Transmission Measurements

AN INTRODUCTION TO FUNDAMENTALS FOR AUSTRALIAN POST OFFICE TECHNICIANS

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An Introduction To Transmission Measurements

FOREWORD

This pamphlet, issued as a special supplement to "TELEGEN" June, 1967, was prepared by Mr. D. L. Shaw, B.E., A.M.I.E. Aust., Engineer Class 3, P.M.G. Research Laboratories. It is based on many years' engineering experience in the New South Wales Country Installation Section.

The author's intention is to provide technicians with a simple exposition of fundamental concepts applied to transmission measuring techniques and instruments in a modern telecommunication network. The technician is guided in simple steps toward an understanding of fundamental principles and is shown how to avoid some common errors and misconceptions.

INTRODUCTION

Modern telecommunication networks are dependent on the reliable performance of many types of transmission devices such as amplifiers and carrier systems. Transmission measurements are the means of testing that these devices are in fact operating correctly. Therefore, it is of the utmost importance that today's technician really understands the theory of transmission measurements and that he be skilled in the use of his testing instruments.

The aim of this article, is to explain in simple terms the theory of the common types of transmission measurement procedures used by technicians. The principal features of modern transmission measuring sets are described and there are three sections on the common "traps" and "pitfalls" for the unwary.

FUNDAMENTAL CONSIDERATIONS

A modern telecommunication network is capable of transmitting a wide range of "information signals", e.g.:—

- Telephony
- Telegraphy
- Broadcast Programme
- Data
- Picturegrams

The performance of the network's transmission devices could be studied by measuring the voltage of a particular information signal as it passed through them. However, for normal measurement work this approach is just not practical. The reason is that the "information signal", for example, human speech, is of an extraordinarily complex nature and it is very difficult to measure. Therefore, we compromise by studying the behaviour of an artificial signal as it passes through the network. This technique has the tremendous advantage that the voltage and the frequency of the test signal can be adjusted to whatever values are required. Part of the skill of transmission measurements is the selection of the frequency and the voltage of the test signal so that it will be approximately equal to that of the real information signal at the point of measurement.

For example, human speech for economical telephony purposes is considered as being made up of frequencies between 300 and 3400 c/s., so that study of the behaviour of transmission devices over this band of frequencies will give a good indication of their performance when transmitting actual speech signals.

The Two-Basic Test Instruments

Two basic instruments are required, one to produce the test signal and the other to measure the voltage of the test signal.

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

a test oscillator,

an oscillator

a sender

a source

a level oscillator.

The two basic facilities of a signal generator are:

(i) the ability to adjust the frequency of the test signal, and

(ii) the ability to adjust the voltage of the test signal.

The voltage of the test signal is measured by an instrument called a level measuring set (LMS). It is also referred to as:

a receiver

a level meter

a transmission measuring set (TMS).

The term transmission measuring set (TMS) is often taken to mean level measuring set (LMS). Actually this is not correct as the International Telecommunication Union defines a TMS as "an apparatus consisting essentially of a sending circuit of specified impedance(s) (e.g. 600 ohms) capable of sending a known power **and** a level measuring set". The A.P.O. TMS is a good example as it contains an oscillator (sending circuit) **and** a level measuring set.

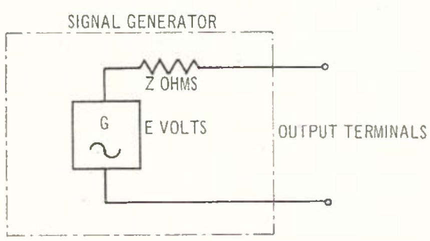

Fig. 1 — Equivalent Circuit of a Signal Generator

The basic facilities of a level measuring set are:

(i) the ability to measure signals of a wide range of voltages and frequencies, and

(ii) the ability to provide a load of known impedance, if required.

It is realised that these two descriptions are extremely simplified, but it is all that is required at this stage. A much fuller description of these two basic instruments is given later in the article.

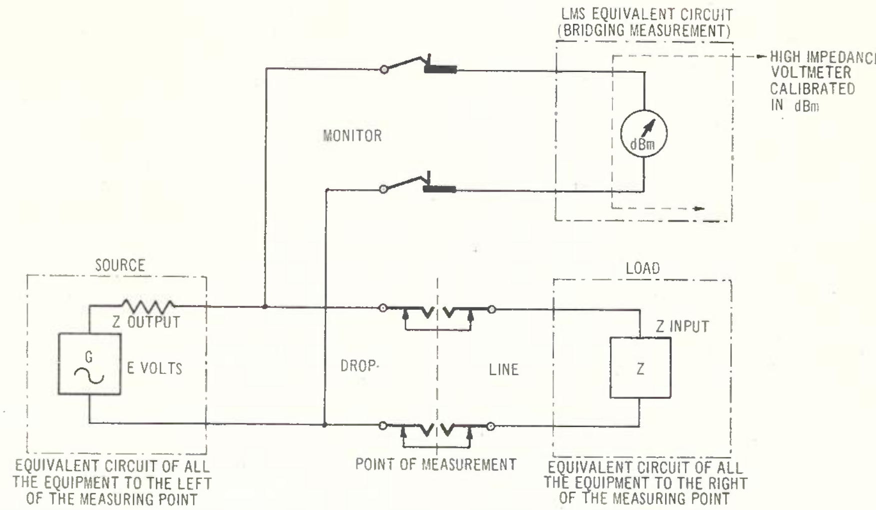

Fig. 3 — Equivalent Circuit of a Bridging Measurement

A Useful Theorem

An understanding of the basic theory of transmission measurements is facilitated by Thevenin's Theorem which explains how to represent a complex circuit by a simple equivalent circuit consisting of a voltage source in series with one impedance. A good example of the application of the Theorem is the equivalent circuit of a signal generator. This instrument contains a complex of oscillators, attenuators and amplifiers which all contribute towards producing an output signal. By using Thevenin's Theorem, the whole complex internal circuitry can be represented as a simple circuit as shown in Fig. 1.

