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The -*hp*- Microwave Reflectometers

EVER since directional couplers were developed, engineers have been interested in using them in reflectometer systems as a means for investigating microwave impedances. Compared to slotted line methods, such reflectometers offered several advantages, the most attractive being that measurements could be made very rapidly over wide frequency ranges. If desired, these measurements could be displayed on an oscilloscope for convenient examination.

Only infrequent use has been made of reflectometers, probably because the accuracies actually obtained in practice did not compare with the accuracies obtained with the slotted line method. The principal reason for poor accuracy was that the high directivities necessary in the reflectometers' directional couplers were obtained only over narrow frequency ranges if at all.

Development of the -*hp*- multi-hole directional couplers,[1] which have high directivities over the complete usual frequency range of a wave guide, has renewed interest in the reflectometer system. This interest, combined with the response to a reflectometer system described in an earlier issue,[2] has prompted development of a number of new -*hp*- equipments to make available a reflectometer whose accuracy when measuring small reflections is comparable to that of slotted line sections and whose speed allows investigation of reflection coefficient over wide frequency ranges in a few seconds' time. Further, the visual presentation obtainable enables non-technical personnel to make microwave impedance investigations on a basis suited to production work.

-*hp*- equipments are now available to form microwave reflectometers for the 8.2—10 kmc and 2.6—3.95 kmc frequency ranges. These systems (Fig. 1) consist basically of two precision directional couplers which feed samples of the incident and reflected voltages to separate detectors. The outputs from these detectors are applied to a new instrument, the -*hp*- Model 416A Ratio Meter, which automatically measures and displays the magnitude of the ratio of reflected to incident voltage, i.e., the magnitude of the reflection coefficient of the device being measured. If a visual presentation of the measured reflection coefficient is desired, the Ratio Meter can be connected to a d-c os-

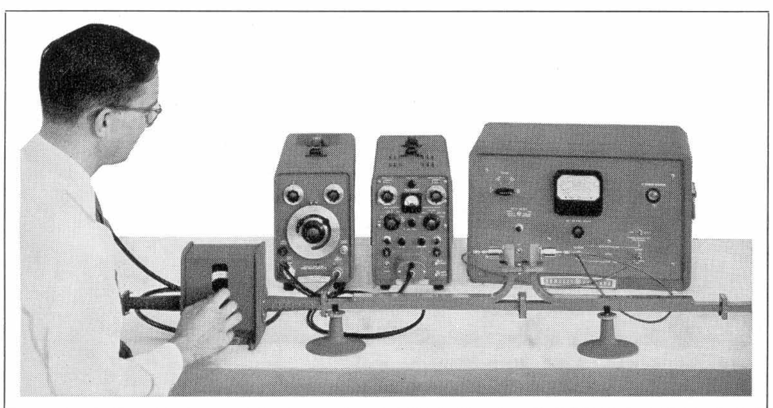

Fig. 1. *Reflectometer set-up being used for making rapid measurements of reflection coefficient magnitude over 8.2—10 kilomegacycle frequency range. Such a reflectometer competes with slotted lines for accuracy in measuring small reflections, is much faster to use over wide bandwidths, is thus better adapted to production applications.*

[1] *E. F. Barnett and J. K. Hunton, "A Precision Directional Coupler Using Multi-Hole Coupling", Hewlett-Packard Journal, Vol. 3, No. 7-8, March-April, 1952.*

[2] *E. F. Barnett, "More About the -hp- Precision Directional Couplers", Hewlett-Packard Journal, Vol. 4, No. 5-6, Jan.-Feb., 1953.*

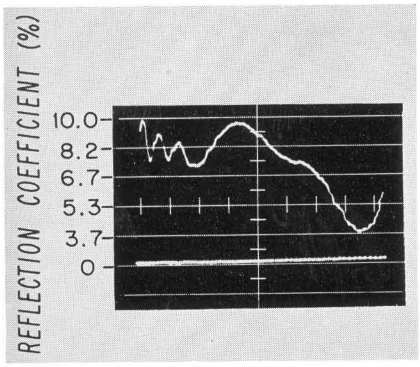

Fig. 3. *Typical scope pattern obtained when using reflectometer with oscilloscope. Above pattern shows measured reflection coefficient in percent over 8.2—10 kmc range.*

SUMMARY

The salient features of the reflectometer method for measuring reflection coefficient can be summarized as follows:

1. Reflectometers are available to measure the magnitude of reflection coefficients rapidly and with good accuracy over the 8.2—10 kmc and 2.6—3.95 kmc frequency ranges. The method is most practical for measuring reflection coefficients of up to approximately 0.5 (VSWR's of 3:1) but can be used with reduced accuracy to measure complete reflection.

2. When the reflectometer is calibrated with a short, accuracies of within approximately ± 0.02 can be obtained for reflection coefficients of 0.1 (VSWR of 1.22). For reflection coefficients of 0.4 (VSWR of 2.3) accuracies of within approximately ± 0.04 (VSWR of 1.08) can be obtained.

3. By suitably compensating residual signals at any one frequency with a slide-screw tuner and the Ratio Meter "Set to Full Scale" control, accuracies of within better than approximately ± 0.005 can be obtained at that frequency.

4. Twenty and ten db directional couplers are recommended for the forward and reverse positions, respectively, because these values accommodate power levels commonly available from signal sources. Higher accuracies will be obtained, however, if two 20 db couplers can be used.

5. The error figures cited are the worst possible error. Because this error consists of the sum of several smaller errors which can have any phase relation, most measurements will be made with somewhat better accuracy than the figures cited.

6. Reflection coefficient is a vector quantity $\rho_L = \frac{E_r}{E_i}$. The reflectometer measures the magnitude of this quantity $\left|\frac{E_r}{E_i}\right|$. Reflection coefficient magnitude is related to VSWR as follows:

$$|\rho_L| = \frac{VSWR-1}{VSWR+1}$$

7. The phase of reflection coefficients can be measured through use of special techniques. Information on how to make phase measurements can be furnished on request.

cilloscope with a long-persistence screen to obtain a presentation such as that shown in Fig. 3.

