JERROLD

Technical Newsletter

Published by JERROLD ELECTRONICS CORPORATION, Philadelphia, Pa.

INDUSTRIAL PRODUCTS DIVISION

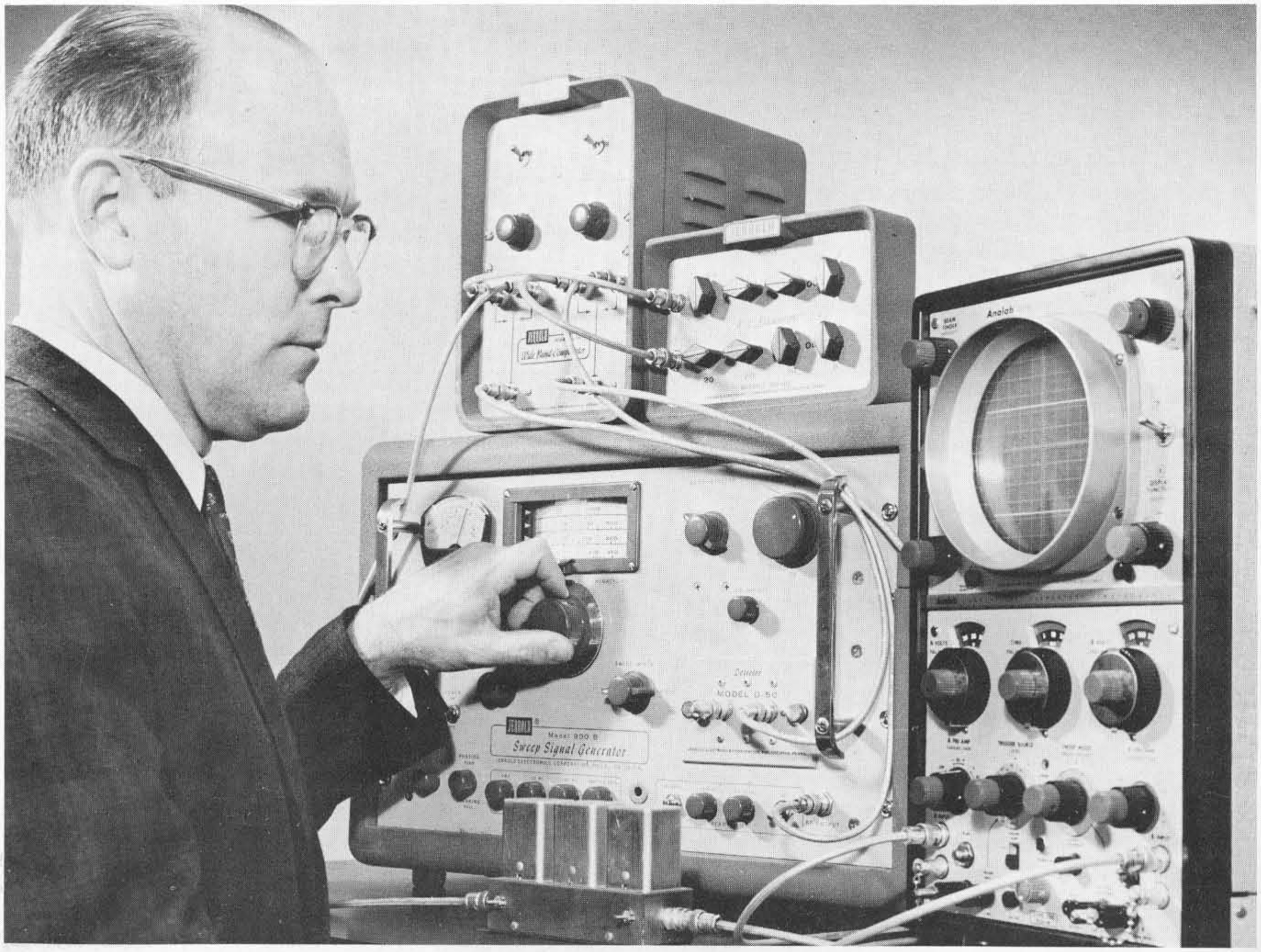
Volume 2, Number 1 **March, 1964**

COMPARISON TECHNIQUE

IMPROVES SWEEP FREQUENCY MEASUREMENTS*

By K. A. SIMONS, Chief Engineer, Jerrold Electronics Corporation

The Jerrold Electronics Corporation maintains a Design Engineering Laboratory at Hatboro, Pennsylvania. The primary function of this organization is the design of electronic equipment, including wide-band amplifiers, filters and associated equipment in the "awkward" frequency range between 5 and 220 mc. This range is called awkward because the upper end is too high for measuring methods suitable for the low communications frequencies, and the lower end is too high for standing-wave line measurements. A number of measuring techniques, developed to meet this situation, are described in this article.



*A major part of this article appeared first under the title "SWEEP MEASUREMENTS MAKING THE TOUGH ONES EASY" in "electronics" Vol. 36, No. 16, April 19, 1963.

BASIC COMPARISON CIRCUIT

The basic technique is to compare transmission through two paths. Figure 1 shows the method used to determine accurately the transmission loss through a network. A test signal source and an output indicator are connected to a DPDT switch so that in one switch position (TEST) the signal is passed through the network the loss of which is to be measured, and in the other switch position (REFERENCE) it is connected through a variable calibrated attenuator.

To make a measurement, the operator throws the switch repeatedly back and forth, while adjusting the attenuator until the output indicator shows identical responses for both switch positions. The loss in the tested network is then equal to that of the attenuator and can be read off from its calibration.

