APPLICATION NOTE 54

Revised 4/15/64

THE RATIO METER IN MICROWAVE SWEPT-FREQUENCY MEASUREMENTS

Editorial Note

Since the introduction of leveled sweep oscillators, reflection and transmission measurements are usually observed on the face of an oscilloscope (see hp Application Note 61). However, if a permanent record is needed, a ratio meter and an X-Y recorder is still an acceptable method for making reflection and transmission measurements.

This Application Note gives details for making ratiometer type calibrations to perform accurate and reliable measurements. Techniques presented here are still of general usefulness and interest to the microwave field, especially in production test applications.

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The historical reflectometer[1] block diagram is shown in figure 1. Typically it consists of a sweep frequency generator driving two high directivity multi-hole directional couplers. These couplers sample the forward and reverse power and compare the detector video outputs in a 1000 cycle ratio meter, which provides for ratio output on an X-Y recorder. One of the basic limitations of this reflectometer method was that the calibration was carried out with a 100% reflection, such as a sliding short. Then the subsequent measurement of the unknown load with a low return loss would place the reverse detector in a significantly different operating power region. For this reason, both detectors had to be matched well with frequency as well as being matched within rather wide limits on the square law detection characteristic. In addition, the range-to-range error of the ratio meter, though small, would still add several percentage points to the overall system error. Other scalar errors, such as the non-similarity of directional coupler coupling characteristics also added to the basic system error.

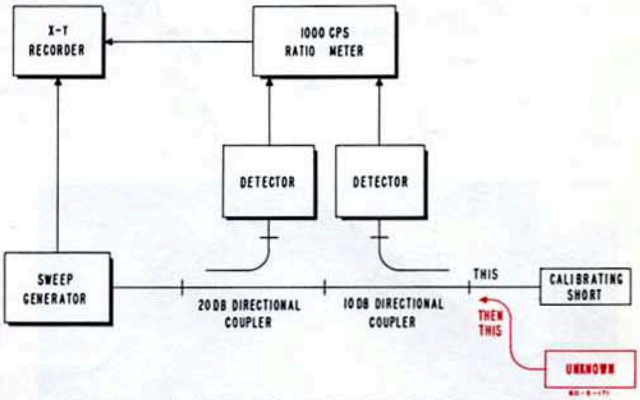

Figure 1. The historical reflectometer

The improved reflectometer system[2] of figure 2A has solved the problem of scalar errors with a rather simple step. It provides for the rf calibration of the system at the exact level of use by means of a broadband rotary-vane attenuator placed in the secondary arm of the reverse coupler. This attenuator provides for accurate broadband attenuation of the microwave signal and yields a calibration grid at appropriate settings of the standard attenuator. Thus scalar errors caused by non-match of coupling factor, variation of the detectors versus frequency and power level, as well as scalar errors in the ratio meter and X-Y recorder, are all calibrated out. The ultimate scalar accuracy is set by the standard attenuator itself. Of course, the overall accuracy of the system is still limited by the reverse coupler directivity vector which remains true of all high directivity reflectometer systems. This factor will be discussed later.

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[1] J. K. Hunton and N. L. Pappas, "The hp Microwave Reflectometers", Hewlett-Packard Journal, Vol. 6 No. 1-2, Sept.-Oct. 1954.

[2] J. K. Hunton and Elmer Lorence, "Improved Sweep Frequency Techniques for Broadband Microwave Testing", Hewlett-Packard Journal, Vol. 12 No. 4, December 1960.

