WILTRON

# SWR AUTOTESTERS AND BRIDGES

# INSTRUCTION MANUAL

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## WARRANTY

All products are warranted against defects in materials and workmanship for one year from the date of shipment except sweep generator oscillators, which have a two-year warranty period. Our obligation covers repairing or replacing products which prove to be defective during the warranty period and which shall be returned with transportation charges prepaid to WILTRON. Obligation is limited to the original purchaser. We are not liable for consequential damages.

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# SECTION I
# GENERAL INFORMATION

## 1-1. INTRODUCTION

This manual describes the WILTRON Series 59, 63, 67, and 97 SWR Autotesters and the Series 58, 60, 62, 64, and 87 SWR Bridges. The manual is organized as follows:

SECTION I, GENERAL DESCRIPTION, contains a general description of SWR Autotesters and bridges, definitions of key microwave terms, and specifications.

SECTION II, MICROWAVE MEASUREMENTS, provides information and procedures for making transmission and return loss measurements.

SECTION III, RETURN LOSS MEASUREMENT ACCURACY, contains discussions on factors affecting return loss measurement accuracy such as directivity, test port match, and the error-producing effects of adapters. An error-compensating technique using the average reflection from an open and short to establish a return loss calibration reference is also discussed.

SECTION IV, MICROWAVE MEASUREMENT CHART, contains a description and examples of how the WILTRON Microwave Measurement Chart may be used.

SECTION V, THEORY OF OPERATION, contains a brief theory of operation for SWR Autotesters and bridges.

SECTION VI, PERFORMANCE CHECKS AND MAINTENANCE, contains information regarding performance verification and routine maintenance of SWR Autotesters and bridges.

The APPENDIX contains a listing, including general description and specifications, of the WILTRON line of precision microwave measurement instruments.

## 1-2. GENERAL DESCRIPTION

The SWR Autotesters and bridges described in this manual are broadband microwave measurement instruments. They are used with other test instruments for making fixed- and swept-frequency return loss (SWR) measurements over a wide range of radio frequencies. Return loss measurements are made to check the performance of systems, subsystems, and microwave components such as amplifiers, directional couplers, attenuators, filters, splitters, and terminations. The WILTRON SWR Autotesters and bridges offer significant advantages over other microwave measurement devices such as slotted lines and dual-directional couplers. Advantages include using an unmodulated microwave source and providing a greater degree of accuracy over a broader frequency range for both direct and comparison-type measurements.

The WILTRON SWR Autotesters and bridges are precision-balanced Wheatstone bridges. Except for the two four-port comparison-type instruments (Model 59A50 and Model 58A50) that use an offset termination in the reference arm, every model has an internal precision reference termination included in one arm of its bridge. The only difference between the SWR Autotester and the SWR bridge is that the SWR Autotester contains a built-in RF detector. However, because the SWR bridge does not contain a built-in detector, it offers a greater degree of flexibility in low-level signal measurements where additional RF amplification is required. Also, the undetected RF output of the bridge can be applied directly to the detectors of a network analyzer or other RF signal-processing equipment where phase information is needed.

## 1-3. RF REFLECTION MEASUREMENT TERMS

Radio frequency reflection measurement terms such as return loss, SWR, reflection coefficient, and percentage of reflected power are all related. All of these terms are used, often interchangeably, to describe the relationship between incident and reflected RF energy. Throughout this manual, with one exception, the term "return loss" will be used in describing the reflected signal measurements. The term "SWR" will be used to describe the graticule overlays, as these are calibrated for SWR.

## 1-4. EXPLANATION OF TERMS AND SPECIFICATIONS

The following paragraphs provide definitions of key microwave terms, an explanation of SWR Autotester and bridge specifications, and a statement of the detector response law.

### 1-4.1 Definitions of Key Microwave Terms

a. Balanced Line. A line or circuit utilizing two identical conductors, each having the same electromagnetic characteristics with respect to other conductors and ground.

b. Balun. A device which provides coupling and matching between a balanced line and and an unbalanced (i.e., coaxial) line.

c. Characteristic Impedance. The characteristic impedance of a uniform transmission line is the ratio of the applied voltage to the resultant current at the point where the voltage is applied, when the line is of infinite length. Characteristic impedance is commonly used to denote the impedance that may be connected to a transmission line or microwave device to provide an impedance-matched termination, i.e., a termination which will not reflect power, thus simulating a line of infinite length.

d. Directivity. Directivity is defined as the ratio between: (1) output power when the test port signal is fully reflected, and (2) output power when the test port is perfectly terminated. This ratio is expressed in dB and is derived from the formula:

$$\text{Directivity (dB)} = 10 \log_{10} \frac{P_1}{P_2},$$

where $P_1$ is the output power when the test port signal is fully reflected

$P_2$ is the output power when the test port is perfectly terminated.

e. Incident Power or Signal. Power flowing from the signal source to a load or device under test.

f. Insertion Loss or Gain. The loss or gain produced by adding (inserting) a device into a signal transmission path. Normally equivalent to the transmission loss or gain of the device measured between its input and output terminals.

g. Microwaves. A term applied to radio waves in the frequency range 1000 megahertz and upwards. Generally defines operation in the range where circuit resistances, capacitances, and inductances are composed of distributed rather than lumped constants.

h. Phasor. An entity which includes magnitude and direction in a reference plane.

i. Precision Connector. A coaxial connector designed to mate with another connector in such a way that electrical discontinuities in the transmission line are eliminated or minimized. These connectors are intended to combine the inherent advantages of coaxial devices (broadband performance, mechanical flexibility, low cost) with the electrical efficiencies (minimum contact resistance and VSWR) previously available only with waveguide.

j. Reflected Power or Signal. Power reflected from the load or device back to the signal source because of an impedance mismatch at the load or device input.

k. Reflection Coefficient. The vector ratio of the reflected voltage to the incident voltage. If the point of reflection is a pure resistance, reflection coefficient is the numerical ratio of the reflected voltage to the incident voltage. The absolute value of this term is symbolized by the Greek letter Rho ($\rho$).

l. Reflectometer. A microwave system arranged to measure the incident and reflected voltages and to indicate their ratio.

m. Return Loss. The ratio of reflected to incident power expressed in dB. It is defined as $-20 \log_{10}\rho$, where $\rho$ is the absolute value of the reflection coefficient.

n. Scalar. A quantity that has magnitude (voltage, dB), but not direction (phase). See definition of phasor.

o. Source Match. The dynamic return loss of a sweep generator output port. The source match indicates how well the RF leveling system maintains the output characteristic of the sweep generator under varying load conditions. A poor source match connected to a relatively poor load will generate a standing wave. This standing wave indicates that the power delivered to the load is dependent upon phase and distance.

p. Standing-Wave Ratio (SWR). The scalar amplitude of VSWR.

q. Test Port Match. The mismatch at the test port that is a summation of all the impedance discontinuities as seen by the load, looking back toward the source.

r. Unbalanced Line. A line or circuit that is asymmetrical with respect to ground and/or other conductors and that usually has ground serving as one of the circuit conductors (such as a coaxial line).

s. Voltage Standing Wave Ratio (VSWR). A phasor quantity that is the measured ratio of the field strength of a voltage maximum to that of an adjacent minimum within a stationary wave system, e.g., waveguide or coaxial cable. The VSWR of a line is equal to the ratio of the characteristic impedance of the line to the impedance of the load connected to the output end of the line.

### 1-4.2 Explanation of SWR Autotester and Bridge Specifications

The key terms used to specify characteristics of the SWR Autotesters and bridges listed in Tables 1-2 and 1-3 are explained below. This listing is arranged alphabetically.

a. Accuracy. This term defines the accuracy with which an SWR Autotester or bridge can make a reflected signal measurement. An example of an accuracy expression is as follows: $0.01 \pm 0.06\rho^2$. The first part of this term, 0.01, represents the directivity limit of the device as expressed in a reflection coefficient value (refer to the RF Measurement Chart, Table 4-1). The second part of the term, $\pm 0.06\rho^2$, represents the depreciation in accuracy due to test port mismatch (impedance discontinuity). The test port mismatch term is a two-part expression. The numerals 0.06 represent the inherent test port mismatch expressed in a reflection coefficient value; the symbol $\rho$ is the reflection coefficient of the device under test (DUT), and the whole expression $0.06 \times \rho^2$ represents the error caused by the reflected signal being re-reflected by the test port mismatch (refer to paragraph 3-2.2).

b. Detected Output Connector (SWR Autotester only). The type of connector installed on the DETECTED SWR OUTPUT port.

c. Detector Output Polarity (SWR Autotester only). The polarity of the detected output.

d. Directivity. A figure of merit expressed in dB. This figure represents the ratio of the power levels as seen at the output port under the following two conditions:

(1) when the test port signal is fully reflected, and (2) when the test port is perfectly terminated (refer to paragraph 3-2.1).

e. Frequency Sensitivity. The maximum variation in output power/voltage that can be expected due to a change in frequency over the specified range when the input power is held constant.

f. Input Impedance. The input impedance of the device.

g. Insertion Loss. This is the loss from the RF INPUT port to the DEVICE UNDER TEST port.

h. Maximum Power Input. This is the maximum power, in watts, that can be safely applied to the device.

i. Output Time Constant. The amount of time required for the selected output pulse to either rise from the 10% to the 90% point or fall from the 90% to the 10% point on the waveform.

### 1-4.3 Detector Response Law

Detector response law refers to the response of a detector at different radio frequency input power levels. The detector response laws are given in Table 1-1 below.

## 1-5. SWR AUTOTESTERS, SPECIFICATIONS

Specifications for the SWR Autotester Series 59, 63, 67 and 97 are given in Table 1-2.

## 1-6. SWR BRIDGES, SPECIFICATIONS

Specifications for the SWR Bridge Series 58, 60, 62, 64 and 87 are given in Table 1-3.

