HEWLETT-PACKARD COMPANY

# APPLICATIONS OF THE 416A RATIO METER

## APPLICATION NOTE 42

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TAKEN FROM HEWLETT-PACKARD MODEL 416A
RATIO METER INSTRUCTION MANUAL

# SECTION IIB

# APPLICATIONS OF THE 416A RATIO METER

## 2B-1 GENERAL

This section is furnished as an appendix to Section 2A. The material contained in this section deals with the set-ups and techniques connected with operating the 416A in typical applications. Information is given for using the 416A in a slotted line system and also information on general applications using the 416A Ratio Meter. The main portion of this section is devoted to application details involving the 416A in reflectometer set-ups. Techniques and relative accuracies obtainable under different conditions are discussed in detail, including the steps needed to correct for all errors.

## 2B-2 SLOTTED LINES

GENERAL - With the 416A used as the SWR indicator in a slotted-line setup, an advantage in accuracy is obtained. The twin-input feature of the 416A makes it possible to sample reference and standing-wave voltages simultaneously, thus eliminating errors which would otherwise result from source amplitude variations during measurement.

Techniques which may be used in measuring standing-wave ratios, possible sources of error, and general precautions to be observed in setting up and operating a slotted-line system are discussed in texts such as Terman & Pettit's Electronic Measurements, in the Hewlett-Packard Journal article Good Practice in Slotted Line Measurements (Vol. 3, Nos. 1, 2), and in instruction literature on hp slotted-line sections, such as the book on the Model 805 Slotted Line.

The following instructions are limited to those which are specific to the use of a Model 416A in a slotted-line system.

Equipment Requirements - A typical waveguide slotted-line setup, using a 416A as the SWR indicator, is shown in Figure 2B-1.

Signal Source - Must include facilities for amplitude modulation at 1 kc rate.

Directional coupler and associated detector - High directivity coupler required; Model 752D (20 db coupling coefficient) recommended for reference coupler. Detector must be square law.

CAUTION

No ratio meter indication can be obtained unless signal from reference detector and signal from probe detector are of same polarity.

Slotted Line Section - The probe detector used with the 416A must be a square-law device.

Operating Procedure -

a. Put signal source into operation.

b. Assemble system. Arrangement of devices is indicated in Figure 2B-1.

NOTE

To avoid danger of overloading ratio meter and probe detector, do not connect probe to 416A at this time.

c. With 416A plugged into source of specified voltage and frequency, and power switch at ON, allow warm-up period of approximately five minutes.

d. Set EXCESS COUPLER LOSS at 0 DB.

e. Check that SET TO FULL SCALE is not fully clockwise.

Fully clockwise is maximum gain; some margin of gain must be available at start of calibration procedure.

f. Check that modulation frequency and level of input signal are within 416A operating limits. Procedure is given in 416A Operating Procedure.

g. Connect output of probe detector to REFLECTED/PROBE input on the 416A.

h. Calibrate the ratio meter:

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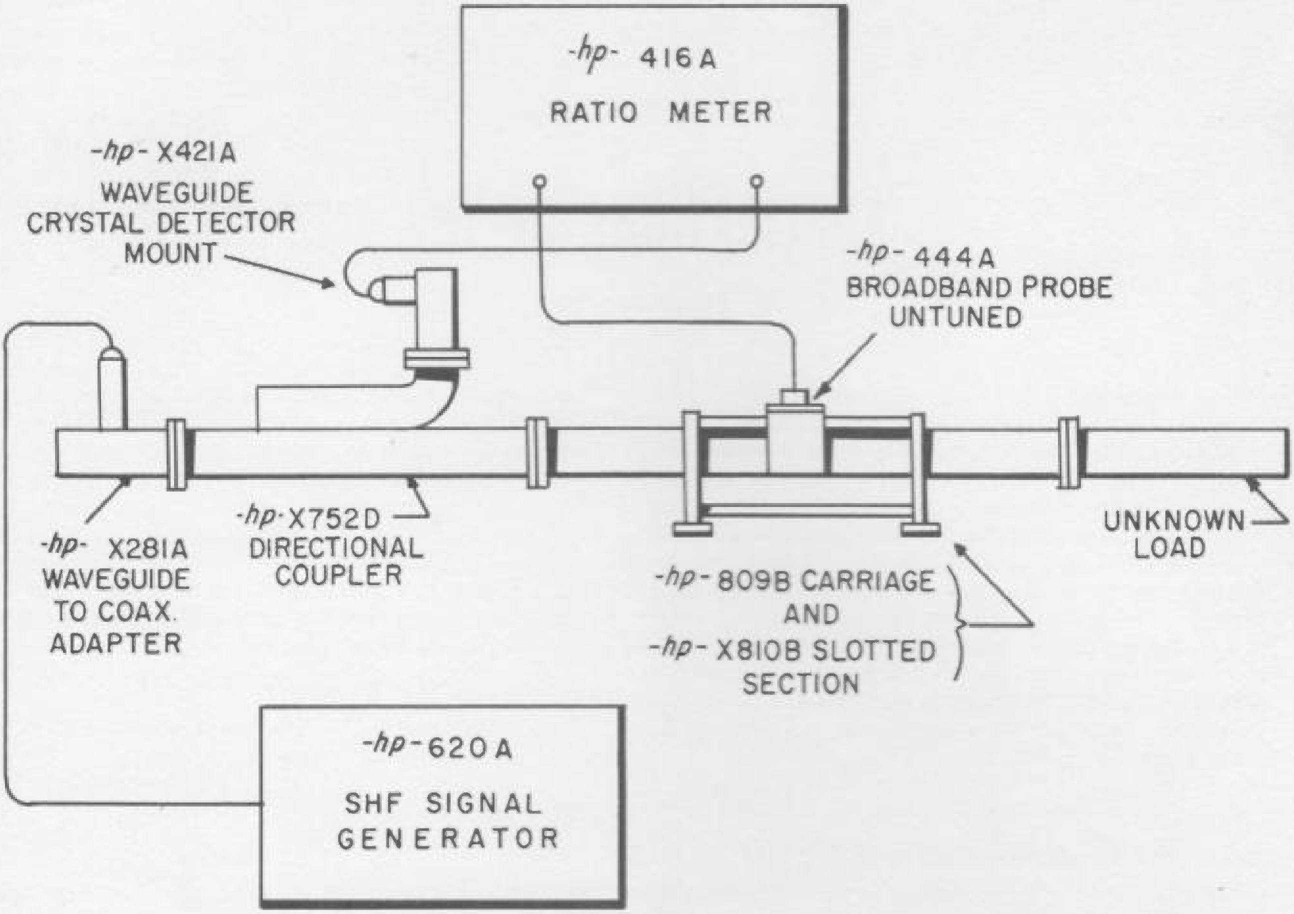

Figure 2B-1. Block Diagram Showing Typical Slotted Line System Using the Model 416A as a SWR Indicator.

(1) Set RANGE switch to lowest range practicable.

(2) With probe penetration at minimum, move probe along the line to obtain a maximum reading.

(3) Adjust SET TO FULL SCALE to obtain a reading of exactly "1" on the SWR scale.

i. Move the probe along the line to obtain a minimum reading. It may be necessary to change the setting of the RANGE switch to obtain a readable indication.

The minimum reading (numerically highest SWR indication) is the standing-wave ratio.

NOTE

When the ratio meter is used in a slotted-line system, the indication on the PERCENT REFLECTION (REFLECTOMETER) scale is irrelevant, does not indicate the reflection coefficient of the load under measurement, and cannot be used to calculate the standing-wave ratio from the formula $\frac{1 + [P]}{1 - [P]}$, There is no connection between the indications on the PERCENT REFLECTION and SWR scales as each is calibrated for use only in its particular type of system.

## 2B-3 GENERAL APPLICATIONS

Requirements - The ratio meter may be used to make measurements of the ratio of any two parameters when certain conditions are fulfilled.

a. The two voltage waveforms, for which the ratio meter will form the ratio, must be in phase and must either be 1 kc voltages or, in the case of r-f, must be modulated at a 1 kc rate.

b. The rms voltage of the 1 kc components must be within certain voltage ranges.

(1) The incident channel input rms voltage range is 3 mv to 100 mv with the EXCESS COUPLER LOSS switch in the 0 DB position. When this switch is in the 10 DB position, the range is 0.3 mv to 10 mv.

(2) The reflected channel input rms voltage range is from about 3 $\mu$v to 100 mv.

NOTE

The meter is calibrated to read the square root of the actual input voltage ratio. This fact must be kept in mind when linear transducers are used.

Example (Figure 2B-2) - The transfer function of an r-f amplifier is to be measured and the available signal generator has an output that is not flat with frequency.

Because the Model 416A is designed so that accurate ratio readings may be obtained regardless of signal source amplitude variations which may occur during measurement, a measurement system using the 416A avoids the necessity for an r-f signal generator which has an output that is independent of frequency. The procedure for setting up and operating a typical measurement system of this type is described below.

a. Set up the signal generator so that the signal is modulated at 1 kc.

b. Connect the generator output to the amplifier input through an attenuator of such range that the signal into the amplifier can be attenuated sufficiently to compensate for the gain of the amplifier.

c. With the instrument plugged into a source of specified voltage and frequency, and the power switch at ON, permit a warm-up period of approximately five minutes.

d. Set the ratio meter EXCESS COUPLER LOSS switch at 0 DB and the RANGE switch at 0 DB 100%.

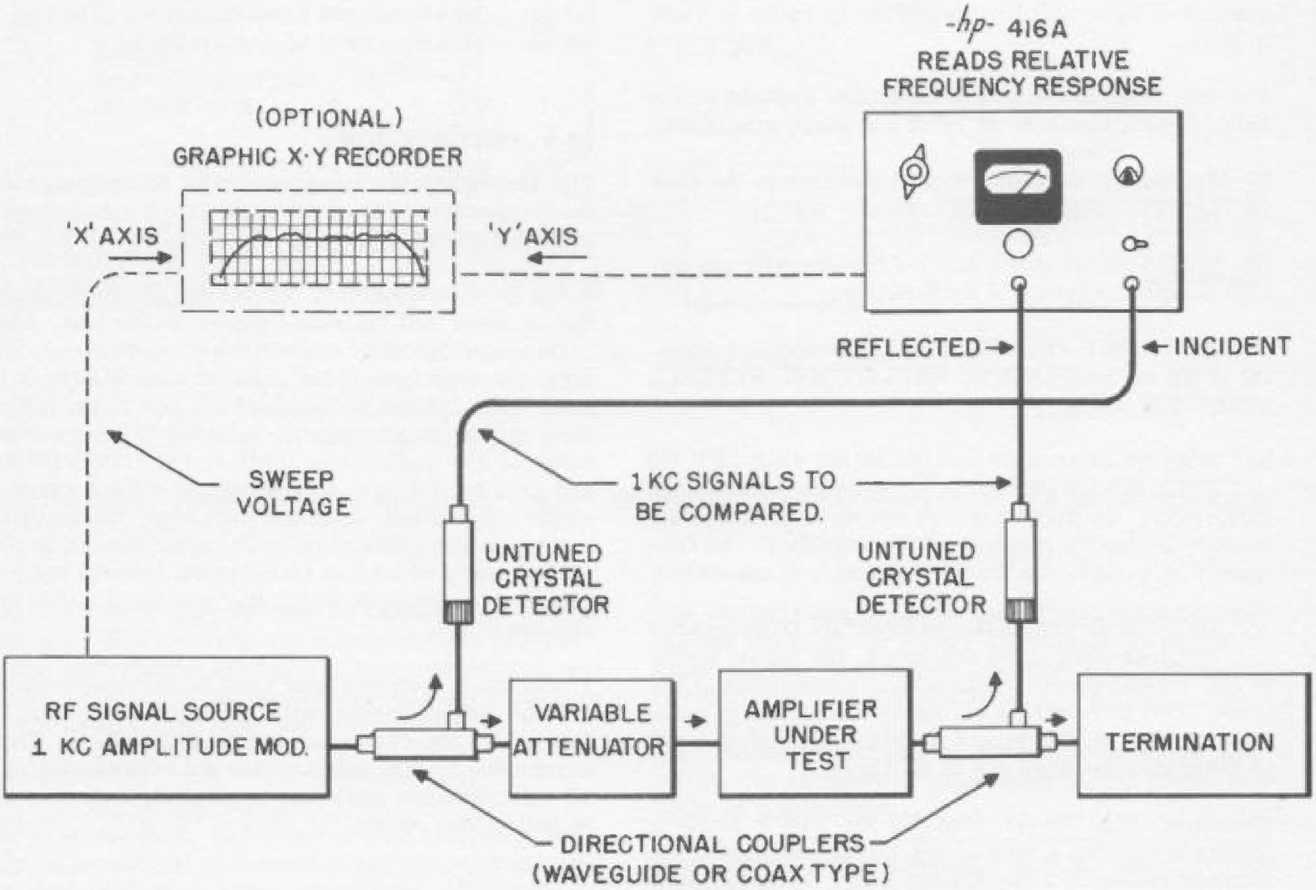

Figure 2B-2. Model 416A Typical Applications: Measurement of Amplifier Relative Frequency Response

e. Use two crystal detectors to produce two 1 kc voltages proportional, respectively, to amplifier input and output rf voltages.

(1) Connect one detector so that it monitors the signal input to the amplifier. (This connection must be made between the signal generator and the input to the attenuator, see Figure 2B-2.) Connect the output of this detector to the Model 416A INCIDENT/REFERENCE input.

(2) Connect the other detector so that it monitors the output of the amplifier. The output of this detector will be connected to the Model 416A REFLECTED/PROBE input, but is not connected at this time.

f. Check that the modulation frequency and level of the input signal are within the operating limits of the Model 416A. Procedure is given in the 416A Operating Procedure.

g. Calibrate the ratio meter.

(1) Set the external attenuator to offer the same amount of loss that the amplifier is rated to yield in gain.

For the calibration procedure, the signals at the ratio meter inputs must be of the same amplitude.

(2) Connect the amplifier-output detector to the 416A REFLECTED/PROBE input.

(3) Set the signal generator r-f frequency to the design center frequency of the amplifier.

(4) Adjust SET TO FULL SCALE to obtain a reading of 100 on the PERCENT REFLECTION (REFLECTOMETER) scale.

h. With the attenuator and the Model 416A SET TO FULL SCALE control at the settings made during calibration, the circuit is now set up to measure the relative frequency response of the amplifier. As frequency is varied, the transfer function is measured.

i. To minimize errors due to departure from square-law operation of the detectors, the signal levels at the crystal detectors should be essentially at the same level both during calibration and during measurements. Power levels should be less than 1 mw (0 dbm) into the crystals at all times.

Example (Fig. 2B-3), (Set-Up for Filter Test) - Diagram showing a typical set-up for measuring the characteristics of a Microwave Filter using two 416A Ratio Meters and dual pen type recorders for a simultaneous visual presentation of reflected and transmitted power. This type set-up can be used in production to tune a microwave duplexer system, etc. By using a sweeping oscillator the proper band pass characteristics can be quickly obtained. Each tuning adjustment change will be displayed by the pen recorders, thus facilitating quick adjustment.

Wavemeters inserted in the Incident Power channel can be tuned to the band limits of interest and will introduce marker pips in the response curves which can be used as reference points.

## 2B-4 REFLECTOMETER SYSTEMS AND MEASUREMENT TECHNIQUES - GENERAL

The remainder of Section 2B is devoted to a detailed discussion of reflectometer systems and measurement techniques. The main topics are as follows:

## 2B-5 INTRODUCTION

The reflectometer is an assembly of devices which makes possible the direct and rapid measurement of the magnitude of the reflection coefficient of a load.

In the hp reflectometer*, directional couplers sample the incident and reflected power in the line, and a ratio meter instantly computes and continuously displays the magnitude of the reflection coefficient of the load. The system is designed for use in the microwave region, is particularly valuable in the measurement of low reflection coefficients (low VSWRs), and is fast and easy to operate at either swept or single frequencies. Like the voltmeter, the frequency meter, or any other electronic measurement device, the accuracy which can be obtained depends upon the degree of care with which the device is calibrated and operated.

The relative accuracy which can be obtained from the various reflectometer calibration refinements is indicated by the curves shown in Fig. 2B-4. These curves are typical only and are not representative of all reflectometer systems; in general, accuracy will be better than shown.

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* Discussed in Hewlett-Packard Journal (Vol. 6, No. 1-2); A copy of this article may be obtained from the Hewlett-Packard Company.

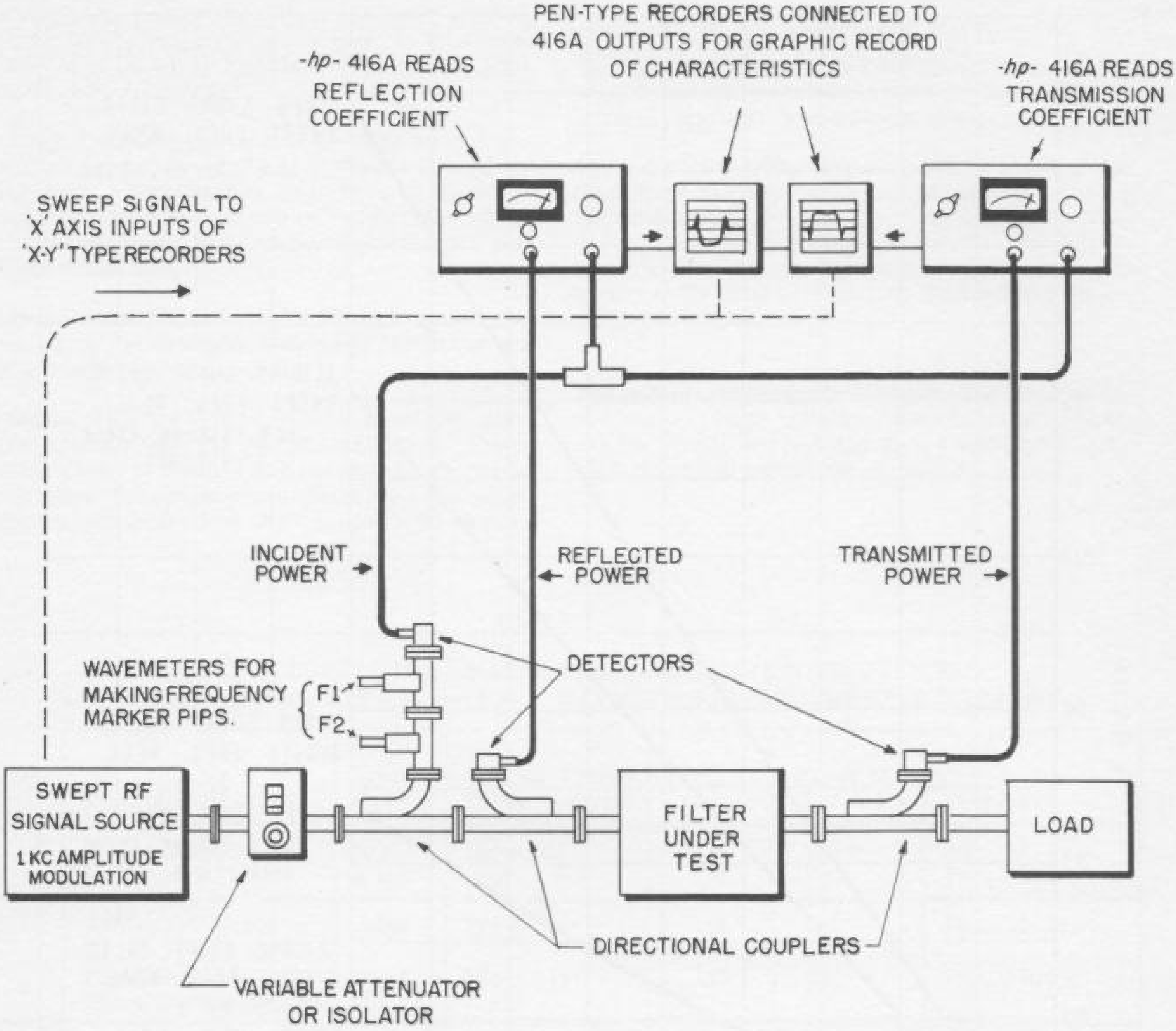

Figure 2B-3. Model 416A Typical Application: Measurement of Characteristics of a Waveguide Filter

There are three good methods for calibrating a reflectometer. The methods are progressively more detailed, and involve increasing amounts of time and effort. The accuracy obtained from each method is proportional to the time and effort expended.

The first method, calibrating with a sliding short only, is the easiest to use and offers accuracy suitable for most production-type applications. When operating at single frequencies and measuring low reflection coefficients, a high degree of accuracy is obtained by calibrating with a sliding short.

The second method, calibrating system scalar error*, makes possible for swept-frequency operation the same degree of accuracy that can be obtained when operating at single frequencies.

Calibrating reflectometer scalar error is the equivalent, for example, of calibrating the frequency response of a voltmeter.

The third method is a refinement of the other two, and offers the ultimate in accuracy.

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* See paragraph 2B-10, Definitions.