This technique has been used for many years for precise transmission measurements in the telephone art. (See, for example, the article "Transmission Measuring for Manufacture," by George W. Pentico in THE WESTERN ELECTRIC ENGINEER, October, 1961.)

The technique has some of the basic advantages of the more familiar null-bridge measuring method, namely:

1. High source output and a sensitive indicator make very precise settings possible.
2. Other characteristics of the source and indicator have little effect on the accuracy of the result. Neither needs to be calibrated, and the amplitude stability need only be constant long enough for a comparison to be made.
3. Calibration accuracy is entirely determined by a convenient passive attenuator.

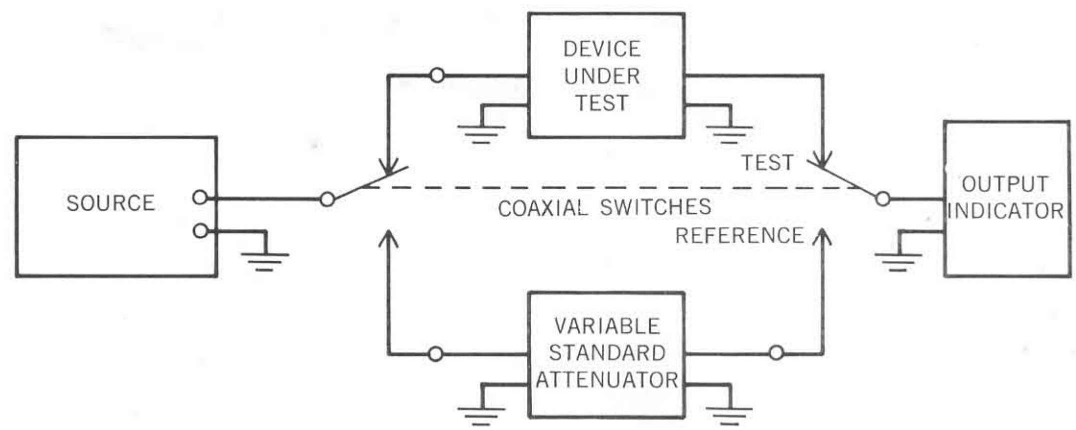


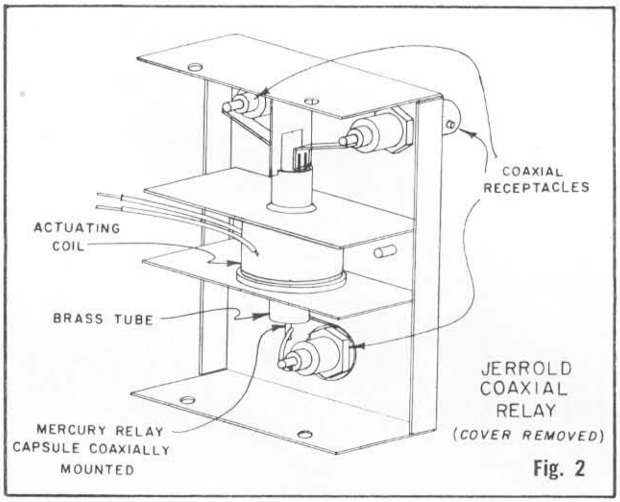
Fig. 1

COMPARISON WITH SWEEP DISPLAY

This approach is a "natural" for sweep frequency testing over wide frequency bands. Sweep frequency generators and oscilloscopes are notoriously as poor on calibration as they are good on sensitivity, while stable and accurate attenuators are common. To adapt to the sweep situation, the basic technique is modified in two respects:

1. High frequency measurements necessarily involve coaxial transmission lines; thus the comparison switch, as part of the transmission system, must be coaxial with an impedance matching that of the associated lines.

2. Oscilloscopic display of a sweep frequency response curve requires periodic repetition of the measurement (usually 60 times per second) so the eye can see a steady pattern. The "switch" must also operate period-



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COAXIAL
RELAY
(COVER REMOVED)

Fig. 2

ically so that the calibration may be seen as part of this stationary pattern. To achieve periodic switch operation, a high speed coaxial relay is used. The construction is illustrated in Figure 2. A Clare mercury-wetted relay capsule is mounted so that it forms a well-matched coaxial structure. This unit operates at high speeds (up to 60 cps) with no bounce and with very long life.

Switches have been in full-time operation in our laboratory for five years with negligible failures.

MEASURING LOSS BY COMPARISON

The test set-up for measuring and displaying the high frequency loss of a network by the sweep-frequency comparison method is diagrammed in Figure 3. The output of a Sweep Frequency Generator, sweeping across the desired band at a 60-cycle rate, is connected to one of two SPDT coaxial switches. The other switch is connected to the input of a wide-band detector. The switches transmit alternately through the network under test and through the variable attenuator.

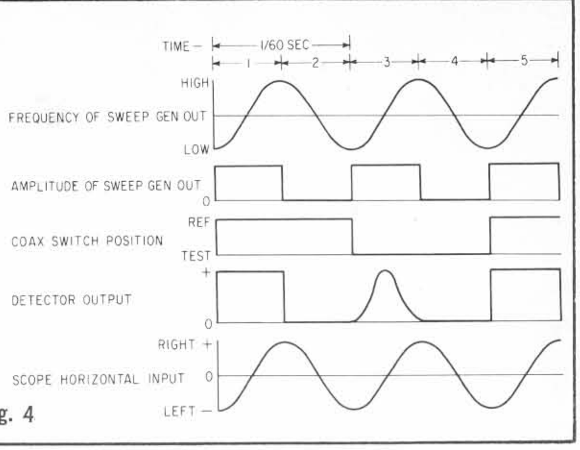


Fig. 4

When this detector output is applied to an oscilloscope's vertical input terminals, and a voltage, with its instantaneous magnitude phased to match the instantaneous frequency of the generator, is applied to the horizontal output terminals, the scope traces out the display illustrated in Figure 4f. (In the example shown, the horizontal deflecting voltage must be a 60-cycle sine-wave phased as shown, to agree with the waveform and phase of the frequency modulation.)

