, and a small current from the 50 c/s power supply is fed in series with the oscillator output to a calibrating lamp. The lamp will then vary in brightness at a rate equal to the difference between the oscillator output and power supply frequencies. A screw-driver adjustment is provided to bring about the change in the oscillator frequency in the manner indicated above. Synchronism between the power supply and oscillator output can occur for two distinct adjustments to the fixed oscillator frequency - when it is set above and when it is set below the variable oscillator frequency by the amount of the power supply frequency. In the latter case, an error of 100 c/s in the dial reading would result. Consequently, it is necessary to check the calibration at points both 50 c/s above and 50 c/s below the point of zero frequency on the film scale to ensure that the calibration has been made on the correct (difference) sideband.

The 100 kc/s point is checked against the resonant frequency of a crystal. A mark appears on the film scale of each oscillator at the measured resonant frequency of the individual crystal; that is, at or close to 100 kc/s. With the film scale set to this mark, the calibrating key is operated to connect the crystal across the grids of the amplifying stage and the calibrating lamp across the oscillator output. The oscillator frequency is then varied with the screw-driver control provided until the lamp is extinguished. This indicates that the oscillator frequency and the resonant frequency of the crystal are identical. The crystal at resonance, behaving as a low impedance shunt, reduces the oscillator output sufficiently for the calibrating lamp to be extinguished.

Calibration procedure is set out on an etched plate fixed to the front panel of the oscillator, although reference is lacking to the necessary precaution relating to the 50 c/s calibration mentioned. Where 60 c/s is referred to on this plate, read 50 c/s or the power supply frequency.

/ Battery

Battery Operation. Where a 17B oscillator is to be used for field testing, it is advantageous to add facilities enabling battery operation. While the nominal anode voltage is given as 180 volts, the makers mention that satisfactory operation is possible between 150-200 volts, with decreased or increased power output. Extending the limits further, it has been found that, with the anode voltage supplied by a 135 volt battery, a power output of +24.5 db above 1 mW is possible, compared with +30 db at 180 volts. The difference in the measured harmonic percentages for the two conditions is inappreciable, and the output impedance is unaffected. The value of this low voltage battery operation lies in the drop in current consumption from 100 mA to 72 mA.

5.7 Ryall-Sullivan Beat Frequency Oscillator. This oscillator employs two high frequency dynatron oscillators, one fixed at 100 kc/s and the other variable from 100 down to about 84 kc/s, so covering the frequency range 0 to 15,000 c/s. The oscillator operates from 22 and 130 volt batteries for cathode and anode supplies respectively, and dry cell batteries for bias.

(A dynatron is a screen-grid valve (tetrode) operated with the anode potential much lower than the screen potential. An examination of Fig. 17 of Paper No. 5, Long Line Equipment I, shows that, between anode voltages x and y, the anode current decreases whilst the anode voltage increases. More common circuit elements behave in the reverse manner, that is, the current flowing through them increases as the voltage across them increases. Thus, if the voltage across a circuit element increases from 8 to 10 volts and the current increases from 0.5 to 1 ampere, then the resistance of the element will be 2 volts divided by 0.5 ampere, or 4 ohms. If, however, the voltage increases from 8 to 10 volts and the current decreases from 1 to 0.5 ampere, then the increase in current is -0.5 ampere and the resistance is -4 ohms. In other words, when an increase in the voltage across a circuit element is accompanied by a decrease in current, then that element has a negative resistance. The screen-grid valve in the above reference exhibits a negative resistance between anode voltages x and y. Dynatron oscillators employ a screen-grid valve with the anode and screen voltages adjusted, so that the anode current decreases with increasing anode voltage over the operating portion of this characteristic. When a tuned circuit is connected in the anode circuit of a valve having these adjustments, the negative resistance presented by the valve characteristic can neutralise, either wholly or partly as required, the positive resistance in the tuned circuit, thus making that circuit extremely selective.)

/ Fig. 3

Fig. 3 shows a block schematic circuit of the Ryall-Sullivan oscillator.

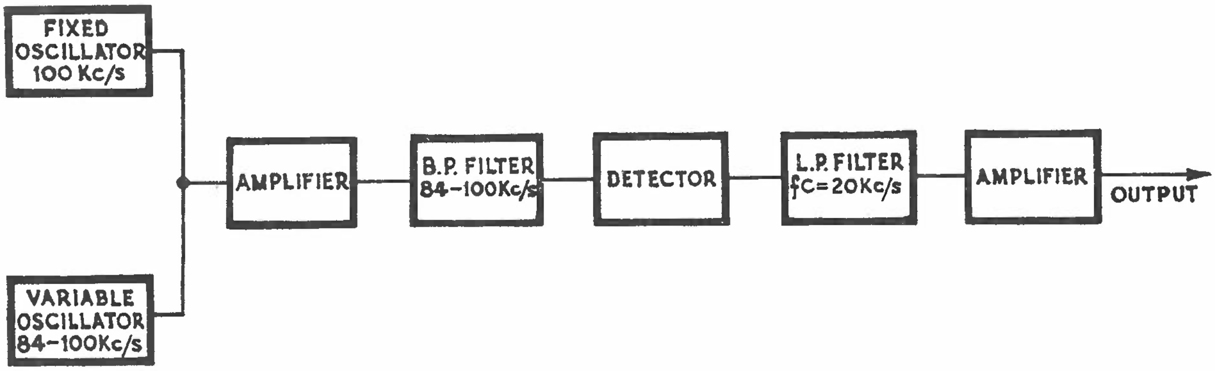

FIG. 3 - BLOCK SCHEMATIC OF RYALL-SULLIVAN OSCILLATOR.

The outputs of the fixed and variable frequency oscillators are first amplified by a two stage amplifier before being applied to the detector (which performs the modulation) via a band-pass filter. This filter eliminates any harmonics of the two oscillator frequencies which might be produced by the amplifier. The detector or modulator produces sum and difference frequencies, the difference frequencies (0 to 15,000 c/s) being passed by the low-pass filter and amplified by a two-stage amplifier.

The output impedance is 600 ohms non-reactive, the output voltage at this impedance being within ±0.1 db from 20 to 12,000 c/s.

The output power is a maximum of 300 milliwatts with an anode battery supply of 130 to 150 volts and a Type LS6A valve in the output stage. By changing this valve for a Type PX25 and increasing the anode voltage applied to this valve to 350 or 400 volts, the output power can be increased to a maximum of 3 watts.

6. VOLTMETERS AND AMMETERS USED IN A.C. MEASUREMENTS. (Also see Applied Electricity III, Paper No. 10.)

6.1 The wide range of frequencies covered by A.C. measurements on transmission lines and equipment eliminates any possibility of employing dynamometer or moving iron type ammeters and voltmeters, the wide range necessitating meters whose performances are independent of frequency. For this reason, the ammeters and voltmeters used are of the thermo-couple type, the rectifier type or valve type. In all of these instruments, the actual meter used is a D.C. meter, the thermo-couple, rectifier, or valve providing a source of D.C. actuated by the alternating current or voltage being measured.

6.2 The thermo-couple consists of two dissimilar metals in contact, this junction being heated either directly or indirectly by a heater through which the alternating current being measured is passed or across which the alternating voltage being measured

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is applied. The different characteristics of the two metals result in a difference of potential between them when the junction is heated, and, if a sensitive D.C. milliammeter is connected between them, as in Fig. 4, either the current flowing through, or the voltage applied across, the heater can be indicated.

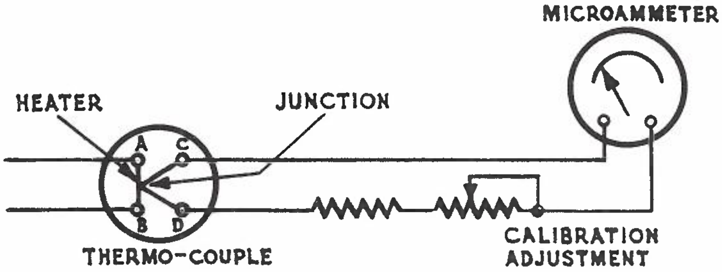


FIG. 4 - THERMO-COUPLE METER.

The milliammeter is calibrated to read heater current or voltage as required, and not the voltage or current produced by the thermo-couple.

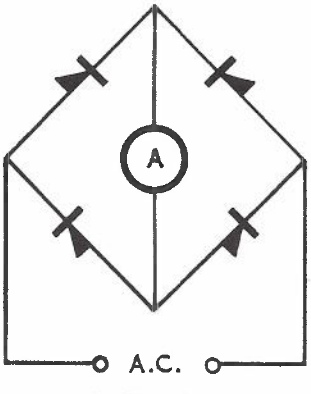
Almost any combination of dissimilar metals will produce the thermo-couple effect, but some combinations are better than others. Bismuth and antimony or copper and nickel are frequently used.

For general use, there are four standard thermo-couples, as follows -

(i) Type C with a heater resistance of 5 ohms and a safe current carrying capacity of up to 75 milliamperes.
(ii) Type N with a heater resistance of 46.5 ohms and a safe current carrying capacity of up to 15 milliamperes.
(iii) Type J with a heater resistance of 600 ohms and a safe current carrying capacity of up to 5 milliamperes.
(iv) Type AM with a heater resistance of 90 ohms and a safe current carrying capacity of 3.7 milliamperes.

As with other types of ammeters and voltmeters, shunts and multipliers can be used to extend and contract the range of the instruments.

6.3 The rectifier meter employs a bridge connected metal rectifier circuit, across two diagonal corners of which is connected an ordinary D.C. moving coil current meter. The A.C. to be measured is connected to the remaining two corners, as shown in Fig. 5.



RECTIFIER METER.
FIG. 5.

Although the full-wave bridge connected rectifier circuit is not essential, it is more usual to employ this than a half-wave circuit.

As in other types of voltmeters, series resistance is added to provide accurate voltage readings. Shunts and multipliers can be used to extend and contract the range of the instrument.

For the measurement of extremely small currents and voltages, the instrument can be preceded by an amplifier. When used as a current indicating device under these conditions, the current to be

/ measured

measured is passed through a resistance, the voltage drop across which is applied to the input of the amplifier. The instrument then reads the voltage drop produced across the resistance but is calibrated in terms of the current flowing through it. When used as a voltmeter, it is, of course, necessary to preserve the high impedance input.

6.4 Valve type voltmeters employ valves as the rectifying elements. The valve employed as the rectifier may be a diode, or a triode biased to cut-off. A D.C. moving coil current measuring meter is used as an indicating device. This principle can be used for either voltmeters or ammeters. When used as a voltmeter, it is necessary to preserve the high impedance input. When used as an ammeter, the current to be read is passed through a resistance, the instrument then reading the voltage drop produced across that resistance by the current flowing through it. The meter is, of course, calibrated in terms of the current flowing through the resistance. As in the rectifier type, the instrument may be preceded by an amplifier when extremely small currents or voltages are to be measured.

7. DECIBEL MEASUREMENTS AND METERS.

7.1 As discussed in Paper No. 1 of Long Line Equipment I, the decibel has two main applications in telephone practice, namely -

(i) To express the gains or losses of circuits or circuit elements in terms of the common logarithm of the ratio of the power sent into the circuit or element and the power delivered by it to a load. As the result is merely the common logarithm of a power ratio, the decibel has no physical significance as a unit when used in this sense, that is, it does not express an amount of power as do the expressions "3 watts" or "5 watts."

(ii) To express the amount of power present at a point in a circuit by referring that amount of power to some predetermined amount, for example, 1 milliwatt. Thus, 1 watt represents an amount of power, or "power level," which is 30 db greater than, or above, 1 milliwatt. Similarly, 1 microwatt represents a power level of 30 db below 1 milliwatt. The amount of power to which all other amounts are referred is termed the "reference" level or, more generally, "zero" level. Powers above the zero level are referred to as positive, for example, +30 db, whilst powers below zero level are referred to as negative, for example, -30 db. Applications of this method of expressing the powers present in the various parts of a circuit are illustrated in Figs. 12, 13 and 14 of Paper No. 6, Long Line Equipment II.

7.2 Communication circuits usually employ matched impedances, for example, aerial lines are terminated at each end by equipment

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whose impedance is 600 ohms, the nominal characteristic impedance of such circuits, whilst equipment terminating carrier cable (for example, a cable carrier system) has an impedance of 135 ohms, the nominal characteristic impedance of such cables. Because of this fact, measurements of db loss or gain over such circuits can be carried out by means of voltage or current measurements and the application of the formulae derived in Paper No. 1 of Long Line Equipment I.

$$\text{db loss or gain} = 20 \log_{10} \frac{\text{Voltage Input}}{\text{Voltage Output}} = 20 \log_{10} \frac{\text{Current Input}}{\text{Current Output}}.$$

Fig. 6 illustrates the method using voltmeters, the measurement being the loss produced by an aerial line having a nominal characteristic impedance of 600 ohms.

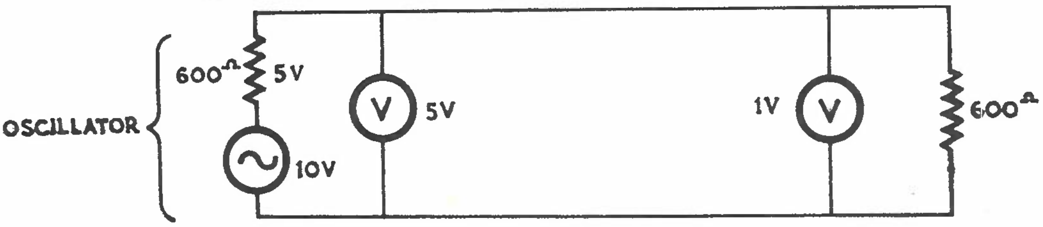

FIG. 6 - MEASURING LINE LOSS USING VOLTMETERS.

The impedance of the oscillator is 600 ohms, as is the termination at the distant end of the line. The voltages indicated in Fig. 6 are for explanatory purposes only and may not represent any set of conditions encountered in practice. The oscillator voltage is assumed to be 10 volts, half of which is dropped across the 600 ohm internal impedance of the oscillator, the other half being applied to the 600 ohm line and termination, as indicated by the voltmeter at the sending end. The voltmeter at the distant end indicates 1 volt across the 600 ohm termination, so that the line loss would be -

$$\begin{aligned}\text{db loss} &= 20 \log_{10} \frac{5 \text{ volts}}{1 \text{ volt.}} \\ &= 20 \log_{10} 5 \\ &= 20 \times 0.69897 \\ &= 14 \text{ db (approximately).}\end{aligned}$$

Exactly the same result would be obtained by connecting milliammeters in series at the sending and receiving end. The current read at the sending end would be -

$$\frac{10 \text{ volts}}{1,200 \text{ ohms}}$$

because the generator voltage is sending current into its 600 ohm internal impedance and the 600 ohm impedance of the line.

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The current at the receiving end would be -

$$\frac{1 \text{ volt}}{600 \text{ ohms}}$$

$$\therefore \text{ db loss} = 20 \log_{10} \frac{\dfrac{10 \text{ volts}}{1{,}200 \text{ ohms}}}{\dfrac{1 \text{ volt}}{600 \text{ ohms}}}$$

$$= 20 \log_{10} \frac{10}{1{,}200} \times \frac{600}{1}$$

$$= 20 \log_{10} 5$$

$$= 20 \times 0.69897$$

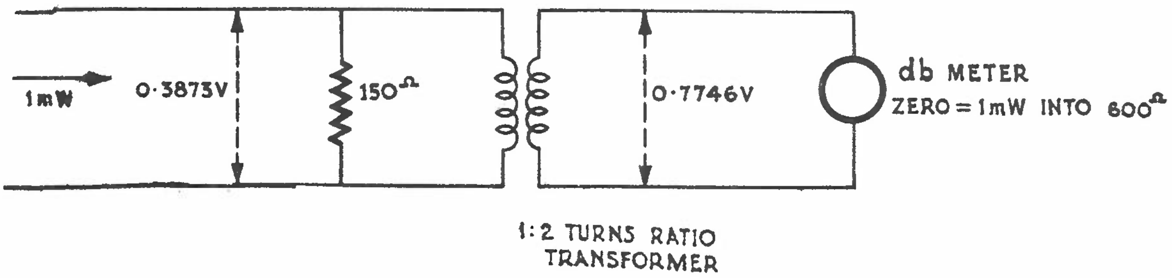
$$= 14 \text{ db (approximately).}$$

7.3 The power level in db above or below a zero reference level can be read directly from a voltmeter or ammeter calibrated to read db above and below a centre scale reading, which represents zero reference level, instead of being calibrated to read volts or amperes. For example, if zero level in Fig. 6 is 1 milliwatt, then the voltmeters could be designed to give a centre scale reading of 0.7746 volt, this being the voltage across 600 ohms when 600 ohms is absorbing 1 milliwatt of power. This centre scale reading could be marked zero. As the amount of power applied to 600 ohms increases, the voltage across it increases, thus causing the meter to read above zero. Conversely, as the amount of power applied to 600 ohms decreases, the voltage across it decreases, thus causing the meter to read below zero. As an example, a power of 0.25 milliwatt would produce a voltage of 0.3873 across 600 ohms. A power ratio of 1 milliwatt to 0.25 milliwatt is 6 db, so that the scale reading produced by the 0.3873 volt would indicate -6 db. Ammeters would be calibrated to indicate the zero or centre scale reading on 1.291 milliamperes, this being the current through 600 ohms when absorbing 1 milliwatt.

7.4 When a db meter calibrated to a zero of say 1 milliwatt into 600 ohms is used to measure the power in impedances other than 600 ohms, incorrect results will be obtained unless necessary adjustments are made. For example, 1 milliwatt into 150 ohms represents a voltage of 0.3873 across the 150 ohms or a current of 2.582 milliamperes through it. Thus, a db meter calibrated on a voltage basis to a zero of 1 milliwatt into 600 ohms would read -6 db instead of zero. This means that, when using

/ a

a db meter calibrated to a zero of 1 milliwatt into 600 ohms for reading power levels in 150 ohm circuits, 6 db would have to be added to all readings. For other impedances, the factor to be added or subtracted would, of course, depend on the impedance. Similarly, a db meter calibrated on a current basis to a zero of 1 milliwatt into 600 ohms would read +6 db when connected in a 150 ohm circuit where the power is 1 milliwatt, as the current would be 2.582 milliamperes. Thus, 6 db would have to be subtracted from all readings. Another solution is to employ matching transformers. For example, by connecting a transformer having an impedance ratio of 4 to 1, which means a turns ratio of 2 to 1, as in Fig. 7, a db meter calibrated on a voltage basis to a zero of 1 milliwatt into 600 ohms can be used to read directly the powers in 150 ohm circuits.



TRANSFORMER USED WITH db METER.

FIG. 7.

7.5 When an ordinary ammeter or voltmeter instrument is used as a db meter, the scale divisions become closer with increased values below zero. This can be seen by considering a db meter calibrated on a voltage basis to a zero of 1 milliwatt into 600 ohms. A zero reading will be obtained on 0.7746 volt. If the voltage is now doubled, the power will be 4 milliwatts, because power is proportional to the square of the current or voltage, or a current or voltage increase. Thus, doubling the voltage produces a reading of +6 db, and halving the voltage will produce a reading of -6db. In other words, a change of reading from zero to +6 db is produced by a voltage increase of 0.7746 volt, whilst a change of reading from zero to -6 db is produced by a voltage decrease of 0.3873 volt. To provide a uniform scale, the width of the air-gap between the pole pieces and moving coil of a db meter varies from a maximum when the meter is reading its maximum to a minimum when the meter is reading its minimum.

/ Fig. 8.

Fig. 8 shows a comparison between a meter with a uniform air-gap and one designed so that the flux across the air-gap increases towards the position of minimum reading.

(a) With Normal Air-Gap and Uneven Scale.

(b) With Varying Air-Gap and Even Scale.

DECIBEL METERS.

FIG. 8.

Because of the air-gap becoming smaller as the coil moves from the +5 position to the -5 position of Fig. 8b, the flux increases correspondingly, thus causing smaller increments of current or voltage to produce approximately equal movements of the moving coil and, therefore, approximately equal scale readings.

8. DETECTOR AMPLIFIERS.

8.1 Some of the A.C. measurements made on lines and equipment are such that precise values of current, voltage or power are not necessary. For such measurements, an indicating device only is required, the measurements being carried out on a comparison basis. The indicating device can be a meter or a pair of headphones.

8.2 For voice frequency measurements, headphones alone can be used, preceded by an amplifier if the level of the signal is too low to produce enough output from the headphones. For frequencies above the V.F. range, it is necessary to reduce the signal frequency to within the V.F. range before applying it to headphones, where such are used, and, in cases where the signal level is very low, it is necessary to amplify it before the frequency changing process takes place. Also, in many cases, headphones are not convenient, and meters are required. These requirements have led to the development of Detector Amplifiers which perform the following functions -

(i) Amplify signals so that they will produce an appreciable indication on a meter or from headphones.

(ii) When headphones are used, to provide a method of lowering the frequency of high frequency signals to a frequency within the V.F. range so that they can be heard.

/ (iii)

(iii) When a meter is used, to rectify the signal after amplification so that the resultant D.C. can provide an indication on a D.C. meter.

(iv) When it is necessary to gain an indication of the amplitude of some particular frequency from a number of frequencies present simultaneously, to reject all unwanted frequencies and accept only that required. This is done by tuning the detector amplifier.

Some of the detector amplifiers used for A.C. tests will now be briefly described.

8.3 The 7400 (1A) Detector Amplifier. This Detector Amplifier is a thermionic valve device for detecting and indicating, aurally or visually, alternating currents, the frequencies of which are above 3,000 c/s. It is designed primarily for use in making crosstalk and impedance measurements on lines over the carrier frequency range up to 50,000 c/s. This detector amplifier must ordinarily be employed in a comparison measuring circuit, since it is not a calibrated indicator.

When used for aural reception, the apparatus functions as a beat frequency or heterodyne detector, and the presence of the high-frequency current applied to the input is made known by a note of audible frequency in a telephone receiver, produced by beating with a local oscillator included in the circuit. When used as a visual indicator, the high-frequency current is made evident by the deflection of a meter in the anode circuit of a rectifier valve. The change from one function to the other is accomplished with a single key switch.

The set has greater sensitivity as a heterodyne detector than as a rectifier. In the first capacity, the gain varies somewhat with the frequency, but, in general, it may be said that an input of 0.5 micro-ampere at any frequency in the carrier range is sufficient to cause an audible note in the telephone receiver. When acting as a rectifier with full gain, the relation between input current and rectifier current will be approximately as shown in the following table -

Frequency	Input Required to Produce a Rectified Current of 0.5 Milliampere.
3,000	15 micro-amperes.
5,000	19 micro-amperes.
10,000	45 micro-amperes.
30,000	290 micro-amperes.

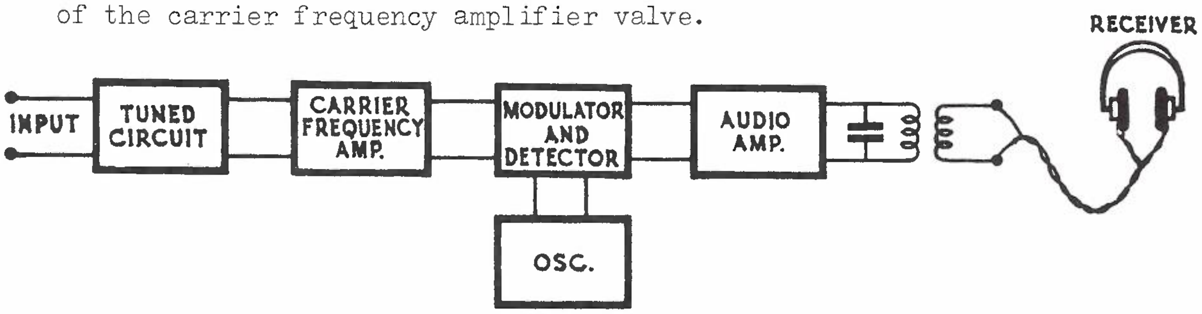
/ The

The input circuit of the detector amplifier is balanced to earth, and has an impedance which is practically constant at 600 ohms over the entire carrier frequency range up to 50,000 c/s.

Description of Circuit. When used as a detector (as shown in Fig. 9a), the circuit consists of an input tuned circuit, a single stage of carrier frequency amplification, an oscillator, a detector and a single stage of audio frequency amplification. The potential of the carrier frequency impressed upon the tuned circuit is controlled by a potentiometer in the input. The potentiometer works into the tuned circuit through a transformer which is shielded and balanced. The tuned circuit employs the principle of simple resonance and uses three coils to cover the frequency range satisfactorily. A switch mounted on the face of the detector selects the coil which is to be used. The first valve in the circuit, the carrier frequency amplifier, is connected across the condenser of the tuned circuit.

The local oscillator consists of a simple thermionic valve circuit with the frequency controlled in the usual way by the constants of its feedback circuit. An adjustable resistance is used in series with this feedback, in order to maintain the output at a reasonably uniform value throughout the entire frequency range.

When the unit is used as a detector, the output of the oscillator is fed into the detector valve through the secondary winding of a transformer, whose primary is coupled directly to the output of the carrier frequency amplifier valve.



(a) Used as a Detector (Aural).

(b) Used as a Rectifier (Visual).

DETECTOR AMPLIFIER (7400-1A).

FIG. 9.

The frequencies resulting from the modulation in the detector valve are then passed on to the final valve, an audio frequency amplifier, and thence through a transformer into the telephone receiver. The output side of this transformer is of low impedance, so as to allow the efficient use of the telephone receiver which is part of an ordinary headset.

The high frequency components of modulation are by-passed by the 0.02 μF condenser which is shunted across the output transformer, and, therefore, do not affect the receiver.

When in use as a rectifier (see Fig. 9b), the oscillator circuit is cut off, the detector valve is converted into a second stage carrier frequency amplifier and the last valve acts as a rectifier.

8.4 The 2A Detector Amplifier. (See Fig. 10.) This detector amplifier is designed to cover the frequency range up to 150 kc/s.

A gain-frequency characteristic flat to within very close limits is attained. This feature, combined with the flat output-frequency characteristics of the 17B oscillator, facilitates measurements and the speed with which they can be carried out. From the viewpoint of open wire measurements, it suffers the disadvantage of being untuned. Portability is considerably benefited by the inclusion of self-contained anode and filament batteries.