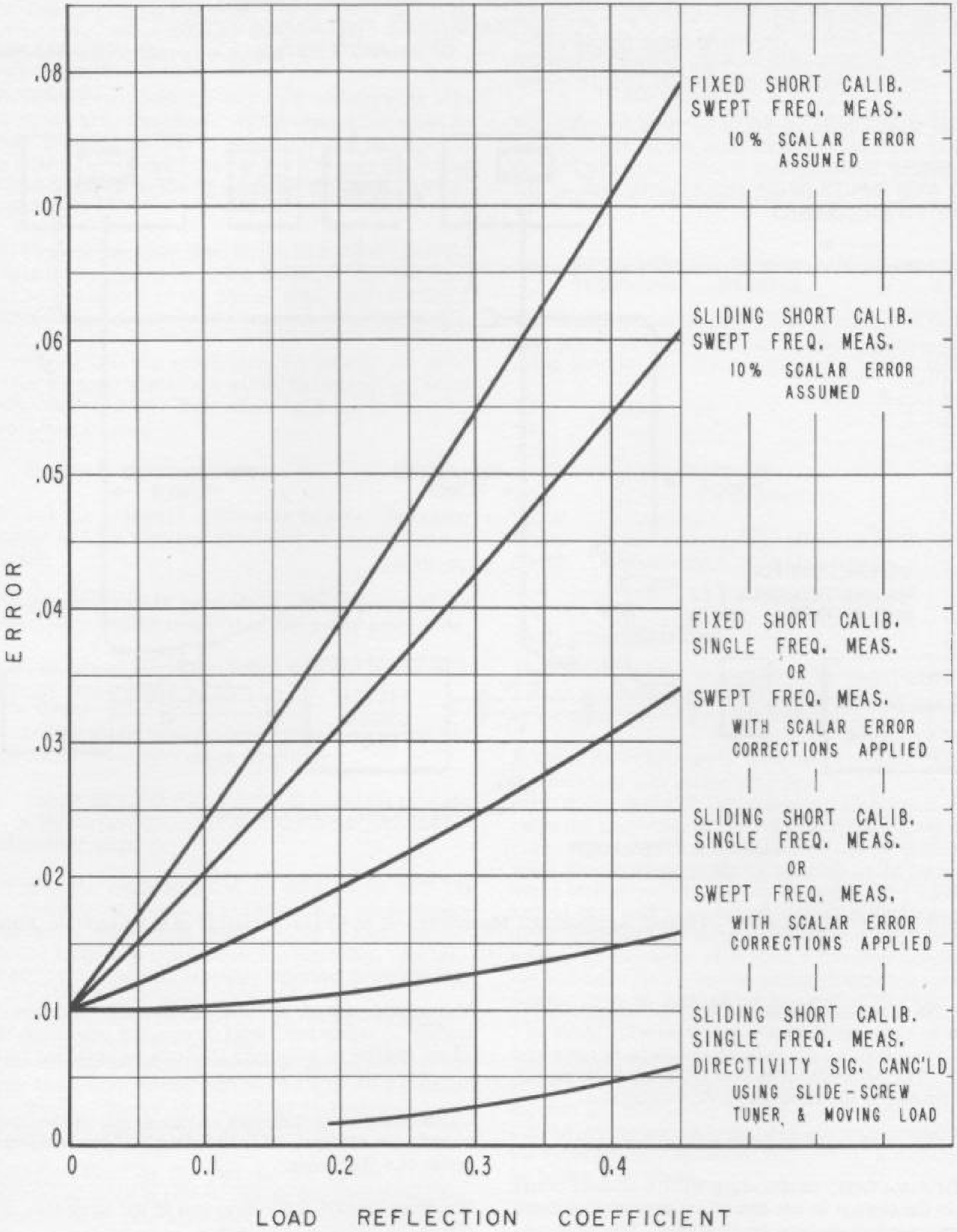

Figure 2B-4. Typical Error Curves for Waveguide Reflectometer Systems

For single-frequency operation, the third method involves the use of a slide-screw tuner to eliminate the largest of the error signals, the directivity signal at the reverse coupler.

For swept-frequency operation, the third method involves the measurement of error signals as well as scalar error. With the data obtained from the measurements, error curves can be constructed which will define the limits of error for any reflection coefficient of interest.

Unless a component (such as a detector) requires replacement, or the waveguide is damaged, error curves need be constructed only once.

The degree of accuracy required from a reflectometer system depends upon the type of application. From the data given in Table 1 and the curves shown in Figure 2B-4, the operator can select the calibration method which gives him the accuracy he needs.

NOTE

The figures given in Table I are presented as a guide only, to indicate the relative accuracy which can be obtained from each calibration method.

Generally much better accuracy will be obtained than the figures shown in Table I would indicate. The error figures were assembled from measurements made during the calibration of several reflectometer systems, and the results obtained from the worst frequency in the band were used as the basis for the error computations.

The only practical way to determine the limits of error in a particular reflectometer system is to measure the error, and compute it on a system basis for each reflection coefficient of interest.

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TABLE I

RELATIVE ACCURACY OBTAINABLE FROM CALIBRATION TECHNIQUES
in the measurement of p s of 0.01 and 0.4 WAVEGUIDE REFLECTOMETER SYSTEMS

| Calib. Meth. | Type of Calibration | Type of Oper. | ► Rule-of-Thumb Error Formula | ► ● Error at p of 0.01 | Error at P of 0.4 | Procedure |
|---|---|---|---|---|---|---|
| I | Sliding Short | Single<br>Swept | 1%p +.01*<br>11%p + .01* | .01<br>.01 | .014**<br>.054 | Par. 2B-6a<br>Par. 2B-6b |
| II | Sliding Short, Scalar Error Curves Applied | Swept | 1%p + .01* | .01 | .014 | Par. 2B-6c |
| | Fixed Short, Scalar Error Curves Applied | Swept | 5%p + .01* | .01 | .03 | Par. 2B-6d |
| III | Sliding Short, Slide-Screw Tuner and Moving Load | Single | | # | .005 | Par. 2B-6e |
| | Sliding Short, Limits-of-Error Curves Applied | Swept | | ± limits of error defined. | | Par. 2B-6f |
| | Fixed Short | Single<br>Swept | 5%p + .01*<br>15%p + .01* | .01<br>.012 | .03<br>.07 | Par. 2B-6g<br>Par. 2B-6h |

p = reflection coefficient
► = see NOTE, above
● = see Figure 2B-4 for error curves
* = directivity signal
** = corresponds to residual VSWR of less than 1.02 in a slotted line
\# = negligible

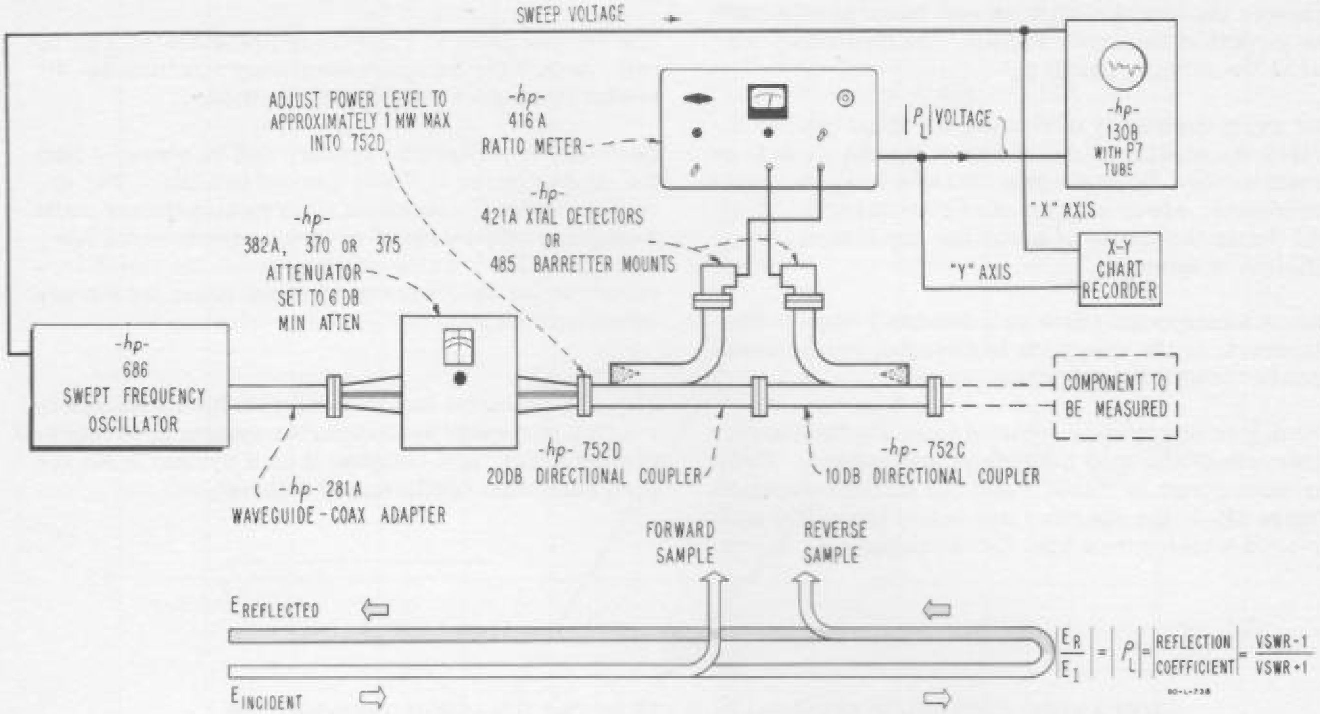

Figure 2B-5. Typical Waveguide Reflectometer System Arranged for Swept-Frequency Operation in S or H Band.

The following paragraph describes the assembly, operation, and calibration of a reflectometer system.

## 2B-6 ASSEMBLY

NOTE

Tables 2 and 3 at the end of the paragraph list by model number the equipment required for operating a reflectometer in the S, G, J, H, X, P, and K bands.

a. Reflectometer System Components -
A typical reflectometer system, arranged for swept-frequency operation in the S or H band, is shown in Fig. 2B-5. The following is a list of the devices and accessories required in the assembly of such a system.

(1) Devices

Signal source:
A microwave signal source with 1) facilities for amplitude modulation at 1 KC, and 2) sufficient capacity to deliver, with the source isolated, at least 1 mw into the forward coupler.

1 KC amplitude modulation is required because the inputs to the Model 416A Ratio Meter are sharply tuned to 1 KC.

Waveguide precision attenuator or Model 365A Isolator
To eliminate reflections from the generator: 1) there should be approximately 5 db attenuation between the generator and the line, or 2) the generator should be isolated from the line.

Device for sampling incident power:
Generally a directional coupler with a 20 db coupling coefficient is used as the forward coupler. A coupler with a directivity of 40 db or better, such as one of the ⓗⓟ Model 752D series, must be used.

Device for sampling reflected Power:
Generally a directional coupler with a 10 db coupling coefficient is used as the reverse coupler. A coupler with a directivity of 40 db or better, such as one of the ⓗⓟ Model 752C series, must be used.

Two matched square-law detectors:
Either crystal detectors or barretters may be used. Detectors used in a reflectometer must have low SWR, flat frequency response across the band, square-law characteristics over a 40 db range, and high sensitivity.

Waveguide Reflectometer Detector Mounts have the characteristics required for reflectometer use. Crystal detectors are available for operation in the X and P bands, and barretter-equipped mounts are available for operation in the S, G, and J bands.

When barretters are used, connection to the ratio meter must be made through a barretter-matching transformer.

Meter which can indicate the ratio between two voltages:
Model 416A Ratio Meter.
A. Voltages proportional to incident and reflected power are applied to the inputs of the 416A, and the meter indicates their ratio.

Since incident and reflected powers are sampled simultaneously, any signal-source amplitude variation during a measurement will affect both channels in the same degree, and therefore such amplitude variation will introduce no error in the ratio reading.

B. A d-c voltage proportional to meter pointer travel is available for oscilloscope or recorder operation.

If visual presentation of measured reflection coefficient is desired:
D-c oscilloscope with long-persistence screen, such as the Model 130A Low Frequency Oscilloscope, or an X-Y Chart Recorder.

Two coaxial, BNC-terminated cables for making connections to oscilloscope.

(2) Accessories

Waveguide adapter:
With Model 670 oscillators, use Model 281A Waveguide to Coaxial Adapter.

With Model 686 oscillator, use of flexible waveguide is advisable.

Sliding short:
Model 920A Adjustable Shorts are designed for the sliding-short calibration procedure.

Two BNC-to-BNC coaxial cables for making connections to ratio meter:
Type AC-16K Cable Assemblies

Waveguide Supports:
Model AC-24 Waveguide Stands
Model X25 Waveguide Clamps

For simple calibration, two stands are sufficient. When utilizing calibration refinements, three stands are desirable.

Waveguide clamp fasteners:
A clamp which exerts approximately a 70 lb. pressure, such as the Monogram Safety Clamp. (The Monogram Safety Pliers are required for adjustment of the clamp.)

Simple calibration setup: 12 clamps
Calibration refinements: 18 clamps

(b) Assembly

The following order has been found practical in assembling a reflectometer system.

(1) Adjust the waveguide-stand clamps to the desired height, and place the two stands about 18 inches apart.

Height of the stands is optional, but when a Model 382A Broadband Precision Waveguide Attenuator is used, adjustments will be reduced to a minimum if the height of the waveguide section of the attenuator is used as a standard.

(2) Connect the directional couplers back-to-back.

A. Fit the 20 db coupler into the left-hand stand and the 10 db coupler into the other stand.

The auxiliary (curved) guide should be uppermost, and the curved sections should face each other at the center of the line (see Figure 2B-5).

B. Align the couplers and fasten them together.

To avoid spurious signals, precise alignment of waveguide flanges is requisite. Guide holes will accommodate 8-32 screws. The outside edges of the two flanges should be in alignment before clamps are secured.

C. Connect the output end of the line attenuator to the Model 752D (20 db) coupler.

D. Connect an adapter to the input end of the attenuator.

(1) If the signal source has a coaxial output, use a 281A wave-guide-to-coaxial adapter.

(2) If the signal source has a waveguide output, use of flexible waveguide is advisable.

E. Connect the adapter to the output of the signal source.

A Type N male to Type N male cable for this purpose is furnished with the Model 670.

F. If one of the Model 670 oscillators is used as a signal source, connect it to its power supply, the 717A.

G. Connect a detector to the auxiliary-arm output of each directional coupler.

TABLE 2

EQUIPMENT REQUIRED FOR WAVEGUIDE REFLECTOMETER SYSTEMS
SINGLE-FREQUENCY OPERATION

| Type of Equipment | Model No. | | | | | | |
|---|---|---|---|---|---|---|---|
| | S Band 2. 6-4. 0 KMC | G Band 4. 0-6. 0 KMC | J Band 5. 85-8. 2 KMC | H Band 7. 0-10. 0 KMC | X Band 8. 2-12. 4 KMC | P Band 12. 4-18 KMC | K Band 18-26. 5 KMC |
| Ratio-Indicating Meter | 416A | 416A | 416A | 416A | 416A | 416A | 416A |
| BNC-to-BNC cables (2) | AC-16K | AC-16K | AC-16K | AC-16K | AC-16K | AC-16K | AC-16K |
| Detectors (2) | S485D | G485D | J485D | H485D | X421A (matched) | P421A (matched) | Two matched square-law detectors. |
| Barretter-Matching Transformers | AC-60K | AC-60K | AC-60K | AC-60K | | | |
| Forward (20 db) Directional Coupler | S752D | G752D | J752D | H752D | X752D | P752D | K752D |
| Reverse (10 db) Directional Coupler | S752C | G752C | J752C | H752C | X752C | P752C | K752C |
| Attenuator | S375A | G382A | J 382A | H382A | X382A | P382A | K375A |
| Waveguide-to-Coaxial Adapter | S281A | G281A | J281A | H281A | X281A | not req.with 626A, 628A | not req. with 628A |
| Signal source | 616B 1.8-4.0 KMC | 618B 3.8-7.6 KMC | 618B 3.8-7.6 KMC<br>620A 7.0-11 KMC | 620A 7.0-11 KMC | 620A 7.0-11 KMC<br>626A 10-15.5 KMC | 626A (10-15. 5KMC)<br>628A (15-21 KMC) | 628A (15-21 KMC) |
| Waveguide stands (3) | AC-24 | AC-24 | AC-24 | AC-24 | AC-24 | AC-24 | AC-24 |
| Clamps | S25 | G25 | J25 | H25 | X25 | P25 | K25 |
| Waveguide Clamp Fasteners (18) | * | * | * | * | * | * | * |
| Monogram Safety Pliers | ** | ** | ** | ** | ** | ** | ** |
| Adjustable Short | S920A | G920A | J920A | H920A | X920A | P920A | K920A |
| <u>REFINEMENTS</u> Isolator | | | | | X365A | | |
| Slide-Screw Tuner and Moving Load | S870A<br>S914A | G870A<br>G914A | J370A<br>J914A | H870A<br>H914A | X870A<br>X916A | P870A<br>P914A | K870A<br>K914A |

* Monogram Mfg. Co., 3H Side Grip Clamp

** Monogram No. 300 Safety Pliers

TABLE 3

EQUIPMENT REQUIRED FOR WAVEGUIDE REFLECTOMETER SYSTEMS
SWEPT-FREQUENCY OPERATION

| TYPE OF EQUIPMENT | MODEL NO. | | | | | |
|---|---|---|---|---|---|---|
| | S Band 2.6-4.0 KMC | G Band 4.0-6.0 KMC | J Band 5.85-8.2 KMC | H Band 7.0-10.0 KMC | X Band 8.2-12.4 KMC | P Band 12.4-18 KMC |
| Ratio-Indicating Meter | 416A | 416A | 416A | 416A | 416A | 416A |
| BNC-to-BNC Cables (2) | AC-16K | AC-16K | AC-16K | AC-16K | AC-16K | AC-16K |
| Detectors (2) | S485D | G584D | J485D | H485D | X421A (matched) | P421A (matched) |
| Barretter-Matching Transformers | AC-60K | AC-60K | AC-60K | AC-60K | | |
| Forward (20 db) Directional Coupler | S752D | G752D | J752D | H752D | X752D | P752D |
| Reverse (10 db) Directional Coupler | S752C | G752C | J752C | H752C | X752C | P752C |
| Attenuator | S375A | G382A | J382A | H382A | X382A | P382A |
| Waveguide-to-Coaxial Adapter | S281A | G281A | J281A | H281A | | |
| Signal Source | 683A<br>2-4<br>KMC | 684B<br>4.0-8.1<br>KMC | 684B<br>4.0-8.1<br>KMC | H01 686A<br>7-11<br>KMC | 686A<br>8.2-12.4<br>KMC | 687A<br>12.4-18<br>KMC |
| Waveguide Stands (3) | AC-24 | AC-24 | AC-24 | AC-24 | AC-24 | AC-24 |
| Clamps | S25 | G25 | J25 | H25 | X25 | P25 |
| Waveguide Clamp Fasteners (18) | * | * | * | * | * | * |
| Monogram Safety Pliers | ** | ** | ** | ** | ** | ** |
| Adjustable Short | S920A | G920A | J920A | H920A | X920A | P920A |
| REFINEMENTS<br>D-C Oscilloscope with Long-Persistence Screen | 120<br>122A<br>130 | 120<br>122A<br>130 | 120<br>122A<br>130 | 120<br>122A<br>130 | 120<br>122A<br>130 | 120<br>122A<br>130 |
| Two coaxial, BNC terminated cables for connections to oscilloscope | AC-16B or AC-16D | AC-16B or AC-16D | AC-16B or AC-16D | AC-16B or AC-16D | AC-16B or AC-16D | AC-16B or AC-16D |
| Slide Screw Tuner and Moving Load | S870A<br>S914A | G870A<br>G914A | J870A<br>J914A | H870A<br>H914A | X870A<br>X916A | P870A |

* Monogram Mfg. Co., 3H Side Grip Clamp

**Monogram No. 300 Safety Pliers

H. Connect the Model 416A Ratio Meter to the system.

(1) If 421A crystal detectors are being used:

(a) Connect forward detector to INCIDENT/REFERENCE input.

(b) Connect reverse detector to REFLECTED/PROBE input.

Type AC-16K Cable Assemblies (BNC-to-BNC) should be used.

(2) If 485 barretter mounts are being used, connection to the 416A should be made through a Type AC-60K matching transformer. Cables for the required connections are supplied with the AC-60K.

(a) Connect forward detector to INCIDENT/REFERENCE input on AC-60K.

(b) Connect reverse detector to REFLECTED/PROBE input on AC-60K.

(c) Connect INCIDENT/REFERENCE output on AC-60K to INCIDENT/REFERENCE input on ratio meter.

(d) Connect REFLECTED/PROBE output on AC-60K to REFLECTED/PROBE input on ratio meter.

(e) The AC-16A Cable Assembly (dual banana plug to dual banana plug) supplied with the AC-60K is for making the connection between the bias supply (output terminal J4-BIAS on the rear of the ratio meter) and the BIAS input on the AC-60K matching transformer. This connection should not be made at this time.

Never connect the bias supply to the barretters until the Model 416A has been turned on for approximately five minutes.

