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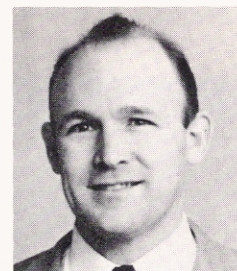
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August, 1960

A Bridge Method of Sweep Frequency Impedance Measurement

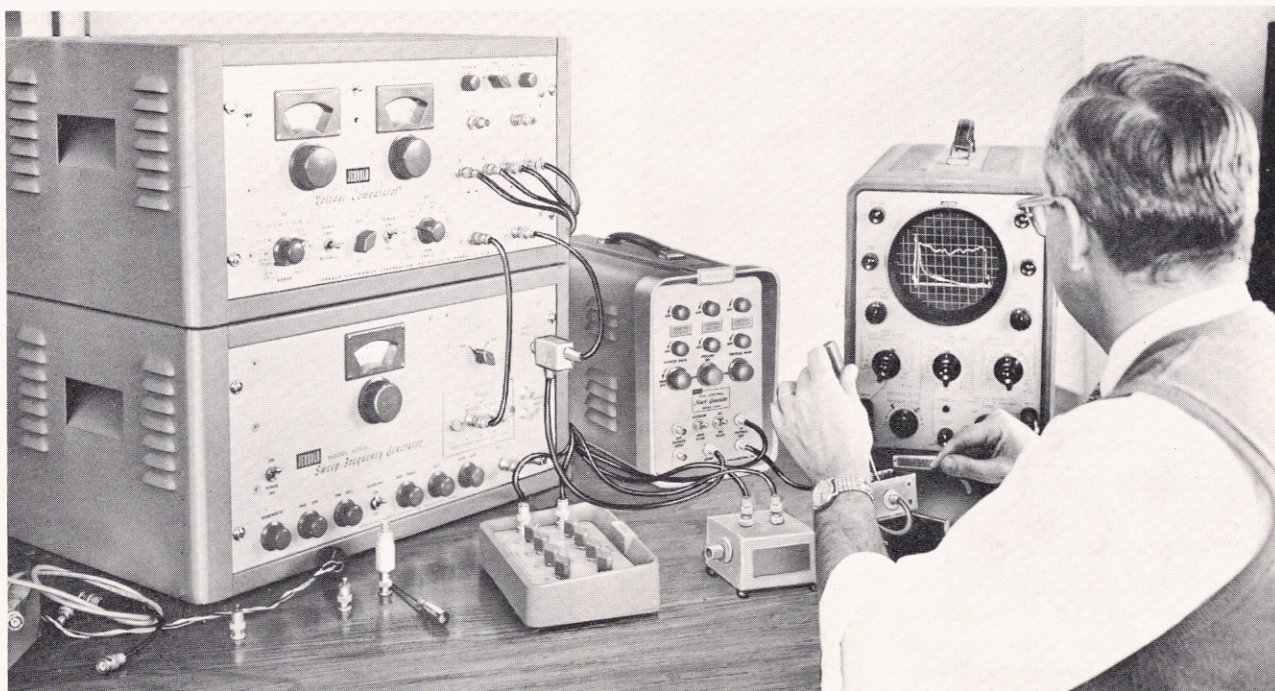
by KEN SIMONS, Chief Engineer, Jerrold Electronics Corp.

The following is an extract of a speech given by Mr. Simons at the First Annual Eastern Engineering Seminar, May 5, 1960, Hotel Bradford, Boston, Massachusetts.



SUMMARY:

A matched bridge circuit is described providing oscilloscopic display and measurement of return loss vs. frequency. Units have been constructed allowing measurement of 50 db return loss over a 50 to 1 frequency range (4-200 MC). The technique is useful from low audio frequencies up to several hundred megacycles.

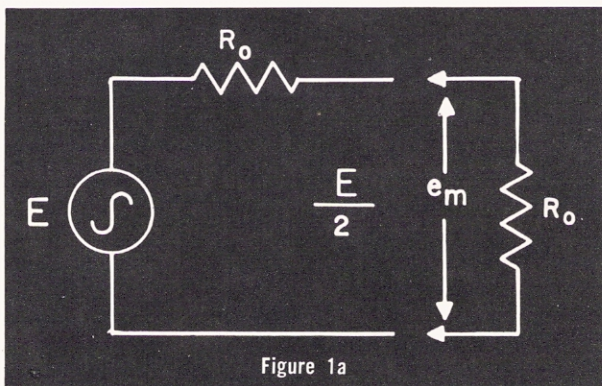


A typical test set-up utilizing Jerrold Models—900-A Sweep Frequency Generator, VC-12 Voltage Comparator, CM-6 Marker Generator, AV-75 Variable Attenuator and KSB-75 ohm Bridge; to show an optimum termination, 4 mcs to 100 mcs, with a 50 db reference.