Table 1-1. Detector Response Law

| IF<br>RF Power Input Is: | THEN<br>Response Is: | AND<br>1/2 Voltage Change Is: |
|---|---|---|
| below -18 dBm | square law | 3 dB power change |
| 0 to -18 dBm | in transition | continuous transition |
| 0 to +20 dBm | linear | 6 dB power change |

## Table 1-2. SWR Autotesters, Specifications

| MODEL | FREQUENCY RANGE | DIR. (dB) | ACCURACY (2) | | INPUT Z (ohms) | TEST PORT CONNECTOR TYPE | PHYSICAL |
|---|---|---|---|---|---|---|---|
| **SERIES 63 SWR AUTOTESTERS** | | | | | | | |
| 63N50<br>63NF50<br>63A50 | 10 to 4000 MHz | 40 (1) | $0.01 \pm 0.06\rho^2$ | | 50 | Type N Male<br>Type N Female<br>GPC-7 | Dimensions:<br>6.7 x 5.1 x 2.54 cm<br>(2 5/8 x 2 x 1 inches)<br>excluding connectors<br>Weight:<br>340 grams (12 ounces) |
| **SERIES 67 SWR AUTOTESTERS** | | | | | | | |
| 67N50<br>67NF50<br>67B50<br>67BF50<br>67N75<br>67NF75<br>67B75<br>67BF75<br>67FF75 | 10 to 1000 MHz | 40 | $0.01 \pm 0.1\rho^2$ | | 50<br>50<br>50<br>50<br>75<br>75<br>75<br>75<br>75 | Type N Male<br>Type N Female<br>BNC Male<br>BNC Female<br>Type N Male<br>Type N Female (3)<br>BNC Male<br>BNC Female<br>Type F Female | Dimensions:<br>6.7 x 5.1 x 2.54 cm<br>(2 5/8 x 2 x 1 inches)<br>excluding connectors<br>Weight:<br>170 grams (6 ounces) |
| **SERIES 59 COMPARISON SWR AUTOTESTER** | | | | | | | |
| 59A50 | 10 MHz to 18 GHz | 36 | 10 MHz - 8 GHz (4)<br>$0.016 \pm 0.06\rho^2$ | 8 GHz - 18 GHz (4)<br>$0.016 \pm 0.1\rho^2$ | 50 | GPC-7 on Test and Reference Ports | Dimensions:<br>7.6 x 5 x 2.8 cm<br>(3 x 2 x 1 1/8 inches)<br>excluding connectors<br>Weight:<br>340 grams (12 ounces) |
| **SERIES 97 SWR AUTOTESTERS** | | | | | | | |
| | | | 10 MHz - 8 GHz | 8 GHz - 18 GHz | | | |
| 97A50 | 10 MHz to 18 GHz | 36 | $0.016 \pm 0.06\rho^2$ | $0.016 \pm 0.1\rho^2$ | 50 | GPC-7 | Dimensions:<br>7.6 x 5 x 2.8 cm<br>(3 x 2 x 1 1/8 inches)<br>excluding connectors<br>Weight:<br>340 grams (12 ounces) |
| 97A50-1 | | 40 | $0.01 \pm 0.06\rho^2$ | $0.01 \pm 0.1\rho^2$ | | GPC-7 | |
| 97S50<br>97SF50 | | 35 | $0.018 \pm 0.08\rho^2$ | $0.018 \pm 0.12\rho^2$ | | WSMA Male<br>WSMA Female | |
| 97S50-1<br>97SF50-1 | | 38 | $0.013 \pm 0.08\rho^2$ | $0.013 \pm 0.12\rho^2$ | | WSMA Male<br>WSMA Female | |
| 97N50<br>97NF50 | | 35 | $0.018 \pm 0.08\rho^2$ | $0.018 \pm 0.12\rho^2$ | | Type N Male<br>Type N Female | |
| 97N50-1<br>97NF50-1 | | 38 | $0.013 \pm 0.08\rho^2$ | $0.013 \pm 0.12\rho^2$ | | Type N Male<br>Type N Female | |

ALL MODELS

Insertion Loss (from input to test port): 6.5 dB nominal
Detector Output Polarity: Negative
Output Time Constant: 2 $\mu$s
Maximum Power Input: 0.5 watts
Input Connector: Type N Female except 67B and 67F Series which have BNC Female.
Detected Output Connector: BNC Female

(1) 46 dB directivity available as Option 1. Option 1 accuracy: $0.005 \pm 0.06\rho^2$.

(2) Where $\rho$ is the reflection coefficient being measured. Accuracy includes the effects of test port reflections and directivity.

(3) 75Ω Type N Female connectors will withstand occasional mating with 50Ω connectors without damage.

(4) When used with 28A50-1 Precision Termination. The effective directivity of the bridge can be increased to 60 dB by using the magnified reflection return loss measurement technique with the 18A50 Air Line and 29A50-20 Offset Termination.

## Table 1-3. SWR Bridges, Specifications

| MODEL | FREQUENCY RANGE | DIR. (dB) | ACCURACY (2) | INPUT Z (ohms) | TEST PORT CONNECTOR TYPE | PHYSICAL |
|---|---|---|---|---|---|---|
| SERIES 60 SWR BRIDGES | | | | | | |
| 60N50<br>60NF50<br>60A50 | 5 MHz to 2 GHz | 40 (1) | $0.01 \pm 0.09\rho^2$ | 50 | Type N Male<br>Type N Female<br>GPC-7 | Dimensions:<br>6.7 x 5.1 x 2.54 cm<br>(2 5/8 x 2 x 1 inches)<br>excluding connectors<br>Weight:<br>340 grams (12 ounces) |
| SERIES 62 SWR BRIDGES | | | | | | |
| 62N50<br>62NF50<br>62B50<br>62BF50<br>62N75<br>62NF75<br>62B75<br>62BF75<br>62FF75 | 10 to 1000 MHz | 40 | $0.1 \pm 0.12\rho^2$ | 50<br>50<br>50<br>50<br>75<br>75<br>75<br>75<br>75 | Type N Male<br>Type N Female<br>BNC Male<br>BNC Female<br>Type N Male<br>Type N Female (3)<br>BNC Male<br>BNC Female<br>Type F Female | Dimensions:<br>5.7 x 3.5 x 2.86 cm<br>(2 1/4 x 1 3/8 x 1 1/8 inches)<br>excluding connectors<br>Weight:<br>170 grams (6 ounces) |
| SERIES 87 SWR BRIDGE | | | | | | |
| 87A50 | 2.0 to 18.0 GHz | 35 (4) | 2 to 3 GHz: $0.018 \pm 0.31\rho^2$<br>3 to 4 GHz: $0.018 \pm 0.2\rho^2$<br>4 to 18 GHz: $0.018 \pm 0.12\rho^2$ | 50 | GPC-7 | Dimensions:<br>7.3 x 5.1 x 2.86 cm<br>(2 5/8 x 2 x 1 1/8 inches)<br>excluding connectors<br>Weight:<br>340 grams (12 ounces) |
| SERIES 64 SWR BRIDGE | | | | | | |
| 64A50 | 3 GHz to 8 GHz (5) | 36 (6) | $0.016 \pm 0.12\rho^2$ | 50 | GPC-7 | Dimensions:<br>7.3 x 5.1 x 2.86 cm<br>(2 7/8 x 2 x 1 1/8 inches)<br>excluding connectors<br>Weight:<br>284 grams (10 ounces) |
| SERIES 58A50 COMPARISON SWR BRIDGE | | | | | | |
| 58A50 | 2.0 to 18.0 GHz | 35 | 2 to 3 GHz: $0.018 \pm 0.32\rho^2$ (7)<br>3 to 4 GHz: $0.018 \pm 0.2\rho^2$<br>4 to 18 GHz: $0.018 \pm 0.11\rho^2$ | 50 | GPC-7 | Dimensions:<br>6.7 x 5.1 x 2.2 cm<br>(2 5/8 x 2 x 7/8 inches)<br>excluding connectors<br>Weight:<br>340 grams (12 ounces) |
| ALL MODELS<br>Insertion Loss (from input to test port): 6.5 dB nominal<br>Maximum Power Input: 0.5 watts<br>Input Connector: Type N Female, stainless steel, except 62B and 62F Series which have BNC Female. | | | | | | |

(1) Option 1 has 46 dB directivity with an accuracy of $0.005 \pm 0.09\rho^2$.

(2) Where $\rho$ is the reflection coefficient being measured.

(3) 75Ω N Female connectors will withstand occasional mating with 50Ω connectors without damage.

(4) 38 dB directivity available with Option 1. Option 1 accuracy:
2 to 3 GHz: $0.011 \pm 0.31\rho^2$; 3 to 4 GHz: $0.011 \pm 0.2\rho^2$;
4 to 18 GHz: $0.011 \pm 0.11\rho^2$.

(5) 2 to 8 GHz frequency range available as Option 2. Option 2 accuracy:
2 to 3 GHz: $0.016 \pm 0.16\rho^2$; 3 to 8 GHz: as specified above.

(6) 42 dB directivity available as Option 1 (3 to 8 GHz). Accuracy: $0.008 \pm 0.12\rho^2$.

(7) When used with Model 28A50-1 Termination. Accuracy is even greater when the bridge is used with an 18A50 Air Line and a 29A50-20 Offset in the magnified reflection return loss measurement technique.

# SECTION II

# MICROWAVE MEASUREMENTS

## 2-1. INTRODUCTION

This section contains information for performing transmission and return loss measurements. Step-by-step procedures are presented for the following microwave measurement techniques: (1) Ripple Averaging, (2) Magnified Reflection, (3) Direct-Reading Measurements Using the Model 501 Logarithmic Level Meter, and (4) SWR Measurements Using Graticules. General information in the nature of equipment capabilities and uses is presented for the WILTRON Model 560 Scalar Network Analyzer and Model 501B Logarithmic Level Meter.

## 2-2. GENERAL TEST EQUIPMENT REQUIREMENTS

To ensure accuracy, the test equipment used in the return loss measurement system should have the following characteristics:

a. RF Sweep Generator - Leveled output of +7 dBm or greater with output match <1. 8.

b. Oscilloscope - Vertical sensitivity of 10$\mu$V/cm or greater.

c. Logarithmic Display Instrument, such as a network analyzer - At least 60 dB dynamic range.

d. SWR Autotester or Bridge - Directivity of 35 dB or greater.

e. Test Cables - Correct characteristic impedance to match the RF sweep generator, SWR Autotester or bridge, and device under test (DUT).

## 2-3. TRANSMISSION AND RETURN LOSS MEASUREMENTS USING THE MODEL 560 SCALAR NETWORK ANALYZER

The WILTRON Model 560 Scalar Network Analyzer is used in conjunction with a sweep generator to provide a scalar analysis of return loss and transmission loss/gain characteristics.

The Model 560 has two measurement channels (A and B), which allow simultaneous measurements of return loss and transmission (insertion) loss/gain. Each channel has a built-in memory, allowing the reflectometer calibration data to be stored and automatically subtracted from the measured data. For return loss measurements, the reflectometer calibration data consists of a zero dB reference that is the average of an open and a short reflection. For transmission loss/gain measurements, the reflectometer calibration data consists of the full measure of system residual reflections, as seen at the test port of an SWR Autotester or bridge.

Figure 2-1 shows the Model 560 Scalar Network Analyzer and its companion RF Detector and SWR Autotester. The Model 560-97XXX SWR Autotester is the only SWR Autotester recommended for use with the Model 560; however, any of the WILTRON bridges may be used, as long as the bridge output is detected using the Model 560-7XX RF Detector.