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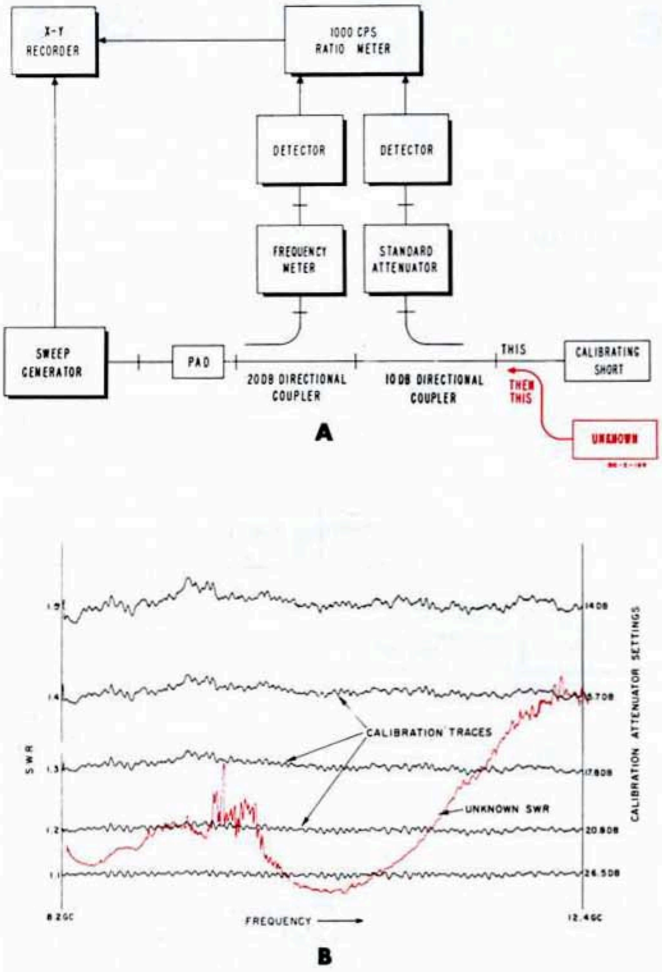

Figure 2. Typical block diagram for measuring swr, and the resulting X-Y plot. Calibration traces are made with the standard attenuator set to expected values of return loss.

SWR MEASUREMENT

A typical improved microwave impedance measurement setup is shown in figure 2A. With reference to the curves of figure 2B the calibration and measurement procedure is as follows: Place the 100% calibrating short on the reverse coupler and set in the expected return loss value into the standard rotary vane attenuator. For instance, if the expected swr is to run around 1.2 the standard attenuator should be set to 20.8 db. Set the ratio meter range and the X-Y recorder sensitivity so that the pen remains on scale for the full horizontal sweep. Make an X-Y plot[3] versus frequency with this attenuation setting. The second calibration line is plotted using the same procedure except with a slightly higher return loss value set into the standard attenuator. Two or three calibration lines will typically give enough information for go-no-go testing, although additional lines may be made for specific cases where the entire variation of the swr is desired. After this calibration is complete, remove the calibrating short and replace it with the unknown load. Remove all of the attenuation from the standard attenuator and trigger the final measurement sweep. The final curve as shown in figure 2B plotted against the calibration grid is the swr characteristic within the accuracy of the system.

DIRECTIVITY MEASUREMENT

The technique as shown above may be extended to a number of different measurements limited only by the ingenuity of the designer. A few of these will be shown to illustrate the utility of these calibration techniques. Figure 3A shows the block diagram used for making a directivity test of multi-hole precision waveguide couplers. With reference to figure 3A and figure 3B, which is the final X-Y plot of a precision coupler, this procedure is followed: With 100% reflection caused by the calibrating short, set in return losses of 40, 41, and 42 db on the standard attenuator and plot these calibration grid lines sequentially. (In figure 3B, calibration grid lines of 38, 40, 42 and 46 db were used for illustrative purposes.)

Notice that since the ratio meter no longer has to be calibrated for a meter reading of 100%, the full gain of the ratio meter may be used to provide additional dynamic range and, thus, use more of the ultimate sensitivity of the system. All of the calibration takes place with the standard rotary-vane attenuator. Set the attenuator back to zero db and replace the short with a precision sliding load.