The curve presents the loss as it varies with frequency in the unit under test, together with a base line showing zero response (infinite loss) and the REFERENCE trace showing the loss corresponding to the attenuator setting.

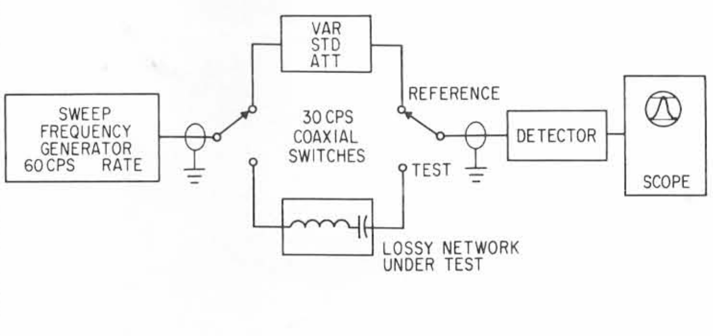


Fig. 3

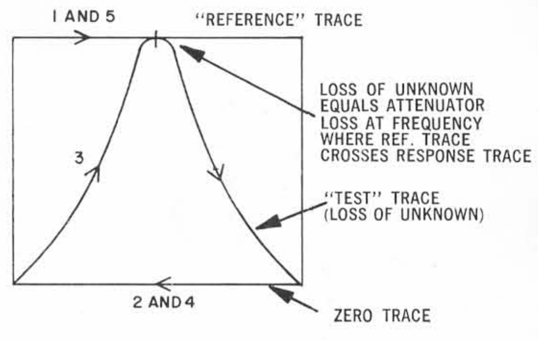


Fig. 4f

Figure 4 illustrates the manner in which the display is generated. The frequency of the sweep output varies sinusoidally between an upper and a lower limit (Figure 4a) at a 60-cycle rate. The output is cut off during the return trace (Figure 4b) to form a zero reference trace. The coaxial switches are transferred at a 30-cycle rate (Figure 4c) allowing the development of a full trace in the REFERENCE position followed by a full trace in the TEST position. As a result, the detector output (Figure 4d) goes through four conditions in each thirtieth of a second; first indicating reference output, second delivering zero output, third following the loss curve of the unit under test and fourth repeating the zero output trace.

The REFERENCE trace crosses the TEST trace at those frequencies where the loss of the unit under test precisely equals the loss of the standard attenuator.

The scope trace photograph in Figure 5 shows the insertion loss measurement of a triple-tuned band-pass filter. The attenuator was set at 1.0 db and the point at which the REFERENCE trace crosses the response shows a loss of 1.0 db at a 7-mc band-width centered on 125 mc. It is a major advantage of this presentation that the accuracy of the measurement is not affected by the constancy of the sweep output across the band, the flatness of the detector, or by drift or other changes in scope gain and centering.

In cases where very small attenuation differences are to be observed, it is convenient to increase the vertical gain and recenter the trace to show a highly expanded view of part of a response pattern. This is illustrated in the series beginning with Figure 6. A Jerrold 900-B sweep frequency generator was set to sweep between zero and 200 mc, and a short coaxial jumper was connected between its output and a detector. The scope vertical gain was increased to about four times that required to show the change from zero to full output, and the centering readjusted to bring the resulting trace onto the screen.

Under this condition the screen showed a change of only 0.2 db per division and the resulting trace (Figure 6) shows the sweep output to be constant within ± 0.2 db. With the same sweep and scope settings, the sweep output was then connected through two coaxial switches (Jerrold Model FD-30) transferring between a short jumper and a variable attenuator (Jerrold Model AV-50) connected through two 2-foot coaxial cables.