Voltage amplification is provided by a two-stage amplifier feeding a diode rectifier, with the valve of a valve voltmeter across the load resistance. The indicating meter in the anode circuit of this tube is calibrated to read in db. The scale is large and open and calibrating facilities are provided. The uniform gain-frequency characteristic is based upon two resistance-capacity coupled pentode stages, in which the circuit constants have been proportioned in such a manner as to achieve the desired uniformity as distinct from maximum gain and voltage output.

The rectifier-valve voltmeter section is so designed as to provide a rectified output that varies in logarithmic fashion, giving an approach to a linear db scale on the indicating meter. Another feature of considerable practical value is the current limiting action of the vacuum tube voltmeter circuit that provides extreme compression of the meter range near to maximum deflection, so that, irrespective of input to the amplifier, the meter needle cannot go off scale.

Sensitivity is such that an input of approximately 53 db below 1 mW will cause the indicating meter to read zero on the scale

/ Fig. 10

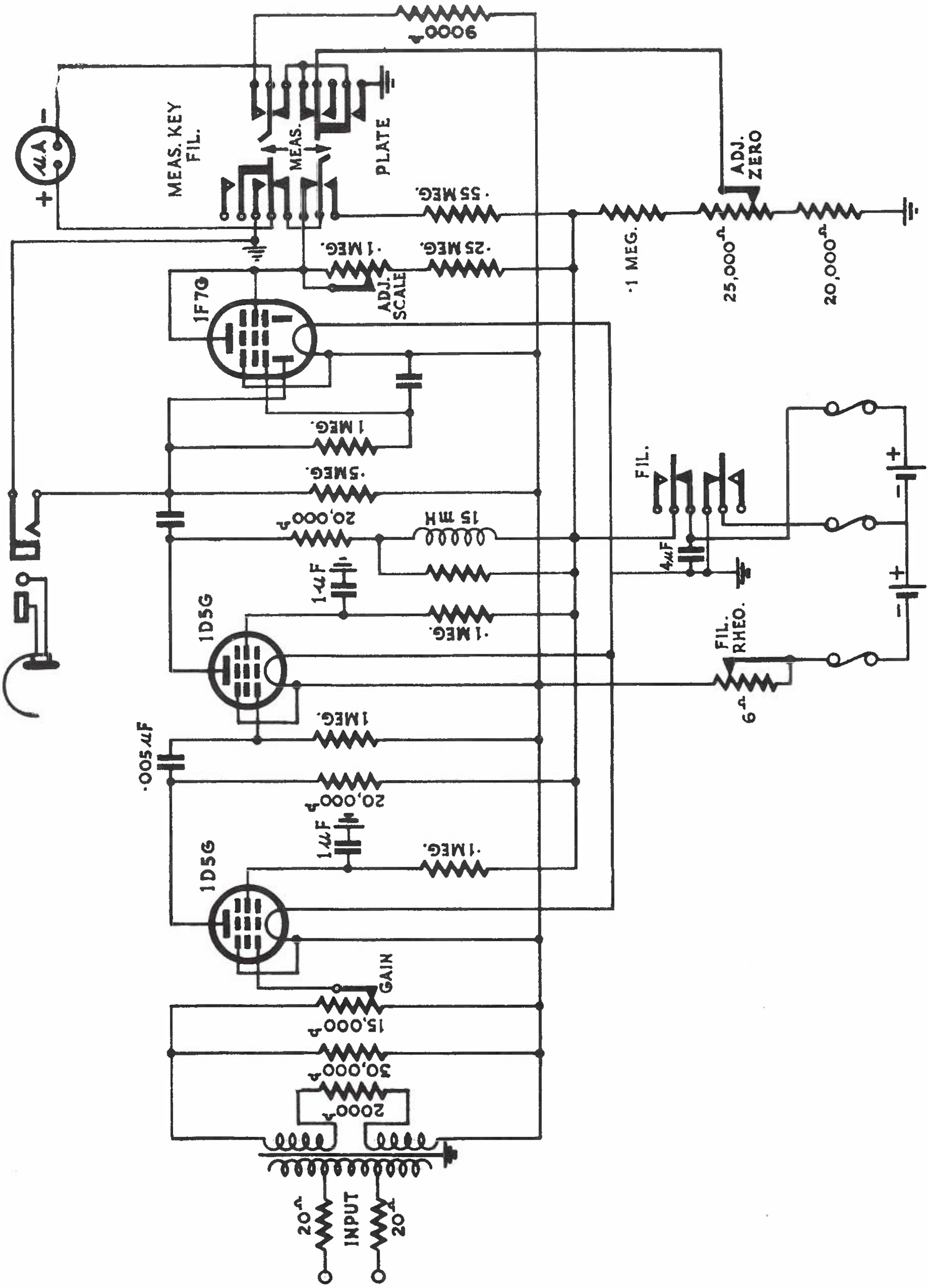


FIG. 10 - CIRCUIT OF 2A DETECTOR AMPLIFIER.

with the gain control set to maximum. This sensitivity holds with frequency from 5-150 kc/s within limits of ±0.25 db, provided the filament voltage is adjusted to the correct value and the anode voltage is maintained above an indicated minimum. Provision is made for the indicating meter to function as a voltmeter across the filament and anode batteries.

Input Impedance. The 2A Detector Amplifier has been designed with operation on 135 ohm circuits as the prime consideration, although the input transformer also provides a 600 ohm input impedance. The 135 ohm input is maintained to within some ±2 ohms from 5-150 kc/s, giving a reflection coefficient of better than 1%. The nominal 600 ohms input impedance, on the other hand, for the particular instrument tested is nowhere better than 490 ohms, the worst value being 403 ohms at 100 kc/s, the reflection coefficient in this case being 20%. This figure can be considerably improved by the addition of suitable series resistance. To change from 135 ohms to 600 ohms input impedance, the leads connected to tappings of the input transformer primary are unsoldered and connected to the extreme ends of the winding.

As stated above, a reading of zero on the meter scale is obtained for an input of -53 db. The calibration extends downwards to -4 below zero, at which point the needle falls off scale.

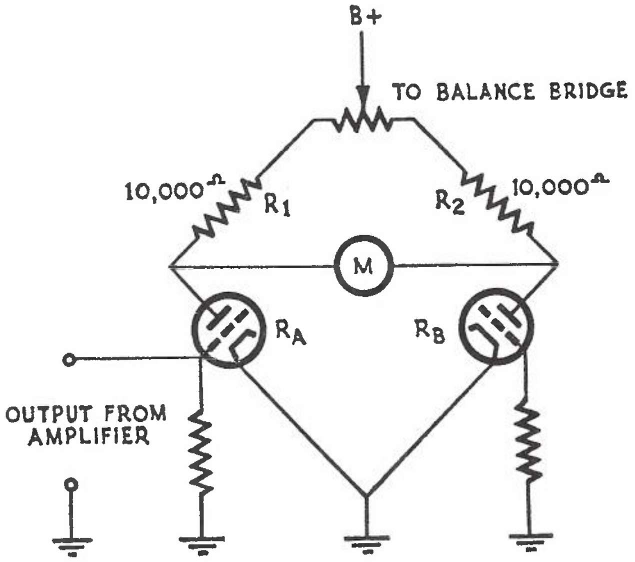
8.5 The 3A Detector Amplifier. This Detector Amplifier provides an input circuit having either an untuned or a highly selective characteristic as required. In both cases, the indication is visual, although headphones can be used for the audio-range.

As a selective amplifier, the input is continuously tunable over the range 750 c/s to 350 kc/s. The range is covered with five switched tuning coils tuned by fixed decade condensers in conjunction with a variable condenser. The amplifier consists of three resistance-capacity coupled stages feeding a balanced valve detector and a D.C. indicating meter. The selective circuit can be switched into circuit between the secondary of the input transformer and the first amplifier valve.

The detector is in the form of a bridge, as shown in Fig. 11. Two similar triodes function as two equal arms of the bridge and two resistances as the remaining two arms. The indicating meter is connected across the valve anodes and reads zero when the bridge is accurately balanced by adjustment of the resistance arms. One valve functions as a balance only, and has its grid connected to earth. The second valve functions as a grid detector, rectifying the amplified signal. This rectification brings about a change in anode current which upsets the bridge

/ balance

balance and causes a deflection of the indicating meter. There is no effect, as in the 2A Detector Amplifier, to limit the meter needle swing, and the very high gain of the amplifier requires considerable care if the meter needle is to escape damage.



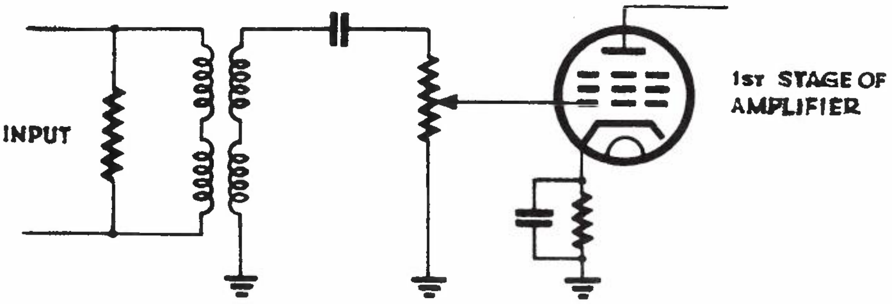
CIRCUIT OF BRIDGE TYPE DETECTOR IN 3A DETECTOR AMPLIFIER.

FIG. 11.

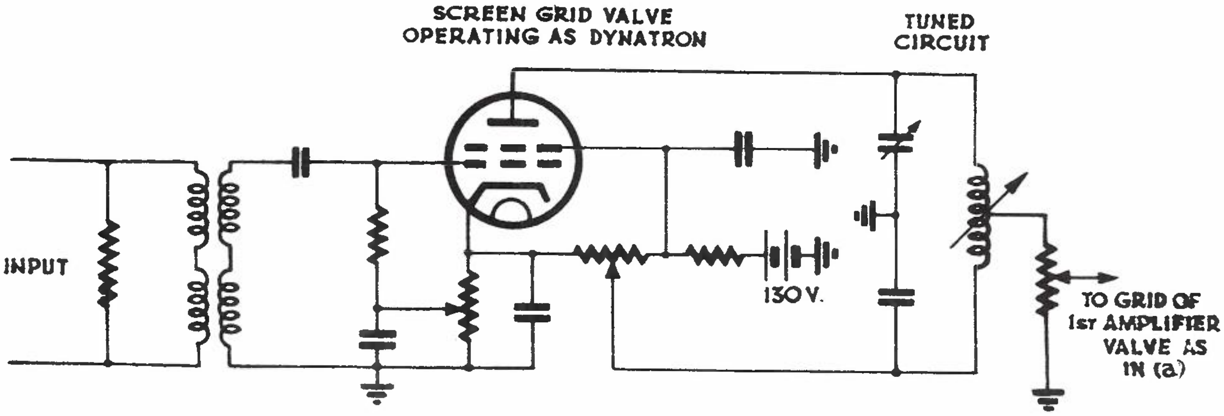
The selective circuit operates on the dynatron principle and, while rather critical of adjustment, provides selectivity of a high order. The operation of the circuit depends upon the negative anode resistance characteristic of a screen-grid valve operating with anode voltage lower than the screen voltage. With a resonant circuit connected into such an anode circuit, the resistance of the resonant circuit can be reduced with marked increase in selectivity. In the 3A Detector Amplifier, the negative anode resistance of the valve and, consequently, the selectivity can be controlled by varying the grid bias. Maximum selectivity is obtained where the equivalent series resistance of the negative anode resistance is equal to the effective series resistance of the resonant circuit at the resonant frequency. This condition satisfies the requirements for oscillation to commence, so that, for maximum stable selectivity, it is necessary that the "Selectivity Control" be carefully adjusted to bring the circuit to oscillation, and then brought back to a point just below that at which oscillation ceases.

/ Figs.

Fig. 12a and 12b compare the tuned and untuned conditions.



(a) Untuned Condition.



(b) Tuned Condition.

(Dynatron and Tuned Circuit inserted between Input and 1st Amplifier Stage.)

INPUT CIRCUIT OF 3A DETECTOR AMPLIFIER.

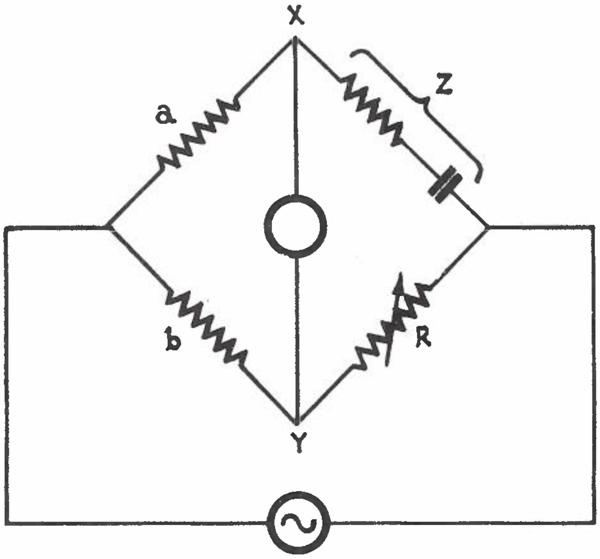
FIG. 12.

Sensitivity. In the selective condition, the sensitivity is dependent upon care in the adjustment of the "Selectivity Control." It is given by the makers as mid-scale meter deflection for an input 110 db below 1 mW. Used with an untuned input, the sensitivity is some 80 db. This is considerably higher than that of the 2A Detector Amplifier.

The gain-frequency characteristic in the untuned condition falls by approximately 2 db from 1 kc/s to 150 kc/s.

9. IMPEDANCE BRIDGES.

9.1 As has been discussed in other Papers of this Course of Technical Instruction, a Wheatstone Bridge is the most accurate and convenient method of determining the values of unknown resistances. This also applies to determining the values of unknown impedances. In determining impedances, however, phase angles have to be considered as well as magnitudes, so that the variable arm of the bridge should contain reactance as well as resistance. To illustrate this point, Fig. 13 is included.



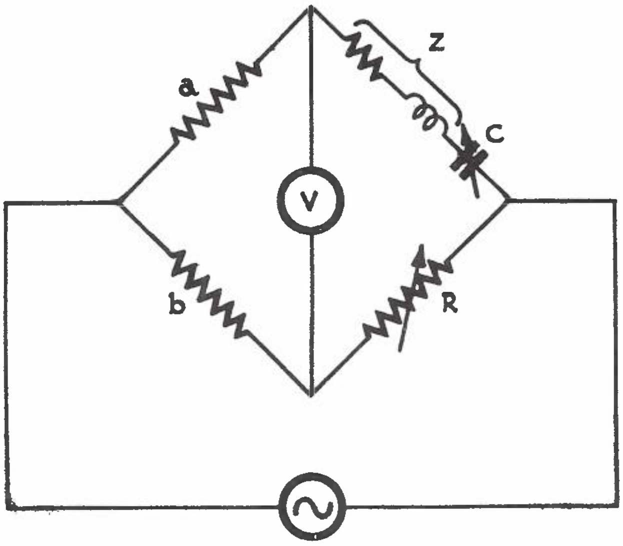
RESISTANCE BRIDGE USED TO MEASURE IMPEDANCE.

FIG. 13.

It might be thought that, when a = b, the bridge will balance when R equals the magnitude of Z. Such will not be the case, however, because, even though both Z and R be, say, 1,000 ohms, the current through b and R will be in phase with the voltage applied across them from the generator, whilst that through a and Z and through b and R are not equal. Thus, some voltage difference always exists between points X and Y, so that the bridge will not balance. The solution is to connect a variable condenser in series with R, so that the phase as well as the magnitude of Z will be taken into account. The bridges employed in practice are either "Series" bridges, which means that the resistance and reactance in the variable arm are in series, or "Parallel" bridges, which means that they are in parallel. The bridge in Fig. 13 is a series bridge.

/ 9.2

9.2 The bridges used for impedance measurements on long line equipment employ a resistance and a capacity in the variable arm. If an impedance with an inductive reactance is being measured, the bridge will not balance with a capacity in the adjustable arm. Provision is made in the bridges to move the capacity from the adjustable arm into the arm under test, as in Fig. 14.



MEASUREMENT OF IMPEDANCE WITH INDUCTIVE OR POSITIVE REACTANCE.

FIG. 14.

A balance will now be obtained when the capacitive reactance of the bridge condenser equals the inductive reactance of the impedance under test, and the resistance in the variable arm equals the resistance in the impedance under test.

Some of the bridges used for impedance measurements on long line equipment will now be described.

9.3 The 4A Impedance Bridge. The 4A Impedance Bridge is a testing unit designed to measure the impedance of lines, filters, coils and other apparatus, which is associated with, or part of, telephone or telegraph systems. The bridge is satisfactory for measurements of impedances between 50 and 10,000 ohms over a range extending from 200 c/s to 35 kc/s. The bridge is of the hybrid coil type, and is arranged for connecting an unknown impedance to one side of the coil and balancing against a known adjustable impedance (resistance and capacity) on the other side. A hybrid coil arrangement is used because of the low losses produced by such coils as compared with the losses produced by a bridge with resistance arms. The known resistance is controlled by four dial switches, as shown in the

/ panel

panel arrangement of the bridge, and is variable from 0 to 11,110 ohms in steps of 1 ohm. The known capacity is adjustable by four similar dial switches, and ranges from 0 to 11.11 µF in steps of 0.001 µF. A variable air condenser with a maximum capacity of 1,500 µµF allows for fine adjustment. Fig. 15 illustrates the face equipment of a 4A Bridge.

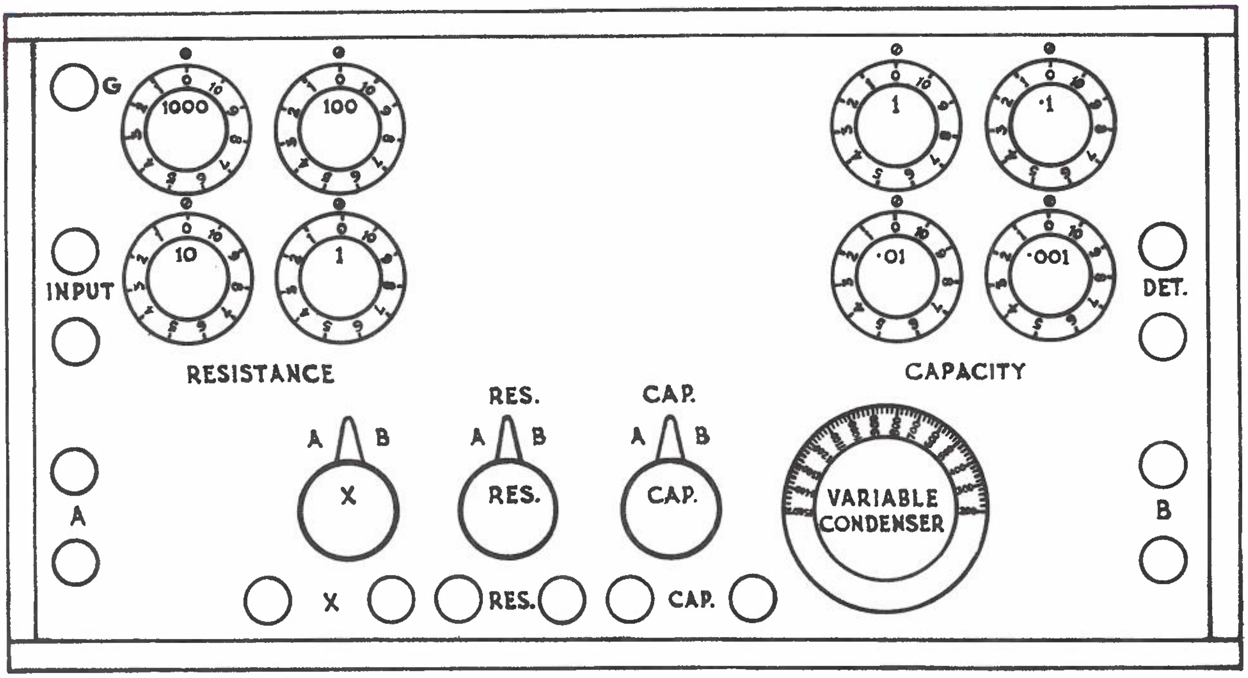


FIG. 15 - 4A IMPEDANCE BRIDGE PANEL ARRANGEMENT.

The unknown impedance and the known adjustable impedance are both connected to the hybrid coil through a set of three switches, and Fig. 16 shows five of the nine possible circuit connections which may be effected with the bridge by means of these switches. The switches "X", "RES" and "CAP" are operated to the positions shown at the right of each sketch to obtain the particular combination desired. These switches are also shown on the panel arrangement drawing. The first of these switches "X" controls the location in the circuit of the unknown impedance, and it may be operated to either the A or B side of the hybrid coil. The second switch marked "RES" governs the location of the adjustable resistance. The "RES" key may be operated to either the A or B position of the hybrid coil, and, in the mid-position, is connected to a separate pair of terminals. The third switch marked "CAP" performs the same function for the adjustable capacity.

When making line measurements, screened transformers are required in the A and B arms to prevent longitudinal currents affecting the hybrid coil and producing errors in readings.

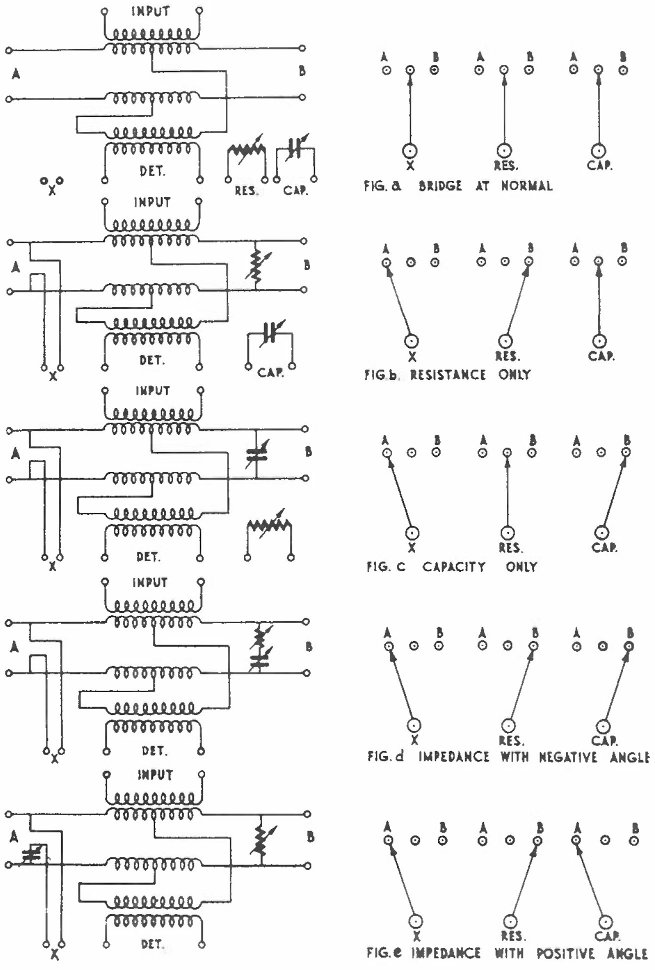
/ Transformers

Transformers used have a 1 : 1 ratio and are provided with electrostatic screens which must be earthed.

The measuring current is supplied by an oscillator connected to the input terminals. The receiver is used as an indicator at audio frequencies, and a detector amplifier is used at carrier frequencies. When a condition of balance is obtained, tone will not be heard in the receiver, or the meter on the detector amplifier will read zero with maximum gain.

The bridge will read values of resistance, capacity and impedance with positive and negative angles. With switches X, R and C in the centre position, terminals A and B are connected to the hybrid coil, as shown in Fig. 16a. Terminals X are disconnected. Resistance and capacity standards are connected to their respective terminals. This permits additional resistance and capacity being added.

9.2 Measurements. To measure Resistance (see Fig. 16b), the resistance standards switch, R is operated to B side, and the unknown resistance switch, X, is operated to A side. Switch C remains in centre position.



SOME COMBINATIONS ON 4A IMPEDANCE BRIDGE.
FIG. 16.

To measure Capacity (see Fig. 16 c), the capacity standards switch, C, is operated to B side, and the unknown capacity switch, X, is operated to A side. Switch R remains in centre position.

To measure Impedance with negative angle (see Fig. 16d), the resistance standards switch, R, is operated to B side. Resistance and capacity standards are connected in series on the B side of the hybrid coil. Switch X is operated to A side, and the unknown impedance is connected to the A side of the hybrid coil.

If, say, a condenser is being measured and the condenser has a resistance component, work will be done on the resistance which also slows up the rate of charge and discharge of the condenser. When balancing, some value

/ of

of resistance must be added in series with the capacity standard to produce the same phase angle on this arm of the bridge as on the unknown arm. Otherwise, no matter how finely the capacity standard was varied, it could not produce a balance, as the currents in each half of the bridge, although equal, would not rise and fall in unison. The capacity standard arm would be at 90 degrees for all values, but the unknown would be at some value less than 90 degrees.

In making measurements, the resistance standard is first set at a low figure, about 10 ohms, and the capacity standard is varied until the point of lowest tone is reached, indicating that the two capacities are fairly closely balanced.

The resistance standard is now increased or decreased until a lower value of tone is heard, and a finer balance is made on the capacity standard. Adjustment of capacity and resistance is continued until the point of no tone is obtained. Then -

$$\text{Reactance } X = \frac{1}{\omega C}$$

$$\text{where } \omega = 2\pi f$$

and C = capacity reading in farads.

The resistance reading obtained equals the Effective Resistance of the combination at the measuring frequency.

