THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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

TRANSMISSION MEASUREMENTS
BASIC PRINCIPLES.

PREVIOUSLY CP 236

1. INTRODUCTION.

1.1 Transmission measurements are made to check the performance of the many transmission devices that comprise the telecommunication network. Transmission measurements are broadly divided into two categories:-

(i) Measurements on transmission lines, for example, open wire, twisted pair, and coaxial cables. These measurements are taken to determine the suitability of these lines for the application of line transmission equipment, or to check their performance in service.

(ii) Measurements on transmission equipment. These measurements are taken to ensure that the equipment is installed to specifications and operates as required.

1.2 In the telecommunication network we are normally concerned with the transmission of A.C. signals. For this reason a large proportion of transmission measurements are A.C. measurements.

To correctly evaluate the performance of lines and equipment it is essential that all transmission measurements be accurate. To ensure this accuracy, a technician must have a thorough understanding of testing equipment and testing techniques.

1.3 This paper describes the basic theory of the common types of transmission measurements and also the principles of some simple types of measuring equipment. Specialised measurement techniques and measuring equipment are described in other course papers.

2. GENERAL.

2.1 Wide ranges of "information signals" are transmitted in a modern telecommunication network. Examples of these information signals are:-

- Telephone.
- Telegraph.
- Data.
- Audio Programme.
- Video Programme.
- Picturegram.

The performance of the lines and equipment in the network, could be best evaluated by measuring the voltage of a particular information signal at various points in the transmission path. However, in most cases, this approach is not practical. The main reason is that the information signals, for example, human speech, video signals, etc., are of an extremely complex nature and are difficult to measure.

For normal testing, an artifical test signal is used. The voltage and frequency of this test signal is generally selected so that it will approximately equal the normal information signal. The use of a separate test signal has the advantage that, by careful selection of frequency and voltage, lines and equipment can be tested under extreme conditions of operation.

2.2 Two basic test instruments are required to make transmission measurements. One is required to produce the test signal and the other is required to measure the received test signal.

A test signal is produced by an instrument called a "signal generator". It is also referred to as:-

- An oscillator.
- A test oscillator.
- A level oscillator.
- A sender.

In general the two main requirements of a signal generator are:-

- The facility to vary the frequency of the test signal.
- The facility to vary the amplitude of the test signal.

The amplitude of the test signal is measured with an instrument commonly called a transmission measuring set (T.M.S.). It is also referred to as:-

- A receiver.
- A level meter.

In general, the two main requirements of a transmission measuring set are:-

- The facility to measure the amplitude of signals over a wide range.
- The facility to provide a load of known impedance, if required.

Typical signal generators and transmission measuring sets include more facilities than those listed. Additional information is given in Sections 5 and 4 respectively.

2.3 Precautions. When making A.C. measurements, errors can easily result unless careful consideration is given to the selection of test equipment, test frequencies, test voltages, etc. The incorrect selection of test equipment, or perhaps a faulty test circuit arrangement, rarely causes complete loss of received test signals, but rather produces incorrect test results.

The main factors that should be considered before making transmission measurements are:-

(i) Frequency range.

(ii) Impedance.

(iii) Type of circuit.

(iv) Test levels.

(v) Type of measurement.

2.4 Frequency Range. The information signals that are transmitted in the telecommunication network, range in frequency from sub-audio for telegraphy to the extremely high frequencies used in broadband telephony and video programme.

In selecting test equipment for any transmission measurement it is important to ensure that the required test frequencies can be produced, and that these test frequencies can be measured accurately. It is this second point, in particular, which can cause errors. The majority of transmission measuring sets are limited in receive frequency range. A number of factors, such as the frequency response of transformers or amplifiers in the test equipment, bring about this limiting effect.

The frequency range, for transmission equipment, can be divided into a number of broad categories. Measuring equipment is not necessarily subdivided into the same categories, but the divisions serve as a guide in selecting test equipment. The division of the frequency range for telephony is broadly:-

(i) V.F. or audio range.	50Hz - 15kHz
(ii) Three channel carrier range.	6kHz - 30kHz
(iii) Twelve channel carrier range.	6kHz -150kHz
(iv) Broadband carrier range.	60kHz - 12MHz

In addition, test equipment is also designed for the start-stop signals used in telegraphy and for the special signals used in video transmission testing.

Some test equipment, usually robust in construction, is accurate in the lower frequency ranges only. Other test equipment is accurate over a wide frequency range but is usually fairly expensive.

★ 2.5 Impedance. The impedance of a transmission line is a function of its primary constants. For this reason the actual impedance of transmission lines is different for different types. The nominal characteristic impedances of transmission lines are:-

(i) V.F. loaded cable pair.	1200 ohms	
(ii) Open wire pairs.	600 ohms	
(iii) Non-loaded cable pairs (V.F. range).	150-600 ohms	(depends on frequency and wire size).
(iv) Non-loaded cable pairs (Carrier range).	135 ohms	
(v) Coaxial cable pairs.	75 ohms.	

The same values of characteristic impedance, as those listed for transmission lines, are used for telecommunication equipment. Impedance matching is simplified when a transmission line and its associated equipment have the same nominal impedance. A general relationship exists between impedances of communication equipment and the frequency ranges which they use. Table 1 shows this relationship.

Impedance (ohms)	Approx. Frequency Range (kHz)	Impedance (ohms)	Approx. Frequency Range (kHz)
1200	0.3 - 3.4	135/150	30 - 600
600	0.3 - 40	75	60 - 12000

TABLE 1. RELATIONSHIP BETWEEN IMPEDANCE AND FREQUENCY.

2.6 Type of Circuit. The arrangement of circuit components for transmission equipment falls into three basic categories, which are described with reference to the series circuit components. These categories are:-

(i) Balanced.

(ii) Balanced-to-ground.

(iii) Unbalanced.

The majority of open wire and pair cable trunk lines are balanced lines. Coaxial cable pairs are unbalanced. With the exception of equipment associated with balanced lines, transmission equipment is normally unbalanced. This has the advantage of reducing the number of circuit components.

Typical examples of these circuits are shown in Figs. 1, 2 and 3. For simplicity, resistive elements are shown in each circuit. In practice, the circuits could be comprised of resistors, capacitors, inductors or combinations of these elements.

Balanced Circuit. Fig. 1 shows a typical balanced circuit. The circuit derives its name from the fact that the series components are included equally in each side of the circuit.

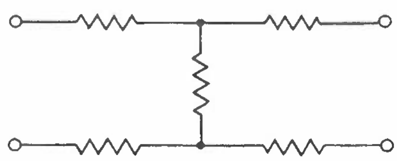


FIG. 1. TYPICAL BALANCED CIRCUIT.

Balanced-to-ground Circuit. The component arrangement of a typical balanced-to-ground circuit is shown in Fig. 2. The arrangement is the same as the balanced circuit but the centre tap of the shunt element is taken to ground. This circuit arrangement can be obtained for some transmission test equipment, and is used by some transmission devices. It has the advantage that the effects of longitudinal currents are reduced.

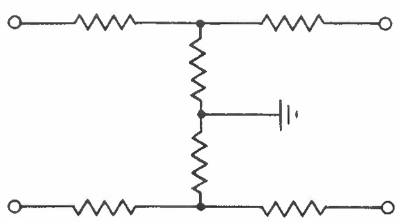


FIG. 2. TYPICAL BALANCED-TO-GROUND CIRCUIT.

Unbalanced Circuit. Fig. 3 shows a typical arrangement for an unbalanced circuit. The series components are included in one side of the circuit only. The side of the circuit which does not include components is normally connected to ground.

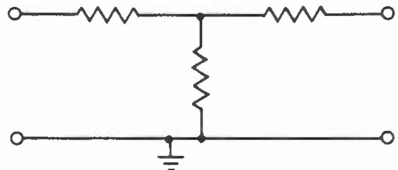


FIG. 3. TYPICAL UNBALANCED CIRCUIT.

The necessity to know the circuit arrangement of the test equipment and the equipment or line under test becomes apparent when examples of faulty interconnection are shown. Fig. 4 shows balanced to earth test equipment connected to unbalanced equipment for testing purposes. An effective short circuit, indicated by the dotted line, causes a change in circuit values. The circuit conditions change in a number of ways and an error results.

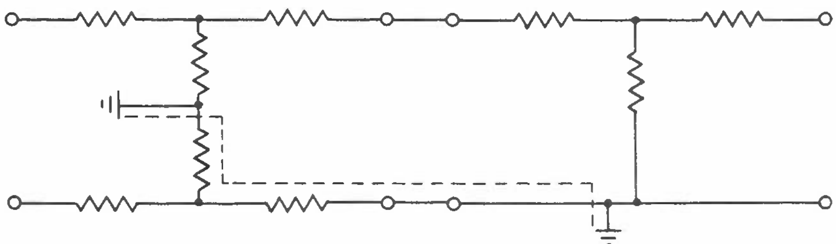


FIG. 4. FAULTY INTERCONNECTION - BALANCED-TO-GROUND TO UNBALANCED.

Another example is shown in Fig. 5, where interconnection is made between unbalanced test equipment and an unbalanced circuit under test. A transposition in the connection places an effective short circuit across the circuit. In this example no result is obtained and this may cause the testing officer to examine the test set-up. In some cases, however, this may be the anticipated result and an error may occur.

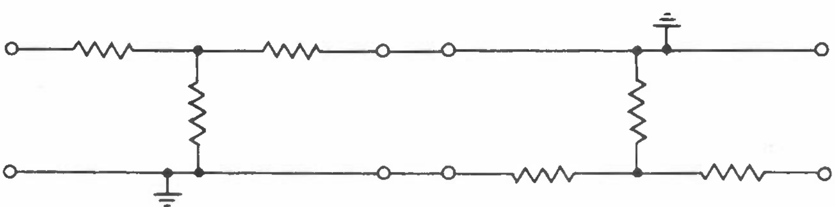


FIG. 5. FAULTY INTERCONNECTION - UNBALANCED TO UNBALANCED.

2.7 Test Levels. In general, the test signals used in transmission measurements are selected to substitute for the real information signals. The two factors to consider for the test signal are frequency and level. The subject of frequency is introduced in para. 2.4. Normally the test level chosen for any measurement is similar to the normal circuit transmission level. Too high a test level may cause overload of transmission equipment and introduce errors. Too low a level may allow circuit noise to mask the test signal. For certain tests (for example, harmonic distortion, limiting, linearity, etc.), levels either above or below the normal circuit levels are required.

2.8 Type of Measurement. Many different types of transmission measurements are made and consideration must be given to this when selecting test equipment. Additional information is given in Sections 3 and 4.

3. TYPES OF TRANSMISSION MEASUREMENTS.

3.1 Many different transmission measurements are made on transmission lines and transmission equipment, and often many different circuit arrangements can be used for any one type of measurement. The particular test circuit arrangement used is determined by the equipment available, the accuracy required and the results expected, etc.. A number of different transmission measurements are listed in this paragraph. Some of these measurements are made regularly, but others are made only at the time of installation, or when considered necessary because of fault incidence or complaints.

3.2 Transmission Measurements on Lines. Before proceeding with A.C. measurements on transmission lines, it is often necessary to make certain D.C. measurements. The D.C. tests normally made are:-

- Insulation Resistance. This test is made between the two wires, and between each wire and earth, of the circuit on which measurements are to be made. Any abnormal behaviour, such as low and/or varying insulation resistance or unequal insulation resistance between each wire and earth, should be investigated. The test is made because any low insulation resistance can affect A.C. tests; for example, crosstalk is more severe on circuits with low insulation resistances. Therefore, 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 current.

- 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 with a Wheatstone Bridge. From a knowledge of the make-up of the circuit to be measured, it is possible to check the loop resistance. Abnormal behavior, such as high and/or varying loop resistance and resistance unbalance, should be investigated and cleared to ensure a true indication for any A.C. measurements.

The principal A.C. measurements made on lines, together with the main reasons for making them, are as follows:-

- Characteristic Impedance versus Frequency. This measurement is made to check that the practices employed in the erection of an aerial line, the jointing or loading of a cable, etc., 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. This enables these constants to be determined from practical cases rather than purely theoretical considerations.

- 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 circuit outside the over-all transmission performance standard. This measurement includes the gains of amplifiers and the losses produced by individual items of transmission equipment.

- 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.

- Noise and the Harmonic Analysis of Noise. Noise measurements are made to determine the amount of noise present on a line. When noise is present, its harmonic analysis is of great assistance in determining the source of the noise.

- Return Loss. This measurement is made to determine the extent of an impedance mismatch, for example, at the junction of cable and open wire lines, or when a line is terminated in a standard reference impedance.

- 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 addition of balancing capacitors.

- Admittance Unbalance. The capacity unbalance measurements take into account only the capacity unbalances existing between the four wires of each quad. "Within quad" balancing is sufficient to eliminate or suitably reduce crosstalk at audio frequencies. At carrier frequencies, however, it is necessary to consider not only within quad crosstalk but also crosstalk from quad to quad brought about by impedance unbalance (admittance). The capacity and effective 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.

- Mutual Capacity Deviation. Coaxial and carrier type cable, that is, cables designed and manufactured specifically for operating carrier systems over its pairs, are manufactured and jointed in such a manner that the mutual capacity of each pair is maintained within narrow limits over the entire length of the cable. Any variation in the mutual capacity of a pair over the length of the cable causes impedance changes which, at carrier frequencies, result in reflection and so increases crosstalk. The mutual capacity of each pair is measured for pre-determined short lengths of the cable, and these lengths are jointed in such a manner that little deviation of the mutual capacity of each pair takes place over the entire length of the cable.

3.3 Transmission Measurements on Equipment. Some of the measurements made on transmission lines are also made on transmission equipment. The main measurements on transmission equipment are:-

- Insertion Loss or Gain versus Frequency. The gain or loss versus frequency response of equipment is tested and should conform with specified requirements. For V.F. equipment the response is normally referred to 800Hz and for carrier equipment the response is normally referred to a mid-frequency.

- Return Loss versus Frequency. In this measurement the impedance of equipment is checked using a precision non-inductive resistor as a reference.

- Harmonic Distortion. This measurement checks the power level of the new frequencies (harmonics) produced in transmission equipment. To make the measurement a pure sine wave test signal is applied.

- Intermodulation Distortion. This measurement determines the amount of intermodulation which occurs in transmission equipment when two or more sine wave frequencies are applied at the input.

- Noise. The noise contribution of transmission equipment is checked by a noise measurement. The input to the transmission equipment is terminated in its characteristic impedance when making the measurement.

- Linearity (Overload). The power handling capacity of equipment is tested in this measurement which is applied particularly to amplifying equipment.

- A.C. Balance. In this measurement the relative values of the impedances of each side of a circuit to ground are checked. In a balanced circuit these values should be equal.

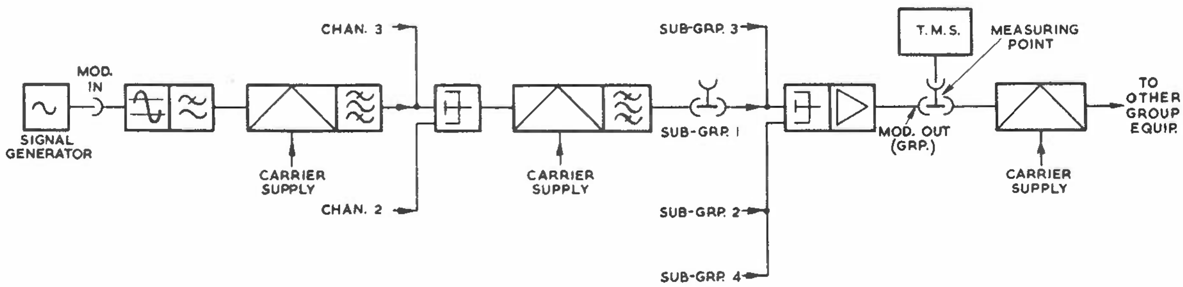
Many other transmission measurements, such as, carrier leak, modulation depth, group delay, etc. are made. The details for these measurements, together with additional information concerning the measurements listed, are given in other papers of the course.

4. BRIDGING AND TERMINATED MEASUREMENTS.

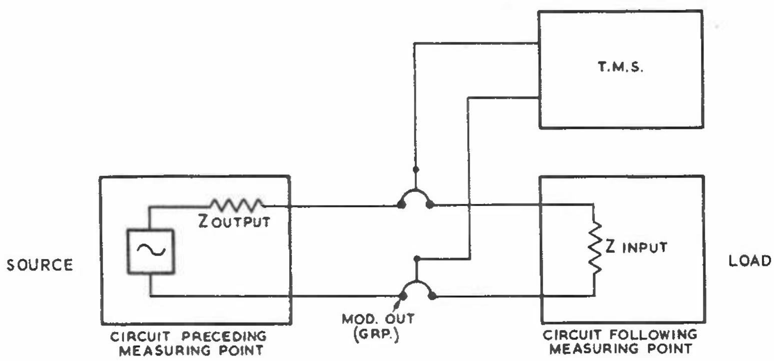
4.1 In transmission measurements the amplitude of the test signal is measured as it passes through the transmission equipment and lines. For example, in a carrier telephone system, measurements can be made at definite points such as, HYB.LINE, TRANS.AMP. OUT, REC.AMP.OUT, etc..

At any measuring point in a circuit, the input to the measuring point can be considered as a "source" and the output from the measuring point can be considered as being applied to a "load". In communication equipment the output impedance of the source is made equal to the input impedance of the load. Fig. 6(a) shows, in simplified form, part of a carrier telephone system. A test signal voltage is applied at MOD. IN. When a measurement is to be taken at MOD OUT (Group), the group amplifier and previous equipment can be regarded as a source and the group modulator and subsequent group equipment can be regarded as a load. This is shown in Fig. 6(b).

Transmission equipment is comprised of inductive, capacitive and resistive components and, although a nominal characteristic impedance can be stated, it is often found that the actual impedance is other than the stated impedance. The impedance of the equipment also changes with changes in frequency and, because of this, errors can occur when making measurements.



(a) Part of Carrier Telephone System.



(b) Source and Load with Respect to Measuring Point.

FIG. 6. CONCEPT OF SOURCE AND LOAD.

4.2 Bridging Measurements. Fig. 6(b) shows that the voltage of the test signal at the point of measurement is the voltage developed across the load. This voltage is measured by "bridging" a high impedance voltmeter across the circuit at this point. This is illustrated in Fig. 7.