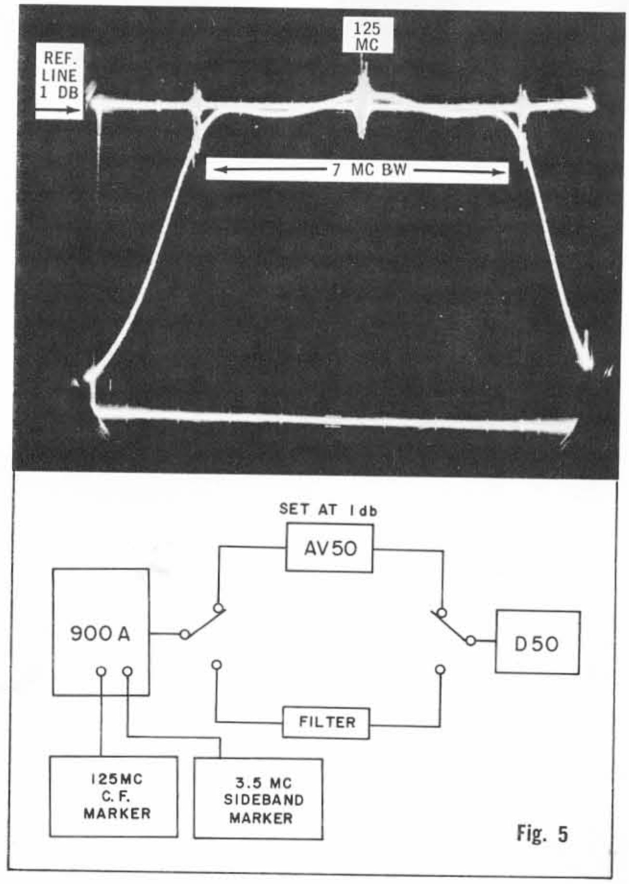


Fig. 5

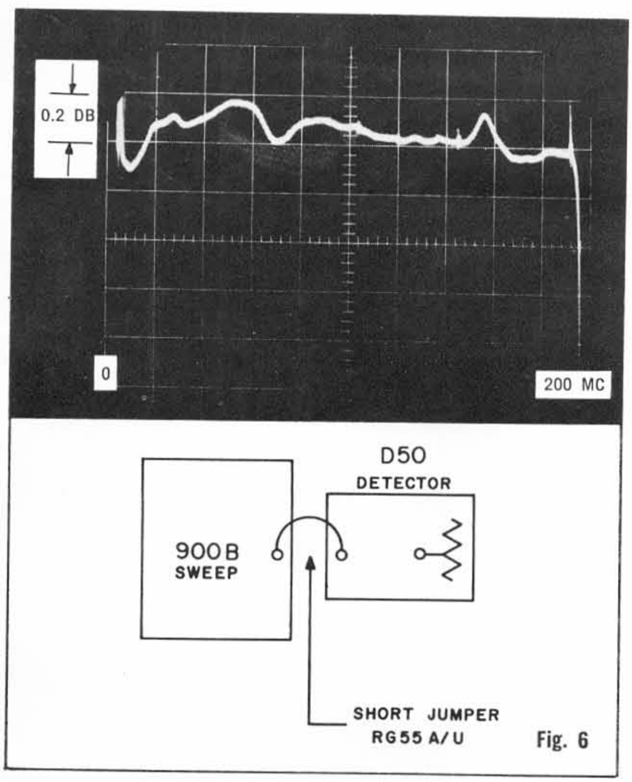
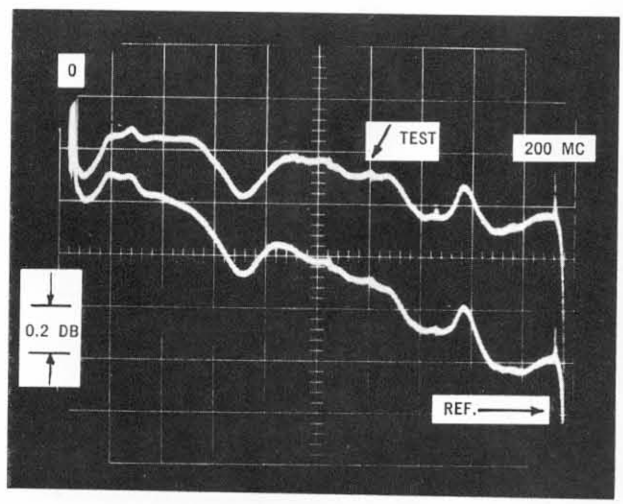


Fig. 6



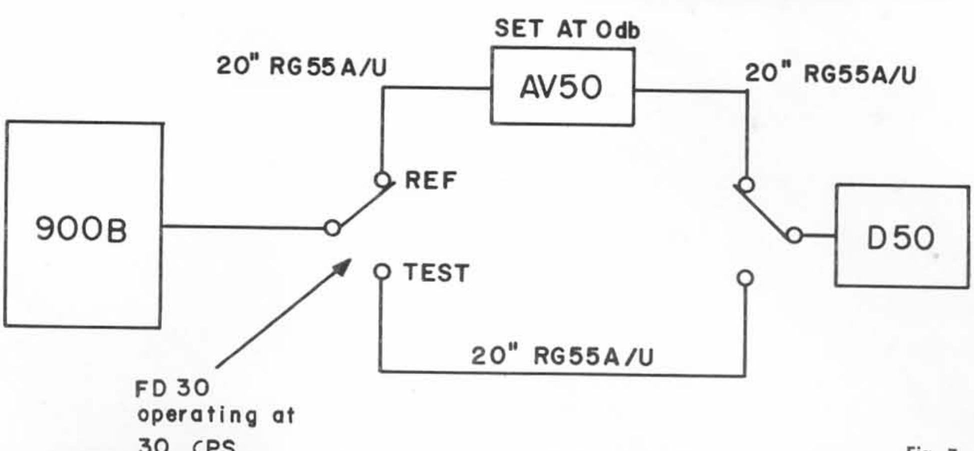


Fig. 7

The resulting photograph (Figure 7) compares the jumper loss with the attenuator insertion loss (at zero setting) continuing with the same expanded vertical scale. By careful inspection it can be seen that the TEST (upper) trace is slightly down at the high end (compared with Figure 6) indicating that the coaxial switches and short jumper have added about 0.2 db loss at 200 mc, while the REFERENCE (lower) trace shows that the attenuator and its longer cables have added about 0.8 db loss at the high end.