At present, the reflectometer for the 8.2—10 kmc range uses silicon crystals in broadband mounts as detector elements, while the reflectometer for the 2.6—3.95 kmc range uses barretters in broadband mounts as detectors. Since barretters offer advantages over crystals in reflectometer applications in that their characteristics are more nearly square-law, development of broadband barretter mounts for the 8.2—10 kmc range has been initiated. Reflectometer equipments for other frequency ranges are also in final development.

OPERATION

The signal for the reflectometer must be amplitude-modulated at a 1,000-cps rate (usually with a square wave), since the voltage-indicating system in the Ratio Meter is designed for a 1,000-cps (± 40 cps) frequency. In addition, for rapid broadband investigations, the signal should be swept over the range of interest and should provide a corresponding sweep voltage for the

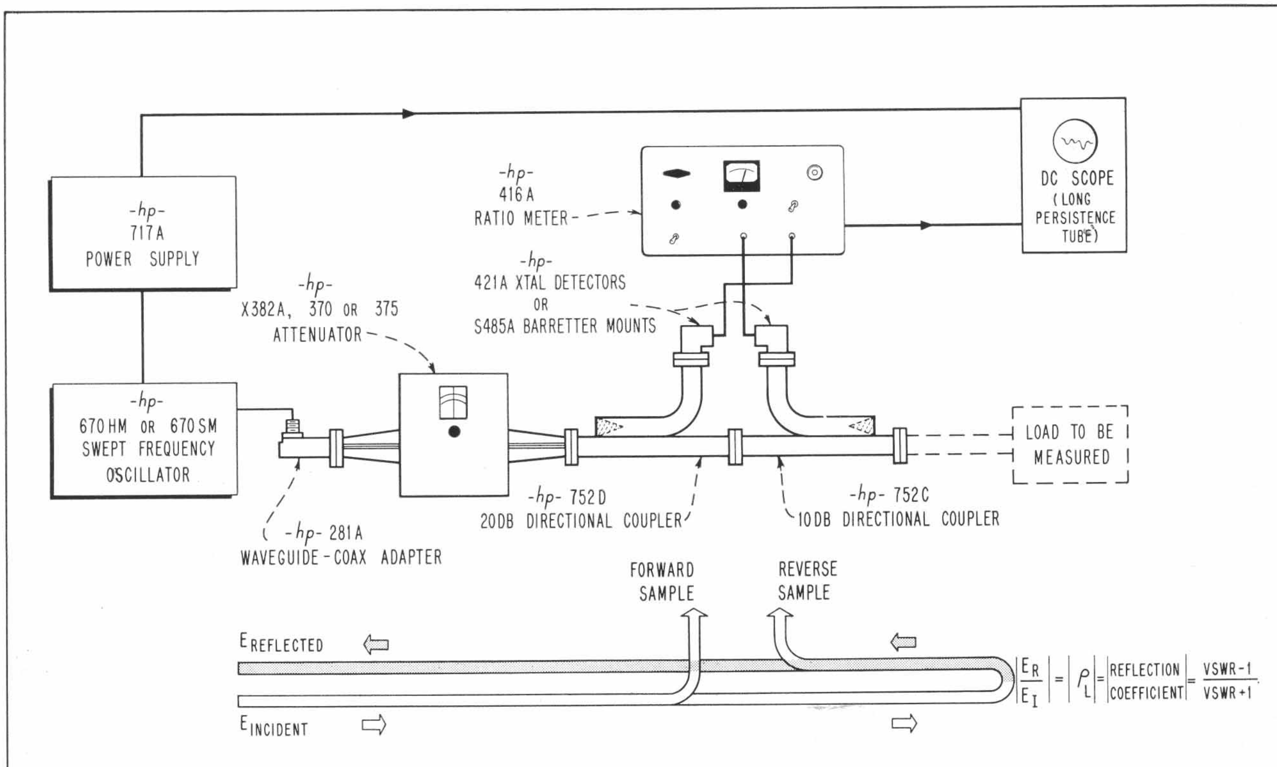

Fig. 2. *Components of microwave reflectometers. "S" preceding model numbers indicates equipments for 2.6—3.95 kmc range; "X" indicates 8.2—10 kmc range. Unmarked numbers are for either range. Not shown are AC-60K Matching Transformers which match S485A detectors for 2.6—3.95 kmc reflectometer to Ratio Meter.*

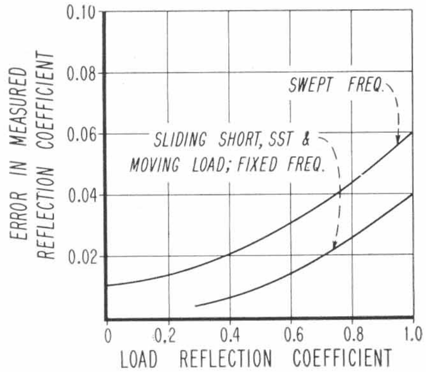

Fig. 4. *Accuracy obtained with reflectometer on swept-frequency operation after calibration and on single-frequency operation after minimizing residual signals.*

horizontal deflection system of an oscilloscope.

Power from the source flows down the main arms of the two couplers (Fig. 2) and impinges on the load. The power split off by the 20 db forward coupler is all passed to the forward detector, since the directivity characteristic of the multi-hole directional couplers prevents any but a negligible amount of the split-off power from turning back and being absorbed in the coupler's internal termination. The power split off the incident wave by the 10 db reverse coupler, however, is essentially all absorbed in that coupler's internal termination because of the reversed direction of connection of that coupler (Fig. 2).

If the magnitude of the reflection coefficient $\left|\frac{E_r}{E_i}\right|$ of the load is, say, 0.1, 10% of the incident voltage will be reflected back toward the source. As this reflection passes back through the main arm of the reverse coupler, a 10 db split occurs and is applied to the reverse detector. The remainder of the reflection will proceed back toward the generator where it will be absorbed in the generator impedance and in the termination in the forward coupler.