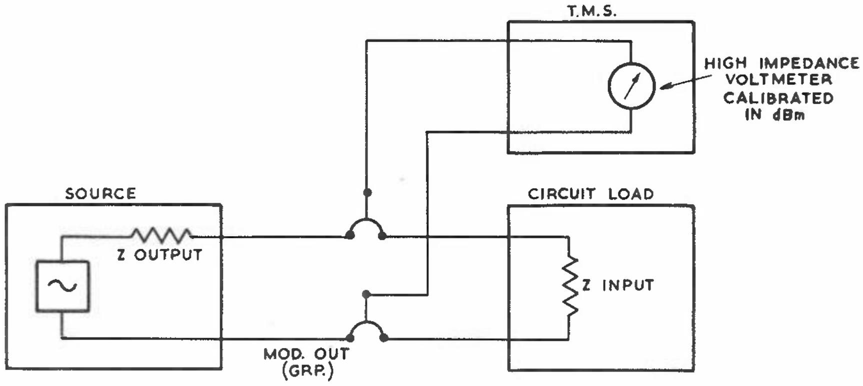


FIG. 7. BRIDGING MEASUREMENTS.

A bridging measurement is a measurement of the voltage of a test signal across the real circuit load. Bridging measurements are also referred to as:-

- Level measurements.

- High impedance (H.I.) measurements.

- Through measurements.

A bridging measurement has the advantage that the through circuit connection is not broken. This is of importance in making measurements on high capacity multi-channel systems.

4.3 Terminated Measurements. It is often necessary to test the performance of equipment when working into a load of accurately known impedance. In this case the normal circuit load is disconnected and replaced by an artificial load of known impedance. This is normally provided by the transmission measuring set. This type of measurement is called a terminated measurement. An example of this is shown in Fig. 8. In this case the circuit is broken at MOD. OUT (Group) and terminated with the artificial load included with the voltmeter.

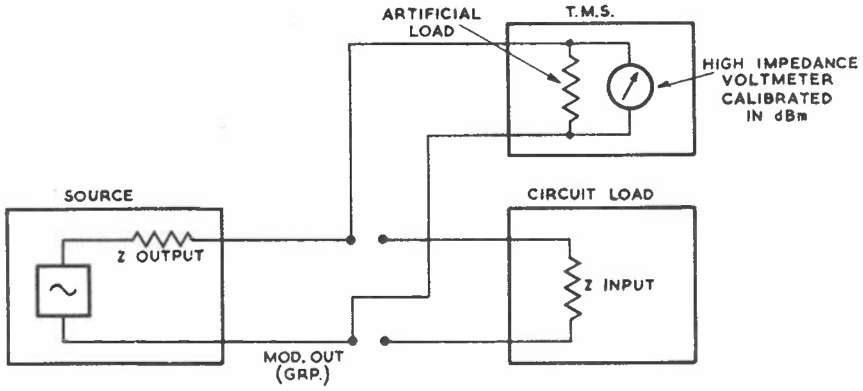


FIG. 8. TERMINATED MEASUREMENTS.

A terminated measurement is a measurement of a test signal across an artificial load of known resistance. Terminated measurements are also referred to as:-

- Loss measurements.

- 600 ohms, 135 ohms, etc. (Terminating Z) measurements.

The main advantage of a terminated measurement is that the artificial load serves as a reference standard. It is a "pure" resistance which remains constant in value over the frequency range. The real load is nearly always not a pure resistance and therefore changes its impedance with frequency.

A disadvantage of terminated measurements on working systems, is that the circuit has to be broken to make the measurement.

The test access arrangements for some transmission equipment are such that the insertion of a test plug breaks the circuit and disconnects the real load. Terminated measurements must be made in these circumstances.

4.4 The two words, "level" and "loss" are often used in relation to transmission measurements. Each word, however, has several different meanings and this can lead to misunderstandings if a common approach is not adopted by all technicians.

The word "level" can mean:-

- A general term for the "amplitude" or "voltage" of a signal and is usually expressed in decibels with reference to 1mW (dBm).

- A type of measurement. A "bridging" measurement is often referred to as a "level" measurement (Para. 4.2).

- A type of meter or oscillator. Some manufacturers refer to their test equipment as level meters or level oscillators; this means that the test equipment can measure or send test signals of various levels.

The word "loss" can mean:-

- The attenuation of a circuit; and also an abbreviation for the term "insertion loss". These are not strictly synonomous and additional information is given in Section 7. For example a pad which introduces a loss of 6dB in a circuit is said to have a loss of 6dB.

- A type of measurement. A "terminated" measurement is often referred to as a "loss" measurement (Para. 4.3).

When referring to types of measurements it is advisable to use the terms "bridging" and "terminated" in preference to level and loss. The words level and loss can then be used in the other categories listed, without any fear of misunderstanding.

5. TRANSMISSION MEASURING SETS.

5.1 Important factors in the design of all test instruments are the speed at which transmission tests can be made, and the simplicity of the circuit set-up to perform these tests. The majority of transmission measurements are made on equipment and lines at transmission equipment stations. Some measurements are made in test laboratories and others in the field, for example, at cable head poles, or in jointing or loading pits. Transmission measuring sets are designed to suit all of these conditions and range from the extremely sophisticated laboratory type to the compact and robust field type instruments. The choice of instrument to use for a particular measurement depends on the type of measurement, the location, and the degree of accuracy required.

Although it is generally accepted that a transmission measuring set is basically a "receiver", it is quite common for other items to be included in the unit. For example, one typical T.M.S. includes an 800Hz oscillator. T.M.S's. of this nature are usually designed for specific measurement purposes.

5.2 The basic functions of transmission measuring sets are:-

- The ability to make bridging and terminated measurements at one or a number of circuit impedances. Typical impedances are 1200, 600, 150, 135 and 75 ohms.
- The ability to measure a wide range of signal voltages. In most cases these are "wideband" measurement; that is, measurements made with no frequency restriction apart from the inherent restriction of the T.M.S.

The more sophisticated transmission measuring sets have additional facilities such as:-

- The ability to make "selective" or "tuned" measurements; these are sometimes called "channel" measurements.
- The ability to make "weighted" measurements.
- The ability to measure impedance, return loss and balance-to-ground.

5.3 Transmission measuring sets are sometimes divided into categories according to the type of meter circuit used in the instrument. The three types of meter circuits in common use are:-

- Rectifier bridge type.
- Vacuum tube type.
- Thermocouple type.

The relative advantages and disadvantages of these meters are described in the paper "A.C. Measurements" (A.E.2). The main points are outlined in this paper.

(i) Rectifier bridge type. Meters of this type are in common use in the Department. Earlier meter have the disadvantage of a restricted frequency range. This is brought about by the interelectrode capacity of the metal rectifiers having a shunting effect on high frequencies. Later meters, using diodes in the bridge circuit, do not suffer this frequency restriction. Rectifier meters are reasonably sensitive, and voltmeters with a sensitivity of 20,000 ohms per volt and greater are quite common.

(ii) Vacuum tube type. This type of instrument has its greatest application in the high frequency circuits of broadband, radio telephone and T.V. systems. Its two main advantages are firstly, a high input impedance and secondly, accuracy over a very wide frequency range. This accuracy extends, in some cases, to as high as 1000mHz.

(iii) Thermocouple type. These meters are generally accurate over a wide frequency range; up to several megacycles per second in most cases. They are not used extensively for transmission measurements because they have the disadvantages of being sluggish in operation, and in most cases are only suitable for terminated measurements.

5.4 A basic circuit of a typical transmission measuring set is shown in Fig. 9. The input switch provides, in this example, 1200, 600, 150, and 75 ohm non-inductive resistors for the terminated measurements and an associated open circuit position for the high impedance measurements. The input transformer is added to give the T.M.S. a balanced input and high impedance. The transformer must have a flat frequency response over the range of the instrument, good balance to earth, and should suppress longitudinal currents. The range switch controls the input level to the amplifier. Range switches typically are calibrated in 10dB steps as shown in the diagram. The level range that can be measured varies considerably for different instruments.

★ The received signal is amplified and applied to the meter circuit. A D.C. meter, calibrated in dBm, is situated in a full wave rectifier bridge. The stability of the amplifier gain in critical as far as accuracy is concerned, and for this reason the amplifier employs a large degree of negative feedback.

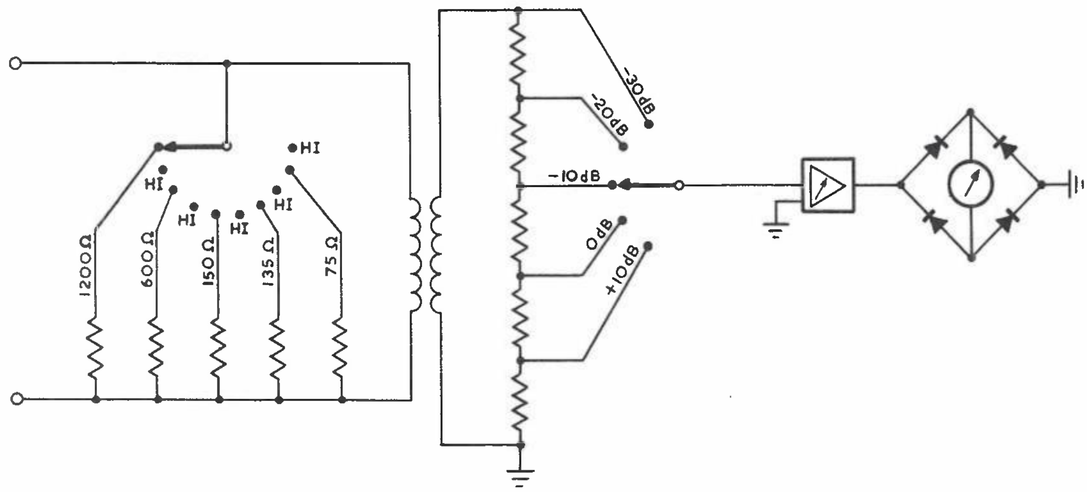


FIG. 9. SIMPLIFIED DIAGRAM OF T.M.S.

5.5 Transmission measuring sets, designed for use with more than one impedance, employ one of two methods of measurements. These are:-

- Power level measurements.

- Voltage level measurements.

(i) Power Level Measurements. In this case the instrument is adjusted so that with one milliwatt of power dissipated in the load (regardless of load impedance), the meter will indicate 0dBm. With one milliwatt dissipated in the load, the voltage developed for the various values of impedance are as shown in Table 2.

Impedance (ohms)	Voltage (volts)
1200	1.095
600	0.775
150	0.388
135	0.368
75	0.274

TABLE 2. VOLTAGE AND RESISTANCE RELATIONSHIP FOR 1mW.

When making a measurement at 600 ohms, a voltage of 0.775 volts is applied to the input terminals and the meter reads 0dBm. When the meter is used at 150 ohms, a voltage of 0.388 volts is applied to the input terminals. To produce the required indication of 0dBm, the voltage gain of the amplifier is doubled. The same principle applies for other values of impedance. For example, the amplifier gain must be reduced to obtain the correct indication for a 1200 ohm terminating impedance. The gain of the amplifier is changed automatically when the impedance switch is set. This is the reason for a terminated and H.I. position associated with each impedance.

(ii) Voltage Level Measurements. In this case the instrument is calibrated for 0dB with 1mW dissipated in a specified resistance, for example 600 ohms. In this example a voltage of 0.775 volts is produced. The instrument remains in this condition regardless of the value of the terminating impedance. An instrument of this type is only accurate when used with a terminating impedance of the value for which it is calibrated (calibrated impedance). When used to measure across an impedance other than the calibrated impedance an error results. For example, when a high impedance meter calibrated for 600 ohms is used for a measurement across a 150 ohm resistance, there is 1mW dissipated in the 150 ohm resistor and a P.D. of 0.388 volts occurs. This voltage produces a deflection of -6dBm on the meter scale. This inaccuracy of 6dB exists over the entire level range and, therefore, accuracy can be obtained by adding a "correction factor" of 6dB.

The same principle applies regardless of the relative impedances of the terminating impedance and the calibrated impedance. Correction factors are calculated using the formulae:-

$$\text{Correction factor in dB} = 10 \log \frac{\text{Calibrated } Z}{\text{Terminating } Z} \quad \text{where calib. Z is the larger.}$$

$$\text{Correction factor in dB} = 10 \log \frac{\text{Terminating } Z}{\text{Calibrated } Z} \quad \text{where term. Z is the larger.}$$

When the calibrated Z is larger than the terminating Z the correction factor is added. When the calibrated Z is smaller than the terminating Z the correction factor is subtracted.

Fig. 10 is a power level correction chart for instruments calibrated for 600, 150 and 75 ohms. An example, assuming a terminating impedance of 1200 ohms used with a 600 ohm calibrated meter is included.

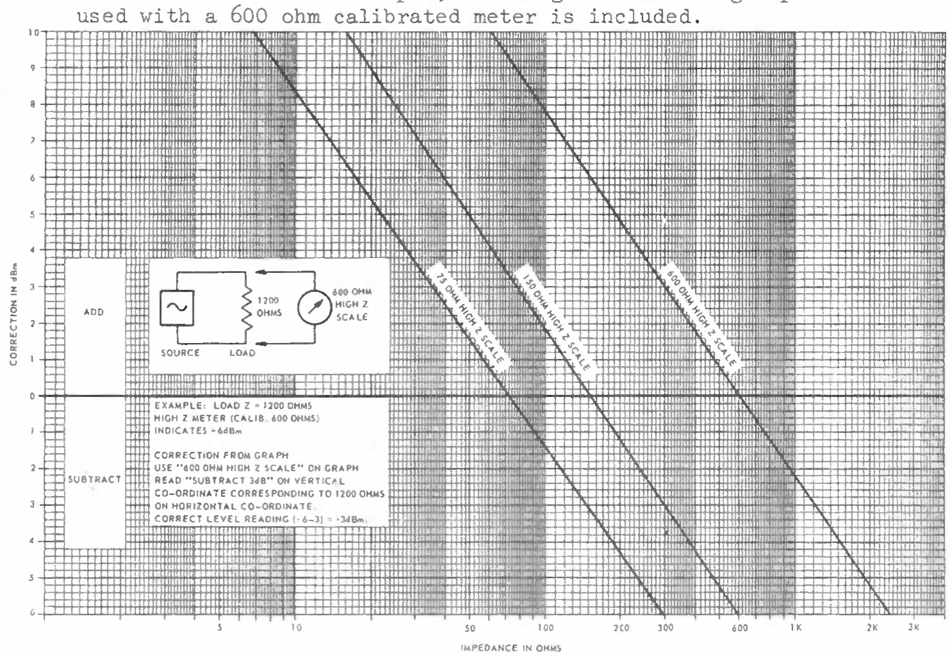


FIG. 10. POWER LEVEL CORRECTION CHART.

5.6 Selective Measurements. The measuring set described in para. 4.4 is a wideband type instrument which measures the combined voltage of all the frequencies applied at the input. These frequencies often consist of the test signal frequency plus some other unwanted signals, such as carrier leak or noise frequencies, which are not required. This problem can be overcome by the use of a selective type instrument which is capable of selecting and measuring the required frequency.

The simplified circuit of a selective T.M.S. is shown in Fig. 11. The circuit is similar to that of the wideband T.M.S. but with a frequency selecting circuit added before the meter. The operation of the frequency selecting circuit is similar in principle to that of a superheterodyne radio receiver. The incoming signal is modulated with a variable frequency local oscillator, and an intermediate frequency (I.F.) is selected by a filter, amplified and applied to the meter circuit. The I.F. stage filter has a narrow bandwidth, about 100Hz, and it is possible to select one frequency from a number of frequencies.

An example of frequency translation in a simple frequency selecting circuit is given. A test signal of 100kHz is applied to the input terminals of a selective T.M.S. In the modulator this frequency is modulated with a frequency of 102kHz from the local oscillator. The lower sideband product of modulation (2kHz) is selected by the band pass filter and applied to the meter. The frequency control dial, associated with the local oscillator, indicates 100kHz. This simple frequency translation is not practical because it does not give "image" frequency rejection. In the example quoted an image frequency of 104kHz can be received. To ensure image frequency rejection, a typical frequency selecting circuit employs three modulation stages. Additional information is given in other course papers.

Selective T.M.S's can be used for terminated or bridging measurements and can be of the "power level" or "voltage level" measurement type. The operating features described for wideband instruments apply to selective instruments.

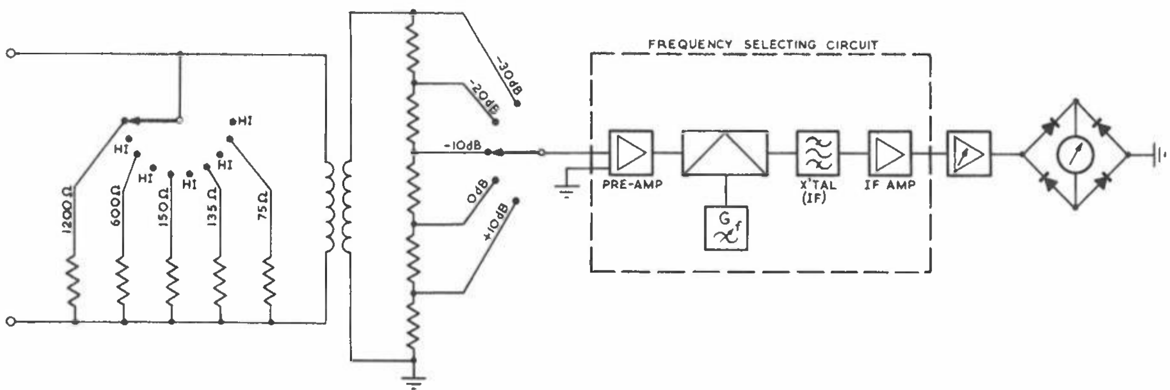


FIG. 11. SIMPLIFIED CIRCUIT OF SELECTIVE TYPE T.M.S.

Selective measurements are very useful for checking the progress of a test signal or pilot frequency through a working system. Bridging measurements can be made at various points without affecting the normal transmission signals.