For the directivity measurement a perfect load which would introduce no reflection at the output flange of the reverse coupler would be desirable. The only signal then reaching the reverse detector would be that directivity signal which arrives at the reverse detector because of hole array imperfections and flange discontinuities at the reverse coupler output flange. Since it is not possible to achieve a perfect load, a tapered polyiron load may be used and its small reflection effect cancelled by sliding the moving load during an extremely slow rf sweep. By sliding the moving load back and forth all possible phase combinations between the directivity vector and the load vector are encountered and the combined signal arriving at the reverse detector then swings between the sum and difference of these two vectors. If as shown in figure 3B the swing between limits is rather small, this means that the load reflection is small compared with the directivity vector. Under these conditions a good approximation for directivity is the average value of the swing; thus, it is seen that the coupler tested is well within specifications, which are 40 db of directivity.

To arrive at the true couper directivity as commonly defined, the main line transmission loss must also be added to the above readings. (For instance, in a 3 db coupler, 3 db would be added to the above measurements, while in a 10 db coupler, 0.46 db would be added, and so on.) The above description of directivity offers

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[3] All X-Y plots illustrated were made with a Moseley Model 3S X-Y Recorder.

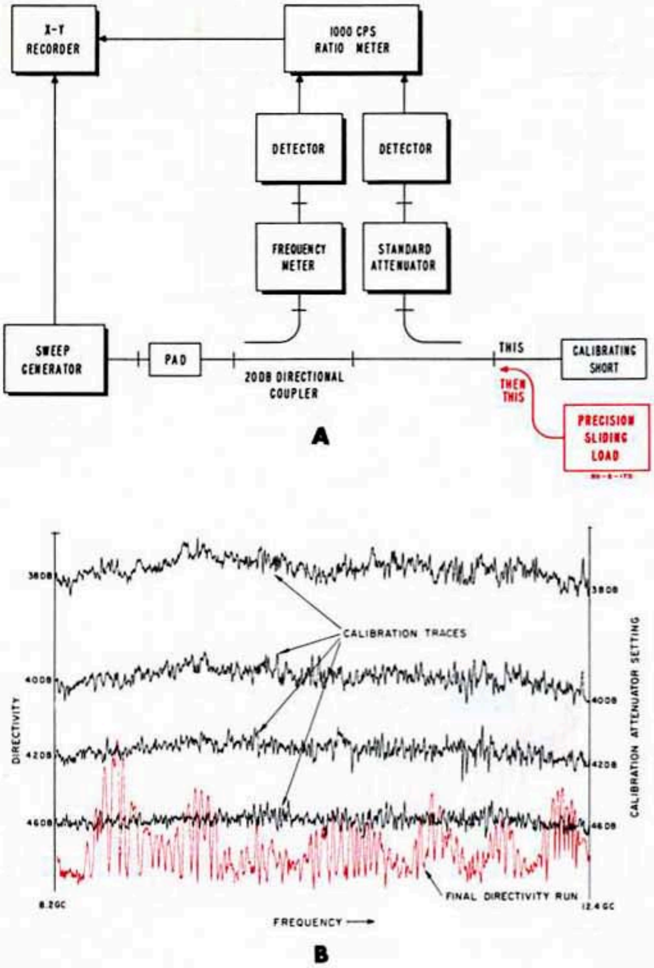

Figure 3. Coupler directivity measurement block diagram, and X-Y plot for a coupler with a specified directivity of 40 db. Average value of the final run is a good approximation of the directivity.