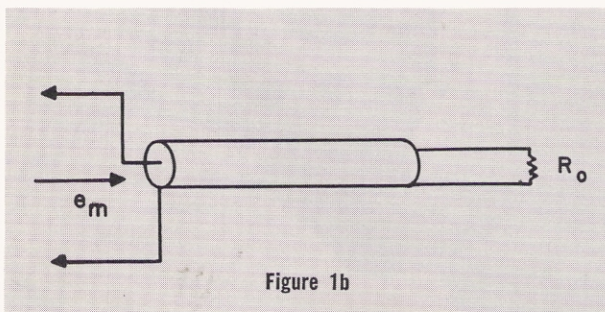
FUNDAMENTALS:

Since high frequency measurements frequently require unavoidable lengths of transmission line, high frequency measuring techniques usually involve an application of transmission line principles. The bridge circuit to be described is no exception. Understanding its operation requires a clear picture of the concepts of reflection coefficient and return loss.

Consider an AC generator with internal impedance R_0 and a voltage E as illustrated in Figure 1 (a). When the output

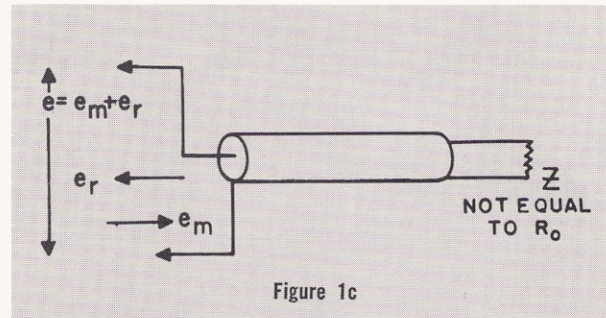


of this generator is connected to a load having an impedance equal to R_0 , the output voltage is $\frac{E}{2}$. In the particular case where this load is the input impedance of a section of transmission line having a characteristic impedance R_0 , it is convenient to consider the input voltage as consisting of two components—a main voltage wave (e_m) which travels down the line away from the generator, and a reflected wave (e_r) which travels back from the far end towards the generator. When the transmission line section is terminated in R_0 , the reflected wave is zero and the input voltage is simply e_m Figure 1 (b).

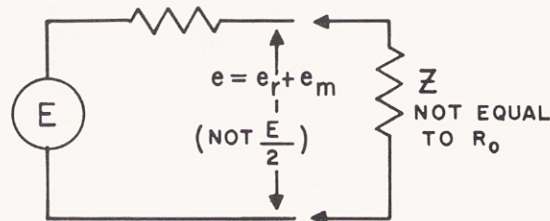


This terminology can be applied even when there is no transmission line in the circuit. It may correctly be said in reference to Figure 1 (a) that the voltage across the load R_0 is e_m .

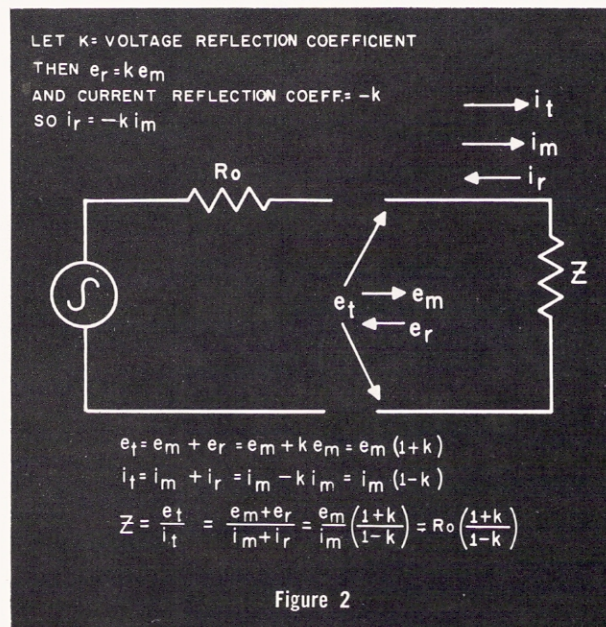
In the case where the generator feeds a section of transmission line terminated in some impedance other than R_0 , the input voltage can be considered to be the sum of e_m and e_r (Figure 1c). Similarly the voltage across any load



connected to a generator can be considered to be the sum of a main wave and a reflected wave (Figure 1d).



A convenient way of describing the relation between the main and reflected waves is to use the reflection coefficient. Figure 2 illustrates a generator feeding a load having any impedance " Z ". The voltage and current across this load



are expressed in terms of their main and reflected components. The quantity k is defined as the ratio of the reflected voltage e_r to the main voltage e_m . The current reflection coefficient is numerically equal to the voltage reflection coefficient and has the opposite sign, so that the relationships indicated in Figure 2 hold true. A significant point is that the impedance of the load can be fully described by the internal impedance of the generator and the voltage reflection coefficient. The relation is:

$$Z = R_0 \frac{1 + k}{1 - k}$$

Note that k is a complex number involving the relation between not only the magnitudes of the main wave and reflected wave, but also their phase angles.

A further convenience is achieved by expressing the reflection coefficient logarithmically. The "Return Loss" is defined as $20 \log_{10} k$. Thus, it is the ratio of e_r to e_m expressed in decibels. The interrelation between Return Loss, Reflection Coefficient and VSWR is indicated on the Nomograph of Figure 3.