Often there can be miscellaneous signals close to the test signal, and unless the frequency selecting circuit is carefully tuned, misleading results can occur. A simple test to ensure that the correct signal is being measured is to remove the test signal at the source and note that the reading drops to nothing.

5.7 There are some types of transmission measuring sets that can only make terminated measurements. Examples of these are the Western Electric 30A and the Victorian Meter Laboratories transmission measuring sets.

These meters are calibrated for 135 ohms and provide a permanent 135 ohm termination. The W.E. instrument in particular, is extremely accurate, but both instruments are limited in their use, because of their inability to perform bridging measurements, and the need for matching when working with impedances other than 135 ohms. Matching transformers are included for this purpose.

These instruments are termed "comparison" measuring sets because of their suitability for comparison type measurements.

A simplified block diagram of a typical comparison type T.M.S. is shown in Fig. 12. Provision is made for an external test oscillator to be applied at the input. By means of the changeover key the test signal voltage can be applied to either the "adjust" or "compare" sections of the circuit. The details of the use of a circuit of this type for measurements of gain and loss are included in Section 7.

The jack designations are typical of those used in comparison measuring sets. The uses of these access points are not given in detail in this paper.

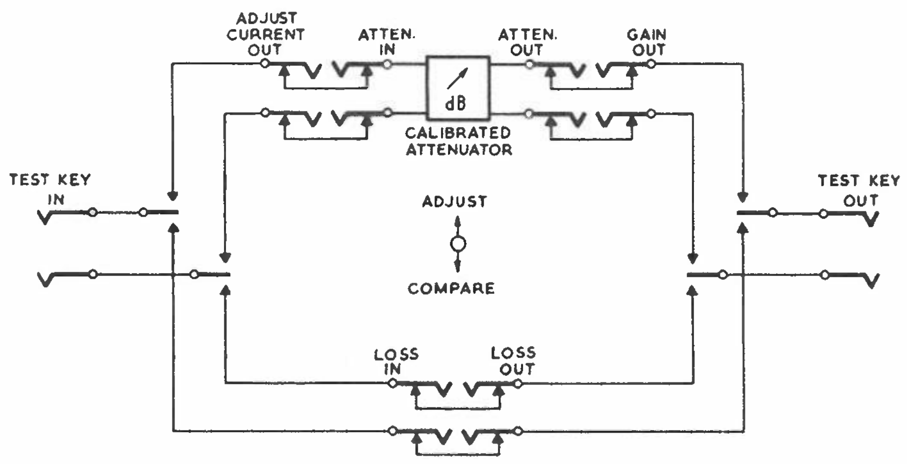


FIG. 12. SIMPLIFIED DIAGRAM - COMPARISON TYPE T.M.S.

5.8 Use of Matching Transformers. Under some circumstances it is necessary to employ transformers for impedance matching purposes. Ideally the transformer should have a flat frequency response over the range to be measured, otherwise it is necessary to know the frequency limitations of the transformer to avoid errors. When the loss versus frequency characteristic of the transformer is known, measurements can be made over a wide frequency range, and corrections can be made to compensate for the transformer frequency response.

6. SIGNAL GENERATORS.

6.1 Signal generators can broadly be divided into two types; those producing a sine wave test signal and those producing pulses. For audio and carrier frequency measurement the sine wave type are generally used. For telegraph, data and video transmission testing the pulse type are generally used, and details of these test instruments are given in other papers of the course. The circuit details of sine wave type oscillators are included in A.E.2. This paper describes their use for transmission measurements.

All signal generators provide two basic facilities:-

- The ability to vary the frequency of the test signal.

- The ability to vary the voltage of the test signal.

The more sophisticated signal generators have additional facilities such as:-

- The ability to vary the output impedance.

- The ability to modulate the test signal.

- The ability to be physically coupled to a T.M.S. (This feature simplifies the test equipment set-up).

- The ability to monitor the oscillator level with an inbuilt level meter.

6.2 Signal generators (oscillators) are divided into two basic types which are:-

- Resistance-capacitance oscillators (R.C.O.). Usually Wein bridge type.

- Beat-frequency oscillators (B.F.O.).

Both these oscillator types are widely used in modern instruments. The R.C. oscillator has one slight disadvantage in that the overall frequency range of the instrument is produced in a number of discrete ranges. Normally this is not a serious disadvantage but when a "sweep" oscillator is required, a B.F.O. is used because of its ability to produce its entire frequency range with one control.

6.3 It is desirable that all test oscillators meet the following requirements:-

- Low harmonic content in the output.

- Constant output level over the entire frequency range.

- Constant output impedance over the entire frequency range.

- Accurate frequency scale (preferably linear) and some form of frequency calibration.

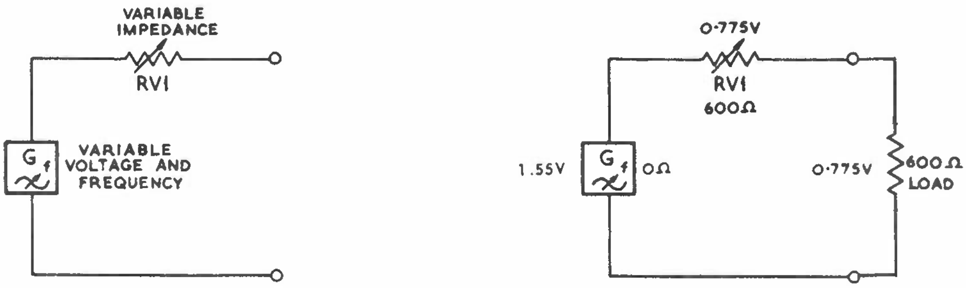
- Variable control of output level over a wide range.

- Output frequency and output power should not vary with normal changes in temperature or power supply voltages.

The degree with which various oscillators meet these requirements is related to their cost and to the functions for which they are required.

6.4 The equivalent circuit of a signal generator is shown in Fig. 13. The oscillator provides a very low impedance voltage source. The frequency and voltage of the source can be varied. This voltage source is then built out with resistors to give the required output impedance. The control, RV1, achieves this function in Fig. 13(a). Typical impedance values are 600, 135, and 75 ohms.

The source voltage is adjusted by connecting to a termination of the same impedance as the signal generator. Fig. 13(b) shows a 600 ohm signal generator connected to a 600 ohm load, and the output adjusted to 0dBm (1mW). Under open circuit conditions the source voltage equals 1.55 volts; with the load connected 0.775 volts is dropped internally and 0.775 volts is dropped across the load. In the diagram the signal source is assumed tc be 0 ohms and RV1 equal to 600 ohms.



(a) Equivalent Circuit. (b) Adjustment of Output Voltage.

FIG. 13. SIMPLE SIGNAL GENERATOR.

6.5 Fig. 14 shows a simplified diagram of a signal generator. The output of the basic oscillator is transformer coupled to the output circuit which includes variable resistors to control the output impedance. A level meter is bridged across the oscillator output and indicates signal level. The meter calibration is such that it gives the correct value of the test signal at the output terminals when the load impedance is equal to the oscillator output impedance. The transformer turns ratio is arranged to give a high impedance bridging effect on the basic oscillator.

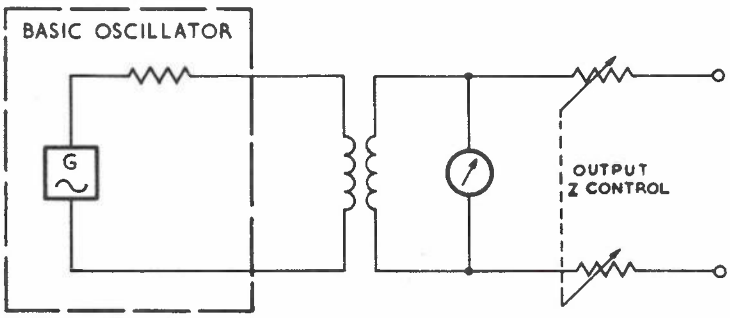


FIG. 14. SIMPLIFIED CIRCUIT OF SIGNAL GENERATOR.

6.6 A large variety of test oscillators are in use in the Department. Some of these are general purpose oscillators and others are designed for specific measurements. For example, a general purpose oscillator producing a range of frequencies from 0Hz to 620kHz is suitable for general carrier frequency measurements but is not normally suitable for measurements of audio frequency response. An accurate audio frequency oscillator is required for the latter measurement.

It is important, when selecting an oscillator for a measurement, to ensure that the instrument chosen meets the test requirements.

7. GAIN AND LOSS MEASUREMENTS.

7.1 There are many different methods of measuring gain and loss. The exact method used for any measurement depends on the equipment available, and the degree of accuracy required.

7.2 Insertion Loss and Insertion Gain. These terms are often used in association with measurements and are defined as follows:-

- When a network is introduced between a generator and a load, the resultant decrease or increase of power in the load is known as the insertion loss or insertion gain.

It is usual to express this loss or gain of power in dB. Insertion loss or gain takes into account the following factors:-

The attenuation or gain of the network itself.

The loss of power due to mismatch between the generator and the load which may have existed before the addition of the network.

The mismatch between the generator and the network (if any).

The mismatch between the network and the load (if any).

From these points we can see that the insertion loss or gain of a network not only depends on the network, but also on the circuit into which it is inserted.

To measure insertion loss or gain we must know the impedance of the generator and the load and simulate these values with test equipment of identical values. Two measurement are taken. They are:-

- The power delivered to the load before the insertion of the network.

- The power delivered to the load after the insertion of the network.

When these power levels are recorded in dBm a direct comparison is made. When voltage measurements are recorded the gain or loss must be calculated.

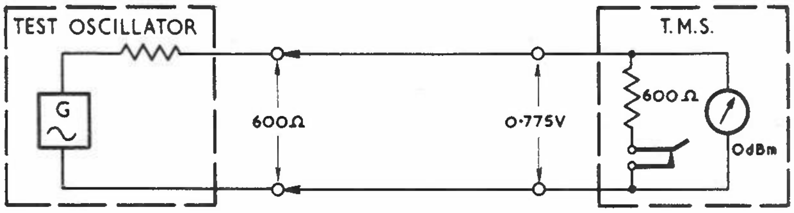
It is generally accepted that the expressions loss or gain as applied to measurements, automatically imply "insertion loss" or "insertion gain".

In a number of cases measurements of loss and gain are taken at more than one frequency. That is, the frequency response of the circuit under test is measured. To do this a variable frequency signal generator is required.

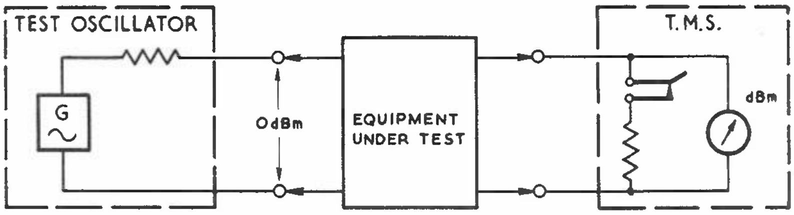
In general two methods of measurement can be used to measure loss or gain. They are known as the "direct method" and the "comparison method".

7.3 Direct Method. This method is a simple matter of obtaining the difference between input levels and output levels of the circuit under test, but unless care is used misleading results can occur.

Fig. 15 shows a simple arrangement for direct measurement of loss. In Fig. 15(a), the output of a test oscillator is measured. A circuit impedance of 600 ohms is assumed, and with a level of 0dBm, a voltage drop of 0.775 volts exists across the 600 ohm terminating resistance in the T.M.S. In Fig. 15(b) this signal is applied to the equipment under test and the output level is measured. The difference in dB between the measured input and output levels represents the insertion loss of the equipment.



(a) Measurement of Input Level.



(b) Measurement of Output Level.

FIG. 15. DIRECT MEASUREMENT OF LOSS.

The same procedure can be applied to measurement of gain. In this case it is important that the test signal level is within the operating level range of the equipment as too high a level can cause overload of amplifying equipment.

7.4 Faulty Techniques. The results obtained using the method described for Fig. 15. should be accurate. Inaccurate results often occur however, when bridging measurements are taken of the input and/or output of an item of equipment under test. Fig. 16 shows a typical test set-up where inaccuracies can occur.

An oscillator, with the same impedance as the nominal input impedance of the amplifier, is applied to the amplifier. The amplifier output is terminated with a resistance equal to the nominal amplifier output impedance. Two T.M.S's are used to make bridging measurements across the amplifier input and output. The nominal input impedance value is assumed to exist but if the impedance is some other value, then an incorrect indication of the signal level will be obtained and an error will result. In a similar manner, if the amplifier were working into the normal circuit load and a bridging measurement was made, inaccuracies would occur if the load impedance varied from its nominal value.

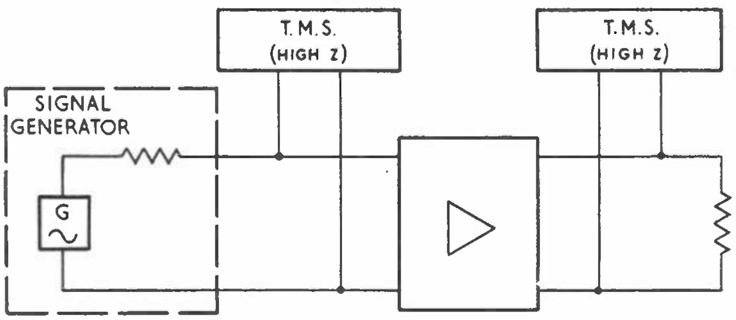


FIG. 16. DIRECT MEASUREMENT OF GAIN - FAULTY TECHNIQUE.

Another common practice which introduces errors is adjustment of test signal input level during frequency response measurements. In this case a high impedance meter is bridged across the test circuit input, as shown in Fig. 17. The signal generator output is adjusted, at each frequency, to maintain constant level. Quite often the input impedance of the equipment under test varies with frequency, and causes a consequent change in signal level. The testing officer, by adjusting to compensate for this change in signal level introduces an error because the "insertion loss or gain" of the circuit incorporates the loss introduced because of mismatch.

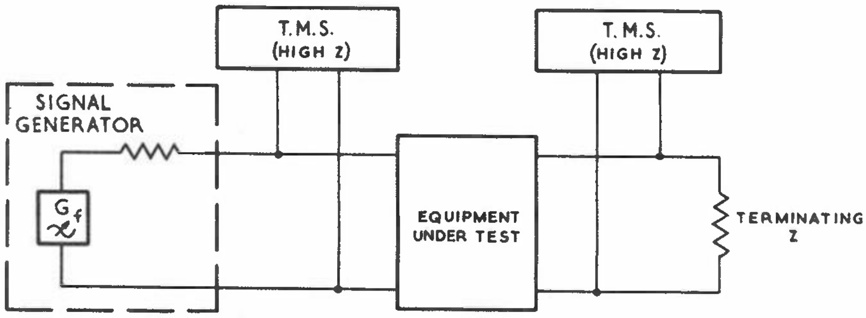


FIG. 17. DIRECT MEASUREMENT OF FREQUENCY RESPONSE - FAULTY TECHNIQUE.

7.5 To obtain correct results for the measurements described in para. 6.4, the test arrangement shown in Fig. 18 should be used. In this example the test signal level is measured across a reference termination before application to the amplifier. The difference in dB between this level and the measured output levels equals the insertion gain of the amplifier. When making a frequency response measurement the test signal level is checked separately at each frequency. When the output versus frequency response of the oscillator is known to be flat this check is not necessary.

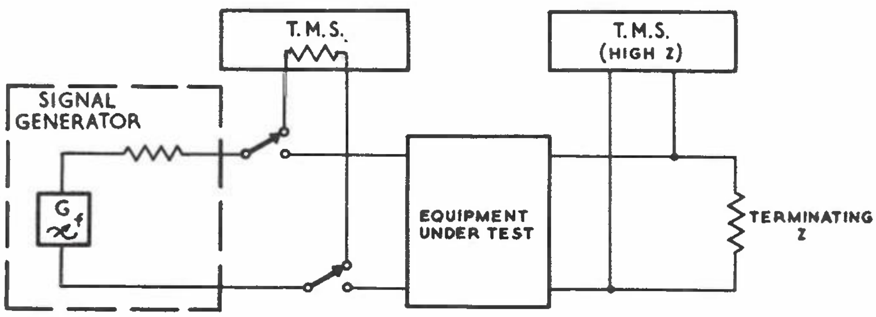


FIG. 18. DIRECT MEASUREMENT OF GAIN - CORRECT TECHNIQUE.

7.6 In Figs. 16, 17 and 18, two T.M.S's are shown; one at the circuit input and one at the output. This is normally not necessary, unless the input and output terminals are remote from each other. When these terminals are situated locally, one T.M.S. can be connected to either the input or output terminals.

7.7 Comparison Method. An accurate but simple method of measuring loss or gain is the comparison method. This method compares the known accurate loss of an attenuator with the item of equipment under test, to find the gain or loss.

Fig. 19 shows a simple circuit arrangement to measure the loss of an item of equipment. With the switch in the "Compare" position the test signal is applied via the equipment under test to the indicating device. With the switch in the "Adjust" position the test signal is applied via the attenuator to the indicating device. When the same deflection is obtained on the indicating device in both the Compare and Adjust position, the attenuator loss is equal to the insertion loss of the equipment under test.

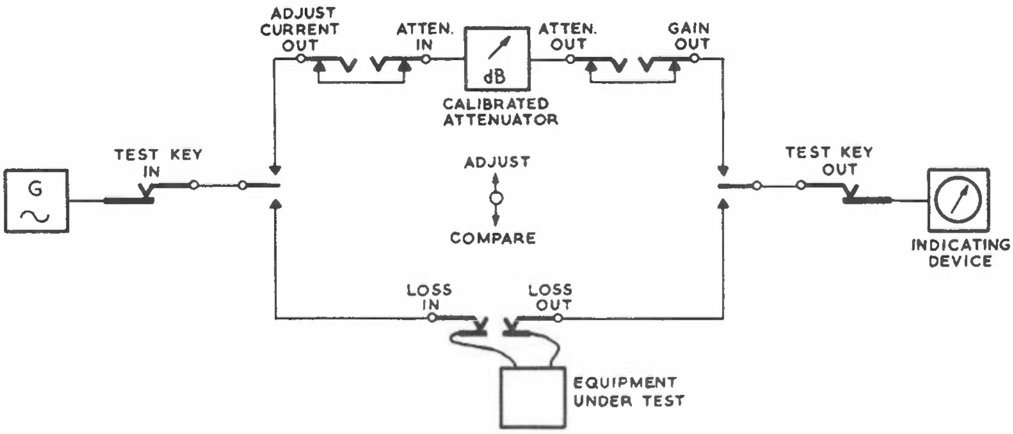


FIG. 19. COMPARISON MEASUREMENT OF LOSS.