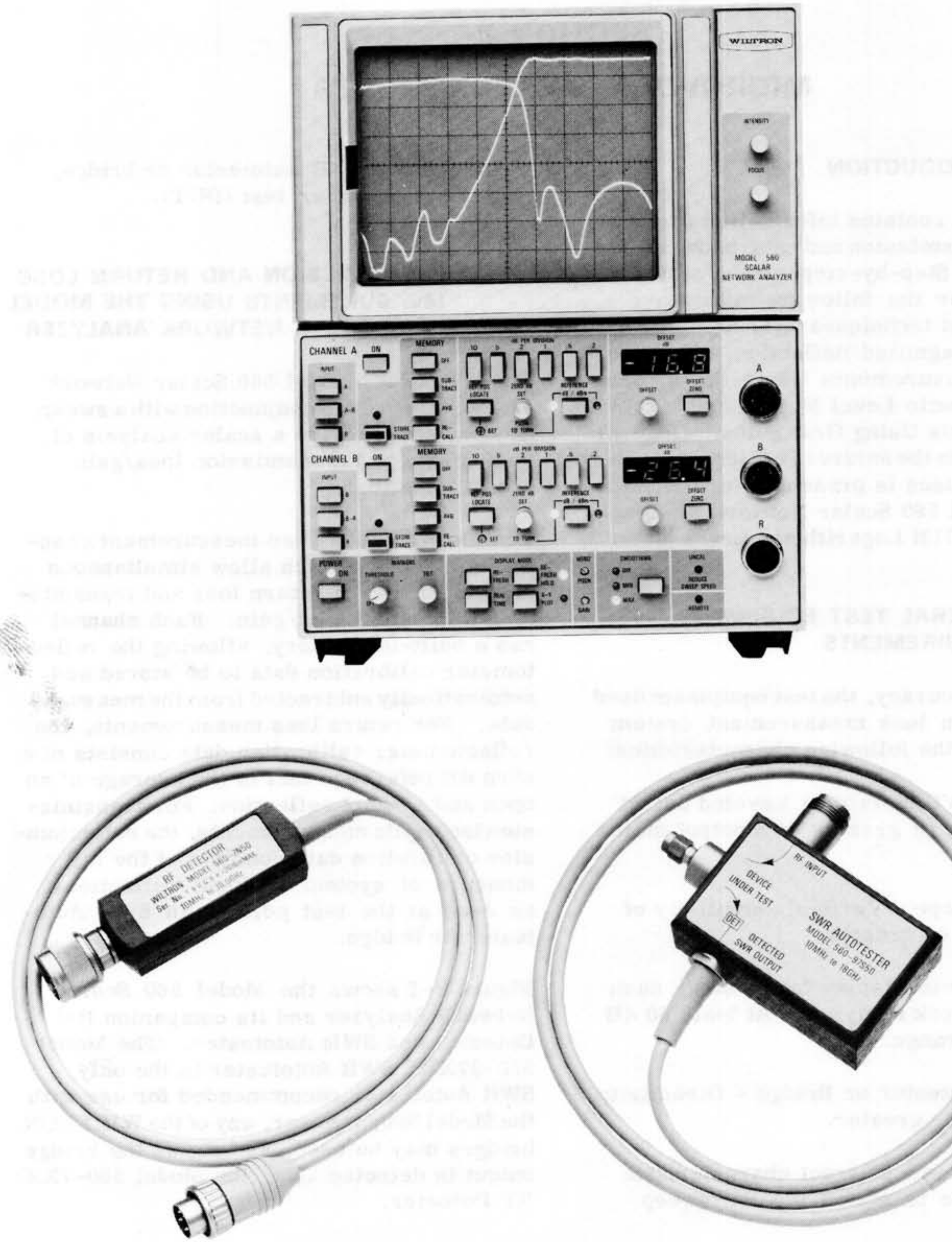



Figure 2-1. Model 560 Scalar Network Analyzer With Companion RF Detector and SWR Autotester

## 2-4. RETURN LOSS MEASUREMENT TECHNIQUES USING AN AIR LINE

The uncertainty of broadband microwave return loss measurements has prompted the development of new equipment and techniques. New equipment consists of (1) a four-port comparison SWR Autotester with a frequency range of 10 MHz to 18 GHz, (2) a four-port comparison SWR bridge with a frequency range of 2 to 18 GHz, (3) a 16 mm (diameter) air line with a frequency range of 0.4 to 8 GHz, and (4) an 18 mm (diameter) air line with a frequency range of 2 to 18 GHz. New techniques consist of ripple-averaging and magnified reflection. The ripple-averaging technique can reduce errors from a range of 20 to 60%, to an error of ±2%. The magnified reflection technique permits return loss values of 26 to 54 dB to be measured with the four-port comparison SWR Autotester or bridge.

The following paragraphs provide (1) a description of the air line and a discussion of its construction and special-handling requirements, (2) a description of the ripple-averaging technique with a procedure detailing its use, (3) a description of the magnified reflection technique with a procedure detailing its use, (4) a suggested method for taking the average of ripple patterns, and (5) a description of how to analyze magnified reflection ripple patterns.

### 2-4.1 Air Lines

As part of a small-reflection measurement program, WILTRON has developed a series of precision-manufactured high return loss (60 dB) air lines. These air lines are used both as impedance standards and as delay lines for the error-signal averaging techniques described below.

As shown in Figure 2-2, the air line is constructed with a beadless connector on the end that connects to the device under test (DUT). (This end connects to the test port when measuring the directivity of the SWR Autotester or bridge; refer to paragraph 4-2.1.) A beadless connector is used on this end to provide a connection with minimum reflection. The connector on the opposite end of the air line does contain a bead; this bead keeps the center conductor captive, thereby fixing the reference plane for the beadless end.

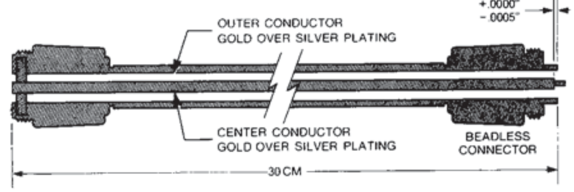



Figure 2-2. Cross-Sectional View of an Air Line With GPC-7 Connectors

Attaching the beadless end of the air line to the device to be measured requires extreme care. Because there is no bead holding it rigid, the center conductor of the air line has to be manually mated with the center conductor of the DUT before the outer ring of the connector can be tightened. Once the DUT has been attached, however, it provides the necessary center conductor support so that the bead is not required for proper air line operation. Connection is usually made easier by orienting the air line in the vertical position.

### 2-4.2 Ripple-Averaging Technique

Ripple-averaging is a technique for separating the error signal caused by directivity (paragraph 3-2.1) from the signal reflected from the device under test (DUT).

To accomplish signal separation, this technique uses an SWR Autotester or bridge to take advantage of the following two facts: (1) the reflected signal and the directivity signal arrive at the RF OUTPUT port with a phase relationship that depends in part on the difference in electrical distances in the two signal paths, and (2) the phase difference between the reflected signal and the directivity signal changes when the test frequency is swept. Typically, this phase change is relatively small and the amplitude relationship of the two signals is often indeterminate. However, when a suitable length of line, e.g., an air line, is inserted between the SWR Autotester or bridge and the DUT, a "long-line effect" occurs and the phase changes are greatly increased. In return loss measurements, this results in an intentionally-introduced ripple signal (directivity error signal) being imposed on the signal reflected from the DUT.

A typical ripple pattern with phasor diagram is shown in Figure 2-3. As shown by the dotted line in this figure, the reflected signal can easily be extracted from the ripple pattern by taking the average between one signal peak and the next trough. A suggested method for taking this average is described in paragraph 2-4.4.

The general effect of the ripple-averaging technique is that the desired reflection can be measured exclusive of the directivity signal. This results in the ability to

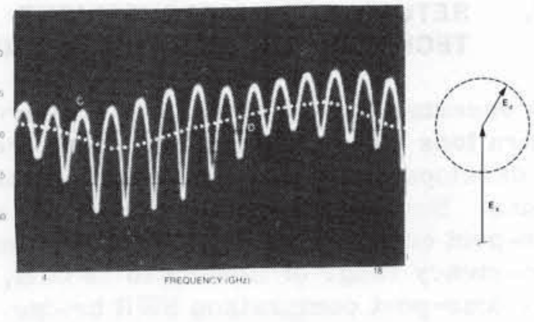


Figure 2-3. Calibration Reference With an Open

accurately measure return loss signals to within about 6 dB of the SWR Autotester or bridge directivity value. So long as the device being measured produces a smoothly-varying reflection as frequency is swept, the resolution normally achieved is approximately 0.2 dB (±2%).

The equipment setup and procedure for using this technique are presented in Figure 2-4 and Table 2-1, respectively.

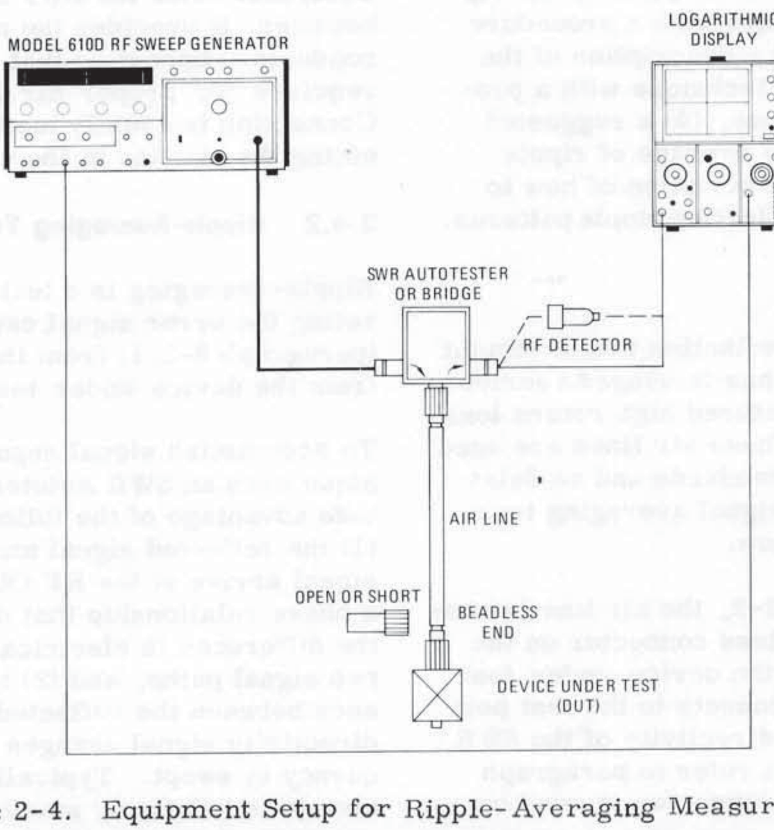



Figure 2-4. Equipment Setup for Ripple-Averaging Measurements

Table 2-1. Ripple-Averaging Procedure

1. Turn equipment on and allow for the required warmup time.

2. Connect equipment as shown in Figure 2-4, except do not connect DUT to air line.

3. Connect a short on the beadless end of the air line.

NOTE

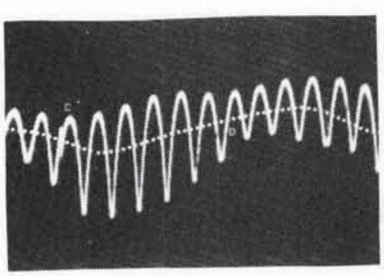
This procedure does not specify any particular model of logarithmic display; consequently, the controls are referred to by their functional names.