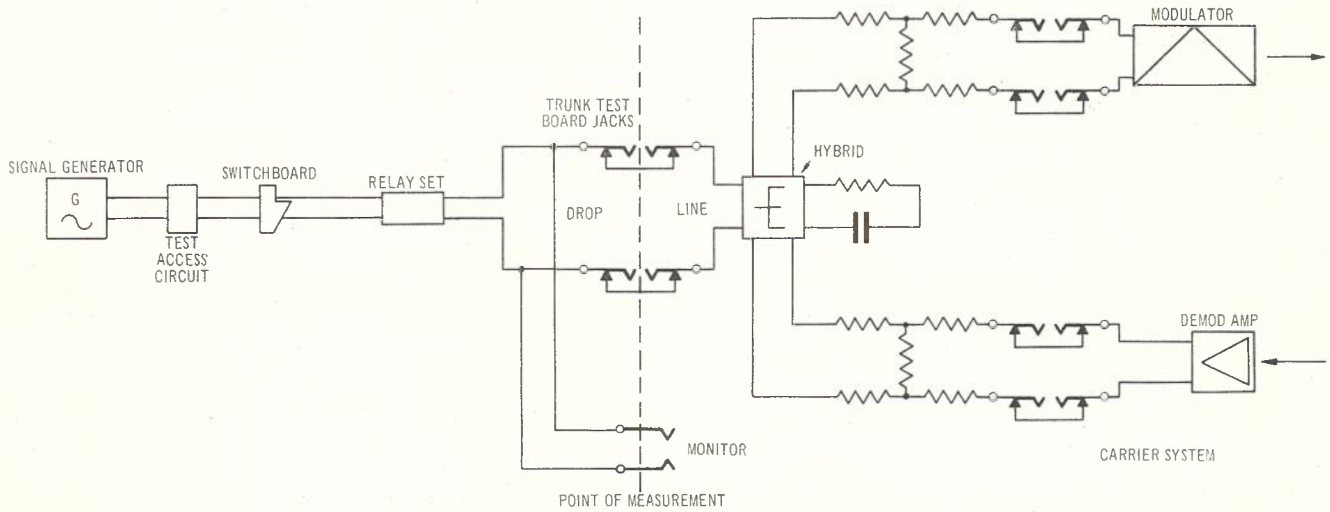

Fig. 2 — A Typical Transmission Measurement Situation

The impedance Z is known as the output impedance of the instrument. The equivalent voltage generator is considered as having zero impedance and a voltage of E volts. The value of this voltage is that which would be measured by a high impedance voltmeter at the output terminals **with no load connected.** All signal generators have the facility of being able to adjust the frequency and voltage of this equivalent voltage generator. Many have the extra facility of being able to set the value of Z, the output impedance, to one of a number of values, for example, 1200, 600, 150, 135 or 75 ohms.

The Concept of Source and Load

In transmission measurements the voltage of the test signal is measured as it passes through the transmission devices. The actual measurements are made at definite points such as hybrid line, transmit amplifier out, directional filter out, etc. At this "point of measurement" it is very useful to apply the concept of source and load.

Suppose we wanted to measure the voltage of the test signal at the "line" jack of a carrier channel on a trunk test board, as shown in Fig 2. By using Thevenin's Theorem, we can consider everything to the left of the point of measurements as being the *source* and equivalent to a voltage generator in series with an internal impedance. Everything to the right of the point of measurement can be considered as the *load* and equivalent to a single impedance. The complete circuit is represented by the simple circuit of Fig. 3. The equivalent load is always the input impedance of the next transmission device, the hybrid in this case. In communication work, the practice is to match impedances, i.e., to make the output impedance of the source equal to the input impedance of the load.

Bridging Measurements

From Fig. 3, it will be seen that the voltage of the test signal at the point of measurement is, in fact, the voltage developed across the load.

If we were to use a voltmeter with a high impedance input (a level measuring set) at the point of measurement by using the monitor jacks, the voltage of the test signal that is developed across the real load could be read. (N.B. Monitoring jacks on Trunk Test Boards are not normally used for measurement purposes, however, the concept is useful for this explanation.)

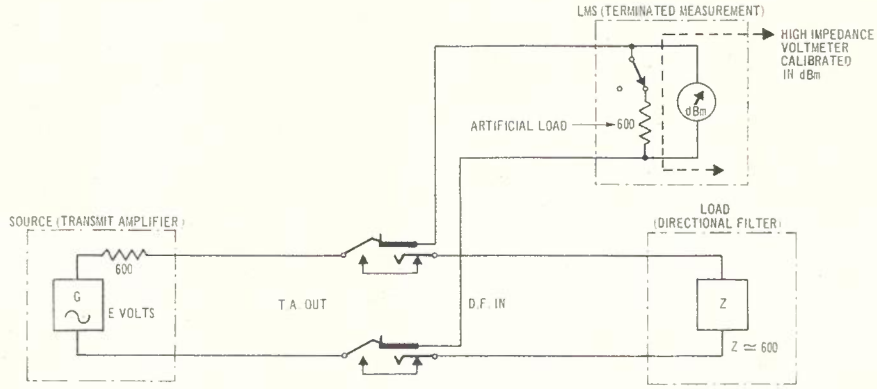

Fig. 4 — Equivalent Circuit of a Terminated Measurement

Thus, a bridging measurement is one where the voltage of the test signal across the *real* load is measured. Bridging measurements are also referred to as:

level measurements, or

high impedance (HI) measurements,

or

through measurements.

A bridging measurement has the important advantage that the connection between the elements of the carrier system is not broken. This is of importance when making maintenance tests on systems with many channels. In many of the modern compact miniaturised carrier systems, nearly all the test points are of the bridging variety. They are provided as small test sockets at a convenient location on the equipment panels. As "selective" type level measuring sets are becoming more widely used, bridging type measurements are becoming more common. "Selective" type LMS's are described later in the article.

There are some practical limitations on the term "high impedance input". It is usually arranged that the "high impedance" is of the order of 10 times the circuit impedance (e.g. 10 x 600 = 6 K ohms). In practice a LMS used in the bridging condition does introduce a small "bridging loss" of about 0.2 dB into the circuit under test. In very accurate work it would be necessary to take this effect into account. At the high frequencies used in broadband carrier equipment a special probe is used to avoid the high bridging losses that would be introduced by the capacitance of ordinary test leads.

Terminated Measurements

Often it is necessary to test the performance of the source when working into a load of accurately known impedance. In this case, the real load is disconnected and replaced by an artificial load of known impedance which is provided by the level measuring set. (See Fig. 4.)

An example of this is to set the output of a carrier system transmit amplifier to a value of +18 dBm across a 600 ohm load.

This type of measurement is called a "terminated" measurement because we terminate the source in a load of known impedance. It is also referred to as:

a "loss" reading, or on some meter panels

as "Z" 600, 150, 75, etc.

Questions which might arise are: "Why measure the source's performance when working into an artificial load?" "Why not measure its performance when work-

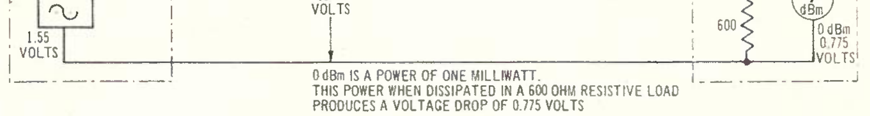

Fig. 5 — Adjusting the Output of a Signal Generator to OdBm

ing into its real load?" The answer is that the artificial load serves as a reference standard. It is a "pure" resistance which remains constant in value over the frequency range. Therefore, we can say with confidence that the source will behave in a particular manner when working into the standard load. The real load, however, nearly always is not a pure resistance and it changes its impedance with frequency.

The output of signal generators must always be adjusted by making a terminated reading. For example, Fig. 5 shows how to set the output of the signal generator to 0 dBm.

Many carrier systems provide special break jacks that disconnect the real load when the plug is inserted (as shown in Fig. 4) This enables terminated readings to be easily made. This technique has the disadvantage for a working system that the circuit has to be broken to make a measurement.

The Confusion of "Level" and "Loss" Terminology

The two words "level" and "loss" are widely used by telecommunication people, often with different meanings.

The word *level* can mean:

(i) a general term for the "strength" or "voltage" of a signal, for example "low *level* signals", "*level* measuring set", and "what signal *level* are you sending?";

(ii) a type of measurement — a bridging measurement is very often referred to as a *level* measurement;

(iii) an adjective to describe a test instrument, for example, one manufacturer refers to his equipment as a *level* meter and a *level* oscillator. In this case, it means equipment that can send and measure test signals of various levels or strengths.

The word *loss* also can mean two things:

(i) the attenuation of a circuit, and also an abbreviation for the term "insertion loss". An example: this pad has a *loss* of 6 dB;

(ii) a terminated measurement. Terminated readings are often referred to collectively as a *loss* measurement.