Fig. 20 shows a simple circuit arrangement to measure the gain of an amplifier. In this case the attenuator and amplifier are in tandem in the Adjust side of the circuit. When the same deflection is obtained in both the "Compare and "Adjust" positions, the attenuator loss is equal to the amplifier insertion gain. It is important for the attenuator to precede the amplifier to prevent overload of the amplifier, and also to prevent damage to the attenuator resistors, which could occur with high power levels applied.

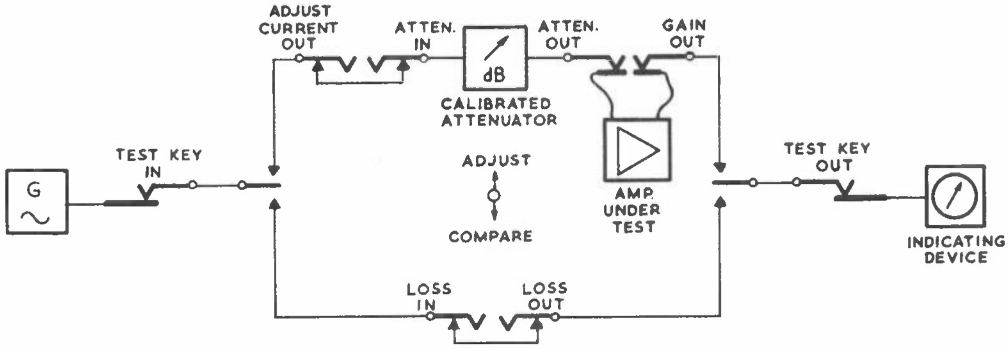


FIG. 20. COMPARISON MEASUREMENT OF GAIN.

Although a changeover key, a calibrated attenuator and an indicating device are incorporated in some transmission measuring sets, a separate changeover key, attenuator and indicating device can be used to provide the required circuit arrangements.

The procedure for making a comparison measurement of gain or loss can be divided into three steps. With reference to Figs. 19 and 20 these steps are:-

(i) Switch to the "Compare" position and obtain a suitable deflection on the indicating device. (An easily recognized deflection point is required).

(ii) Switch to the "Adjust" position and obtain the same deflection on the meter by adjusting the calibrated attenuator.

(iii) The loss indicated by the calibrated attenuator equals either the loss or gain of the equipment under test and can be recorded as such.

By using a variable frequency oscillator as a test signal source, a frequency versus gain or loss characteristic can be established.

7.8 Use of Correction Factor. We saw in para. 5.5 that a correction factor is necessary when using voltage level type T.M.S's for measurements across impedances other than the calibrated impedance of the instrument. Fig. 21 shows the test set-up when making a measurement in a 135 ohm impedance circuit, using a dB meter calibrated for 600 ohms. It is important that the circuit is terminated in its nominal characteristic impedance; this avoids impedance mismatch. The T.M.S. is bridged across this termination, and therefore is used in its high impedance condition. In the example shown the correction factor of 6.5dB is added to the recorded level to obtain the correct result.

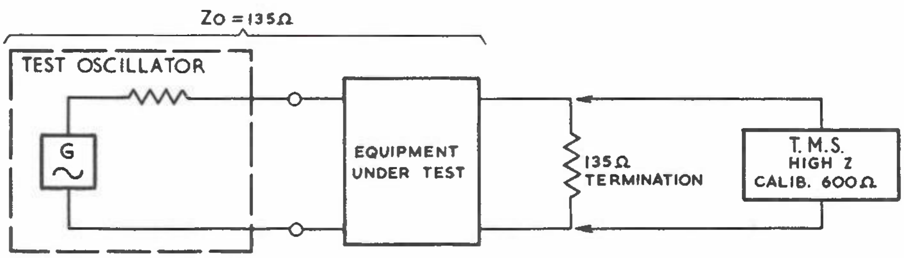


FIG. 21. USE OF CORRECTION FACTOR.

7.9 Voltage Readings. Although the majority of transmission test levels are measured in dBm it should be noted that voltage measurements are sometimes made. When the circuit voltage and impedance are known, the level in dBm can be calculated.

In some cases the anticipated voltage readings at various points in a circuit may already be determined for a particular level of input signal. Voltage testing is used particularly when the impedance of the circuit is either unknown or of some unusual value.

The sensitivity of the test voltmeter should be considered. In most cases when a reference voltage is quoted in a circuit, it is referred to a voltmeter with a particular sensitivity.

8. OVERLOAD MEASUREMENTS.

8.1 Measurements of overload are performed to determine the power handling capacity of equipment. The overload measurement is sometimes incorporated in a linearity test in which the gain of a circuit is checked over a wide range of input levels. The approximate point at which an amplifier overloads can be determined by relatively simple measurements of the amplifier behaviour.

Overload occurs when the input signal to the amplifier is sufficiently high to cause one or more of the electron tubes or transistors to drive into the non-linear portion of their characteristics. This results in non-linear distortion; new frequencies are produced (harmonics and intermodulation products) and the output signal wave shape is distorted. Overload also results in a reduction of amplifier gain. The overload point of an amplifier is that level of input signal above which a unit increase in input level does not cause an equal increase in output level; that is, the gain of the amplifier drops and distortion increases considerably. The test arrangements for measurement of overload point make use of these points.

8.2 Fig. 22 shows a simple circuit arrangement to measure amplifier overload point. The feature of reduced gain is used to determine the overload point. A test signal is applied via a calibrated attenuator, at a level such that overload should not occur, to the input of the amplifier under test. The output of the amplifier is applied via a calibrated attenuator to a T.M.S. The calibrated attenuators and oscillator output are adjusted to give a suitable deflection on the T.M.S. A frequency about the middle of the amplifier range is normally used as a test frequency. Attenuation is then removed from the input attenuator in unit steps, for example steps of 1dB, and at the same time attenuation is added, to the same value, in the output attenuator. While the gain remains constant the deflection point remains the same. When the overload point is reached the amplifier gain decreases and a unit increase in input level does not give a unit increase in output level and the meter deflection decreases. The last point at which the amplifier gain remains constant is the amplifier overload point. The overload point is expressed for either the input level or output level or both. For example, an amplifier with a gain of 50dB may overload with an input level of -23dBm. The overload point is expressed as, input level -23dBm, output level +27dBm.

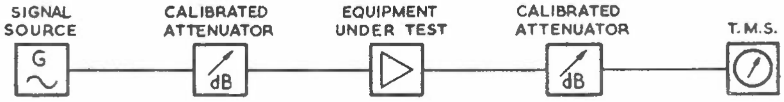


FIG. 22. AMPLIFIER OVERLOAD POINT TEST.

8.3 The change in waveform which occurs when an amplifier is overloaded can be used to determine the overload point. A simple circuit arrangement, is used. A pure sine wave test signal is applied via an attenuator to the amplifier under test. The amplifier output is viewed on a C.R.O. and the input level is increased until distortion of the wave shape occurs. The last point at which distortionless output is obtained is the overload point.

9. IMPEDANCE AND RETURN LOSS MEASUREMENTS.

9.1 Impedance. One of the major problems in a telecommunication network is the maintaining of matched impedance conditions throughout the network. Many different types of lines and equipment are connected in tandem, and at each connecting point the problem of avoiding an impedance mismatch exists. In addition, all transmission lines and the majority of equipment have an impedance characteristic that varies with frequency. This complicates the matching problem. Satisfactory matching conditions can exist at one frequency but, because of relative impedance changes, a severe mismatch can occur at other frequencies.

9.2 Return Loss and Reflection Loss. Although it is sometimes necessary to know the impedance of lines and equipment it is often more important to know the effect of these impedances in a circuit. This effect is best expressed as "return loss" or "reflection loss".

9.3 Return Loss is the logarithmic ratio of the power reflected from a termination to the incident power, that is, the power that would be absorbed in a load under correctly matched conditions. This is expressed in the formula:-

$$\bigstar \quad \text{Return loss in dB} = 10 \log. \frac{\text{Incident power}}{\text{Reflected power}}$$

The formula for expressing the return loss, in decibels, between two impedances Z1 and Z2 is:-

$$\text{Return loss in dB} = 20 \log. \frac{Z1 + Z2}{Z1 - Z2} \quad \text{(when Z1 and Z2 are resistive).}$$

With correctly matched conditions between a source and a load (Fig. 23), no transmitted power is returned to the source; that is, all the transmitted power is absorbed by the load. This can be seen by applying the formula dB = 20 log. $\frac{Z1 + Z2}{Z1 - Z2}$.

Under matched conditions $\frac{Z1 + Z2}{Z1 - Z2}$ is equal to infinity so that theoretically the return loss approaches this figure. A practical figure for return loss under matched conditions is 45 to 50dB.

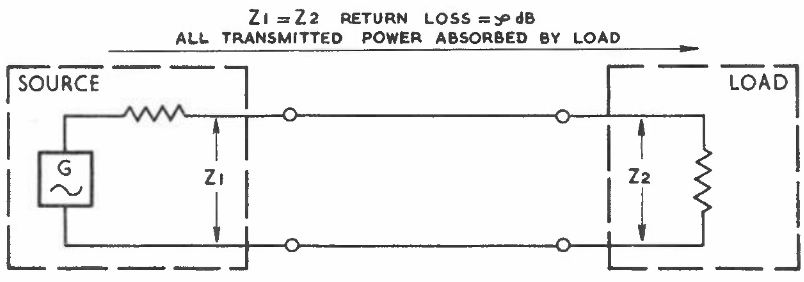


FIG. 23. RETURN LOSS UNDER MATCHED CONDITION.

For the extreme conditions of mismatch, with either a short circuit or open circuit load (Fig. 24), all of the transmitted power is returned to the source. In this case the ratio $\frac{Z1 + Z2}{Z1 - Z2}$ approaches unity and the return loss figure approaches 0dB.

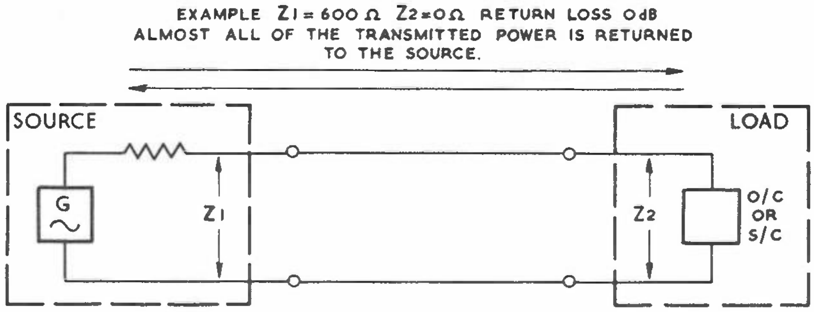
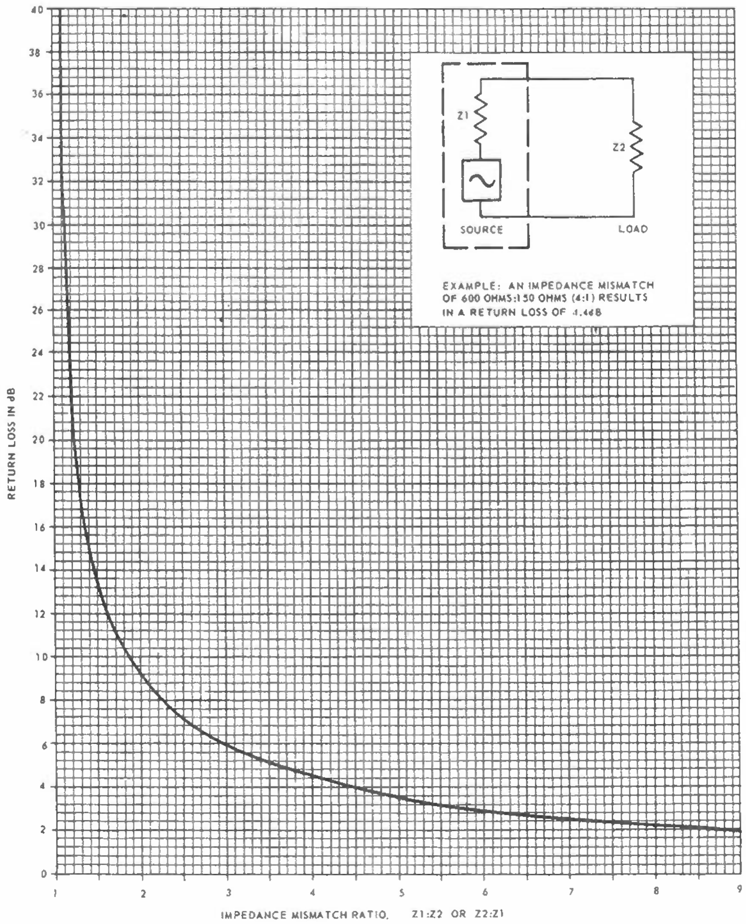


FIG. 24. RETURN LOSS UNDER EXTREMES OF MISMATCH.

The relationship between impedance mismatch ratio and return loss is shown in graph form in Fig. 25. The graph is accurate for resistive conditions only but is included because many Departmental applications are resistive or approach this condition.



★ FIG. 25. RELATIONSHIP BETWEEN IMPEDANCE MISMATCH AND RETURN LOSS.

9.4 Reflection Loss is the logarithmic ratio of the incident power to a load, that is, the ratio between the power that would be absorbed under correctly matched conditions, to the power absorbed by the load. This is expressed in the formula:-

$$\text{Reflection loss in dB} = 10 \log. \frac{\text{Incident power}}{\text{Absorbed power}}$$

For correctly matched conditions, the incident power equals the absorbed power and the reflection loss equals 0dB.

For a mismatch condition the value of reflection loss depends on the degree of mismatch; it is low for a slight mismatch, and high for a bad mismatch.

Fig. 26 shows in graph form the relationship between impedance mismatch ratio and reflection loss for resistive conditions.

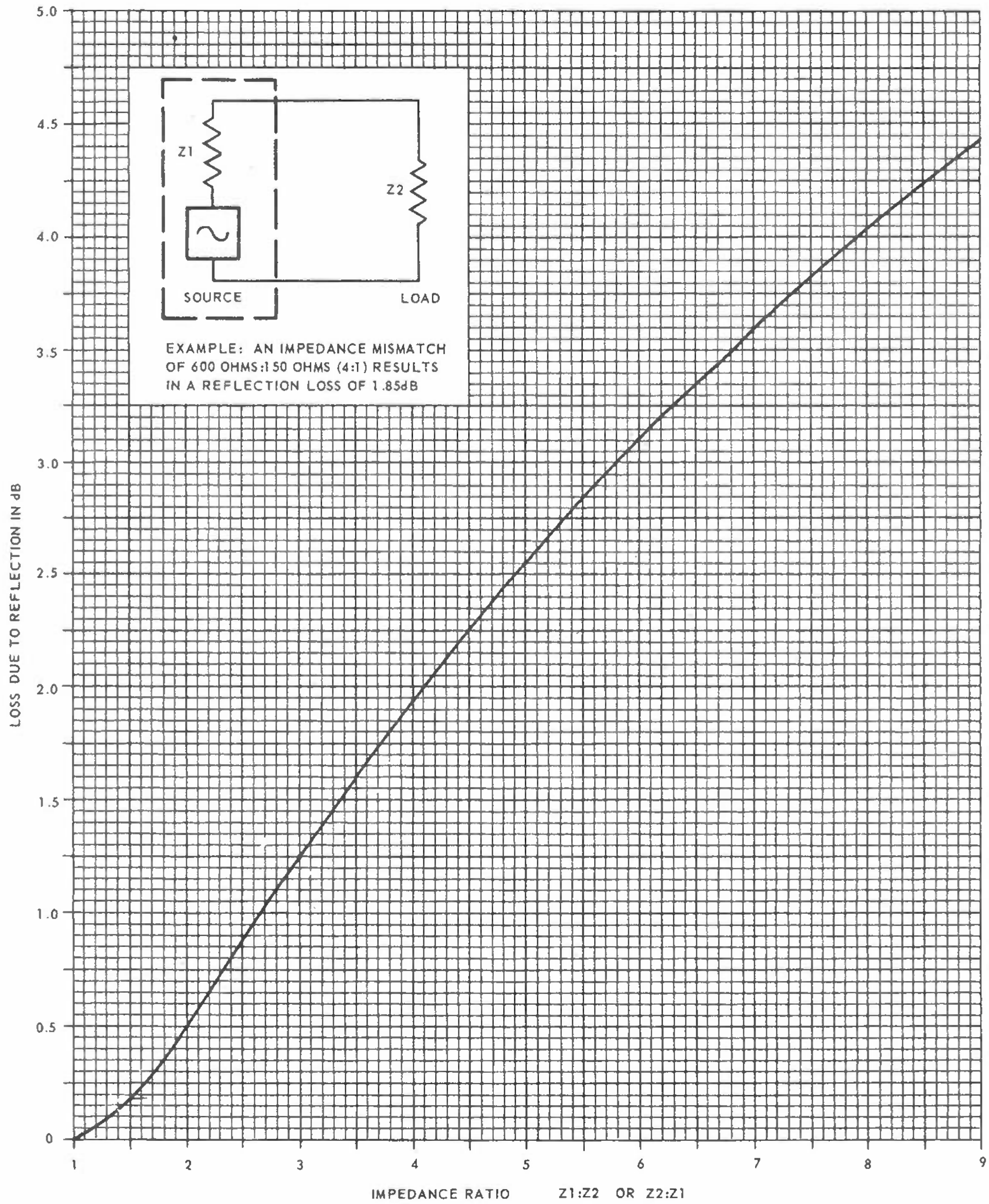
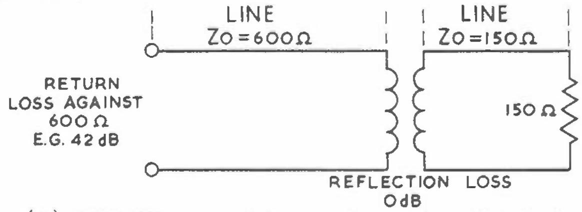


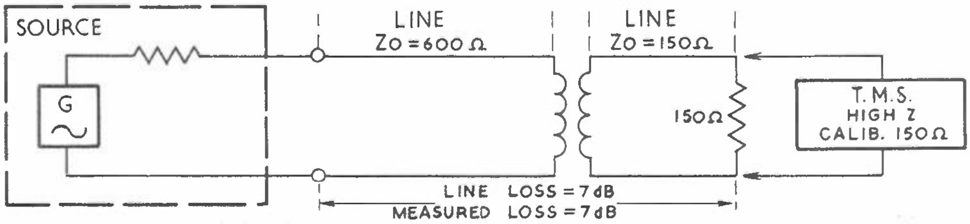
FIG. 26. RELATIONSHIP BETWEEN IMPEDANCE MISMATCH AND REFLECTION LOSS.