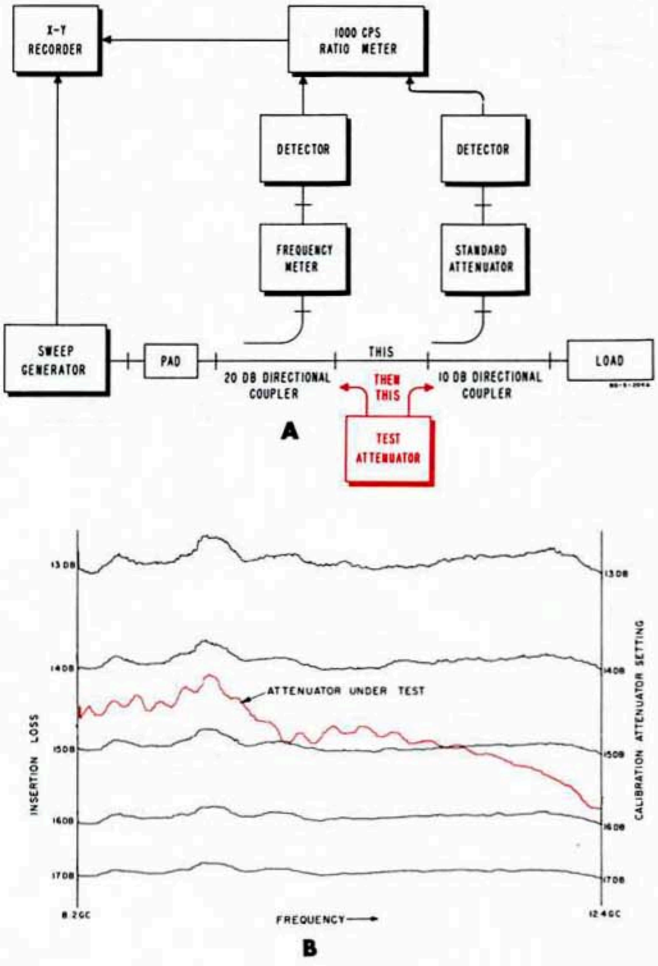

Figure 4. Typical setup for measuring attenuation, and the plot of a 15 db attenuator with a specified accuracy of ± 2 db.

an excellent technique for selecting couplers for specific application in systems which require exceedingly high directivity values over discreet bandwidths. This can be seen from figure 3B. The coupler tested had values over 45 db over a rather large segment of the band. This coupler if used in a production test reflectometer over only that given portion would result in directivity ambiguities of reflection coefficient of less than 0.005.

ATTENUATION MEASUREMENT

The block diagram of figure 4A and the calibration record of figure 4B show a typical swept frequency setup for making broadband attenuation measurements. In this case the reflected channel of the ratio meter becomes the transmission channel by placing the coupler-detector in the forward direction. The transmission detector should be isolated from the unknown test device by either a coupler or pad, so that power transmission versus frequency deviations will not cause significant broadband mismatch errors. These are considered later under error analysis.

Again, calibration grid lines are run using the precision standard attenuator set on and around the expected values of attenuation. After the unknown is inserted in the line the standard attenuator is set back to zero, and the final measurement curve may be easily run. (Note again that all system scalar errors are calibrated out using the precision standard attenuator because the transmission detector is made to operate under calibrate conditions in the same power regions as it will operate in the final measure condition.) Figure 4B shows the characteristics of a flap attenuator set to the 15 db position.

CRYSTAL MATCHING

A typical block diagram and associated series of measurements are shown in figures 5A and 5B for making matching curves of crystal detector mounts. Again, calibration grids are plotted using the standard attenuator to set up 1 db increments on a control crystal mount. With the precision attenuator set back to the center attenuation value (13 db in figure 5B), the crystal mounts under test are then applied sequentially to