To avoid confusion, the terms bridging and terminated should be used when referring to types of measurements because these terms clearly describe the nature of the measurement.

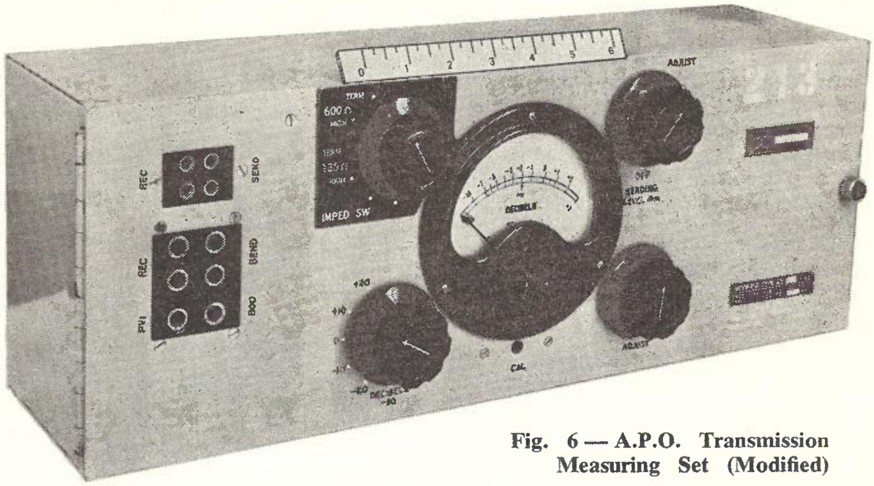

Fig. 6 — A.P.O. Transmission Measuring Set (Modified)

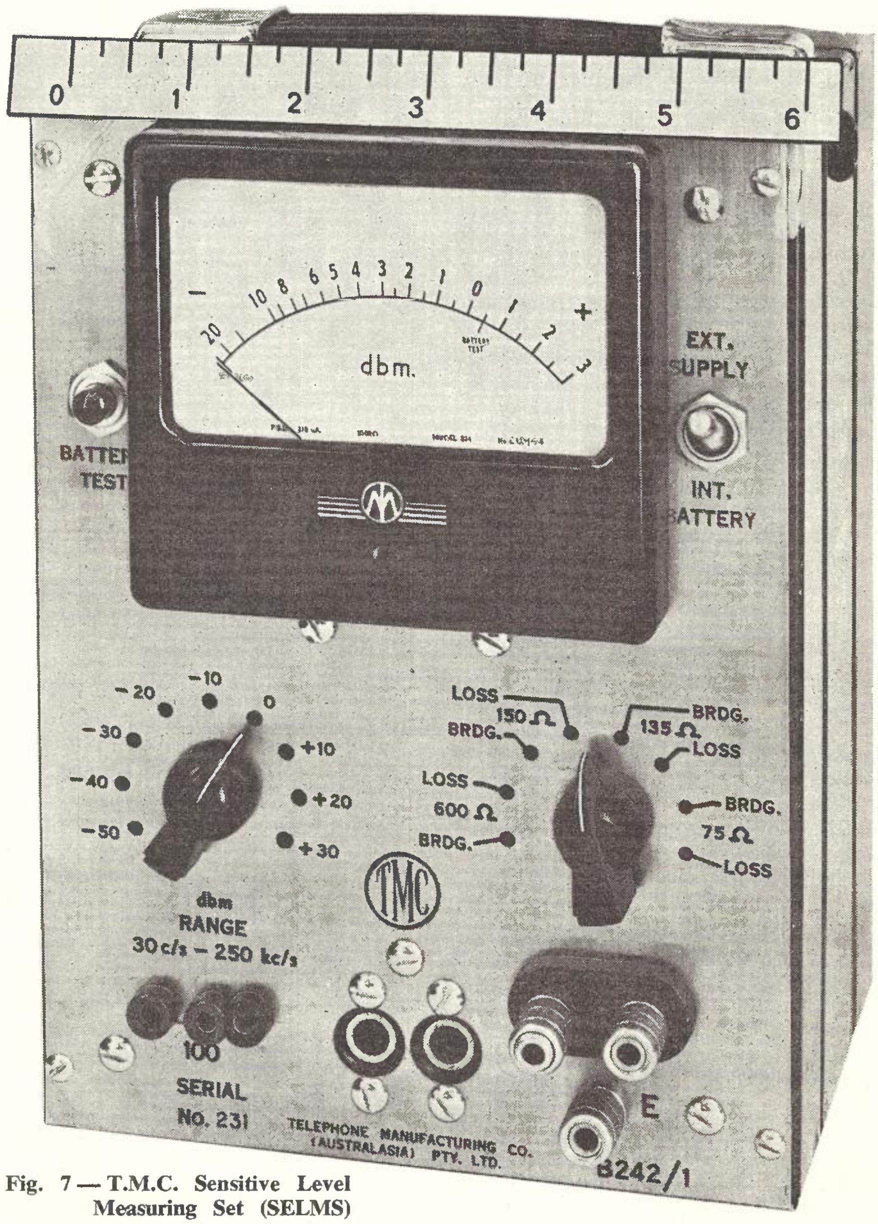

Fig. 7 — T.M.C. Sensitive Level Measuring Set (SELMS)

LEVEL MEASURING SETS

There are many varieties of transmission measuring sets, level measuring sets, and signal generators, all having certain common basic facilities; the choice of which one to buy depends on what it is required to do, and the degree of technical excellence required.

Figs. 6 to 10 show some of the transmission measuring equipment that is currently being used by the Australian Post Office.

Modern telecommunication level measuring sets (LMS) provide the following common basic facilities:

(i) the ability to make bridging and terminated measurements at one or a number of circuit impedances, e.g., 1200, 600, 150, 135, 75 ohms;

(ii) the ability to measure a wide range of signal voltages within a specified frequency range. Some LMS's have the extra facility of being able to make "selective" or "tuned" measurements.

Also, some of the more versatile instruments have the additional features of being able to measure "weighted" signals, return loss, balance to ground and impedance. (See Figs. 8 and 9.)

Just about all modern direct reading LMS's use the basic circuit shown in Fig. 11 which is, in fact, that of a special AC voltmeter.

Considering the elements of the circuit in progression, the first element is the input impedance switch. This switch provides the non-inductive load resistors for the terminated measurements (e.g. 600, 150, 75 ohms) and the open circuit for the bridging or high impedance measurement. The next element is the input transformer which gives the meter a balanced input and a high impedance. This transformer has to be of very high quality to provide for special requirements, e.g., excellent frequency response, good balance to earth and suppression of longitudinal noise signals. The next item is the range switch, which reduces the voltage of the input signal to a value that can be handled by the amplifier.

The amplifier amplifies the signal and feeds it through a full wave rectifier into a moving coil DC meter which is calibrated in dBm. The reliability of the instrument depends very much on the gain stability of the amplifier. This stability of gain is achieved by the use of feedback.

The instrument is so adjusted that when one milliwatt of power is being dissipated in its input load resistor for a terminated reading, the meter will be reading 0 dBm. It is useful to remember the following:

0 dBm (1 mW) =

1.095	volts	across	1200 ohms
0.775	,,	,,	600 ohms
0.387	,,	,,	150 ohms
0.274	,,	,,	75 ohms

Similarly, when making a bridging measurement, 0.775 volts applied to the input terminals will make the meter read 0 dBm in the "600 ohm" high impedance setting.