If precise measurements are to be made it is **not** essential that either curve be precisely flat, but it **is** essential that the loss on the TEST side, before inserting the unknown, be the same as that on the REFERENCE side. This condition was satisfied by inserting additional cable on the TEST side (totalling 137 inches) so that the insertion losses in both circuits were close to identical. The resulting trace was photographed (Figure 8a) and shows considerably less than 0.05 db difference between the two circuits over the whole frequency range from low frequencies up to 200 mc. Inserting an additional 0.5 db into the standard attenuator gave the result illustrated in Figure 8b, showing that this set-up could be used for loss measurements involving very small attenuation differences.

Figure 9 shows how this approach was applied to a practical measuring problem. We wanted to test a repeater amplifier designed for long cascaded runs in television distribution systems. The amplifier, together with its equalizer, is required to have gain equalizing as closely as possible the loss of 2000 feet of a particular coaxial cable between the frequencies of 5 and 95 mc. To test this, the cable, the equalizers and the amplifier were connected, each following the other on the TEST side of the comparison circuit, with a jumper providing a zero loss reference on the REFERENCE side. The resulting response (illustrated in Figure 9b) shows that the combination of cable plus equalizer plus amplifier had zero loss within about ± 0.25 db between 5 and 95 mc. The fine grained ripple is primarily due to variations in the cable's transmission characteristic.

The usefulness of this technique is obvious, first in the fact that it would take many hours to make this measurement using point-by-point techniques and even then the accuracy would be questionable, and second in the fact that the necessary refined adjustments of the equalizer and amplifier can be carried out quickly and accurately while observing the display, which could not be done with a point-by-point approach.

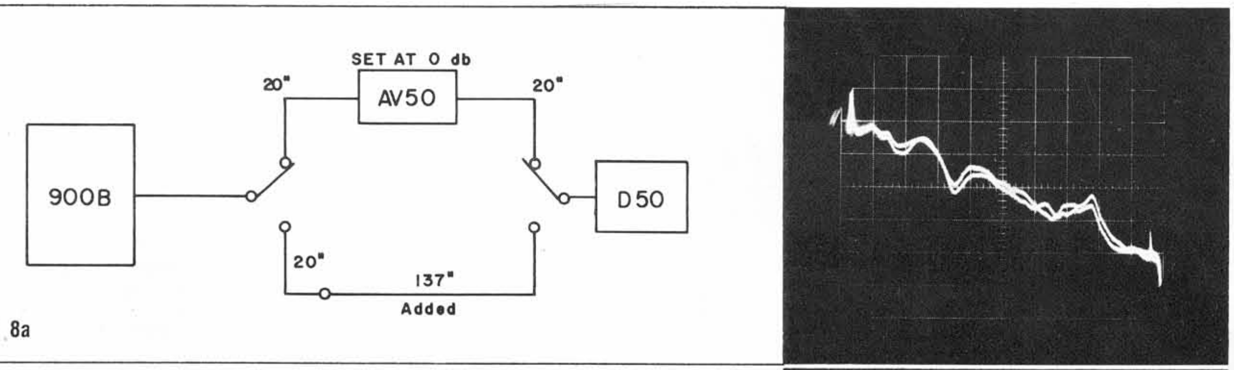


Fig. 8a

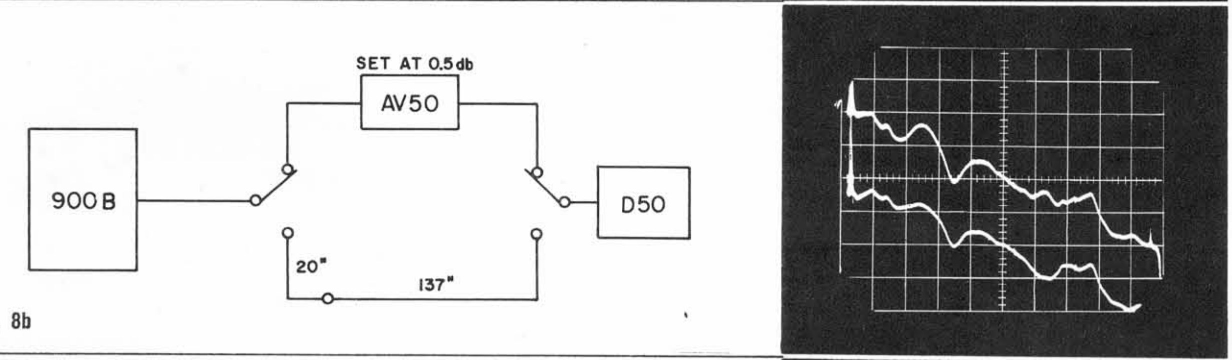


Fig. 8b

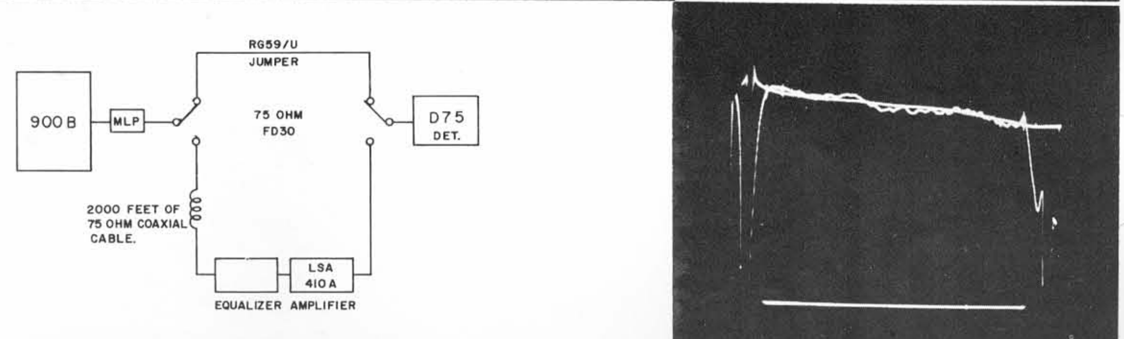


Fig. 9

MEASURING GAIN BY COMPARISON

The comparison technique can be used effectively for the measurement of amplifier gain. The basic circuit is diagrammed in Figure 10. By using a jumper as a zero loss reference and inserting the variable attenuator ahead of the amplifier on the TEST side, the REFERENCE line is made to cross the amplifier response curve at the point where the attenuator loss equals the amplifier gain. The resulting display is illustrated in Figure 11.