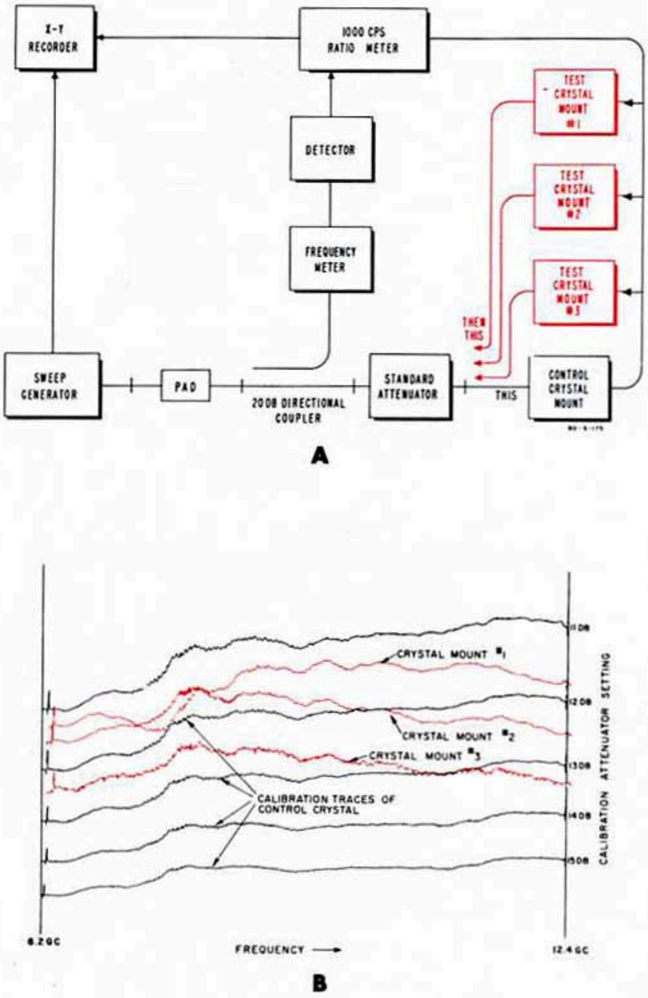

Figure 5. The frequency response characteristics of three crystals, and the system used. The control crystal is normally pre-calibrated, point-by-point.

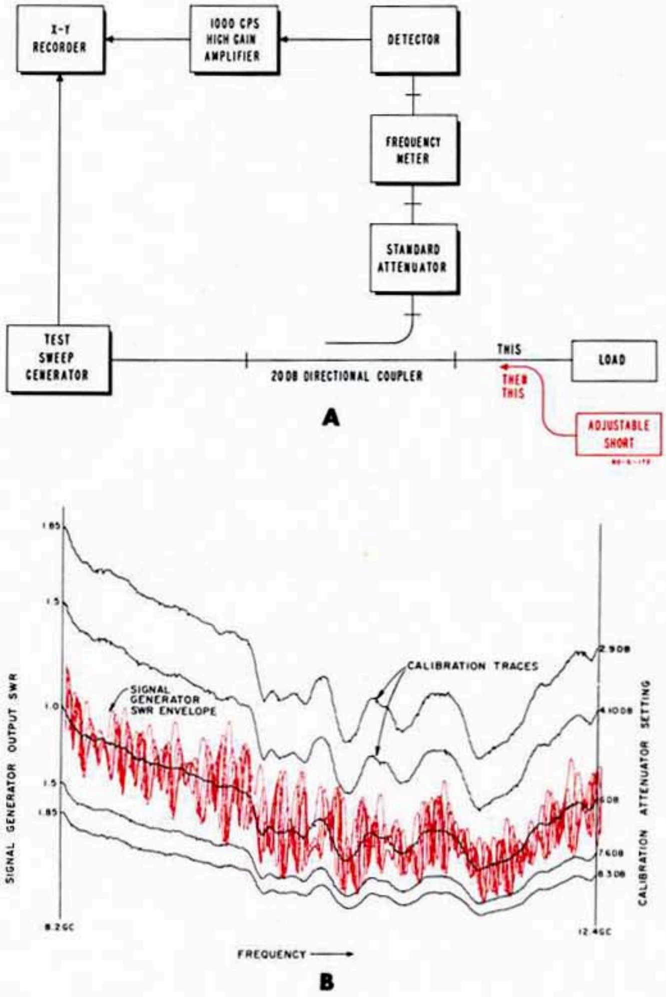

Figure 6. Block diagram and X-Y plot for measuring the output swr of a typical backward wave oscillator having a specified swr of 2.

the test setup and one curve run for each. Figure 5B shows a series of three mounts run against the control unit and it can be noted that the variations are quite close together in broadband frequency response. An additional calibration grid may be made at a lower detection power level to check square law operation of one mount versus the other. By plotting both high and low power levels of each mount on a transparent sheet, it is possible to match crystal detectors simply by holding two of the sheets against a light table along with a calibration grid on a third transparent sheet. Crystals may then be selected for frequency response and square law so that the two curves track within 1 db at both levels. The control crystal is normally calibrated for frequency response point-by-point against a power meter.