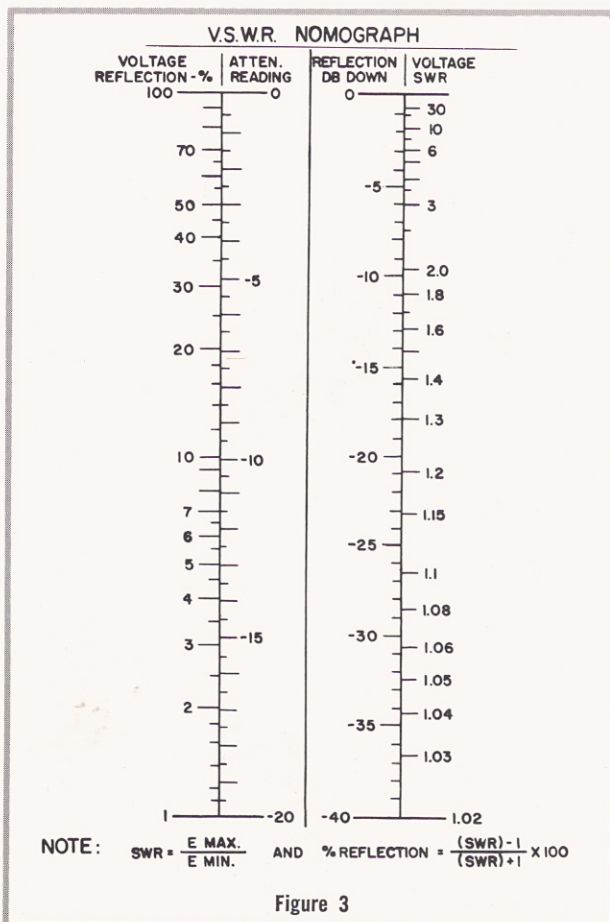


Figure 3

THE BRIDGE PRINCIPLE:

A convenient way of measuring an unknown impedance would be to separate the reflected wave from the main wave and to measure its relative magnitude and phase angle. This is commonly done in high-frequency and microwave testing by the use of a directional coupler. Another approach is the use of a bridge.

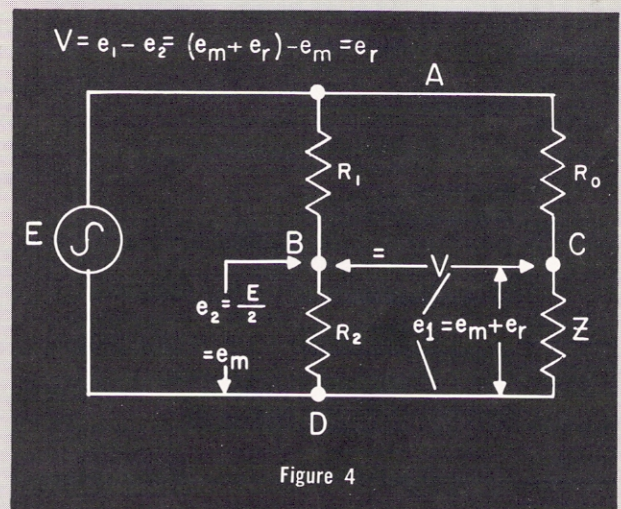


Figure 4

Figure 4 illustrates how a bridge can provide a voltage equal to the reflected wave. A generator having zero internal impedance feeds a load Z through a resistor R_0 . The voltage e_r across Z is equal by definition to e_m plus e_r . If a second divider consisting of two equal resistances R_1 and R_2 is connected across the voltage source, the voltage e_2 across the lower resistor will be equal to $\frac{E}{2}$ which is the same as e_m . If the voltage between the center points of the two dividers is measured, it is found to be the difference between e_m plus e_r and e_m , which is e_r . Thus, the output voltage "V" of this network is identical to the reflected voltage component from the impedance Z .

THE TERMINATED BRIDGE:

Unfortunately, this simple circuit involves the use of a voltage source having zero internal impedance and a voltage measuring device having infinite impedance which measures the difference of voltage between two points, neither of them grounded. As a practical matter, these conditions are difficult to approach.

Fortunately, an alternative configuration is available. The terminated bridge illustrated in Figure 5 has several characteristics which make it especially suitable for this application. When all six resistances are equal, the impedance seen looking into the network at the terminals left after disconnecting any one of the resistances is always equal to R_o . Thus, for example, in Figure 5 the impedance seen between A and D with #1 resistor removed is equal to R_o . When the resistors are equal to the characteristic impedance of a particular coaxial cable, the bridge has matched input and output impedances.