9.5 Applications of Return Loss and Reflection Loss. The formulae quoted in paras. 9.3 and 9.4 give an indication of the relationship which exists between return loss and reflection loss. This relationship is directly concerned with the relative impedances of the source and the load. Transmission measurements can be made to determine impedance and return loss but reflection loss is normally calculated rather than measured directly.

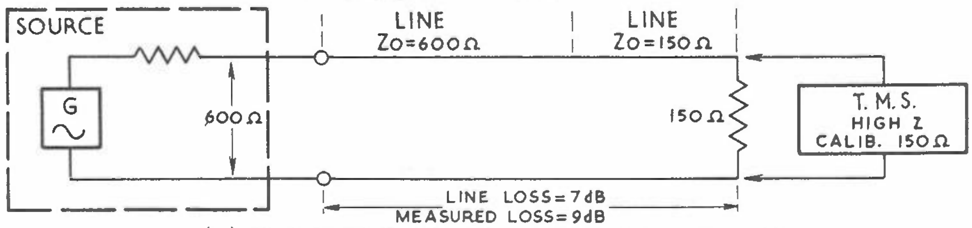
A typical example is included to help explain the terms. Fig. 27(a) shows a trunk line of mixed construction correctly matched by means of a transformer. The return loss measurement is high (for example 42dB) and the reflection loss is negligible. Fig. 27(b) shows that the measured loss of this circuit is equal to the calculated line loss. The line loss can be calculated if the transmission characteristics of the line are known. In the example, a line loss of 7dB is assumed. In Fig. 27(c) the matching transformer is removed from the circuit. The measured loss is now 9dB. That is, 7dB calculated loss plus 2dB reflection loss. (Approximate value from Fig. 26). A measurement of return loss would indicate a lower figure. The return loss measured at point B would be equal to 4dB. (Refer Fig. 25). The return loss measured at point A is the sum of the return loss at B plus the attenuation undergone by the signal during transmission from A to B and the return from B-A. This is equal to 4 + (2 × 7) = 18dB.



(a) Open Wire to Cable - Correctly Matched.



(b) Measurement of Loss - Correctly Matched.



(c) Measurement of Loss - Incorrectly Matched.

FIG. 27. RELATIONSHIP BETWEEN RETURN LOSS AND REFLECTION LOSS.

The example in Fig. 27 shows that:-

(i) Return loss measurements give an indication of the degree of impedance mismatch. A high return loss figure at a point in a circuit indicates negligible mismatch at that point.

(ii) Return loss figures do not numerically indicate how much loss will be caused due to an impedance mismatch.

(iii) When taking return loss measurements the insertion loss of the testing circuit must be taken into the calculation (See para. 9.8).

(iv) Reflection loss indicates numerically the actual loss caused due to the impedance mismatch.

9.6 Measurement of Impedance. It is often necessary to measure the characteristic impedance versus frequency of transmission lines, and in isolated cases it is necessary to measure the impedance versus frequency of items of equipment. The measurements are normally made with laboratory type instruments such as the Western Electric 5A impedance bridge or the Siemens and Halske level meter.

The impedance bridge used, and the circuit details for measurement of line impedance, depend largely on the frequency range to be covered. The circuit arrangement is more complex in the higher frequency ranges.

The general method used, is to measure the impedance of the line from one end, firstly with the distant end short circuited. Measurements are made at selected frequencies in the frequency range concerned. The impedance is then measured at the same spot frequencies with the distant end open circuited. The characteristic impedance can be calculated for each frequency using the formula:

$$Zo = \sqrt{Zsc \times Zoc}$$

where:

Zo = characteristic impedance

Zsc = the measured impedance with a short circuit at the distant end.

Zoc = the measured impedance with an open circuit at the distant end.

The main elements of typical impedance bridges are shown in Fig. 28. The bridges used in the Department are, resistance arm bridges, resistance hybrid bridges and hybrid coil bridges. In each case the balance arm is a variable resistance. A signal generator is applied to the input terminals and a T.M.S. (Detector) is connected to the detector terminals. The line or equipment under test is connected to the line terminals, and in the examples shown is assumed to be resistive. (Zero phase angle). When the value of the resistor in the balance arm is equal to the resistance of the line or equipment, a null is obtained on the T.M.S. From this test the impedance of the circuit under test can be established from the settings of R.

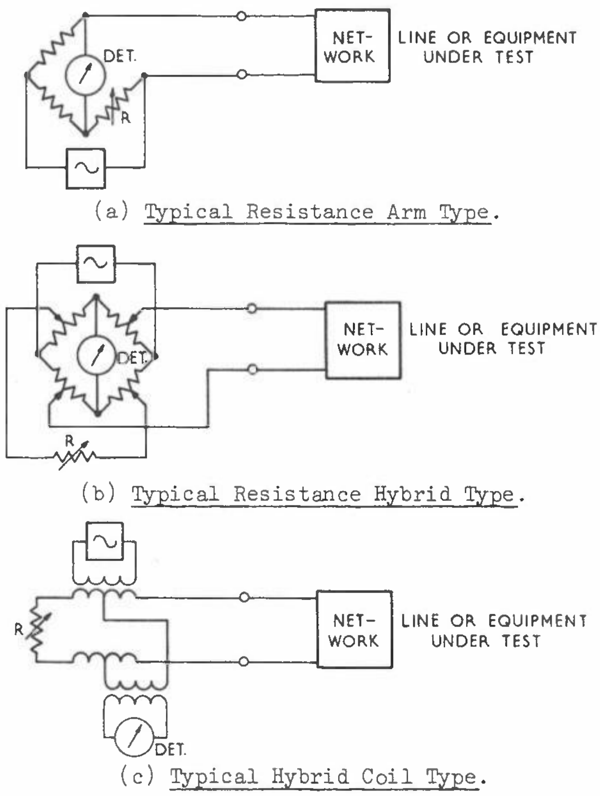
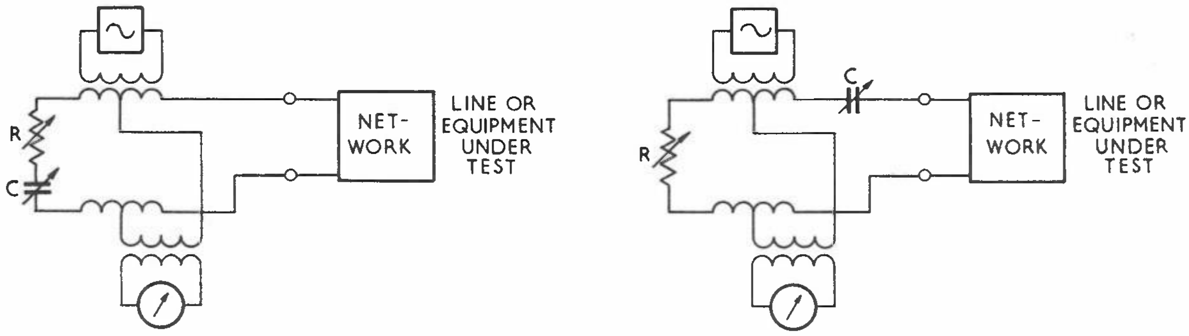


FIG. 28. MAIN ELEMENTS OF TYPICAL IMPEDANCE BRIDGE - RESISTIVE CIRCUIT UNDER TEST.

To enable measurements of impedance and phase angle to be taken, a variable capacitor and variable resistor are included in the bridge. Fig. 29(a) shows the circuit arrangement for measurement on a line or equipment which is basically capacitive. (Negative phase angle). Fig. 29(b) shows the arrangement for measurement on a line or equipment which is basically inductive. (Positive phase angle). In each case, when a balance is obtained, the impedance and phase angle can be calculated from the settings of R and C. Some bridges measure resistance and capacitance and the impedance is calculated from these results.



(a) Negative Phase Angle. (b) Positive Phase Angle.

FIG. 29. MAIN ELEMENTS OF TYPICAL IMPEDANCE BRIDGE - CAPACITIVE AND INDUCTIVE CIRCUITS UNDER TEST.

A check measurement of impedance can be made without laboratory type instruments. A number of methods can be used and although the results obtained are not precise, they are usually sufficiently accurate to be used for locating faults or checking the operation of equipment.

One such method is illustrated in Fig. 30. The oscillator impedance is built out with RV1 to a value approximating the unknown impedance.

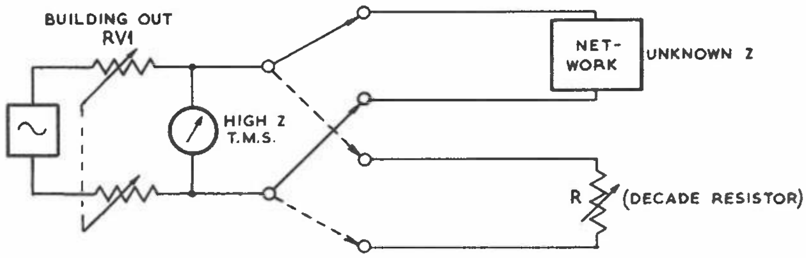


FIG. 30. CHECK OF IMPEDANCE BY COMPARISON METHOD.

The test procedure is divided into the following steps:-

- Note the change in the meter reading when the unknown impedance is connected.
- Connect the decade resistor in place of the unknown impedance and adjust for the same reading as obtained in the first step.
- The impedance of the line or equipment under test is taken directly from the decade resistor setting.

Fig. 31 shows another method which is used in some routine checks and makes use of an A.P.O. T.M.S.

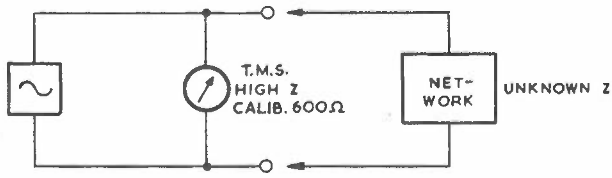


FIG. 31. CHECK OF IMPEDANCE USING A.P.O. T.M.S.

The procedure for this test is divided into the following steps:-

- Connect the circuit as shown in Fig. 31.

- Set the oscillator level and frequency as required.

- Note the difference in dB between the T.M.S. readings with the unknown impedance connected and disconnected from the circuit.

- Use curve A of Fig. 32 to find the unknown impedance. For example, if a difference of 14dB is obtained then the unknown impedance is equal to 150 ohms.

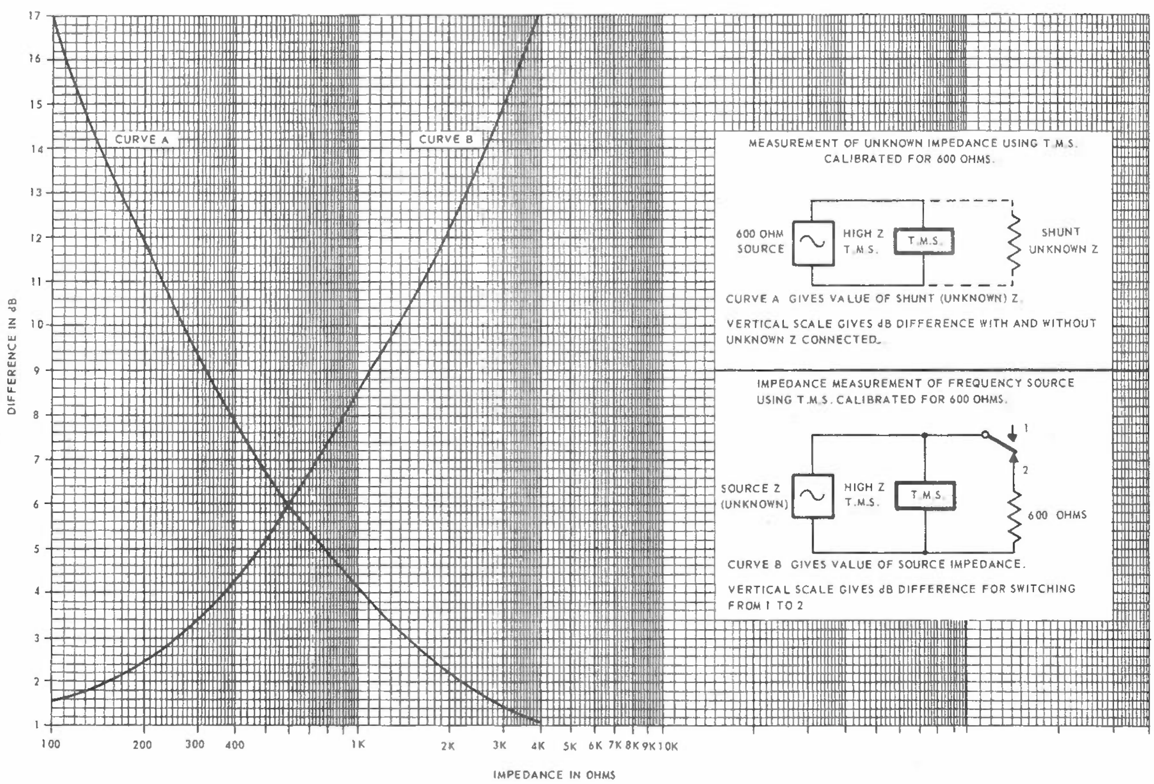


FIG. 32. CHART FOR MEASUREMENT OF UNKNOWN LOAD Z OR UNKNOWN SOURCE Z.

The impedance of a signal source can be determined by a similar test. Fig. 32 shows a suitable circuit arrangement. The test is divided into the following steps:-

- Connect the circuit as shown in Fig. 33.

- Operate the "loss/level" key to the loss position and note difference in dB in readings.

- Use "curve B" of Fig. 32 to determine the unknown impedance. For example, if a 2dB difference is obtained the source impedance is calculated to be 150 ohms.

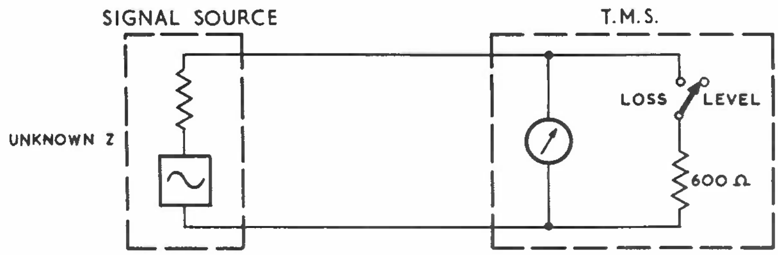


FIG. 33. CHECK OF SIGNAL SOURCE IMPEDANCE USING A.P.O. T.M.S.

The Siemens and Halske level/meter and oscillator uses the voltage divider principle to measure impedance. The unknown impedance is connected in series with a known reference resistance across the low output impedance of the oscillator. The circuit arrangement is shown in Fig. 34.

The reference impedance is low in value compared to the range of impedances that can be measured. This minimises the error which would occur when measuring an impedance with a large reactive component. A reference impedance of 2 ohms is typical and errors are further minimised by limiting the range of impedance that can be measured by the instrument. (Typical values are from 50 - 3,000 ohms).

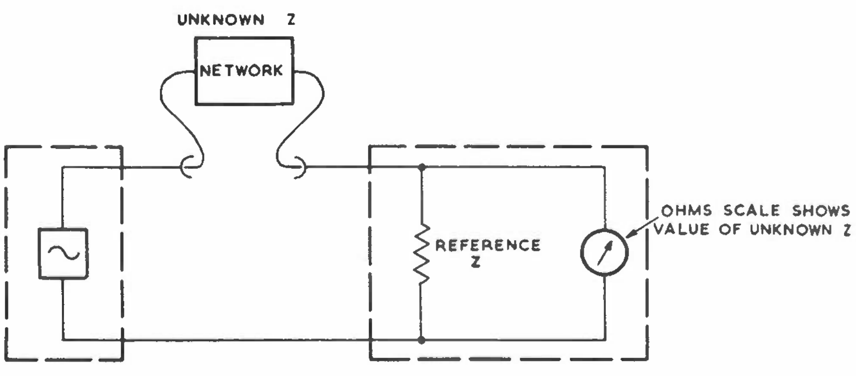


FIG. 34. MEASUREMENT OF IMPEDANCE USING THE VOLTAGE DIVIDER METHOD.

9.7 Measurement of Return Loss. The basic item of equipment required for a return loss measurement is an impedance bridge. This can either take the form of a resistance bridge or a hybrid coil type. The principles of a return loss measurement are shown in Fig. 35. The circuit is arranged, as shown, with a test oscillator and level meter connected to opposite sides of the hybrid. A reference termination of 600 ohms (Z1) and the circuit under test (Z2) are connected to the other terminals.

To measure return loss using this method, it is necessary to ensure that the hybrid and level meter are suitable over the frequency range to be measured. A resistive bridge has the advantage of being independant of frequency.

All bridges have a nominal basic loss, and this must be deducted from the overall results obtained to find the actual return loss. To determine a correction figure for a simple bridge arrangement of the type shown in Fig. 35, it is necessary to measure the loss across the hybrid, firstly with Z2 identical to Z1, and secondly with Z2 equal to either a short circuit or an open circuit. The difference in dB is equal to the basic loss of the bridge, and is subtracted from the loss obtained for any measurement, to give the actual value of return loss. For example, if a correction figure of 6dB is calculated and a total loss of 31dB is measured, then the return loss is equal to 25dB.