4. On logarithmic display:

   a. Position the dB/division control for a comfortable setting, depending upon the value of return loss expected from the DUT. (1 dB/division is usually required to accurately measure return loss signals on the order of 20 dB.)

   b. Position the offset control to center the ripple waveform on the face of the display.

5. On the face of the display, lightly trace a line that represents the average of this ripple pattern (see below).



NOTE

When the Model 560 Scalar Network Analyzer is used with this procedure, the average of an open and a short is used to establish the reference reflection. Also, it is not necessary to draw a line on the CRT screen. On the 560, one front panel control causes the open and short reflections to be electronically averaged, and another control causes the averaged reflection to be electronically subtracted from the DUT reflection.

6. Remove the short, and connect the beadless end of the air line to the DUT.

NOTE

In the following steps, instructions are given for measuring the worst point on the frequency sweep.

7. On the logarithmic display:

   a. Adjust the offset and, if necessary, the dB/division control(s) to observe the entire frequency sweep.

   b. Observe the sweep; the point of maximum return loss is where the average value of the ripple pattern peaks the most positive.

   c. Position the dB/division control to obtain maximum resolution at this point; adjust the offset control to superimpose this portion of the trace on the reference line.

   d. Read the return loss, in dB, from the indicator associated with the offset control.

### 2-4.3 Magnified Reflection Technique

The magnified reflection method of measuring return loss combines measurement technique with specially-designed, precision-built equipment to enable a reflection of less than 5% to be measured using an SWR Autotester or bridge. The precision-built equipment consists of a four-port comparison bridge (58A50) that operates from 2 to 18 GHz and a four-port comparison SWR Autotester (59A50) that operates from 10 MHz to 18 GHz. Either of these two instruments, when used with a precision air line and the procedure in Table 2-2, allows the measurement of return loss signals from 26 to 54 dB.

The test setup for making magnified reflection measurements is shown in Figure 2-5. This equipment setup uses a four-port comparison SWR Autotester or bridge with a termination installed on its comparison (reference) port. This termination is known as an offset; it is used because it produces a relatively constant reflection with frequency.

The offset installed on the comparison SWR Autotester or bridge is designed to produce a reflection of substantial proportions -- usually 20 dB. Since the performance of the comparison SWR Autotester or bridge itself is high and there are no other significant sources of undesired reflections, the effective directivity of the instrument becomes that of the offset, i.e., 20 dB. It is not necessary, however, to know the value of the offset, as will be seen when using the procedure. The value of the offset is measured on the logarithmic display.

How this essentially constant and relatively large offset signal is used in swept-frequency measurements can be described in terms of the phasor diagram in Figure 2-6. Here, in contrast to the ripple-averaging method previously described, the signal to be measured is smaller than the 20 dB offset signal of the instrument. Like the ripple-averaging method, when the test frequency is swept, a ripple pattern is produced; however, now the ripple pattern is caused by the small, unknown signal rather than by the directivity signal. By determining the

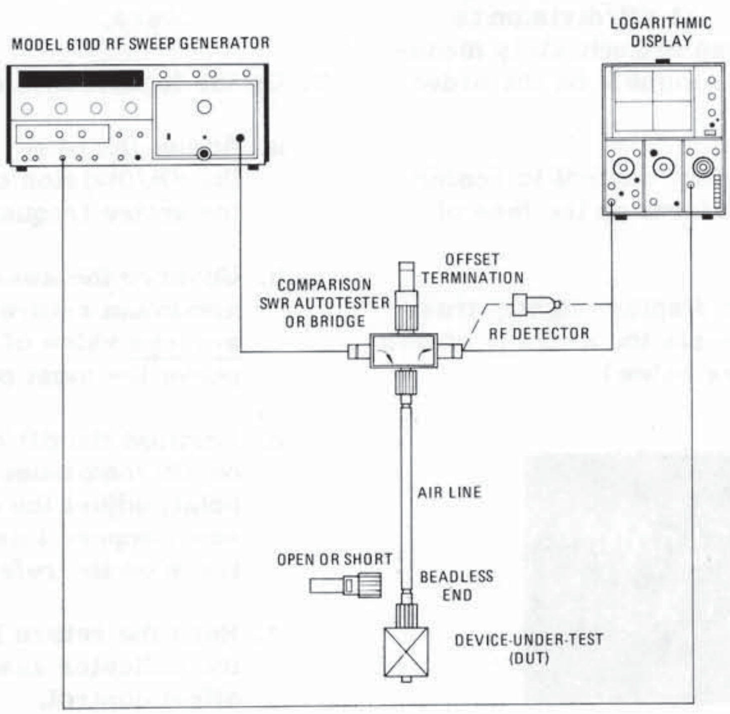



Figure 2-5. Equipment Setup for Magnified Reflection Measurements

Table 2-2. Magnified Reflection Procedure

1. Turn equipment on and allow for the required warmup time.

2. Connect equipment as shown in Figure 2-5, but do not connect the device under test (DUT).

3. Connect a short on the beadless end of the air line.

   NOTE

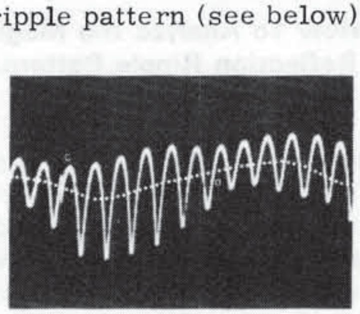
   This procedure does not specify any particular model of logarithmic display; consequently, the controls are referred to by their functional names.

4. On logarithmic display:

   a. Position the dB/division control for a comfortable setting, depending upon the value of return loss expected from the DUT. (1 dB/division is usually required to accurately measure return loss signals on the order of 20 dB.)

   b. Position offset control to center the ripple waveform on the face of the display.

5. On the face of the display, lightly trace a line that represents the average of this ripple pattern (see below).



   NOTE

   When the Model 560 Scalar Network Analyzer is used with this procedure, the average of an open and a short is used to establish the reference reflection. Also, it is not necessary to draw a line on the CRT screen. On the 560, one front panel control causes the open and short reflections to be electronically averaged, and another control causes the averaged reflection to be electronically subtracted from the DUT reflection.

6. Remove the short, and connect the beadless end of the air line to the DUT.

   NOTE

   In the following steps, instructions are given for measuring the worst point on the frequency stop.

7. On the logarithmic display:

   a. Adjust the offset and, if necessary, the dB/division control(s) to observe the entire frequency sweep.

   b. Observe the sweep and note the point where the peak-to-peak ripple has the greatest amplitude.

   c. Adjust the offset control to place the average value of this ripple on the reference line which was drawn on the display during calibration.

   d. From the indicator associated with the offset control, note the reading; this is the value, in dB, of the offset-termination that is connected to the reference port.

8. Measure the peak-to-peak value of this ripple and, using the process described in paragraph 2-4.5, convert this value to return loss. This is the return loss of the DUT.

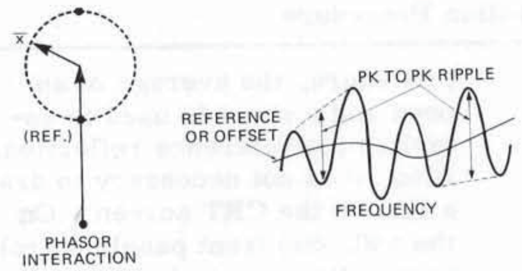



Figure 2-6. Magnified Reflection Ripple Waveform Showing Phasor Interaction

peak-to-peak amplitude, in dB, of this ripple, the value of the reflected signal can be determined using the Microwave Measurement Chart, Table 4-1. (Paragraph 2-4.5 discusses how to analyze this ripple pattern.) Since the unknown is measured with respect to the offset, the constant reflection produced by the offset is itself termed the "offset."

The effective limit of this method is set by the 60 dB residual reflection (return loss) of the precision air line. The magnified reflection ripple technique typically permits measurements to be made to within about 6 dB of this value. Consequently, test instruments and devices having a frequency range within a 1 to 18 GHz band and having return loss signals as small as 54 dB can be measured using this method.

This method of measuring return loss provides three advantages: (1) small reflections of 50 dB or so are actually measured at a signal level that is only 20 dB below a full reflection, (2) the directivity of the four-port SWR Autotester or bridge is cancelled by being incorporated into the signal produced by the offset-termination, and (3) the swept display gives an immediate indication proportional to the magnitude of the unknown reflection. This means that adjustments may be made to the DUT while watching the results in real time.

The advantages of this method may be summarized by saying that the measurements produced by this method are neither sensitivity- nor directivity-limited.

### 2-4.4 Suggested Method for Taking the Average of Ripple Patterns

A suggested method for taking the average of ripple waveforms is illustrated in Figure 2-7. As shown, the average can readily be taken by (1) connecting two adjacent peaks or troughs, and then (2) measuring the distance, in dB, between the connecting peaks or troughs and the opposite peak or trough. If the peak-to-peak value is less than 3 dB, simply halving the dB value will give the average value, within 0.1 dB. If the peak-to-peak value is 3 dB or greater, determine the average by referring to the Microwave Measurement Chart, Table 4-1.

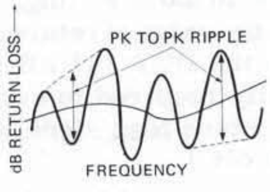



Figure 2-7. A Method for Taking the Average of Ripple Patterns

### 2-4.5 How To Analyze the Magnified Reflection Ripple Pattern

The waveform in Figure 2-8 was taken from a logarithmic display. The dB/division control on the logarithmic display was set to provide a vertical sensitivity of 0.5 dB/division; the offset control was adjusted to display the waveform 20 dB below the calibration reference.

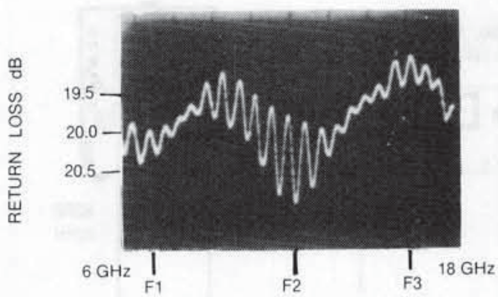



Figure 2-8. Typical Magnified Reflection Ripple Waveform Obtained Using a 20 dB Offset

The waveform shown in Figure 2-8 represents the interaction of two signals. One signal is that of the instrument's offset termination, which is 20 dB. The other signal (ripple) is the return loss of the device-under-test (DUT). When the test frequency is swept, the reflected signal from the DUT imposes a ripple on the offset signal. The interpretations of the waveform for the three frequencies shown (F1, F2, and F3) are described in the following paragraphs.

Frequency F1

The peak-to-peak ripple at this frequency is approximately 0.4 dB. On the Microwave Measurement Chart, Table 4-1, under the column headed "REF ± x Peak to Peak Ripple--dB," the closest value to 0.4 is 0.3890. The value in the column headed "x dB Below Reference" that corresponds to 0.3890 is 33. A close reading of the ripple waveform in Figure 2-8 reveals that the average value of this waveform is 20.1 dB. This is the value of the offset. By adding the value obtained from the RF Measurement Chart (33 dB) to the value of the offset, the measured value of the reflected signal is found to be 53.1 dB.