MEASUREMENT OF THE OUTPUT SWR OF A SIGNAL GENERATOR

Figures 6A and 6B show the simplified block diagram and the X-Y recorder plots of the output swr of a signal generator. The technique used is to apply a movable short at the output of the forward coupler and by adjusting the short's position back and forth, the 100% reflection is made to vary through all phases. Thus, the signal re-reflected by the generator and subsequently sampled by the forward coupler assumes various values across the band.

Calibration grids are plotted by setting in 6 db on the standard attenuator with a good load on the output. Two lines are now plotted, one above and one below this 6 db line, for a specified value of swr by setting the attenuator at a value of 20 Log 2 $(1 - \rho_g)$ for the upper swept frequency plot and 20 Log 2 $(1 + \rho_g)$ for the lower swept frequency plot. After resetting the standard attenuator to 6 db, several sweeps are made through the band, each time placing the adjustable short in a slightly different position. The resulting plot, therefore, is a series of oscillations about the original 6 db line and the envelope is the output swr. The curve shown on figure 6B is the output swr of a typical X-band backward wave oscillator for which the swr specification is 2.

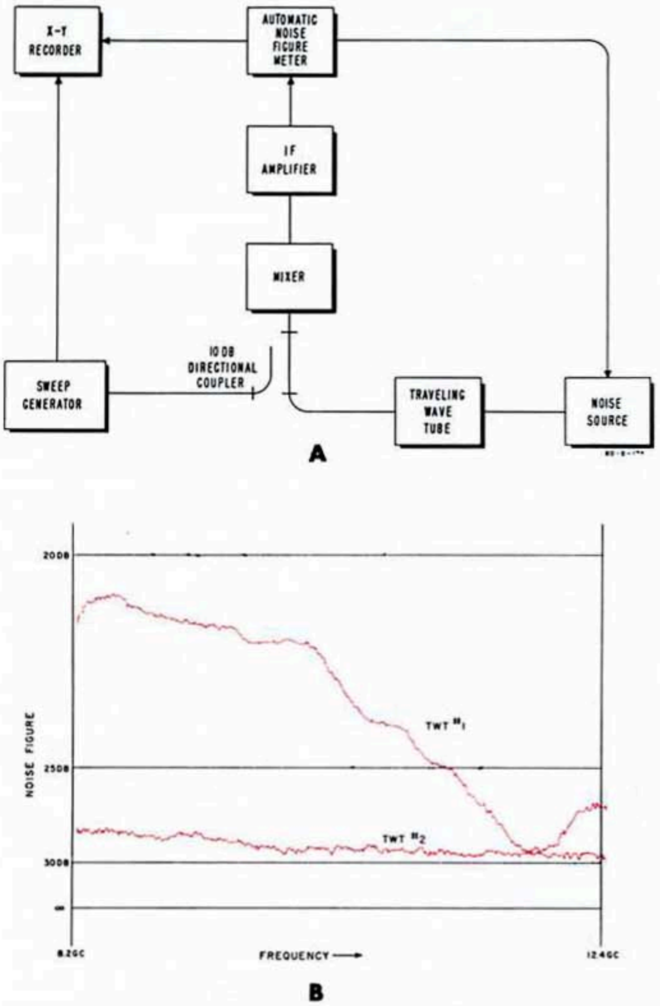

Figure 7. The noise figure for such broadband microwave devices as traveling wave tube amplifiers can be analyzed as shown. Receiver noise figure is negligible compared to the TWT contribution.