I. Connect a load across the open end of the reverse coupler waveguide.

J. If an oscilloscope is to be used, make the following connections:

(1) Connect the OUTPUT/J3 connector on the rear of the Model 416A to the oscilloscope vertical input.

(2) Connect the signal source sweep-voltage output to the oscilloscope horizontal input.

Two AC-16B (BNC to dual banana plug) or two AC-16D (BNC to open) cable assemblies are required.

## 2B-7 OPERATION OF THE SYSTEM

Procedures for putting component equipments into operation may be found in the instruction book for each equipment.

(a) Turn on ratio meter.

(1) Check that the EXCESS COUPLER LOSS switch is at 10 DB.

At the 10 DB position, the EXCESS COUPLER LOSS switch introduces an additional 10 db of gain in the ratio meter incident channel. This 10 db gain compensates for the 10 db difference between the coupling coefficients of the forward and reverse couplers.

(2) If barretter detectors are used, complete connections between ratio meter and barretter-matching transformer after ratio meter has been turned on for about five minutes.

Connect BIAS input on AC-60K assembly to J4-BIAS output on rear of 416A. Use AC-16A cable (double banana plug to double banana plug) supplied with transformer assembly.

(b) Set line attenuator for 5 or 6 db.

(c) Turn on signal source.

Unless there is a Model 365 Isolator* in the line, when the signal source is a klystron oscillator the oscillator output attenuator should be set for some attenuation, to provide some isolation between the klystron and the line.

(d) If oscilloscope is used, turn on oscilloscope.

(e) Check that the modulation frequency and the level of the input signal are within the 416A operating limits.

(1) Requirements:
A. The modulation frequency must be 1 KC ±40 cycles.

B. The signal shall have the lowest level practicable: near to, but above, the 416A minimum.

C. Attenuation of the signal to the proper level, so far as possible, shall take place at the line attenuator. The system should be operated with as much attenuation inserted in the line as possible.

(2) Frequency and Level Indicator:
The tuning eye on the Model 416A provides indication that the frequency and level of the signal are within

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*Available only for X band.

the input requirements of the ratio meter. Conditions indicated by the tuning eye are as follows:

A. Level and frequency within 416A input range: Appreciable movement of the tuning eye shadow.

B. Either level or frequency, or both, outside of 416A input range: no movement of the shadow.

C. Signal level at high end, but within, 416A input range: shadow just closes.

D. Overload: shadow overlaps.

(3) Procedure:

A. Disconnect cable from 416A REFLECTED/PROBE input.

B. If tuning eye shadow does not move, increase level of signal.

If shadow moves, appreciably, proceed with step 2B-8.

If shadow does not move, adjust the frequency of the modulating voltage (at the signal source).

To avoid a subharmonic of 1 KC, always start at the high-frequency end of the adjustment and slowly adjust toward the low-frequency end.

When modulating frequency is 1 KC ±40 cycles the tuning eye shadow will move.

C. By adjustment at line attenuator (preferable) or signal source (or both) bring signal to level which is near to but above 416A minimum.

D. At all frequencies of interest, check that level of signal is above the 416A minimum.

E. Reconnect cable to REFLECTED/PROBE input.

(f) When an oscilloscope is to be used, calibrate the oscilloscope. Procedure is given in paragraph 2B-9.

(g) Calibrate the reflectometer. Procedures are given in paragraph 2B-8.

## 2B-8 CALIBRATION

(a) Sliding Short, Single-Frequency Operation:
(1) Disconnect the load and connect a Model 920A Adjustable Short to the end of the waveguide (see Figure 2B-6).

(2) Check that RANGE switch on 416A is at 0 DB100%.

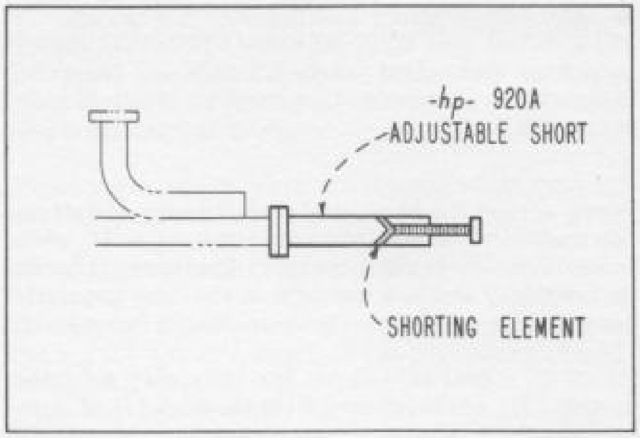


Figure 2B-6. Model 920A Adjustable Short Connected to Wave-guide Reflectometer

(3) Adjust 416A SET TO FULL SCALE control for convenient reference on PERCENT REFLECTION (REFLECTOMETER) scale; 90 is recommended.

(4) Slide short while noting maximum and minimum indications on reflectometer scale.

(5) Subtract minimum reading from maximum, and divide by two.

For example, if maximum and minimum readings noted while the short is slid are 89 and 93 respectively:

The difference is .04, and half the difference is .02.

(6) Slide short to get minimum indication again.

(7) Adjust SET TO FULL SCALE to obtain a meter indication which is equal to the reflection coefficient of the calibrating load (100) minus the quantity obtained in step (5).

For the values used above, SET TO FULL SCALE would be adjusted to obtain a meter indication of 98.

(b) Sliding Short, Swept-Frequency Operation:
(1) Disconnect the load and connect a Model 920A Adjustable Short to the end of the waveguide.

(2) Check that RANGE switch on 416A is at 0 DB 100%.

(3) Determine best frequency to use for calibration procedure.

Either of two methods, measurement or approximation may be used.

A. Measurement:
For greatest accuracy, measure system frequency response, and select frequency at which response is average. This procedure is given in 2B-12 subparagraph 3a.

B. Approximation:
Sweep across the band, and note 1) range of reflection coefficient versus frequency readings or 2), when an oscilloscope is used, slope of the trace. Choose the frequency at which the ratio is average; generally the average will occur at a midband frequency.

(4) With signal source set for frequency selected in step (3), perform steps (3) through (7) of subparagraph A, above.

C. Sliding Short, Scalar Error Curves Applied-Swept-Frequency Operation:
(1) Measure scalar error across the band, and compute absolute error for each reflection coefficient of interest.

Procedures are given in 2B-12, Sub-paragraphs 2 and 3.

(2) Calibrate with a sliding short.

A. Set the signal source for the frequency selected during the scalar error measurement procedure (2B-12, para. 3a, step G).

B. Perform steps (1) through (7) of subparagraph A, above.

(3) To readings obtained during measurement, apply correction at each frequency for the scalar error found at that frequency.

D. Fixed Short, Scalar Error Curves Applied-Swept-Frequency Operation:
(1) Measure scalar error across the band, and compute absolute error for each reflection coefficient of interest.

Procedures are given in 2B-12, Sub-paragraphs 2 and 3.

(2) Calibrate with a fixed short.

A. Set the signal source for the frequency selected during the scalar error measurement procedure (2B-12, sub-para. 3a, step G).

B. Perform steps (1) through (3) of subparagraph G, below.

(3) To readings obtained during measurement; apply correction at each frequency for the scalar error found at that frequency.

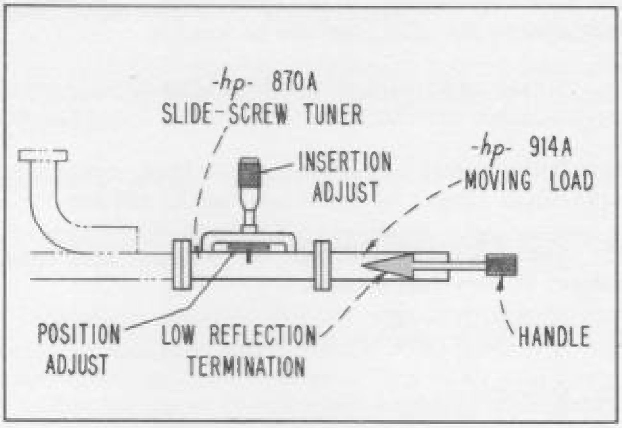


Figure 2B-7. Model 870A Slide-Screw Tuner and Model 914A Moving Load Connected to Waveguide Reflectometer.

E. Sliding Short, Slide-Screw Tuner and Moving Load Single-Frequency Operation:

(1) Disconnect the load, and connect a Model 870A Slide-Screw Tuner and Model 914A Moving Load to end of waveguide (see Figure 2B-7).

NOTE

It is recommended that the load of the 914A be modified to give a reflection slightly greater than the directivity signal. See modified load, 2B-10, Definitions, for suggested modification procedure.

(2) Set 416A RANGE at -30 DB 3%.

(3) Adjust phase of reflection from tuner probe.

A. Check that probe on tuner is all the way out.

Micrometer screw is used to adjust probe insertion (see Figure 2B-7).

B. Slide load for maximum indication on reflectometer scale of ratio meter.

C. Adjust probe for some penetration, to get small difference (1/4 to 1/2 db) in ratio meter reading.

D. Adjust horizontal position of probe while watching variation in ratio meter reading.

Thumb-operated knurled wheel is used to adjust probe horizontal position.

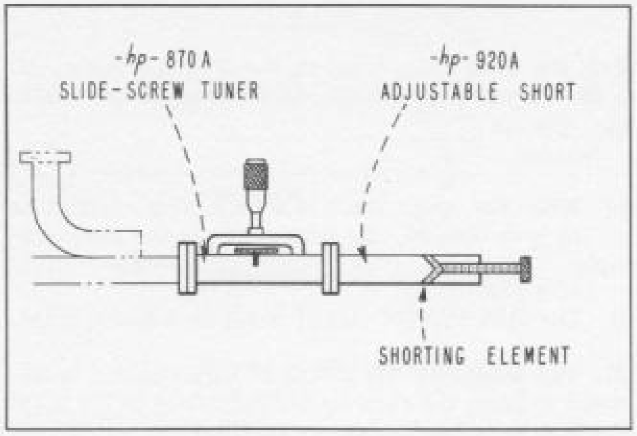


Figure 2B-8. Model 870A Slide-Screw Tuner and Model 920A Adjustable Short Connected to Waveguide Reflectometer.

E. Set probe at position where lowest reading is obtained.

(4) Adjust magnitude of reflection from probe.

A. Adjust probe penetration for small decrease in meter indication (a couple of db, for example).

B. Slide load for maximum ratio meter indication.

C. Adjust probe penetration for another small decrease in meter indication, and then slide load for maximum ratio meter indication.

D. Repeat step C until meter variation, as load is slid, is minimum. Generally the variation can be reduced to 1 db, or less.

This is a trial-and-error process, but in general:

1. If, after an increase in probe penetration, sliding of load shows an increase in the maximum indication, retract probe to decrease penetration.

2. So long as maximum shows continuing decrease as probe is inserted deeper, continue increasing probe penetration.

(5) Leave slide-screw tuner at setting at which there is smallest variation as load is slid.

(6) Disconnect the 914A from the slide-screw tuner, and connect a Model 920A Adjustable Short (see Fig. 2B-8).

(7) Perform the sliding-short calibration procedure given in sub-paragraph a, above.

F. Sliding Short, Limits-of-Error Curves Applied Swept-Frequency Operation:

(1) Measure limits of error across the band, and construct area-of-ambiguity curves for each reflection coefficient of interest.

Procedures are given in 2B-12, sub-paragraphs 2 through 5.

(2) Calibrate with a sliding short.

A. Set the signal source for the frequency selected during the error measurement procedure (2B-12, para. 3a, step G).

B. Perform steps (1) through (7) of subparagraph A, above.

(3) For readings obtained during measurement, note at each frequency the limits of error (scalar error ±maximum spurious signal error) found at that frequency.

This procedure reduces ambiguity to a minimum, since the reflection coefficient of interest will be known to lie within the area defined for each frequency by the limits of error found at that frequency.

G. Fixed Short, Single-Frequency Operation:

(1) Connect a short across the end of the waveguide.

(2) Check that RANGE switch on 416A is at 0 DB 100%.

(3) Adjust 416A SET TO FULL SCALE control to obtain an indication of 100 on the PERCENT REFLECTION (REFLECTOMETER) scale.

NOTE

Use of a fixed short for the calibration procedure may result in an inaccurate setting of ratio meter gain. For this reason, a sliding short is recommended. Calibration with a sliding short is easy (see subparagraph A., above), and ensures that ratio meter gain will be set accurately.

H. Fixed Short, Swept-Frequency Operation:

(1) Connect a short across the end of the waveguide.

(2) Check that RANGE switch on 416A is at 0 DB 100%.

(3) Determine best frequency to use for calibration procedure. (See subparagraph b (3) above).

(4) With input signal at frequency selected in (3), adjust 416A SET TO FULL SCALE control to obtain an indication of 100 on the PERCENT REFLECTION (REFLECTOMETER) scale.

## 2B-9 OSCILLOSCOPE CALIBRATION

NOTE

During the oscilloscope calibration procedure the ratio meter must be indicating on the scale which is to be used during operation.

(a) To calibrate an oscilloscope, set an upper reference and a zero reference, and then calibrate graticule lines between the two. The procedure is as follows:

(1) Connect a short across the load end of the waveguide.

(2) Check that the 416A RANGE switch is at 0 DB 100%.

(3) Adjust 416A SET TO FULL SCALE control to obtain a reading of 100 on the PERCENT REFLECTION (REFLECTOMETER) scale.

(4) Establish the zero reference on the scope graticule.

A. Disconnect cable connected to scope vertical input.

This cable is incoming from the 416A OUTPUT/J3 connector, and carries a d-c voltage which is proportional to 416A meter pointer travel.

B. Adjust oscilloscope gain to position beam on one of the lower lines of the graticule.

A grease pencil may be used to mark the zero designation on the graticule.

(5) Establish the upper reference on the graticule.

A. Reconnect cable to scope vertical input.

B. Adjust scope gain to position beam on top line of graticule. Mark this line 100%.

(6) Check that zero and 100% fall exactly on designated lines by repeating steps (4) and (5), and readjusting scope gain as required.

(7) Decrease 416A gain (adjust SET TO FULL SCALE control) until oscilloscope beam rests on the next graticule which is to be calibrated.

(8) Mark this line with the ratio indicated on the reflectometer scale of the 416A.

(9) Repeat this procedure for the other graticule lines which are to be calibrated.

NOTE

With the 416A indicating on the 0 to 100 scale, 30 is the lowest ratio which can be read on the scale.

(b) When the upper limit is a reflection coefficient of less than 30, the procedure is the same except:

(1) The 416A RANGE switch is set on a lower scale.

(2) The 416A SET TO FULL SCALE control is adjusted to bring the ratio meter indication to the ratio which is to be used as the upper limit.

For example, if a reflection coefficient of 22.5% is to be used as the upper limit:

A. The RANGE switch would be set at -10 DB 30%.

B. SET TO FULL SCALE would be adjusted to bring the 416A reading to 22.5 on the 10 - 30 scale.

C. Oscilloscope gain would be adjusted to position the beam on one of the top lines of the graticule.

(c) After the oscilloscope is calibrated, the 416A SET TO FULL SCALE control should be readjusted for 100% indication on the ratio meter (by one of the procedures given in sub-paragraph 4).

## 2B-10 DEFINITIONS

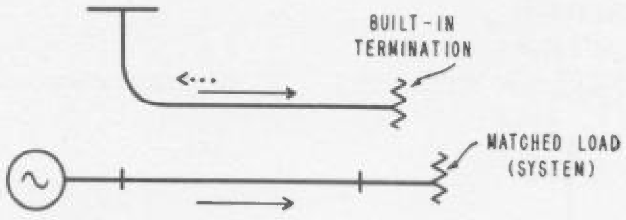
The scope of these definitions is limited. The words and terms included in the Section are defined only with respect to the manner in which they are used in the text of this Application Note. It is not intended that the following be considered complete definitions.

Auxiliary arm or guide - Secondary arm of directional coupler; waveguide transmission line for sampled power.

Coupler - Directional coupler.

Coupling coefficient (coupling) - Ratio, expressed in db, between power entering the main arm of the coupler in one direction to power coupled into the auxiliary arm in the same direction.

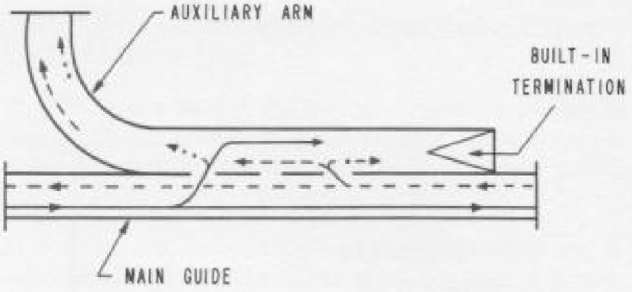
Directional coupler - A device consisting of two transmission lines coupled together in such a way that a wave traveling through one line in one direction excites a wave in the other guide, ideally, in one direction only. This property makes it possible to sample the power traveling in one direction in a transmission line.



——→ = Power Flowing in Forward Direction

<···· = Power Flowing in Reverse Direction

Figure 2B-9. Direction of Power Flow, Directivity Definition



——→ = Direction of Incident Wave

←- - - = Direction of Reflected Wave

·-→ / ←·· = Reverse-Coupled Power in Auxiliary Arm

Figure 2B-10. Waveguide Directional Coupler, Cross-Sectional View.

For explanation of coupler functioning, see definition of directivity.

Directivity - A specification of the directional property of a coupler.

Directivity is defined as 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 flowing only in the forward direction in the main arm.

"Forward" and "reverse" as used in this definition are defined in Figure 2B-9.

NOTE

The following brief description of Model 752 directional couplers is only for the purpose of amplifying the above definition of directivity. For a fuller description of directional couplers, see the Hewlett-Packard Journal, Vol. 3, #7-8, March-April 1952.

A Model 752 directional coupler consists of two waveguide sections, the main arm and the auxiliary arm, bonded together along their broad faces (see Fig. 2B-10). At one end of the auxiliary arm there is a built-in matching termination, at the other end is the auxiliary-arm output. Coupling is obtained by an array of accurately placed holes along the adjacent faces.

Power flowing in either direction in the main arm couples through the holes, exciting in the auxiliary arm waves which propagate in both directions. The design of the coupling array is such, however, that only waves traveling in the same direction as the exciting wave in the main arm add together in phase, whereas waves traveling in the other direction cancel almost entirely because of the phase differences between them. Direction of power flow in both arms is indicated in Fig. 2B-10.

Waves traveling in the solid-line direction in the main guide propagate strongly in the same direction in the auxiliary arm and appear at the auxiliary arm output.

The very small wave traveling in the dot-dash line direction flows to the matched termination.

Waves traveling in the broken-line direction in the main guide propagate strongly in the same direction in the auxiliary arm and flow into the matched termination. The VSWR of this termination is less than 1.01 over the coupler frequency range.

The very small wave traveling in the dotted-line direction plus any reflection from the termination appears at the auxiliary-arm output. The sum of the two is indicated by the dotted-line arrow at the output.

The ratio of the power flowing in the broken-line direction in the auxiliary arm to the power indicated by the dotted-line arrow at the auxiliary arm output is called the directivity of the coupler.

In any one coupler directivity will vary somewhat with

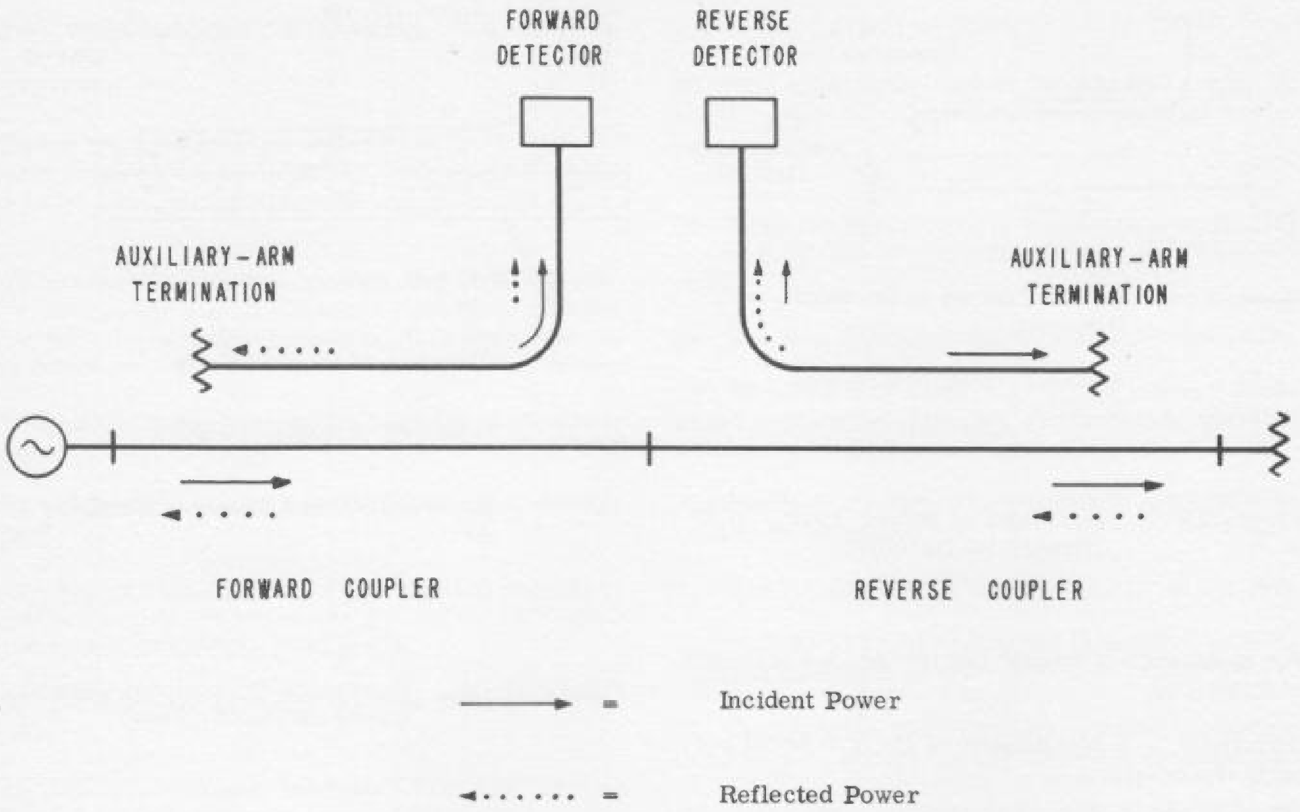


Figure 2B-11. Direction of Main Signals in Typical Directional Couplers in Waveguide Reflectometer System.

frequency. Directivity will vary also from coupler to coupler. By specification, however, the directivity of hp Model 752 couplers is always greater than 40 db.