If the voltage component of the initial incident wave in the above example is assigned an arbitrary value of 0 db, the voltage level at the forward detector will have a value of —20 db. If the load's reflection coefficient is then 0.1 (20 db), the voltage level at the reverse detector will theoretically be —30 db. In practice, this level will be some 0.5 db low because of the power split from the incident wave by the forward and reverse couplers. Even more significant, though, is the fact that the level at the reverse coupler should be —40 db for the above example, since the assumed reflection coefficient was 0.1 and the level at the forward detector is —20 db. This 10 db discrepancy arises because the coupling values of the two directional couplers differ by 10 db. Both this discrepancy and the 0.5 db loss are very simply corrected by the calibration process described later.

Since the forward and reverse detectors consist of barretters or silicon crystals operated at low levels, they have a square-law characteristic. To preserve the true ratios of the forward and reverse voltage components at the outputs of these detectors, the Ratio Meter is calibrated on a square-law basis. This calibration also permits the Ratio Meter to be used, if desired, as a direct-reading indicator with crystal detectors in slotted line set-ups.

CALIBRATION AND ACCURACY

In principle the reflectometer method is superior to the slotted line method for measuring small reflections, because it measures the ratio of two quantities of dissimilar magnitude: [reflected voltage] ÷ [incident voltage]. By comparison, the slotted line method, at least for the important case of small reflections, measures the ratio of two quantities of similar magnitude: [incident voltage + reflected voltage] ÷ [incident voltage — reflected voltage]. In this case a small error in either quantity results in a relatively large error in the calculated value of reflected voltage or reflection coefficient. Further, the reflectometer is insensitive to changes in generator output level, changes that can cause relatively large errors in slotted line measurements when measuring low reflections.

While there are a number of possible errors in reflectometer systems,

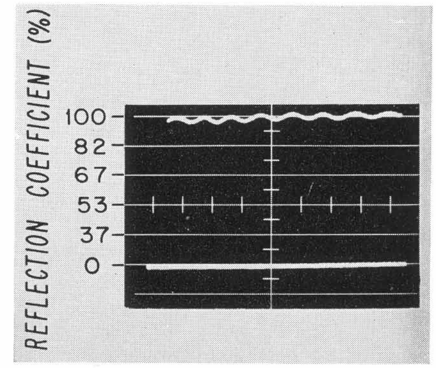

Fig. 5. *Typical scope pattern obtained when calibrating reflectometer with a short (100% reflection). Ripples in pattern are largest when measuring large reflections, become small when measuring small reflections.*

these are corrected by the calibration procedure to achieve an over-all accuracy on small reflections comparable to that of precision slotted lines. In specific terms the reflectometer system of Fig. 1, when calibrated, will give accuracies of reflection coefficient within ±0.02 (VSWR = 1.04) for loads of 0.1 reflection coefficient (VSWR = 1.22). Lower reflection loads will give accuracies approaching 0.01 reflection coefficient (1.02 VSWR).

To simplify the calibration process, the Ratio Meter is provided with two controls. One of these is an "Excess Coupler Loss" switch which changes the gain in the incident channel by 10 db. This compensates for the difference in coupling values when 20 and 10 db couplers are used in the reflectometer. The second control is a "Set to Full Scale" control which adjusts the gain of the inci-

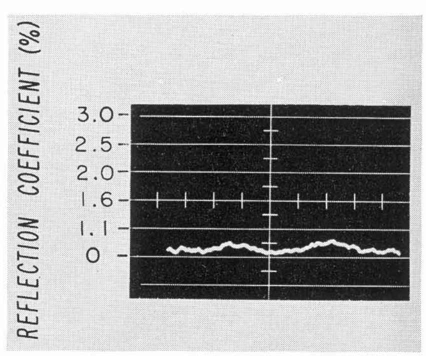

Fig. 6. *Typical scope pattern obtained when low-reflection 914A moving load is connected to the reflectometer. Reflection coefficient of moving load itself is not more than 0.005 at any frequency, so error in reflectometer can be seen to be less than 0.01 at any frequency.*

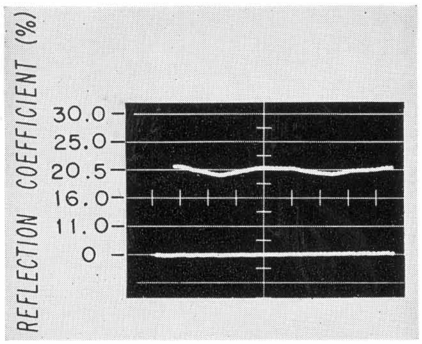

Fig. 7. *Typical oscilloscope pattern obtained when using Model X916 series standard reflections to provide a known reflection. Pattern shown is from an X916E 20% reflection.*

dent channel over a small range to compensate for the 0.5 db of power lost through splitting by the directional couplers.

The calibration process itself consists simply of setting these two controls for a Ratio Meter reading of 100% while a short is connected to the output of the reflectometer. Since the reflection coefficient of the short (1.00 or 100%) is known, adjusting the "Set to Full Scale" control removes most of the errors. The actual accuracy obtained is a function of the reflection coefficient of the load being measured as shown in Fig. 4 and described later.

When a reflectometer system is calibrated with a short, an oscilloscope presentation like that in Fig. 5 will be obtained. Although the fact that the pattern is not a smooth, straight line may be disturbing at first glance, it should be noted that the ripples and curvature are a residual error analogous to the residual error in slotted lines. Further, the ripples are much larger when measuring a large reflection coefficient (as is done when calibrating), than when measuring small reflection coefficients for which the reflectometer method is recommended. Thus, the fact that the ripples are relatively large should be ignored when calibrating with a short. The "Set to Full Scale" control should be adjusted so that the ripples fall equally above and below the 100% value; and this will give the accuracy shown for swept-frequency operation in Fig. 4.

To clarify further the point that ripples diminish when measuring small reflection coefficients, Fig. 6 is offered. This oscillogram shows the same residual ripple error illustrated in Fig. 5 as that error exists when measuring very small reflection coefficients. To make the oscillogram of Fig. 6, a low reflection load of about 0.005 was connected to the system, and it can be verified that the accuracy indicated by the swept-frequency curve in Fig. 4 is obtained.

The ripples obtained when calibrating are caused by small residual spurious signals which combine in random phase relations. The slight slope in Fig. 4 is caused by slight differences in the detector frequency characteristics and by differences in the coupling characteristics of the directional couplers. Slope is a constant-percentage type effect, while spurious signals usually reach a definite limit, which can be compensated at any single frequency but not over a wide frequency range.