When the meter is used at another impedance, for example 150 ohms, the gain of the amplifier is effectively doubled in order to produce the same

Fig. 8 — A.W.A. Transmission Measuring Set Type A220

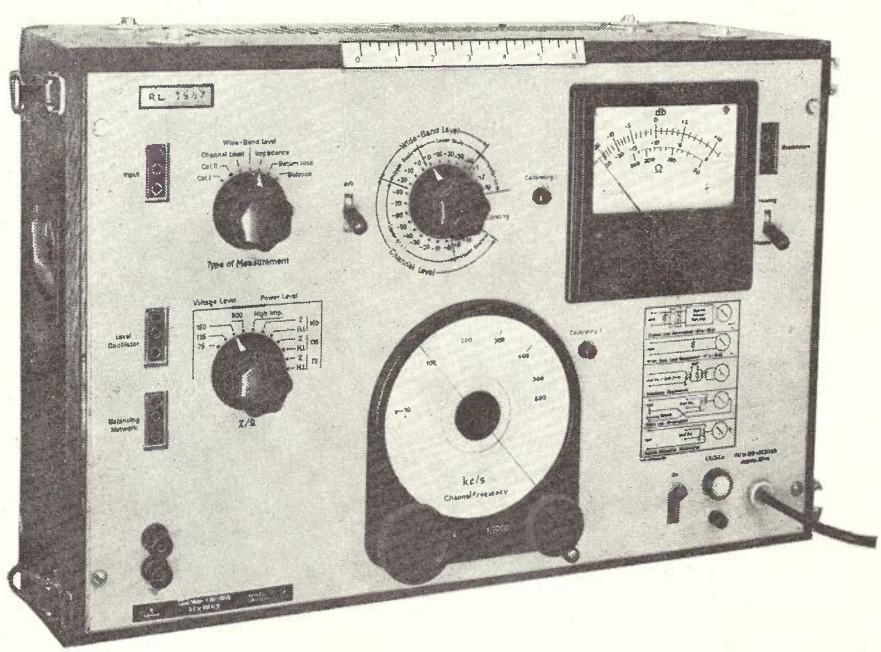

Fig. 9 — Siemens Level Measuring Set

0 dBm reading on the meter. This change is done automatically inside the instrument when the input impedance settings are changed. This is the method of operation, as used by the Australian Post Office, for *power level* measurements.

Some European instruments use a system known as *voltage level* measurements. In this case, the instrument is calibrated for 0 dB for 1 milliwatt across 600 ohms (0.775 volts) and *remains* in this condition no matter what other input impedance is used. When using one of these instruments, it is necessary to add 6 dB for 150 ohm terminated reading and 9 dB for a 75 ohm terminated reading to convert the meter indication into a *power level* reading.

75 ohm measurements are always associated with the high frequencies that are used in broadband carrier systems. At these frequencies coaxial type test leads are usually used and the circuit is unbalanced (one leg is earthed).

The measuring set described so far is known as the wideband type. It measures the combined voltage of all the signals applied at the input. These signals may often consist of our test signal and some other signals such as carrier leak that we don't want. One way of overcoming this problem is to have a means of tuning to our test signal. This is known as a selective or channel measurement and the principle is the same as tuning a radio set to a particular broadcasting station.

The basic circuit of a measuring set in the selective or channel level condition is shown in Fig. 12. The operation is basically the same as that used in the ordinary superheterodyne radio receiver. The incoming signal is mixed (modulated) with a variable frequency local oscillator and a fixed intermediate frequency (IF) is produced. This IF is filtered, amplified and fed to the rectifier and meter. The filter in the IF stage