Frequency F2

The peak-to-peak ripple of the F2 frequency is shown to be approximately 1.09 dB. As shown in Table 4-1, this ripple corresponds to a signal value 24 dB below the reference. According to the waveform photograph, the reference is approximately 20.2 dB; consequently the reflected signal from the DUT is 44.2 dB.

Frequency F3

Using the same process as described above, the return loss of the reflected signal at F3 is determined to be 51.3 dB (32 dB below the reference).

## 2-5. DIRECT-READING TRANSMISSION AND RETURN LOSS MEASUREMENTS USING THE MODEL 501 LOGARITHMIC LEVEL METER

Figure 2-9 shows a test setup and Table 2-3 provides a procedure for making direct measurements, in dB, of transmission (insertion) loss. With a slight modification, (dotted line), the configuration can also measure return loss. The setup shown uses a WILTRON Model 501 Logarithmic Level Meter.

Once the device under test is connected in the circuit, the loss (or gain) can be read directly on the meter (for fixed frequency) or on the oscilloscope (for swept frequency). The sensitivity of the measurement is variable from 10 dB to 0.5 dB per division, and is controlled from the front panel of the logarithmic level meter.

The logarithmic meter will normally operate with signals ranging from below -40 dBm to +20 dBm. The instrument automatically corrects for the changing response law of the RF detector (square law at low signal level, linear at high). A calibrated offset control having a resolution of 0.1 dB and an overall range of ±100 dB eliminates scope linearity errors and permits the use of maximum sensitivity, even at high signal levels.

The procedure covers both transmission and reflection measurements. The calibration procedure for matching the Model 501 response to a particular detector is given in the Model 501 Logarithmic Level Meter Instruction Manual.

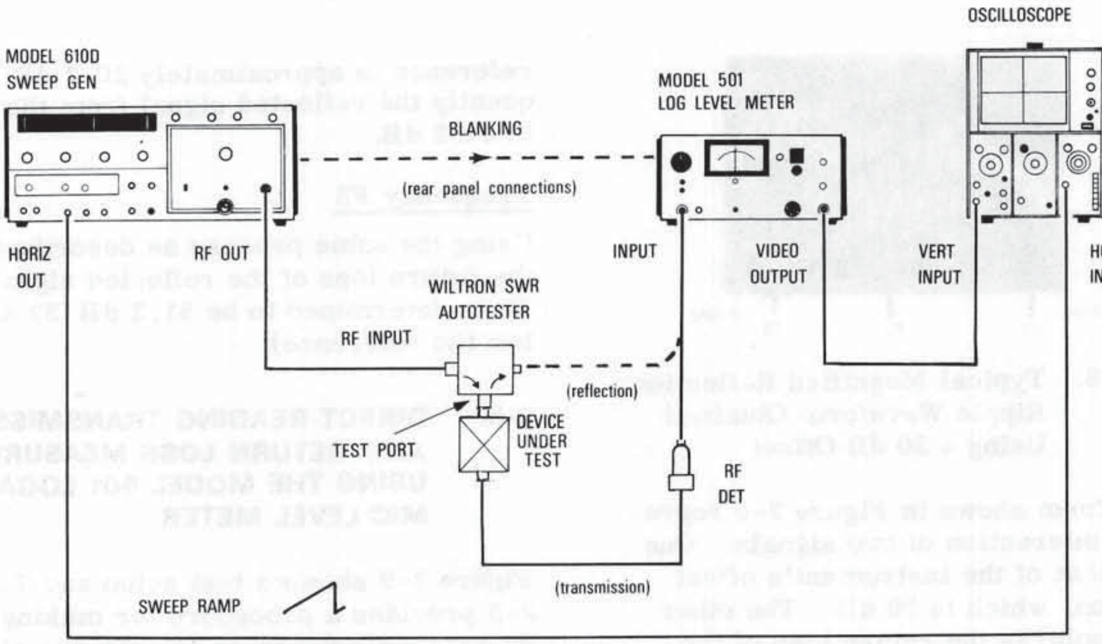



Figure 2-9. Equipment Setup for Measuring Transmission (Insertion) Loss Using Model 501 Logarithmic Level Meter

Table 2-3. Procedure for Direct Logarithmic Measurements

| | |
|---|---|
| 1. Connect equipment as shown except do not connect device under test into circuit. Instead, connect an RF detector between the test port of the SWR Autotester and the INPUT of the Model 501.<br><br>2. Set controls as follows:<br><br>Model 610D Mainframe<br><br>VAR FREQ MARKER: INTENSITY<br>AMPLITUDE: Fully CCW<br>SWEEP MODE: Line Sync<br>SWEEP TIME VERNIER: CAL<br>FREQ SELECTOR: F1 TO F2<br>RETRACE RF: ON<br>F1: Low frequency of interest<br>F2: High frequency of interest<br>VAR FREQ MKR: Mid-range<br>POWER: ON<br>LEVELING: INT<br><br>RF Plug-In<br><br>RF POWER LEVEL: 1/2 maximum | RF: OFF<br>FREQUENCY RANGE (some models): Full<br><br>Model 501 Logarithmic Level Meter<br><br>POWER: ON<br>OFFSET: 00.0 dB<br>OFFSET Polarity: Minus (-)<br>SENSITIVITY: 10 dB/div<br>PANEL METER: OFF<br>FILTER: OUT<br>BLANKING POLARITY (rear panel): +<br>ZERO dB SET: UNLOCK<br><br>Oscilloscope<br><br>Vertical Input: GND<br>Vertical Input Polarity: +<br>Sensitivity: 1V/div<br>Horizontal Input: EXT (sweep off)<br>Horizontal Input: DC<br>Horizontal Input Polarity: +<br>Horizontal Sensitivity: 1V/div<br>Power: ON |

Table 2-3. Procedure for Direct Logarithmic Measurements (Continued)

3. Adjust Horizontal Sweep as follows:

   a. Adjust focus and intensity to obtain a trace.

   b. Adjust vertical position to align trace with center of graticule.

   c. Adjust horizontal gain and horizontal position until trace is exactly 10 divisions wide and centered horizontally on graticule.

   d. Set vertical input of scope to DC.

4. Set RF Power Reference Level:

   a. On RF plug-in, position RF switch to ON.

      NOTE

      The trace may be off-screen. Use ZERO dB SET control to bring trace back onto screen.

   b. On Model 501, use ZERO dB SET to exactly align trace and retrace vertically on CRT screen.

   c. On RF plug-in, adjust SLOPE control to get both ends of trace at same vertical level.

   d. On Model 501, increase SENSITIVITY control to 1.

   e. Repeat steps b and c.

   f. On Model 501, lock the ZERO dB SET control.

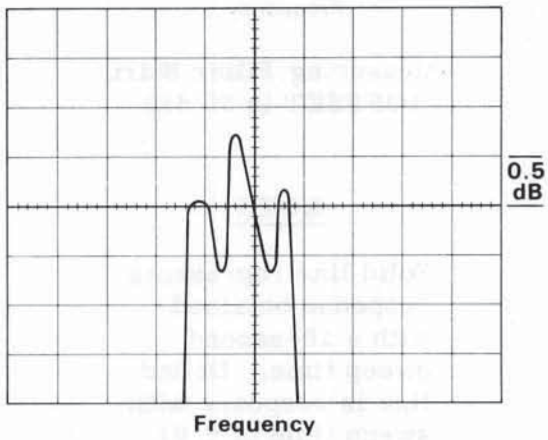
5. Measuring Insertion Loss:

   a. On RF plug-in, position RF switch to OFF. Connect device under test and RF detector as shown in Figure 2-9.

   b. Position RF switch to ON and position Model 501 SENSITIVITY control to 10.

   c. On Model 610D, increase marker AMPLITUDE, and use VAR FREQ MKR control to center marker on response curve.

   d. On Model 501, increase SENSITIVITY control to 0.5; adjust the OFFSET dB control to align top of response curve with reference trace (see figure below). The OFFSET counter now reads insertion loss.



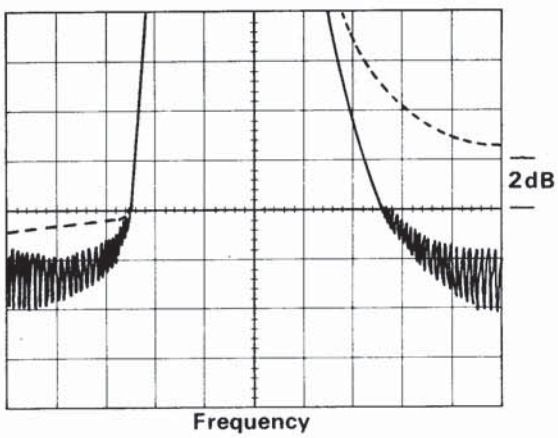

Using OFFSET Control to Measure Insertion Loss (OFFSET = 2.2 dB)

Table 2-3. Procedure for Direct Logarithmic Measurements (Continued)

6. Measuring the Skirt of the Filter:

   a. To measure skirt of the response curve, position the SENSITIVITY and OFFSET controls as appropriate (see example below).

   b. Use a very slow-frequency sweep. Low-level signals are distorted by a fast sweep.




Measuring Filter Skirt (OFFSET is 36 dB)

NOTE

Solid line represents response obtained with a 10-second sweep time. Dotted line is response with sweep time of 0.01 seconds.

7. Measuring Return Loss

   a. Position RF switch of plug-in to OFF.

   b. Disconnect device under test from the test port of the SWR Autotester. Remove RF detector from circuit.

   c. Connect coax cable between the detected output of SWR Autotester and input of Model 501 (see dotted line in Figure 2-9).

   d. Unlock ZERO dB SET control.

   e. Set RF power reference (see steps 4a through 4f).

   f. Connect device under test to test port of SWR Autotester. Be sure to terminate output of device under test.

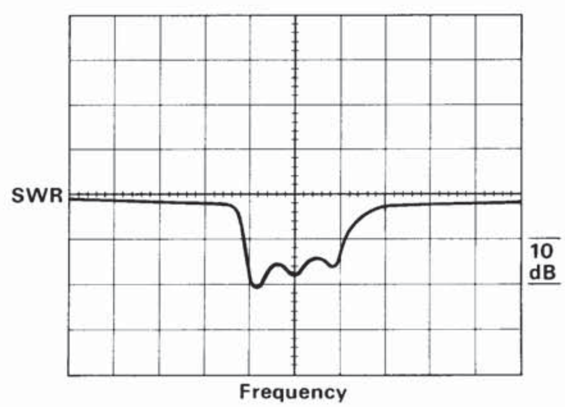
   g. Position RF switch on plug-in to ON.

   h. On Model 501, decrease SENSITIVITY control to 10 to properly identify response curve.

NOTE

The return loss is a low-level signal. Use a slow sweep time to avoid distorting the trace.

   i. Increase SENSITIVITY control to either 1 or 0.5. Increase OFFSET control to accurately read return loss.