CALIBRATING WITH STANDARD REFLECTIONS

Another method for calibrating a reflectometer involves the use of "standard reflections". Although this method is not as accurate as calibrating with a short at the proper r-f level, it is faster for some applications.

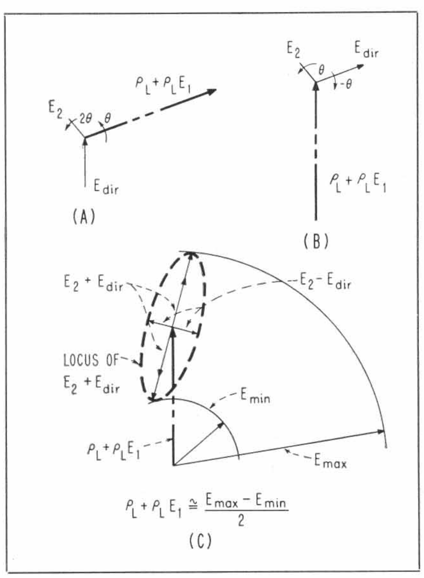

Fig. 8. *Diagram illustrating the three residual signals in reflectometer. (b) above is (a) redrawn to show relative rotation of vectors. (c) shows how taking arithmetic mean of maximum and minimum readings gives approximate value of desired reflection ρ_T.*

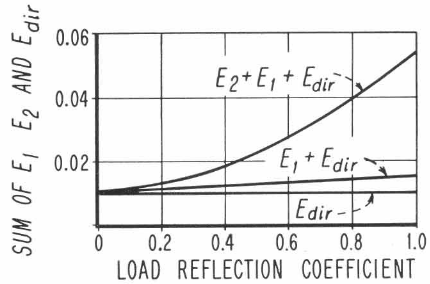

Fig. 9. *Sum of three residual signals as a function of load's reflection coefficient.*

The standard reflections consist of sections of undersize wave guide whose dimensions are accurately held to give known values of reflections. These reflections, the Model X916 series, have been designed for the 8.2—10 kmc reflectometer to give reflection values of 0.00, 0.05, 0.10, 0.15, and 0.20.

When used with the reflectometer, the reflections provide a line (Fig. 7) equal to the value of the reflection used. This line can be used as a "go—no go" mark when checking reflection coefficients of a number of similar devices. The use of standard reflections is thus particularly suited to production applications where non-technical personnel may be using the equipment.

SINGLE FREQUENCY MEASUREMENTS OF SMALL REFLECTIONS

When using a reflectometer on a wide-band basis, it often becomes desirable to investigate the reflection coefficient of the device being measured in more detail in the vicinity of a narrow frequency range. Usually, this situation occurs when the wide-band measurements indicate that the performance of the device being measured is marginal over a narrow range.

To investigate these situations, the accuracy of the reflectometer can be made very high by using special measurement techniques. These techniques consist of minimizing the small residual signals that can exist in a reflectometer as well as in nearly any measurement system. Those accustomed to minimizing the residual signals in slotted line systems will

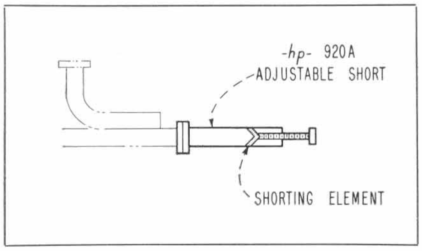

Fig. 10. *Model 920A adjustable short connected to output of reflectometer.*

recognize the similarity of reflectometer techniques in this respect to slotted line techniques.

It can be shown that the residual signals in the reflectometer, whether those that arrive at either the forward or reverse detector, can all be made equivalent to an error signal at the reverse detector. This error signal can be divided into three parts:

(a) a signal E_{dir} caused by imperfect directivity in the reverse coupler.

(b) a signal $\rho_L E_1$ which is proportional to the reflection coefficient of the load being measured, and

(c) a signal E_2 which is proportional to the square of the reflection coefficient of the load being measured.

These signals are diagrammed in vector form in Fig. 8.

At a single frequency it is possible to compensate almost exactly for these three signals. For example, the directivity signal E_{dir} can be compensated by inserting a slide-screw tuner just beyond the reverse coupler and setting up an equal and opposite cancelling signal. The signal $\rho_L E_1$ which is proportional to the load's reflection coefficient can be compensated by properly adjusting the "Set to Full Scale" control on the Ratio Meter while a unity-reflection adjustable short is connected to the system. If this signal is compensated for a 100% reflection, it will be compensated for all other reflection values (at that frequency), since it is proportional to the reflection coefficient of the load being measured. The third error signal E_2, because it is proportional to the square of the load's reflection coefficient, will become insignificant when measuring small reflections (Fig. 9).

To examine in detail how these residual signals are compensated, consider first the signal $\rho_L E_1$ which is proportional to the load's reflection coefficient. This signal by its nature adds directly to the signal ρ_L which is the desired reflection to be measured. To be able to compensate for $\rho_L E_1$, it is first necessary to identify the magnitude of $E_{dir} + E_2$ and thus isolate it from $\rho_L + \rho_L E_1$. This can be done by connecting an adjustable short at the output of the reverse coupler (Fig. 10). As the short is moved, the phase of all but the directivity signal will be changed. This is equivalent to rotating the two vectors $\rho_L + \rho_L E_1$ and E_2 in Fig. 8. Since vector E_2 is related to ρ_L^2 however, it will rotate twice as fast as vector $\rho_L + \rho_L E_1$, which is related merely to ρ_L. This circumstance will allow the value of $\rho_L + \rho_L E_1$ to be determined almost exactly by taking the arithmetic mean of the maximum and minimum readings obtained on the Ratio Meter as the short is moved. To compensate for residual error $\rho_L E_1$, then, it is only necessary to set the meter pointer in the Ratio Meter so that a 100% reading (total reflection) occurs midway between the pointer excursions. Error signal $\rho_L E_1$ will then have been essentially eliminated because the reflection coefficient of the short (100%) is known and because the meter pointer has been set to that value. The remaining meter excursions are caused by E_{dir} and E_2 and can be compensated as follows:

To tune out the directivity signal E_{dir}, the adjustable short should be removed and replaced as diagrammed in Fig. 11 with a slide-screw tuner and moving load which has a very small reflection coefficient. With this arrangement two signals will be present as shown in the vector diagram of Fig. 12. First, the (usually larger) directivity signal E_{dir} will occur, and secondly, a smaller reflection E_L will occur from the moving load and will change in phase as the load is moved. The signal E_2 will not be noticeable since it is dependent on the square of

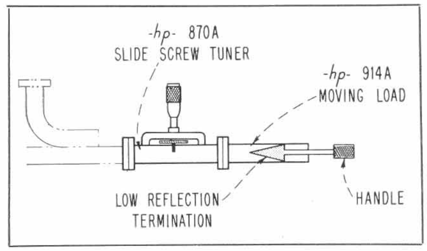

Fig. 11. *Model 870A slide-screw tuner and 914A moving load connected to output of reflectometer.*

the load's reflection coefficient and since the reflection coefficient of the 914A moving load is very small.

The technique of tuning out the directivity signal is to adjust the slide-screw tuner so that minimum *variation* of the Ratio Meter pointer occurs as the load is moved. If this adjustment is made carefully, the Ratio Meter pointer can be made almost completely free from variation. If both signals should happen to be very small at a particular frequency, the pointer will drop into the noise region of the Ratio Meter where any variations will be so small as to be insignificant. When meter pointer variation is minimized, the directivity signal E_{dir} will have been almost completely compensated. Since signal $\rho_L E_1$ has already been compensated and signal E_2 naturally becomes very small, the residual error in the reflectometer will ordinarily be very small (less than about 0.005 or a VSWR of 1.01).

When the "Set to Full Scale" control and the slide-screw tuner have been adjusted in the foregoing manner, the reflectometer is ready to make its most accurate measurements. It should be noted, however,

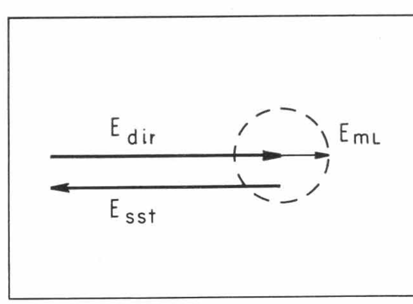

Fig. 12. *Reflection E_{sst} from slide-screw tuner cancels directivity signal E_{dir} so that only 0.005 or less reflection from 914A moving load remains.*

that the system will be flat only at a single frequency.

So far the error contributed by the Ratio Meter itself has not been discussed. Ratio Meter error, however, is so small that it can be included in the 0.005 tolerance given above. The Ratio Meter is rated as being accurate within 3% of full scale, so that on the lowest (3%) range Ratio Meter tolerance is only 0.0009.

EQUIPMENT CONSIDERATIONS

For most accurate wide-band use of a reflectometer, a number of considerations apply to the equipments which are used as the components of the reflectometer. These considerations are discussed below.

SIGNAL SOURCE

The signal source, as discussed earlier, must be square-wave modulated at a rate of 1,000-cps and must be swept at a low rate for wide-band use. To avoid obscuring narrow-range phenomena or fine structure in the plot of ρ_L *vs.* frequency, the sweep rate should not exceed about 2–3 cycles per second.

Power provided by the signal source should be not less than about 1 milliwatt (0 dbm). This requirement occurs because, when measuring small reflections in the order of 1% with a 0 dbm signal, the power level into the reverse detector will be in the vicinity of —50 dbm. The output of the detector for such an input is approximately 1 microvolt, close to the noise level in the system. It further happens that levels of approximately 0 dbm offer advantages in the accuracy obtained when calibrating with crystal detectors, as will be described later.

The power should be supplied from a reasonably well matched source to minimize reflections from the source. The type 670 oscillator indicated in the diagrams has a maximum output of approximately +10 dbm to provide a margin for isolating the source impedance with a 6–10 db pad.

DIRECTIONAL COUPLERS

Directional couplers have three characteristics that are significant in reflectometer use. First, there is the directivity characteristic of the couplers. This is the ratio of the power flowing in the forward direction in the auxiliary arm of the coupler to the power flowing in the reverse direction when power is only flowing in the forward direction in the main arm. In the *-hp-* multi-hole couplers, this ratio is at least 40 db. In fact, at most frequencies the ratio is 46 db (0.5% voltage-wise) or more. As mentioned earlier, it is the high directivity of these couplers over a waveguide frequency range that makes the reflectometer system practical. The 40 db directivity can contribute a small error in swept operation, but this can be compensated at fixed frequencies, as described earlier. The error in swept operation is included in that shown in Fig. 4.

The second characteristic of directional couplers is only of passing interest in reflectometer usage, because it is accounted for in the calibration process. This characteristic is the accuracy of the mean coupling over the frequency range of the system. The couplers are rated as being accurate in this regard within 0.4 db, but any inaccuracy is compensated when the "Set to Full Scale" control on the Ratio Meter is adjusted during the calibration procedure.

The third coupler characteristic that affects the reflectometer is the variation in coupling as a function of frequency. More specifically, if the difference in coupling between the two couplers is not constant with frequency, the pattern obtained on the oscilloscope will have a slope. If significant, this slope will be noticeable in the calibration process and can be corrected by applying to the measured value a factor which is the inverse of the slope error.

CRYSTAL DETECTORS

Crystal detectors, which are the type of detectors presently used in the 8.2–10 kmc reflectometer, have three characteristics that are of importance in reflectometer use. First is the accuracy of the square-law relation of the crystals, i.e., the linearity between input r-f power and output audio voltage from the detectors. The *-hp-* Model X421A Waveguide Crystal Detector Mounts indicated in Fig. 2 are specially designed to achieve minimum deviation from an accurate square-law characteristic. To achieve this, the resistive load for the crystals is incorporated into the mounts and is selected to obtain minimum square-law deviation, as indicated by the curves in Fig. 13. By selecting load resistances, the deviation of the detectors from a true square-law characteristic is held to less than ±1 db for an input range from 0 dbm to noise level.