Directivity signal - A spurious signal present in the output of a coupler because the directivity of the coupler is not infinite.

By specification the directivity of hp Model 752 couplers is always greater than 40 db. Therefore, the voltage of the directivity signal will never be more than 1% of the voltage at the reverse detector when a load having unity reflection coefficient is terminating the main line.

Directivity signals in a reflectometer system are indicated in Figure 2B-11.

The directivity signal in the forward coupler is proportional to the amplitude of the reflected wave.

The directivity signal in the reverse coupler is proportional to the amplitude of the incident wave.

Forward coupler - Directional coupler which samples incident power.

Incident power or signal - Forward power, flowing from generator to load.

Main arm or guide - Primary arm of directional coupler; waveguide transmission line for incident and reflected power.

Modified load - Low-reflection load with removable imperfection applied to obtain a small reflection.

By taping a piece of wire to the side of a low-reflection movable load (Model X916Aor Model 914A), a reflection coefficient can be obtained which will be within the limits required for the procedure used to measure the directivity of a coupler. Since the reflection obtained will be a function of frequency as well as size of wire and position on the load, specific instructions cannot be given, and details of the modification

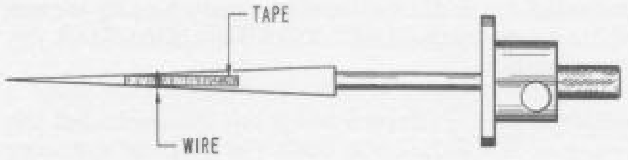


Figure 2B-12. Load of Model X916A Modified to Obtain Small Reflection

will have to be worked out on a trial-and-error basis. However, the following general instructions will be found practical:

a. Use a narrow, relatively long (approximately 3/16" x 1-1/2") strip of tape to strap wire to load. Masking tape is excellent for this purpose.

b. For a reflection-producing material, use a small piece (about 3/16" long) of medium-gauge (No. 21-24, AWG) wire, such as a piece of resistor lead.

c. Strap wire vertical to length of load.

Allow length of tape both to right and left of wire so that wire may be repositioned without removing tape. See Figure 2B-12.

With wire taped to load as shown in Figure 2B-12, wire may be shifted along the load simply by exerting thumb-nail pressure against wire in direction of desired motion.

d. To increase reflection, shift wire toward pointed end of load; to decrease reflection, shift wire toward handle of load.

The load of a Model X916A, arranged as shown in Figure 2B-12, was used when making measurements in the 8.2 kmc to 10 kmc region of the X band. Using a 3/16" piece of No. 22 wire:

At 8.2 kmc, with wire approximately 2" from tip, a reflection 34 db down from the reference was obtained.

At 10 kmc, with wire approximately 1-3/4" from tip, a reflection 34 db down from the reference was obtained.

NOTE

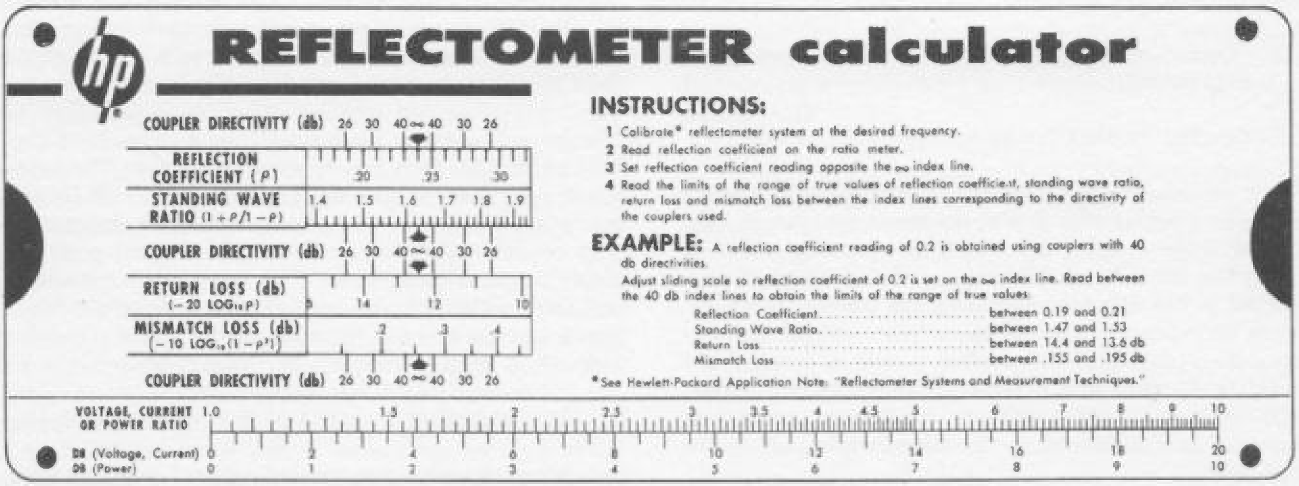
For a given position of the wire, signal level will tend to drop as frequency is increased. Therefore, when making measurements at the high end of a wide band, it is probable that it will be necessary to shift the position of the wire toward the pointed end of the load to maintain the reflection at sufficiently high a level to keep measurements above the noise level of the indicating instrument.

---

Reflected power - Reverse power, flowing from load to generator.

Reflectometer Calculator - Slide rule designed by Hewlett-Packard Co. Includes the following scales:

Reflection coefficient
Standing-wave ratio
Return loss
Mismatch loss



**INSTRUCTIONS:**

1 Calibrate* reflectometer system at the desired frequency.
2 Read reflection coefficient on the ratio meter.
3 Set reflection coefficient reading opposite the ∞ index line.
4 Read the limits of the range of true values of reflection coefficient, standing wave ratio, return loss and mismatch loss between the index lines corresponding to the directivity of the couplers used.

**EXAMPLE:** A reflection coefficient reading of 0.2 is obtained using couplers with 40 db directivities.

Adjust sliding scale so reflection coefficient of 0.2 is set on the ∞ index line. Read between the 40 db index lines to obtain the limits of the range of true values:

| | |
|---|---|
| Reflection Coefficient | between 0.19 and 0.21 |
| Standing Wave Ratio | between 1.47 and 1.53 |
| Return Loss | between 14.4 and 13.6 db |
| Mismatch Loss | between .155 and .195 db |

*See Hewlett-Packard Application Note: "Reflectometer Systems and Measurement Techniques."

Figure 2B-13. The Reflectometer Calculator

The slide rule is so arranged that the limits of the range of true values, set by the directivity of the reverse coupler used, also may be read.

While available, the Reflectometer Calculator may be obtained by writing to the Hewlett-Packard Company.

Return loss - Level of reflected power (number of db reflected power is down from incident power).

Reverse coupler - The directional coupler which samples the wave reflected from the load.

In a reflectometer, the device generally used has a coupling coefficient of 10 db (the power coupled into the auxiliary arm is 0.1 of that flowing in the main arm).

As is explained in greater detail in the definition of directivity, among the characteristics given a directional coupler by its design are:

(1) A portion of the power which is forward-going in the coupler main arm will be coupled into the auxiliary arm.

(2) The same proportion of the power which is reverse-going in the main arm will also be coupled into the auxiliary arm.

(3) At one end of the auxiliary arm is an output, at the other end is a built-in matching termination.

A. The signal coupled in one direction appears at the auxiliary-arm output.

B. The signal coupled in the other direction is almost entirely absorbed at the termination.

In a reverse coupler:

(a) Coupled reflected power appears at the auxiliary-arm output.

(b) Coupled incident power is largely absorbed.

When the coupler is connected in the direction which a reverse coupler has in a reflectometer system, the signal at the coupler output will be down about 1/2 db from the level it would have were the coupler connected in the same direction as the forward coupler. This difference in reverse coupler output level is because a portion of the incident power is coupled into both the forward and reverse couplers before it reaches the load, and therefore, the power incident on the load is reduced by the amount coupled off by the couplers.

This loss, which upsets the proportion which the incident and reflected signals should have, is compensated for in the calibration procedure by means of the gain control (SET TO FULL SCALE) on the ratio meter.

Scalar errors - Errors which are independent of the phase of the reflection coefficient of the unknown load (e.g., departures from square-law response of the detectors).

Errors of this type can be eliminated by a calibration procedure (measuring the scalar errors and applying correction at each frequency at which error is found).

## 2B-11 MEASUREMENT CONSIDERATIONS

(a) General -

Errors in a reflectometer system can be divided into two main categories:

(1) Those which result from sensitivity variations (scalar quantities).

(2) Those which result from spurious signals (vector quantities).

In the first category are the errors which are a function of frequency and signal amplitude. These sensitivity variations can be measured and the amount of error they will introduce into a ratio reading can be computed accurately. Sensitivity variations include:

(1) Variation with frequency of the difference between the coupling coefficients of the two directional couplers.

(2) Variation with frequency and/or amplitude between the detection efficiencies of the two detectors.

(3) Variation with signal amplitude in detector sensitivity. (At higher input signal levels the detector does not obey square-law perfectly.)

The second category includes all the spurious r-f signals which appear at the reverse detector. The magnitudes of the various spurious signals can be determined, but their total effect on measurements can only be estimated in terms of their worst possible phase combinations, since they are vector quantities and have unknown phases relative to one another. The spurious signals which must be taken into consideration may be divided into two groups:

(1) The directivity signal in the reverse coupler.

(2) Signals which are re-reflected from the load.

Procedures for measuring scalar error and spurious signals are given in 2B-12, Measurement of Errors.

Considerations involved in making the measurements are discussed in the following paragraphs.

(b) Measurement of Scalar Error - General

The detection efficiency of a detector and the coupling characteristics of a directional coupler vary somewhat with frequency. Also, the output of the detector will deviate somewhat from square-law at the input signals of higher level. If, however, the characteristics of the detector and coupler in the forward arm were identical to those in the reverse arm, variations with frequency would introduce no error in the ratio reading because the ratio of reverse detector output to main-guide reflected power and the ratio of incident detector output to main-guide incident power would be the same. In practice, however, the characteristics of the equipments in the two arms are not identical, and therefore the variations do not track at every point.

In single-frequency operation, a difference in proportionality between the two detector outputs can be compensated for, at the level and frequency used for calibration, when the ratio meter is calibrated.

Calibration involves supplying to the ratio meter an incident signal and a reflected signal with a known ratio (usually the system is terminated with a short to provide a known ratio of 100%). If the ratio indicated by the meter is other than the known ratio, the level of one of the signals is less than it should be. To bring the signals to the levels they should have with respect to each other, a variable gain adjustment (SET TO FULL SCALE) is provided in the ratio meter reflected-channel input. When, during calibration, SET TO FULL SCALE is adjusted to bring the meter indication to that of the known ratio, so far as the ratio-indicating circuits of the meter are concerned, the proportionality which the signals should have is established. The gain setting, therefore, at the frequency used during calibration, essentially overcomes the variation in efficiency between the two arms of the reflectometer system. And thereafter, for measurements made at the same frequency, the reflected signal will receive the proper degree of amplification to establish correct proportionality between the signals.

Thus in single-frequency operation, differences in efficiency between the two arms can be compensated for during calibration. In swept-frequency operation, however, the gain setting which is correct for the variations which exist at the calibrating frequency may insert too much gain at some frequencies and too little at others. In swept-frequency operation, therefore, the error resulting from differences between the arms can be eliminated only by measuring the differences, computing the magnitude of error that will result, and applying this data as a correction factor.

Determination of scalar error is a three-step process:

(1) Measurement of detector/coupler frequency-response error.

The major part of this deviation will come from the relative frequency sensitivity of the two detector/coupler combinations. However, since the signal source output level will vary with frequency, some of the deviation will come from the differences between the characteristics of the two detectors as functions of level. For purposes of simplification, the deviation (as a function of frequency) resulting from the two effects combined is designated "detector/coupler frequency-response error".

(2) Measurement of detector sensitivity-with-signal level error.

Detector sensitivity-with-signal-level error is determined by measuring the amount of reverse detector deviation from square-law* over the range of levels encountered during reflectometer calibration and operation. While the level at the detector input is primarily a function of the reflection coefficient, it is also a function of frequency because of variations with frequency in signal source output level.

(3) Algebraic addition of the two types of error, and computation of the absolute error for each reflection coefficient and frequency of interest.

(c) Measurement of detector/coupler frequency-response error -

To measure frequency-response error, it must be known that any differences between ratio readings as frequency is varied occur only because of variations associated with changes in frequency. Therefore, the measurement setup must be essentially free of spurious signals.

By reversing the direction of the reverse coupler** and terminating the system in a low-reflection load, spurious signals reflected from the load are reduced to such a low level that they are negligible.

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*Square-law is discussed briefly in subparagraph c.

**See 2B-10 Definitions, reverse coupler.

Attenuation in the line and the use of a 20 db forward coupler reduce the spurious signals reflected from the generator to such a low level that they also are negligible.

The data obtained from the measurements will be used:

(1) To determine the best frequency to use for calibration.

(2) To compute the percent of error present at various frequencies after calibration.

Step-by-step instructions for making the measurements are given in Section 2B-12, para. 3a. The procedure includes the following steps:

(1) A reference is set at one frequency in the band of interest.

A condition of 100% reflection is set up, and then ratio meter gain is adjusted to obtain a reference at which ratios both above and below the reference may be read easily (such as 90%).

(2) The frequency is varied, and the ratio reading obtained at each frequency is noted.

At some frequencies there may be an increase in detector-coupler efficiencies, in which case the ratio reading will be higher than the reference.

Readings of 91 or 92 may be obtained, for example.

At other frequencies there may be a decrease in detector-coupler efficiencies, and ratio readings will be lower than the reference.

Readings of 86 or 87 may be obtained, for example.

(3) The calibration frequency is chosen.

For lowest across-the-band error, the frequency at which detector-coupler efficiencies are average should be used for calibration procedure.

For example, if the high reading were 91 and the low reading were 86, the frequency at which the reading was about 88.5 would be the frequency to use for the calibration.

(4) Assuming calibration at the chosen frequency, percent and direction of error across the band is determined. See Table 4, Section 2B-12.

The direction of error is simply the arithmetical direction. For example:

If the ratio reading at the calibrating frequency is 87:

A reading of 86 is a -1% error.
A reading of 88 is a +1% error.

(d) Measurement of detector sensitivity-with-signal-level error -

In order to calibrate a voltmeter or ratio meter, it is necessary to assume that the detector follows some fixed detection law. The Model 415B indicator and 416A ratio meter have been calibrated on the basis that the detector follows square-law; that is, that detector output voltage is proportional to the square of the r-f input voltage. Crystal diode detectors do follow a square-law characteristic at low input levels, but at higher levels they depart from this characteristic. The output-versus-input characteristic of a typical X421A Waveguide Crystal Detector Mount is indicated in Figure 2B-14.

If at all times both the forward and reverse detectors could be operated at input levels below -20 dbm, no appreciable error would be introduced because of detector characteristics since each detector would be operating in its square-law region during both calibration and operation.

Operating the forward detector at levels within the detector square-law region offers no problem. Since in the forward arm of a reflectometer the signal has the same level during both calibration and operation, the dynamic range over which the forward detector must operate is determined solely by variation (usually within 10 db) in power output from the signal source. Thus sufficient attenuation can be used ahead of the forward detector to reduce the signal to a level which 1) will be above the minimum required by the ratio meter and 2) will be within the range over which the detector obeys square-law.

In the reverse arm, however, the signal must be at a much higher level during calibration than it will be when a reflection is being measured since calibration generally is performed at 100% reflection, and reflection coefficients being measured may be as low as 1%.

Sufficient attenuation ahead of the reverse detector to bring the signal used during calibration within the range over which the detector obeys square-law perfectly would, when low reflection coefficients are being measured, reduce the signal to a level which would be below the minimum required by the ratio meter.

Generally, therefore, during calibration the level of the signal into the reverse detector will be above that at which the detector obeys square-law, in which case there will be a different ratio between the detector output and the reflected power in the main guide

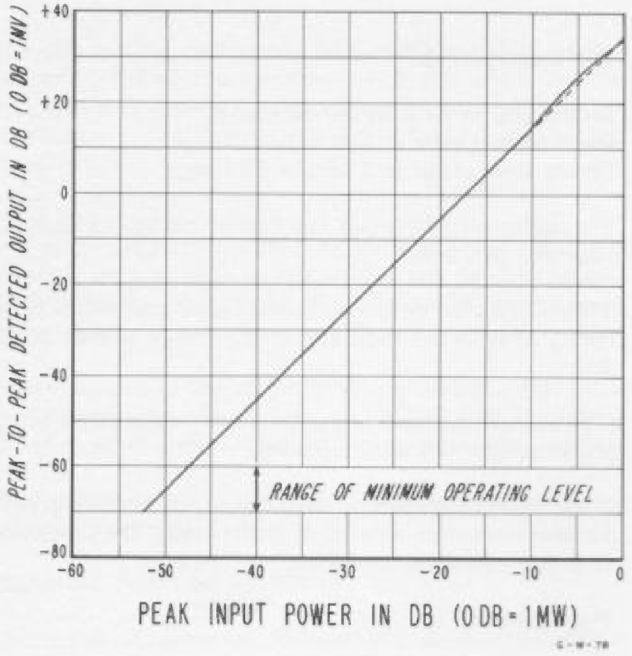

Figure 2B-14. Square-Law Characteristics at 20°C of Typical 421A Crystal Detector

during calibration than there will be during operation in the square-law region.

This difference is indicated in the following equations. Voltages and powers referred to are identified in Figure 2B-15. With a 10 db reverse coupler, the reverse detector output will have the following values:

(1) Detector being operated in square-law region

$$V_{ar} = 0.1\,(k_r\, V^2 RF_r)$$

(2) Detector being operated outside square-law region

$$V_{ar} = 0.1\,[\,k_r V^2 RF_r + E_r(VRF_r)]$$

where:

$VA_r$ = audio voltage at detector output
$VRF_r$ = r-f voltage at detector input
$PRF_r$ = reflected power in main guide
$k_r$ = square-law coefficient for reverse detector
$E_r$ = reverse detector error term

Accuracy of calibration is achieved only if detector outputs bear the same ratio to main-guide powers during operation that they do during calibration. Therefore, if calibration is performed at a level outside the square-law region, ratio meter gain will be set a little too high or a little too low for operation in the square-law region.

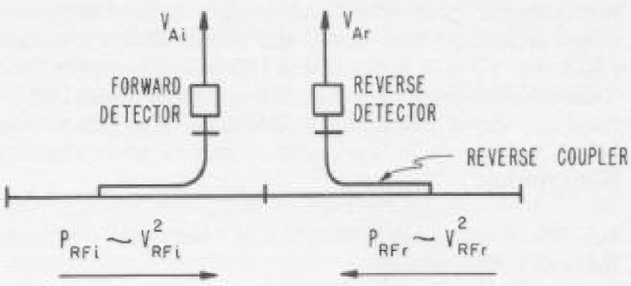

Figure 2B-15. R-F and Audio Voltages in a Reflectometer System.

The variation of detector sensitivity with signal level can be measured, however, and with the data obtained from such measurements, the magnitude and direction of error introduced into ratio readings can be computed.

Measurements are required only for the reverse detector. Aim of the measurement technique is:

(1) To determine whether detector response is square-law over the range of levels at which the detector may be expected to operate.

(2) If it is found that the detector does not obey square-law, to determine at representative frequencies in the band of interest and at levels corresponding to various reflection coefficients, the magnitude and direction of error that will result.

Step-by-step instructions for making the measurement are given in Section 2B-12. The procedure includes the following steps.