Example. If frequency = 1,000 c/s, reading of capacity = 2 μF and reading of resistance = 60 ohms, find the impedance and angle.

$$\text{Reactance} = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \frac{1 \times 10^6}{2 \times 3.14 \times 1{,}000 \times 2}$$

$$= \frac{1 \times 10^6}{6{,}280 \times 2} = \frac{10^6}{12{,}560} = 80 \text{ ohms.}$$

$$\text{Impedance } Z = \sqrt{R^2 + X^2} = \sqrt{60^2 + 80^2}$$

$$= \sqrt{10{,}000} = 100 \text{ ohms.}$$

$$\text{Angle } \theta = \tan^{-1}\frac{X}{R} = \tan^{-1}\frac{80}{60}$$

$$= \tan^{-1} 1.3 = 53^\circ 8'$$

$$\text{and } Z = 100 \text{ ohms } \underline{/53^\circ 8'} \text{ ohms}$$

To measure Impedance with positive angle (see Fig. 16e), operate resistance standards switch, R, to B side, capacity standards switch, C, to A side and impedance to be measured, switch X, to A side. Resistance standards are connected to B side of hybrid coil, and capacity standards are connected in series with unknown impedance on A side of hybrid coil to neutralise the inductive reactance component of the impedance. The capacity standard must be adjusted to establish a condition of resonance, that is, the inductive reactance is balanced by the capacity reactance. In this condition,

/ the

the e.m.f. and current are in phase, and the only component acting in the resonant arm is pure resistance, which can be balanced at the B arm by the resistance standards. It is not possible to obtain a full balance until a state of resonance is obtained on the A side. In making a measurement, the resistance standard is first set at a low figure, say, 10 ohms, and the capacity varied until the point of lowest tone is reached. This is an indication that the inductance and capacity are being matched. Adjust resistance standards for lower value of tone, and capacity standards until point of no tone is reached. If the ohmic resistance of the circuit being measured is known, the resistance standards can be set about this value, simplifying the balance.

At resonance, the positive reactance equals the negative reactance, that is -

$$\omega L = \frac{1}{\omega C}$$

where C = capacity reading in farads.

An impedance with an effective resistance of 60 ohms, positive reactance 100 ohms and negative reactance 100 ohms would be 60 ohms zero angle.

$$\frac{R}{60 \text{ ohms}} \left| \begin{array}{l} + X = 100 \text{ ohms} = \omega L \\ \\ - X = 100 \text{ ohms} = \dfrac{1}{\omega C} \end{array} \right.$$

Impedance offered by circuit is -

$$Z = \sqrt{X^2 + R^2}$$

where R = effective resistance (R reading on bridge),
and X = reactance.

To find Inductance -

At resonance, $\omega L = \frac{1}{\omega C}$

$$\therefore L = \frac{1}{\omega^2 C}$$

where L = inductance in henrys,
$\omega = 2\pi f$,
and C = capacity readings in farads at resonance.

Example 1.

Frequency = 1,000 c/s.
Capacity arm = 2 μF.
Resistance arm = 60 ohms.
Reactance $\frac{1}{\omega C}$ = 80 ohms.
Impedance $Z \underline{/\theta}$ = 100 $\underline{/53^\circ 8'}$ ohms.

/ Example 2.

Example 2.

A 50 + 50 ohms high impedance "A" relay, both windings connected in series-aiding, is balanced on the bridge with the following readings -

$$R = 3{,}078 \text{ ohms}, \quad C = 0.0187\ \mu F, \quad f = 1{,}000 \text{ c/s}.$$

Find (i) Reactance of windings,
(ii) Impedance offered at 1,000 c/s, and
(iii) Inductance.

(i) At resonance, $\omega L = \frac{1}{\omega C}$

$\therefore$ Positive Reactance $= \frac{1}{\omega C}$

$$= \frac{1}{6{,}280 \times 0.0187 \times 10^{-6}} = \frac{1}{6{,}280 \times 187 \times 10^{-10}}$$

$$= \frac{10{,}000{,}000{,}000}{6{,}280 \times 187}$$

$$= \underline{\underline{8{,}515 \text{ ohms}}}.$$

(ii) Impedance $Z = \sqrt{X^2 + R^2}$

$$= \sqrt{8{,}515^2 + 3{,}078^2}$$

$$= \underline{\underline{9{,}054 \text{ ohms}}}.$$

(iii) Inductance $L = \frac{1}{\omega^2 C} = \frac{1}{4\pi^2 f^2 C}$

$$= \frac{1}{39.4 \times 1{,}000^2 \times 0.0187 \times 10^6}$$

$$= \frac{1}{39.4 \times 10^6 \times 187 \times 10^{-10}}$$

$$= \frac{1}{39.4 \times 187 \times 10^{-4}} = \frac{10^4 \times 10}{394 \times 187}$$

$$= \frac{10^5}{394 \times 187} = \frac{100{,}000}{73{,}678}$$

$$= \underline{\underline{1.3 \text{ henrys}}}.$$

/ 9.3

9.3 The 5A Impedance Bridge (S.T.C.). This bridge is designed for impedance measurements up to 150 kc/s, and employs a parallel resistance-capacitance balancing circuit instead of the series circuit employed in the 4A bridge described above. Fig. 17 shows a picture of the bridge, whilst Fig. 18 shows some possible measuring conditions, the different circuit arrangements being brought about by the operation of keys.

The bridge is of the balanced hybrid-coil type and has R and C components reading to 11,111 ohms (minimum steps of 0.1 ohm) and 1.111 μF (minimum steps given by air condenser calibrated in μμF × 10) respectively. The components are double-screened, and the hybrid coil exhibits a high degree of balance to earth in respect both of the ratio arms and the "Unknown" terminals. The capacity standards are wired permanently on one side of the hybrid coil, the residual capacity being balanced out with a trimming condenser on the opposite side (see Fig. 18). The unknown impedance and the resistance standards are interchanged about the two sides of the hybrid for change of sign in the reactive component by operation of the two keys marked X and RES respectively.

9.4 W.E. 5A Impedance Bridge. (See Fig. 19.) This bridge is designed for the measurement of both Impedance and Return Loss. It differs from the S.T.C. bridge in being of the resistance ratio arm type, as distinct from the more common hybrid coil arrangement. The ratio arms consist of four pairs of equal resistances with the "known" and "unknown" impedances connected between the mid-points of the opposite pairs.

One decade only and a slide wire take care of the restricted R range of 1,100 ohms. This value can be effectively extended by the expedient of switching a 1,000 ohm resistance in shunt across the "unknown" terminals. The C range is also rather restricted, having a maximum capacity of 0.111 μF contained in two decades and an air condenser. Each operation of the CAP. STD. key places a small variable balancing condenser across the side of the bridge opposite to that occupied by the capacity standards. Operation of an UNBAL.-BAL. key provides either unbalanced or balanced operating conditions.

For measurement of negative angle impedance, both the resistance and capacity standards are connected to the S_1-S_2 ("known") side of the bridge by operating the RES. STD. and CAP. STD. keys to the S_1-S_2 position. The RES. STD. key remains at S_1-S_2 for positive angle measurement, but the CAP.STD. keys are set to X_1-X_2 (connecting to the "unknown" side of the bridge). This causes some change in zero balance conditions and requires that separate zero balancing be carried out for change of sign in the measured impedance.

/ Fig. 17

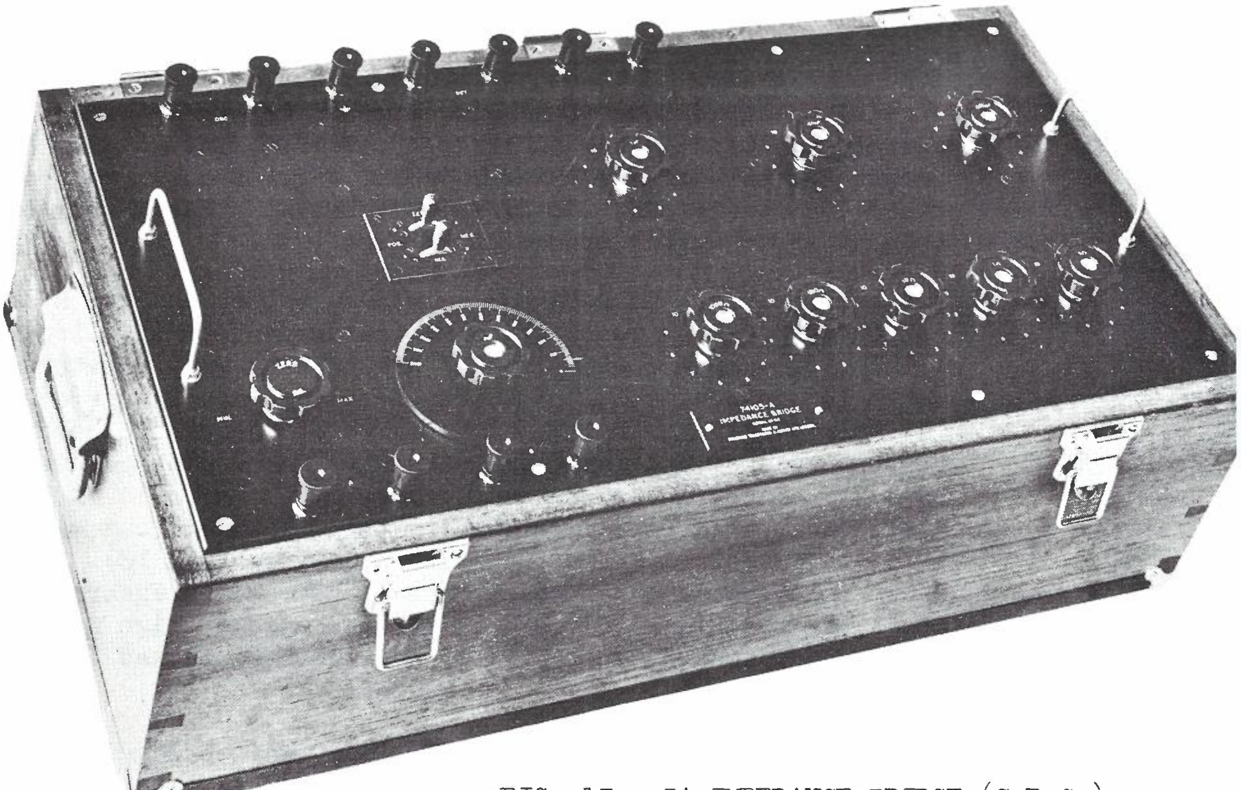


FIG. 17 - 5A IMPEDANCE BRIDGE (S.T.C.).

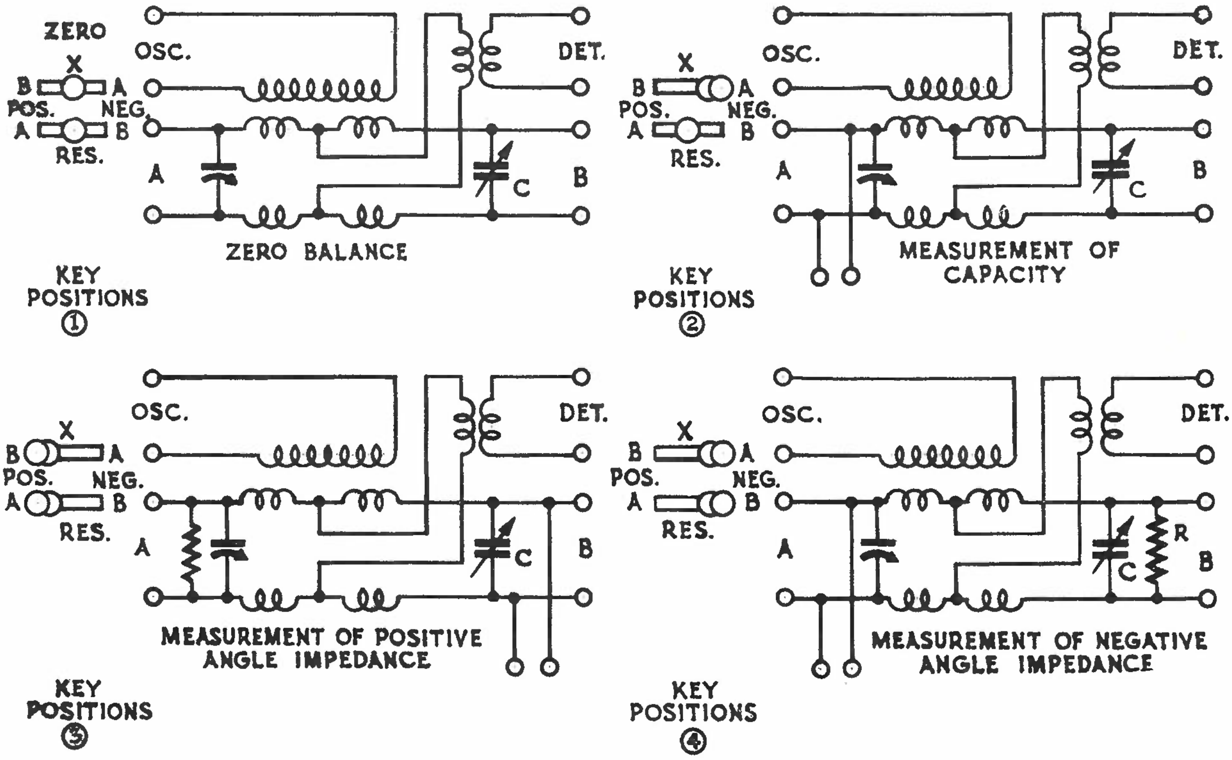
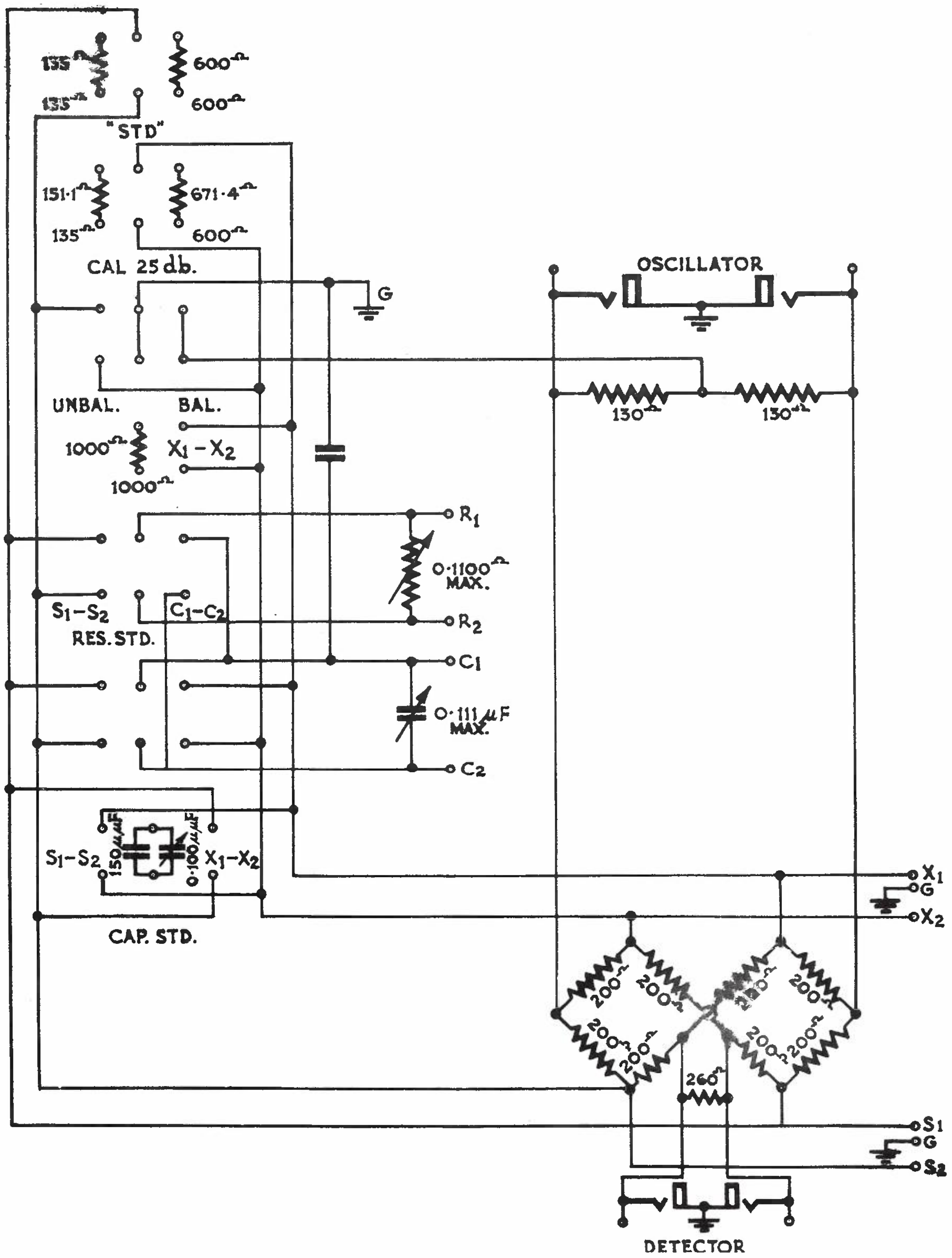


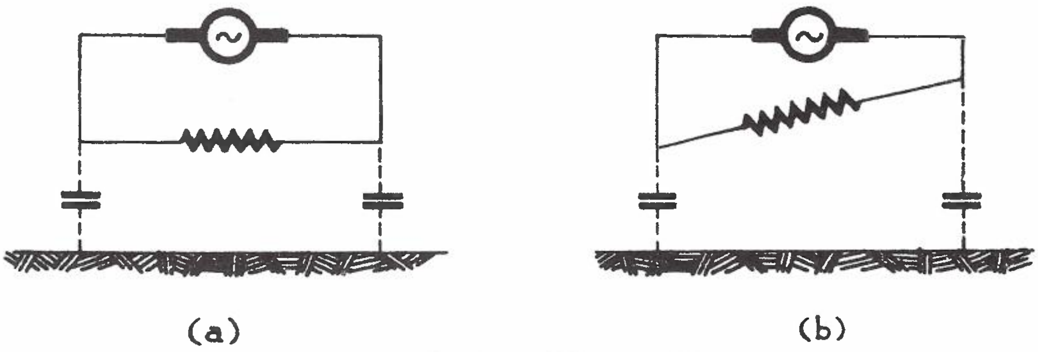
FIG. 18 - 5A BRIDGE SCHEMATIC OF TESTING CONDITIONS.



SCHEMATIC CIRCUIT OF W.E. 5A BRIDGE.

FIG. 19.

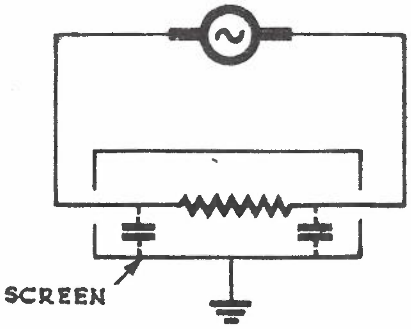
9.5 General Notes on Series and Parallel Bridges. When accuracy is required, the capacity between the earth and the components in the balancing arm of an A.C. bridge must be taken into account. Figs. 20a and 20b show the capacity to earth about the ends of a resistance, to which an alternating voltage is applied, for two positions of this resistance with respect to the earth.



CAPACITIES TO EARTH.

FIG. 20.

From Fig. 20, it will be seen that the resistance is shunted by two capacities to earth in series, and that, as the position of the resistance with respect to the earth changes, the shunt capacity changes. This will mean that the resistance is shunted by a capacitive reactance, which varies with the position of the resistance with respect to earth. If the capacity to earth is made independent of the position of the resistance with respect to the earth, corrections can be made in the calibration of the bridge to take into account the effect of this fixed capacity. This is done by enclosing the bridge components in metal cans, called "screens," which are earthed. The effect of the screen on the resistance of Fig. 20 is indicated in Fig. 21, from which it will be seen that the capacity between the resistance and the screen, which is the capacity between the resistor and earth, is independent of the position of the resistor with respect to the earth. Further, the screen equalises the capacities to earth. This screening is also extended to the leads connecting the various components together. The 4A and 5A bridges described previously employ fairly elaborate screening arrangements because of the number of components employed, but the reasons for this screening are the same as those outlined above, that is, to equalise capacities to earth, where necessary, and to make that capacity to earth independent of the position of the components with respect to the earth. This /screening

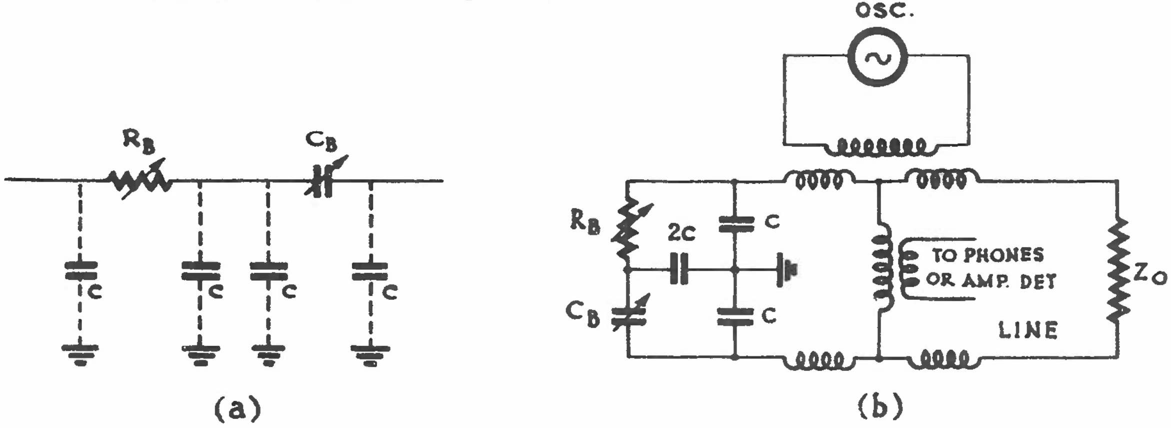


EFFECT OF SCREEN.

FIG. 21.

screening applies not only to bridge components but also to components of other testing equipment employed on A.C. measurements.

In Paper No. 4 of Long Line Equipment I, it was pointed out that the transposition of aerial circuits and the formations employed in quad cables result in voltages being induced, either electrostatically or inductively, across each wire of each circuit from neighbouring circuits. These voltages act in the same direction along each wire of the circuit and, if unequal, the difference between them produces a resultant voltage which is responsible for sending a disturbing current, evident as cross-talk or noise, around the circuit (see Fig. 4, Paper No. 4, Long Line Equipment I). These voltages are called "longitudinal" voltages, because they act along each wire of a circuit. It was also pointed out, in connection with Fig. 10 of the Paper mentioned above, that equal longitudinal voltages along each wire of a circuit can cause interference if the impedances to earth from each wire of a circuit are unequal or unbalanced. The balancing circuit of a 4A bridge provides an impedance which is unbalanced to earth, even though the screening arrangements equalise the distributed capacities and make them independent of the position of the bridge with respect to the earth. The capacities present in the series balancing circuit of a 4A bridge are shown in Fig. 22a, and their arrangement in the bridge circuit proper is shown in Fig. 22b.



(a) (b)

R_B = RESISTANCE IN BALANCE

C_B = CAPACITY IN BALANCE

C = EQUAL CAPACITIES TO EARTH

UNBALANCE TO EARTH IN 4A BRIDGE.

FIG. 22.

An inspection of Fig. 22b will show that the impedances to earth from each side of the line via the hybrid coil windings and balancing circuit are not equal at any frequency. The impedance to earth from one side of the line is provided by R_B in series with

/2C

2C, these, in turn, being in parallel with C, whilst the impedance to earth from the other side is provided by C_B in series with 2C, these, in turn, being in parallel with C. Thus, with equal longitudinal voltages on each side of the circuit under test, unequal currents will flow to earth at the balancing circuit via the identical windings of the hybrid coil. Unequal voltage drops will be produced across these windings, so that, even though the bridge is balanced as regards the impedance being measured, an unbalance will be indicated in the phones or on the output meter of the amplifier. When a balance is obtained, this balance will not give a true indication of the impedance of the line under test, as it is a balance brought about not only for the impedance of the line but also for the effect of the unbalance to earth.

At voice frequencies, the reactances of the capacities to earth, shown in Fig. 22, are high enough to produce little effect, so that the 4A bridge can be used as in Fig. 22b for measuring line impedances at audio frequencies. At carrier frequencies, however, the reactances of the capacities to earth produce noticeable effects, these increasing as the frequency is raised. It is desirable, therefore, to prevent the longitudinal voltages from sending current into the hybrid coil balancing circuit. This is done by connecting between the bridge and line under test a screened transformer, which is accurately balanced about the centre point of the windings, this centre point being earthed. By this means, the equal longitudinal voltages on the line will cause equal currents to flow in the two halves of the line windings of the transformer, and, as these currents flow in opposite directions in the two half windings, the resultant flux is zero and no voltage is induced across the winding to which the bridge is connected. Fig. 23 illustrates the idea, the principle being the same as the Phantom Circuit described in Paper No. 4 of Long Line Equipment I.

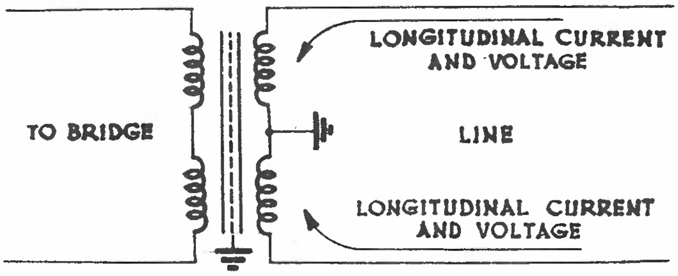


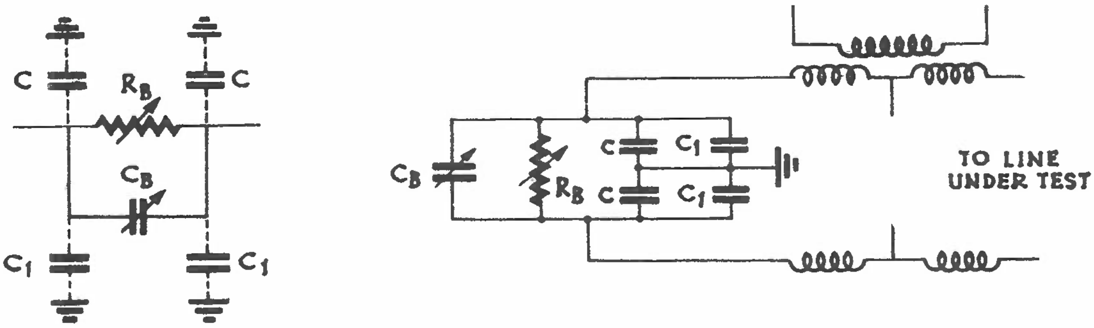
FIG. 23 - BALANCED TRANSFORMER.