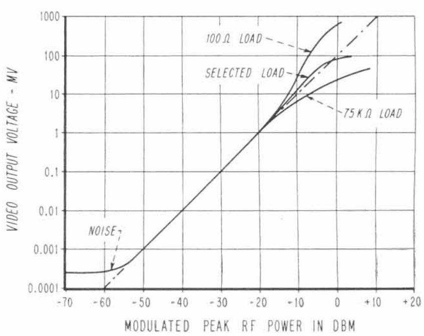

Fig. 13. *Typical square-law characteristic of X421A crystal detector with selected built-in load resistance. Since small but significant deviation from true square-law characteristic occurs at levels above about —5 dbm, calibration at lower levels is recommended.*

The error introduced into a measurement because of detector variation from square-law is a function of the power level applied to the detector when the system is calibrated. This error is plotted in Fig. 14. From this curve it will be seen that it is desirable to operate the

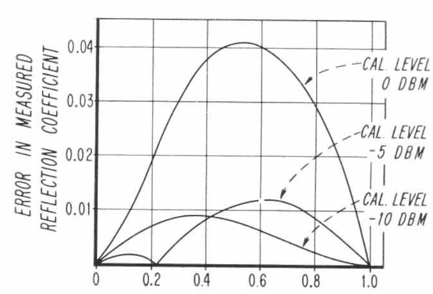

Fig. 14. *Effect of calibration level at crystal detector on accuracy of reflectometer.*

reverse detector at levels no higher than —10 to —5 dbm when calibrating. If a 10 db coupler is used in the reverse position, this requirement will mean that the output from the signal source should not exceed approximately 0 to +5 dbm. The error contributed by detector characteristic variations will then not exceed approximately 0.005 for low values of reflection coefficients.

The second characteristic of crystal detectors that influences their use in reflectometers is the input VSWR of the mounts. If the mounts are not a perfect match for the system, some of the power applied to a mount will be reflected. This will lead to small spurious signals in the reflectometer. The effect of these is included in Fig. 4.

The third significant characteristic of detectors is their rectification efficiency as a function of frequency. This characteristic is similar to the frequency variation in coupling in directional couplers in that it is deviations from a constant difference in rectification efficiency that are of significance. Such deviations in detector characteristics also lead to a slope in the oscilloscope presentation. To minimize such slope, the Model X421A detector mounts are available in matched pairs when intended for reflectometer use.

BARRETTERS

When used as detector elements for the reflectometer, barretters are subject to the same three considerations as crystals, i.e., accuracy of square-law characteristic, input VSWR, and rectification efficiency with frequency. In each of these respects, however, barretters are usually superior to crystals. For this reason broadband barretter mounts have been developed for the 2.6—3.95 kmc reflectometer and are being developed for other microwave ranges.

Since barretters require biasing power to raise their resistances to convenient levels, later models of the 416A Ratio Meter are provided with a special jack on the back of the instrument for supplying barretter bias current. This jack is arranged to operate with two *-hp-* AC-60K Matching Transformers to supply 8.75 ma ±10% to barretters. The Matching Transformers also serve to match the barretters to the Ratio Meter signal input jack.

ADJUSTABLE SHORT

Since the adjustable short is used for calibration purposes, it is assumed that it has a reflection coefficient of 1.00 (total reflection). The Model 920A short indicated in the diagram has a loss of less than 0.01 db over that of a carefully-constructed fixed short. This loss is equivalent to that encountered in only a few inches of waveguide. The error introduced by this loss is thus too small to be noticed, even in the highest-accuracy measurements.

MOVING LOAD

The 914A moving load consists of a flat termination mounted in a section of wave guide and provided with an extension rod for moving the termination. The termination has a small reflection of not more than 0.005 so that it is well-suited to checking the reflectometer.

OSCILLOSCOPE

For reflectometer use, an oscilloscope must be direct-coupled because of the low-frequency sweep rates employed. In addition, a long-persistence crt is desirable.

—J. K. Hunton and N. L. Pappas

SPECIFICATIONS

-hp- MODEL 717A KLYSTRON POWER SUPPLY

BEAM SUPPLY:
VOLTAGE RANGE: 800 to 1,000 volts.
CURRENT: 25 ma, maximum.
REGULATION: (a) For constant load, less than ±0.1% output voltage change for ±10% variations from 115-volt line. (b) Less than ±1% output voltage change for output currents from 0 to 25 ma.

HUM: Less than 10 millivolts.

REFLECTOR SUPPLY:
VOLTAGE RANGE: 0 to 600 volts in 3 ranges; 0-300, 200-400, 300-600 volts.
CURRENT: 1 ma maximum; source resistance approximately 300 K ohms.
REGULATION: For constant load, less than ±0.05% change for ±10% variations from 115-volt line.
HUM: Less than 10 millivolts.
SQUARE WAVE MODULATION: (a) Amplitude adjustable 0 to 60 volts peak-to-peak. (b) Rise and decay times less than 10 microseconds. (c) Frequency adjustable from 400 to 1,000 cps.
SINE WAVE MODULATION FOR FM'ing: (a) Amplitude adjustable from 0 to 300 volts peak-to-peak. (b) Frequency: line voltage frequency. (c) Oscilloscope horizontal sweep voltage: 15 volts peak-to-peak, phase adjustable ±45° with respect to modulating voltage.
EXTERNAL: Terminals available for applying external modulating voltage. System will pass 3 microsecond pulses.

GRID SUPPLY:
VOLTAGE RANGE: 0 to +30 volts, open circuit, referred to cathode potential.
SQUARE WAVE MODULATION: (a) Amplitude adjustable 0 to 60 volts peak-to-peak. (b) Rise and decay times less than 10 microseconds. (c) Frequency adjustable from 400 to 1,000 cps.
EXTERNAL: Terminals available for applying external modulating voltage. System will pass 3 microsecond pulses.
FILAMENT SUPPLY: 6.3 volts ac., 2 amps.
CONNECTORS: (a) "Oscilloscope Output" and "External Modulation," BNC Type. (b) Klystron voltages, 6 standard -hp- terminals, see "Accessories Furnished" below.
POWER SUPPLY: 115/230 volts ±10%, 50/60 cps, approximately 150 watts.
SIZE: 7" wide, 10¾" high, 18" deep.
WEIGHT: 34 lbs., shipping weight approximately 85 lbs.
ACCESSORIES FURNISHED: Output cable, matching panel jack one end, other end terminated in plug for -hp- 670 series SHF Oscillator.
PRICE: -hp- Model 717A Klystron Power Supply $375.00.