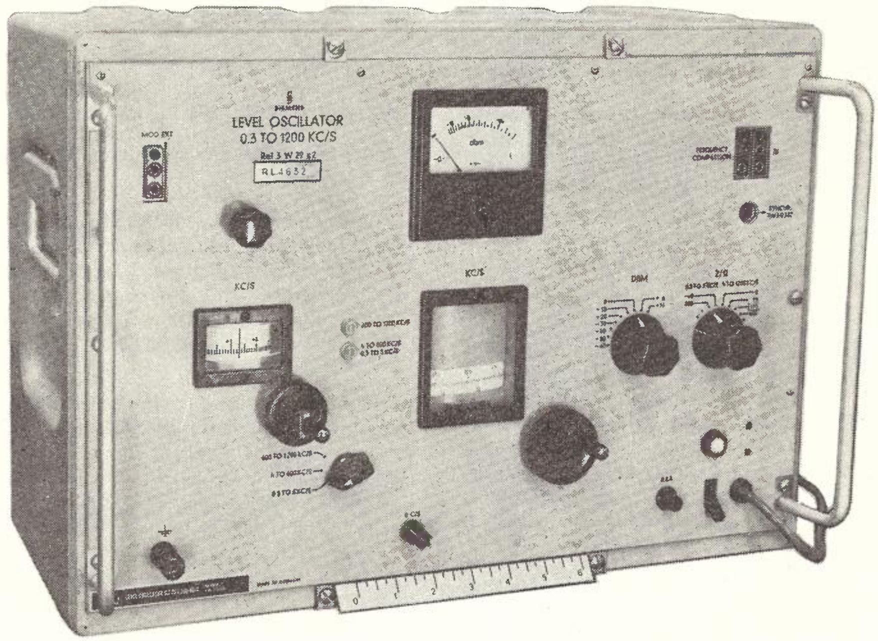

Fig. 10 — Siemens Level Oscillator

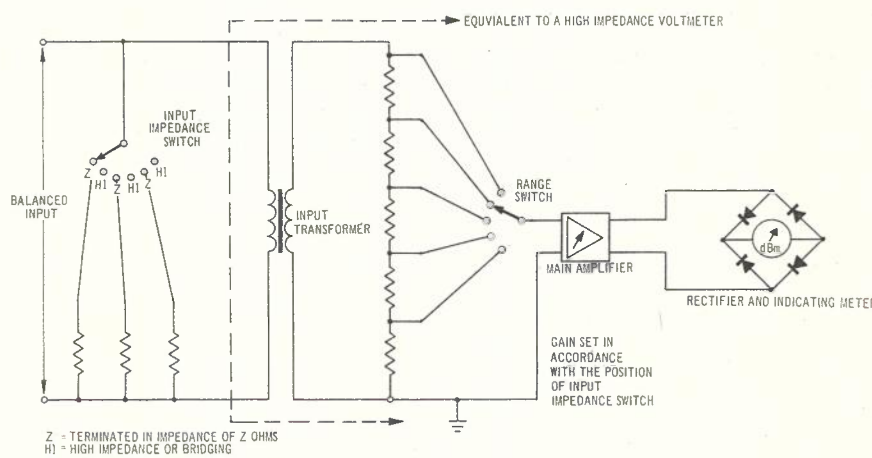

Fig. 11 — Simplified Circuit of LMS in the Wideband Condition

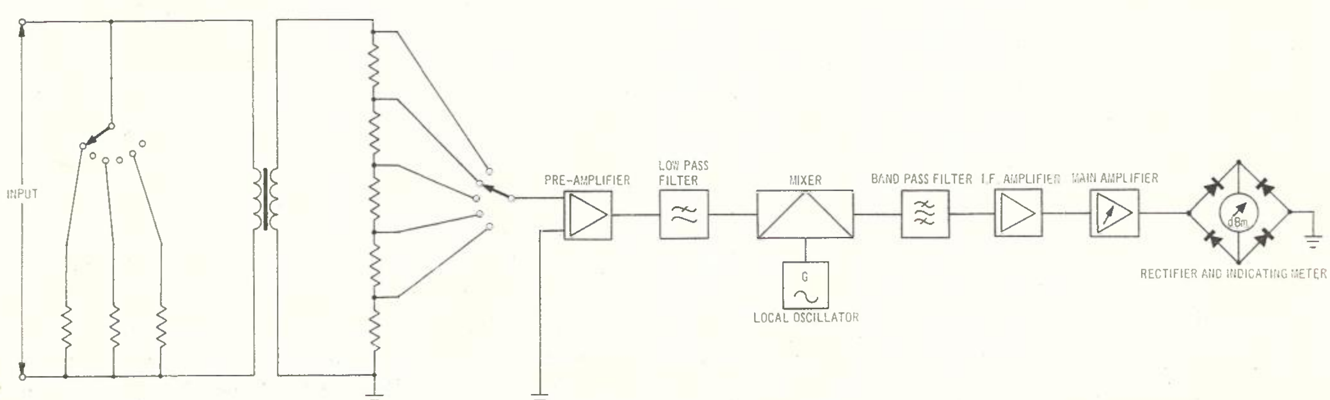

Fig. 12 — Simplified Circuit of LMS in the Selective Condition

produces a very narrow band width of about 300 c/s. Consequently, it is possible to select the test signal from amongst a number of other frequencies.

Selective measurements are very useful for maintenance activities; by using the selective facility and a bridging measurement it is possible to check the progress of a test signal through a working system. One example is the checking of the pilot signal in a working carrier system.

A **practical pitfall** when making selective measurements, is that miscellaneous signals very close to the frequency of the test signal may be present in which case it is easy to mistakenly tune into the wrong signal. A simple check to see that you are measuring the correct signal is to remove the test signal at its source. **This can save hours of work.**

Another practical pitfall that can occur when selective measurements are being made on working broadband carrier systems, is that some selective LMS's have the undesirable characteristic of allowing some of the frequencies from their frequency mixing stage to appear at the instrument's input terminals. Even though this leakage is at a very low level, it has been known to cause interference on other channels of the broadband system. One way to reduce the possibility of interference is to tune the LMS to approximately the required frequency before connecting the LMS to the circuit under test.

There are some older level measuring sets that can only make terminated measurements. Two examples are the Western Electric 30A and the Victorian Meter Laboratories' dB meter. The 30A can make 135 and 600 ohm terminated measurements from —10 to +30 dBm. It also has an elaborate calibrating procedure which when carried out enables it to measure 1 milliwatt across a 135 ohm load with great accuracy.

The VML meter is only really accurate about the 0 dBm scale reading, and has to be zero corrected for temperature. It is useful for setting the output of a 600 ohm source to 0 dBm. This 0 dBm output can then be used as a means of checking another LMS's performance. This is called the substitution method of checking meters.

SIGNAL GENERATORS

All signal generators (oscillators) provide two basic facilities:

(i) the ability to adjust the frequency of the test signal;

(ii) the ability to adjust the voltage of the test signal.

More advanced types, as shown in Fig. 10, provide the additional facilities of:

(iii) being able to set the output impedance to a value from the range 1200, 600, 150, 135 or 75 ohms;

(iv) being able to modulate the test signal;

(v) being able to be electrically coupled to a level measuring set which is physically alongside the signal generator. This is a very useful facility when doing frequency responses of equipment in the laboratory.

A signal generator has the basic equivalent circuit shown in Fig. 13.

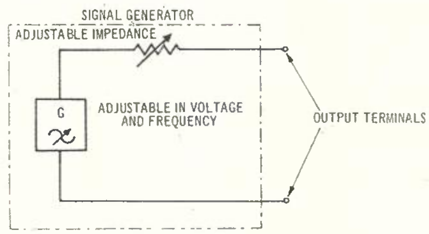

Fig. 13 — Equivalent Circuit of a Signal Generator

The oscillator provides a very low impedance voltage source which may be adjusted in frequency and voltage. This voltage source is then built out with resistors to give the required output impedance. The simplified output circuit is shown in Fig. 14.

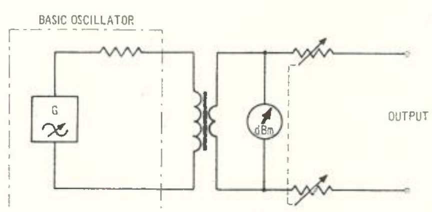

Fig. 14 — Simplified Circuit of a Signal Generator

Some instruments have an inbuilt level measuring set to show the output of the oscillator. This LMS is effectively located in the circuit shown in Fig. 14. The meter calibration is arranged so that it gives the correct value of the test signal at the output terminals only when the load impedance is equal to the output impedance of the oscillator. The actual oscillator circuit is either a beat frequency oscillator or a resistance capacitor oscillator. Both types are widely used in modern instruments. Beat frequency oscillators often have an adjustment so that the instrument's frequency scale zero point can be checked.

COMMON MISTAKES

Three common mistakes made in transmission measurements are:

(i) Making a bridging instead of a terminated measurement. This produces a reading 6 dB too high;

(ii) making a terminated instead of bridging measurement. This produces a reading 3.5 dB too low;

(iii) not setting the impedance of the signal generator or transmission measuring set to be the same as that of the equipment under test. This produces a range of errors from 0.5 to 4.0 dB. (See also the section "Improvisation".)

Bridging Instead of Terminated Measurement

Fig. 15 (top) shows how the measurement is being correctly made with the LMS providing the 600 ohm load. The voltage measured by the LMS is 0.775 volts.

Fig. 15 (bottom) shows how the measurement is being incorrectly made. In this case, because the LMS is in the high impedance bridging condition, there will be practically no current flow and the voltage measured by the LMS will be double what it ought to be, i.e. 1.55 volt. Now, LMS scales are calibrated in dB rather than volts, according to the relation:

$$dB = 20 \log_{10} \frac{E_S}{E_R}$$

where E_R is the voltage produced by the reference power across the specified load (e.g. 0.775 volts for 1 mW across 600 ohms) and E_S is the voltage of the test signal across a load of the same specified resistance (e.g. 600 ohms).
In this case, the new reading will be given by

$$dB = 20 \log_{10} \frac{1.55}{0.775}$$

$$= 20 \log_{10} 2$$

$$= 20 \times 0.3010$$

$$= +6.0$$

There is a useful corollary from this example. When measuring the output of a source, with the impedances of source and LMS matched, the difference between a terminated and bridging measurement is always 6 dB. This is a very quick and effective method of checking the output impedance of a source (such as the directional filter output of a carrier system). For example, if the input impedance of the LMS is known to be 600 ohms and if the difference between bridging and terminated readings is 6 dB, then the output impedance of the source is 600 ohms. If the difference is greater than 6 dB, the source impedance is greater than 600 ohms and vice versa.

Terminated Instead of Bridging Measurement

When this mistake is made the source has two 600 ohm loads in parallel; the real load and the load provided by the LMS. (See Fig. 16.)