The screen mentioned above is an earthed copper foil with an insulated lap joint which separates the primary and secondary windings, or a layer of wire having one end connected to earth. This screen prevents energy, including that due to the longitudinal voltages, being transferred between the primary and secondary

/ windings

windings via the mutual capacity which exists between the windings. The lines of force of the electrostatic fields produced by either winding, and which produce the energy transfer via the mutual capacity, now terminate on the earthed screen instead of including the other winding. However, even with such precautions as screened and balanced transformers, the 4A bridge is suitable for use up to a frequency of only 35 kc/s.

Parallel bridges are more satisfactory in respect to balance to earth. Fig. 24a shows the capacities to earth about the ends of the components in the balancing circuit of a parallel bridge, whilst Fig. 24b shows the combination in a bridge circuit proper.



(a) (b)

CAPACITIES IN PARALLEL BRIDGE.

FIG. 24.

The capacities C about the ends of the balancing resistor R_B are equalised, as are those about the ends of the balancing condenser C_B, the network so formed being balanced to earth.

10. ATTENUATORS.

10.1 Many A.C. measurements necessitate the use of a variable attenuator, that is, one which will introduce known amounts of attenuation into circuits. Such attenuators must produce an attenuation which is independent of frequency over the range of frequencies for which they are designed and, therefore, are constructed of non-inductive resistances. The characteristic impedance of the attenuators should match that of the circuits in which they are to be used, for example, 600 ohms for aerial circuits or 135 ohms for cable circuits. Further details are given in Long Line Equipment I, Paper No. 3.

/ 11.

11. TRANSMISSION MEASURING SETS.

11.1 The speed at which transmission tests can be made and the simplicity of the circuit set-up required to perform those tests are important features, particularly with regard to field testing. Field tests are frequently made from such points as cable head poles, jointing or loading pits, and so on, and testing equipment for use at such situations must be robust and capable of being set up in a confined space. Further, as many tests, for example, insertion loss, crosstalk and impedance, are encountered time and again, it is desirable to make a single item of testing equipment perform as many of these tests as possible. Transmission Measuring Sets have been developed for this purpose, those described in the following paragraphs being the A.P.O. Transmission Measuring Set and the 30A Transmission Measuring Set.

11.2 The A.P.O. Transmission Measuring Set. The A.P.O. Transmission Measuring Set comprises an 800 c/s oscillator and a loss and level meter calibrated in db to a zero of 1 milliwatt into 600 ohms. A schematic circuit is shown in Fig. 25.

The oscillator unit is a Hartley circuit containing a 6J7 valve connected as a triode, that is, with the anode and screen and suppressor grids connected together. The output of this oscillator is taken to a pair of jacks, labelled "Send," via an attenuator, labelled "Adjust," and a three position key. When this key is in the normal position, the oscillator is connected to the "send" jacks via the "adjust" attenuator. In the "adjust" position, the output of the oscillator is connected to the meter via the "adjust" attenuator, by means of which attenuator the output level from the oscillator may be adjusted. When the output is adjusted to zero (1 milliwatt into 600 ohms), the operation of the key to the "-40 db" position applies a level of -40 db on 1 milliwatt into 600 ohms to the "send" jacks, as the operation of the key to the "-40 db" position connects a 40 db pad between the "adjust" attenuator and the "send" jacks. The output impedance of the oscillator is 600 ohms.

The loss and level measuring circuit consists of a two-stage amplifier employing negative feedback. Two resistance coupled 6J7 valves are used, the first stage as a pentode and the second stage as a triode.

The meter is connected in a bridge rectifier circuit and forms part of the feedback circuit. A range switch controls a resistance potentiometer connected across the secondary winding of the input transformer, and varies the sensitivity in 10 db

/ Fig. 25

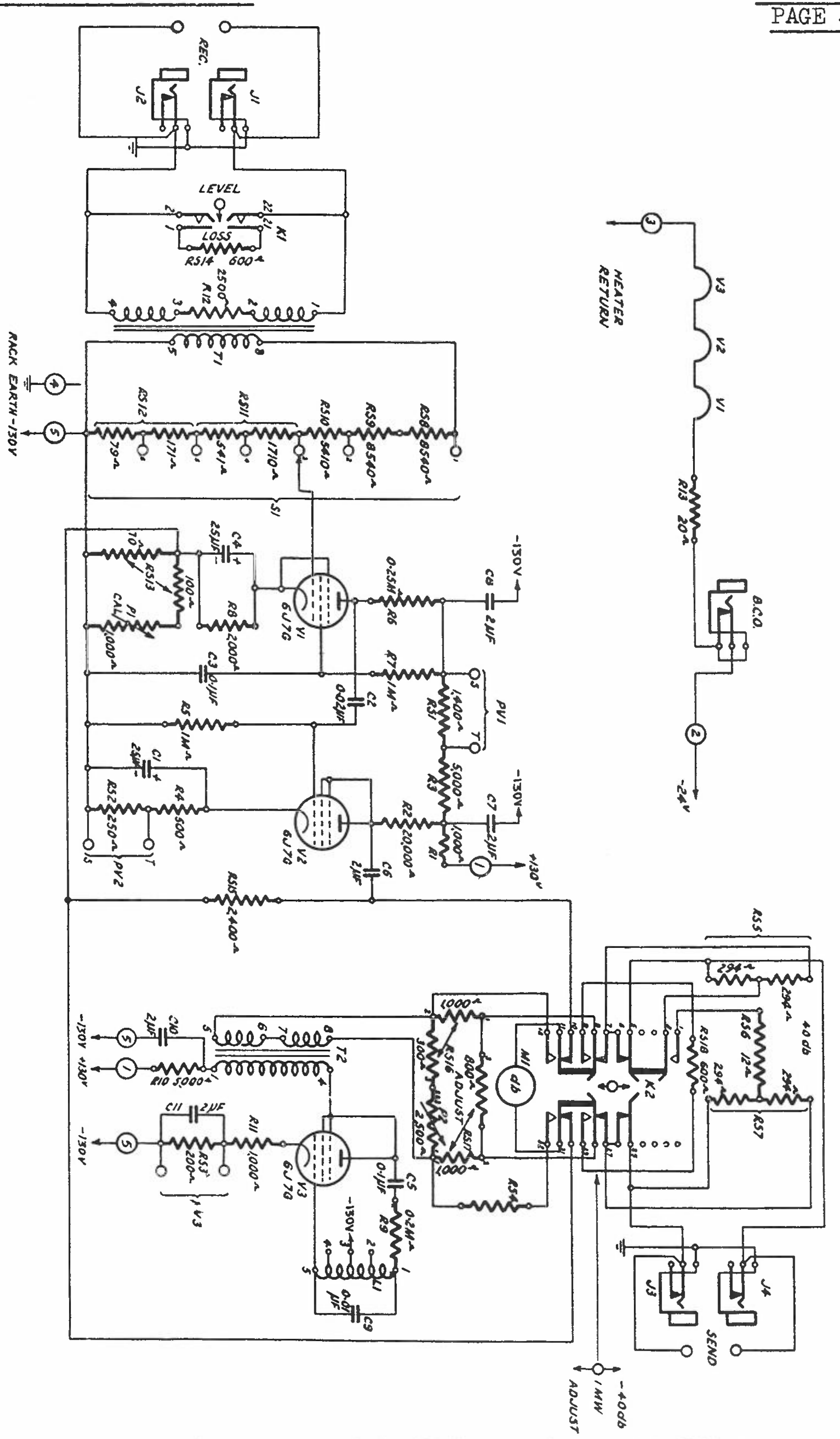


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FIG. 25 - A.P.O. TRANSMISSION MEASURING SET.

steps from +30 db to -20 db. A two position key marked "Loss-Level" enables a 600 ohm termination to be provided in the "Loss" position. In this position, the set measures the power absorbed by this 600 ohm resistance in terms of the voltage across it. The calibration of the meter is, of course, in db. In the "Level" position, the input impedance is about 20,000 ohms, so that levels can be read without the presence of the set affecting the currents and voltages in the circuit under test.

The set is designed to operate from a 130 volt anode supply and a 24 volt filament supply.

11.3 The 30A Transmission Measuring Set. (See Fig. 26.) The 30A Transmission Measuring Set is a portable and specialised version of a "Test and Adjust" circuit used for the measurement of gain and loss. It has been developed primarily for use with "J" (Open Wire) and the "K" (Cable) type carrier equipment, and on that account all the incorporated circuits are of 135 ohms impedance. For measurements on 600 ohm circuits, two screened and balanced transformers are included, having good frequency characteristics to 150 kc/s, although the loss-frequency characteristics are such as to require correction with frequency for the gain or loss measurements concerned.

The attenuators in the set enable gain measurements of about 90 db to be made, though with certain limitations it is possible to extend the measurement range to 120 db.

Loss measurement is limited for each case by the maximum permissible input to the circuit under test, but, by recourse to the 2A amplifier detector in place of the thermo-couple meter, losses of considerable magnitude can be measured.

This measuring set consists basically of an input and output measuring circuit, separated by a comparison circuit consisting of two separate paths selected by a four pole, double-throw, "Test-compare" key. The input circuit consists of jacks for connection to the source of test current, and a finely graded potentiometer for adjustment of the current. The output circuit consists of a thermo-couple measuring circuit with inbuilt facilities for calibration, and preceded by three 10 db pads for protection. These pads are progressively removed from the circuit by separate non-locking keys. A variable attenuator is included in one of the two comparison paths. Jacks have been interposed through the circuit at points necessary for flexibility.

The scale of the meter is calibrated directly in db referred to 1 milliwatt, and extending from -10 db to +3.4 db with zero at about mid-scale. Scale accuracy is at its best between the

/ Fig. 26

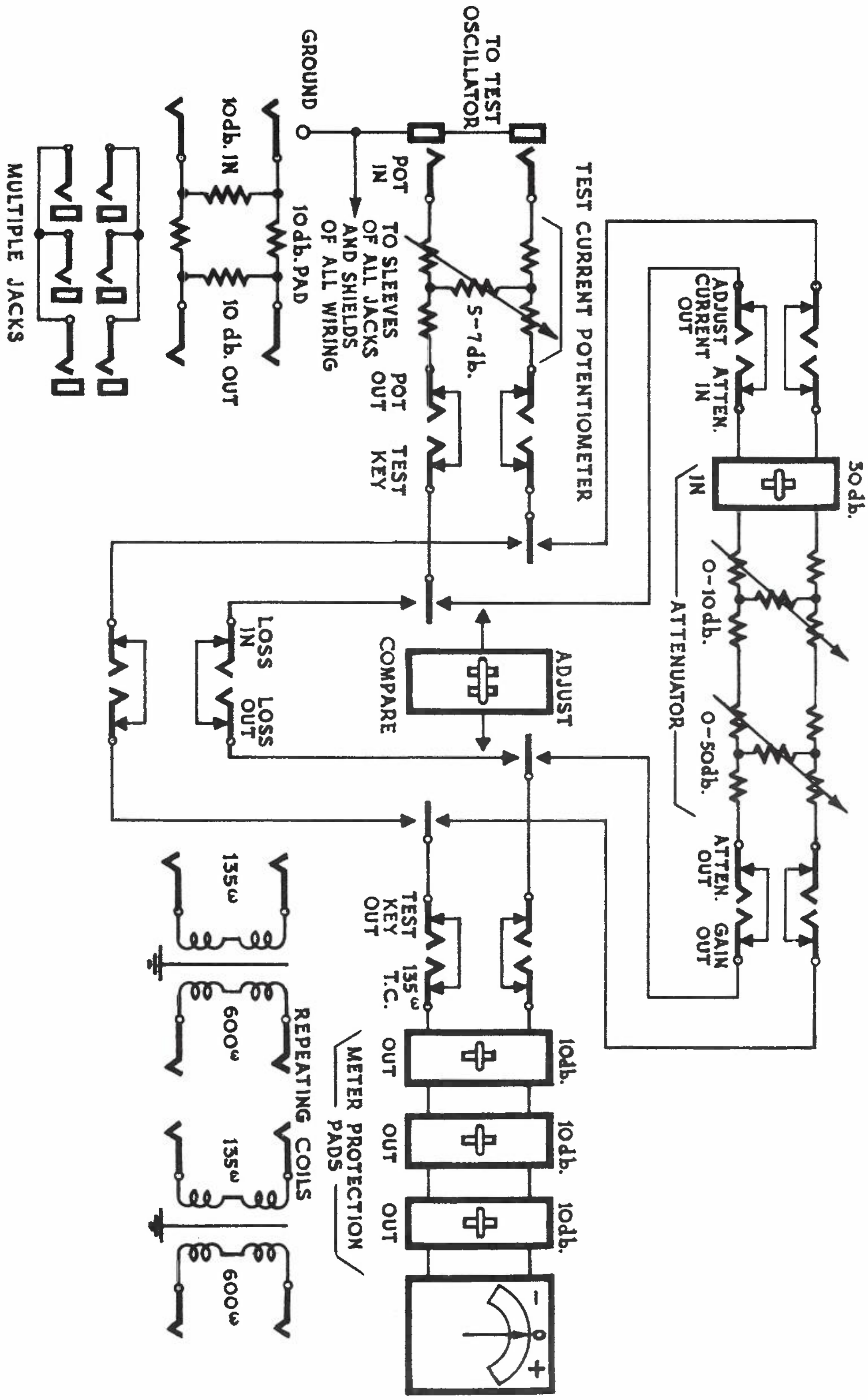

FIG. 26 - 30A TRANSMISSION MEASURING SET.

limits ±1 db either side of zero, and each decibel is subdivided in 0.1 steps, making it possible to follow accurately small increments and decrements of current. Calibration of the measuring circuit is simple. The calibrating switch is moved to each of three positions in turn, and the appropriate knob for each position is adjusted to bring the meter to zero on the scale.

12. TEST QUESTIONS.

1. State the principal A.C. measurements used in transmission work.

2. What are the important features of oscillators used for testing purposes?

3. Draw a simple current of a typical testing oscillator.

4. Describe a thermo-couple and give a typical example of its practical application.

5. Describe, with simple circuit, an impedance bridge.

END OF PAPER.

COMMONWEALTH OF AUSTRALIA.

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COURSE OF TECHNICAL INSTRUCTION.

LONG LINE EQUIPMENT III.

TRANSMISSION MEASUREMENTS (Continued).

CONTENTS:

1. INTRODUCTION.

1.1 This Paper will deal with some of the A.C. measurements most frequently made on lines and equipment, using the equipment described in Paper No. 4 of this book. For some measurements, additional equipment not described in Paper No. 4 is necessary, for example, when measuring crosstalk a Crosstalk Measuring Set is necessary. Such equipment is described in the appropriate section of this Paper.

1.2 Most measurements dealt with are divided into three sections, as follows -

(i) Measurements made at voice frequencies.
(ii) Measurements at frequencies to about 30 kc/s.
(iii) Measurements at frequencies above 30 kc/s.

This division is brought about by the way in which the frequencies employed in telephone communication gradually extended upwards. Originally, only the V.F. band was transmitted over lines, and this band did not involve very critical treatment of circuits to avoid the effects of electrostatic and electromagnetic couplings between them, because such couplings do not cause much trouble at voice frequencies. The introduction of single and three-channel carrier systems raised the frequencies to be handled to about 30 kc/s. The use of these higher frequencies necessitated more critical arrangements to eliminate coupling between circuits and also some changes in testing equipment and technique.

The introduction of Type J, Type K and 17-Channel Carrier Systems, with frequencies extending up to 150 kc/s in the Type J case, meant even more critical circuit arrangements and testing technique. Thus, whilst most items of test equipment designed for the three-channel 30 kc/s upper frequency limit are satisfactory for V.F. tests, some items do not prove satisfactory at frequencies much above 30 kc/s. Similarly, some equipment designed for the 150 kc/s upper limit is not altogether satisfactory over the V.F. range. The fact that much of the testing equipment has been designed for specific frequency ranges, together with the necessity for taking precautions over the higher portions of the frequency range which are not necessary over the lower portions, leads to the division outlined earlier.

2. MEASUREMENT OF LINE IMPEDANCE.

2.1 It is frequently necessary to measure the Characteristic Impedance versus Frequency of a line, for the purpose of checking that the measured impedance approximates that calculated from the primary constants, to extract the primary constants of the line where they are not available, to check that impedance irregularities do not exist, and so on.

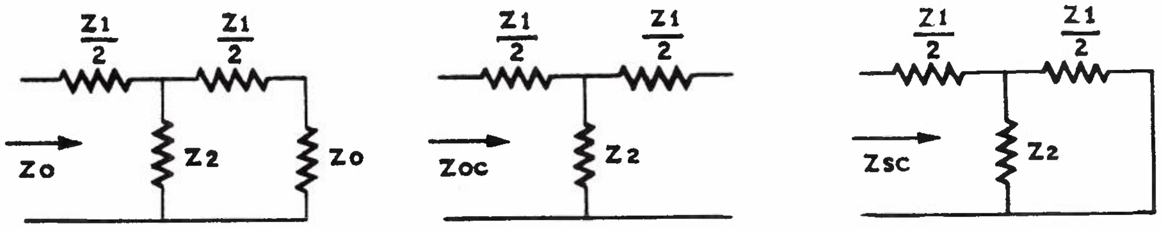
2.2 The method used is to measure, by means of an impedance bridge, the impedance of the line from one end with the distant end open circuited over the frequency range concerned, and then measure the impedance with the distant end short-circuited. By calculating the open circuited and short-circuited impedances for each frequency from the bridge readings and applying the formula

$$Z_o = \sqrt{Z_{oc} Z_{sc}}$$

for each frequency, the characteristic impedance versus frequency of the line will be obtained. Z_{oc} and Z_{sc} are the open and short-circuited impedances respectively of the line.

/ 2.3

2.3 This formula can be proved by a consideration of the T Section dealt with in Paper No. 3 of Long Line Equipment I. This T Section is shown in Fig. 1, together with its open and short-circuited conditions.



(a) Termination = Z_o (b) Termination = Open Cct. (c) Termination = Short Cct.

T SECTION WITH VARIOUS TERMINATIONS.

FIG. 1.

From Paper No. 3 of Long Line Equipment I -

$$Z_o = \sqrt{Z_1 Z_2 + \frac{Z_1^2}{4}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

From an inspection of Fig. 1b -

$$Z_{oc} = \frac{Z_1}{2} + Z_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From an inspection of Fig. 1c -

$$Z_{sc} = \frac{Z_1}{2} + (Z_2 \text{ in parallel with } \frac{Z_1}{2})$$

$$= \frac{Z_1}{2} + \frac{Z_2 \frac{Z_1}{2}}{Z_2 + \frac{Z_1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Multiply the second term of (3) by $\frac{2}{2}$ and

$$Z_{sc} = \frac{Z_1}{2} + \frac{(Z_2 \frac{Z_1}{2}) \times 2}{(Z_2 + \frac{Z_1}{2}) \times 2}$$

$$\therefore Z_{sc} = \frac{Z_1}{2} + \frac{Z_1 Z_2}{Z_1 + 2Z_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

/ By

By multiplying (2) by (4) -

$$Z_{oc} Z_{sc} = Z_1 Z_2 + \frac{Z_1^2}{4}$$

$$\text{but } Z_1 Z_2 + \frac{Z_1^2}{4} = Z_o^2$$

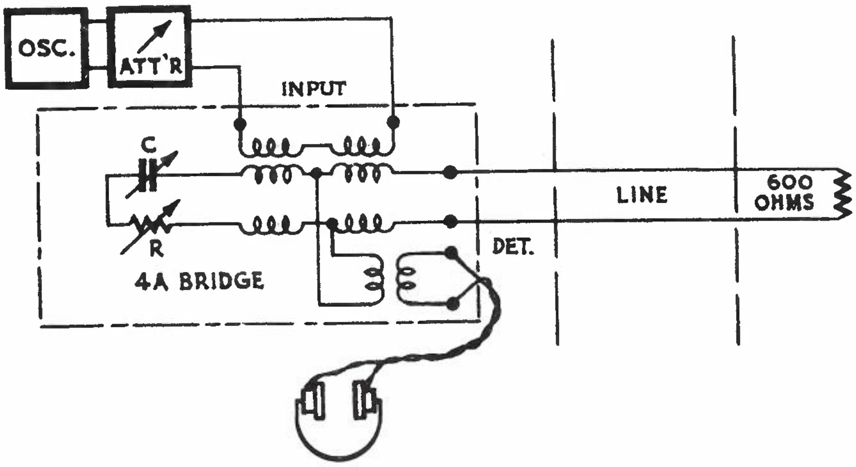
$$\therefore Z_o^2 = Z_{oc} Z_{sc}$$

$$\therefore Z_o = \sqrt{Z_{oc} Z_{sc}} \quad \dots\dots\dots\dots\dots\dots\dots (5)$$

Equation (5) is the characteristic impedance of the T Section shown in Fig. 1. This equation also applies to the telephone line, because a telephone line is made up of a series of such sections, as was shown in Paper No. 1 of Long Line Equipment I.

2.4 Measurement of Line Impedance at Voice Frequencies with a 4A Bridge. When measuring the impedance of an open-wire trunk line for the purpose, for instance, of designing a voice frequency repeater balance-network, the theoretically correct method is to measure and calculate the characteristic impedance of the line at each of the frequencies stated below and to terminate the line in its characteristic impedance for each subsequent measurement. In practice, however, it has been found that sufficiently accurate results are obtained by making measurements with the distant end of the line terminated in a 600 ohm non-inductive resistance. The distant end of the line is, therefore, terminated in 600 ohms, the 4A bridge is connected as shown in Fig. 2 and the oscillator is adjusted to the frequency at which the required measurement is to be made. (Impedance versus frequency measurements are made on voice frequency circuits, commencing at 200 c/s and proceeding in steps of 100 c/s to 2,800 c/s.) A pair of headphones is connected across the terminals of the 4A bridge designated "DET". The resistance dials and capacity dials are then adjusted until tone is not heard in the headphones, the absence of tone indicating that the bridge is balanced, that is, the resistance and capacity in the variable arms of the bridge are equal respectively to the resistance and capacity of the line under measurement. If the line which is being measured is inductive, the capacity C in the 4A bridge is connected in series with the line by operating a key associated with the bridge. The measurements are then continued in steps of 100 c/s to 2,800 c/s. For each measuring frequency, the resistance in ohms and the reactance in ohms (calculated from the bridge capacity reading) are recorded in a data book, and, at the completion of the run, the values are plotted on a graph. The points plotted on the graph are then joined by means of curves, which form the basis of the design of the balance-network.

/ Fig. 2

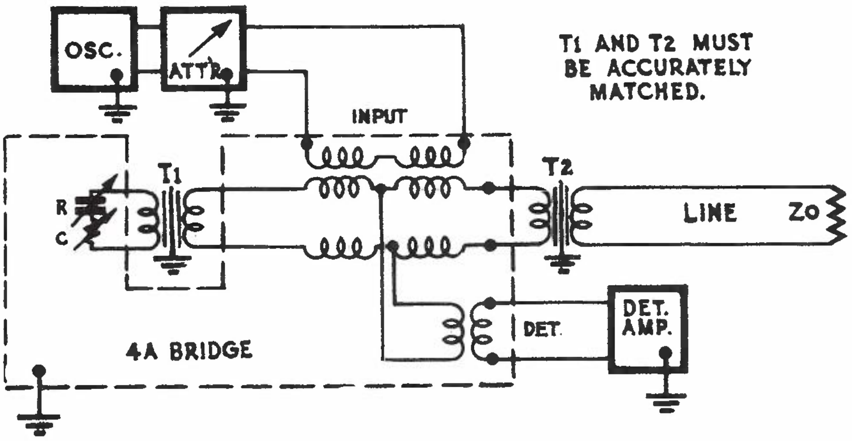


USE OF 4A BRIDGE TO MEASURE LINE IMPEDANCE AT VOICE FREQUENCIES.

FIG. 2.

A typical impedance versus frequency characteristic for a 40 lb. cable pair has been illustrated in Fig. 13, Paper No. 1, Long Line Equipment II.

2.5 Measurement of Line Impedance at Carrier Frequencies with a 4A Bridge. When a 4A bridge is used to measure line impedances at carrier frequencies up to 35 kc/s, this being the highest frequency for which the 4A bridge is designed, the circuit arrangement shown in Fig. 3 should be used.



USE OF 4A BRIDGE TO MEASURE LINE IMPEDANCE AT CARRIER FREQUENCIES.

FIG. 3.

Because of unbalances to earth inherent in the 4A bridge, a screened and balanced transformer is connected between the line under test and the bridge, as discussed in Paper No. 4 of this book. An identical transformer must be connected between the balancing circuit and the hybrid as in Fig. 3, so that the bridge components will measure the line impedance, the transformer on the balancing side taking care of that on the line side of the hybrid. As the frequency is changed, it is necessary to tune the detector amplifier to the new frequency when a tuned detector amplifier is used.

When making an Impedance versus Frequency measurement over trunk lines at carrier frequencies of up to 30 kc/s, it is necessary to have the line terminated in its characteristic impedance. This value is determined by making impedance measurements at 3 kc/s, 8 kc/s, 16 kc/s and 30 kc/s, first with the distant end of the line open-circuited and then with the distant end short-circuited. The mean value of the four readings taken with the line open-circuited is then regarded as the open-circuit impedance, that is, Z_{oc}, and the mean value of the four readings taken with the line short-circuited is regarded as the short-circuit impedance, that is, Z_{sc}.

The formula $Z_o = \sqrt{Z_{oc} Z_{sc}}$ is then applied to obtain the average characteristic impedance over the frequency range concerned.

These measurements are made by balancing the bridge as described for audio-frequency measurements. (When a 2A or 3A detector amplifier is used, a balance is indicated when a minimum reading is obtained on the detector amplifier meter with the detector amplifier producing its maximum gain.)

2.6 <u>Interpretation of Results obtained with Series Bridges</u>. In Paper No.1 of Long Line Equipment I, an expression was developed from which the characteristic impedance of a line at any frequency could be calculated from a knowledge of the primary constants of the line concerned. This expression was -

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The characteristic impedances of various classes of line were worked out using Equation (6) and the primary constants listed in Table 1 of the above reference, the results being Table 2 of that reference when the frequency is 800 c/s. The impedance values in Table 2 indicate that, at 800 c/s, the characteristic impedances of the various lines listed therein contain a resistive component and a capacitive component.

/ In

In Table 1 and Fig. 13 of Long Line Equipment II, Paper No. 1, the calculation was carried a step further, in that the characteristic impedance of a 40 lb. cable pair was calculated at a number of frequencies between 200 c/s and 3,000 c/s, the results there being expressed in terms of the resistance and capacitive reactance at each frequency.