The following example shows how return loss can be determined:

- With a level of 0dBm applied to the hybrid, and Z2 equal to an open circuit the meter indicates -6dBm (the loss across the hybrid). The return loss with this extreme mismatch is 0dB, so to obtain the correct value of return loss it is necessary to subtract 6dB from the total loss. The same result is achieved for a short circuit value for Z2.

- With 0dBm applied to the hybrid and Z2 equal to 300 ohms, the meter indicates -15.5dBm. The return loss for a 2:1 mismatch is equal to 9.5dB (Refer Fig. 25). A correction of 6dB is required to obtain this result.

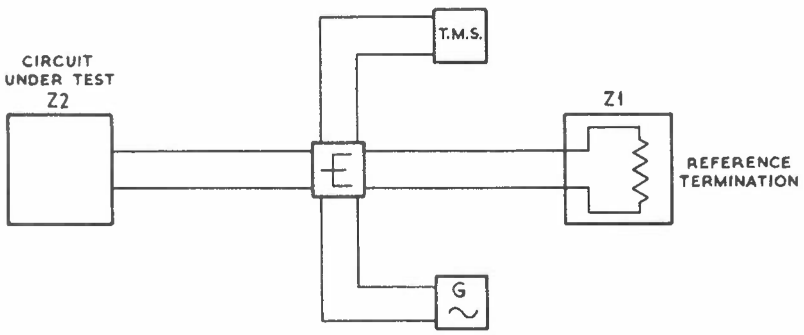


FIG. 35. BASIC PRINCIPLE OF RETURN LOSS MEASUREMENT.

Some Company instruments incorporate return loss calibrating facilities in their impedance bridges. For example, the Western Electric 5A bridge, uses as a basis for calibration the fact that a mismatch of 600 ohms: 671.4 ohms produces a return loss of 25dB. Precision resistors of 600 ohms and 671.4 ohms are connected to opposite sides of the bridge and the circuit is calibrated. For calibration for 135 ohms testing resistor values of 135 ohms and 151.9 ohms are used to give the same 25dB value of return loss.

It should be noted that the return loss figure gives no indication as to whether an unknown impedance is larger or smaller in value than a reference impedance. The test merely indicates the degree of mismatch.

The majority of return loss measurements are made using a precision value resistor as a reference impedance. For certain tests, however, it is necessary to measure the return loss of one section of a circuit against another. This is shown in Fig. 36 where the return loss is measured at the junction of a transmission line and associated filter equipment.

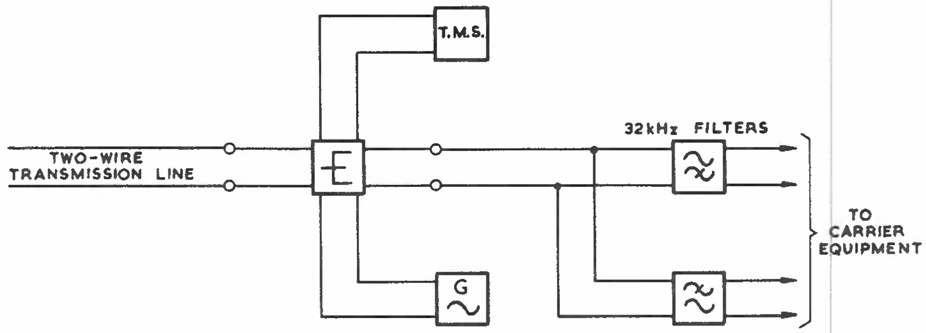


FIG. 36. RETURN LOSS MEASUREMENT AT JUNCTION OF TRANSMISSION LINE AND EQUIPMENT.

9.8 Unless a return loss measurement is made at the actual point of mismatch, a correction is made for the loss which exists between the test equipment and the point of mismatch.

An example is shown in Fig. 37 where a 600 ohm line, with a total loss of 15dB, is terminated with a load impedance of 150 ohms. The return loss measured at point A equals 34dB. The mismatch at point B causes a return loss of 4dB and the additional 30dB occurs in the circuit loss from A-B and from B-A. The impedance mismatch at B is masked by the transmission line. To ensure that all major mismatches are detected, return loss measurements are made from as many circuit points as practicable. In the example shown a return loss measurement of the terminating equipment, against a reference resistance of 600 ohms, would determine the mismatch condition.

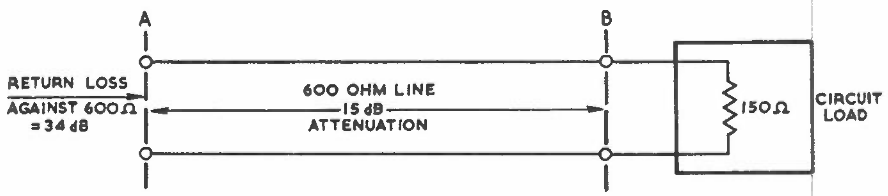


FIG. 37. MASKING OF MISMATCH CONDITIONS.

10. NOISE AND DISTORTION MEASUREMENTS.

10.1 The subjects of noise and non-linear distortion are often related in the field of measurements. There are two reasons for this; firstly, some forms of distortion produce new frequencies which can be regarded and measured as noise frequencies, and secondly, a combined measuring set is commonly used to measure both noise and harmonic distortion.

10.2 Noise. In communications, interference is called noise even though it may be electrical rather than auditory in nature. Noise measurements are made on an electrical basis and from the results an assessment is made of the anticipated effect on the aural signal produced.

A measurement of noise normally includes interference due to "crosstalk" as well as interference due to the noise frequencies. A definition of both noise and crosstalk is included.

(i) Types of Noise Interference which may affect voice communication are defined as:-

(a) Thermal noise. Sometimes called white noise or random noise; it is inherent in any circuit and is produced by the random movement of electrons in conductors, electron tubes and semiconductor devices. Thermal noise is spread uniformly throughout the frequency spectrum.

(b) Impulse noise. Unlike thermal noise, impulse noise occurs in bursts and is not spread uniformly through the frequency spectrum. Some types of impulse distortions are produced by natural causes such as lightning or other electrical disturbances. A great proportion of impulse noise is man-made, resulting from induction from traction systems, power lines, power switching systems, ignition systems, etc. In telephone communication systems, impulse noise is also caused by dialling and switching impulses.

(ii) Types of Crosstalk are generally considered to exist in three categories:-

(a) Intelligible crosstalk, which is in the same frequency range, but lower in amplitude than the original or desired signal.

(b) Unintelligible crosstalk, which is translated in frequency, or appears in the disturbed circuit in an inverted order.

(c) Babble which is crosstalk from a number of sources, either intelligible or unintelligible. With babble, the resulting sound has an apparent syllable rate, but because of the number of interfering signals, does not appear as intelligible crosstalk. Babble is normally evident during the busy-hour periods and is similar to noise.

10.3 The disturbing effect of noise is generally less than that of crosstalk because in most instances no recognizable syllabic pattern is discernable. However, the disturbing effect on any one circuit depends upon the type of noise and its frequency distribution. Many types of noise are man-made and can be eliminated, or at least reduced in magnitude.

10.4 Measurement of Noise. Noise is commonly expressed as a signal-to-noise ratio. That is, the difference is expressed in dB between the nominal signal level and the noise level at a point in a circuit. Fig. 38 shows this relationship. In this example a signal-to-noise ratio of 50dB exists; this can be expressed as -50dBm0.

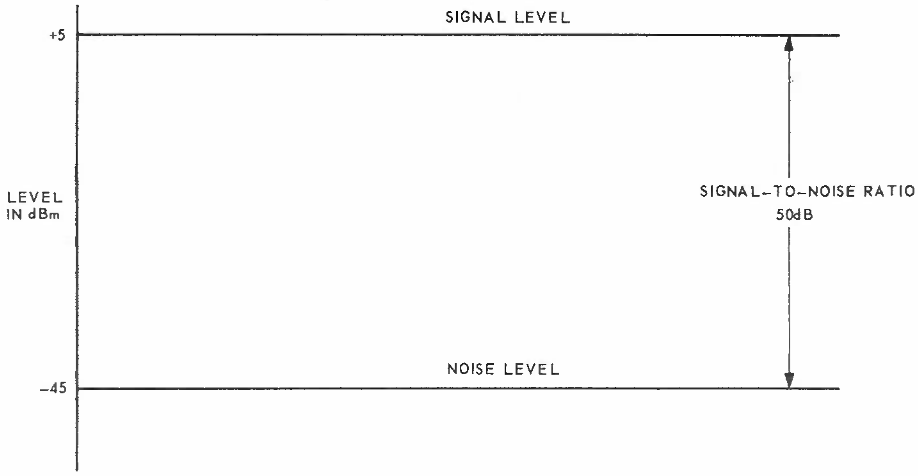


FIG. 38. SIGNAL TO NOISE RATIO.

The noise contribution of a transmission device can also be expressed in terms of its "noise figure". The noise figure is equal to the input signal to noise ratio divided by the output signal to noise ratio. For example, an item of equipment with an input signal to noise ratio of 60dB and an output signal to noise ratio of 50dB has a noise figure of 10dB. Because both input and output values of signal to noise ratio are expressed logarithmically, the division is made by subtraction. The noise figure is the difference in dB between them. The figure of 10dB, in the example, is an indication of the amount of noise introduced by the item of equipment.

10.5 Weighting. The interfering effect of noise is generally different to the measured noise power amplitude. This is because the human ear is more susceptible to some frequencies than others within the V.F. range. Noise frequencies between about 600Hz and 1kHz have a severe interfering effect but frequencies at either end of the range have only a slight interfering effect.

Fig. 39 shows the approximate interfering effect of noise frequencies in the V.F. range.

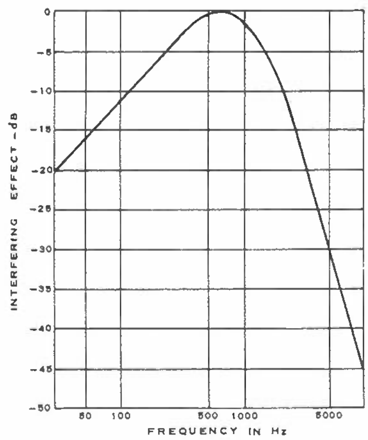


FIG. 39. INTERFERING EFFECT OF NOISE IN THE V.F. RANGE.

★ It is often necessary to measure the actual interfering effect of noise. To do this a weighting network is included in the measuring circuit before the noise meter. The weighting network offers low attenuation to frequencies around 1kHz and high attenuation to the extreme frequencies. The result is that the meter indicates the interfering effect that the noise present in the circuit would have on the average human ear.

The loss versus frequency characteristic of a typical audio weighting network is shown in Fig. 40. A measurement of noise with a weighting network included is termed a "weighted" noise measurement, and a measurement without the network is termed a "flat" noise measurement.

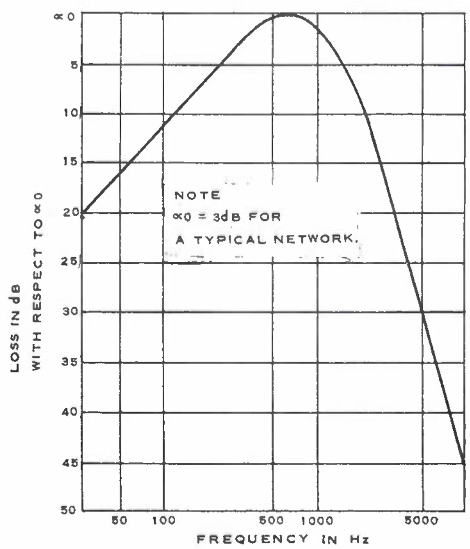


FIG. 40. FREQUENCY VERSUS ATTENUATION CHARACTERISTICS OF TYPICAL AUDIO WEIGHTING NETWORK.

10.6 The basic test arrangement for measurement of noise level is shown in Fig. 41. The input to the circuit under test is terminated in its characteristic impedance, and a noise measuring set (level meter) is connected across the output as shown. Any frequencies present at the output are measured as noise because they must be produced within the circuit under test or induced into it from external sources. It can be seen that the noise measurement includes any crosstalk which may be present.

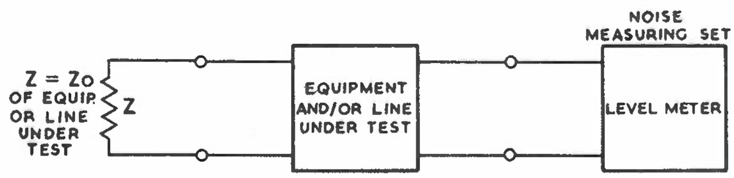
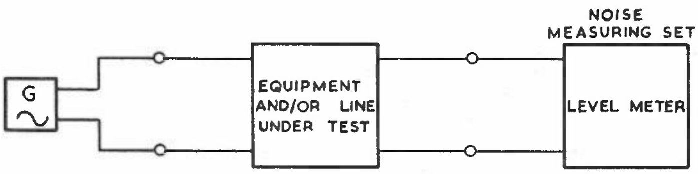
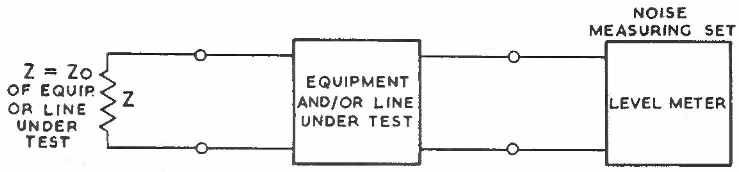


FIG. 41. MEASUREMENT OF NOISE LEVEL.

Fig. 42 shows the test arrangement for measurement of signal to noise ratio. In Fig. 42(a) a test signal is applied, at the normal circuit level, to the equipment under test. The output signal level is recorded. In Fig. 42(b) the test signal is removed and the circuit input terminated in its characteristic impedance. The power level is now measured at the output and the signal to noise ratio is equal to the difference in dB between the two level readings. This measurement is a "flat" noise measurement.



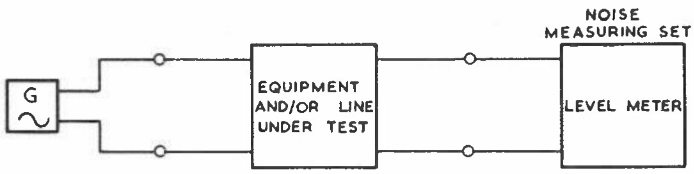
(a) Measurement of Signal Level.



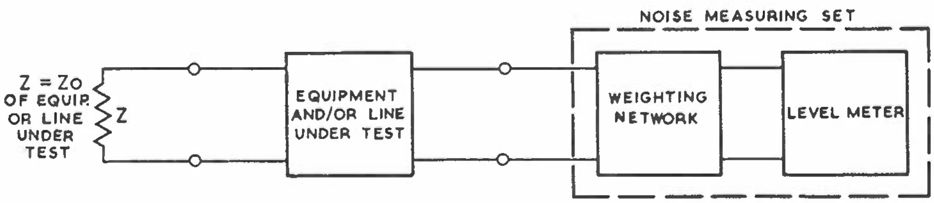
(b) Measurement of Noise Level.

FIG. 42. MEASUREMENT OF "FLAT" SIGNAL-TO-NOISE RATIO.

The basic test arrangement for a "weighted" noise measurement is shown in Fig. 43. The test procedure is similar to that for the "flat" noise measurement but a "weighting" network is included in the circuit. The weighting network is included in the noise measuring set. The normal circuit level is established in Fig. 43(a) and the weighted noise level in Fig. 43(b). The signal-to-noise ratio is the difference in dB between the two levels.



(a) Measurement of Signal Level.



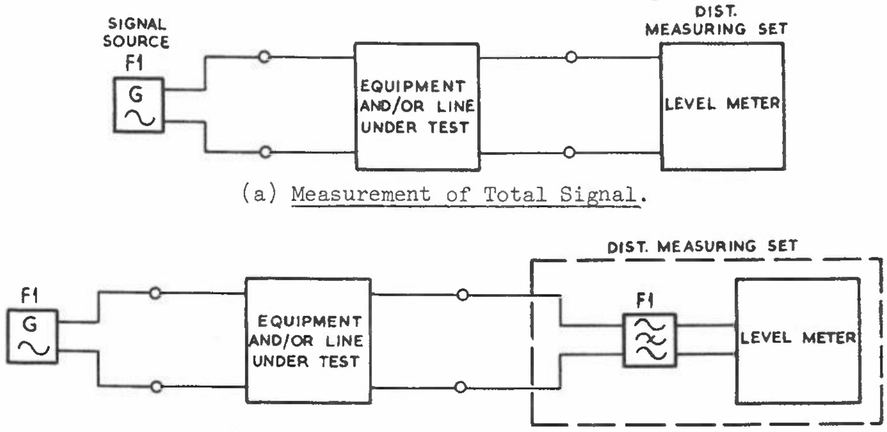
(b) Measurement of Noise Level.

FIG. 43. MEASUREMENT OF "WEIGHTED" SIGNAL-TO-NOISE RATIO.

10.7 Distortion. Distortion is the general term used to describe any change in waveform of a signal. The three basic types of distortion are, frequency distortion, non-linear distortion and delay distortion. When referring to noise and distortion measurements, the type of distortion concerned is "non-linear distortion". Non-linear distortion is sub-divided into harmonic distortion and inter-modulation distortion and it is harmonic distortion which is normally measured. The degree of harmonic distortion occurring in a circuit gives an indication of the degree of inter-modulation distortion.

10.8 Measurement of Harmonic Distortion. The basic test arrangement for measuring harmonic distortion is shown in Fig. 44. In Fig. 44(a) a test signal (a pure sine wave) is applied to the equipment under test. The output level is indicated on a level meter (Distortion Measuring set). In Fig. 44(b) a sharply tuned band stop filter of exactly the same frequency as the test signal is added before the measuring equipment. This blocks the test signal but allows any harmonic frequencies produced in the equipment under test to pass. Harmonic distortion is measured in percentage and can be expressed as:-

$$\text{Harmonic Distortion} = \frac{\text{Value of harmonics}}{\text{Value of total signal}} \times \frac{100}{1}$$



(a) Measurement of Total Signal.

(b) Measurement of Harmonics Only.

FIG. 44. MEASUREMENT OF HARMONIC DISTORTION.

Noise frequencies as well as harmonic products are measured in the harmonic distortion measurement. These noise frequencies are ignored in the calculation of harmonic distortion, when the noise requirement for the equipment under test is satisfactory.