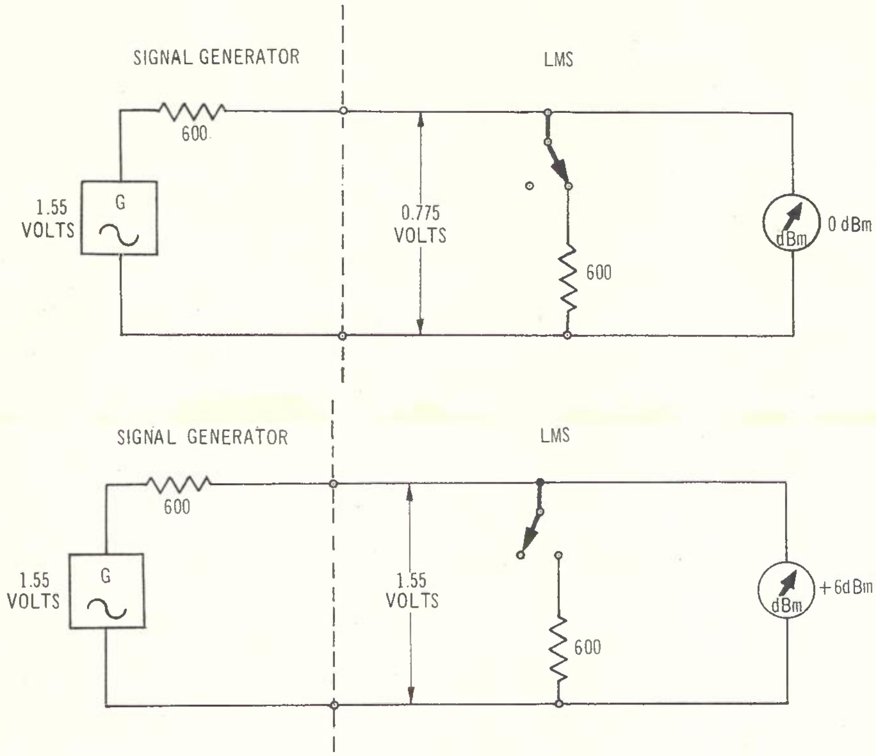

Fig. 15 — Correct and Incorrect methods of Making a Bridging Measurement. Top: Correct Method. Bottom: In correct Method.

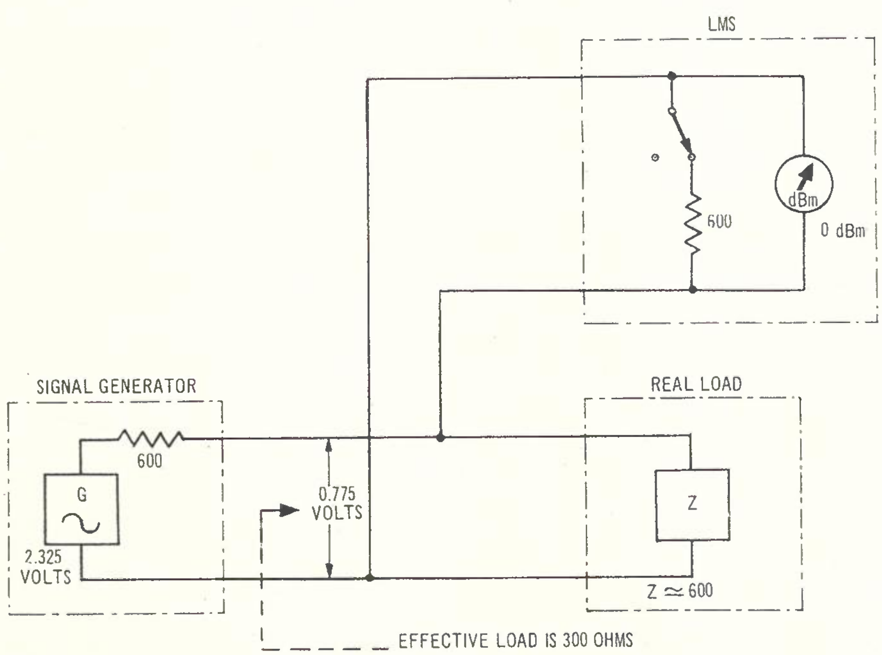

Fig. 16 — Incorrect Procedure for Bridging Measurements

Assume that the signal generator is adjusted so that the meter reads 0 dBm, then the voltage at the output terminals of the source will be 0.775 across a 300 ohm load. The equivalent internal voltage will be given by

$$0.775 = \frac{300}{600 + 300} \times E$$

$$E = 3 \times 0.775 = 2.325 \text{ volts}$$

This *internal* voltage will remain fixed while the signal generator output control remains in the same position. The question is, what will be the voltage across the real load when the LMS is removed?

The voltage across the 600 ohm load will then be

$$V = 2.325 \times \frac{600}{600 + 600}$$

$$= 2.325 \times \frac{1}{2}$$

$$= 1.162 \text{ volts}$$

This signal level can be expressed in dB because the meter is calibrated according to the law:

$$\text{dB} = 20 \log_{10} \frac{E_S}{E_R}$$

$$= 20 \log_{10} \frac{1.162}{0.775}$$

$$= 20 \log_{10} 1.50$$

$$= 20 \times 0.175$$

$$= +3.5$$

Thus, our meter is reading 3.5 dB *lower* than it would if a proper bridging measurement had been made.

Incorrect Impedance Setting

A similar approach can be used to illustrate the effect of not setting the correct impedance. For example, if a LMS in the 150 ohm terminated condition is used to adjust the output of a 600 ohm signal generator to apparently 0 dBm, the actual power that the generator would dissipate in a 600 ohm load would be +1.9 dBm. This means that the technician, when he realises the mistake and changes the LMS to the 600 ohm condition should get a 1.9 dB rise in his meter reading.

A Common Misunderstanding

When measuring frequency responses, some technicians mistakenly use a bridg-

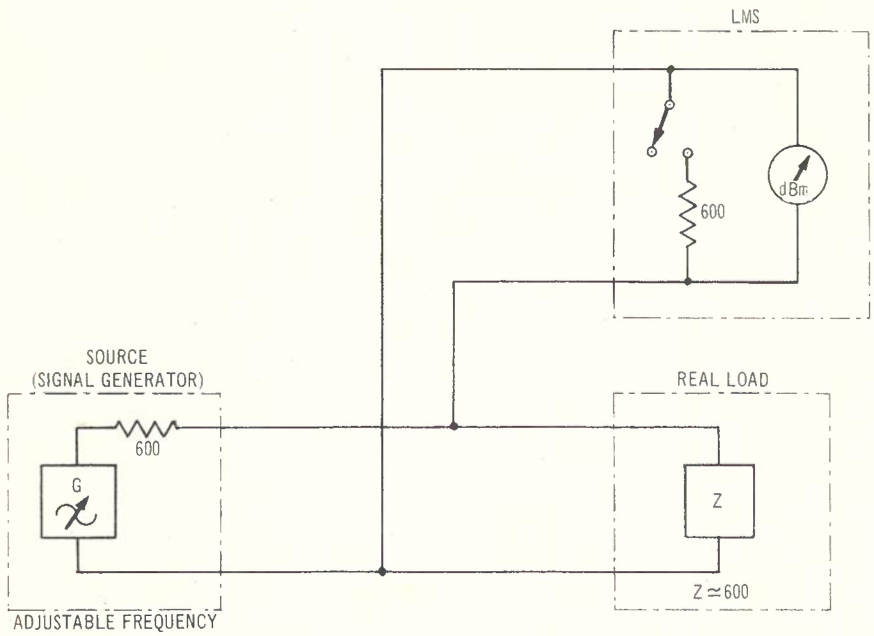

Fig. 17 — Incorrect Method of Checking the Output of a Signal Generator

ing measurement to ensure that they are sending a constant signal level, this method (see Fig. 17) is generally not correct and their conscientious efforts are in vain.