(1) Detector response is measured at the highest signal level the detector will see during use of the reflectometer.

A. The signal applied to the reverse detector has approximately the same level as that which the detector will see when a 100% reflection is being used for the ratio meter calibration procedure.

In the setup used when measuring variation in detector sensitivity with signal level, the reverse coupler is turned around with respect to the direction it has in a reflectometer system. This reversal results* in approximately 1/2 db more power at the coupler

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*See 2B-10 Definitions, reverse coupler, for a discussion of the conditions which cause the 1/2 db difference in level at the coupler output.

output than is present with the coupler turned the other way. Actually, therefore, the signal at the detector input will have a level about 1/2 db higher than that which the detector will see when a 100% reflection is used for the calibration procedure. The error this 1/2 db difference in level may introduce generally can be neglected.

B. The detector output level is measured. This is the reference level.
For convenience:

(1) A voltmeter which is calibrated for square-law detectors, such as the hp 415B, is used for the measurement.

(2) The gain of the 415B is adjusted to get a convenient reference. Generally a reference of 1 db on the 30 db range can be obtained.

(3) The input to the detector is attenuated by a known amount.

The line attenuator is set for a value which will reduce the signal to one of the levels which the detector will see during actual measurement of reflection coefficients. The levels at which measurements should be made of course will differ from application to application.

The level which the signal in the main guide should have relative to the reference level to correspond to a given reflection coefficient is the return loss* of the load in db. The amount of attenuation required to bring the signal to the proper level may be found 1) by substituting the desired reflection coefficient for $\rho$ in the expression $20 \log \frac{1}{\rho}$, or 2) by finding the value of the return loss with a Reflectometer Calculator. *

(4) The level the attenuated signal has at the output of the detector is compared to the level it would have if the detector were obeying square-law at both the level used in step (1) and the level used in step (2).

This comparison is made by noting the db value of the difference between the reference [step (1) B] and the meter indication, and then comparing this difference with the known amount of line attenuation used.

If the db value of the difference and the known amount of attenuation are the same, the detector is being operated in its square-law region both at the level which will be used during calibration and at the level used in step (2).

For example, if:

Reference is 1 db on the 30 range
Input to detector is attenuated 26 db
Meter indication is 7 on the 50 range

The difference between reference and meter indication will be 26 db.

Therefore, the detector is obeying square-law perfectly at both the high end of the range and at 26 db down.

(5) Direction and percent of any deviation from square-law are determined.

If the difference noted in step (4)is numerically greater than the known amount of attenuation, the deviation is in the - (minus) direction.

For example, if:

Input to detector is attenuated 26 db
Difference noted in step (4) is 26. 2 db

Then detector output is lower than it would be if detector were obeying square-law at both high and low input levels. Therefore, 26. 2 db is a -0. 2 db deviation.

Conversely, if the difference noted in step (4) is numerically less than the known amount of attenuation, the deviation is in the + direction; a difference of 25. 8 db would be a +0. 2 db deviation, for example.

To convert db error to percent error, see Table 5, Section 2B-12.

For example, with the input to the detector attenuated 14 db:

If the difference noted in step (4) were 14. 4 db there would be a 0. 4 deviation. Table 5 shows a 0. 4 db deviation to be approximately 4. 8%. Since 14. 4 is numerically greater than 14, the error will be -4. 8%.

If the difference noted in step (4) were 13. 6 db, the deviation also would be 0. 4 db, but in the other direction, and the error would be +4. 8%.

NOTE

The percent error is percent of reflection coefficient.

(d) Determine total scalar error -
Percent Error -

If the frequency-response error and the square-law error are not in the same direction, they will tend to offset each other. Therefore, the scalar error percent total (which is the multiplier used to compute

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*See 2B-10 Definitions

the effect of scalar error on a ratio reading) is obtained by taking the algebraic sum of the percent of frequency-response error and the percent of square-law error. This percent is percent of reflection coefficient.

(1) Absolute Error -
Absolute error is the amount by which a given ratio reading will be high or low. It is the product of the reflection coefficient and the total scalar error percent figure.

The direction of the absolute error (whether the ratio meter reading will be high or low) will be the same as that of the deviation which causes the error.

For example, if scalar error for a 0.3 reflection coefficient is -1.75% at 8.0 kmc:

Absolute error is -0.00525.

When the ratio meter indicates 0.3, the reflection coefficient actually is 0.30525.

(e) Measurement of Spurious Signals - General -
In any measurement system operated at microwave frequencies, there will be spurious signals. These signals are caused by dis-continuities in the system, some mismatch between components, and by lack of infinite directivity in the sampling devices. (In the directional coupler, the small signal which results from finite directivity* is called the directivity signal. *)

Because of the attenuation used in the line and the high attenuation of the forward coupler, in a reflectometer system the reflections from the generator, the reflections from the forward detector, and the directivity signal in the forward coupler are reduced to such a low level that they may be disregarded.

The only spurious signals of consequence, therefore, are those which are present at the input to the reverse detector. These signals are of two types:

(1) A signal proportional to the incident signal: the directivity signal in the reverse coupler.

(2) A signal proportional to the square of the reflection coefficient.

The reverse-traveling (reflected) wave encounters discontinuities which cause reflections to be returned to the load and re-reflected. These signals therefore, are proportional to the square of the reflection coefficient. They are in phase and thus at the input to the reverse detector may be considered as one signal.

The signal at the input to the reverse detector therefore, is the sum of two spurious signals and a signal (called the reflected signal in the following discussions) which is proportional to the reflection from the load.

Spurious signals are vector quantities and may have any phase angle with respect to the reflected signal. Since phase relations between the signals are unknown, the effect of the spurious signals on a ratio reading cannot be determined exactly. For any specific reflection coefficient, however, the top and bottom limits of the area of error can be defined.

Spurious signals will contribute maximum error when the error signals are all in phase at the same time that their total combination is either in phase or 180° out of phase with the reflected signal. The range of error, therefore, is bounded at the top by the reading which will occur when all signals are in phase with the reflected signal, and at the bottom by the reading which will occur when the spurious signals are 180° out of phase with the reflected signal.

The area within these top and bottom limits is designated the area of ambiguity and, after appropriate measurements, can be computed for any reflection coefficient of interest.

The area of ambiguity curve is built around the scalar error curve. Thus the area of ambiguity curve completely predicts the limits of assured accuracy with respect to a specific reflection coefficient in a specific reflectometer system.

Table 10, Section 2B-12, is a typical work sheet for the procedures involved in defining the area of ambiguity for each of several reflection coefficients.

To define the area of ambiguity for a reflection coefficient of interest:

(1) At various frequencies across the band, the directivity of the coupler is measured, and the directivity in db is converted to a voltage ratio to obtain the amount of error the directivity signal will cause in a ratio reading.

This error will be the same at all values of reflection coefficient since the directivity signal is proportional to incident, not reflected, voltage.

(2) The spurious signal re-reflected from the load

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*See 2B-10, Definitions, directivity and directivity signal.

is measured at various frequencies across the band, and the error it will contribute at the reflection coefficient of interest is computed.

(3) The value the directivity and spurious signals have when they are in phase is obtained by algebraically adding the values obtained in steps (1) and (2).

(4) The top and bottom limits of the area of ambiguity are determined at each frequency by 1) adding algebraically and 2) subtracting algebraically absolute scalar error and the sum of the spurious signals.

Typical area of ambiguity curves for reflection coefficients of 0.3, 0.2, 0.1 and 0.05 are shown in 2B-12, Figure 2B-26. These curves were plotted from data taken during measurements made in a typical reflectometer system.

Procedures for determining the error due to the directivity signal and the spurious signals re-reflected from the load and for determining the area of ambiguity are given in Section 2B-12, paragraphs 4 and 5.

Considerations governing these procedures are given below in sub-paragraphs f and g.

(f) Determination of error due to directivity signal in reverse coupler -

To determine ±limits for the error which the directivity signal can contribute to a ratio reading, directivity of the coupler in db must first be measured. Once the directivity of the coupler is known, the proportion of incident voltage which will appear at the reverse coupler auxiliary-arm output can be found by converting directivity (in db) to the corresponding voltage ratio.

Considerations involved in the error determination procedure are discussed below.

(1) The Reference -

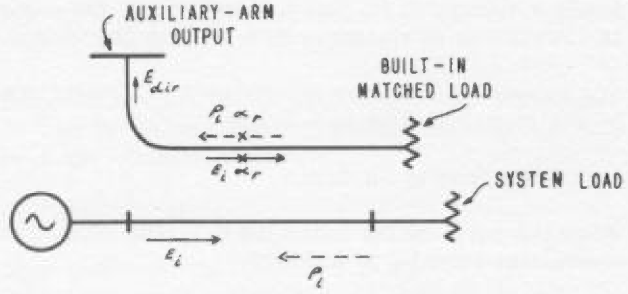
The reference used is the level the reflected signal has under conditions of 100% reflection.

To understand the relation of this reference to the measurement of directivity there should be some understanding of 1) the main signals in the coupler and 2) the ratio which will exist between signals because of the directivity of the coupler.

With a wave traveling in only one direction in the main arm, the power coupled into the auxiliary arm will flow in two directions: a strong signal will flow in the same direction as the flow in the main arm and a relatively small signal will flow in the reverse direction.

Since the directional coupler is a symmetrical device, when waves are traveling in both the forward and reverse directions in the main arm the same fraction of both waves will be coupled into the auxiliary arm.

A built-in matching termination at one end of the auxiliary arm absorbs power flowing into it. Thus of the two strong signals in the coupler auxiliary arm, only one appears at the auxiliary-arm output. Of the two weak signals, one is absorbed by the built-in load, the other (the directivity signal) appears at the auxiliary-arm output. These signals are indicated in Figure 2B-16, and identified as follows:



$E_i$ = Incident Voltage

$\rho_i$ = Reflected Voltage

$E_i \alpha_r$ = Incident Voltage Coupled into Auxiliary Arm of Coupler

$\rho_i \alpha_r$ = Reflected Voltage Coupled into Auxiliary Arm of Coupler

$E_{dir}$ = Directivity Signal, Proportional to Incident Voltage

Figure 2B-16. Main Signals in Reverse Coupler, Waveguide Reflectometer System

A portion (at the reverse coupler, usually 0.1) of forward-going power is coupled into the auxiliary arm of the coupler.

The greater part of the forward-going signal is absorbed in the built-in matched load.

A small reverse-going signal (not shown) appears at the auxiliary-arm output.

Directivity signal Edir is the sum of the reverse-going signal and any reflection from the built-in load.

The same portion (0.1) of reverse-going reflected power is coupled into the auxiliary arm of the coupler.

Reverse-coupled signal $\rho 1 \propto r$ appears at the auxiliary-arm output. The small signal (not shown) propagates toward the built-in load and is absorbed there.

The ratio of the incident voltage coupled into the auxiliary arm ($E_i \propto r$) to the small amount of incident voltage ($E_{dir}$) which "sneaks around the corner" to the auxiliary-arm output is a function of the directivity of the coupler. Therefore, the directivity of the reverse coupler may be determined by measuring the ratio, $\frac{E_i \propto r}{E_{dir}}$.

Since under conditions of 100% reflection, signal $\rho 1 \propto r$ is approximately equal to signal $E_1 \propto r$, signal $E_1 \propto r$ may be "found" by using the level which the coupler output has at 100% reflection as the reference.

(2) The Directivity Ratio -

By determining the level of the directivity signal with respect to the reference, the directivity ratio, $\frac{E_i \quad r,}{E_{dir}}$ will be established.

However, since the directivity signal at the coupler output is part of a complex signal, the level of the directivity signal relative to the reference cannot be determined directly.

(3) The Directivity Signal -

The output of the reverse coupler is the vector sum of three signals: 1) the reflected signal, 2) the directivity signal, and 3) a spurious signal proportional to the square of the reflection coefficient. Thus, the output of the coupler may be considered as the vector sum of three unknowns.

The method used to separate the directivity signal from the other signals consists, essentially, of 1) deleting one of the unknowns, 2) setting up sum and difference equations with two of the unknowns, the directivity signal and reflected signal, and 3) solving for the unknowns.

The spurious signal proportional to the square of the reflection coefficient is removed from the system by using a load with a very low reflection coefficient. With such a load, the spurious signal re-reflected from the load is reduced to so low a level that it is negligible.

The sum and difference equations are set up by measuring the level the reflected signal and directivity signal have when they are in phase and the level they have when they are 180° out of phase.

The desired phase shift is obtained by using a movable load. The phase of the reflection from the load will shift as the load is moved while the directivity signal being proportional to incident voltage will remain fixed in phase with respect to the reflected signal.

Computations involved in solving for the two unknowns have been made and the results presented in chart form as Figure 2B-23, Section 2B-12. The level which each signal has may be obtained from the chart.

Either of two methods may be used to provide identification for the directivity signal:

(a) Making the measurement with two different loads. The signal which, after separation, is found to have the same level in both measurements is known to be the directivity signal.

(b) Using a load that is known to have a reflection higher in level than that of the directivity signal.

The signal which, after separation, is found to have the lowest level is known to be the directivity signal.

(4) The Procedure -

A. Reference is set.

The level the coupler output has at 100% reflection is used as the reference.

(1) For optimum accuracy, a sliding short is used for the reference-setting procedure.

(2) The gain of the voltage indicator is adjusted to give the reference a convenient value, such as 0 db.

For these procedures it is desirable to use a voltmeter which is calibrated for use with square-law detectors, such as an Model 415B.

B. Load is chosen.

The two requirements which the load must meet are:

(1) The reflection coefficient of the load must be low enough that the spurious signal re-reflected from the load is negligible.

(2) The reflection coefficient of the load must be high enough that the reflected signal will be higher in level than the directivity signal.

The directivity specification for Model 752 directional couplers is 40 db. This means that the directivity signal will be down at least 40 db. Therefore, a load with a reflection down about 34 to 38 db will meet both requirements.

The procedure for modifying a low-reflection load to obtain a suitable mismatch is detailed in Definitions under modified load.

C. Sum and difference values are obtained -
As the load is moved, maximum and minimum readings will be obtained as the phase of the reflected signal swings from the in-phase to the 180° out-of-phase relation with respect to the directivity signal.

What is required from the measurements is the level the in-phase and out-of-phase combinations have with respect to the reference. Therefore, the difference between the meter reading in db and the reference is the value recorded.

D. Sum and difference equations are solved -
Equations involving all sum and difference combinations likely to be encountered in directivity measurements have been solved, and the results assembled in chart form (Figure 2B-23). With the chart, therefore, once the in-phase and out-of-phase levels obtained in step C are known, the level each signal has with respect to the reference is easily determined.

Instructions for using the chart are given in Section 2B-12, paragraph 4a (5).

The values obtained from the chart are:

(1) The directivity of the coupler.

(2) The return loss of the load.

Arrangement of the signal-separation chart is as follows:

Sum values (min. number of db) are plotted on the vertical scale.

Difference values (max. number of db) are plotted on the horizontal scale.

Each point defined by the intersection of a horizontal and vertical co-ordinate is also the intersection of two curved co-ordinates. Assuming that the sliding load has been adjusted so that its return loss is less (in db) than the directivity of the coupler, then:

(a) Directivity is plotted on the broken-line curved co-ordinate.

(b) Return loss is plotted on the solid-line curved co-ordinate.

E. Error is determined -
The relative amplitude of the directivity signal is found in the voltage ratio corresponding to the directivity in db, and may be obtained either from conversion tables or as described in Measurement of Errors Paragraph 4a (6).

Since the directivity signal at the reverse coupler is proportional to the incident signal, the amplitude of the directivity signal will remain constant whatever the reflection coefficient of the load.

For example, if the directivity of the coupler is 46 db, limits of the error contributed by the directivity signal will be ±0.005 whether the reflection is 100% or 1%.

(g) Determination of error due to spurious signals re-reflected from load -
To measure spurious signals re-reflected from the load it is necessary first to remove the directivity signal from the system, leaving as the only signals of consequence, the reflection from the load and the spurious signals re-reflected from the load.

After the directivity signal is cancelled, the spurious signal error factor can be determined. With the error factor, the ± limits of error for any reflection coefficient of interest can be computed.

(1) Cancellation of directivity signal -
To perform the directivity signal cancellation procedure, any other spurious signals must be removed from the system. Therefore, the load should have so small a reflection that the spurious signals reflected twice from the load become negligible. Ideally, the reflection from the load should be greater than that of the directivity signal.

The modified load* used in the procedure for determing directivity is arranged to satisfy the same two conditions, and therefore, is excellent for the purpose.

The means used to cancel the directivity signal is the ⓗⓟ Model 870A Slide-Screw Tuner which can be adjusted to set up a signal which has the same magnitude as the directivity signal and is 180° out of phase with it. The tuner consists of a slotted section with an adjustable probe mounted on a precision-built carriage. The reflection from the probe is the signal which counteracts the directivity signal.

As probe depth is adjusted, magnitude of the signal is varied.

As probe position is adjusted, phase of the signal is varied.

A. The phase of the probe signal should be adjusted first.

---

*See 2B-10, Definitions

(1) Check that the probe is out of the line.

This ensures that the directivity signal and reflected signal are essentially the only signals in the system.

(2) Slide the load to obtain a maximum indication on the db scale of the Model 415B (connected to the output of the reverse detector).

At this position of the load, the reflected signal and the directivity signal are in phase.

(3) Adjust the probe for some penetration, to obtain a small reflection.

A meter change of 1/4 to 1/2 db is about right for the magnitude of reflection desired from this step.

Since the signal from the probe could be either in phase or out of phase with the directivity and reflected signals, the change in meter reading may be either positive or negative.

(4) Shift the position of the probe horizontally, to bring the signal from the probe 180° out of phase with the other two signals. Relations of the signals as the signal from the probe approaches the 180° out of phase condition is indicated in Figure 2B-17.

With horizontal travel of the probe, the meter indication will vary. When meter indication reaches minimum, the signal from the probe is 180° out of phase with the other signals.

B. The magnitude of the signal from the probe is adjusted.

With the signal from the probe 180° out of phase with the sum of the directivity and reflected signals, relations between the signals will be as follows:

(1) So long as the magnitude of the signal from the probe is less than or equal to the directivity signal, the probe signal will subtract from the sum of the directivity and reflected signals.

Therefore, as the load is slid after each probe adjustment, the meter will indicate a steadily decreasing maximum.

(2) When, however, probe penetration becomes too great, the signal from the probe will start to add to the other signals, and the meter will indicate an increase in the maximum.

To adjust the magnitude of the signal from the probe:

1. Adjust the probe for a slight increase in depth of penetration. As the signal from the probe becomes greater, the meter will indicate a decrease in signal level.

For most rapid completion of the procedure, which at best must be a trial-and-error process, it is recommended that adjustment of the probe proceed in steps which result in not more than a couple of db decrease in the meter indication.

2. Slide the load while noting the direction of the maximum.

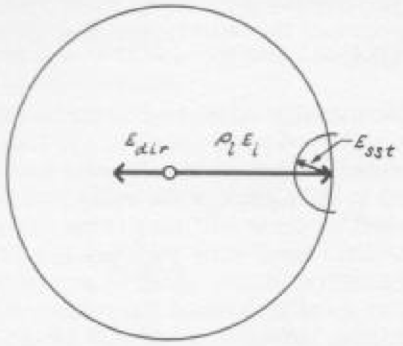
While the maximum is decreasing, probe penetration is in the proper direction.

If the maximum increases, probe penetration should be decreased.

3. Continue alternating steps 1 and 2 until there is little variation in the meter indication as the load is slid.

The closer the probe signal gets to the proper magnitude, the smaller will be the meter variation as the load is slid.

When the meter variation is the minimum obtainable (generally about 1 db), the slide-screw tuner is at optimum setting.

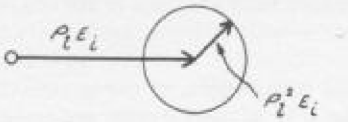


$E_{dir}$ = Directivity Signal

$\rho_l E_l$ = Reflected Signal

$E_{sst}$ = Reflection from Slide-Screw Tuner Probe

Figure 2B-17. Phase Relations during Slide-Screw Tuner Adjustment as small reflection from SST Probe approaches 180° out-of-phase condition. Vector Diagram



$\rho_l \epsilon_i$ = Reflected Signal

$\rho_l^2 \epsilon_i$ = Spurious Signals Re-reflected from Load

Figure 2B-18. Phase Relations, Reflected Signal and Spurious Signals Re-reflected from Load. Vector Diagram.

(2) Determination of error factor -
To perform this stage of the procedure, the modified load (X916A or 914A) is replaced by a sliding short (Model 920A), the reverse detector is connected to the REFLECTED/PROBE input of the ratio meter, and the forward detector is connected to the INCIDENT/ REFERENCE input.

With the slide-screw tuner at the setting obtained in step (1) and the system terminated in a short, there are two signals of consequence in the system, the reflected signal and the spurious signal re-reflected from the load.

The spurious signal is caused by discontinuities which reflect the reflected power back to the load where it is re-reflected. Therefore, the spurious signal is proportional to the square of the reflection coefficient of the load and its phase will vary twice as fast as that of the reflected signal when the load is moved. Relatively, therefore, as the short is moved the spurious signal is rotating around the reflected signal in the relationship indicated in Figure 2B-18.