-hp- MODEL 670HM SHF OSCILLATOR

FREQUENCY RANGE: 7.0 kmc to 10.0 kmc.
OUTPUT POWER: Approximately 10 mw entire frequency range.
ATTENUATOR RANGE: 100 db.
MODULATION: (a) Grid Modulation for optimum swept-frequency performance. (b) Reflector Modulation for optimum single-frequency performance. Modulating signals must be provided from external source (normally the -hp- 717A Power Supply). Pulses as short as 3 microseconds can be produced.
MECHANICAL SWEEP: Fully adjustable to cover any 10% or larger portion of the 7.0 kmc to 10.0 kmc spectrum. Sweep rate approximately 12 to 60 complete cycles per minute depending on swept frequency range. (Special sweep rates available at additional charge.)
SWEEP VOLTAGE PROVIDED: Linear voltage proportional to mechanical sweep. (Approximately 50 volts change provided for 7 to 10 kmc swept frequency range.)
CONNECTORS: (a) Coaxial Type N on Panel for r-f output. (b) Type BNC at rear for sweep voltage. (c) Special connector with mating piece furnished for external power supply.
POWER SUPPLY: Operates from 115 v, 50-60 cps, 25 watt source. Also requires external supply such as -hp- Model 717A Klystron Power Supply which will provide 1,000 volts, 20 ma; 0 to 600 volts, 5 ma; 6.3 volts ac, 0.6 amp.
KLYSTRON TUBE: Raytheon 5721. (Supplied with instrument.)
ACCESSORIES FURNISHED: Power cable.
ACCESSORIES AVAILABLE: -hp- AC-16Q 6' RF Cable $12.00.
-hp- AC-16D 44" Video Cable $2.65.
PRICE: -hp- 670HM SHF Oscillator, Cabinet Mount, $850.00. (Can be obtained without sweep motor for manual operation at $750.)

Specifications continued next page

-hp-

MODEL 670SM UHF OSCILLATOR

Similar to Model 670HM described above except covers frequency range from 2.6 to 3.95 kmc.

PRICE: *-hp-* 670SM UHF Oscillator, Cabinet Mount, $1,000.00. (Can also be obtained without sweep motor for manual operation at $900.00.)

-hp-

MODEL 416A RATIO METER

METER PRESENTATION: (a) As a Reflectometer: Percent reflection (magnitude of reflection coefficient). Four ranges, full scale values of 100%, 30%, 10%, 3% reflection. (1.00, 0.30, 0.10, 0.03 reflection coefficient.) (b) As a VSWR Indicator Voltage Standing Wave Ratio. Four ranges, 1 to 3, 3 to 10, 10 to 30, 30 to 100 VSWR. (c) Decibel scale for either application: 0 to 10 db, 40 db total, ranges spaced exactly 10 db.

ACCURACY: ±3% of full-scale value for 20 to 1 range of incident or reference r-f power.

CALIBRATION: Square-law, for use with Crystal Detectors or barretters.

FREQUENCY: 1,000 cps ±40 cps.

INPUT VOLTAGE: Incident or Reference Channel: 3 mv to 100 mv rms. Reflected or Probe Channel: 0.3 mv to 100 mv rms. (Square-wave or sine-wave).

INPUT IMPEDANCE: Approximately 75 K ohms, each channel.

EXCESS COUPLER LOSS: Provision made for increasing sensitivity of the Incident Channel by 10 db for reflectometer setups employing couplers with different coefficients. Under certain circumstances, accuracy can be improved by this procedure.

OUTPUT: Connectors provided for oscilloscope and for high impedance recorder.

ADJUSTMENTS: "Set to Full Scale" control for initial calibration with 100% reflection, or at VSWR peak.

INTERNAL CHECK: "Eye" tube continuously monitors input amplitude (and frequency indirectly) to assure proper operating range for instrument and for crystal detectors.

CONNECTORS: Type BNC.

POWER SUPPLY: 115/230 volts ±10%, 50/60 cps, 90 watts.

SIZE: Cabinet Mount: 12½" high, 20¾" wide, 14½" deep. Rack Mount: Panel 10½" high, 19" wide, 14½" deep.

WEIGHT: Cabinet Mount: 32 lbs., Shipping weight approximately 88 lbs. Rack Mount: 28 lbs., Shipping weight approximately 78 lbs.

ACCESSORIES FURNISHED: 2 *-hp-* AC-16K Cable Assemblies. Consists of 4 ft. of RG-58/U 50-ohm coaxial cable terminated on each end with UG-88/U type BNC male connectors.

ACCESSORIES AVAILABLE: *-hp-* AC-60K Matching Transformer for matching two 200-ohm barretters to Ratio Meter input. Barretter bias current of 8.75 ma ±10% supplied by Ratio Meter. Price on request. Includes one AC-16A and two AC-16K Cable Assemblies. Also available: *-hp-* AC-16D Cable Assembly $2.65.

PRICE: *-hp-* Model 416A Ratio Meter, Cabinet Mount, $365.00. *-hp-* Model 416AR Ratio Meter, Rack Mount, $350.00.

-hp-

MODEL X382A PRECISION ATTENUATOR

FREQUENCY RANGE: 8.2 - 12.4 kmc.

WAVEGUIDE SIZE: 1" x ½".

POWER-HANDLING CAPACITY: 10 watts, average, continuous duty.

SIZE: Length, 15½"; Height, 7¾"; Depth, 4½".

CALIBRATED RANGE: 0 - 50 db.

ATTENUATION AT ZERO SETTING: Less than 1 db. Calibration data available on request.

PHASE SHIFT: Variation less than 1° for attenuator settings up to 40 db at any frequency.

VSWR: Less than 1.15 entire range of attenuation and frequency.

ACCURACY: ±2% of the reading in db, or 0.1 db, whichever is greater. Includes calibration error plus frequency error.