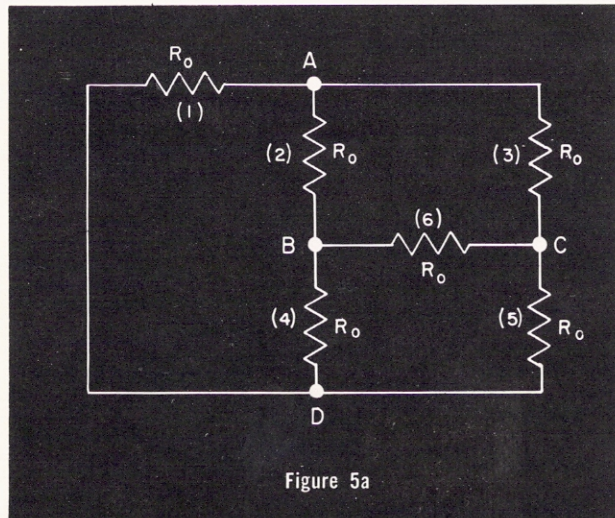


Figure 5a

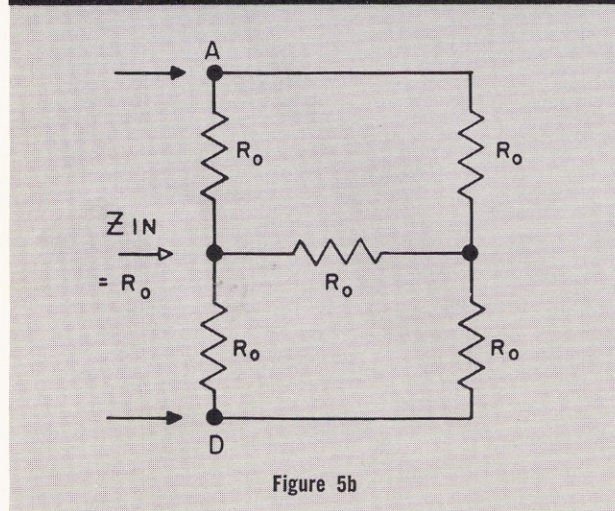
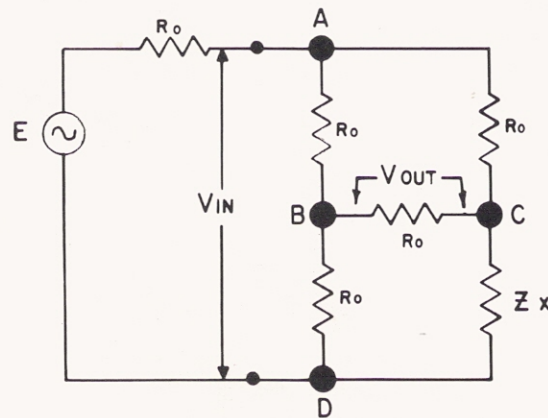


Figure 5b

The terminated bridge has the further advantage that it provides an output voltage precisely equal in magnitude and phase to a constant times the reflection coefficient of the unknown. This is illustrated in Figure 6 which states



$$\text{TRANSMISSION LOSS } (20 \log_{10} \frac{V_{IN}}{V_{OUT}}) =$$

$$\text{RETURN LOSS OF } Z_x + 12 \text{ db } (= 20 \log_{10} \frac{1}{4} \frac{Z_x - R_o}{Z_x + R_o})$$

Figure 6

that the transmission loss from V_{in} , the input terminals of the bridge, to V_{out} is equal to the return loss of Z_x (referred to R_o) plus 12 db. This relation is fully derived in Appendix I. It may be understood better by referring to Figures 7 and 8. Figure 7 shows that the input voltage to a matched load connected between C and D (e_m) is equal to the bridge input V_{in} reduced by 6 db.

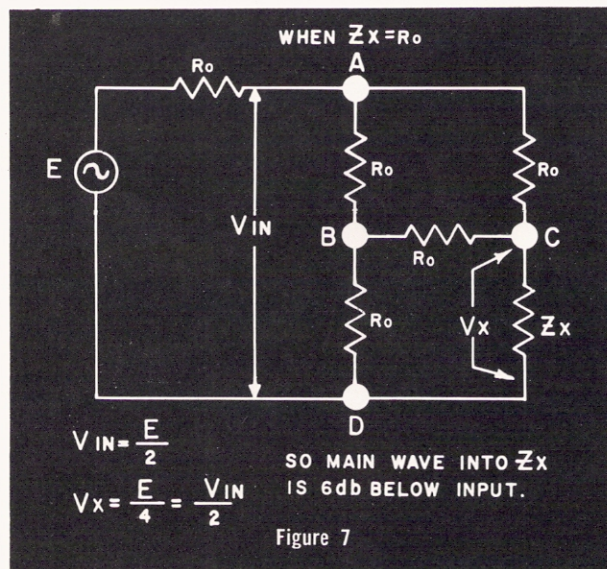
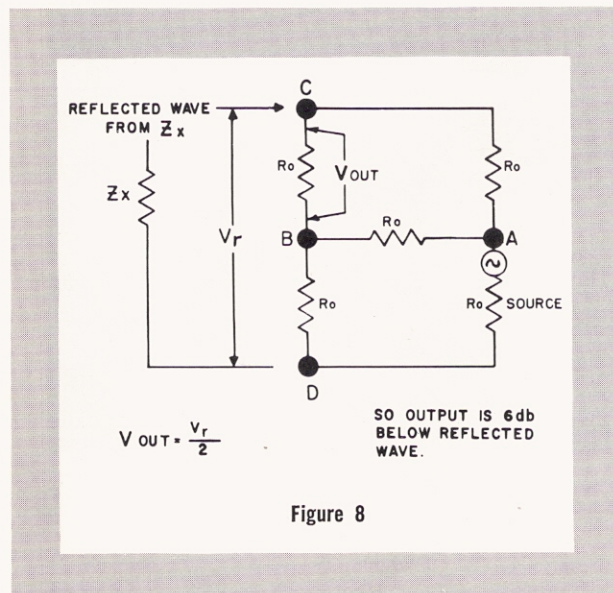
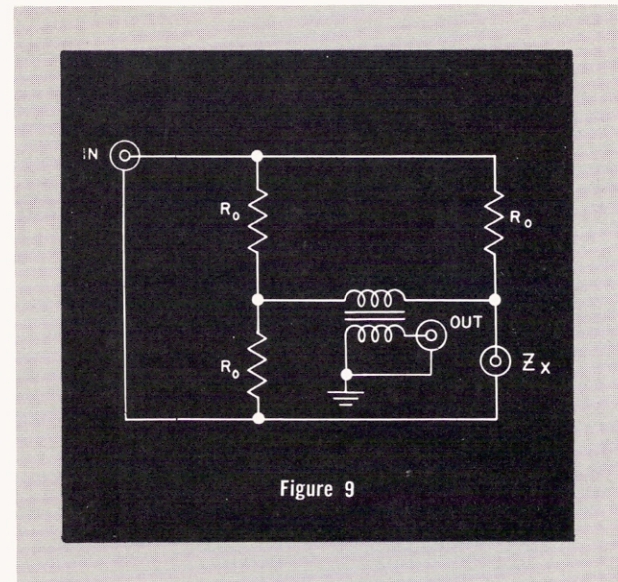