If a series bridge is employed to measure the characteristic impedance of a 40 lb. cable pair by the "open and short-circuited impedance" method outlined above, the values of bridge resistance obtained would be identical with those in Table 1 of Paper No. 1, Long Line Equipment II, whilst the reactance of the bridge capacity readings would be identical with the reactance values of that Table at the frequencies concerned. At a single frequency, therefore, the impedance of a telephone line consists of a resistance in series with a condenser, the values of resistance and capacity being appropriate to the frequency concerned and the type of line under consideration. As the equivalent resistance and capacity of a line change with frequency, a network whose resistance and capacity change correspondingly would be required, for example, in the balance network of a V.F. repeater. For this reason, networks more complex than a single resistance and capacity are generally required in balance networks, some of which were illustrated in Figs. 14, 15 and 16 of Paper No. 1, Long Line Equipment II.

The fact that the impedance of a line contains a resistance and capacitance in series can be illustrated from Equation (6) above. The leakance of cable pairs, particularly trunk cable pairs, can usually be neglected because such cables are kept under gas pressure. Thus, Equation (6) becomes -

$$Z_o = \sqrt{\frac{R + j\omega L}{j\omega C}}$$

$$\therefore Z_o = \sqrt{\frac{R}{j\omega C} + \frac{j\omega L}{j\omega C}}$$

$$\therefore Z_o = \sqrt{\frac{L}{C} + \frac{R}{j\omega C}} \quad \text{........................(7)}$$

/ The

The first term under the radical of Equation (7) indicates that the characteristic impedance will contain a real component, that is, a resistance, whilst the second term indicates that the characteristic impedance will contain an imaginary component which, because of the j in the denominator, will be a capacitive reactance.

2.7 Measurement of Line Impedance with Parallel Bridges. When using a 5A (parallel) bridge, the transformers shown in Fig. 3 are not necessary, because parallel bridges, as explained in Paper No. 4 of this book, provide an inherent balance to earth. It is necessary, however, to transform the parallel resistance and capacity readings obtained to the equivalent series values. For example, the characteristic impedance of a 40 lb. cable pair contains a resistive component of 522 ohms and a capacitive reactive component of 507 ohms at 200 c/s, these components being connected in series. A series bridge would read 522 ohms resistance and a capacity of 1.569 µF, whilst a parallel bridge would read 1,014 ohms resistance and 0.7845 µF capacity. (A comparison of these two circuits would show that their impedances, as regards both magnitude and angle, are identical.) Thus, when a parallel bridge is used to measure line impedance, it is necessary to transform the values of resistance and capacity obtained on the parallel bridge to their equivalent series values. This is done by using the following formulae -

$$R = \frac{r}{1 + \omega^2 C^2 r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$X_c = \frac{\omega C r^2}{1 + \omega^2 C^2 r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

where R = series resistance,

X_c = series capacitive reactance,

$\omega = 2\pi f$,

r = resistance reading on parallel bridge, and

C = capacity reading on parallel bridge.

The resistance and capacity readings plotted in the curves of Figs. 14, 15 and 16 of Paper No. 1, Long Line Equipment II, were obtained with a parallel bridge and should be compared with Fig. 13 of that Paper, this latter curve being typical of a curve obtained with a series bridge.

/ 2.8

2.8 Measurement of Line Impedance above 30 kc/s. Many tests are carried out with the testing equipment located a little distance from the circuit under test, particularly open wire and cable tests. In order to prevent impedance irregularities being introduced by the leads between the testing equipment and the circuit under test, it is necessary that these leads have substantially the same characteristics as the circuit under test. This applies particularly to tests employing frequencies much above 30 kc/s. Thus, "spaced" leads are used to connect the testing equipment to the lines under test, the spacing between the leads being the same as those between the circuit under test. The spacings for aerial wire above 30 kc/s may be 9" or 6", and the appropriate spaced leads must be used. For cables, twisted O.D.T. can be used for test leads, but the leads should be kept as short as possible. Apart from these precautions, the procedure is the same as that described for making impedance measurements with parallel bridges.

2.9 Locating an Impedance Irregularity on a Line. On a line which is entirely free from irregularities, the curve so plotted will be smooth and free from peaks. However, on a line which has one or more intermediate irregularities, such as intermediate lengths of cable, the curve drawn will exhibit peaks, and, where a peak recurs at regular intervals, the distance between the testing station and the irregularity which causes the peak can be determined from the formula -

$$d = \frac{v}{2S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

where d = distance from the testing station to the irregularity in miles,
v = the velocity of propagation of an electromagnetic wave in miles per second, and
S = the separation between two adjacent recurring peaks in cycles per second.

This method of locating the position of irregularities is not precisely accurate, but it is useful in determining whether there are irregularities in the line not due to the line's normal composition.

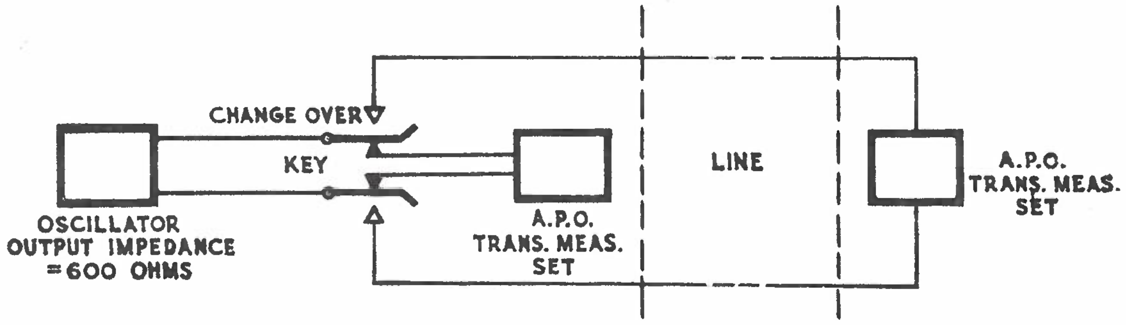
Fig. 5 of Paper No. 1, Long Line Equipment I, could be used as an example. Here, **2**S in Equation (10) is 6 kc/s, v is 165,000 miles per second, so that d is 27.5 miles as against 28.2 measured miles.

/ 3.

3. ATTENUATION MEASUREMENTS.

3.1 There are many methods of making attenuation measurements, the exact method used being determined by the equipment available. The two methods outlined here are representative of line measurements up to 30 kc/s and measurements above that frequency.

3.2 Attenuation Measurement up to 30 kc/s. Fig. 4 illustrates a circuit set up which could be used for measuring the loss over a line with a characteristic impedance of 600 ohms.



MEASUREMENT OF LINE LOSS UP TO 30 kc/s.

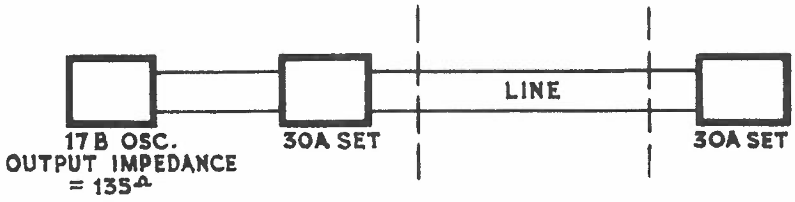
FIG. 4.

Both transmission measuring sets are operated in the loss position. The output of the oscillator is adjusted with the change-over key unoperated until a suitable level, say, zero, is obtained on the transmission measuring set at the sending end. The key is then operated and the oscillator output sent to line, the received power being read on the transmission measuring set at the distant end. The difference between the two readings is the loss produced by the line when terminated in 600 ohms, for example, if zero level is sent and the received level is -8, then the loss is 8 db. To show one variation of this test, the key could be eliminated and the transmission measuring set at the sending end could be operated in the "level" condition. This method is suitable up to 30 kc/s only, because the A.P.O. transmission measuring sets are designed for measurements only up to that frequency.

3.3 Attenuation Measurements above 30 kc/s. The most convenient method of making measurements above 30 kc/s is to use 30A transmission measuring sets in lieu of the A.P.O. type used in the

/ preceding

preceding test. Fig. 5 illustrates the set up for measuring the loss over a cable pair with a characteristic impedance of 135 ohms, which is the impedance for which the 30A set is designed.



MEASUREMENT OF LINE LOSS USING 30A SETS.

FIG. 5.

After calibration of the 30A sets, the line under test at the sending end is patched to the "loss in" jacks of the 30A set there. (For details of 30A set, see Fig. 26 of Paper No. 4.)

The key on this 30A set is operated to the "adjust" position and the attenuator set to a loss equal to the desired sending level above 1 mW. The oscillator output, in conjunction with the test potentiometer, is adjusted for a zero (1 mW) reading on the 30A meter. (For example, if +25 db is to be sent, 25 db is inserted in the attenuator
The oscillator output is then adjusted so that, with the three 10 db meter protection pads switched out, the 30A meter reads zero.) The key on the sending 30A set is now operated to the "compare" position, which means that the output of the oscillator is sent to line.

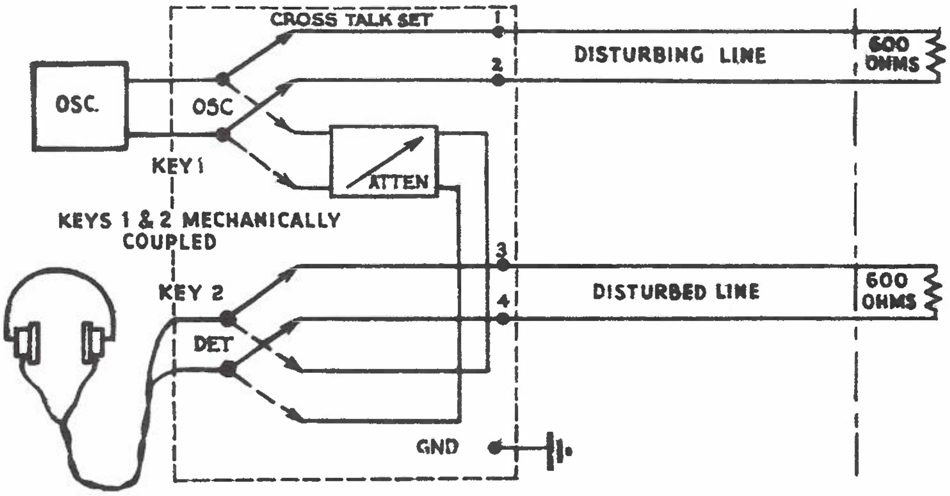
At the receiving end, the line being measured is patched to the "Attenuator in" jacks with the attenuator adjusted to maximum loss. With the key in the adjust position, the attenuator is adjusted for a zero reading on the 30A meter. The loss is the difference between the oscillator output - which is the attenuator setting at the sending end - and the attenuator reading at the receiving end. For example, if +25 db is sent from the oscillator and 12 db in the receiving attenuator produces a zero reading at the receiving end, then the loss between the oscillator and meter is 25 db. As 12 db of this represents loss in the attenuator, then the line loss is 25 db - 12 db = 13 db. Losses up to 30 db can be measured by this method using 17B oscillators, as their maximum output is +30 db.

/ 4.

4. CROSSTALK MEASUREMENTS.

4.1 Apparatus Used. Crosstalk measurements on lines are made using an oscillator and a 74051A Crosstalk Measuring Set. This Crosstalk Measuring Set consists essentially of an attenuator, switching keys and terminals. At audio frequencies, a pair of headphones serves as a detector, but, at carrier frequencies, a detector amplifier is necessary. With the exception of the source of testing current and the detector, the crosstalk set contains all the apparatus necessary for making crosstalk measurements.

4.2 Measurement of "Near-End" Crosstalk at Audio Frequencies. In order to measure crosstalk at audio frequencies, the disturbing line and the disturbed line are both terminated in 600 ohm resistances at their distant end and are connected to the crosstalk set as shown in Fig. 6.



NEAR-END CROSSTALK MEASUREMENT AT AUDIO FREQUENCIES.

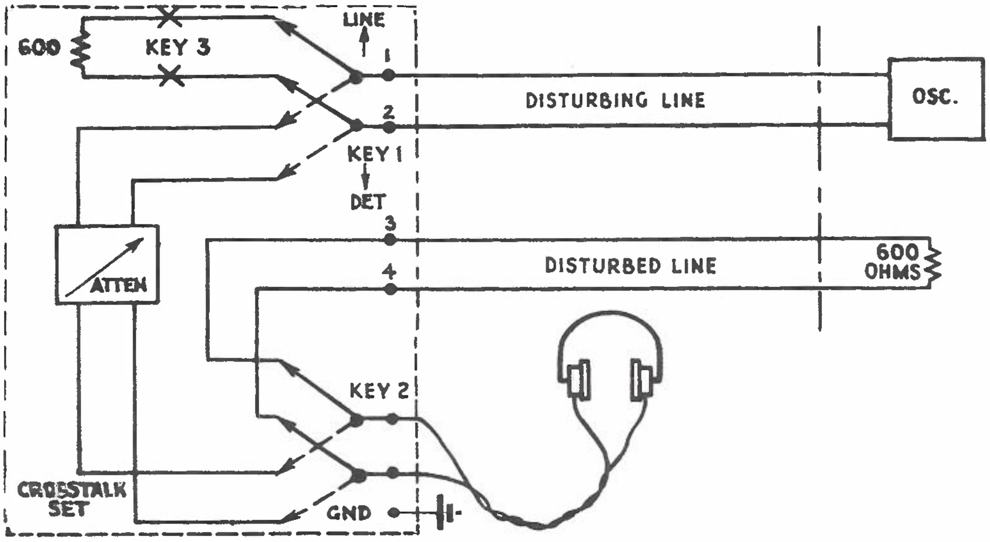
FIG. 6.

The terminal of the Crosstalk Measuring Set marked "GND" is connected to earth, and the output of the oscillator is connected to the terminals marked "OSC." The disturbing circuit is connected to terminals 1 and 2 marked "LINE," and the disturbed circuit is connected to the "LINE" terminals Nos. 3 and 4. A pair of headphones is connected to the terminals designated "DET," and the output of the oscillator is then adjusted until a definite tone is heard in the headphones when the keys are in the "LINE" Position, the frequency of the oscillator having first been adjusted to that at which the measurement is required to be made. The keys are then thrown alternately to

/ positions

positions "LINE" and "DET," adjusting the crosstalk set until the magnitude of the tone in the headphones is the same for either position of the keys. The crosstalk set is actually a variable attenuator with a scale calibrated in db. The number of db indicated on the attenuator scale in the crosstalk set is the measure of "Near-End" crosstalk which exists between the two lines.

4.3 Measurement of "Far-End" Crosstalk at Audio Frequencies. In order to measure "far-end" crosstalk at audic frequencies, the disturbing line and the disturbed line are connected to the crosstalk set as shown in Fig. 7.



FAR-END CROSSTALK MEASUREMENT AT AUDIO FREQUENCIES.

FIG. 7.

The terminal marked "GND" is connected to earth. The headphones are again connected across the terminals marked "DET," and, in this case, the oscillator is connected to the distant end of the disturbing line. Key 3 is thrown to the position marked with the impedance, which is closest to that of the disturbing line under test, the characteristic impedance of the line having first been determined. For an aerial line at audio frequencies, however, the 600 ohm position is suitable. The distant end of the disturbed line is also terminated in its characteristic impedance, which, for an aerial line at audio frequencies, is approximately 600 ohms. The output of the oscillator is then raised until a definite tone is heard in the headphones with Keys 1 and 2 in the "LINE" position. The keys are then operated alternately to the positions "LINE" and "DET," and the crosstalk meter is again adjusted until the tone heard in the headphones is the same for

/ both

both positions of the keys. The db indication on the attenuator scale in the crosstalk set then represents the amount of crosstalk in db which exists between the two lines when the disturbing current is being fed in at the distant end of the disturbing line.

4.4 Determination of Crosstalk Versus Frequency Characteristic. In order to determine the crosstalk versus frequency characteristics of any two lines at audio frequencies, "near-end" and "far-end" crosstalk measurements are made, as described, over a range of frequencies beginning at 200 c/s and proceeding in steps of 100 to 2,800 c/s, with one line as the disturbing circuit and the second line as the disturbed circuit. Each measurement is then repeated with the lines transposed, that is, the first line being the disturbed circuit and the second line the disturbing circuit. It will be found convenient to transpose the lines after each measurement, so that only one series of oscillator adjustments is necessary. The results of the measurements are then recorded in a data book, and, on completion of the run, the results are plotted on a graph and the points are then joined by means of lines. The points plotted when the first line was the disturbed circuit are joined by a full line, and those points plotted when the second line was the disturbed circuit are joined by a broken line. These graphs then represent the crosstalk versus frequency characteristics of the two lines concerned, one form being used for the two "near-end" characteristics and another form for the two "far-end" characteristics.

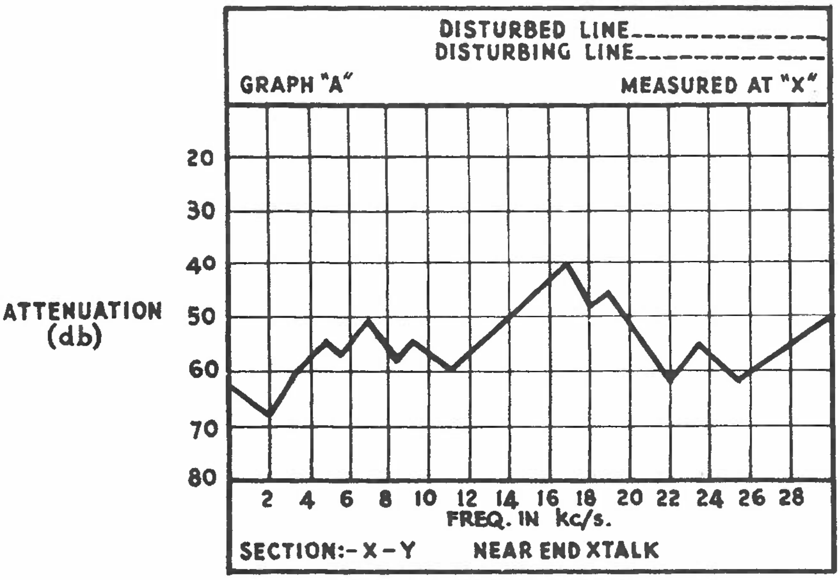
4.5 Measurement of Crosstalk at Carrier Frequencies up to 30 kc/s. For measuring "near-end" and "far-end" crosstalk at carrier frequencies, the procedure outlined for audio frequencies is followed, excepting that a pair of matched 600/600 ohm carrier transformers is required. One pair of transformers is inserted between the crosstalk set and the disturbed line, and the other pair is inserted between the crosstalk set and the disturbing line. These transformers are for the purpose of isolating the measuring equipment and minimising the effect of longitudinal currents. Also, the pair of headphones is used in conjunction with a 1A detector amplifier, because carrier frequencies above approximately 8,000 cycles per second are not audible and the heterodyne facility of the detector amplifier is necessary. Whether for "near-end" measurements or for "far-end" measurements, the procedure is to adjust the oscillator and the tuned circuit of the detector amplifier to the frequency at which the measurements are required to be made. The output of the testing

/ oscillator

oscillator is then raised until a definite beat note is heard in the headphones. Keys 1 and 2 are then thrown alternately to the position "LINE" and "DET," and the measuring dial is turned until the magnitude of the tone in the headphones is the same for both positions of the keys. The crosstalk in db between the two lines at the particular frequency is then read from the crosstalk meter. Alternatively, a 2A or 3A detector amplifier could be used, the meter thereon taking the place of headphones.

In order to prepare a crosstalk versus frequency characteristic, crosstalk measurements, both "near-end" and "far-end," are made, commencing at 3 kc/s and proceeding in steps of 0.5 kc/s until the maximum frequency for which the characteristic is required is reached. The results of the readings are recorded in a data book and, on completion of the run, the results are plotted and graphs are then drawn as described for the audio frequency characteristic.

Fig. 8 shows a typical crosstalk versus frequency characteristic of two typical open wire lines.



TYPICAL CROSSTALK VERSUS FREQUENCY CHARACTERISTICS OF TWO OPEN WIRE LINES.

FIG. 8.

4.6 The 51A Crosstalk set, if used at frequencies much above 50 kc/s, is subject to increasing error, and can be regarded as unsuitable. Since no self-contained set is available for use in 600 ohm circuits, it becomes necessary to arrange a comparison circuit from individual components.

/ General

General Method. The requirements are a 17B oscillator, Muirhead attenuator, Muirhead key, and a 2A or 3A amplifier-detector, arranged as indicated in Fig. 9.

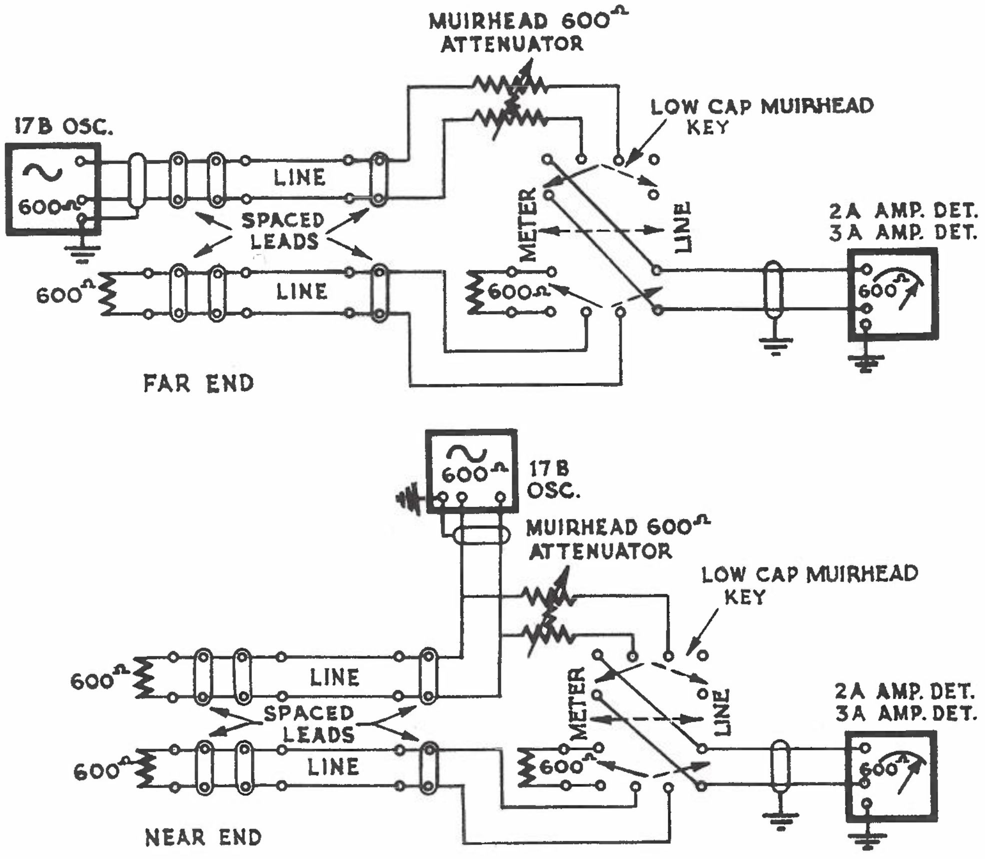


FIG. 9. CROSSTALK MEASUREMENTS AND SCHEMATIC CIRCUIT.

It will be seen that for "near-end" measurements the oscillator is connected across the "disturbing" line, and the comparison attenuator in parallel, the assumption being that current from the oscillator will divide equally over the two paths. For normal 9 inch spaced open wire lines, the impedance at the higher frequencies varies little from 630 ohms, and inappreciable error has been indicated by comparison between measurements made with the parallel connection and with the oscillator connected in turn to the "disturbed" line and attenuator, as the key is changed from the "line" to "meter" positions respectively.

For the "meter" position of the key, the "disturbed" line is shown terminated in 600 ohms; discretion can be used as to the necessity for this. In the "line" position, there is no provision for terminating the "disturbed" line behind the attenuator, but the attenuator will normally be set at a loss value more than adequate to take care of this.

/ The

The tuning of the amplifier-detector is preferably accomplished with the key in the "meter" position to obviate the possibility of tuning to an interference frequency instead of the oscillator frequency. It might be noted here that a meter, as compared to headphones, does not give discrimination between a wanted signal frequency and a near-by interfering signal of comparable strength. On that account, selectivity of a higher order is required for a meter type instrument than would be necessary in the case of a heterodyne type of amplifier-detector using headphones.

With the 2A amplifier-detector, the 600 ohm tappings on the input transformer should be used. Spaced test leads should be used at the measuring end and at the terminating end, unless the terminations are placed right at the open wires.

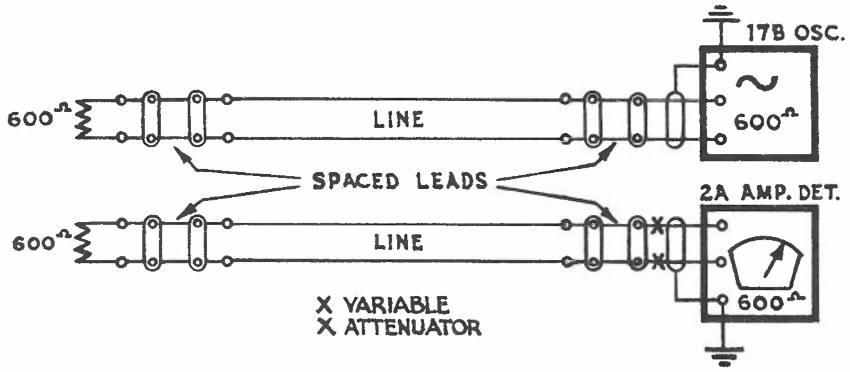
The arrangement for "far-end" measurement differs from the near-end only in the disposition of the oscillator. Measurement is accomplished as follows: By operation of the key to the "line" position, the amplifier-detector is connected directly to the "disturbed" line, and a suitable deflection of the meter is obtained by adjustment of the gain control. The key is then operated to the "meter" position, connecting the amplifier-detector to the disturbing signal source through the variable attenuator, which is adjusted to give the same reading as previously obtained. The attenuator reading will then indicate the crosstalk attenuation between the two circuits.

Two sets of "far-end" measurements should be made, the second following reversal of the two circuits in respect of the "disturbing" and "disturbed" function. This reversal should not normally be necessary for near-end measurements.