As the short is moved, the reflection coefficient indicated by the ratio meter will vary from a maximum when the signals are adding (p max) to a minimum when they are 180° out of phase ( p min).

Provided pmax is approximately unity, the error factor $k_1$ is given by the following expression:

$$k_1 = \frac{p\max - p\min}{2}$$

For any p of interest, the maximum error $\Delta p$ due to spurious signals re-reflected from the load is given by the following expression:

$$\Delta p = k_1 p^2_1$$

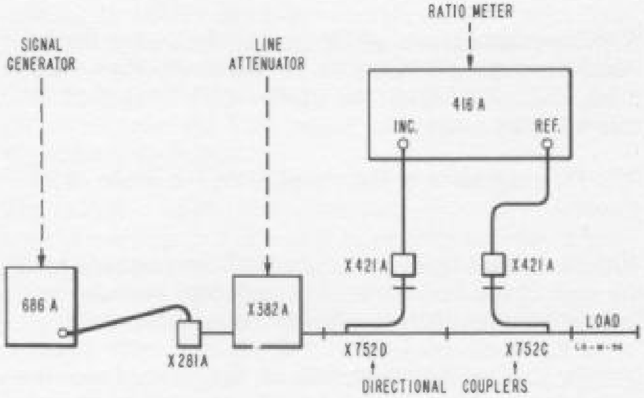
## 2B-12 MEASUREMENT OF ERRORS

(a) General -
In any microwave measurement system, there are several sources of error. Where maximum accuracy is required, it is desirable to measure the amount of error which can be contributed by each of these sources. With the resulting data, curves can be plotted which will define the limits of error for any reflection coefficient of interest.

The following paragraphs detail procedures that may be used to build error curves which will completely predict the limits of assured accuracy for a given range of reflection coefficients in a specific reflectometer system.

The following test equipment is required:

| | |
|---|---|
| Model 415B | Standing Wave Indicator<br>sensitive voltage indicator with square-law calibration |



LEGEND

| | | |
|---|---|---|
| 686A | - | SHF Swept Frequency Oscillator |
| X281A | - | Waveguide to Coaxial Adapter |
| X382A | - | Broadband Precision Waveguide Attenuator |
| 416A | - | Ratio Meter |
| X421A | - | Waveguide Crystal Detector Mount |
| X752D | - | 20 db Waveguide Directional Coupler |
| X752C | - | 10 db Waveguide Directional Coupler |

Figure 2B-19. Typical Waveguide Reflectometer System.

| | |
|---|---|
| Model X916A | Standard Reflection (or Model 914A Moving Load)<br>low-reflection movable load |
| Model 920A | Adjustable short<br>sliding short |
| Model 870A | Slide-screw Tuner<br>adjustable probe mounted on precision-built carriage |

(b) Setting of Signal Level -
Set the input signal level to a level which gives appreciable narrowing of the eye shadow angle.

When adjusting the level of the signal:

(1) Always use the lowest level which, at all frequencies in the band of interest, will be within the operating limits of the 416A.

(2) Reduce the signal to the desired level, so far as practicable, at the line attenuator. Sufficient attenuation in the line practically eliminates any effect due to reflections from the generator.

Whenever the correction data resulting from error measurements are to be used, the input signal must have the same level as that used when obtaining the error data.

With reflectometer set up as indicated in Fig. 2B-19:

A. Put system into operation.

B. Check modulation frequency on input signal.

C. Adjust level of input signal.

These procedures are detailed in paragraph 3 of Section 2B-11, subparagraphs a, b, and c, respectively.

D. At signal source, measure level of output at setting obtained in step C above.

ⓗⓟ Model 430C Microwave Power Meter and Model 477B Coaxial Thermistor Mount are suitable for making this measurement.

E. Record signal level, and the frequency at which the level was measured.

F. Record line attenuator setting obtained in step C, above.

(c) Determination of Scalar Error -
For discussion of scalar error, see 2B-11, Measurement Considerations.

Variations between the sensitivity characteristics of the directional couplers and detectors used in the forward and reverse arms of waveguide measurements systems can contribute error to ratio readings. In single-frequency operation this error is almost completely compensated for when the ratio meter is calibrated. In swept-frequency operation the error contributed by differences between the relative sensitivities of equipments used in the forward and reverse arms cannot be compensated for at all frequencies across the band. The amount of deviation at any one frequency, however, is a scalar quantity which can be measured, its effect on ratio readings computed, and the resulting data used to build error curves for the band of interest.

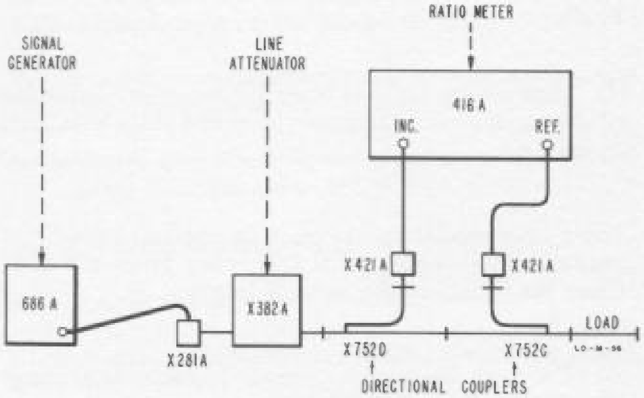
To determine scalar error:

(1) Variations with frequency are measured [detector/coupler frequency-response error (subpara. a)].

(2) Variations with amplitude are measured [detector sensitivity-with-signal-level (square-law) error (subpara. b)].

(3) The two sets of data are combined (subpara. c).

(d) Measurement of detector/coupler frequency-response error -
For a discussion of this procedure, see 2B-11, Measurement Considerations.



LEGEND

X916A = Standard Reflection (Matching Load)

Figure 2B-20. Typical Test Setup, Frequency-Response Error Measurements

From data obtained, the frequency-response curve for the band of interest can be determined. The purpose of measuring amplitude-constancy-with-frequency is two-fold:

To determine the proper frequency to use for the calibration procedure.

To determine percent of error across the band after calibrating with the chosen frequency.

(1) Reverse the 10 db coupler so that the 20 db and 10 db couplers are in tandem, as indicated in Fig. 2B-20. Terminate the system in a perfect load (0.00 reflection), such as a Model X916A Standard Reflection or a low-reflection load such as a Model 914A Moving Load.

(2) Frequency and signal level:
Frequency: low-edge-of-band frequency.
Level: set in paragraph 2c.

(3) Set reference ratio on 416A.

A. Set RANGE switch at 0 DB 100%.

B. Adjust SET TO FULL SCALE for convenient reference.

Should be less than 100% (90%, for example).

Table 4, immediately following step **H**, is a work sheet for the procedure detailed in steps D, E, F, G.

(4) Measure the ratio at other frequencies across the band and, for each frequency, record ratio indicated by the 416A.

For a representative curve, it is recommended that readings be taken at equal frequency intervals at at least six points in the band of interest.

(5) For each frequency measured, compute percent of deviation from the reference.

(6) Select calibration frequency.

From the deviation-vs-frequency data, choose as the calibration frequency that with the deviation closest to the mean.

(7) Determine across-the-band frequency-response error which will be present after the system is calibrated.

From the readings obtained in step 4, compute the percent that the ratio reading at each sampled frequency deviates from the ratio reading at the calibration frequency.

(8) <u>Example.</u> Band of interest: 8.0 to 10.0 kmc

A. Set signal source for 8.0 kmc.

B. Set reference ratio on 416A:

1. Set RANGE switch at 0 DB 100%.

2. Adjust SET TO FULL SCALE to get indication of 90 on reflectometer scale.

C. Set signal source for 8.4 kmc.

D. Note and record ratio meter indication.

In the reflectometer system used when making the measurements recorded in Table 4, a reading of 89 was obtained at 8.4 kmc.

Figures shown in Table 4 are typical; measurement data will vary with each reflectometer system.

E. Perform steps C and D at 8.8, 9.2, 9.6 and 10.0 kmc.

F. At each frequency, compute percent of deviation from reference ratio.

See Table 4 for typical work sheet.

G. Select the calibration frequency.

As indicated by the figures shown in Table 4 deviation at 9.6 kmc is closest to the mean, and 9.6 kmc should be used when calibrating the ratio meter.

H. Compute frequency-response error which will be present after calibration.

See last column in Table 4.

## TABLE 4

## TYPICAL WORK SHEET FOR FREQUENCY-RESPONSE ERROR MEASUREMENTS

| Frequency (KMC) | 416A Reading | % Deviation from 416A Reference | % Deviation from Value at Calib. Freq. |
|---|---|---|---|
| * 8.0 | 90 | 0 | +3.0 |
| 8.4 | 89 | -1.0 | +2.0 |
| 8.8 | 86 | -4.0 | -1.0 |
| 9.2 | 86.5 | -3.5 | -0.5 |
| ** 9.6 | 87 | -3.0 | 0 |
| 10.0 | 87 | -3.0 | 0 |

* Frequency used for setting reference

** Best frequency for calibration

(e) Measurement of detector sensitivity-with-signal-level error -
For a discussion of this procedure, see Section 2B-11, Measurement Considerations.

The following procedure, from which will be obtained the percent error resulting from detector deviation from square law, consists of 1) setting a relatively high level as the reference, 2) attenuating the signal by a known amount, 3) measuring the level which the attenuated signal has at the detector output, and 4) computing the percent and direction of any deviation between a) the level the signal should have (known number of db down from the reference) and b) the level the signal has at the detector output (number of db down from the reference as indicated by the meter).

(1) A level comparable to that which the reflected signal will have during calibration is set as the reference.

(2) The known values by which the input to the detector is attenuated should be those which will bring the signal to levels which will be encountered during the actual measurement of reflection coefficients. In the following procedure, the values of attenuation used are those which will bring the signal to the level which the reverse detector will see when reflection coefficients of 0.3, 0.2, 0.1, and 0.05 are being measured.

At the level corresponding to each reflection coefficient of interest, measurements are made at each frequency selected when measuring frequency-response error.

Table 6 is a typical work sheet for the procedures detailed below.

A. Disconnect reverse detector from the REFLECTED/PROBE input on the Model 416A.

B. Connect reverse detector to a sensitive voltage indicator with square-law calibration.

An hp Model 415B Standing Wave Indicator is suitable for making this measurement.

The test setup is indicated in Figure 2B-21.

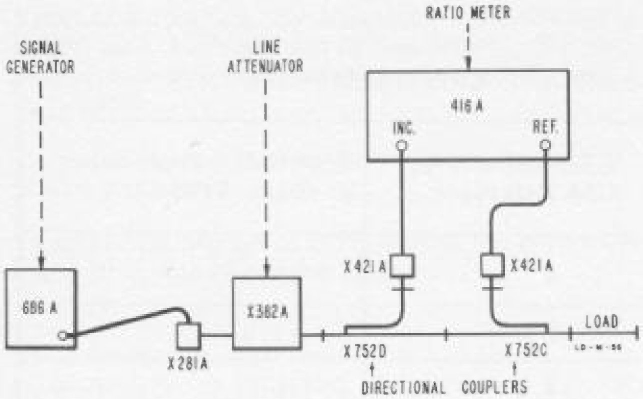
Set the 415B selector switch at 200,000 Ω.

C. Set signal source for low-edge-of-band frequency and to proper level set in paragraph 2c.

D. At signal source, adjust modulating frequency to get peak indication on 415B.

E. Check line attenuator setting. Should be same as set in paragraph 2c.

These instructions will assume a setting of 5 db.



LEGEND

415B = Standing Wave Indicator

Figure 2B-21. Typical Test Setup, Detector Sensitivity-With-Signal-Level Error Measurements.

F. Adjust 415B GAIN control to get a convenient reference on the DB scale.

These instructions will assume a reference of 1 db on the 30 scale.

G. At the line attenuator, increase the attenuation noted in step E by 10. 4 db.

At the 5 db setting assumed in step E, the line attenuator is now set at 15. 4 db.

The additional 10. 4 db attenuation will bring the signal to the level the reverse detector would see if a reflection coefficient of 0. 3 were being measured.

H. Note indication on the 415B.

If characteristics of the detector are true square-law, the 415B indication will be 1. 4 db on the 40 scale (10. 4 db lower than the reference set in step F).

I. If the difference is not 10. 4 db, record percent and direction of the deviation.

Use Table 5 to convert db difference to % difference.

Deviation will be in the minus direction if the difference is numerically greater than 10. 4, will be in the plus direction if the difference is numerically less.

For example, if the difference indicated by the 415B is 10. 5 db, there is a -0. 1 db deviation. Converting to percent (see Table 5), the deviation is found to be -1. 5%. If the difference were 10. 3 db, the deviation would be +1. 5%.

J. At each frequency selected for the frequency-response error measurement (para. a, step 4):

(a) Return line attenuator to setting it had in step E.

(b) Perform steps F through I.

An example of a work sheet, using typical values is given in Table 6.

K. Reset signal source to deliver low-edge-of-band frequency used in step C.

L. Return line attenuator to setting it had in step E.

M. Adjust 415B GAIN control to get the reference used in step F.

N. At line attenuator, increase attenuation set in step L by 14 db.

Additional 14 db loss will bring signal to level detector would see if reflection coefficient of 0. 2 were being measured.

O. Note indication on the 415B.

If difference between step M and step O readings is greater or less than 14 db, compute percent and direction of the deviation, as outlined in step I.

P. At each of the frequencies used in step J, repeat steps L through O.

Q. With line attenuation increased 20 db over that noted in step E, repeat steps K through P.

Additional line loss of 20 db will bring signal to level detector would see if reflection coefficient of 0.1 were being measured.

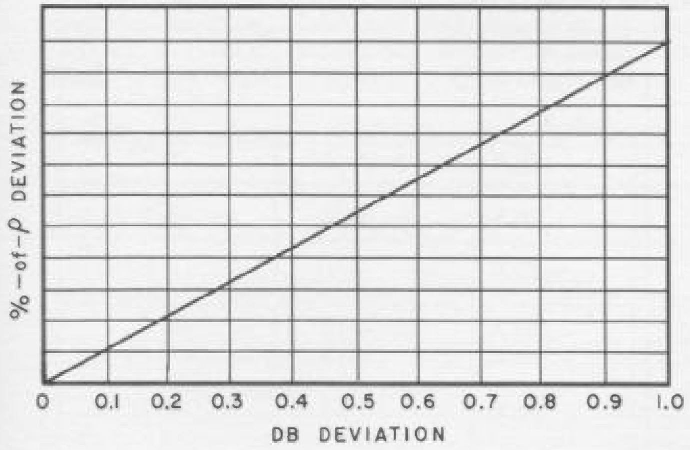
R. With line attenuation increased 26 db over that noted in step E, repeat steps K through P.

Additional line loss of 26 db will bring signal to level detector would see if reflection coefficient of 0.05 were being measured.

(f) Determination of total scalar error - Total scalar error is determined by combining the percent of frequency-response deviation and the percent of square-law deviation, and then computing absolute error (amount that should be added or subtracted, depending on the direction of the error from the ratio meter reading).

TABLE 5

CONVERSION CHART: DB to %-of-ρ



Total scalar error is computed for each reflection coefficient of interest at each sampled frequency in the band of interest.

Table 7 is a typical work sheet for the procedures being discussed.

(1) Percent Error -

A. Formula:

For each reflection coefficient of interest and at each sampled frequency in the band of interest:

I Note %-of-ρ frequency-response error.

II Note %-of-ρ square-law deviation.

III Algebraically add the percentages noted in I and II.

Table 7 shows %-of-ρ scalar error totals computed from the typical data given in Tables 4 and 6.

B. Example:
ρ of interest: 0.2
Sampled frequency: 8.0 KMC.

I %-of-ρ frequency-response error: +3.0%.

From Table 4, %-Deviation-from-Value-at-Calib.-Freq. column.

II %-of-ρ square-law deviation: -7.0%.

From Table 6, %-Deviation-from-Square-Law column.

III Algebraic sum: -4.0%.

(2) Absolute Error -

A. Formula:

I Amount: reflection coefficient times scalar error percent total.

II Direction: Same as direction of scalar error percent total.

-% scalar error results in a - error.

Ratio indicated by 416A will be lower than it should be by amount of absolute error.

+% scalar error results in a + error.

Ratio indicated by 416A will be higher than it should be by amount of absolute error.

B. Examples:
ρ of interest: 0.2

Scalar error percent total: -4.0%.

I Amount: 0.2 x 0.04 = 0.008.

II Direction: minus.

When the 416A indicates 0.2, the reading will be low by 0.008; the reflection coefficient actually is 0.208.

ρ of interest: 0.05.

Scalar error percent total: +5.0%.

I Amount: 0.05 x 0.05 = 0.0025.

II Direction: plus.

When the 416A indicates 0.05, the reading will be high by 0.0025; the reflection coefficient actually is 0.0475.

(g) Measurement of Spurious Signals -

For a brief discussion of spurious signals, and of the procedures detailed in the following subparagraphs, see 2B-11, Measurement Considerations.

The only spurious signals of consequence at the input to the reverse detector are the directivity signal and the spurious signals re-reflected from the load. Procedures for determining the limits of maximum error these signals can introduce are given in the following subparagraphs.

(h) Determination of error due to directivity signal in reverse coupler -

The following procedure, from which will be obtained the limits for the error which can be contributed by the directivity signal, consists of 1) setting a reference which has the same level as that of the incident signal, 2) selecting a load with a

## TABLE 6

## TYPICAL WORK SHEET FOR DETECTOR SENSITIVITY WITH SIGNAL LEVEL MEASUREMENTS

| Frequency (KMC) | $\rho$ Corresponding to Attenuation | Attenuation (DB) | Level of Attenuated Signal (DB) | Deviation (DB)* | % Deviation from square-law*(% of $\rho$) |
|---|---|---|---|---|---|
| | 0.3 | 10.4 | | | |
| 8.0 | | | 10.8 | -0.4 | -4.75 |
| 8.4 | | | 10.7 | -0.3 | -3.5 |
| 8.8 | | | 10.5 | -0.1 | -1.25 |
| 9.2 | | | 10.6 | -0.2 | -2.5 |
| 9.6 | | | 10.8 | -0.4 | -4.75 |
| 10.0 | | | 10.8 | -0.4 | -4.75 |
| | 0.2 | 14 | | | |
| 8.0 | | | 14.6 | -0.6 | -7 |
| 8.4 | | | 14.5 | -0.5 | -6 |
| 8.8 | | | 14.2 | -0.2 | -2.5 |
| 9.2 | | | 14.4 | -0.4 | -4.75 |
| 9.6 | | | 14.5 | -0.5 | -6 |
| 10.0 | | | 14.5 | -0.5 | -6 |
| | 0.1 | 20 | | | |
| 8.0 | | | 20.8 | -0.8 | -9 |
| 8.4 | | | 20.6 | -0.6 | -7 |
| 8.8 | | | 20.4 | -0.4 | -4.75 |
| 9.2 | | | 20.5 | -0.5 | -6 |
| 9.6 | | | 20.6 | -0.6 | -7 |
| 10.0 | | | 20.6 | -0.6 | -7 |
| | 0.05 | 26 | | | |
| 8.0 | | | 26.8 | -0.8 | -9 |
| 8.4 | | | 26.7 | -0.7 | -8 |
| 8.8 | | | 26.4 | -0.4 | -4.75 |
| 9.2 | | | 26.6 | -0.6 | -7 |
| 9.6 | | | 26.6 | -0.6 | -7 |
| 10.0 | | | 26.7 | -0.7 | -8 |

$\rho$ = Reflection coefficient

* = For conversion of DB deviation to % of $\rho$, see Table 2

## TABLE 7

### TYPICAL WORK SHEET FOR TABULATION OF TOTAL SCALAR ERROR

| ρ | ERROR | FREQUENCY | | | | | |
|---|---|---|---|---|---|---|---|
| | | ►8.0 | 8.4 | 8.8 | 9.2 | 9.6 | 10.0 |
| 0.3 | *% | -1.75 | -1.5 | -2.25 | -3.0 | -4.75 | -4.75 |
| | **Absolute | - .00525 | - .0045 | - .00675 | - .009 | - .01425 | - .01425 |
| 0.2 | % | -4.0 | -4.0 | - .35 | -5.25 | -6.0 | -6.0 |
| | Absolute | - .008 | - .008 | - .007 | - .0105 | - .012 | - .012 |
| 0.1 | % | -6.0 | -5.0 | - .575 | -6.5 | -7.0 | -7.0 |
| | Absolute | - .006 | - .005 | - .00575 | - .0065 | - .007 | - .007 |
| 0.05 | % | -6.0 | -6.0 | -5.75 | -7.5 | -7.0 | -8.0 |
| | Absolute | - .003 | - .003 | - .0029 | 0.0038 | - .0035 | - .004 |

* = Algebraic sum of %-Deviation-at-Calib.-Freq. column, Table I, and %-Deviation-from Square-Law column, Table III.