Figure 7

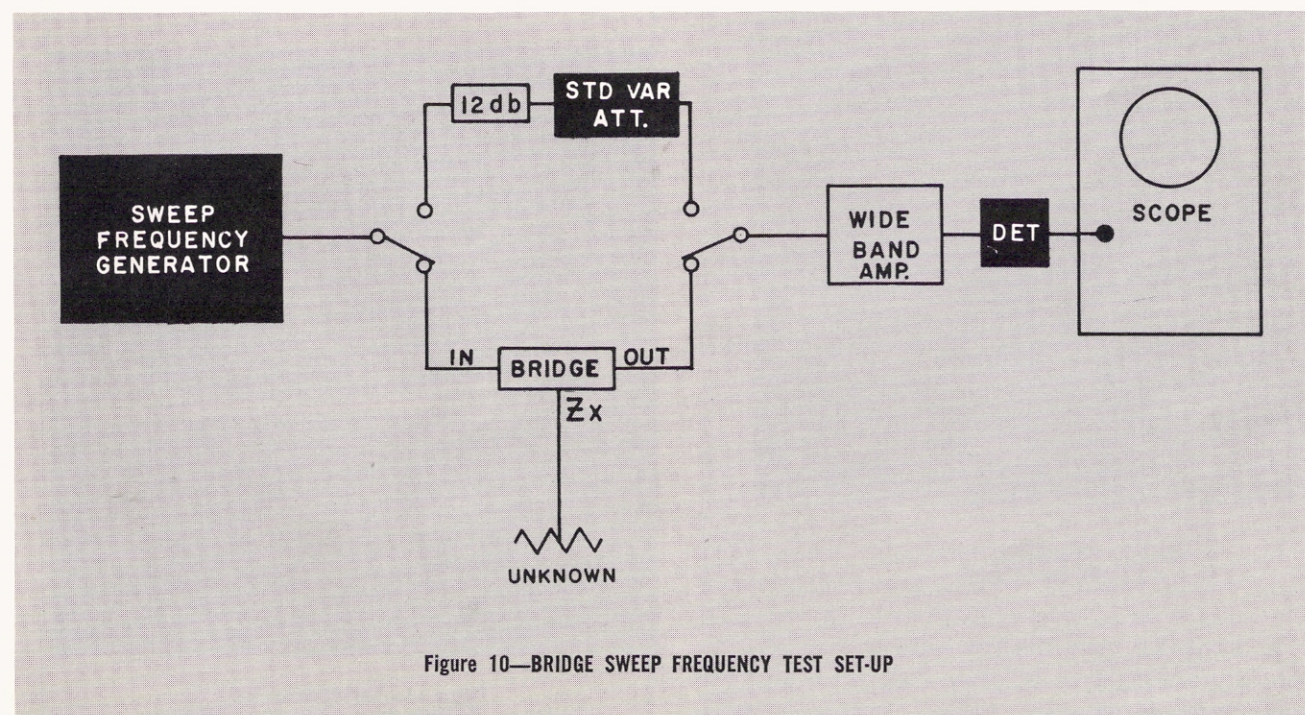
In Figure 8 the bridge is redrawn to show the voltage division experienced by the return wave from Z_x . It comes back into terminals C and D and is attenuated 6 db before coming out of terminals B and C.