4.7 <u>Measurement of Crosstalk Peaks and Troughs</u>. Where interference conditions are such as to allow the use of the untuned 2A amplifier-detector, or the 3A in its untuned condition, very useful variations in the above technique are possible. For "far-end" crosstalk, the measurements of most consequence are, in general, those indicating the peaks in the crosstalk curve, as indicated by the lowest values of crosstalk attenuation. "Near-end" measurements are valuable mainly from considerations of transposition design, the figures of most consequence, in this case, being for the peaks and the troughs of the curve. These figures for both "far" and "near-end" conditions are obtainable in the following manner, making use of the test set-up of Fig. 9. A measurement is made at 150 kc/s in the normal manner. The comparison key is then left in the "line" position, connecting the amplifier-detector to the "disturbed" line. The oscillator frequency is then slowly reduced and the movement of the meter needle observed, operating the variable attenuator, if necessary, to keep the needle on scale. The peaks and troughs of crosstalk will be indicated by the extremes of upward and downward movements of the needle respectively. Measurements are made at these points, and at intermediate points if it should be required to fill out the curves.

/ Fig. 10

Fig. 10 illustrates a rapid method, applicable to "near-end" conditions only, whereby crosstalk values at the peaks and troughs and at any intermediate points may be obtained. It is made possible by the exceptionally flat Output-frequency and Gain-frequency characteristics of the 17B oscillator and 2A amplifier-detector.



MEASUREMENT OF PEAKS AND TROUGHS OF "NEAR-END" CROSSTALK.

FIG. 10.

A preliminary calibration is achieved by feeding the maximum output of the 17B oscillator to the input of the 2A through a variable attenuator which is adjusted to give a zero reading on the 2A scale. The attenuator reading thus obtained is the calibration figure required by the method. This figure will be in the vicinity of 83 db, and, if it is obtained at a frequency round 50 kc/s, it will be found that the total variation with frequency between 3-150 kc/s will not exceed some 0.5 db.

To carry out measurements, the oscillator is connected directly to the "disturbing" line and the 2A to the "disturbed" line through the variable attenuator. The oscillator is then run slowly through the frequency range from 150 kc/s downwards, the attenuator being adjusted at the same time to maintain a zero reading of the meter. The attenuator readings can be taken at the peaks and troughs, as indicated by the extremes of meter movement, and/or at desired frequencies. The crosstalk value for any particular frequency is given by the subtraction of the attenuator reading for that frequency from the original calibration reading. Since the meter reads to -4.0 below the zero point of calibration, it is possible to measure crosstalk of the order of 87 db.

Crosstalk measurements obtained by untuned amplifier-detector methods provide a maximum of useful information without the necessity for a long series of measurements at closely spaced frequencies. However, there are limitations to their use, due to the effects of interference, and discretion is necessary on the part of the operator. The accuracy of any measurement is appreciably affected if the level of interference is less than 8 db below that of the crosstalk signal for the particular frequency concerned.

/ Where

Where this condition is not met, the measurement must be made with the amplifier-detector (where the 3A is used) in the tuned condition. In the case of the 2A, which is not tunable, the measurement can only be indicated as being greater than the ascertained maximum value that can be measured with accuracy.

5. MEASUREMENT OF RETURN LOSS.

5.1 As has been discussed previously in these books, the equipment which terminates each end of a line has an impedance equal to the characteristic impedance of the line concerned. By this means, reflection is prevented. When a line is not terminated in its characteristic impedance, reflection takes place, the precise amount of energy reflected being determined by the extent to which the impedance of the termination departs from the characteristic impedance of the line. Total reflection takes place when the termination is either an open circuit or a short circuit. Energy is proportional to I^2R, I being zero in the case of an open circuit and R being zero in the case of a short circuit. The energy reflected back from an incorrect termination, or from any point in a circuit where an impedance change will cause reflection, can be regarded as a loss, because the source of supply sends energy into a circuit and only a portion of that energy is absorbed by the termination. The remainder consists of the energy lost due to attenuation and that reflected and returned to the source.

5.2 When each end of a line is terminated by equipment whose impedance equals the characteristic impedance of the line, a condition of matched impedances exists. This is shown in Fig. 11.

Under the conditions shown in Fig. 11, the generator will deliver maximum power to its load, which is the line and distant termination, and the line will deliver maximum power to its load, which is the termination. Should the generator and/or terminating impedances differ from the characteristic impedance of the line, or should the characteristic impedance of the line change somewhere along its length, reflection takes place and some of the power delivered by the generator is reflected at the mismatch and returned to the generator. The ratio, expressed in db, of the amount of power sent into a perfectly matched circuit, for example, Fig. 11, to the amount of power reflected should a mismatch be present (for example, if the termination of Fig. 11 is some impedance other than the characteristic impedance of the line) is called the "Return Loss."

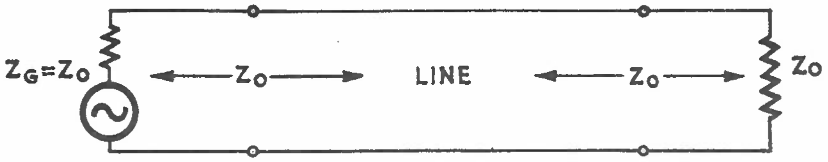


FIG. 11. LINE TERMINATIONS FOR MATCHED IMPEDANCES.

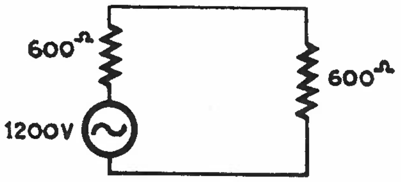
5.3 To illustrate the significance of the return loss, the following example is worked out.

$$\text{In Fig. 12, } I = \frac{1{,}200 \text{ volts}}{1{,}200 \text{ ohms}} = 1 \text{ ampere}$$

$$\text{thus power delivered to load } (I^2R) = 600 \text{ watts.}$$

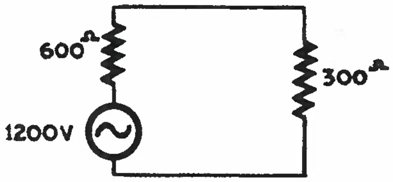
$$\text{In Fig. 13, } I = \frac{1{,}200 \text{ volts}}{900 \text{ ohms}} = 1\tfrac{1}{3} \text{ amperes}$$

$$\text{thus power delivered to load } (I^2R) = \frac{1{,}600}{3} = 533\tfrac{1}{3} \text{ watts.}$$



MATCHED CIRCUIT.

FIG. 12.



MISMATCHED CIRCUIT.

FIG. 13.

In Fig. 13, it can be assumed that the power sent into the circuit is 600 watts, which is the power which would be sent into Fig. 13 when perfectly matched as in Fig. 12, but -

$$600 \text{ watts} - 533\tfrac{1}{3} \text{ watts} = 66\tfrac{2}{3} \text{ watts}$$

is reflected by the impedance mismatch. Thus, $\frac{66\frac{2}{3}}{600}$ or one-ninth of the power sent into the circuit is reflected. The return loss in db is 10 times the common logarithm of the reciprocal of this ratio. Thus -

$$\begin{aligned}\text{Return Loss} &= 10 \log_{10} 9 \\ &= 10 \times 0.9542 \\ &= 9.542 \text{ db.}\end{aligned}$$

This return loss of 9.54 db means that, in the case worked out (an impedance mismatch of 600 ohms to 300 ohms), the reflected

/ power

power due to the mismatch is 9.54 db below the power which would be sent into the circuit under perfectly matched conditions, that is, 600 ohms to 600 ohms.

5.4 The return loss can be calculated from a knowledge of the impedances concerned. In Fig. 14a is shown a matched circuit and in Fig. 14b is shown a mismatched circuit.

(a) MATCHED CIRCUIT.

(b) MISMATCHED CIRCUIT.

FIG. 14.

The power absorbed by the load on the generator of Fig. 14a will be -

$$\left(\frac{E}{2Z_T} \times \frac{E}{2Z_T}\right) \times Z_T = \frac{E^2}{4Z_T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

The power absorbed by the load in Fig. 14b will be-

$$\frac{E}{(Z_T + Z_R)} \times \frac{E}{(Z_T + Z_R)} \times Z_R = \frac{E^2 Z_R}{(Z_T + Z_R)^2} \quad \ldots\ldots\ldots\ldots\ldots \quad (12)$$

The reflected power in Fig. 14b will be the difference between Equations (11) and (12), that is -

$$\frac{E^2}{4Z_T} - \frac{E^2 Z_R}{(Z_T + Z_R)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

The ratio of the power reflected to the power delivered under perfectly matched conditions will be given by the ratio of Equation (13) to Equation (11), that is -

/ E^2

$$\frac{\dfrac{E^2}{4Z_T} - \dfrac{E^2 Z_R}{(Z_T + Z_R)^2}}{\dfrac{E^2}{4Z_T}}$$

which simplifies to -

$$\frac{(Z_T - Z_R)^2}{(Z_T + Z_R)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

The return loss in db will be 10 times the common logarithm of the reciprocal of Equation (14), because equation (14) is the ratio of the reflected power to the power which would be sent into the circuit when matched conditions prevail. Thus -

$$\text{Return Loss} = 10 \log_{10} \frac{(Z_T + Z_R)^2}{(Z_T - Z_R)^2}$$

$$\therefore \text{Return Loss} = 20 \log_{10} \frac{Z_T + Z_R}{Z_T - Z_R}$$

In the example worked out earlier, Z_T = 600 ohms and Z_R = 300 ohms. Thus -

$$\text{Return Loss} = 20 \log_{10} \frac{600 + 300}{600 - 300}$$

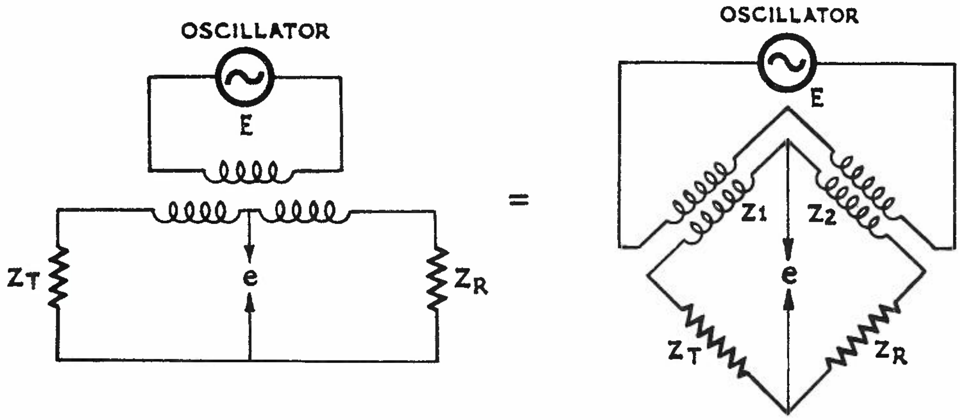
$$= 20 \log_{10} 3$$

$$= 20 \times 0.47712$$

$$= 9.5424 \text{ db.}$$

5.5 Measurement of Return Loss. Impedance bridges are used for the measurement of return loss, the two impedances between which the return loss measurement is to be made being connected to opposite arms of the bridge.

Fig. 15 shows the principle applied to a hybrid coil type of impedance bridge.



MEASUREMENT OF RETURN LOSS USING HYBRID COIL BRIDGE.

FIG. 15.

The loss across the hybrid coil between the oscillator and the mid-points of the hybrid coil will be -

$$\text{db loss} = 20 \log_{10} \frac{E}{e}$$

where E = oscillator voltage,

and e = voltage across mid-points of hybrid.

The voltage e will be the difference between the voltage across Z_1 and the voltage across Z_T. The voltage across Z_1 will be -

$$\frac{E}{Z_1 + Z_2} \times Z_1 = \frac{E\ Z_1}{Z_1 + Z_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

The voltage across Z_T will be -

/ E

$$\frac{E}{Z_T + Z_R} \times Z_T = \frac{E\ Z_T}{Z_T + Z_R} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

e will be the difference between Equation (15) and (16), that is -

$$e = \frac{E\ Z_T}{Z_T + Z_R} - \frac{E\ Z_1}{Z_1 + Z_2}$$

$$e = E\left(\frac{Z_T}{Z_T + Z_R} - \frac{Z_1}{Z_1 + Z_2}\right) \quad \ldots \quad (17)$$

As the hybrid coil windings are identical, then $Z_1 = Z_2$ and Equation (17) becomes -

$$e = E\left(\frac{Z_T}{Z_T + Z_R} - \frac{1}{2}\right)$$

which simplifies to -

$$\frac{E}{e} = \frac{2\ (Z_T + Z_R)}{Z_T - Z_R}$$

$$\therefore \text{ Loss across hybrid} = 20 \log_{10} \frac{2(Z_T + Z_R)}{Z_T - Z_R}$$

Now, $20 \log_{10} 2 = 6$

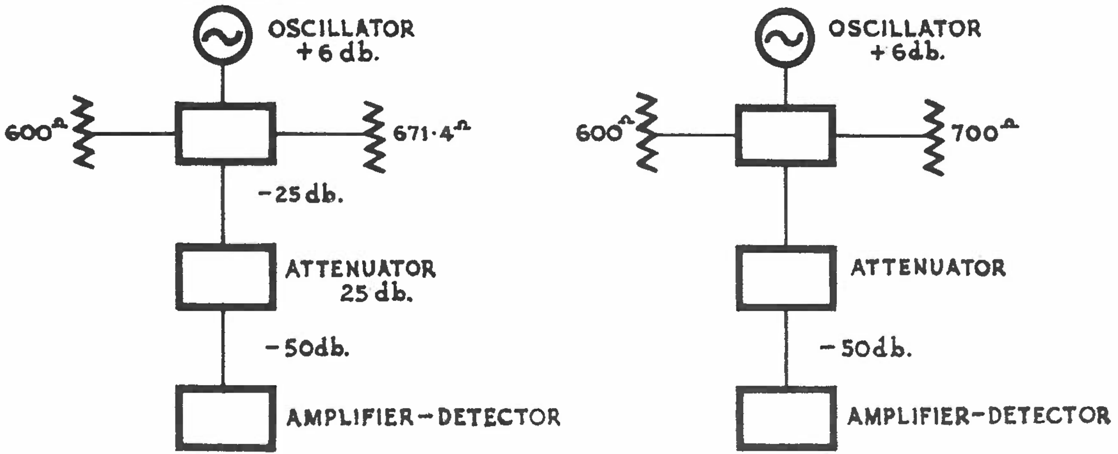
$$\therefore \text{ Loss across hybrid} = 6 \text{ db} + 20 \log_{10}\left(\frac{Z_T + Z_R}{Z_T - Z_R}\right)$$

$$= 6 \text{ db} + \text{return loss}$$

$$\therefore \text{ Return loss} = \text{loss across hybrid} - 6 \text{ db.}$$

/ A

A method of measuring the return loss between two impedances by means of a hybrid coil type impedance bridge is shown in Fig. 16, the return loss being measured against 600 ohms in this case.



(a) Calibrate. (b) Measure.

MEASUREMENT OF RETURN LOSS.

FIG. 16.

Fig. 16a shows the calibration conditions preparatory to commencing the test. The impedances of 600 ohms and 671.4 ohms connected across the opposite arms of the bridge, as in Fig. 15, produce a return loss of 25 db. With the oscillator output at +6 db (referred to 1 milliwatt), the power input to the variable attenuator connected between the mid-points of the bridge and the amplifier-detector is -25 db (that is, the oscillator output minus the loss across the hybrid, which, as proved above, is the return loss +6 db). Set the attenuator at 25 db, which gives an input of -50 db to the amplifier-detector, and adjust the gain control on the amplifier-detector until a convenient reading is obtained. This gives a convenient figure of 50 db on which to base measurements.

Assume, now, that the return loss (22 db approx.) is to be measured between 600 ohms and 700 ohms. The 700 ohms in Fig. 16b replace the calibrating 671.4 ohms of Fig. 16a. In order to obtain the same reading on the meter of the amplifier-detector, the input to it will have to be -50 db again. This means 28 db in the attenuator will, with the 22 db return loss and 6 db hybrid loss, produce the desired -50 db at the

/ input

input to the amplifier-detector and, therefore, the same reading as during calibration. The return loss is therefore -

50 db - attenuator reading = 50 db - 28 db = 22 db.

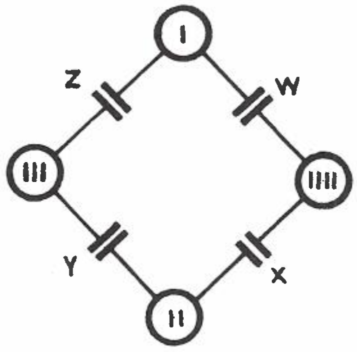
Thus, as the frequency and/or impedance whose return loss against 600 ohms is being measured change, the return loss will be given by -

50 db - attenuator reading.

The figures quoted above may have to be varied to meet different circumstances, but the principle in all cases is the same. For example, when a W.E. 5A bridge, which is a resistance bridge, is used, the oscillator output should be about +25 db, as the loss through a W.E. 5A bridge is not 6 db but 25 db.

6. CAPACITY BALANCING OF CABLES.

6.1 In Paper No. 4 of Long Line Equipment I, it was shown that the capacities produced by the four wires of a cable quad can be reduced to a four capacity network of the type shown in Fig. 17.



CAPACITIES IN QUAD.

FIG. 17.

The designations of the four wires of the quad in Fig. 17, that is, 1, 11, 111 and 1111, are the markings on the paper wrapping about each wire of a quad cable, wires 1 and 11 being one pair of the quad and wires 111 and 1111 being the other.

6.2 The condition for zero capacity unbalance between the four wires of the quad of Fig. 17 is the well known Wheatstone Bridge relation, that is -

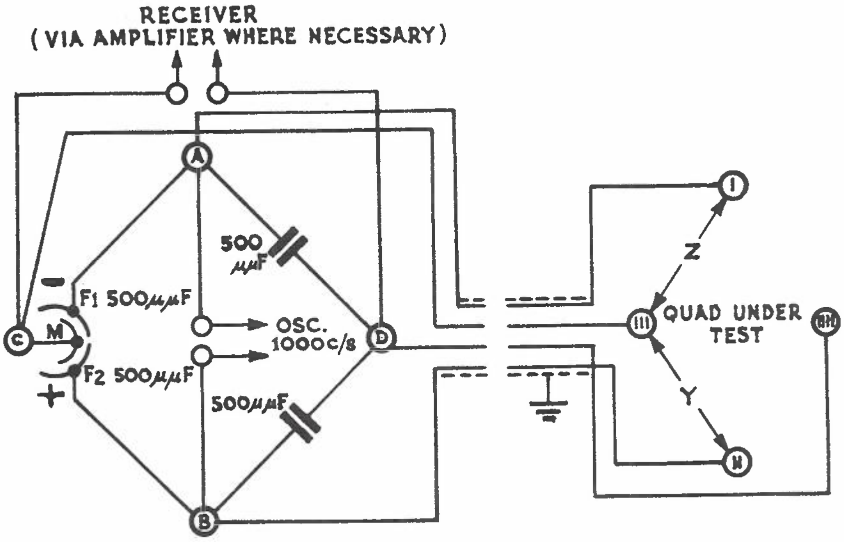
$$W : X :: Z : Y$$

$$\text{or } WY = XZ.$$

/If

If XZ is greater than WY, the unbalance is corrected in practice by operating on Y, whilst if XZ is smaller than WY, the unbalance is corrected by operating on Z. The unbalance which exists when WY > XZ is called a <u>negative</u> unbalance to differentiate it from the condition which exists when XZ > WY, which is called a <u>positive</u> unbalance.

6.3 Fig. 18 shows in schematic form a simple bridge used for the measurement of capacity unbalance, together with connections to a quad under test.



SCHEMATIC CIRCUIT OF SIMPLE TYPE CAPACITY UNBALANCE SET FOR MEASUREMENT OF SIDE-TO-SIDE UNBALANCE.

FIG. 18.

The quad is left open at the distant end, so that any coupling which appears between the pairs is due only to capacity unbalance. As the unbalance to be measured is of a small order, the bridge dial is calibrated in micro-microfarads. A tone of 1,000 c/s is applied to pair 1 and a set of headphones connected across pair 2. Very closely balanced fixed condensers of 500 µµF capacity are connected between wires 1 and 1111 and 11 and 1111 respectively. Their purpose is to complete the bridge circuit and, since they increase the values of Y and Z equally and so do not affect the unbalance being measured, they will not be considered further here. A variable differential condenser with a range of ± 500 µµF is connected to wires 1, 11 and 111, as shown. The dial of this condenser

/ is

is calibrated to read the difference between capacities of the moving plates M to fixed plates F1, on the one hand, and M to F2 on the other hand. Thus, if the moving plates are engaged equally with both F1 and F2, there is 250 μμF capacity on each side, the dial reads zero and the bridge itself is seen to be balanced. If in this condition a tone is heard, it is wholly due to the unbalance between Y and Z of the quad, since the effect of the variable condenser in this position is to add 250 μμF equally to Y and Z.

If now M-F1 is increased to, say, 400 μμF (so adding 400 μμF to Z) in order to eliminate the tone, then M-F2 will be 100 μμF (added to Y) and the dial will read -300 μμF (minus sign because the balancing capacity is added to deficient capacity Z to make it equal to capacity Y, which condition has already been noted as a negative unbalance). On the other hand, if, say, M-F2 must be made 300 μμF, M-F1 will be 200 μμF and the dial reading +100 μμF, indicating that capacity Z exceeds capacity Y by 100 μμF (a positive unbalance).

It is of importance to consider the effect of transposing the wires of either pair separately (not both together) when connecting to the bridge. If, for instance, wires 1 and 11 are transposed, the bridge will perform as before, but capacity Z will now appear to be that between wires 11 and 111, and capacity Y that between wires 1 and 111, so that elimination of the tone requires the same magnitude of added capacity, but on the opposite side of the differential condenser. In other words, a negative unbalance (which means that Y is greater than Z) applies to an excess capacity between wires 1 and 111, as against that between wires 11 and 111. (A similar result will be obtained if wires 1 and 11 are kept straight as originally, and wires 111 and 1111 are transposed instead, but this does not offer any advantage.) It can, therefore, be said that the sign of the unbalance will be changed if the wires of pair 1 of a quad are transposed, and this is the all-important fact made use of in balancing operations.

6.4 For trunk cable testing, Siemens Bros. have developed a Trunk Test Set which measures the following unbalances and mutual capacities, not only within a quad, but also between two quads.

/ Position

Position No.	Designation.	Function.
1	Off	Detector short-circuited.
2	1 - +	Pair 1 to phantom of quad 1.
3	2 - +	Pair 2 to phantom of quad 1.
4	1 - 2	Pair 1 to pair 2.
5	1 - E	Pair 1 to earth.
6	2 - E	Pair 2 to earth.
* 7	+ - E	Phantom quad 1 to earth.
* 8	+1 - +2	Phantom quad 1 to phantom quad 2.
* 9	+1 - 3	Phantom quad 1 to pair 3 (quad 2).
*10	+1 - 4	Phantom quad 1 to pair 4 (quad 2).
*11	1 - +2	Pair 1 (quad 1) to phantom quad 2.
*12	2 - +2	Pair 2 (quad 1) to phantom quad 2.
13	1 - 3	Pair 1 (quad 1) to pair 3 (quad 2).
14	1 - 4	Pair 1 (quad 1) to pair 4 (quad 2).
15	2 - 3	Pair 2 (quad 1) to pair 3 (quad 2).
16	2 - 4	Pair 2 (quad 1) to pair 4 (quad 2).
17	C1	Mutual capacitance pair 1.
18	C2	Mutual capacitance pair 2.
*19	C+	Mutual capacitance phantom quad 1.

The positions marked with an asterisk are those which are excluded when a knob labelled "phantoms excluded" is rotated in a clockwise direction.

Change-over from one measuring circuit to another is effected by means of a 19 position rotary switch. Fig. 19 shows schematic circuits of the Test Set for testing side-to-side unbalances.

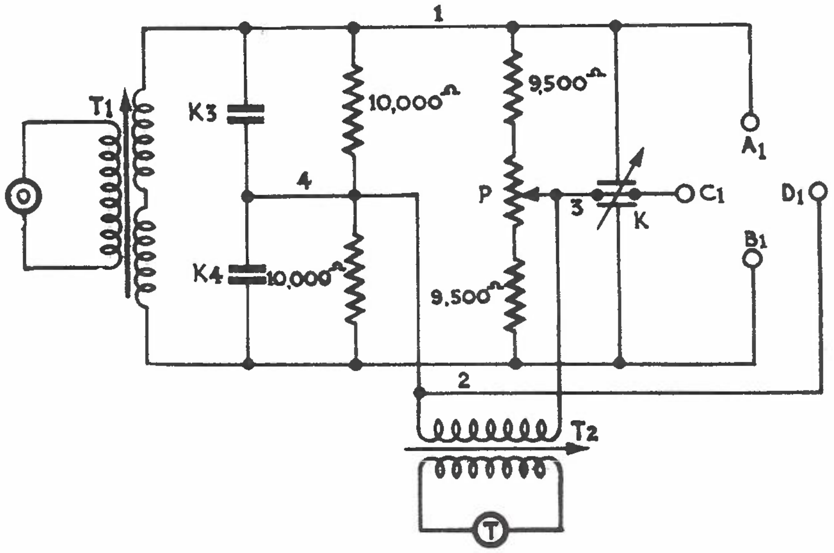


FIG. 19. SCHEMATIC CIRCUIT OF TRUNK TEST SET IN SIDE-TO-SIDE POSITION.

Several additions and modifications to the simple bridge of Fig. 18 are made in the Trunk Test Set of Fig. 19 to avoid errors and facilitate testing. These include -

(i) In order that the dissymmetries in the supply and detector circuits may be without effect on the balance, screened and balanced transformers, T_1, T_2, are interposed between these and the bridge, with the balanced windings towards the bridge.

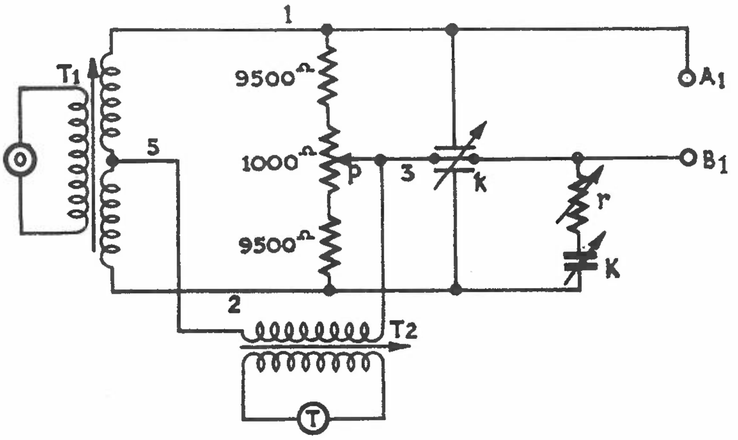
(ii) The balanced windings of the supply transformer T_1 are used as the equal ratio arms instead of resistors.