The photographs in Figure 12 illustrate gain measurement on an amplifier designed to pass television channel 13 for use in rf distribution systems. Figure 12a illustrates the response curve in the TEST position with a frequency marker at band center (213 mc). Figure 12b illustrates a useful frequency marking technique where a low frequency generator (3 mc) is connected simultaneously with a high frequency one and the resulting side-bands mark the channel edges (213 ± 3 mc). Figure 12c illustrates the trace with the coaxial switch running and the attenuator set at 57 db (0.5 db below the maximum amplifier gain).

To obtain a "blown-up" view of the pass band response, the scope gain was turned up and the trace recentered to give the result shown in Figure 12d. This shows that the amplifier response is within 0.1 db across the band. Neither the measurement, nor the alignment which preceded it, could be readily carried out by any single frequency measurement technique.

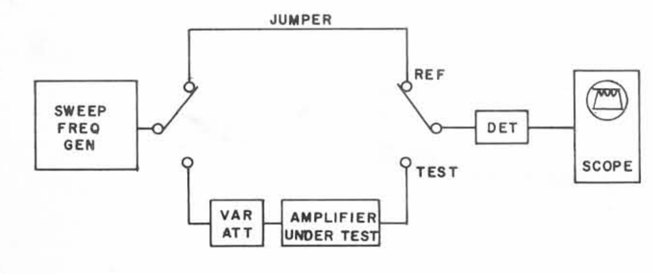


Fig. 10

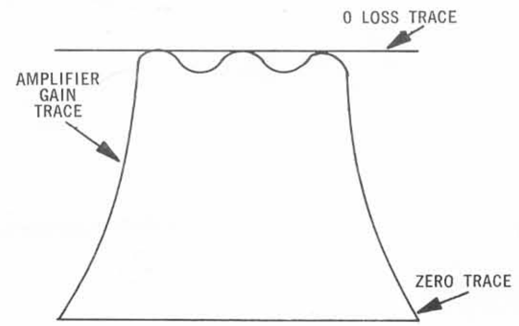


Fig. 11

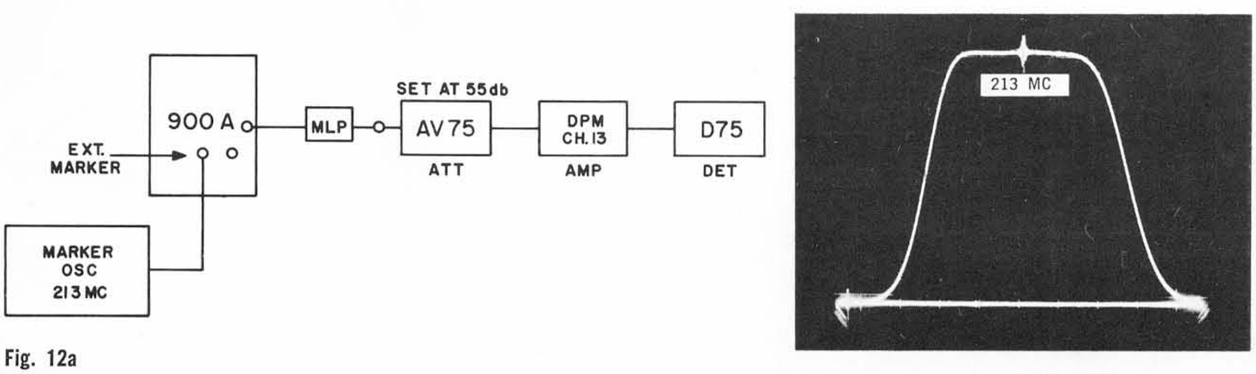


Fig. 12a

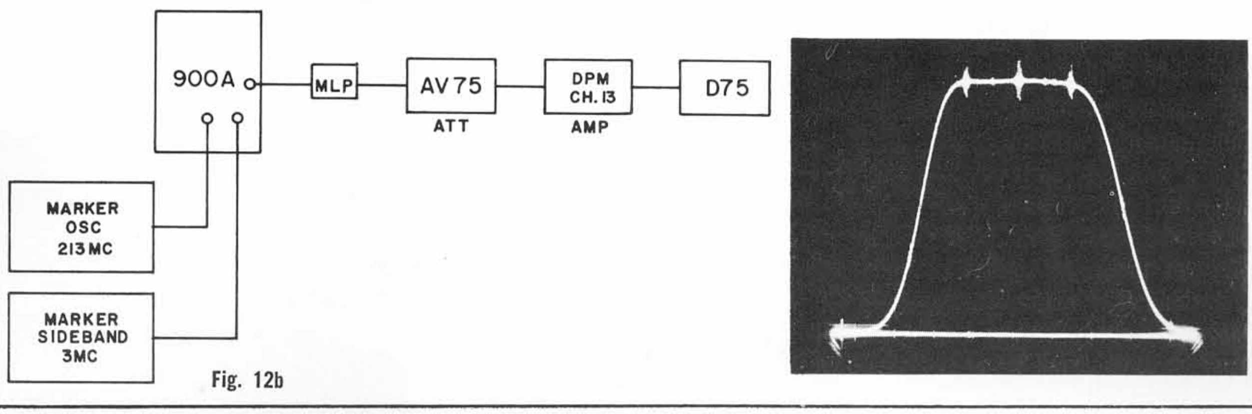


Fig. 12b

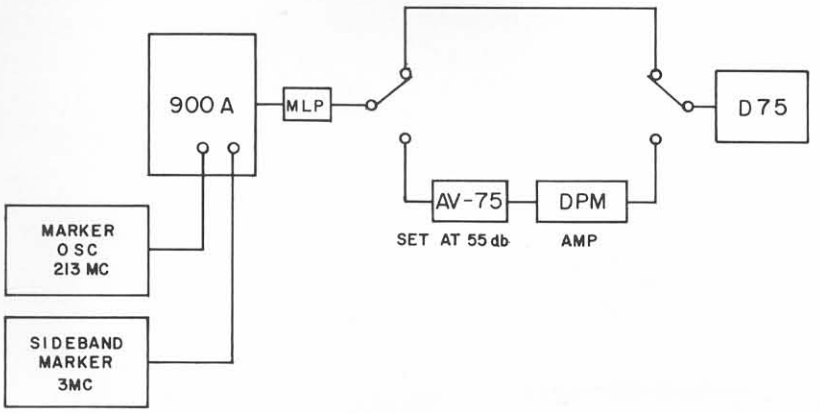
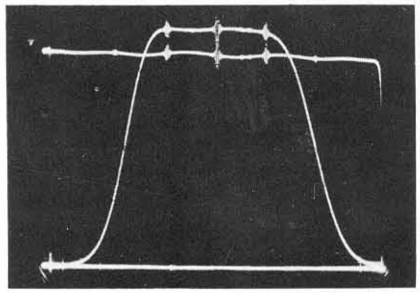


Fig. 12c



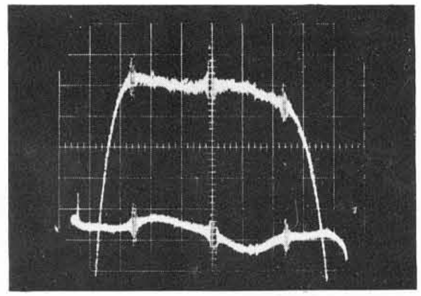


Fig. 12d

MEASURING IMPEDANCE MATCH BY COMPARISON

In addition to gain and loss measurements, a third application of the comparison method was found to be very useful in our laboratory. This involves employing a bridge circuit to provide wide-band display of impedance match characteristics. As described more fully in TNL, Vol. 