As compared with the simple bridge circuit illustrated in Figure 4, the matched bridge has the advantage that the input and output impedances match connecting coaxial cables so that wide band frequency performance can be obtained. The problem of providing a differential voltage measurement between two ungrounded terminals is still present. To build a matched bridge practically, it is necessary to provide a transformer having balanced input terminals as illustrated in Figure 9. It has been found



possible to build such a transformer with a very wide range of frequency response. The resulting bridge is conveniently connected to provide a calibrated sweep display as illustrated in Figure 10. A high-speed coaxial switch (Jerrold Model FD-30) is connected so that in the "up" position it connects the output of the sweep through a 12 db pad and a standard variable attenuator to the input of a wide band amplifier. The amplifier is followed by a detector and scope and displays a curve representing loss vs. frequency. In the "down" position the switches insert the bridge in place of the attenuators. Since the loss of the bridge is equal to the return loss of the unknown plus 12 db, the scope will show a plot of return loss vs. frequency with a reference line corresponding to the setting of the standard variable attenuator.



EXAMPLES OF USE

The performance of a particular bridge is illustrated in Figures 11 to 16 inclusive. This bridge was designed for a characteristic impedance of 75 ohms and the test circuit covered a frequency range from 4 to 100 MC. Figure 11 illustrates the relation between the reference line and the bridge response with the unknown terminal of the bridge open-circuited. The bridge indicates 0 db return loss within about $\frac{1}{2}$ db from 4 to 100 MC.

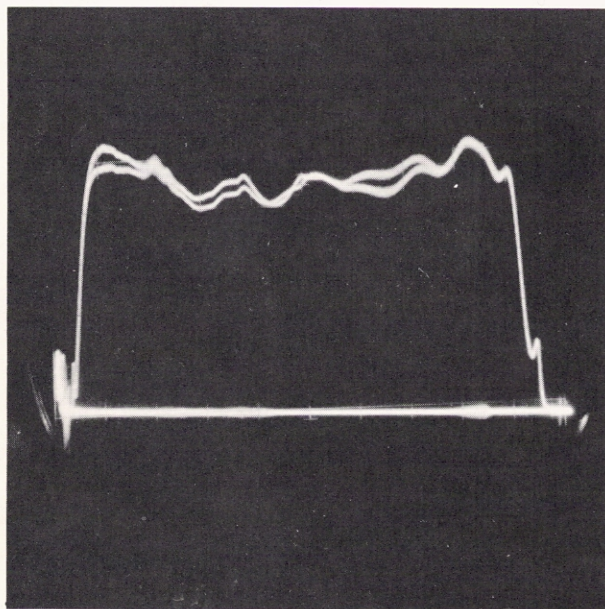


Figure 11—BRIDGE RESPONSE
4-100 mc, Open Circuit

Figure 12 shows the same situation with the unknown terminal short-circuited, again indicating 0 db return loss with approximately $\frac{1}{2}$ db error.

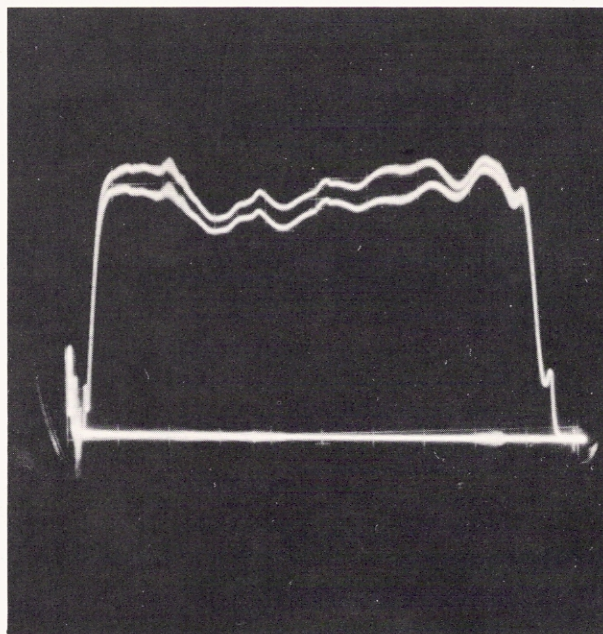


Figure 12—BRIDGE RESPONSE
4-100 mc, Short Circuit

To obtain Figure 13, the X terminal of the bridge was terminated as accurately as possible. In this figure the reference line represents a return loss of 50 db and it is seen that the loss through the bridge indicates a return loss substantially better than 50 db across this entire frequency range. A 50 db return loss corresponds to a VSWR of 1.06 so that it is apparent that this technique is capable of precision comparable with the best that can be obtained with other high frequency measuring techniques.

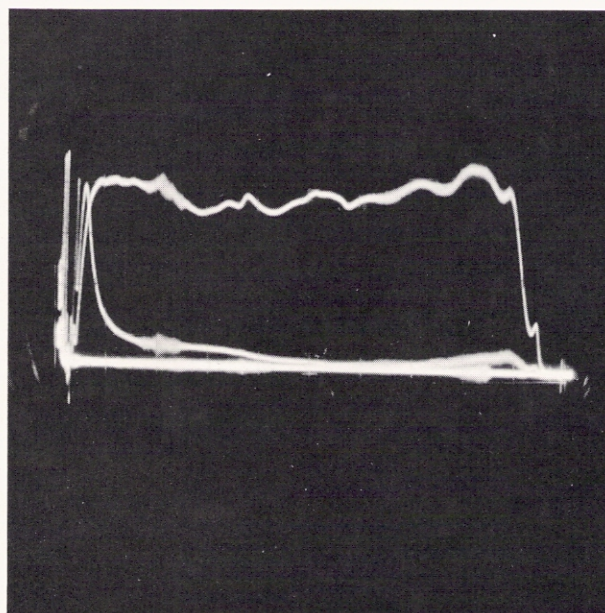


Figure 13—BRIDGE RESPONSE
4-100 mc, Optimum Termination, 50 db Reference

Although this method is extremely **precise**, i.e., it can compare an unknown with a standard and show deviations of considerably less than 1%, its **accuracy** is entirely dependent on the accuracy of the standard impedance against which the bridge is tested. Where suitable standards are available, its accuracy can be nearly as good as its precision.