Measuring Return Loss (Sweep Time = 10 s)

## 2-6. LOW-LEVEL (<-40 dBm) RETURN LOSS MEASUREMENTS USING THE MODEL 501B LOGARITHMIC LEVEL METER

A test setup for making low-level return loss measurements (<-40 dBm) from 1 to 1000 MHz is shown in Figure 2-10. This test setup uses a WILTRON Model 501B Logarithmic Level Meter to provide gain for low-level signals. The Model 501B is similar to the Model 501, discussed in paragraph 2-5. The difference between these two instruments is that the 501B contains a 40 dB RF amplifier located in its front end. The purpose of this amplifier is to provide preamplification of low-level (<-40 dBm) signals before they are applied to the video amplifier. This secondary amplifier can be inserted into the measurement setup through a front panel connector. This amplifier provides the Model 501B with a total dynamic range of 80 dB.

## 2-7. SWR MEASUREMENTS USING GRATICULES

A plastic sheet containing six graticules is available upon request. The graticules may be cut to fit the oscilloscope being used. The top calibration line on the graticule represents an SWR of 1.0, and the bottom line represents the maximum SWR for the range being used. (See Figures 2-11 through 2-16.) Some graticules may be marked "VSWR" instead of "SWR." In either case, the ratio is the same.

To describe the use of the graticules, a test setup is shown in Figure 2-17 and a procedure is presented in Table 2-4. This procedure assumes the use of the WILTRON Model 610D RF Sweep Generator. To obtain accurate measurement results from this procedure, the following precautions must be observed:

a. The impedance of the test cables must match that of the sweep generator, SWR Autotester or bridge, and device under test.

b. The RF output of the sweep generator must be leveled.

c. The RF detector must be operated in the square law region (refer to paragraph 1-4.3).

d. The directivity of the SWR Autotester or bridge must be 35 dB or greater. (WILTRON SWR Autotesters and bridges typically have directivities in excess of 40 dB.)

e. The oscilloscope must have a sensitivity of at least 1mV/div. If the 20 dB or 30 dB graticule is used, a vertical sensitivity of 50μV/div is recommended.

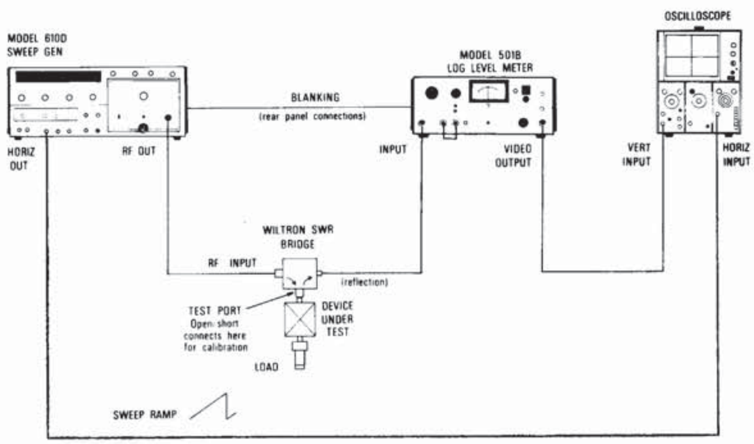



Figure 2-10. Equipment Setup for Making Low-Level (<-40 dBm) Return Loss Measurements Using Model 501B Logarithmic Level Meter