It is essential that sufficient harmonics are applied to the measuring equipment to make the measurement of harmonic distortion realistic. In a channel with a restricted frequency bandwidth, such as most programme channels, it is important to select a fundamental test signal, low enough in frequency, to allow several harmonics to be received by the distortion measuring set. A frequency of 400Hz is commonly used for harmonic distortion measurements on programme channels. On a programme channel with an upper frequency limit of 10kHz, harmonics up to the 25th can be received. If a higher fundamental frequency were used the number of harmonics received would be reduced.

It is normal to apply a test signal at a level suitable to test equipment under peak operating conditions. For example, the harmonic distortion measurement on physical programme channels is made using a frequency of 400Hz at a level 8dB above the normal line-up level.

10.9 A simplified diagram of a typical noise and distortion measuring set (N and D set) is shown in Fig. 45. The input circuit is used to select the required input arrangement, such as, balanced, unbalanced, high impedance, 600 ohms, etc. The function switch can select any of three positions, "CALIBRATE", "DISTORTION" or "NOISE".

In the "CALIBRATE" position, the input signal is applied via a range switch to an amplifier, incorporating a calibrate control, and then to the test meter. The meter is calibrated in % and dB. The calibrate control 'CAL' is used to adjust for full scale deflection with the test signal present. The full scale deflection point is calibrated as 100% and 0dB. For distortion measurements 100% represents total signal, and any new signal level is measured directly as a percentage of this total signal. For noise measurements the calibration to 0dB establishes a reference point. Any new level is measured direct in dB below this reference point, which is normally the nominal circuit level.

A level control circuit (range switch) is added to extend the range of the instrument. When calibrating the N and D set it is important that the range switch indicates 0dB (for noise) and 100% (for distortion).

In the "DISTORTION" position the input signal is applied via a frequency selective device which can be accurately tuned to eliminate the fundamental test frequency. A typical N and D set incorporates a frequency selective unit which can reject individual frequencies in the frequency range from 25Hz to 25kHz. With the fundamental frequency rejected the harmonics are passed to the meter circuit, and the % distortion can be read direct from the range switch and meter scale.

In the "NOISE" position the input signal can be applied direct to the measuring circuit (Flat) or via a weighting network (Weighted). The N and D set is calibrated with a test signal applied at the input of the circuit under test. With this signal removed, and the input to the circuit under test terminated in its characteristic impedance, the signal to noise ratio can be read direct from the range switch and meter scale.

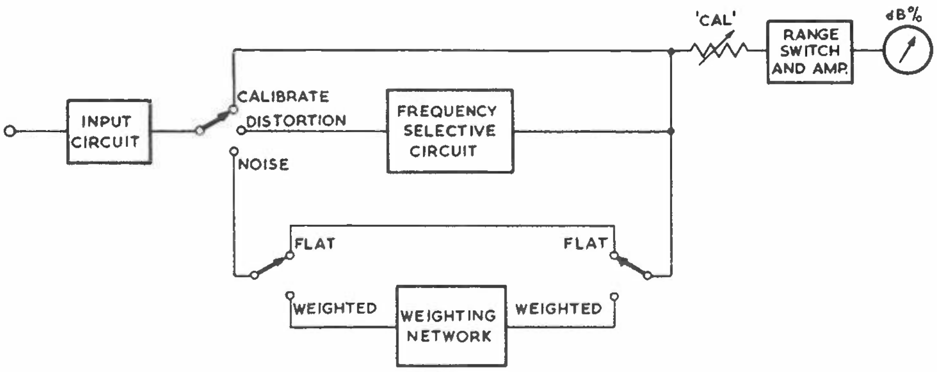


FIG. 45. SIMPLIFIED DIAGRAM OF N AND D MEASURING SET.

11. CROSSTALK MEASUREMENTS.

11.1 Crosstalk between circuits can occur, in the transmission lines, in intra-office wiring or in equipment. Crosstalk falls into the categories listed in para. 10.2. The method of measuring crosstalk depends upon the section of the circuit to be tested. This section describes the principle of crosstalk measurements on transmission lines.

11.2 Crosstalk Terms. Crosstalk is defined as "near-end" crosstalk (N.E.X.T.) and "far-end" crosstalk (F.E.X.T.). These definitions are made with respect to the "disturbing source" and are illustrated in Fig. 46.

G1 represents a disturbing source (for example, a telephone transmitter, a power generator, a telegraph machine, etc.), and crosstalk takes place from the transmission line A-B to the transmission line C-D. The transmission line A-B is called the "disturbing circuit" and the line C-D is called the "disturbed circuit". The crosstalk signal existing at C is termed "near-end" crosstalk because it appears in the disturbed circuit at the end nearest to the disturbing source. The crosstalk signal existing at D is termed "far-end" crosstalk, because it appears in the disturbed circuit at the end distant from the disturbing source. The diagram does not show the electrostatic and electromagnet couplings that cause the crosstalk. The crosstalk does not occur at one point in the line, as shown, but the couplings exist throughout the length of the line.

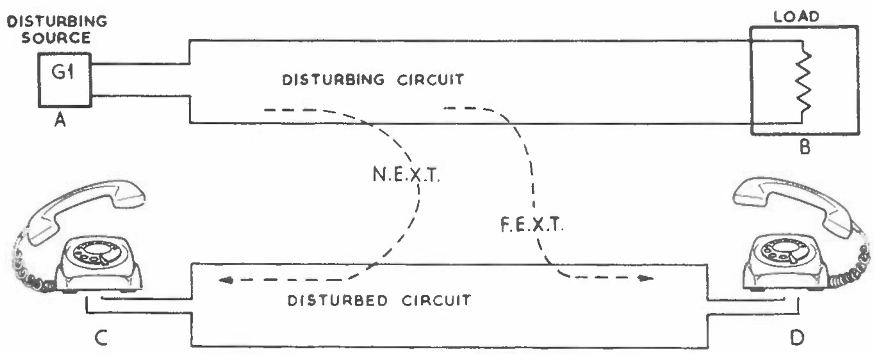


FIG. 46. DEFINITION OF CROSSTALK TERMS.

11.3 When there is a mismatch of impedance at a point between the terminals of either the disturbed line, or the disturbing line, a point of reflection occurs at the mismatch.

When the mismatch occurs in the disturbing pair, the transmitted voltage and current appear to have originated at the opposite end of the line. The reflected voltage causes crosstalk into the other pair which appears as F.E.X.T. This is illustrated in Fig. 47.

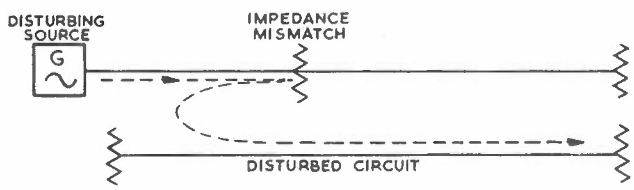


FIG. 47. CROSSTALK WITH MISMATCH IN DISTURBING PAIR.

When the mismatch occurs in the disturbed line, the N.E.X.T. which occurs beyond the mismatch is subject to reflection and appears at the distant end as F.E.X.T. This is illustrated in Fig. 48.

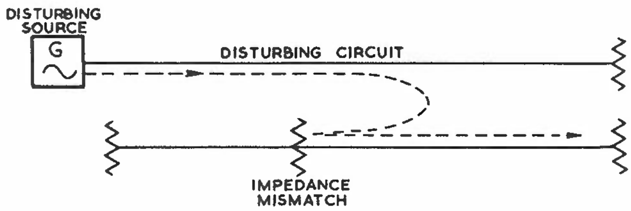


FIG. 48. CROSSTALK WITH MISMATCH IN DISTURBED PAIR.

11.4 Crosstalk can be subdivided into "transverse crosstalk" and "interaction crosstalk".

(i) Transverse Crosstalk is that which occurs between two pairs within a short line section. It can be direct from one pair to another as shown in Figs., 46, 47 and 48 or indirect, from one pair via a third pair to the other. The latter is called "tertiary crosstalk" and is illustrated in Fig. 49.

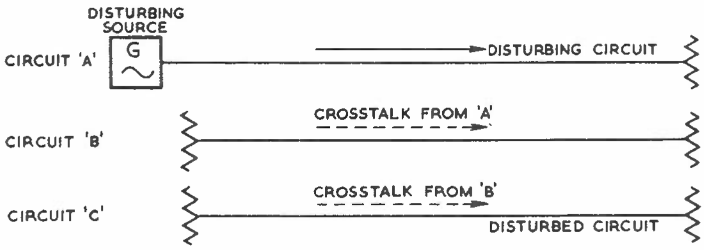


FIG. 49. TERTIARY CROSSTALK.

(ii) Interaction Crosstalk is a form of tertiary crosstalk. The crosstalk signal, however, travels along the third pair for some distance before disturbing the second pair. Fig. 50 shows a simple example of interaction crosstalk.

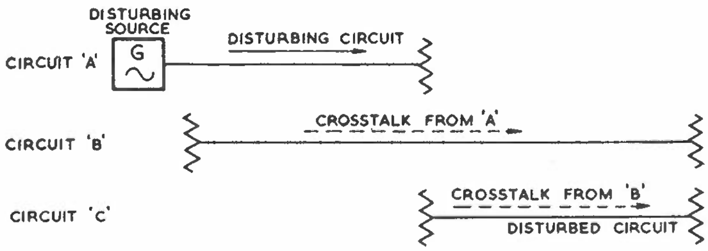


FIG. 50. INTERACTION CROSSTALK.

11.5 In the V.F. range the problem of both near-end and far-end crosstalk exists and, in general, measurements of both are made.

In the carrier frequency range, near-end crosstalk is often ignored because, although it occurs, its effect is obviated by poling of carrier systems. That is, the frequency arrangement for carrier systems is such that near-end crosstalk is not accepted by the receive filters of similar carrier systems operating on the one route. In general, measurement of far-end crosstalk only are made in the carrier frequency range.

11.6 The two crosstalk measurements commonly made on transmission lines are:-

- Crosstalk attenuation.

- Crosstalk ratio.

(i) Crosstalk Attenuation is the logarithmic ratio between the power sent on the disturbing circuit to the power received on the disturbed circuit. This can be expressed in the formula:

$$\text{Crosstalk attenuation} = 10 \log. \frac{\text{Power Sent Disturbing Circuit}}{\text{Power Received Disturbed Circuit.}}$$

Normally these powers are measured in dBm and the crosstalk ratio is equal to the difference (in dB) between these two levels.

(ii) Crosstalk ratio is the logarithmic ratio between the power received by the disturbing circuit to the power received by the disturbed circuit at the point of measurement. This can be expressed by the formula:

$$\text{Crosstalk ratio} = 10 \log. \frac{\text{Power Received Disturbing Circuit}}{\text{Power Received Disturbed Circuit}}$$

Normally these powers are measured in dBm and the crosstalk ratio is equal to the difference (in dB) between the two levels.

For F.E.X.T. there is a difference between crosstalk ratio and crosstalk attenuation. This is shown in Fig. 51. Assuming the insertion loss of pair a - b to be 20dB then the far-end crosstalk ratio is 20dB lower than the far-end crosstalk attenuation. For example, if the measured crosstalk ratio is 50dB then crosstalk attenuation is equal to 70dB. From the same diagram it can be seen that the measuring points for near-end crosstalk ratio and crosstalk attenuation are the same, with the result that near-end crosstalk ratio and near-end crosstalk attenuation are the same value.

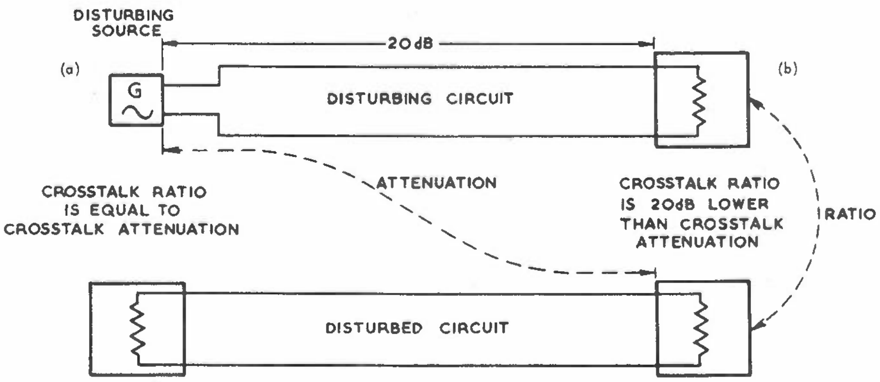


FIG. 51. RELATIONSHIP BETWEEN CROSSTALK RATIO AND CROSSTALK ATTENUATION.

11.7 Measurement of Crosstalk. Crosstalk ratio is the type of crosstalk measurement made for planning purposes. The "comparison" method is often used and a high frequency, low capacity key is required. The changeover key incorporated in a comparison type measuring set can be used.

Fig. 52 shows a test arrangement for measurement of N.E.X.T. At the distant end both lines are terminated in their characteristic impedance. The oscillator is set at the frequency at which the measurement is to be taken, and the changeover key switched to the "COMPARE" position. The T.M.S. (Detector) is adjusted to give a suitable deflection. The changeover key is then switched to the "ADJUST" position and the calibrated attenuator is adjusted to give the same meter deflection. The attenuator reading is then equal to the crosstalk ratio in dB.

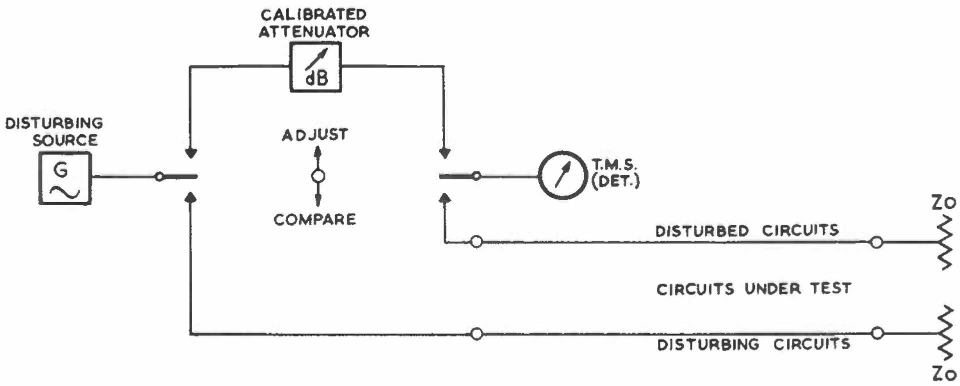


FIG. 52. MEASUREMENT OF NEAR-END CROSSTALK RATIO.

The test arrangement for measurement of far-end crosstalk ratio is shown in Fig. 53. The same test procedure is adopted as for measurement of N.E.X.T.

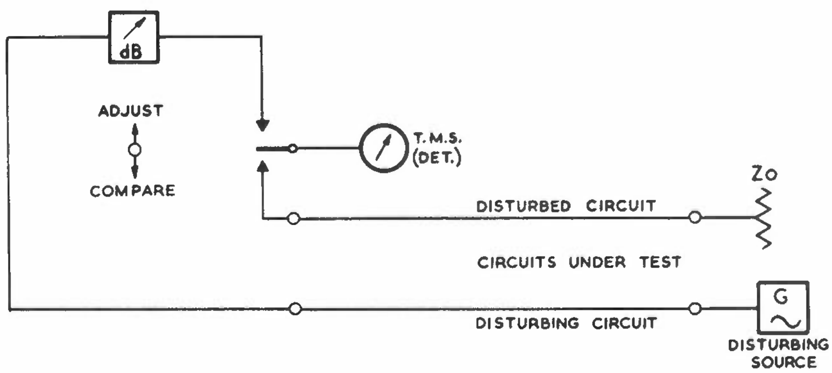


FIG. 53. MEASUREMENT OF FAR-END CROSSTALK RATIO.

11.8 Crosstalk versus frequency characteristics can be obtained by measuring crosstalk at specified frequencies or by using a variable frequency oscillator. By using a variable frequency oscillator the peaks and troughs of crosstalk can be measured and plotted on a crosstalk versus frequency graph. A typical result is shown in Fig. 54.

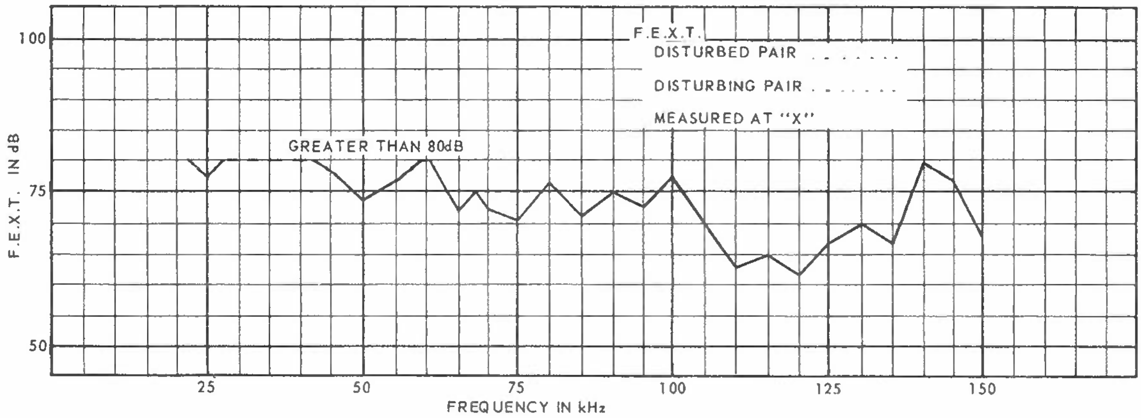


FIG. 54. TYPICAL CROSSTALK VERSUS FREQUENCY CHARACTERISTICS OF TWO OPEN WIRE LINES.

✱ 11.9 Both noise and longitudinal currents have an effect on crosstalk measurements. The effect of noise is checked by noting the difference in the readings with, and without, the test source connected to the line. When the test source is removed the line is terminated in its characteristic impedance. Table 3 gives an indication of the practical correction required for various degrees of noise. The correction is expressed with regard to the difference in dB obtained, with the source on and off.

Difference in dB between readings with test source on and off.	Correction. (Subtract from reading obtained with test source on).
20dB	0.1dB
10dB	0.5dB
3dB	3.0dB

TABLE 3. CORRECTION FOR NOISE.