Figure 14 illustrates the agreement between the reference line and the bridge loss when the bridge was first adjusted for balance with a 75 ohm resistor. A resistor was then substituted whose DC resistance was accurately adjusted to 70 ohms. A 70 ohm resistor in a 75 ohm system gives a VSWR of 1.07 or a return loss of 29.2 db. The reference line on this trace was 30 db.

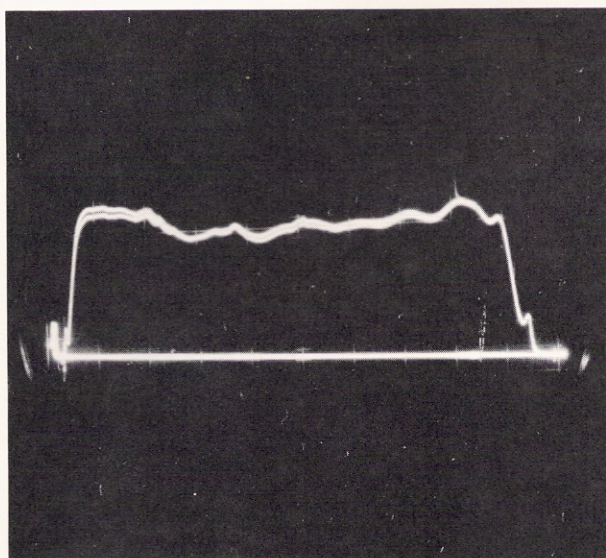


Figure 14—BRIDGE RESPONSE
4-100 mc, 70 ohm Termination, 30 db Reference

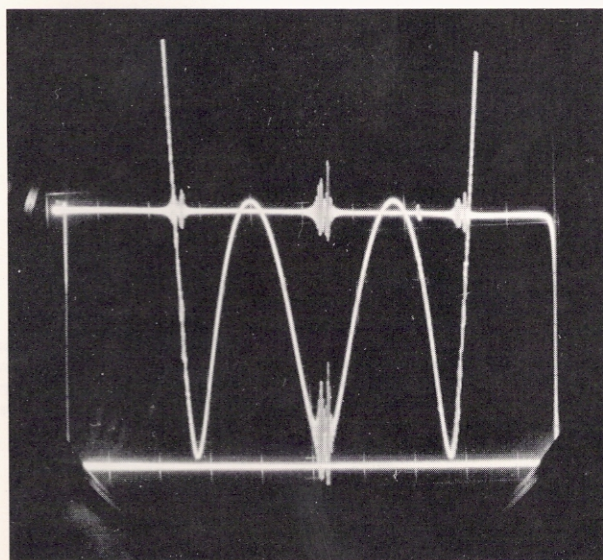


Figure 15 —BRIDGE RESPONSE
Markers 100 mc ± 1.5 mc, 10 db Reference

The delay line method of sweep-frequency impedance measurement (as described in Technical Newsletter #2) provides a convenient method of measuring high frequency impedances with a minimum of equipment. Practical characteristics of delay lines limit the usefulness of this method to relatively wide frequency bands. The bridge technique has no such limitation. It is equally useful for extremely narrow-band measurements or extremely wide-band measurements.

Figure 15 shows the return loss measurement of a triple-tuned filter having a bandwidth of 1.5 MC and a maximum return loss in the pass band of approximately 10 db. Notice the simplicity of this presentation and the ease with which an operator could adjust such a filter to meet given frequency and return loss specifications.

Figure 16 illustrates an extremely wide band measurement. This shows the return loss of a piece of high-grade coaxial cable over the frequency range 4 to 100 MC with a 40 db reference. The bridge provides a way of testing this complicated function with a high degree of speed and accuracy.