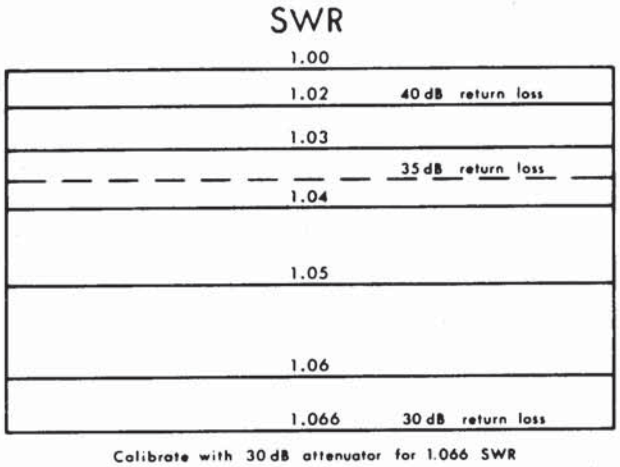



Figure 2-11. Graticule for SWR Values Between 1.00 and 1.066

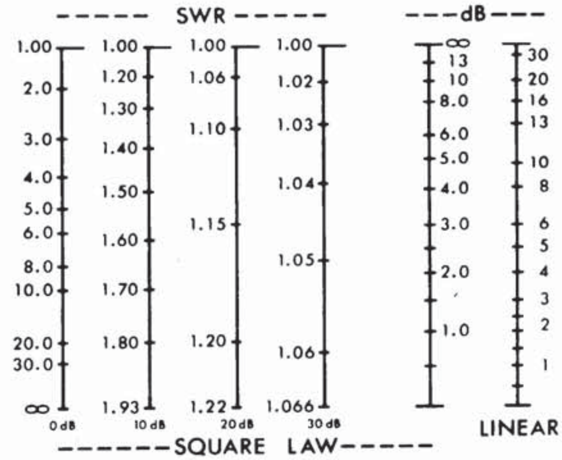



Figure 2-14. Graticule Selection Guide

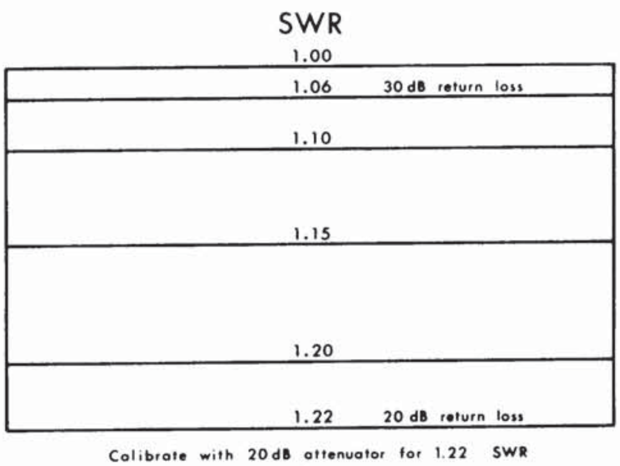



Figure 2-12. Graticule for SWR Values Between 1.00 and 1.22

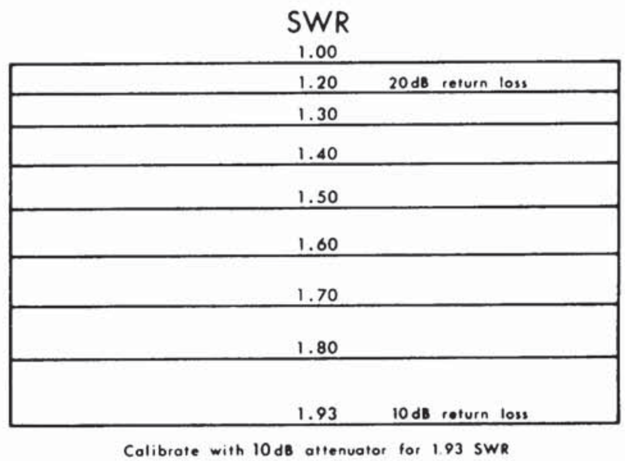



Figure 2-15. Graticule for SWR Values Between 1.00 and 1.93

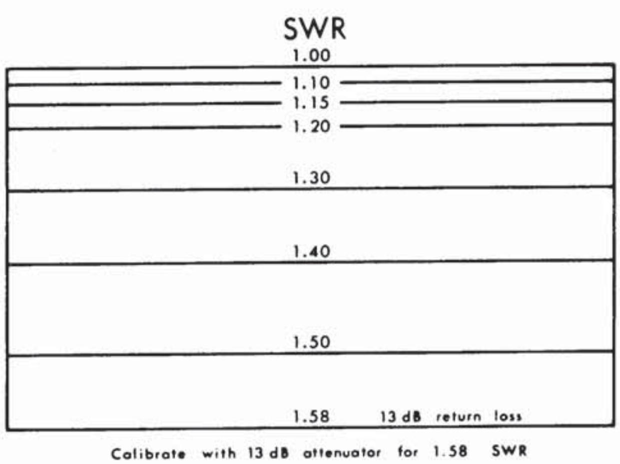



Figure 2-13. Graticule for SWR Values Between 1.00 and 1.58

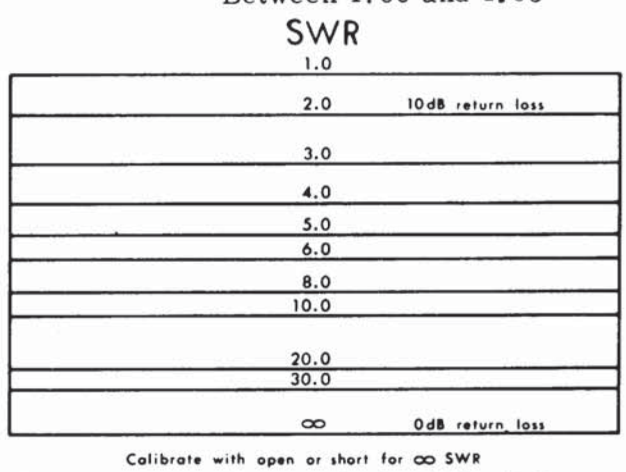



Figure 2-16. Graticule for SWR Values Between 1.0 and ∞

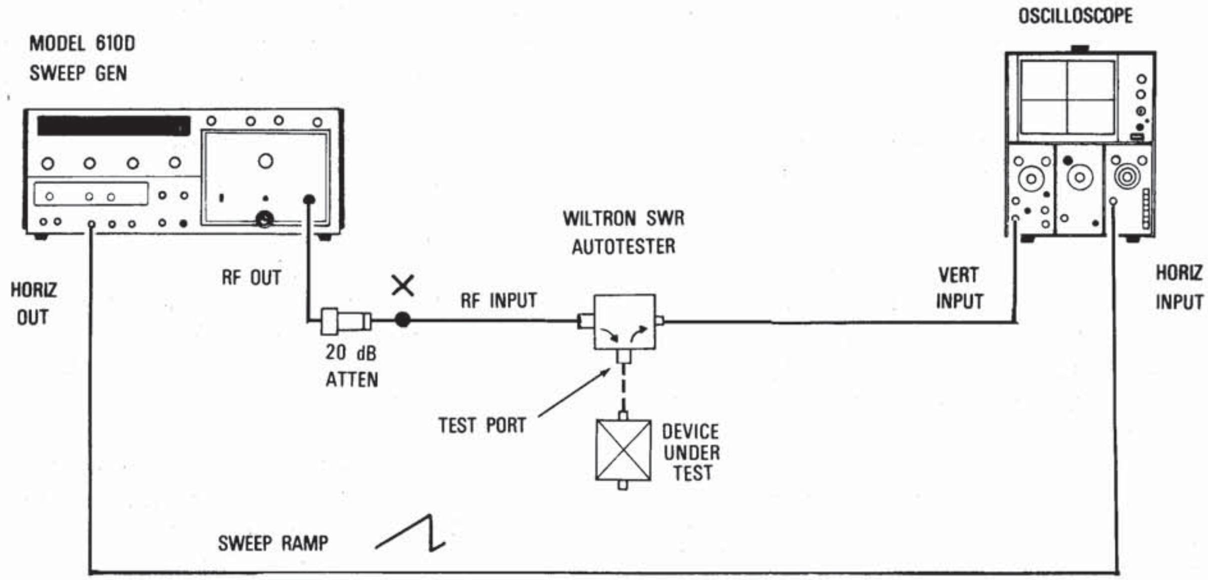



Figure 2-17. SWR Measurement Test Setup

Table 2-4. Procedure for SWR Measurements Using Graticules

| | |
|---|---|
| 1. Connect equipment as shown above but do not connect device under test to test port of the SWR Autotester.<br><br>2. Set front panel controls:<br><br><u>Model 610D Mainframe</u><br><br>VAR FREQ MARKER: INTENSITY<br>AMPLITUDE: Fully CCW<br>SWEEP MODE: LINE SYNC<br>SWEEP TIME (SEC): .1 - .01<br>SWEEP TIME VERNIER: CAL<br>FREQ SELECTOR: F1 TO F2<br>RETRACE RF: OFF<br>F1: Low frequency of interest<br>F2: High frequency of interest<br>VAR FREQ MKR: Mid-range<br>LEVELING: INT<br>POWER: ON<br><br><u>RF Plug-In</u><br><br>RF: OFF<br>RF POWER LEVEL: Fully CW<br>FREQ RANGE (some models): Full | <u>Oscilloscope</u><br><br>Vertical Input: DC<br>Vertical Input polarity: Positive (+)<br>Vertical Sensitivity: 1mV/division or less (1)<br>Horizontal Input: External (sweep off)<br>Horizontal Input: DC<br>Horizontal Input polarity: Positive (+)<br>Power: ON<br><br>3. Set Horizontal Sweep:<br><br>a. On oscilloscope, adjust focus and intensity controls to obtain horizontal trace.<br><br>b. Adjust vertical position to align retrace 3 divisions above center.<br><br>c. Adjust horizontal gain and horizontal position to obtain trace 10 divisions wide and exactly centered on the graticule. |

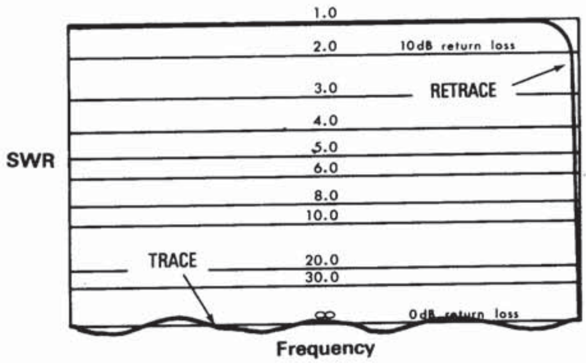
(1) With higher-power plug-ins, decrease to 10mV/division.

Table 2-4. Procedure for SWR Measurements Using Graticules (Continued)

4. First Calibration:

   a. Select the SWR graticule for 0 dB return loss (Figure 2-16) and attach to face of oscilloscope.

   b. Position RF switch on plug-in to ON. Adjust RF POWER LEVEL on RF plug-in and vertical sensitivity controls on oscilloscope until trace and retrace are positioned as shown below.




First Calibration (with Open)

   c. On RF plug-in, adjust SLOPE control for a level display.

NOTE

This completes the initial calibration of the system. The device can now be measured to determine its approximate SWR reading.

5. First Measurement:

   a. Connect device under test to test port of SWR Autotester.

NOTE

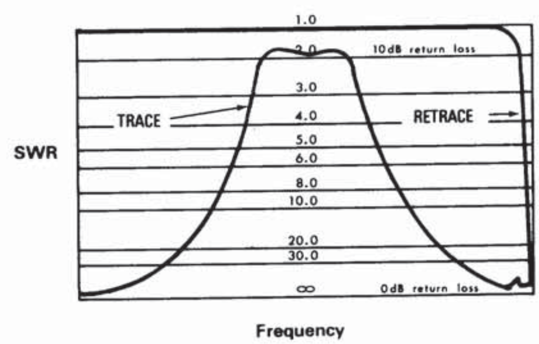
Insure that the output of the device under test is properly terminated.

   b. Observe trace and identify response curve of device under test. Use VAR FREQ MKR control to set an RF pip in the center of the curve.

   c. Set FREQ SELECTOR switch to ΔF mode. Adjust ΔF FREQ to obtain desired width in response curve. Use VAR FREQ MKR control to precisely center the curve on the screen.

   d. Read approximate SWR directly from the 0 dB return loss graticule. Based upon this reading, select the return loss graticule for final calibration or final measurement.

   Example: If the SWR reading is between 1.0 and 2.0 but closer to 2.0, choose the 10 dB return loss graticule (see figure below). If reading is closer to 1.0, choose either the 20 dB or 30 dB return loss graticule.




First Measurement
(Typical Trace, Bandpass Filter)

6. If the 20 dB return loss graticule was selected, proceed to step 7 for final measurement. If 10 dB graticule was selected, disregard step 7 and proceed to step 8 for final measurement. If 30 dB graticule was selected, proceed directly to step 9 for second calibration; disregard steps 7 and 8.

Table 2-4. Procedure for SWR Measurements Using Graticules (Continued)

NOTE

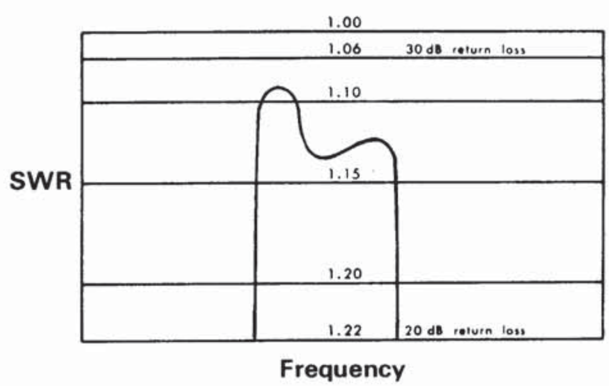
For measurements using 30 dB return loss graticule, a high-power RF plug-in (output power exceeds 1mW), an oscilloscope with vertical sensitivity of 100$\mu$V or less, or both may be required.

7. Final Measurement Using 20 dB Return Loss Graticule

   a. Replace 0 dB return loss graticule with 20 dB return loss graticule.

   b. Remove 20 dB ATTEN (Figure 2-17) and connect output of RF plug-in directly to input of SWR Autotester.

   c. Read SWR (see example below). Any number of similar devices can now be measured without further calibration.



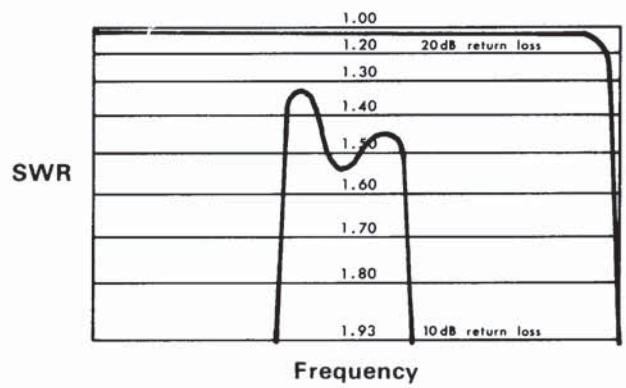

Final Measurement Using 20 dB Return Loss Graticule

8. Final Measurement Using 10 dB Return Loss Graticule

   a. Replace 0 dB return loss graticule with 10 dB return loss graticule.

   b. Remove 20 dB ATTEN (Figure 2-17) and replace with a 10 dB attenuator.

   c. Read SWR (see example below). Any number of similar devices can now be measured without further calibration.




Final Measurement Using 10 dB Return Loss Graticule

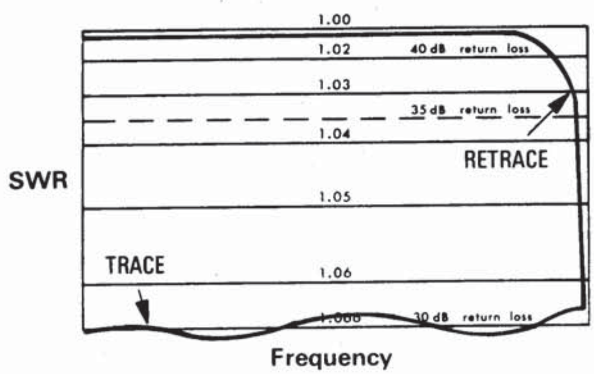
9. Final Calibration Using 30 dB Return Loss Graticule

   a. Replace 0 dB return loss graticule with 30 dB return loss graticule.

   b. Disconnect device under test from test port of SWR Autotester.

c. Add 10 dB attenuator in series with the 20 dB ATTEN already in place (Figure 2-17). Total attenuation between RF plug-in and SWR Autotester should be 30 dB.

d. Adjust RF POWER LEVEL on RF plug-in and vertical sensitivity controls on oscilloscope until trace and retrace are positioned as shown below.

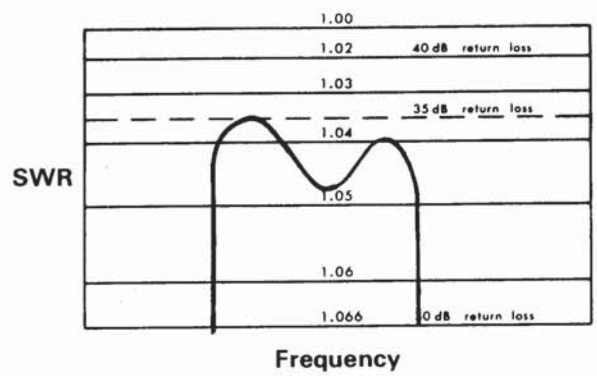



Final Calibration Using
30 dB Return Loss Graticule

10. Final Measurement Using 30 dB Return Loss Graticule

a. Remove the 30 dB of attenuation from between the RF plug-in and the SWR Autotester; connect the output of RF plug-in directly to input of SWR Autotester.

b. Reconnect the device under test and read SWR (see example below). Any number of similar devices can now be measured without further calibration.




Final Measurement Using
30 dB Return Loss Graticule

# SECTION III

# RETURN LOSS MEASUREMENT ACCURACY

## 3-1. INTRODUCTION

This section addresses factors that affect return loss measurement accuracy. Discussions are included for directivity, test port match, test equipment limitations, and the effects of adapters on measurement systems. Also included are discussions covering the following topics: (1) the open/short method for reducing the effects of test port match, (2) precision type N connectors, and (3) the WILTRON SMA (WSMA) connector.