** = % Scalar Error x ρ

► = 8.0 KMC below rated band, Measurements made in reflectometer rated for X band (8.2 KMC - 12.4 KMC).

mismatch so small that spurious signals re-reflected from the load are essentially removed from the system (leaving only the directivity signal and the reflected signal), 3) varying the phase of the reflection from the load to obtain sum and difference values for the two signals as they combine in in-phase and out-of-phase relations, 4) separating the two signals and determining the directivity of the coupler, and 5) converting the directivity to a voltage ratio (which defines the maximum ± error the directivity signal will introduce in a ratio reading).

The directivity signal error is the same at all reflection coefficients since the directivity signal in the reverse coupler is proportional to incident, not reflected, voltage.

The procedure is repeated at various frequencies in the band of interest.

(1) Set up measurement system (see Fig. 2B-22).

A. Change direction of reverse coupler so that forward and reverse couplers are connected back-to-back as in a reflectometer setup.

B. Connect reverse detector output to Model 415B INPUT connector.

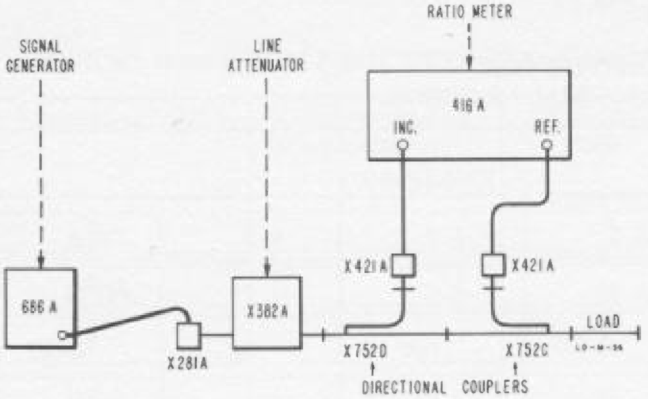
Set 415B selector switch at CRYSTAL.

C. Remove load from Model X916A Standard Reflection (or Model 914A Moving Load), and connect waveguide body to load end of reverse coupler.

1. Support end of measurement system by placing additional waveguide-stand clamp under waveguide body.

2. Check alignment.

Look toward coupler-waveguide connection through end of waveguide body. If inner surfaces are uni-



LEGEND

X920A = Adjustable Short

Figure 2B-22. Typical Test Setup, Measurement of Directivity of Reverse Coupler.

formly dark, alignment is satisfactory. If any line appears, light is striking edge of waveguide, and alignment should be corrected.

D. Check line attenuator setting.

Should be same as set in paragraph 2c.

(2) Set signal source for desired frequency.

Proper level set in paragraph 2c.

(3) Set reference.

A. Connect Model 920A Waveguide Adjustable Short to end of X916A (or 914A) waveguide body.

B. Set 415B RANGE switch for upscale reading.

Generally RANGE switch can be set at 20 when Model 670 or Model 680X signal source is used.

C. Adjust movable short (920A) for maximum indication on 415B.

D. Adjust 415B GAIN control to obtain convenient reading (such as 1 db).

E. Adjust movable short for minimum indication on 415B.

F. Note how many db down minimum indication is from maximum.

G. Determine midpoint of excursion from maximum to minimum.

H. Adjust short to bring meter indication to excursion midpoint.

For example, assuming maximum indication of 1 db, and minimum indication of 2. 6 db, meter excursion is 1. 6 db, and excursion midpoint would be 1. 8 db. Therefore, short would be adjusted to obtain a meter indication of 1. 8.

I. Adjust 415B GAIN control to obtain convenient reading for reference (such as 0 db).

Since reference is set under conditions of 100% reflection, at frequency set in step (2) the 415B is now calibrated to indicate levels with respect to incident signal.

(4) Obtain sum and difference values.

A. Terminate system with movable load which has a reflection down approximately 34 to 38 db from reference set in step (3). To obtain this small a reflection (approximately .013 to .02), a modified* Model X916A (or Model 914A) may be used. Obtaining proper degree of mismatch is a trial-and-error procedure. Limits are as follows:

1. The level the in-phase signals have should be down at least 30. 2 db from the reference.

Assuming reference of 0 db on the 20 range, 415B reading should be no lower numerically than .2 on the 50 range.

If level in-phase signals have is found to be higher than -30. 2 db with respect to the reference, decrease reflection from load by moving wire on modified load away from pointed end of load.

2. To keep above noise region of 415B, it is desirable that the level the out-of-phase signals have, should be no lower than 44 db down from reference.

Assuming reference of 0 db on 20 range, it is desirable that 415B reading be no higher numerically than 4 on the 60 range.

If level out-of-phase signals have is too low, increase reflection by moving wire on modified load toward pointed end of load.

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*See 2B-10, Definitions, modified load, for instructions on modifying a Model X916A or 914A.

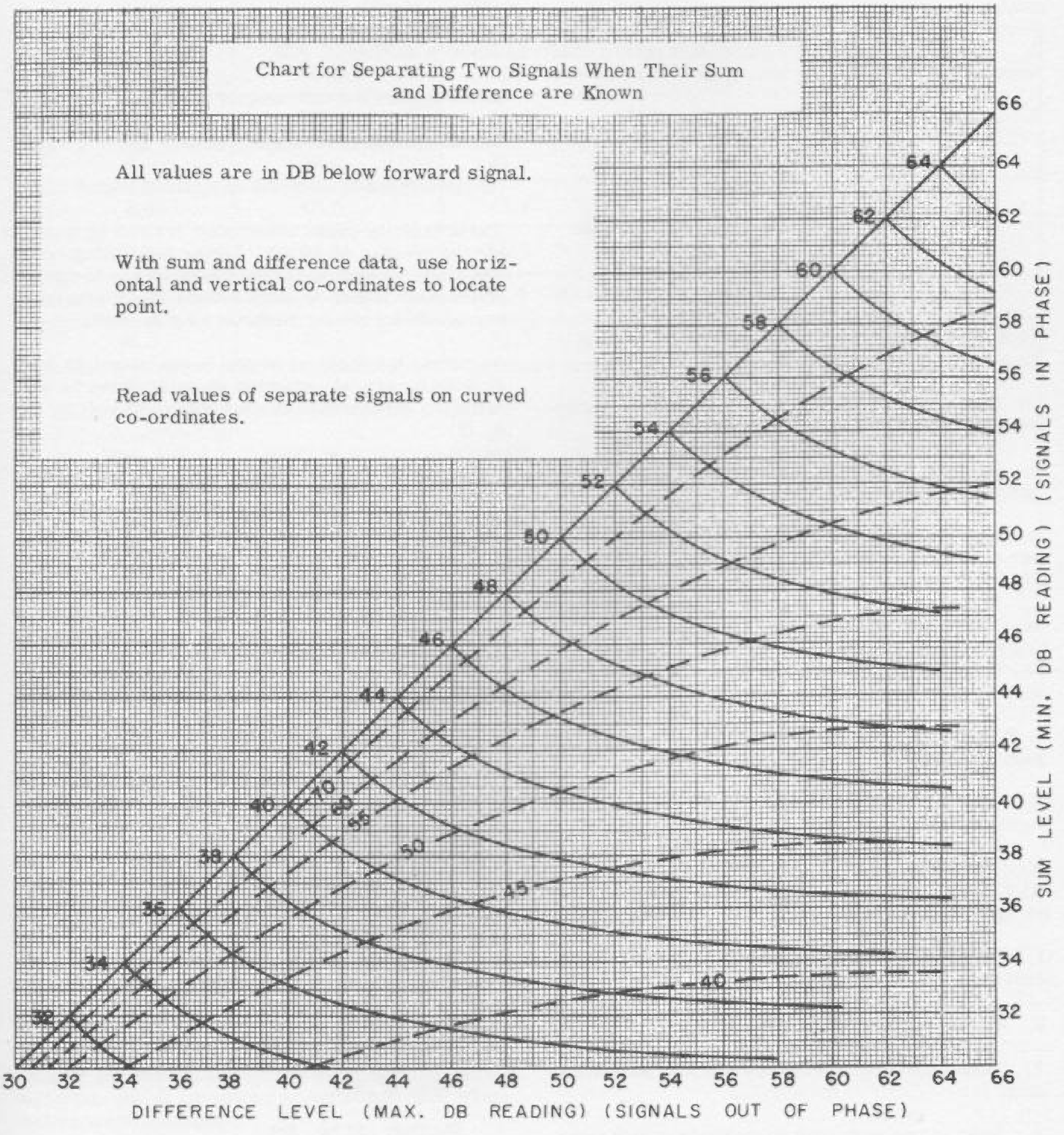


Chart for Separating Two Signals When Their Sum and Difference are Known

All values are in DB below forward signal.

With sum and difference data, use horizontal and vertical co-ordinates to locate point.

Read values of separate signals on curved co-ordinates.

Figure 2B-23. Signal-Separation Chart

B. Slide load, watching variation in 415B indication.

1. Note maximum and minimum indications on db scale.

2. Compare each with reference, and record maximum and minimum levels with respect to reference.

3. Example:

Reference: 0 db on 20 range.

Maximum indication: 9 db on 50 range.
Record level of 39 db.

Minimum indication: 3 db on 60 range.
Record level of 43 db.

Table 8 is typical work sheet for recording directivity signal measurement data.

(5) Separate the signals, using Figure 2B-23, signal-separation chart.

A. Use minimum level (numerically, highest number of db) to locate abscissa.

B. Use maximum level (numerically, lowest number of db) to locate ordinate.

C. Note values of curved co-ordinates which intersect at point found in step B.

D. Since reflection is known to have a higher level than directivity signal:

1. Find level of directivity signal on broken-line curved co-ordinate.

2. Find return loss of load, in db, on solid-line curved co-ordinate.

E. Example:
At 8.4 KMC, signals measured have a maximum level of -32.7 db and a minimum level of -35.3 db.

1. On horizontal scale of signal-separation chart, find 35.3.

2. On the vertical scale, find 32.7.

3. Locate the point where 35.3 and 32.7 axis intersect.

4. Read values on curved co-ordinates which intersect at same point.

Solid-line curved co-ordinate is 34.

Broken-line co-ordinate is 50.5.

5. By arrangement of measurement system, signal which has lowest level is known to be directivity signal.

Level of directivity signal with respect to reference is -50.5 db.

Level of reflection with respect to reference is -34 db.

The directivity of the coupler is 50.5 db.

(6) Determine ±limits for directivity signal error.

The directivity signal error value is found by converting the coupler directivity figure to a voltage ratio. The simplest method for the conversion is to use a db conversion table. If such a table is not available, one of the following methods may be used.

A. Since the incident signal is equivalent to unity, directivity signal error can be determined by substituting directivity-in-db for D, and solving for $d_r$ in:

$$d_r = 10 \; - \frac{D}{20}$$

Example: Coupler has directivity of 50 db.

$$d_r = 10\,\frac{50}{20} = \frac{1}{10\;\frac{50}{20}} = {}_{10}\;\frac{1}{2.5} = \frac{1}{316} = .003$$

The range of directivity signal error will be ±0.003.

B. By using a Reflectometer Calculator:

Example: Coupler has directivity of 50 db.

1. Find difference between directivity in db and 40 (lowest level shown on Reflectometer Calculator).

50 minus 40 = 10.

2. Find 40 on RETURN LOSS scale of Calculator. Read corresponding value on REFLECTION COEFFICIENT scale.

Value is .01.

3. Find 10 on RETURN LOSS scale of Calculator. Read corresponding reflection coefficient.

Value is .316.

4. Multiply .01 by .316.

The range of directivity signal error will be ±0.003.

(7) Repeat steps (2) through (6) at frequencies across the band of interest.

## TABLE 8

## TYPICAL WORK SHEET FOR DETERMINATION OF ERROR DUE TO DIRECTIVITY SIGNAL

| Freq. (KMC) | Max. Level* (DB) | Min. Level** (DB) | Directivity (DB) | ► Error ($d_r$) |
|---|---|---|---|---|
| 8.0 | 36.0 | 48.0 | 44.4 | ±0.006 |
| 8.4 | 39.0 | 43.0 | 54.0 | ±0.002 |
| 8.8 | 42.5 | 47.5 | 57.0 | ±0.0014 |
| 9.2 | 34.5 | 35.5 | 60.0 | ±0.001 |
| 9.6 | 39.5 | 41.5 | 57.0 | ±0.0014 |
| 10.0 | 40.0 | 45.0 | 54.0 | ±0.002 |

* Signals in phase
** Signals out of phase

► $d_r = 10 - \frac{D}{20}$, where D is directivity in db.

Table 8 is a typical work sheet for measurements made in the 8.0 KMC to 10.0 KMC band.

(i) Determination of error due to spurious signals re-reflected from load -
For a discussion of this procedure, see Section 2B-11, Measurement Considerations.

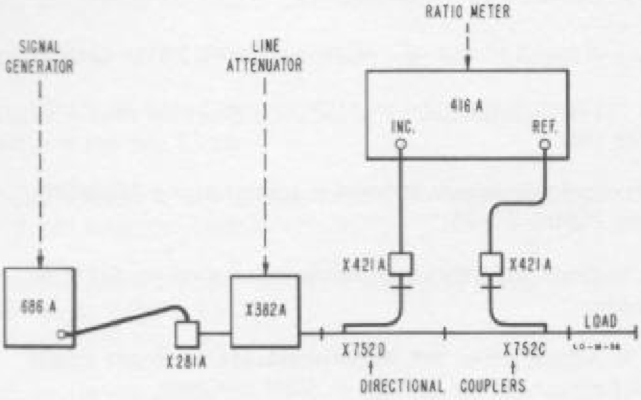
The following procedure, from which will be obtained the limits of error which can be contributed by the spurious signals re-reflected from the load, consists of 1) canceling the directivity signal so that the signal reflected from the load and the spurious signal reflected twice from the load will be the only signals of consequence at the output of the reverse detector, 2) terminating the system with a sliding short, and sliding the short to obtain sum and difference values for the two signals (as the short is moved the spurious signal will change phase twice as fast as the reflected signal, and therefore there will be variation in the ratio meter reading as the signals combine in varying phase relations), 3) calculating the error factor from the magnitude of this variation, and 4) computing error at each reflection coefficient of interest.

(1) Set up measurement system (see Figure 2B-24).

A. Connect Model 870A Slide-Screw Tuner to load end of reverse coupler.

B. Connect reverse detector output to Model 415B. INPUT connector.

Check that 415B selector switch is at CRYSTAL.



LEGEND

X870A = Slide-Screw Tuner

Figure 2B-24. Typical Test Setup, Determination of Error Factor Due to Spurious Signals Re-reflected from Load.

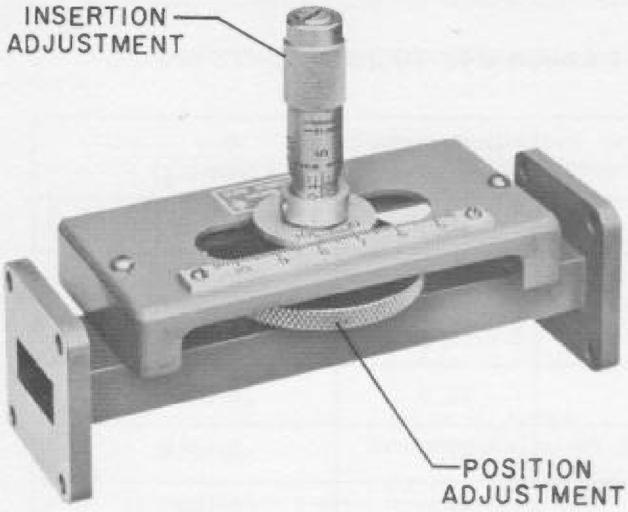


Figure 2B-25. Typical Model 870A Slide-Screw Tuner.

C. Connect modified X916A or 914A to Model 870A.

D. Check line attenuator setting.

Should be same as set in paragraph 2c.

(2) Set signal source for desired frequency.

Proper level set in paragraph 2c.

(3) Cancel directivity signal.

A. Adjust phase of reflection from tuner probe.

1. Check that probe on slide-screw tuner is all the way out.

Micrometer screw is used to adjust probe insertion. See Figure 2B-25.

2. Slide load for maximum indication on 415B db scale.

3. Adjust probe for some penetration, to get small difference (1/4 to 1/2 db) in 415B reading.

4. Adjust horizontal position of probe while watching 415B variation.

Thumb-operated knurled wheel is used to adjust probe horizontal position.

5. Set probe at position where lowest reading (numerically highest number of db) is obtained.

B. Adjust magnitude of reflection from probe.

1. Adjust probe penetration for small decrease in meter indication (a couple of db, for example).

2. Slide load for maximum indication on 415B.

3. Adjust probe penetration for another small decrease in meter indication.

4. Repeat steps 3 and 2 until variation as load is slid is minimum.

This is a trial-and-error process, but in general:

1. If, after an increase in probe penetration, sliding of load shows an increase in maximum indication, retract probe to decrease penetration.

2. As long as maximum shows continuing decrease as probe is inserted deeper, continue increasing probe penetration.

Leave slide-screw tuner at setting at which there is smallest variation as load is slid.

(4) Determine error factor.

A. Replace sliding load (X916A) with sliding short (920A).

B. Disconnect reverse detector from 415B and connect detector to REFLECTED/PROBE input on ratio meter.

C. Adjust 416A SET TO FULL SCALE control for convenient reference on reflectometer scale; 90 is recommended.

D. Slide short while noting maximum and minimum indications on reflectometer scale of ratio meter.

E. Subtract minimum reflection coefficient reading from maximum, and divide by two. This is the error factor. Record it.

For example, when:

Maximum reflection coefficient is .92.

Minimum reflection coefficient is .88.

Variation is 0.04.

Error factor is 0.02.

(5) Determine error factor for other frequencies across band.

## TABLE 9

### TYPICAL WORK SHEET FOR DETERMINATION OF ERROR DUE TO SPURIOUS SIGNALS RE-REFLECTED FROM LOAD

| Freq. KMC | Error Factor | Error $\rho = 0.3$ | Error $\rho = 0.2$ | Error $\rho = 0.1$ | Error $\rho = 0.05$ |
|---|---|---|---|---|---|
| 8.0 | 0.02 | ±0.0018 | ±0.0008 | ±0.0002 | * |
| 8.4 | 0.01 | ±0.0009 | ±0.0004 | ±0.0001 | * |
| 8.8 | 0.0025 | ±0.0002 | ±0.0001 | * | * |
| 9.2 | 0.01 | ±0.0009 | ±0.0004 | ±0.0001 | * |
| 9.6 | * | * | * | * | * |
| 10.0 | 0.01 | ±0.0009 | ±0.0004 | ±0.0001 | * |
| * = negligible | | | | | |

Repeat steps (2) through (4) at other frequencies across the band of interest.

See Table 9.

(6) Determine ± limits of error at each reflection coefficient of interest.

Multiply square of reflection coefficient by error factor to obtain error limits.

For example, when:

Error factor is 0.02.

Reflection coefficient of interest is 0.3.

Error is $(.3)^2 \times .02 = \pm 0.0018$.

Table 9 is typical work sheet for tabulation of spurious signal error values.

(j) Construction of Error Curves - Data for error curves will be taken from work sheets similar to Tables 7, 8, and 9 and can be assembled in a work sheet similar to Table 10.

For each reflection coefficient of interest, the area-of ambiguity curve is plotted around the scalar error curve for the reflection coefficient.

Scalar error (Table 7) has definite direction.

Spurious signal error (Tables 8 and 9) has phase, the direction of which is unknown.