WEIGHT: 5 lbs. net; 19 lbs. shipping.

PRICE: *-hp-* Model X382A Precision Waveguide Attenuator $250.00.

-hp-

MODEL X421A WAVEGUIDE CRYSTAL DETECTOR MOUNT

FREQUENCY RANGE: 8.2 kmc to 12.4 kmc.

SENSITIVITY: Approximately 1 mv/0.01 mw (average value).

VSWR: Less than 1.5 entire frequency range.

FREQUENCY RESPONSE: Flat within ±2 db entire frequency range.

SQUARE-LAW CHARACTERISTIC: Within ±1 db over 40 db range for maximum input power less than 1 mw.

MATCHED PAIRS: When X421A's are ordered as "matched pairs," tolerance on frequency response and square-law characteristics combined, but excluding basic crystal sensitivity, is held to within ±1 db for the pair.

DETECTOR ELEMENT: 1N26 Silicon Diode.

VIDEO LOAD: Optimum value video-load resistor selected and installed for crystal detector supplied.

WAVEGUIDE SIZE: 1" x ½", flat cover flange.

OUTPUT CONNECTOR: Type BNC.

REPLACEMENT CRYSTAL: Supplied with matched video-load resistor: *-hp-* X421A-95A, $15.00.

SHIPPING WEIGHT: Approximately 1 lb.

PRICE: *-hp-* X421A Waveguide Crystal Detector Mount, $75.00. (Includes 1N26 Silicon Diode and matched video-load resistor.)

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MODEL X916 STANDARD REFLECTIONS

MODEL	*Nominal Reflection Coefficient*	*Accuracy of Reflection Coefficient*
X916A	0.00	±0.002
X916B	0.05	±0.0025
X916C	0.10	±0.0035
X916D	0.15	±0.0045
X916E	0.20	±0.007

FREQUENCY RANGE: 8.2 to 12.4 kmc.

WAVEGUIDE SIZE: 1" x ½", flat cover flanges.

SIZE: 1⅝" x 1⅝" x 8⅜" long.

WEIGHT: 2 lbs., packed for shipment.

PRICE: *-hp-* Model X916 Standard Waveguide Reflection $100.00.

-hp-

MODEL S485A DETECTOR MOUNT (with barretter element)

MAXIMUM VSWR: 1.35

FREQUENCY RANGE: 2.60 - 3.95 kmc.

WAVEGUIDE SIZE: 3 x 1½".

LENGTH: 4⅝".

SHIPPING WEIGHT: 7 lbs.

PRICE: $125.00

-hp-

MODEL 370 FIXED WAVEGUIDE ATTENUATORS

	Model S370	*Model X370*
FREQUENCY RANGE (kmc):	2.60 - 3.95	8.20 - 12.4
WAVEGUIDE SIZE (in.):	3 x 1½	1 x ½
WAVEGUIDE TYPE:	RG-48/U	RG-52/U
FLANGE TYPE:	UG-53/U	UG-39/U
CALIBRATION FREQUENCY (kmc):	3.0	10.0
PRICE:	$75.00	$55.00

For db attenuation use suffix on Model No.

3 db	A
6 db	B
10 db	C
20 db	D

POWER HANDLING CAPACITY: 1 watt average, 1 kilowatt peak.

VSWR: Less than 1.15, full frequency range.

ACCURACY: ±0.2 db at calibration frequency.

FREQUENCY SENSITIVITY: Less than ±20% of nominal attenuation value in db, full frequency range.

-hp-

MODEL 375A VARIABLE FLAP ATTENUATORS

	Model S375A	*Model X375A*
FREQUENCY RANGE (kmc):	2.60 - 3.95	8.20 - 12.4
WAVEGUIDE SIZE (in.):	3 x 1½	1 x ½
WAVEGUIDE TYPE:	RG-48/U	RG-52/U
FLANGE TYPE:	UG-53/U	UG-39/U
POWER DISSIPATION:	1 watt	0.5 watt
PRICE:	$110.00	$50.00

-hp-

MODEL 752 DIRECTIONAL COUPLERS

COUPLING: S752C = 10 db coupling
S752D = 20 db coupling
X752C = 10 db coupling
X752D = 20 db coupling

	Model S752	*Model X752*
WAVEGUIDE SIZE (in.):	3 x 1½	1 x ½
FREQUENCY RANGE (kmc):	2.6 - 3.95	8.2 - 12.4
APPROX. LENGTH (in.):	39	15½
SHIPPING WEIGHT (lbs.):	75	6
PRICE:	$210.00	$100.00

DIRECTIVITY: Better than 40 db over entire frequency range.

COUPLING ACCURACY: Mean coupling level is within 0.4 db of specified value.

COUPLING VARIATION: Not more than ±0.5 db over frequency range.

PRIMARY GUIDE VSWR: Less than 1.05 with "perfect" termination.

-hp-

MODEL 870A SLIDE SCREW TUNERS

	Model S870A	*Model X870A*
FREQUENCY RANGE (kmc):	2.6 - 3.95	8.20 - 12.40
WAVEGUIDE SIZE (in.):	3 x1½	1 x ½
WAVEGUIDE TYPE:	RG-48/U	RG-52/U
LENGTH (in.):	9⅞	5½
FLANGE TYPE:	UG-53/U	UG-39/U
SHIPPING WEIGHT (lbs.):	15	3
PRICE:	$170.00	$125.00

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MODEL 920A ADJUSTABLE SHORTS

	Model S920A	*Model X920A*
FREQUENCY RANGE (kmc):	2.60 - 3.95	8.20 - 12.40
WAVEGUIDE SIZE (in.):	3 x1½	1 x ½
WAVEGUIDE TYPE:	RG-48/U	RG-52/U
FLANGE TYPE:	UG-53/U	UG-39/U
PRICE:	$80.00	$50.00

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MODEL 914A MOVING LOADS

	Model S914A	*Model X914A*
FREQUENCY RANGE (kmc):	2.60 - 3.95	8.20 - 12.40
WAVEGUIDE SIZE (in.):	3 x1½	1 x ½
PRICE:	$100.00	$50.00

All prices f.o.b., Palo Alto, California
Data subject to change without notice