1, No. 4, the technique depends on the characteristics of a high frequency bridge having six equal arms (including the impedance of the source and detector). The bridge circuit is diagrammed in Figure 13 and its effect is summarized by the fact that the insertion loss between the input and output terminals is equal to 12 db plus the return loss of that which is connected to the unknown terminal (return loss is the ratio of the reflected wave in a coaxial system to the incident wave, expressed in db). Stating this another way: when a signal is introduced into the input terminal of the bridge, the output signal **is** the reflected wave from the unknown diminished by 12 db.

Thus the bridge makes possible impedance measurements over a wide frequency band, converting impedance variations into loss variations which are then accurately measured by the comparison technique. It is, in effect, a directional coupler giving flat response over a very wide band of frequencies in the "awkward" 5 to 200 mc range. The equipment set-up for impedance sweeping is diagrammed in Figure 14. The bridge is connected to the TEST terminals of the comparison switches and a fixed 12 db attenuator is connected with the standard attenuator in the REFERENCE leg. To obtain adequate gain for the measurement of small reflections, a wide-band distributed amplifier is connected ahead of the detector. The display obtained is shown in Figure 14b, the REFERENCE trace crossing the unknown at a return loss level corresponding to the attenuator setting. The bridge we are now using allows measurement of return loss in the range 0 to 40 db, with an accuracy within ± 1 db.