To plot an area-of-ambiguity curve, therefore:

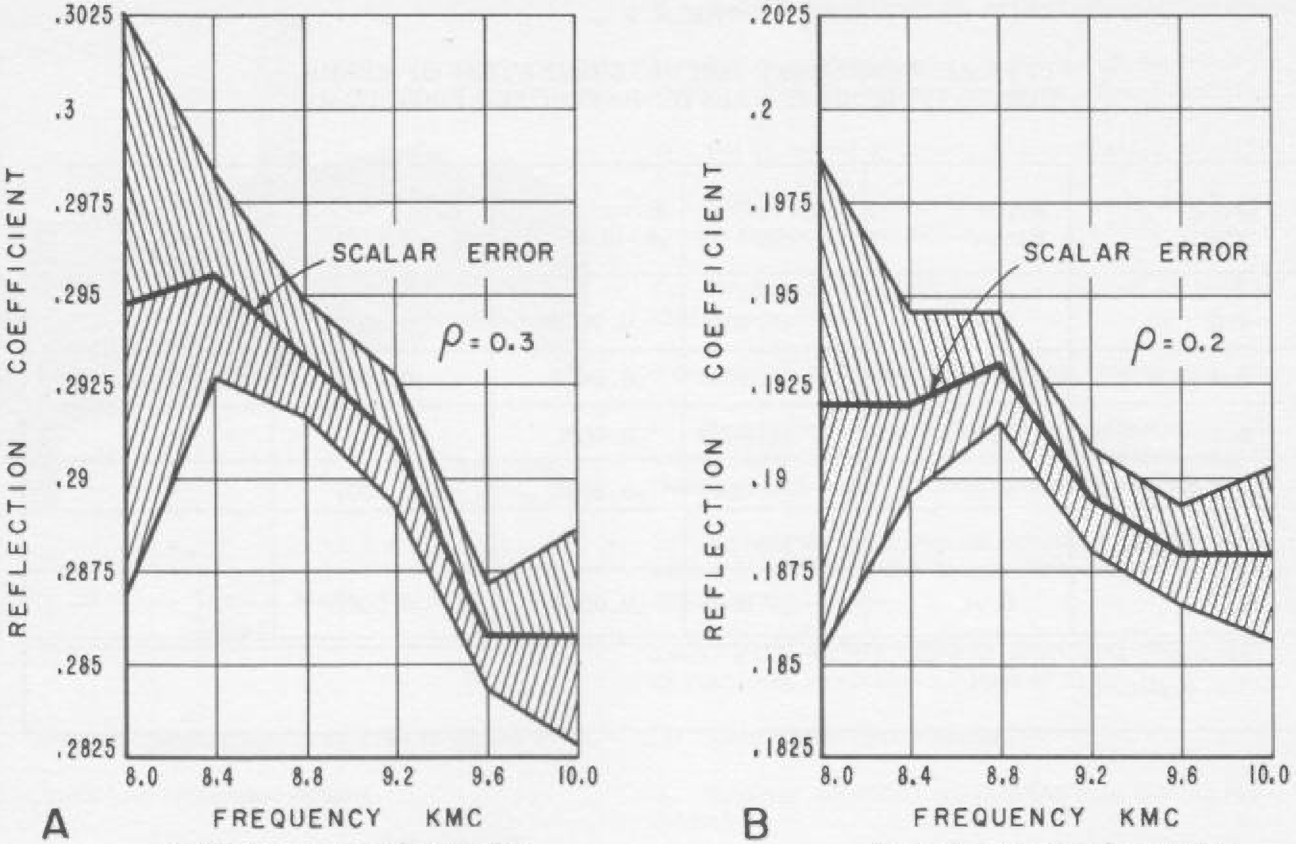
Total scalar error plus total spurious signal error defines the top limit.

Total scalar error minus total spurious signal error defines the bottom limit.

Curves plotted from the data shown in Table 10 are shown in Figure 2B-26.

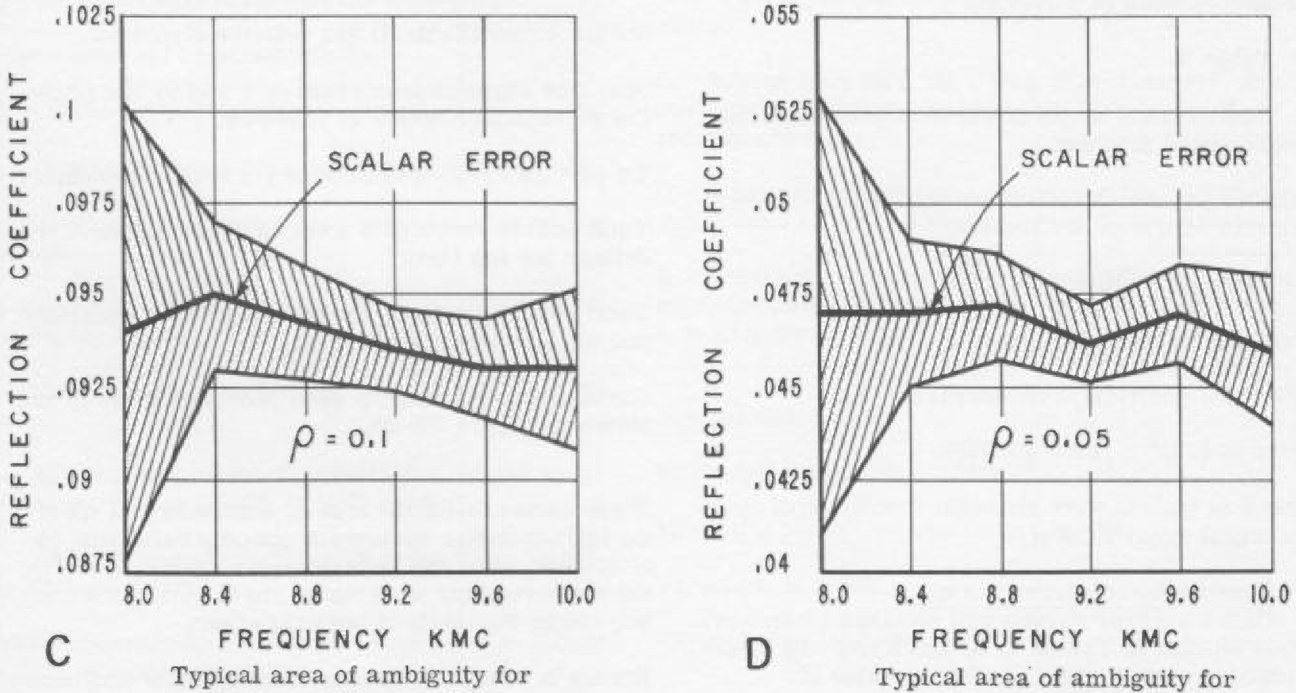
These curves define the area-of-ambiguity in a specific reflectometer system for specific reflection coefficients. For the reflectometer system in which the measurements were made, these curves accurately define the limits of possible error.

Errors in waveguide measurement systems vary with each system and these curves are presented only as examples of procedure and are not intended to define limits of error in reflectometer systems in general.



Typical area of ambiguity for reflection coefficient of 0. 3.

Typical area of ambiguity for reflection coefficient of 0. 2.



Typical area of ambiguity for reflection coefficient of 0. 1.

Typical area of ambiguity for reflection coefficient of 0. 05.

Figure 2B-26. Typical Area-of-Ambiguity Curves, Waveguide Reflectometer System

## TABLE 10

## DATA FOR ERROR CURVES, TYPICAL WORK SHEET

| Frequency KMC | $\rho$ | Error due to Directivity Signal | Error due to Spurious Signals Re-reflected from Load | Total Spurious Signal Error | Absolute Scalar Error | Maximum Positive Error | Maximum Negative Error |
|---|---|---|---|---|---|---|---|
| 8.0 | 0.3 | 0.006 | 0.0018 | ±0.0078 | -0.00525 | +0.00255 | -0.01305 |
| 8.4 | | 0.002 | 0.0009 | ±0.0029 | -0.0045 | -0.0016 | -0.0074 |
| 8.8 | | 0.0014 | 0.0002 | ±0.0016 | -0.00675 | -0.00515 | -0.00835 |
| 9.2 | | 0.001 | 0.0009 | ±0.0019 | -0.009 | -0.0071 | -0.0109 |
| 9.6 | | 0.0014 | * | ±0.0014 | -0.01425 | -0.01285 | -0.01565 |
| 10.0 | | 0.002 | 0.0009 | ±0.0029 | -0.01425 | -0.01135 | -0.01715 |
| 8.0 | 0.2 | 0.006 | 0.0008 | ±0.0068 | -0.008 | -0.0012 | -0.0148 |
| 8.4 | | 0.002 | 0.0004 | ±0.0024 | -0.008 | -0.0056 | -0.0148 |
| 8.8 | | 0.0014 | 0.0001 | ±0.0015 | -0.007 | -0.0055 | -0.0085 |
| 9.2 | | 0.001 | 0.0004 | ±0.0014 | -0.0105 | -0.0091 | -0.0119 |
| 9.6 | | 0.0014 | * | ±0.0014 | -0.012 | -0.0106 | -0.0134 |
| 10.0 | | 0.002 | 0.0004 | ±0.0024 | -0.012 | -0.0096 | -0.0144 |
| 8.0 | 0.1 | 0.006 | 0.0002 | ±0.0062 | -0.006 | +0.0002 | -0.0162 |
| 8.4 | | 0.002 | 0.0001 | ±0.0021 | -0.005 | -0.0029 | -0.0071 |
| 8.8 | | 0.0014 | * | ±0.0014 | -0.00575 | -0.00435 | -0.00715 |
| 9.2 | | 0.001 | 0.0001 | ±0.0011 | -0.0065 | -0.0054 | -0.0076 |
| 9.6 | | 0.0014 | * | ±0.0014 | -0.007 | -0.0056 | -0.0084 |
| 10.0 | | 0.002 | 0.0001 | ±0.0021 | -0.007 | -0.0049 | -0.0091 |
| 8.0 | 0.05 | 0.006 | * | ±0.006 | -0.003 | +0.003 | -0.009 |
| 8.4 | | 0.002 | * | ±0.002 | -0.003 | -0.001 | -0.005 |
| 8.8 | | 0.0014 | * | ±0.0014 | -0.0029 | -0.0015 | -0.0043 |
| 9.2 | | 0.001 | * | ±0.001 | -0.0038 | -0.0028 | -0.0048 |
| 9.6 | | 0.0014 | * | ±0.0014 | -0.003 | -0.0016 | -0.0044 |
| 10.0 | | 0.002 | * | ±0.002 | -0.004 | -0.002 | -0.006 |

* = negligible

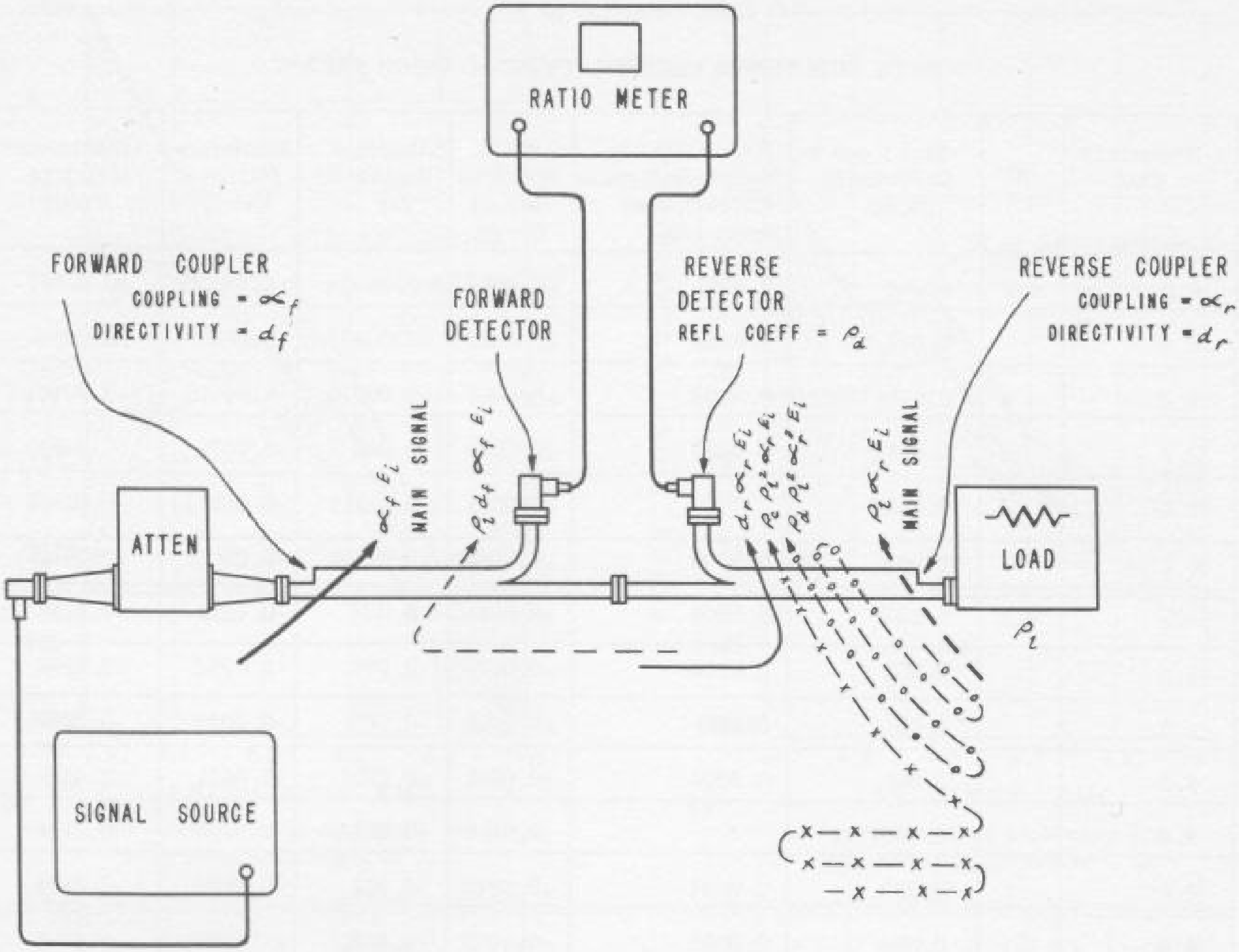


Figure 2B-27. Main and Spurious Signals in a Reflectometer System

In any reflectometer system, however, accuracy will be as good or better than curves shown in Figure 2B-4.

In the previous discussion a number of assumptions and simplifications have been made to reduce the material presented to its most readily understandable form. The following rigorous analysis is included to lend validity to the preceding information and to provide complete data for those who may wish to analyze the error and correction factors for themselves.

Figure 2B-27 indicates the spurious signals present in a reflectometer system. These signals introduce error in the ratio reading because they are not sampled by both detectors, and because they change in magnitude and phase relative to the main signal when the load is changed.

Symbols to be used in developing these equations are as follows:

$\alpha f$ - Coupling voltage ratio of the forward coupler.

$\alpha r$ - Coupling voltage ratio of the reverse coupler.

$d_f$ - Directivity voltage ratio of the forward coupler.

$d_r$ - Directivity voltage ratio of the reverse coupler.

$p_d$ - Reflection coefficient of the reverse detector.

$p_c$ - Reflection coefficient of all discontinuities. between the two couplers (this includes the coupling arrays, any waveguide deformation, and the flange joint).

$p_l$ - Reflection coefficient of the terminating load.

$E_i$ - Incident voltage in the main line.

$S_f$ - Total rf signal at the forward detector input.

$S_r$ - Total rf signal at the reverse detector input.

The magnitudes of the various signals are marked on Figure 2B-4. The total signal at each detector can be written:

$$S_f = \propto_f E_i + p_1 d_f \propto E_i$$

$$= \propto_f E_i (1 + p_1 d_f)$$

$$S_r = p_1 \propto_r E_i + p_c p_1^2 \propto_r E_i + d_r \propto_r E_i + p_d p_1^2 \propto_r^3 E_i$$

$$= \propto_r E_i (p_1 + p_c p_1^2 + d_r + p_d p_1^2 \propto_r^2)$$

The ratio of these two signals is:

$$\frac{S_r}{S_f} = \frac{\propto_r}{\propto_f} \left[ \frac{p_1 + p_c p_1^2 + d_r + p_d p_1^2 \propto_r^2}{1 + p_1 d_f} \right] \quad *$$

$$\frac{S_r}{S_f} = \frac{\propto_r}{\propto_f} \left[ p_1 + p_c p_1^2 + d_r + p_d p_1^2 \propto_r^2 + p_1^2 d_f \right]$$

$$= \frac{\propto_r}{\propto_f} \quad p_1 + \frac{\propto r}{\propto_f} \left[ p_1^2 (p_c + p_d \propto_r^2 + d_f) + d_r \right]$$

Let $p_c + p_d \propto_r^2 + d_f = k_1$ (to represent spurious load reflections).

Then $\frac{S_r}{S_f} = \frac{\propto_r}{\propto_f} p_1 + \frac{\propto r}{\propto_f} (k_1 p_1^2 + d_r)$

The above equation represents the ratio of two rf signals. The actual ratio of detector outputs will include the detection efficiency of the two detectors. This can be written as:

$$R = \frac{k_r \propto_r}{k_f \propto_f} p_1 + \frac{k_r \propto_r}{k_f \propto_f} (k_1 p_1^2 + d_r)$$

where $k_r$ and $k_f$ are the reverse and forward detector efficiencies, $\frac{\text{audio output}}{\text{rf input}}$.

The factor $\frac{k_r \propto_r}{k_f \propto_f}$ involving coupling and detection efficiencies is almost a constant but it varies somewhat with frequency and signal amplitude (the errors of the first category, see Appendix II). It can be written as $K(1 + D_f + D_l)$ where K is a constant independent of frequency and signal amplitude. $D_f$ is the frequency sensitive deviation measured from some reference frequency. $D_l$ is the detector deviation from square-law for different signal amplitudes measured from some reference signal level. The ratio meter reading can be represented, then, by the equation:

$$R = Kp_1 + K(D_f + D_l)\, p_1 + K(k_1 p_1^2 + d_r) \; *$$

The process of calibration of a reflectometer system involves terminating the system with some standard load of known reflection coefficient (usually, but not necessarily, a short circuit) and adjusting ratio meter gain until the meter reads this value of reflection coefficient. This process evaluates the constant K in the equation. Suppose the calibrating load has a nominal reflection coefficient of $p_1o$ and an accuracy of $\pm D_p$. The ratio meter gain would be adjusted to make $R = p_1o$ when $p_1 = (p_1o + D_p)$. The values of $D_f$ and $D_l$ will be zero since they are referenced from the calibration frequency and signal level.

Substituting these values in the equation results in:

$$p_1o = K(p_1o + D_p) + K\left[k_1o(p_1o + D_p)^2 + d_ro\right] \; **$$

From which:

$$K = \frac{p_1o}{p_1o + D_p + k_1o(p_1o + D_p)2 + d_ro}$$

Neglecting the products of small terms in the denominator, this becomes:

$$K = \frac{1}{1 + \frac{D_p}{p_1o} + k_1o\, p_1o + \frac{d_ro}{p_1o}}$$

Having determined this constant K, substitute its value in the equation for the ratio meter reading. This will tell us what the ratio meter will read for any unknown load $p_1$ at any frequency.

$$R = \frac{p_1 + (D_f + D_l)\, p_1 + k_1 p_1^2 + d_r}{1 + \frac{D_p}{p_1o} + k_1o p_1o + \frac{d_ro}{p_1o}}$$

---

*This is of the form $\frac{p_1 + x}{1 + y}$ where x and y are small compared to 1. Performing the division and neglecting products of small terms, this becomes $(1-y)(p_1 + x) = p_1 + x - yp_1$. The negative sign is dropped since the quantities are vectors and we are interested only in their worst summation.

*The term $D_f + D_l$ is always small enough so that when multiplied by another small quantity such as $k_1 p_1 + d_r$, the product is negligible in comparison to the first-order error terms. Therefore, the expression $K(D_f + D_l)(k_1 p_1 + d_r)$ can be neglected in the equation which represents the ratio meter reading.

**The subscript o denotes the values of the various factors at the calibration frequency.

Neglecting the products of small terms in the division, this becomes:

$$R = p_1 + (D_f + D_1)p_1 + k_1 p_1^2 + d_r + \left(\frac{Dp}{p_1 o} + k_1 o p_1 o + \frac{d_r o}{p_1 o}\right) p_1$$

The error in measurement of the load $p_1$ is simply the above meter reading minus $p_1$. Hence:

$$\text{Measurement error} = (D_f + D_1)p_1 + \left(\frac{Dp}{p_1 o} + k_1 o p_1 o + \frac{d_r o}{p_1 o}\right) p_1 + (k_1 p_1^2 + d_r)$$

Coupler-detector sensitivity variations (scalar errors). Error in setting ratio meter gain when calibrating the system.

Spurious signals present when the unknown load terminates the system.

TABLE 11

MAXIMUM MAGNITUDES FOR ERROR FACTORS
(per Component Specifications)

| Error Factor | Waveguide Systems 2.6 to 18 KMC | Coaxial Systems | |
|---|---|---|---|
| | | 1 to 4 KMC | 0.25 to 1 KMC |
| $\alpha f$ | 0.1 (20 db) | 0.1 (20 db) | 0.1 (20 db) |
| $\alpha r$ | 0.32 (10 db) | 0.1 (20 db) | 0.1 (20 db) |
| $d_f$ | 0.01 (40 db) | 0.05 (26 db) | 0.032 (30 db) |
| $d_r$ | 0.01 (40 db) | 0.05 (26 db) | 0.032 (30 db) |
| $p_d$ | 0.2 | 0.5 | 0.2 |
| $p_c$ | 0.01 | * | * |
| $k_1$ | 0.04 | 0.05 | 0.03 |

* = Negligible

TABLE 12

MEASUREMENT ERROR* SINGLE-FREQUENCY OPERATION

| Type of Calibration | Waveguide Systems 2.6 to 18 KMC | Coaxial Systems | |
|---|---|---|---|
| | | 1 to 4 KMC | 0.25 to 1 KMC |
| Fixed Short | $.05Pl + .04Pl^2 + .01$ | $.01Pl + .05Pl^2 + .05$ | $.06Pl + .03Pl^2 + .03$ |
| Sliding Short (waveguide)<br>Alternate Open and Short(Coaxial) | $.04Pl^2 + .01$ | $.05Pl^2 + .05$ | $.03Pl^2 + .03$ |
| With X916C (0.10 standard reflection) (X-band waveguide only) | $.14Pl + .04Pl^2 + .01$ | | |

*Figures represent approximation of maximum error possible; generally error will be less.