Longitudinal currents can be checked by reversing the connections to the oscillator, or to the T.M.S. If longitudinal currents are present the readings will vary. The lowest value of crosstalk obtained should be used. When screened balanced transformers are available, these should be added in the output circuit of the oscillator, and the input circuit of the T.M.S. In this way the longitudinal currents are eliminated.

The use of a tuneable (selective) T.M.S. reduces the effect of noise and longitudinal interference on crosstalk measurements. When measuring crosstalk peaks and troughs a tuneable T.M.S. should be used.

12. SWEEP OSCILLATOR AND LEVEL TRACER.

12.1 Sweep oscillators and level tracers incorporate facilities to make a number of common measurements, and display the results on the screen of a cathode ray tube. The test results are generally displayed as a test trace versus frequency.

The instruments are commonly referred to as "level tracers", but in most cases they incorporate a transmitting section (an oscillator which can function as a "sweep" oscillator) and a receiving section (a cathode ray tube which displays the test results). The receiving section of the instrument can be used independant of the transmitting section.

Measurements of insertion loss and gain, impedance, return loss, and crosstalk can be made with a typical instrument. Each of these measurements can be made at selected individual frequencies, or over a range of frequencies by using the sweep oscillator facility.

12.2 The level tracer has advantages over combined oscillator and level meter arrangements, particularly when results are required quickly. For example, when equalising a line, the frequency versus attenuation response of the line can be permanently displayed and adjustment made to give the required flat response. It is also possible to make comparison measurements. The test trace of equipment or lines under test can be produced on the forward Y axis sweep, and the test trace of standard reference equipment or lines can be produced on the return sweep. The persistance of the cathode ray tube is sufficiently long to enable both traces to be viewed simultaneously.

The test trace results can be photographed to provide a simple means of recording test results. It is also possible to copy the results with pencil on graph paper. A graduated graticule is placed in front of the cathode ray tube, and it is possible for reference results to be marked on the graticule.

12.3 A simplified diagram of a level tracer is shown in Fig. 55. The transmitting section consists of a B.F.O. which can be "swept" by a motor drive over a range of frequencies, or can be set manually to any required frequency.

The receiving section consists of a level measuring circuit and a frequency measuring circuit. These two circuits combine to display the test results as components of a rectangular co-ordinate system on the screen of the C.R.T. One measuring spot is given at a time but as the frequency is varied the measuring curve is traced out accordingly. The signal is received by the level measuring circuit, rectified and applied, via a range switch, to the vertical deflecting plates of the C.R.T.

The frequency measuring circuit generates the deflecting voltage for the horizontal plates. Its input comes either direct from the transmitting section, or if this is not possible, from the amplifier in the level measuring circuit. The latter method is used when the receiving section is used independant of the transmitting section, although it is possible under these conditions to add frequency markers to the screen trace from the transmitting section.

The switching section selects the required test functions, and also allows horizontal deflection from either the transmitting or the receiving circuit. Calibration of the instrument is made by switching the transmitting section direct to the receiving section.

The oscillator output is taken through the switching section to the output jacks, and applied via these jacks to the equipment under test. The signal from the equipment under test is applied to the input jacks. Two sets of input jacks are provided to enable comparison measurements to be made. The signals from the two sets of jacks are alternately switched to the C.R.O., Y axis circuit, to enable the reference and test trace to be produced on the screen.

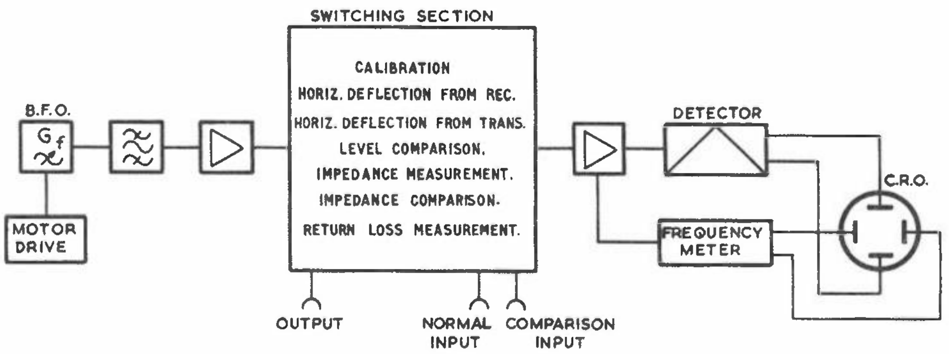
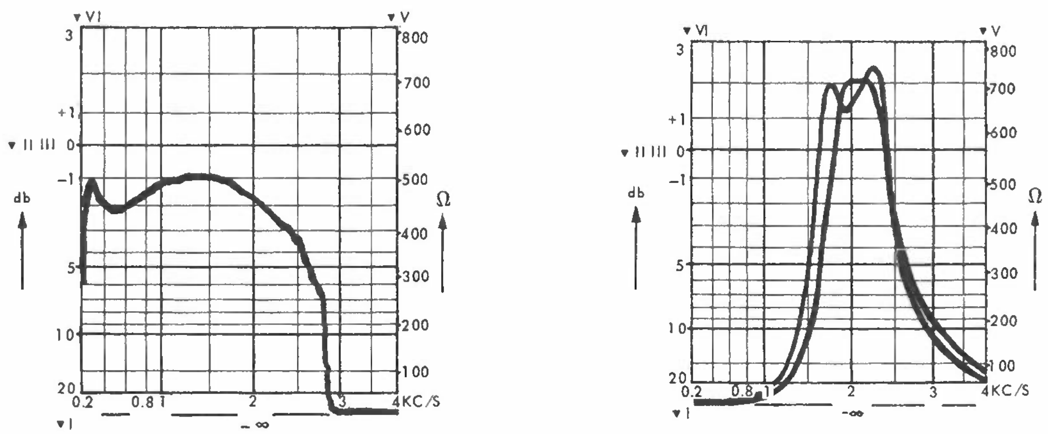


FIG. 55. SIMPLIFIED DIAGRAM OF TYPICAL LEVEL TRACER.

12.4 In Fig. 56, two typical test traces are shown for a level tracer. Fig. 56(a) shows the loss versus frequency characteristic of a V.F. loaded cable pair, and 56(b) shows the response of a filter under test compared with a reference filter of the same type. The filter with the flat response in the pass range is the reference filter.



(a) Frequency Response - V.F. Loaded Cable. (b) Frequency Response Comparison - Filter.

FIG. 56. TYPICAL LEVEL TRACER GRATICULE.

13. A.C. BALANCE.

13.1 When the two sides of a circuit are subjected to the same electrical field, the longitudinal currents flowing in each side are dependant on the impedance of each side. This is illustrated simply in Fig. 57 with a cailho (earthed phantom) circuit. When $Z_1 = Z_2$ and $Z_3 = Z_4$, the ideal balance condition exists and the interference signal to Z_5 and Z_6 is equal to zero.

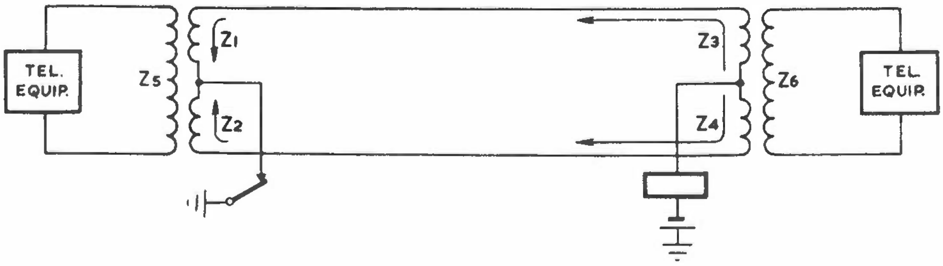


FIG. 57. LONGITUDINAL CURRENTS IN CAILHO (EARTHED PHANTOM CIRCUIT).

13.2 Fig. 58 shows longitudinal currents established by induction from an external source. When the two sides of the circuit are subjected to the same electrical field, the voltages induced in each side are equal. Once again when $Z_1 = Z_2$ and $Z_3 = Z_4$, the interference signal to Z_5 and Z_6 is equal to zero.

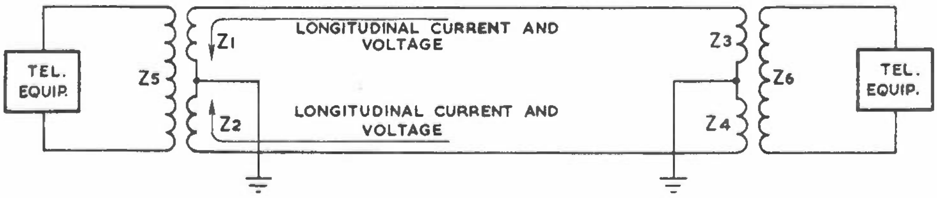


FIG. 58. LONGITUDINAL CURRENTS INDUCED FROM EXTERNAL SOURCE.

13.3 To keep the interference effects from induced longitudinal currents to a minimum, it is essential that transmission lines and equipment are satisfactorily balanced to earth. A.C. balance is expressed in decibels. The formula for balance is as follows:-

$$\text{Balance in dB} = 20 \log. \frac{Z_1 + Z_2}{Z_1 - Z_2}$$

where:
Z_1 equals the impedance of one side to ground.
Z_2 equals the impedance of the other side to ground.

For a circuit with poor A.C. balance the ratio $\frac{Z_1 + Z_2}{Z_1 - Z_2}$ approaches unity and the balance figure approaches 0dB.

For a circuit with good A.C. balance the ratio $\frac{Z_1 + Z_2}{Z_1 - Z_2}$ approaches infinity and the balance figure approaches this value. In practice a balance figure of 35dB or better is suitable for transmission lines and equipment. A figure of 40dB or better is suitable for measuring equipment.

13.4 To ensure accuracy of measurements, it is essential that the effects of longitudinal noise and crosstalk are kept at a minimum. To do this, lines and equipment under test should be balanced to earth as well as possible. It is also important that all measuring instruments and associated cords are balanced to such a degree that they do not adversely affect the overall balance of a test circuit.

When it is suspected that longitudinal currents are affecting test results, a quick check can be made using one of two methods. The first method is to reverse the connection to the receive level meter, or the signal generator, and note the results. When a different level is indicated for each connection then longitudinal currents are present. The second method is to alternately make a direct connection to ground for each side of the circuit and note the change in level in each case. When the circuit is balanced the changes are the same for each connection. When the circuit is unbalanced the change for each case are different.

Longitudinal currents can be eliminated by the use of screened and balanced transformers, and these should be used whenever the effects of A.C. unbalance are obvious.

Fig. 59 shows a screened and balanced transformer connected between a line under test and test equipment. With this arrangement the equal longitudinal voltages produce equal longitudinal currents in the two half windings of the transformer. These currents are in opposite directions, and no voltage is produced across the winding to which the test equipment is connected.

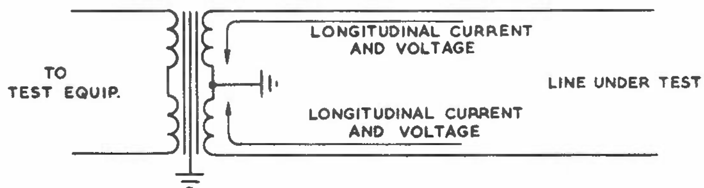


FIG. 59. USE OF BALANCED TRANSFORMER.

When a screened and balanced transformer is connected in the line side of an impedance bridge, it is necessary to connect a similar transformer in the balance network side, to maintain correct balance conditions. This is shown in Fig. 60.

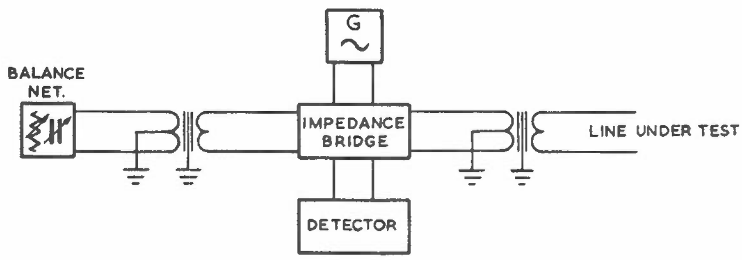


FIG. 60. BALANCED TRANSFORMERS WITH IMPEDANCE BRIDGE.

13.5 Measurement of Unbalance. A number of test instruments incorporate the facility to measure A.C. unbalance. The basic principle of these measurements is an extremely accurate A.C. bridge. The test circuit arrangement is similar to that used for measurement of return loss. It should be noted that there is a similarity between return loss and A.C. balance, and this can be seen by comparison of their respective formulae.

14. *TEST QUESTIONS.*

1. What are the two basic test instruments required for transmission measurements?

2. State the main requirements for:

(i) A signal generator.
(ii) A transmission measuring set.

3. List five factors that should be considered before commencing transmission measurements.

4. State the appropriate frequency ranges for the following types of equipment:

(i) Voice frequency equipment.
(ii) Three channel carrier equipment.
(iii) Twelve channel carrier equipment.
(iv) Broadband carrier equipment.

5. State the impedances that are commonly used by transmission equipment, and indicate broadly the frequency ranges and types of line which these impedances are associated.

6. Show simple circuit arrangements for the following:-

(i) A balanced circuit.
(ii) A balanced-to-ground circuit.
(iii) An unbalanced circuit.

7. With the aid of simple diagrams show how errors can occur because of faulty interconnection of the types of circuits listed in question 6.

8. Give reasons why the choice of test level is important in transmission measurements.

9. It is sometimes necessary to make D.C. measurements on transmission lines before proceeding with A.C. measurements. What are these measurements and why may they be necessary?

10. List the A.C. measurements that can be made on transmission lines and give reasons for these measurements.

11. List the A.C. measurements that can be made on transmission equipment and give reasons for these measurements.

12. What is a "terminated" measurement and when would a terminated measurement be made?

13. What is a "bridging" measurement and when would a bridging measurement be made?

14. What are the three types of meter circuits used by transmission measuring sets and what are the main features of each type?

15. List the facilities provided by typical modern transmission measuring sets.

16. What is meant by the following terms as applied to transmission measuring sets?

(i) Wideband type?
(ii) Selective type?

17. Draw a simplified diagram of a typical wideband transmission measuring set.

18. Draw a simplified diagram of a typical selective transmission measuring set.

14. *TEST QUESTIONS (CONTD).*

19. *A power level type transmission measuring set indicates the actual power level in dBm, regardless of the terminating impedance. State one method of obtaining this feature.*

20. *A voltage level type transmission measuring set is only accurate when measuring across the impedance for which it is calibrated. Describe briefly how accuracy can be obtained for values of terminating impedance other than the calibrating impedance.*

21. *A transmission measuring set is calibrated for use with 600 ohms, and is used to measure the receive level on a 150 ohm cable pair. Draw a simple diagram to show the measuring set-up and state the "correction factor" that would be applied.*

22. *When is a "correction factor":-*

    (i) Added to the measured level?
    (ii) Subtracted from the measured level?

23. *Draw a circuit of a typical comparison type transmission measuring set and show how this set can be used for:-*

    (i) Measurements of gain.
    (ii) Measurements of loss.

24. *State the requirements of a typical test oscillator.*

25. *What are the two main types of test oscillators used for transmission testing?*

26. *Draw a simplified circuit of a signal generator.*

27. *Give reasons for the use of transformers in transmission testing set-ups and state any disadvantages in their use.*

28. *Draw a simple circuit and describe how the "direct method" is used to measure the loss of and item of equipment.*

29. *Insertion loss or gain takes into account four factors. What are these factors?*

30. *Describe how the insertion gain of an amplifier is measured, using the direct method. State all precautions that would be necessary.*

31. *List the steps involved in the measurement of gain or loss by the comparison method.*

32. *When would voltage measurements be made in preference to level measurements in dBm?*

33. *Why are overload measurements made on transmission equipment?*

34. *With the aid of a simple diagram describe how the overload point of an amplifier can be determined.*

35. *Define the term "return loss".*

36. *A return loss measurement gives an indication of the degree of mismatch between two impedances. A high return loss figure indicates severe/negligible mismatch at a point in a circuit.*

37. *Define the term "reflection loss".*

38. *With regard to circuit loss, what does "reflection loss" indicate.*

14. *TEST QUESTIONS (CONTD).*

39. *With the aid of simple diagrams describe how the impedance of lines or equipment can be measured. Assume the following conditions:-*

 (i) Resistive circuit.
 (ii) Inductive circuit.
 (iii) Capacitive circuit.

40. *Draw a simple circuit arrangement for measurement of return loss.*

41. *A return loss measurement is made on a transmission line, at a point some distance from the mismatch. What effect will this have on the result?*

42. *Briefly define the terms "noise" and "crosstalk" as applied to transmission lines and equipment.*

43. *What is meant by a signal-to-noise ratio of 50dB?*

44. *What is the advantage of a "weighted noise measurement" on V.F. circuits?*

45. *Draw a simple circuit to show the principle of a noise measurement.*

46. *With the aid of diagrams explain the principle of:-*

 (i) Measurement of signal-to-noise ratio (flat).
 (ii) Measurement of signal-to-noise ratio (weighted).

47. *State the three basic types of distortion occurring in transmission lines and equipment.*

48. *With the aid of a simple diagram describe the principle of the measurement of harmonic distortion.*

49. *Draw a simplified diagram of a noise and distortion measuring set.*

50. *What is meant by the terms:-*

 (i) Near-end crosstalk.
 (ii) Far-end crosstalk.

51. *Define the following types of crosstalk.*

 (i) Interaction crosstalk.
 (ii) Transverse crosstalk.

52. *With the aid of a simple diagram explain the difference between "crosstalk ratio" and "crosstalk attenuation".*

53. *With the aid of simple diagrams show how crosstalk ratio is measured for:-*

 (i) Near-end.
 (ii) Far-end.

54. *Both noise and longitudinal currents have an effect on measured crosstalk results. How can the effect of noise and longitudinal currents be checked and what action can be taken to obtain correct results?*

55. *State the main uses of a level tracer and any advantages it has over conventional signal generators and transmission measuring sets.*

56. *What factors cause A.C. unbalance in transmission equipment and lines?*

57. *How can the effect of A.C. unbalance in test equipment be offset in a measuring set-up?*

NOTES

END OF PAPER.