NOISE FIGURE MEASUREMENTS

Swept frequency noise figure analysis may be made on broadband microwave devices such as traveling wave tube amplifiers by providing a sweeping receiver and using an automatic noise figure meter. Figures 7A and 7B show the block diagram and a swept frequency plot of noise figure for traveling wave tube amplifiers at specific electrode potentials. The IF amplifier shown has a bandwidth of 1 mc and since the sweeping receiver has full image response, the noise figure meter responds to the average of two 1 mc windows spaced ±30 mc from the local oscillator frequency. This is normally adequate for measurements where the swept frequency plot is not changing rapidly.

For proper accuracy, it is necessary to make a calibrating run on the receiver itself to assure that its noise contribution is negligible. In figure 7A shown, the receiver noise figure remained below 15 db across the band, and thus adds no error to the TWT contribution of approximately 25 - 30 db.

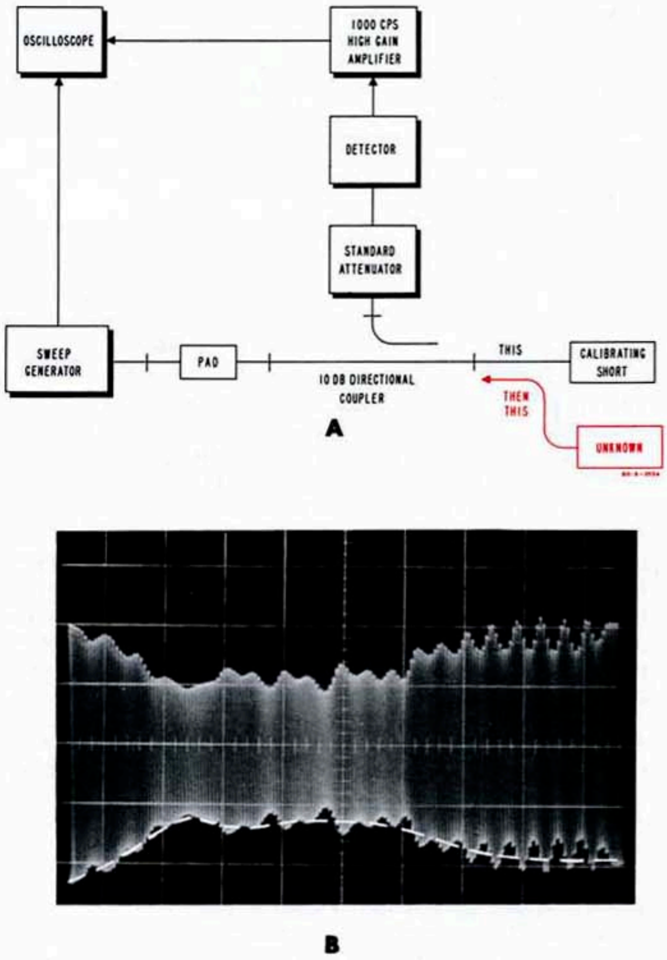

Figure 8. The faster oscilloscope technique, and an oscillogram of a typical calibration. Only the lower calibration line is shown.

FAST VISUAL MEASUREMENTS

Figure 8A shows the block diagram in which an oscilloscope is used for fast load reflection measurements. Such visual measurements are especially useful when adjustments must be made on the test component to bring it within specified limits over a broad frequency band. By using the oscilloscope technique, the slower sweep speeds required when using a ratio meter can be increased, and greater sensitivity can be realized by using the ⓗ Model 415D SWR Meter as a high gain, tuned audio amplifier. One watt ⓗ microwave amplifiers can be used to increase sweep generator output power, where needed.

Using the calibrating short and the standard attenuator, calibration lines are drawn directly on the oscilloscope face. Figure 8B shows a typical calibration of the system with the short in place, and the standard attenuator set at 20 db (reflection coefficient of 0.1). Although two calibration lines are necessary for each reflection signal level, only the lower one has been shown for illustrative purposes. Note that the small variations in signal amplitude (due to multiple system reflections not observed in the two coupler-ratio meter systems discussed earlier) are averaged out with the calibration line. If an adjustable short is used, these small variations can be moved, effectively eliminating generator mismatch effect on the calibration lines.