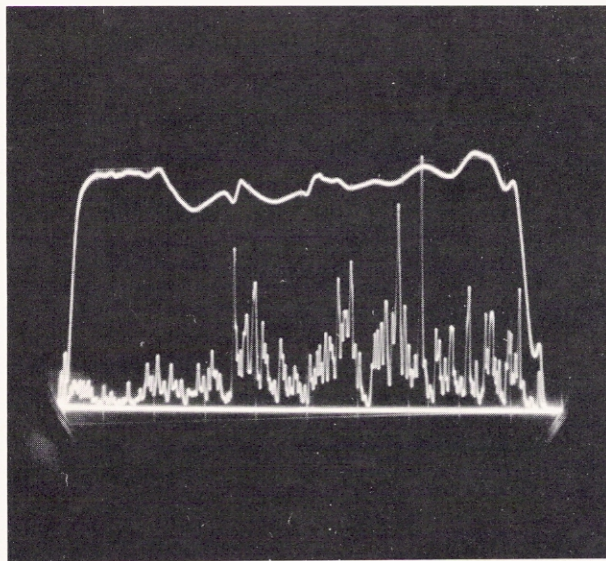
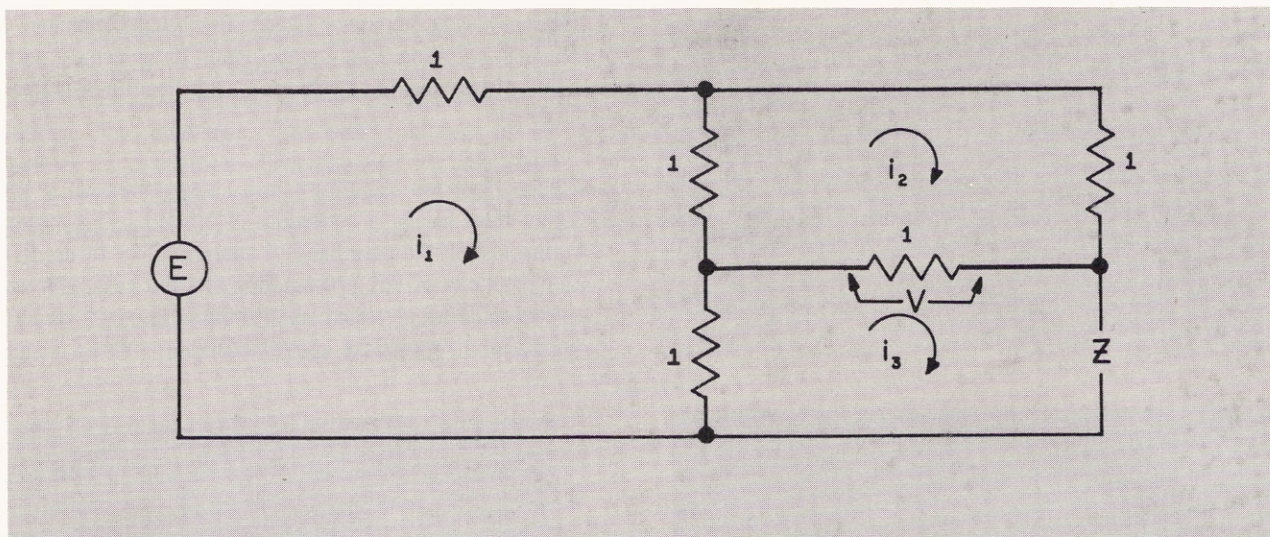


Figure 16—BRIDGE RESPONSE
4-100 mc, Input of 1000' Piece High Grade Coax.,
40 db Reference

The sweep frequency technique has for many years provided a convenient way of observing the frequency variation of gain or loss. More recently it has become possible to measure these quantities simultaneously with the sweep presentation. (See Technical Newsletter #1.) The wide-band return-loss bridge now provides the same degree of convenience in viewing and measuring the frequency variation of return loss and opens a new area of speed and convenience in Laboratory and Production testing of high frequency networks.

APPENDIX I



$$\textcircled{1} \dots\dots\dots E = 3i_1 - i_2 - i_3$$

$$\textcircled{2} \dots\dots\dots 0 = i_1 + 3i_2 - i_3$$

$$\textcircled{3} \dots\dots\dots 0 = -i_1 - i_2 + (2 + Z) i_3$$

$$\textcircled{4} = \textcircled{2} - \textcircled{3} \dots\dots\dots 0 = 4i_2 - (3 + Z) i_3$$

$$\textcircled{5} = \textcircled{1} + (3 \times \textcircled{2}) \dots\dots\dots E = 8i_2 - 4i_3$$

$$\textcircled{6} \text{ Solving } \textcircled{4} \text{ for } i_2 \dots\dots\dots i_2 = \frac{Z + 2}{4} i_3$$

$$\textcircled{7} \text{ Substituting in } \textcircled{5} \dots\dots\dots E = \left[8 \left(\frac{Z + 2}{4} \right) - 4 \right] i_3 = 2(Z + 1) i_3, \quad i_3 = \frac{E}{2(Z + 1)}$$

$$\textcircled{8} \text{ Substituting in } \textcircled{6} \dots\dots\dots i_2 = \frac{Z + 3}{4} \cdot \frac{E}{2(Z + 1)} = \frac{E}{8} \cdot \frac{Z + 3}{Z + 1}$$

$$\textcircled{9} \dots\dots\dots V = 1(i_2 - i_3) = E \frac{1}{8} \cdot \frac{Z + 3}{Z + 1} - \frac{1}{2(Z + 1)}$$

So:

$$V = \frac{E}{8} \cdot \frac{Z - 1}{Z + 1}$$

Represented by

NOTE — Additional copies of this paper and engineering assistance on the application of Measurements By Comparison may be obtained by contacting the Industrial Products Division, Jerrold Electronics Corporation, 15th & Lehigh, Phila. 32, Pa. Phone: BAldwin 6-3456 — Ext. 211.

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