(iii) Some method of compensation for unbalanced leakance is required to secure perfect silence at the balance point. This is provided by a differential resistor, with its slider joined to the moving vanes of the differential condenser. As the range required does not exceed ± 10 micromhos, the device takes the form of a potentiometer P of 1,000 ohms connected between two fixed resistors each of 9,500 ohms. Two fixed resistors of 10,000 ohms are provided across the condensers K_3 and K_4, which are brought into use for the S/S and between-quad measurements. Thus, the leakance balance operates in the same manner for all within (and between) quad unbalances.

(iv) The changes from one bridge to another are effected without disconnecting the cable by means of a single switch S of the rotary type, in which all the necessary alterations to the connections are made by successive movements of a central spindle.

7. MEASUREMENT OF MUTUAL CAPACITY IN CABLES.

7.1 Fig. 20 shows, in schematic form, the circuit arrangement used to test mutual capacity in the Siemens Trunk Test Set.



SCHEMATIC CIRCUIT OF TRUNK TEST SET IN MUTUAL CAPACITANCE POSITION.

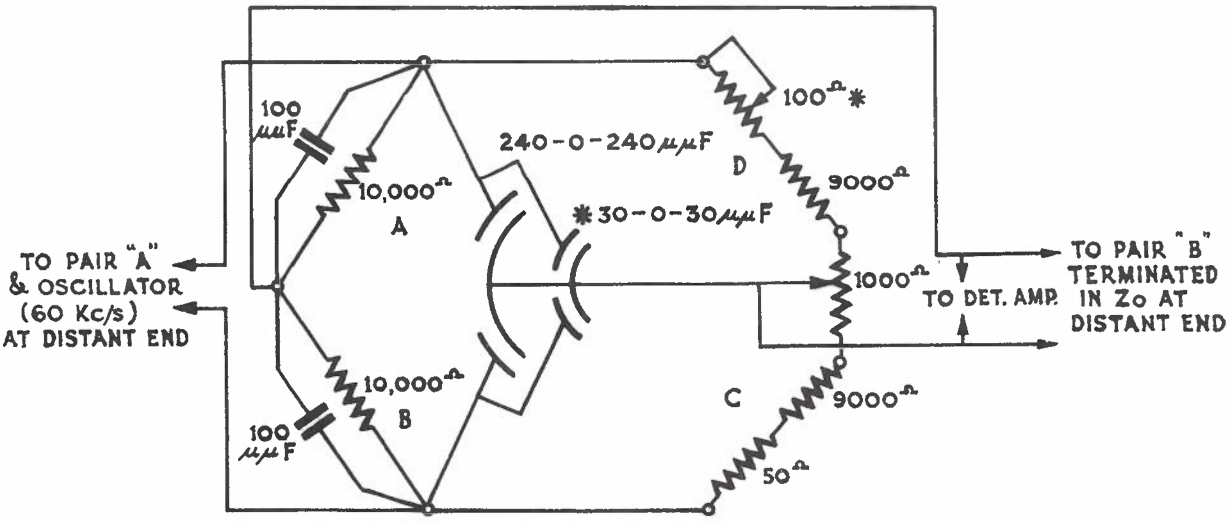
FIG. 20.

The circuit is essentially a bridge circuit with the balanced windings of the input transformer acting as two arms of the bridge, the other two arms being provided by condensers K and k and the mutual capacity to be measured.

The variable condenser required for mutual capacitance is much larger than for capacitance unbalances and is most conveniently obtained from an external condenser K, adjustable in steps of 0.0001 μF, the differential air condenser providing the variation between these steps. A small adjustable resistor r of approximately 100 ohms in series with the large condenser gives an approximate leakance balance, finer variations being made with the potentiometer setting as for unbalances.

8. MEASUREMENT OF ADMITTANCE UNBALANCE IN CABLES.

8.1 To measure the admittance unbalance between the four wires of a quad or the two wires of one circuit in one quad and the two wires of another circuit in another quad, an Admittance Unbalance Set has been developed by Siemens Bros. Fig. 21 shows a schematic circuit of this set.



* indicates trimming controls to adjust to zero.

FAR-END ADMITTANCE UNBALANCE SET SCHEMATIC.

FIG. 21.

8.2 The function of this set is to provide an indication in terms of capacity and leakance of the unbalance existing between two

/ cable

cable pairs. The relevant measurements are usually made at 60 kc/s, and provide the information necessary to the preliminary adjustment of the networks used for crosstalk neutralisation in carrier cables.

There is a similarity in principle to the capacity unbalance set. Each of the four arms consists of a resistance and a capacity in parallel. The components in the case of the "A" and "B" arms are of fixed and equal value, while those of the "C" and "D" arms can be varied about equality by adjustment of the variable resistance R and the differential condenser C. Both R and C carry dials calibrated about a zero point in terms of micromhos and μμF's respectively, with positive and negative indications for the two directions of movement.

The magnitude and sign of the dial settings at balance indicate the unbalance existing between the two pairs of wires concerned. The unbalance measurable is within the limits ± 220 μμF and ± 10 micromhos. The leakance range can be extended in either the positive or negative direction by inserting one or more of four fixed resistances into either one or other of two sets of clips provided. Each resistance adds 10 micromhos to the dial reading.

Sets of terminals are provided for connection to the pairs of two quads along with two change-over keys, enabling either pair of the first quad to disturb either pair of the second quad. A further "test" and "listen" key provides for the connection of a battery and milliammeter to the "disturbed" lines for ready observance of correct termination.

9. TEST QUESTIONS.

1. Describe how the characteristic impedance versus frequency of a line is determined.

2. Describe a method of measuring the attenuation of a line.

3. How are crosstalk measurements made?

4. Why are "return loss" measurements necessary?

5. Describe the method of capacity balancing cables.

END OF PAPER.

COMMONWEALTH OF AUSTRALIA.

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COURSE OF TECHNICAL INSTRUCTION.

LONG LINE EQUIPMENT III.

PAPER NO. 6.

TRANSMISSION MEASUREMENTS (CONTINUED).

CONTENTS:

1. NOISE MEASUREMENTS.

1.1 Apart from crosstalk from neighbouring telephone circuits, noise voltages may be introduced into telephone circuits by induction from neighbouring power lines and traction systems, or directly from such items of equipment as rectifier units, D.C. generators, and so on. The effects of these noise voltages on the ear depend on their wave form, that is, on the frequencies present and on their comparative sensitivity to the ear. To enable the aural effect of these noise voltages to be determined, comparison measurements are made between the interference present in the circuit and that interference which would be produced by a voltage of selected frequency. A frequency of 800 c/s has been standardised for this purpose. Table 1 and the curve shown in Fig. 1 show, under the name "weighting factor", the relative values of the average disturbing effects at various frequencies when the actual voltage at the terminals of a telephone receiver is the same at each frequency. Each weighting factor is related to that at 800 c/s. Thus, referring to Table 1, one volt at 800 c/s will produce on the average ear 1,000/560 or 1.78 times the effect of one volt at 600 c/s. In other words, 1.78 volts or 5 db more power must be applied to the receiver at 600 c/s to produce the same effect on the ear as one volt at 800 c/s.

Frequency	Weighting Factor		
	Relative Values	Neper	db
16.7	0.115	-9.07	-78.8
50	2.48	-6.00	-52.1
100	15.0	-4.20	-36.5
200	105.0	-2.25	-19.6
400	400	-0.92	-8.0
600	560	-0.58	-5.0
800	1000	0	0
1000	1840	+0.61	+5.3
1200	1260	+0.23	+2.0
1400	527	-0.64	-5.6
1600	353	-1.04	-9.0
2000	254	-1.37	-11.9
2400	200	-1.61	-14.0
2800	159	-1.84	-16.0
3500	80	-2.53	-21.9
4000	45	-3.1	-26.9
5000	19	-3.96	-34.4

TABLE 1.

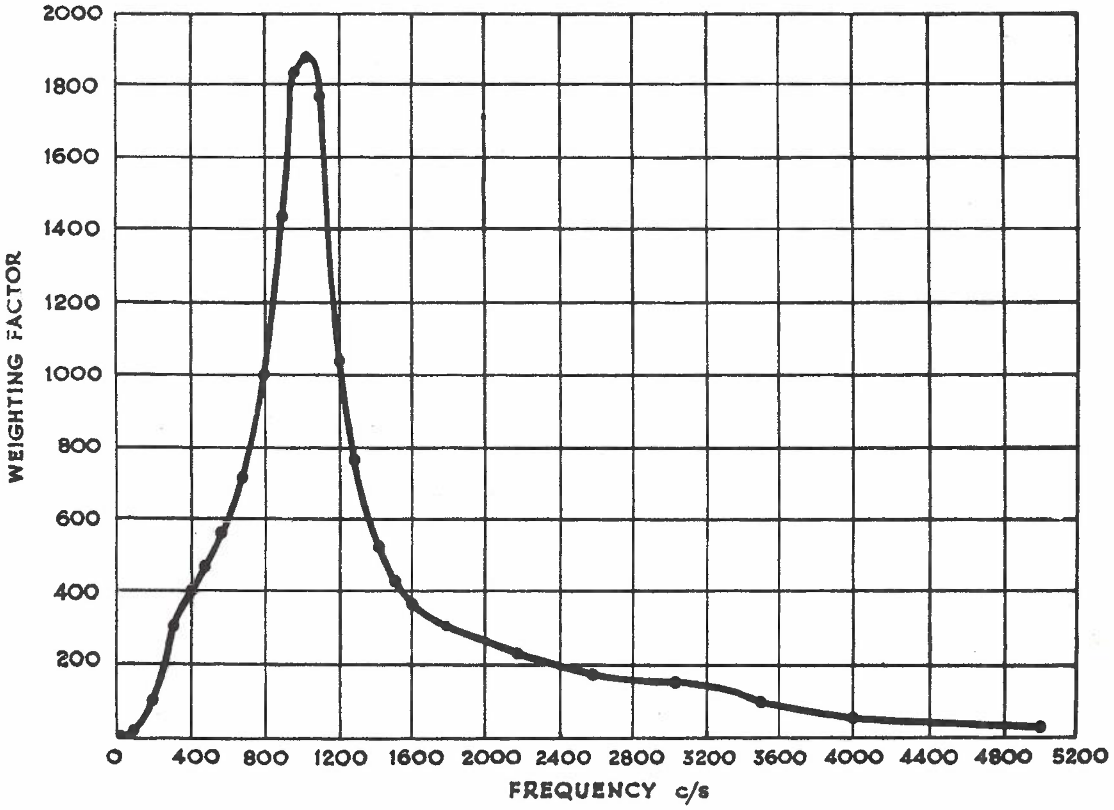
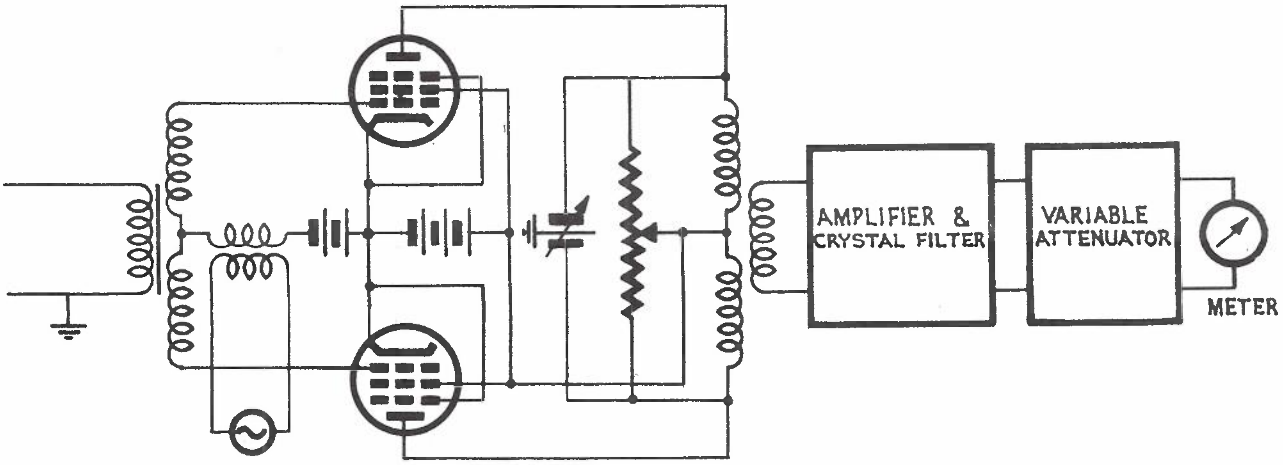


FIG. 1. WEIGHTING FACTOR.

1.2 An instrument has been developed to measure the sum of the correctly weighted voltages of all frequencies in the noise introduced into telephone circuits. This instrument is called a "Psophometer" (Greek psophos = a noise), and the voltage measured by this instrument is called the "psophometric" voltage. The characteristics of the instrument are therefore such that, if a voltage whose amplitude remains constant at all frequencies is applied to the input, the value indicated by the measuring instrument in the output will be proportional to the relative weighting factor of the frequency in question. In other words, the presence of the weighting network between the input and the measuring instrument will mean that 1.78 volts at 600 c/s will produce the same reading as one volt at 800 c/s.

1.3 When the noise introduced into a circuit is of a level high enough to be objectionable, it is usually necessary to analyse that noise into its frequency components so that the source of the noise can be traced. This is done by means of a Wave Analyser. Most wave analysers employ the heterodyne principle, a typical arrangement being shown in Fig. 2.



WAVE ANALYSER (TYPE 636A).

FIG. 2.

The heterodyne oscillator is variable between 0 and 50 kc/s and is applied to the grids of a balanced modulator in the same phase. The noise voltage is applied to the grids of this modulator 180° out of phase, so that this modulator functions as a carrier suppressed modulator of the type discussed in previous Papers of these books. An amplifier tuned to a frequency of 50 kc/s follows the modulator, and the output of this amplifier is applied to a valve voltmeter.

/ To

To illustrate the principle, assume that a noise voltage of a frequency of 5 kc/s is being measured. When the scale of the heterodyne oscillator reads 5 kc/s, that oscillator is developing the difference between 50 kc/s and 5 kc/s, that is, 45 kc/s. Thus, 5 kc/s and 45 kc/s are applied to the balanced modulator, whose output contains the input 5 kc/s and sidebands only. The upper sideband is 50 kc/s, which is passed by the tuned amplifier and measured on the meter. As the oscillator frequency changes, therefore, the different frequency components of the noise are measured. This principle enables a search to be made over the frequency spectrum by means of only one control, that is, the tuning control of the heterodyne oscillator.

2. PROGRAMME TRANSMISSION MEASURING EQUIPMENT.

2.1 Volume Indicators. Volume Indicators are used for the following purposes -

(i) As an indication of a suitable level at a particular point to avoid audible distortion in line amplifying, radio and other equipment.

(ii) As a means of providing a continuous check at a number of points of the transmission losses or gains in a programme network.

(iii) To enable the loudness of programmes, when finally reproduced, to be determined.

(iv) To prevent damage or interruption by overload as may occur in radio transmitters or sound recording equipment.

(v) To carry out sine wave transmission measurements.

Several types of volume indicators having different electrical and dynamic characteristics are in use and are calibrated with reference to different bases. An attempt is now being made to standardise this equipment, and a new unit, the volume unit (VU), has been adopted for expressing the magnitude of the quantity "volume," whilst a new type of volume indicator has been standardised which conforms to specified characteristics.

In order to make practical use of the volume indicator, a reference volume or zero volume level has been established. A suitable definition of reference volume is - "That level of programme which causes a standard indicator, when calibrated and used correctly, to read to a defined mark on the scale, that is, 0 VU."

The connection between "reference volume" and "calibrating power" lies in the fact that both use the same scale mark. They are, however, quite different quantities. Calibration is made with a steady single frequency tone (1,000 c/s) applied to the volume indicator and gives a steady reading at the scale mark. Volume is measured on a programme line by adjusting the associated attenuator until the meter pointer reaches the same scale mark, but only once every 10 seconds with occasional overswings. It will thus be appreciated that there will be peaks many times the calibrating power, but most of the time the level will only be a fraction of the calibrating power. With the attenuator adjusted so that the meter reads 0 VU, the programme level with respect to reference volume is read directly in VU from the calibration on the attenuator.

2.2 Volume Unit. The reference unit is termed the volume unit (VU). The volume unit is like the db in one respect, in that numerically a particular signal will be the same number of VU different in magnitude to some other signal. It is different, however, in that VU only requires an associated + or - sign to designate it completely, whereas the db ratio must, as well as having its sign, be referred to a particular base to fix it correctly.

2.3 Types of Volume Indicators. The various types of volume indicator in use may be divided into two main classes -

(i) The R.M.S. Type, and

(ii) The "Peak" Type.

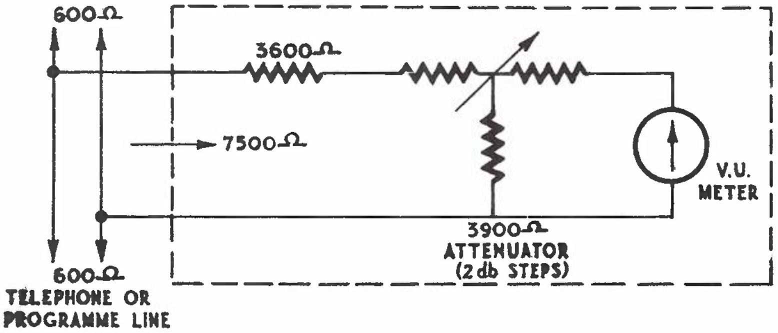
The terms are only relative, the peak type integrating the speech waves for a shorter period of time than the R.M.S. type. In general, the R.M.S. type is less complicated, and, as tests have proved that the peak type has no advantages over the R.M.S. type, the latter has been adopted as standard.

The standard meter is a full wave copper oxide rectifier type and has two scales, a VU scale and a 100 or percentage scale.

The dynamic characteristics are as follows. For a 1,000 c/s voltage of such magnitude as to give a steady reading of 100, the pointer should read 99 in 0.3 second and should then overswing the 100 point by at least 1 per cent. but not more than 1.5 per cent.

/ The

The electrical characteristics are bound up with an associated circuit as shown in Fig. 3.



VOLUME INDICATOR.

FIG. 3.

The meter has an impedance of 3,900 ohms, hence the attenuator has the same value. The attenuator looks back to an impedance of 3,900 ohms towards the line, made up of 3,600 ohms fixed resistance and 300 ohms from the two line impedances in parallel. This is necessary to give correct loss through the attenuator, as, in practice, it is the reading of the attenuator which gives the volume at the measurement point. The 3,600 ohms fixed resistance also ensures that the dynamic characteristics of the meter are correct.

The total impedance of the meter and associated circuit is 7,500 ohms, which makes it high enough to be bridged across the line as a monitoring device with negligible loss. As mentioned previously, the complete volume indicator is required to read 0 VU with 1 milliwatt of 1,000 c/s power in a 600 ohm resistance. Actually, the sensitivity of the meter itself is insufficient for the needle to deflect to the 0 VU point, when connected to that calibrating power, and will only reach -4 VU. This is taken care of by marking the zero position of the attenuator as +4 VU. Adding the reading of the attenuator to the reading of the meter, therefore, gives a net value of 0 VU. The attenuator has eleven steps of 2 db and is designated +4 to +26. The extremes of reading of the complete indicator are, therefore, approximately -

Meter	Attenuator	
-20	+ 4	= -16 VU.
+ 3	+26	= +29 VU.

/ In

In telephone and programme work, the VU scale is the most important and is made predominant. The 100 scale is used for broadcast stations, where the main requirement is to load the transmitter to the 100 per cent. modulation mark, and, for these applications, the percentage scale is made predominant. The 0 VU or 100 mark is at a point about 70 per cent. from the beginning of the scale, leaving adequate margin for overswing.

Other important characteristics of the volume indicator are -

Response versus Frequency. The sensitivity of the volume indicator must not depart from that at 1,000 c/s by more than 0.2 db between 35 and 10,000 c/s, nor more than 0.5 db between 25 and 16,000 c/s.

Harmonic Distortion. The harmonic distortion introduced in a 600 ohm circuit by bridging the volume indicator across it must be less than 0.2 per cent. (R.M.S.).

Overload. The instrument must be capable of withstanding, without injury or effect on calibration, peaks of 10 times the voltage equivalent to a deflection to the 0 VU or 100 per cent. mark for 0.5 second and continuous overload of 5 times the same voltage.

Presence of Magnetic Material. Due to the powerful magnetic material employed in the instrument, it should be mounted on non-magnetic panels. However, panels not more than 1/16th inch thick can be employed if essential.

Temperature Effects. The deviation of sensitivity with temperature should be less than 0.1 db between 50°F. and 120°F. and less than 0.5 db for temperatures as low as 32°F.

2.4 Distortion Factor Meter 74200-A. Occasions arise where it is necessary to be able to determine the harmonic content in a wave form. The harmonic content of the output of an oscillator or amplifier may be the determining factor as to whether an equipped circuit will be satisfactory or not.

When dealing with programme circuits, it is not so important to know the individual harmonics. It is, however, very important to know the ratio that the sum of the harmonics bears to the total output.

The Distortion Factor Meter, in conjunction with an amplifier, will determine the total harmonic content of any wave form which has a fundamental frequency in the range of 20 to 5,000 c/s. The results obtained include all harmonics up to 10,000 c/s.

/ The

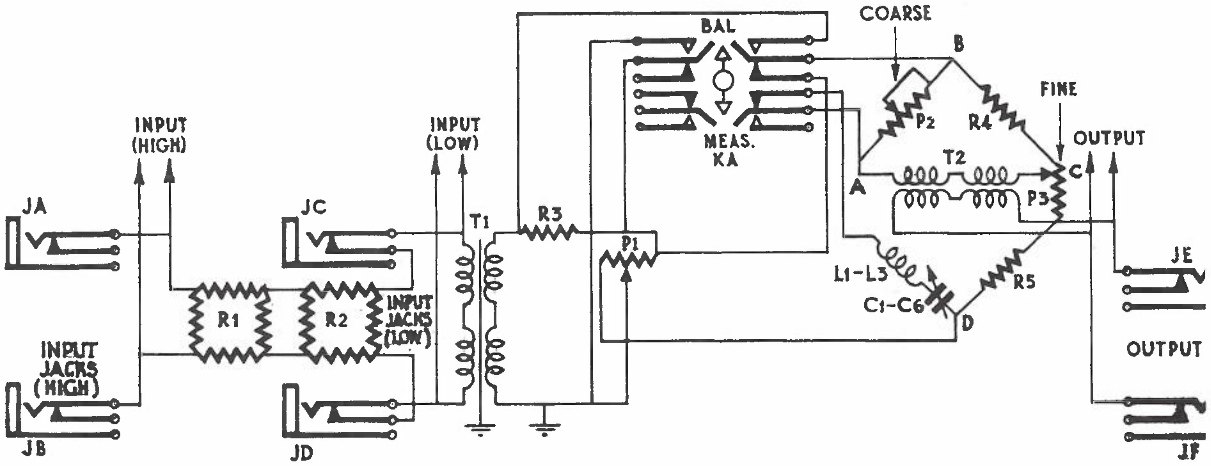
The distortion range is from 0.5 per cent to 10 per cent. The input impedance is 600 ohms, and the sensitivity is such that an input of 15 db below 1 milliwatt is sufficient to measure 1 per cent. distortion. The maximum input current is 10 milliamperes when measuring distortion less than 3 per cent.

The principle employed in the set is -

(i) To eliminate the fundamental frequency from the tone under test by means of a selective circuit, and to obtain a response on a detector or visual indicator which will be proportional to the harmonics alone. This response is noted.

(ii) The selective circuit is then cut out and the unfiltered tone (that is, fundamental and harmonic) is impressed via a calibrated potentiometer on to the same detector. The potentiometer is adjusted until the deflection for the fundamental and harmonics is the same as that obtained for the harmonics alone. The percentage indicated on the potentiometer is the relation the harmonics bear to the total tone.

A schematic of the circuit is shown in Fig. 4.



DISTORTION FACTOR METER (TYPE 74200-A).

FIG. 4.

It will be noted that the chief features of the circuit are a slide wire potentiometer P1, a switch KA and a bridge arrangement ABCD, consisting of three resistance arms and an arm AD having a variable inductance L and a variable capacity C in series. This series resonance bridge is the selective circuit of the set. It is a well-known feature of this type of bridge

/ that,

that, when an alternating potential having a given frequency is applied across the BD points of the bridge, the latter can be tuned by means of the series inductance and capacity and by means of resistance P2, so that there is no voltage across the conjugate points AC.

For this setting of L and C, the bridge will be completely unbalanced at all other frequencies, that is, the arm AD will be effectively open-circuited for all frequencies except the tuned frequency. A simple, sharply tuned, selective circuit is thus available, which enables the elimination from a complex wave form any single frequency component (within the tuning range of L and C) without affecting (except to a negligible degree) the amplitude of the other components.

Referring to Fig. 4, it will be noted that, when the switch KA is thrown to BAL, the circuit is so arranged that the INPUT tone under test is impressed on the BD terminals of the bridge shunted by R1 and R2 which are of low resistance, approximately 10 ohms.

The series resonant bridge circuit is complete, and the response on any detecting equipment connected to the AC terminals will be due to the harmonics alone, if the bridge is tuned to the fundamental. To all other frequency components but the fundamental, the bridge will act as a simple attenuator between the BD and AC terminals.

When the switch is thrown to MEAS, the AD arm of the bridge is open-circuited and the slide wire potentiometer P1 is brought into circuit. The bridge is now completely untuned at <u>any</u> frequency, and acts only as a resistive attenuator between the BD and AC side of the bridge. In this case, it will act as an attenuator for all frequency components. As the bridge components are otherwise unchanged when the key is thrown from BAL to MEAS, the bridge attenuation to the harmonics in the BAL condition will be equal to the bridge attenuation to fundamental + harmonics in the MEAS. condition. If, therefore, only a proportion of the total tone is impressed on to the bridge in this latter condition, it can be stated that, if this proportion is adjusted so that the response is equal to that in the BAL condition, this proportion will be a measure of the ratio, fundamental + harmonics to harmonics. This operation is performed by the switch KA and by adjustment of the potentiometer P1.