ERROR ANALYSIS

The errors inherent in these measuring systems are basically divided between vector errors and scalar errors. The vector error is primarily the directivity of the reverse coupler, and typical multi-hole precision couplers will have more than 40 db of directivity. This results in reflection coefficient errors of 0.01 in the final reading. Since these vector errors arrive at random phase as the band is swept, this becomes an ambiguity on the final reading. For a given reverse coupler setup actual directivity values may be measured on a broadband frequency basis and these values may be applied as limits of error on the calibration grids plotted throughout this paper. It is typically adequate, however, to determine an overall error in the measurement system and to apply this to the specified values of the device being measured and then merely set up a sufficiently tighter production specification to assure the overall sales specification.

A second vector error with second order effects is that caused by the directivity of the forward coupler which causes very slight variations in the forward detected power. Additional vector errors are the mismatch errors caused by the fact that the standard attenuator does not look into a matched system. This causes slight variations of transmitted power in going from the "calibrate" to "measure" condition. For instance, the standard attenuator of figure 2A looks one way into the secondary of a 10 db coupler and the other way into a 1.5 crystal mount. If the attenuator has an swr specification of 1.15 then the ambiguous mismatch errors are less than 0.4 db. This would amount to approximately 5% of the reflection coefficient, or, for example, 0.005 error in a 0.1 measurement. Analysis by flowgraph[4] confirms the error of ± 5% of reading.

Scalar error is set primarily by standard attenuator accuracy. Commercial rotary vane attenuators are specified at ± 2% of reading. For a return loss measurement of -20 db, for instance, 2% of the attenuator results in 5% error in the reflection coefficient reading. In addition, this scalar error may be minimized by point-by-point calibration of the standard attenuator. All other scalar variations such as coupling non-similarity and detector frequency response are calibrated out.

COAXIAL SYSTEMS

Similar measurements to those described above may be made using coaxial reflectometer systems. In those cases, broadband coaxial pads of various values are used as the standard attenuator for calibration. A number of manufacturers provide broadband coaxial attenuators with discreet 1 db values and these can serve as calibrating standards. The random directivity errors are somewhat larger in coaxial systems since the basic coupler directivity cannot be made as high. Thus, in the type N coaxial systems typical measurements are not made to as tight a tolerance as in the waveguide systems.

These tests have resulted in dramatic reduction of test time in certain areas. Directivity measurements on 26.5 - 40 gc directional couplers previously had required 26 point-by-point measurements across the band. Contrast this with several short calibration sweeps and a 10 second measurement sweep of figure 3B and the economy is obvious. In addition, of course, full range operating performance is assured.

TEST EQUIPMENT

The following Hewlett-Packard instruments and equipment items are available for performing the measurements described in this Application Note:

Block Diagram Description	hp Model Numbers
Sweep Generator	680 or 690 series
Ratio Meter	416B
Detector	421A, 423A, 424A, or 485 series
10 DB Directional Coupler	752C series
20 DB Directional Coupler	752D series
Calibrating Short or Adjustable Short	920 series
Frequency Meter	536 or 532 series
Standard Attenuator	382 series
Pad	370, 375, or 382 series
Load or Precision Sliding Load	914 series
1000 CPS High Gain Amplifier	415D
Automatic Noise Figure Meter	340B or 342A
Noise Source	347 series
Oscilloscope	120B, 122A, or 130C

For complete information on each item, see the Hewlett-Packard Microwave Catalog or individual Technical Data Sheets -- available from either your hp field office or directly from Hewlett-Packard.

Acknowledgement: Portions of this Application Note first appeared under the title "Improved Method Cuts Errors in Swept-Frequency Microwave Tests", by John Minck, in the June 7, 1961 issue of Electronic Design.

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[4] J. K. Hunton, "Analysis of Microwave Measurement Techniques By Means of Signal Flowgraphs", IRE Transactions on Microwave Theory and Techniques, March 1960, PP 206-212.