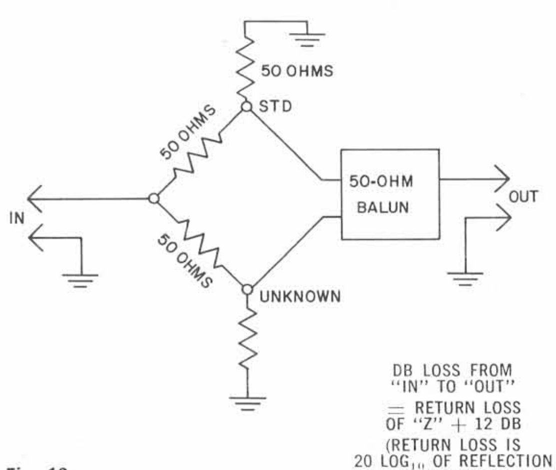


Fig. 13

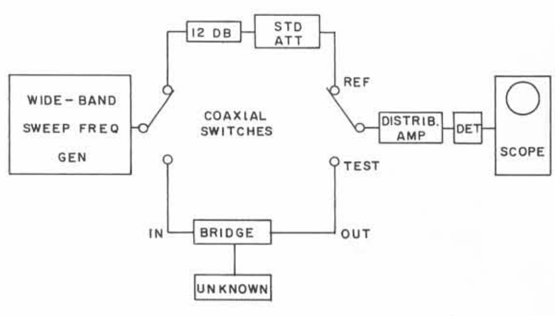


Fig. 14a

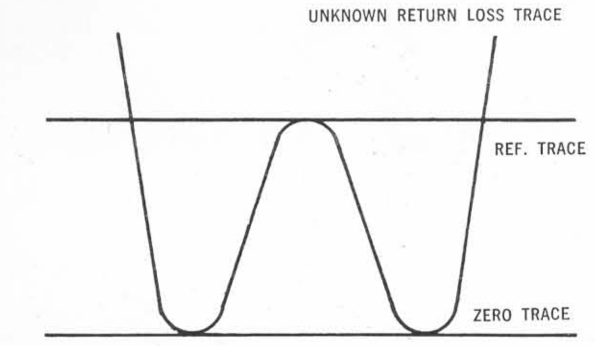


Fig. 14b

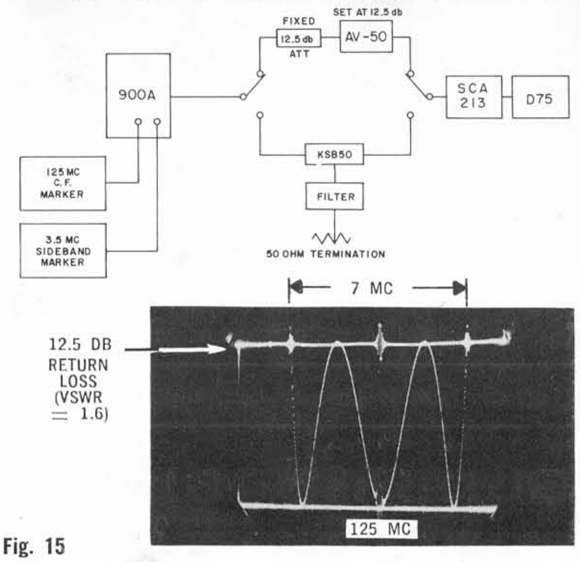


Fig. 15

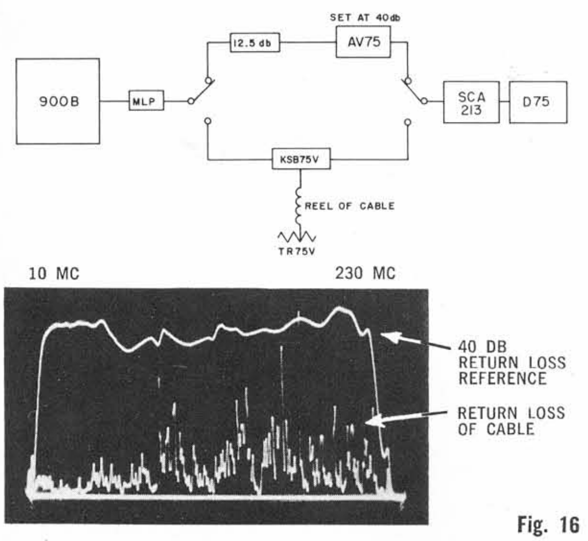


Fig. 16

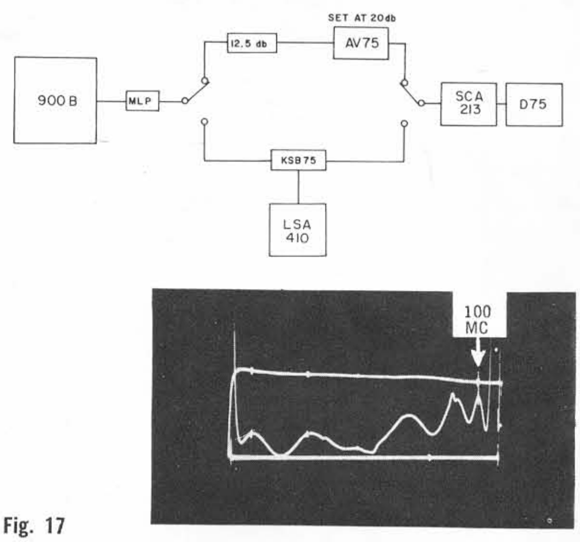


Fig. 17

Figure 15 illustrates measurement of the input impedance of the band-pass filter the insertion loss of which is shown in Figure 5. The filter was aligned for maximum return loss of 12.5 db (max. VSWR of 1.6:1) with Chebishev (equal ripple) match characteristics. Adjustment and measurement were carried out rapidly with the aid of the comparison presentation.

Figure 16 illustrates measurement of the "structural return loss" (the impedance variations due to minor mechanical irregularities) in a 1000-ft. piece of unusually good coaxial cable. The maximum reflection spike at about 150 mc had a return loss level just over 40 db.

Measurement of such a complex characteristic over this frequency range would be a maddening (if not impossible) process by any point-by-point technique.

Figure 17 illustrates the impedance match at the output terminal of the amplifier the response of which was shown in Figure 9. Without the rapid and accurate measurement of match made possible by the return loss bridge, production alignment of this amplifier to meet the required overall performance would be impossible.

CONCLUSION

The comparison technique has been described as it is used at the Jerrold Laboratory for measurement of loss, gain, and impedance match, simultaneously with sweep frequency display of these characteristics. This technique has been found absolutely indispensable in the speed and convenience it contributes to the design and adjustment of a variety of devices in the "awkward" frequency range between 5 and 220 mc.

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. 215.

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