The input impedance is transformed to 600 ohms by means of the shielded and balanced transformer T1. To avoid the creation of harmonics by this transformer, it is necessary to keep the

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input on the primary of the transformer at a low level. The distortion created by this transformer is greatest at low frequencies. The minimum input level can, therefore, be raised slightly with frequency if necessary. The input level can also be raised for large distortion when a small error is less significant.

For accurate measurement of 1 per cent. distortion at 50 c/s, the input level to the transformer must be kept below -10 db referred to 1 milliwatt. In order to enable this to be done when measuring large inputs, a 30 db pad is inserted between the input and the transformer. Two pairs of input jacks are provided, one pair engraved INPUT (HIGH) for high levels and one pair INPUT (LOW) for low levels. Both inputs are connected to contacts on a terminal strip.

2.5 Method of Operation of 74200-A Distortion Factor Meter. Connect the source to be measured to the HIGH INPUT jacks of the Distortion Factor Meter. Connect the jacks marked OUTPUT on the Distortion Factor Meter to the LOW terminals of the 74200-A Amplifier (details later), and switch on the amplifier by means of the ON-OFF key. Set the amplifier potentiometers marked GAIN CONTROL and FINE CONTROL to zero. The three lever switches on the Amplifier should be thrown to LOW METER and ON. Switch the Distortion Meter Key to BAL. Switch on the source which is to be analysed. As the fundamental is most probably untuned initially, it will be found that a deflection is obtained on the Decibel Meter on the amplifier. It is convenient, if the output of the source can be adjusted, to give an initial meter reading somewhere about the mid-scale. Set the RANGE SWITCH to the range which includes the fundamental frequency to be measured, and tune the deflection to a minimum by means of the condenser decade and the COARSE and FINE potentiometers, increasing the gain of the amplifier as necessary as the tuning becomes closer. Now switch the Distortion Factor Meter Key to MEAS and, by means of the Percentage Dial, adjust the new reading to the same reading, that is, mid-scale. The total harmonic content will then be indicated directly on the scale.

2.6 The 74200-A Amplifier. (For use with Distortion Factor Meter.) This amplifier is a high gain type with a flat response curve for a frequency range 20 to 10,000 c/s. It is fitted with a variable gain control giving a maximum gain of about 90 db between input and output impedances of 600 ohms.

The amplifier is a mains operated three-stage resistance-capacitance coupled unit terminating in a metal rectifier and meter. The harmonic content is less than 5 per cent. The noise level at full gain is equivalent to an input of less than 3 microvolts.

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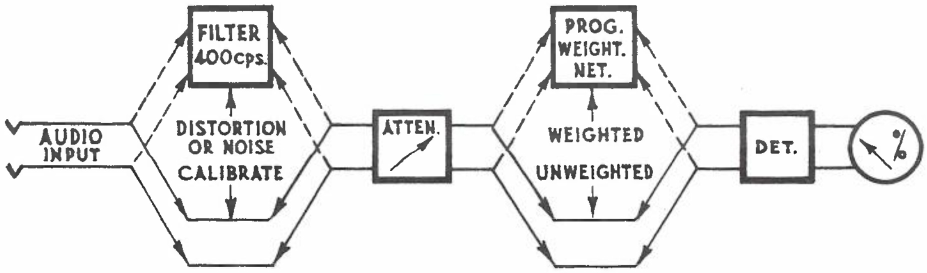
The harmonic content of the amplifier may be disregarded, as it is common to both measurements, and the reading, as indicated on the dial, is really a comparison of voltage variation.

Provision has been made by means of a switch to feed into the circuit at either the first or the second tube, depending on whether it is high or low gain input.

2.7 G.R.732A Noise and Distortion Measuring Set. The G.R. Company's distortion and noise measuring set consists of a linear rectifier used with R.F. input, a filter, an amplifier and a vacuum tube voltmeter. The meter reads distortion directly in per cent., and reads noise and hum level directly in decibel with respect to the normal signal input to the equipment under test. The amplifier has a flat response from 30 to 10,000 c/s, but, in order to present a true picture of the effect of noise on the human ear, the measuring system should have a frequency characteristic similar to that of the normal auditory system, that is, the low and high frequencies must be discriminated against. This is provided for by the addition of a weighting network, the function of which is to attenuate every interfering source (by means of a filter) according to its frequency. A schematic circuit of the noise and distortion measuring set is shown in Fig. 5.



NOISE AND DISTORTION SET.
BLOCK SCHEMATIC OF TYPE G.R.732A.

FIG. 5.

The filter associated with the set has a very sharp cut-off of the fundamental frequency of 400 c/s. It is used when measuring distortion on an incoming circuit. The operation is as follows.

Having first employed the 400 c/s (which is sent from the distant end) to calibrate the receiving set with the key in the flat position, the selecting switch is moved to "Distortion." This action places the filter in circuit and causes the 400 c/s fundamental frequency to be suppressed. The remaining interfering elements are indicated by a direct reading on the meter

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of the percentage distortion. The range covers interference up to 30 per cent. It is important, when sending the 400 c/s to line, that a power of about 23.5 milliwatts (+6 above zero of 6 milliwatts) be transmitted. This is to test the amplifiers and other apparatus at full capacity and represents the instantaneous high programme peaks.

The measurement of noise is taken with the switch in the noise position and with the line at the distant end terminated in 600 ohms. A reading can be obtained either weighted or unweighted with a range available down to 80 db. As the noise sent has been calibrated on a +6 basis when reading distortion, the measurement of noise which follows and which is read without recalibrating should, under these conditions, be referred to +6 db, that is, the reading obtained, say, 54 db is actually only 48 db away from a programme of zero level (average peaks).

The general average noise level (weighted on programme lines) is between 50 and 60 db below zero programme (reference 6 milliwatts). When it is found that a noise level approaches 40 db, action is taken to sectionalise the trouble and later remove the cause.

In the case of distortion, it has been the practice to consider the margin of safety satisfactory so long as the figure of 5 per cent. is not exceeded.

It will be noted from earlier remarks that the noise set is calibrated in the flat position, that is, unweighted. Actually, it would be better if the noise set could be calibrated in the weighted position, then the readings taken would be direct and indicate more truly the noise as heard on the programme. However, on account of insufficient gain of the amplifier, it is not convenient to calibrate in the weighted position.

Examination of the weighting network curve employed for programme circuits will show that a 1,000 c/s weighted calibration would be 10 db down on an unweighted calibration. Therefore, when calibrating in the unweighted position and measuring in the weighted position, the noise level indicated on the meter is actually 10 db (2.5 db insertion loss and 7.5 db due to curve) further away from the signal than it would be if the meter had been calibrated with the weighted network in circuit. Now to correct for this measuring irregularity, due to the method of calibration, and taking 1,000 c/s as a standard, subtract 10 db from the weighted reading, which will give a figure representative of the level of noise as heard and approximately in accordance with C.C.I.F. standards.

3. TEST QUESTIONS.

1. Why are volume indicators used? 2. What is the principle of a "Wave Analyser"? 3. Define the "Volume Unit". 4. How is the harmonic content of a wave form determined?

END OF PAPER.

COMMONWEALTH OF AUSTRALIA.

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COURSE OF TECHNICAL INSTRUCTION.

LONG LINE EQUIPMENT III.

PAPER NO. 7.

TRANSMISSION MEASUREMENTS (CONCLUDED).

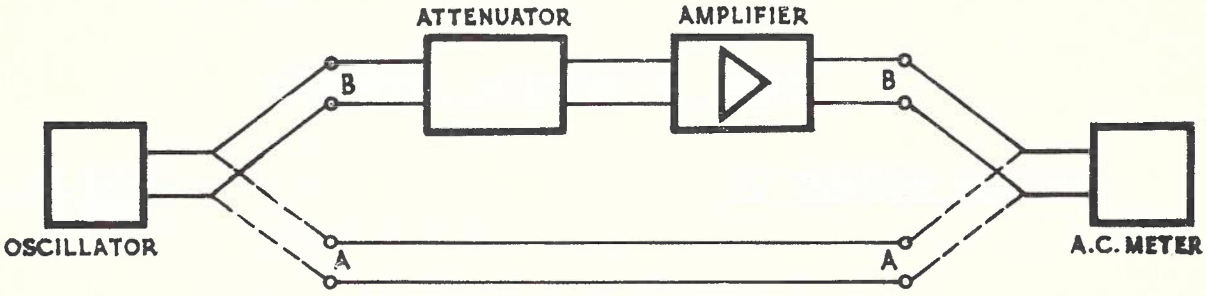
CONTENTS:

1. MEASUREMENT OF OVERLOAD POINT OF AMPLIFIER.

1.1 Overload Characteristics. The approximate point at which an amplifier overloads in actual operation can be determined by relatively simple measurements of the amplifier behaviour. To test the overload point of an amplifier, a direct current microammeter is connected in the grid circuit of the output stage valve, and a sensitive direct current milliammeter is placed in the anode circuit. With 1 kilocycle per second input to the amplifier, the gain is increased until either grid current flows (for a Class A amplifier) or there is a change in I_a, whichever happens first. Either occurrence indicates overload. Reduce the gain until this effect disappears, and then measure the power output. This power is then the overload point. To detect this point in intermediate stages, the same measurement can be made to each stage in turn.

2. MEASUREMENT OF AMPLIFIER GAIN.

2.1 A convenient method of measuring the gain of an amplifier is indicated in Fig. 1.



MEASURING AMPLIFIER GAIN.

FIG. 1.

2.2 A variable frequency oscillator, variable attenuator, an A.C. voltmeter and a change-over key are connected as in Fig. 1. With the key in position A, the oscillator output is adjusted until a convenient reading is obtained on the meter. With the key in position B, the attenuator is adjusted until the same reading is obtained. Under these circumstances, the gain of the amplifier equals the loss in the attenuator.

3. TESTS FOR STABILITY OF V.F. REPEATERS.

3.1 As discussed in Paper No. 1 of Long Line Equipment II, the stability of a V.F. circuit equipped with V.F. repeaters depends on the accuracy of the match between the sections of line and their balance networks.

The effect of an unbalance between the network and the line of a repeater gives rise to "singing" or sustained oscillation around the repeater circuit. This effect can be observed as a continuous tone in the monitoring headset. If a balance network could be designed as an ideal match for a line at all frequencies, the gain which could be used in the repeater would be infinite, assuming that the hybrid coil or three-way transformer was, itself, perfectly balanced.

However, this condition does not exist in practice, and the gain which can be utilised in a repeater is limited by the tendency of the repeater to sing. The singing point is an expression for the lowest gain in the circuit at which a repeater will sing.

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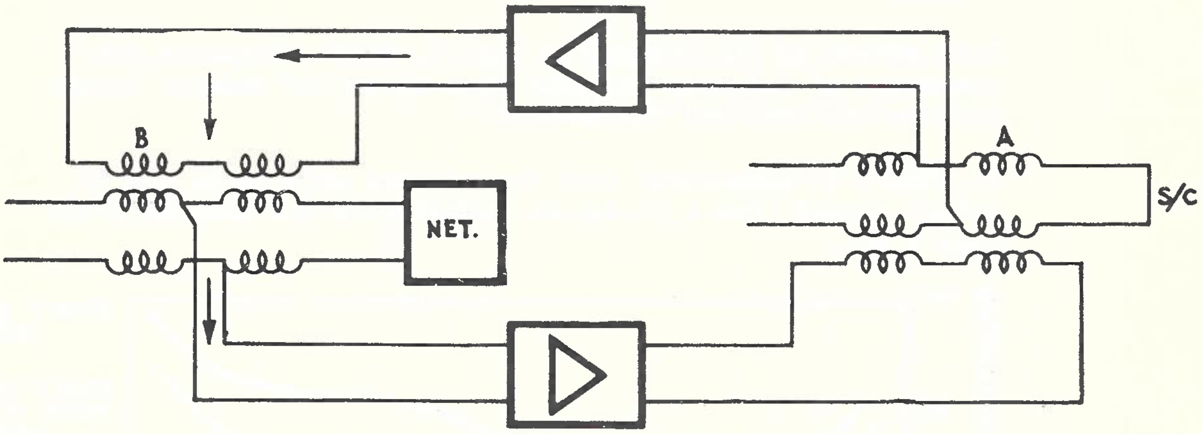
The maximum gain which can be utilised before "singing" commences is taken as a measure of the degree of balance between the network and the line.

3.2 The following simple test has been developed for determining the balancing conditions of a two-wire repeatered circuit.

This test, although not giving such accurate results as may be obtained with other methods, such as the impedance unbalance Measuring Set, has the advantage that measurements may be made rapidly, and that only standard two-wire repeaters are necessary.

Referring to Fig. 2, one hybrid coil "A" may be readily converted into a repeating coil by short-circuiting its line terminals and opening its network terminals. Alternatively, the line terminals may be open-circuited and the network terminals short-circuited. These two methods of conversion are referred to arbitrarily as "Positive Poling" and "Negative Poling", respectively. The current transmitted through the hybrid coil with "Positive Poling" is in approximate phase opposition to that transmitted with "Negative Poling". (When making a test, both methods should be tried, as usually it is found that one phase relationship is more favourable to singing than the other).



HYBRID COIL AS A REPEATING COIL.

FIG. 2.

The balance of the second hybrid coil "B" is tested by increasing the gain in the amplifiers until "singing" is heard in the receiver. This singing occurs when the gain in the amplifiers is sufficient to equal or overcome the loss in coil "B", due to the unbalance between the line and its network. The greater

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the unbalance between the line and the network, the smaller is the loss in the coil and the more easily can singing occur.

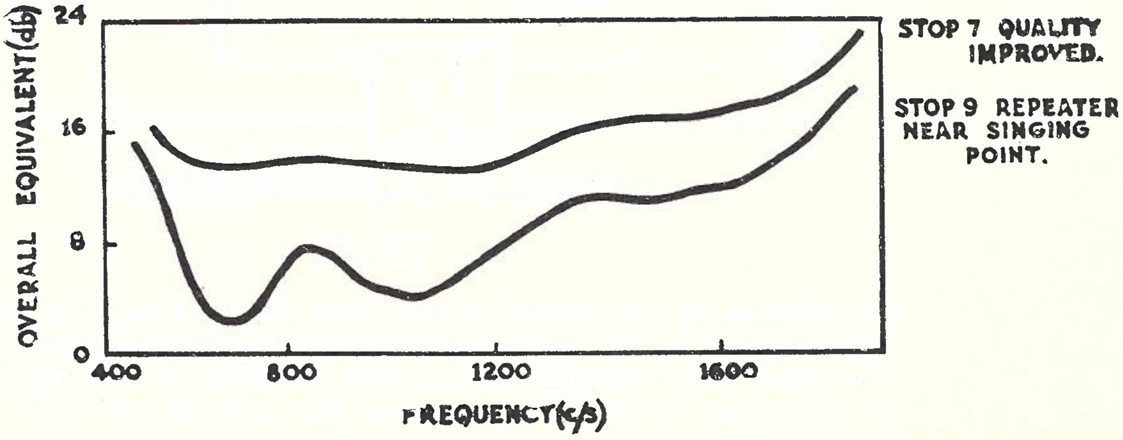
The short-circuit and open-circuit are now changed over to the opposite end of the hybrid coil "A". The reason for this change can be explained as follows -

When the unbalance current, having travelled around the circuit, returns to the input of the hybrid, it may or may not be in phase with the original current at this point. If the return current is directly in phase, the singing point is lower than when the current is out of phase, that is, the circuit has a greater tendency to sing. Two readings are, therefore, taken to discover the condition which brings the currents approximately in phase.

3.3 The phase difference or rotation is brought about by the filters, transformers, vacuum tubes and nature of the unbalance between the line and network. Should it happen that, owing to line troubles, the standard of balance between the line and network is lowered and the repeater gain is not reduced by a corresponding amount, the gain given by the repeater at different frequencies will depart from normal values, giving rise to distortion.

This effect is illustrated by Fig. 3, which indicates the advantage of reducing the gain when an out of balance exists between the line and the network.

It should be remembered that the maximum gain which can be safely worked from a telephone repeater is the singing point less 5 db.



SHOWING ADVANTAGE OF REDUCING GAIN.

FIG. 3.

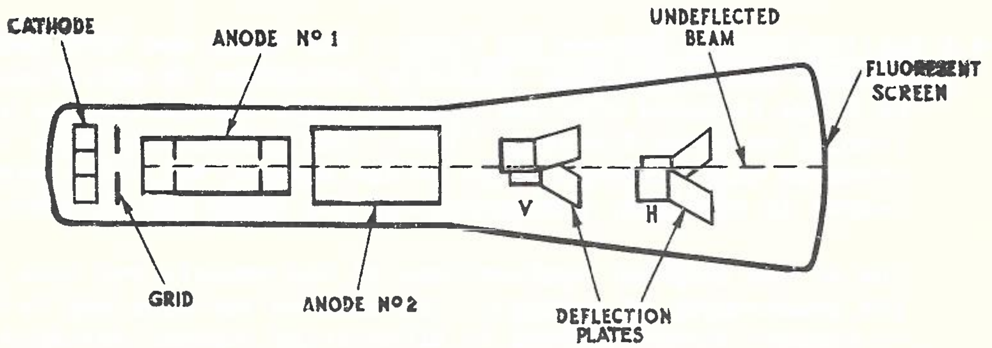
4. CATHODE RAY TUBE.

4.1 The cathode ray tube is a vacuum tube, in which the electrons emitted from a hot cathode are accelerated to give them considerable velocity, formed into a beam, called the cathode ray, and allowed to strike a special translucent screen which fluoresces, or gives off light, at the point where the beam strikes.

A narrow beam of moving electrons is similar to a wire carrying current, and is accompanied by electrostatic and electromagnetic fields which exert a force on the beam in the same way as similar fields do on charged bodies or on wires carrying current.

It will be readily appreciated that, since the beam consists only of moving electrons, its weight and inertia are negligibly small, hence it can be deflected easily and without any appreciable time lag. For this reason, the beam can be made to follow instantly the variations in fields associated with speech, carrier and radio frequencies.

4.2 Construction. The essentials of a typical cathode-ray tube are shown in Fig. 1. The electrode arrangement, which forms the electrons into a beam, is called the "electron gun". In the simple tube structure shown in Fig. 4, the gun consists of the cathode, grid and anodes Nos. 1 and 2. The intensity of the electron beam is regulated by the grid in the same way as in an ordinary tube.



CATHODE RAY TUBE.

FIG. 4.

Anode No. 1 is operated at a positive potential with respect to the cathode, thus accelerating the electrons which pass through the grid, and is provided with small apertures through which the electron stream passes and is concentrated into a

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narrow beam. This anode is also known as the focusing electrode. Anode No. 2 is operated at a high positive potential with respect to the cathode, and further increases the velocity of the electrons in the beam. The electron velocity and sharpness of the beam are determined by the relative voltages on the electrodes.

4.3 Beam Deflection. The gun alone simply produces a small spot on the screen, but, when the beam is deflected by magnetic or electrostatic fields, the spot moves across the screen in proportion to the force exerted. When the motion is sufficiently rapid, retentivity of vision makes the path of the moving spot appear in a continuous line. This is usually termed the "trail".

In the tube under consideration, the spot of light may be shifted to any portion of the screen by means of the two sets of electrostatic deflecting plates V and H. The deflecting plates V produce a vertical shift in the position of the spot, while the spot is shifted horizontally by means of deflecting plates H. In either case, the amount of deflection up or down, to the right or to the left, depends upon the potential that is applied to each set of deflecting plates, while the direction of deflection is dependent upon the polarity of the applied voltage.

Electromagnetic deflection of the beam is accomplished by means of coils instead of deflecting plates. The coils are external to the tube but are mounted close to the glass envelope.

4.4 Applications of Cathode Ray Tubes. The tubes are very useful in circuit investigations. Magnetic deflection is satisfactory up to a few thousand c/s, but electrostatic deflection has practically no upper frequency limit. The cathode ray tube itself produces only a visual image on the screen, but, if a permanent record is required, photographs of the image may be taken.

One of the simplest applications of the cathode ray tube is to the measurement of voltage. The cathode ray tube may be used to measure direct current or alternating current voltages. For direct current measurements, the correct voltages are applied so that the electron beam produces a spot of light in the centre of the screen. The direct current voltage to be measured is then applied to one set of deflecting plates, causing the spot of light to be moved in the direction and to the position corresponding to the voltage on the deflecting plates. When this voltage is applied to the vertical plates, the spot of light will move either upwards or downwards, depending on

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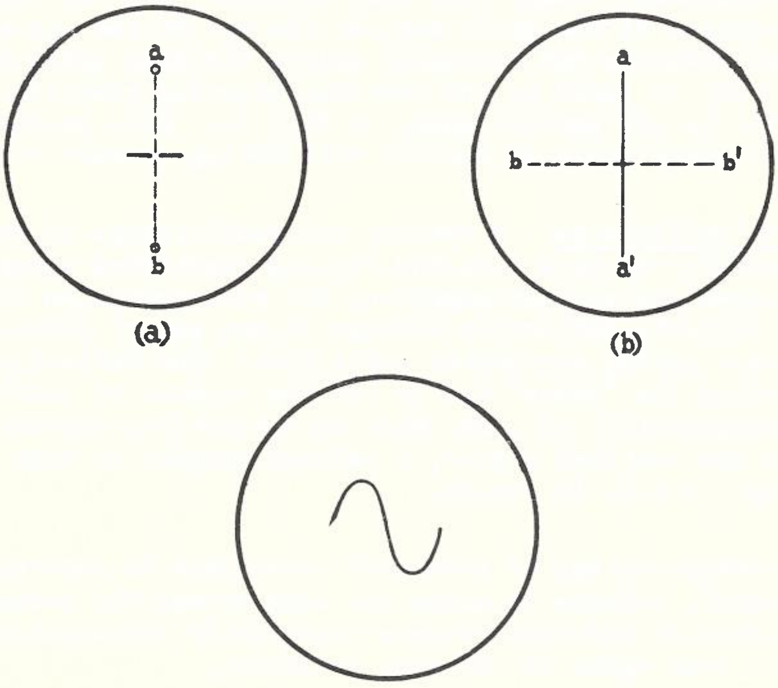
the polarity of the electrodes. The electron stream is, of course, attracted to the positively charged plates, so that, when the upper plate is connected to the positive side of the voltage under test and the lower plate to the negative side, the light spot on the screen will move upwards and assume a position corresponding to the voltage being measured, or as shown at "a" in Fig. 5a. If the connections at the vertical plates are reversed, the spot of light is shifted to point "b". The screen may be calibrated to give a direct reading in volts.

An indication on the screen may also be obtained by applying the voltage to be measured to the horizontal plates. The principle of operation is exactly the same as in the vertical direction.

When an alternating current is applied to either set of deflecting plates, the spot sweeps back and forth with an amplitude proportional to the peak value of the applied voltage. At frequencies above 10 c/s, the sweep of the spot appears as a straight line because of the persistence of vision. If an alternating current voltage is applied to the vertical plates, the image on the screen will be as shown at a-a' in Fig. 5b.



(a) (b)

(c)

CATHODE RAY TUBE PATTERNS.

FIG. 5.

If the same voltage is applied to the horizontal plates, the image on the screen would be in the direction of the horizontal line b-b' in Fig. 5b. At the extreme ends, the line will appear brighter than in the middle. This is due to the fact that, at the peaks of the alternating current cycle, the voltage is changing least rapidly and, consequently, the spot of light moves somewhat more slowly and seems to glow more brilliantly. This phenomenon may be readily visualised by moving an electric torch rapidly up and down and viewing it from a distance. The light will not appear as a spot, but will be similar to the vertical line shown in Fig. 5b.

An alternating current voltage may also be deflected in the form of a curve on the screen of the cathode ray tube as shown in Fig. 5c.

In order to obtain this effect, both sets of deflecting plates must be used. The device whose voltage is under observation is connected to the vertical plates, which results in the formation of a straight vertical line as shown at a-a' in Fig. 5b. Suppose that another varying voltage is applied to the horizontal plates, and this voltage moves the electron beam horizontally (say, from left to right) a given distance for the duration of one cycle and, at the end of the cycle, this voltage reverses and instantly shifts the beam again horizontally (right to left) to the previous starting position. The result will be the pattern shown in Fig. 5c. This pattern is repeated for every cycle of applied alternating current voltage.

4.5 The Oscilloscope. A cathode ray oscilloscope is essentially a cathode ray tube with the various electrodes connected to their respective voltage supplies, but with provision for supplying a suitable deflection voltage on one set of plates, usually those giving horizontal deflection. The deflection voltage is called the "sweep" and is for the purpose of shifting the beam horizontally, so that, when an alternating current is applied to the vertical plates, a pattern similar to that shown in Fig. 5c will be traced.

A sweep voltage of saw-tooth wave-shape is generally the most useful, because it moves the beam across the screen in one direction and then returns practically instantaneously to move the beam again in the same direction.

This is termed a linear sweep and has the advantage that it shows the shape of the wave applied to the vertical plates in the same way in which it is usually deflected graphically.

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The shape of the pattern obviously depends upon the shape of the horizontal sweep voltage, and wave-shapes to provide other than a linear sweep may be desirable for certain purposes. If the horizontal sweep is sinusoidal, the main and return sweeps each occupy the same time, and the spot moves faster horizontally in the centre of the pattern than it does at the ends.

If two sinusoidal voltages of the same frequency are applied to both sets of plates, the resulting pattern may be a straight line, an ellipse or a circle, dependent upon the amplitude and phase relationships. If the frequencies are harmonically related, a stationary pattern will result, but, if one frequency is not an exact harmonic of the other, the pattern will show continuous motion. This is also the case when a linear sweep is used. The sweep frequency and the frequency under observation must be harmonically related or the pattern will not be stationary.

The cathode ray oscilloscope is employed in long line equipment practice for analysing wave-shapes, checking phase and frequency, observing relay contact bounce and a multitude of other important tests.

5. TEST QUESTIONS.

1. How is "Amplifier Gain" measured?
2. Describe a typical cathode ray tube.
3. What are the uses of a cathode ray oscilloscope in transmission work?

END OF PAPER.