Their method is to adjust the signal generator output at each frequency so as to maintain a constant reading on the LMS. Why is this method incorrect? The reason is that it compensates for the natural variations in voltage across the load, as the frequency is varied. Why does the voltage across the load vary with frequency?

The reason is that the impedance of the source and load do vary with frequency. Usually, the impedance of the source is nearly constant with respect to frequency and it is the load impedance that can vary appreciably with frequency. The voltage of the "equivalent generator" of the source is nearly constant with respect to frequency. Thus, when the source is working into a load (such as a transmit amplifier working into a directional filter), we have a "voltage divider" type circuit (See Fig. 17). As the impedance of the load rises above its nominal value, the voltage across it will increase and vice versa.

Thus, it is quite normal for the voltage across the load to vary with frequency, however, the smaller the variation, the better the performance. A frequency response on a carrier channel is then the summation of all the effects of variation of impedances with respect to frequency of all the units that go to make up the channel.

When the technician adjusts the voltage across the *load* to be a constant, he is not allowing the circuit to behave in its normal manner. This incorrect method can produce strange results, one example being "waves" in a channel frequency response.

The correct method is to use terminated measurements as shown in Fig. 5. The output of the source is checked by using a terminated measurement, then the LMS is removed and the load is connected. Most modern signal generators have a very "flat" output when working into a standard load (600 ohms) and, therefore, it is not necessary to check the output at each frequency. The only time to be cautious is when using frequencies near the ends of the signal generator's range. The best practical advice is to do a quick check on the output versus frequency of the signal generator at the required signal level (say —13 dBm) before starting the channel frequency response.

IMPROVISATION

Often in field work the technician has to make some transmission measurements and he finds either he does not have a LMS or his LMS does not have the required impedance range.

Subject to certain conditions a measuring set capable of making measurements of practical use in the field can be improvised by using:

(i) an accurately known non-inductive resistor;

(ii) a 1 : 1 ratio transformer which has a suitable frequency response;

(iii) a high impedance (greater than 5 K ohm) input electronic voltmeter which can measure low level AC signals over the required frequency range.

Note, 1000 ohms per volt multimeters (including AVO meters) are **NOT** suitable.

A practical arrangement for normal wide band measurement is shown in Fig. 18. However, a word of **warning.** The accuracy is very much dependent on the frequency response and power handling capacity of the transformer and the voltmeter. It is hopeless trying to measure a 30 kc/s signal if the transformer only goes to 4 kc/s.

The frequency range of a transformer is usually quoted as the lower and upper —3 dB (half power) points. The "flat" region of the response lies approximately between 3 times the lower half power, and 0.3 times the upper half power frequency. (Details on P.M.G. transformers are given under Serial 6 and in the Standard Stock Title Book, Section 4, pages 90 to 92, 1965 issue.)

The other major problem that a technician finds is that he has to measure a 1200 ohm or 150 ohm circuit when he has only a "600 ohm" LMS.

1200 ohm impedances are found in equipment associated with voice fre-

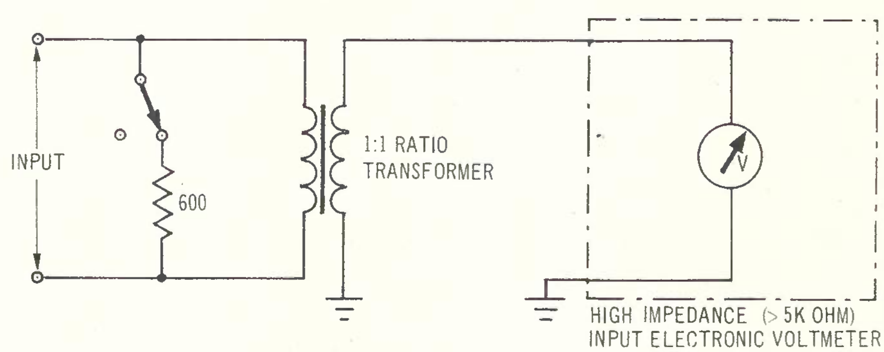

Fig. 18 — Improvising a LMS

quency loaded cables. Modern VF amplifiers have 1200 ohm outputs that can be connected directly to a loaded cable. The particular installation may require that the amplifier output is adjusted to +8 dBm into a 1200 ohm load. The question is how to check the output of the amplifier?

The most accurate way is to make a terminated reading rather than a bridging reading. The reason is that we can make the impedance of the LMS load exactly 1200 ohms non-inductive whilst that of the cable may not be 1200 ohms.

There are three methods that could be used to make this measurement:

(i) use a 1200 ohm resistor and matching transformer;

(ii) use a 1200 ohm resistor only;

(iii) use the LMS in the 600 ohm terminated condition.

The first method is shown in Fig. 19.

A 1200/600 ohm transformer such as a 4012H or 6/102 or 3/1215A could be used. The LMS is used in the 600 ohm bridging (high impedance) condition. The reading of the LMS will be the amplifier output in dBm. Remember, add 0.5 dB for the losses in the transformer.

It is important to realise that we are actually concerned with powers and that +8 dBm (referred to 1 milliwatt) is a power of 6.31 milliwatt whether it is dissipated in a 1200 or a 600 ohm load. A point to remember is that the LMS measures the voltage that the power "produces" across a specified load, hence, the LMS must be set correctly. In this case, (method 1) the LMS is in effect measuring the voltage across a 600 ohm load because of the transformer action.

This measurement could be done with a slightly different arrangement of the equipment. The 1200 ohm resistor could be removed and the load provided by the 600 ohms of the LMS in the terminated condition. In this case, the transformer has a loaded secondary

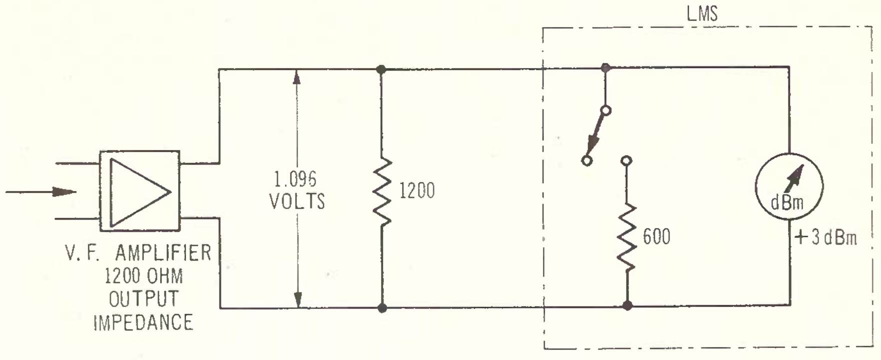

Fig. 20 — Second Improvised Method of Measuring a 1200 Ohm Circuit

and, therefore, will have slightly higher losses.

The second method is shown in Fig. 20.

In this case, the LMS is measuring the voltage across a 1200 ohm resistance and as our meter is calibrated for voltages across 600 ohms, it will **not** give a true reading. However, we can apply a scale correction of 3 dB in this case.

The proof is as follows:

1 milliwatt across 1200 ohms produces a voltage drop of 1.096 volts. Now 1.096 volts applied to a meter which is calibrated for 0.775 volts as being equal to 1 milliwatt will produce a reading given by:—

$$\text{dB} = 20 \log_{10} \frac{E_S}{E_R}$$

$$= 20 \log_{10} \frac{1.096}{0.775}$$

$$= 20 \log_{10} 1.415$$

$$= 20 \times 0.150$$

$$= +3.00$$

Thus, if our LMS reads +11 dBm, the actual power being dissipated in the 1200 ohm resistor is +8 dBm.

Note, methods 1 and 2 ensure that the source is working into its correct load impedance and, thus, its behaviour under test will be normal.

The third method is the "brute force" method and is **not** recommended. The reason is that the 600 ohm load is not matched to the 1200 ohm source. This will give misleading results especially on frequency responses. However, for academic interest, the meter reading is 0.5 dB lower than the power that would be dissipated in the correct 1200 ohms load impedance.

The other common improvisation often attempted is to measure "150 ohm" impedance circuits with a "600" LMS. This can be done but a word of **warning.** LMS's are designed to work within a specific frequency range and if used outside this range the meter indications could be much lower than actual signal strengths. Instruments that provide only a "600 ohm" range might just measure frequencies in the low end of the "150 ohm" and "75 ohm" frequency range. Instruments that provide 600, 150, 135 and 75 ohm conditions are designed to work over a very wide frequency range. Also, if all these impedance ranges are provided there is obviously no need for improvisation. It is interesting to note the relationship between frequencies and impedances that occur in communication equipment.

1200 ohms 200-3400 c/s

600 ohms 30 c/s-140 kc/s approx.

135, 150 ohms 30 kc/s-600 kc/s approx.

75 ohms 60 kc/s and higher.

If measurement of a 150 ohm circuit with a 600 ohm meter is to be attempted either of the two techniques suggested for the 1200 ohm case could be used. Method 1 which uses a matching transformer can only be used where it is certain that the transformer can handle the frequency. Method 2, taking a "600 ohm" **bridging** measurement across a 150 ohm load, is shown in Fig. 21.

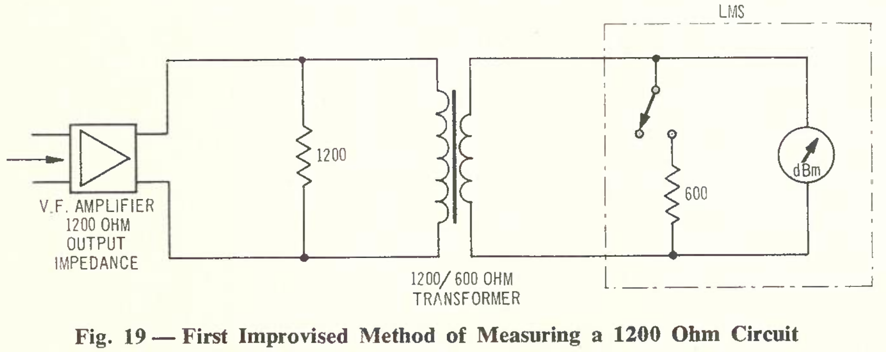

Fig. 19 — First Improvised Method of Measuring a 1200 Ohm Circuit

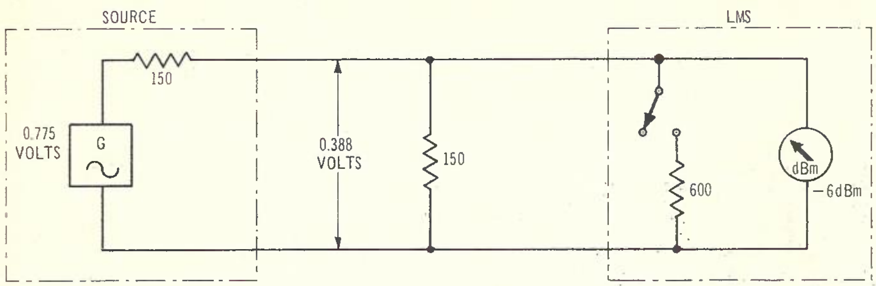

Fig. 21 — A method of Measuring a 150 Ohm Source with a 600 Ohm LMS

Another case is trying to measure a 75 ohm circuit with a 600 ohm meter. As 75 ohm circuits are used in the broadband carrier system, it is almost certain that the carrier station would have a 75 ohm instrument and this improvisation is not necessary and should not be be attempted. For academic interest, the method is to use a 75 ohm resistor and make a 600 ohm bridging measurement across it. The meter scale will give an indication 9 dB lower than the actual power being dissipated in the 75 ohm resistor.

Having to measuring "135 ohm" circuits with "150 ohm" meters often occurs in field work. The first way is to measure in the 150 ohms bridging condition across an accurate 135 ohm resistor. The meter would read 0 dBm when the actual power was +0.46 dBm The second way is to take a 150 ohm terminated reading. If the meter reads 0 dBm, it can be shown by calculation that when the LMS is removed and the true 135 ohm load is connected, very nearly 0 dBm (+0.001 dBm) will be dissipated in it. **Thus for this case there is no need for meter correction.**

The various improvisation methods described are summarised in Table 1.

POWER SUPPLIES

Instruments are either mains or battery operated. When using mains powered instruments, it is advisable to allow the instrument time to warm up before accurate measurements are to be made. Also, the mains voltage should be checked and the instrument's power transformer adjusted accordingly. However, a word of warning: be sure the voltmeter you use is accurate and, secondly, check the instrument's handbook to see what range of mains voltages it will handle. There may be no need to change the power transformer tapping.

With battery operated equipment the important thing is to turn off the instrument when you have finished a series of measurement. When the battery volts get low, the instrument just cannot function correctly and, also, you may discharge the battery beyond its safety limit.

CONCLUSION

The basic fundamentals of practical transmission measurements have been discussed in simple terms in this article. An important further source of information are the handbooks supplied with the various testing instruments. These give the capabilities of the instruments, the restrictions on their use, their order of accuracy and their frequency range, and should be carefully studied. An understanding of the basic principles together with confidence in the use of the test equipment can make transmission measurements a fascinating activity for technicians.

ACKNOWLEDGMENTS

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TABLE 1: SUMMARY OF IMPROVISATION USING A "600 OHM" LMS FOR "1200, 150 AND 75 OHM" MEASUREMENTS

Source Impedance	Method 1 Matched load resistor, matching transformer and bridging measurement	Method 2 Matched load resistor and bridging measurement.	Method 3 Mismatched terminated measurements
1200 ohms	1. Use 1200/600 ohm transformer. 2. Meter gives "true" reading. 3. Add 0.5 dB for transformer losses.	1. Use 1200 ohm load resistor. 2. Meter reads 3 dB **high.**	1. Not recommended. 2. Meter reads 0.5 dB **low.**
150 ohms	1. Use 150/600 ohm transformer. 2. Meter gives "true" reading. 3. Add 0.5 dB for transformer losses. 4. Restricted by the upper frequency capabilities of transformer and LMS.	1. Use 150 ohm load resistor. 2. Meter reads 6 dB **low.** 3. Restricted by the upper frequency capabilities of the LMS.	1. Not recommended. 2. Meter reads 1.9 dB **low.**
75 ohms	1. Use 75/600 ohm transformer. 2. Meter gives "true" reading. 3. Add 0.5 dB for transformer losses. 4. Restricted by the upper frequency capabilities of the transformer and LMS.	1. Use 75 ohm load resistor. 2. Meter reads 9 dB **low.** 3. Restricted by the upper frequency capabilities of the LMS.	1. Not recommended as mismatch, is too great. 2. Meter reads 4.0 dB **low.**