## 3-2. INHERENT FACTORS THAT AFFECT RETURN LOSS MEASUREMENT ACCURACY

Directivity and test port match are two factors that are inherent in all return loss measurements. These two factors greatly affect the accuracy of return loss measurements. Directivity affects large return loss (small reflected signal) measurements, and test port match affects small return loss (large reflected signal) measurements. The following paragraphs provide detailed discussions of these two factors.

### 3-2.1 Directivity (Balance)

Directivity is a term that describes RF leakage in a return loss measurement device. As shown in Figure 3-1, even though the test port of an SWR Autotester or bridge is terminated with a perfect load, there is still a small amount of RF leakage through the device to the output port. This leakage is called the directivity signal, and it occurs because of imperfections within the device itself. These imperfections result from deviations from prescribed geometry, connector mismatches and imperfect internal terminations. Directivity is expressed in dB and is a figure of merit for directional devices. The larger this number, the more accurately the device can measure return loss. Directivity is the ratio, expressed in dB, of the output power when the test port signal is fully reflected to the output power when the test port is perfectly terminated. The formula used to find directivity is: Directivity (dB) = $10 \log_{10} P_1/P_2$, where $P_1$ is the output power when the test port signal is fully reflected, and $P_2$ is the output power when the test port is perfectly terminated.

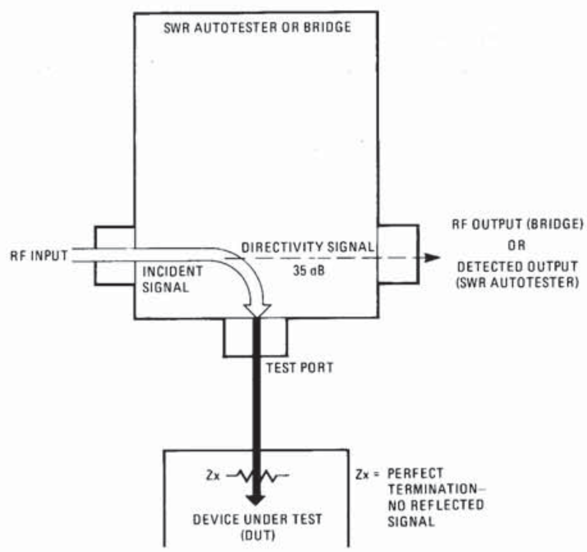



Figure 3-1. SWR Autotester or Bridge With Perfect Termination

Measurement errors due to directivity are most pronounced when measuring small reflected signals. As shown in Figure 3-2, the reflected signal being measured equates to a return loss value of 20 dB. This return loss is only 15 dB larger than the signal due to directivity (35 dB). The phasor diagram shows how the directivity can combine with the reflected signal at the measurement port. The error limits caused by the directivity signal are shown as a 3.12 dB uncertainty. This uncertainty means that the measurement, instead of indicating 20 dB, will indicate anywhere between 18.58 and 21.70 dB.

A more striking example of the directivity error is illustrated in Figure 3-3. In this example, the DUT is absorbing more of the incident signal than in the previous example, and the reflected signal is smaller, now equating to a return loss of 30 dB. This return loss is only 5 dB larger than the signal due to directivity. Referring to the phasor diagram and ripple sine wave of Figure 3-3, it can be seen that the errors due to the directivity signal have become very large--+7.18 and -3.88 dB! Error limits of this magnitude mean that the return loss signal, instead of indicating a measured value of 30 dB, may indicate a measured value anywhere between 26.14 and 37.18 dB.

In summation, directivity is a figure of merit for an SWR Autotester or bridge. The larger the dB number, the more accurately the device can measure small reflections. Measurement inaccuracies due to the directivity signal are more pronounced when measuring very small reflections (large return loss). As demonstrated by the two examples above, a good rule-of-thumb to follow when measuring return loss is to use a directional device that has a directivity at least 20 dB greater than the return loss to be measured.

In some situations, the 20 dB rule may not be practical. In these cases, measurement techniques using an air line may be applied, as described in Section II. These techniques allow an SWR Autotester or bridge with 35 or 36 dB directivity to be used to measure return loss signals as great as 54 dB, with an accuracy that is typically ±2%.

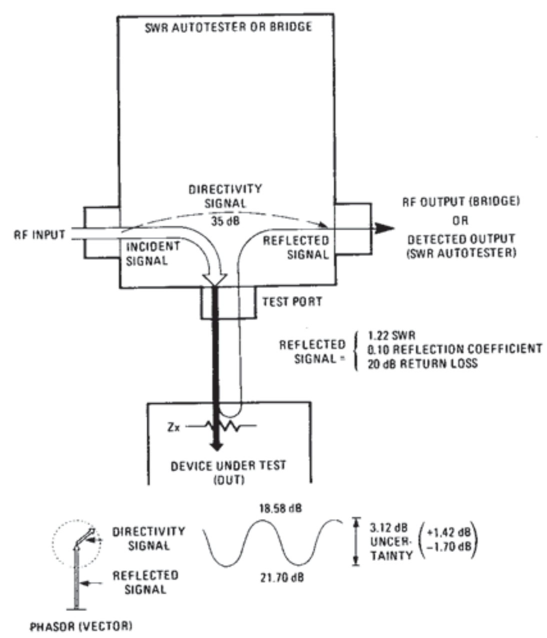



Figure 3-2. SWR Autotester or Bridge With 20 dB Return Loss

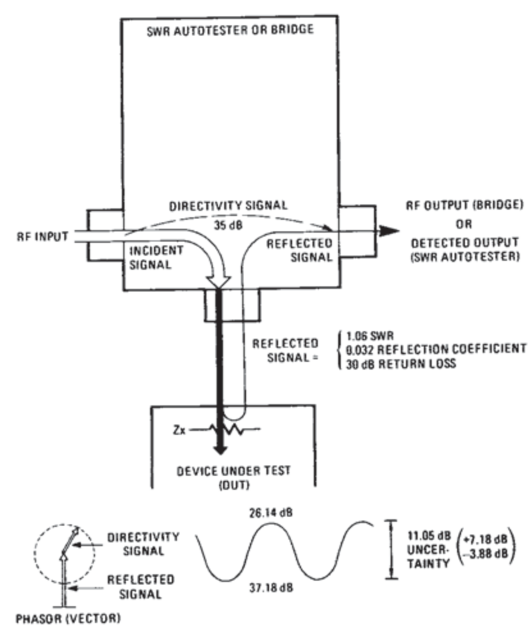



Figure 3-3. SWR Autotester or Bridge With 30 dB Return Loss

### 3-2.2 Test Port Match

The second characteristic of a directional device that may cause inaccuracies in return loss measurements is the test port match. The mismatch at the test port is a summation of all the impedance discontinuities as seen by the load, looking back toward the source. The effects of this mismatch are illustrated in Figure 3-4. In the example shown, 100% of the incident signal is reflected from the short or open back to the SWR Autotester or bridge. Part of this signal is re-reflected by the test port back toward the short or open; the remaining part goes to the RF output port. The signal that was re-reflected by the test port is again reflected by the short or open and goes to the RF output, where it adds vectorially with the main reflection. In a swept-frequency setup, since the re-reflected signal has traveled farther than the main signal, it adds in and out of phase. Since the re-reflected signal is an error signal, it causes an error in the measured return loss value.

As shown in Figure 3-4, the reflected signal is reflected twice by the device under test (DUT) and once by the test port. Consequently, the magnitude of the error signal is $\rho_{TP} \times \rho_{D1} \times \rho_{D2}$, where $\rho_{TP}$ is the reflection coefficient of the test port, $\rho_D$ is the reflection coefficient of the DUT, and the numerals 1 and 2 refer to the different times that the signal is reflected from the DUT. Since $\rho_{D1} = \rho_{D2}$, the error formula due to test port match is $\rho_{TP} \times \rho_D^2$, or for the example shown in Figure 3-4, $.11\rho^2$.

The test port match error formula shows that the error signal is highest when the reflection coefficient is largest, and decreases as the reflection coefficient gets smaller (load offers a better impedance match). This characteristic is illustrated by comparing the phasor diagram and ripple sine wave of Figure 3-4 to those of Figure 3-5. In Figure 3-4, the return loss is 0 dB and in Figure 3-5 the return loss is 20 dB. The significance of this is that the error is largest when the return loss signal is 0 dB (full reflection); this is the reflection magnitude normally associated with the return loss measurement system calibration signal.

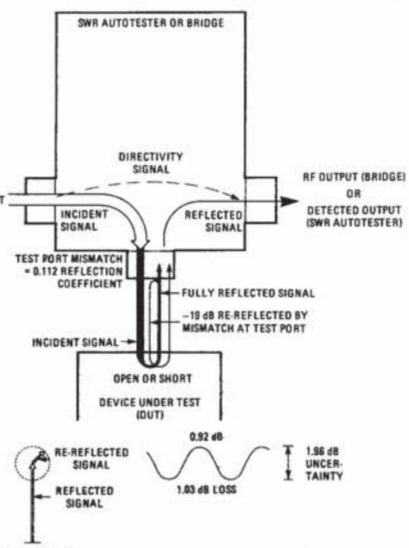



Figure 3-4. Effects of Test Port Match on a Fully Reflected Signal

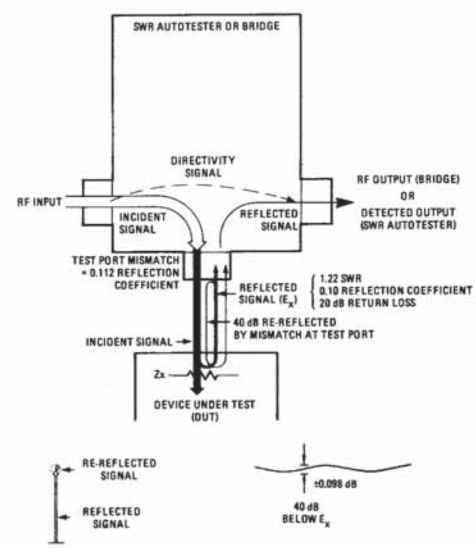



Figure 3-5. Effects of Test Port Match on a 20 dB Return Loss Signal

While this test port match error is significant when performing calibration tasks or when making large return loss measurements, it can be overcome. The Open/Short Calibration Technique, described in paragraph 3-5, compensates for this error when calibrating the test setup for return loss measurements.

The correlation between the values shown for return loss, reflection coefficient, and SWR was obtained from the Microwave Measurement Chart. A description of this valuable microwave measurement tool, along with a discussion on how to use it, is provided in Section IV.

## 3-3. TEST EQUIPMENT LIMITATIONS

In addition to directivity, described in paragraph 3-2.1, another factor that affects the measurement of small reflections is inadequate test equipment. The measurement of small reflected signals requires the use of an RF signal generator with a high signal output and an oscilloscope with a high vertical sensitivity. For example, assume a return loss measurement of 30 dB. Using a signal generator with an output of 1V rms to supply the incident signal results in a reflected signal that is typically only 600$\mu$V after detection. Consequently, in order to display this small signal with adequate vertical resolution, an oscilloscope with at least 100$\mu$V/cm vertical sensitivity is required. However, if accessory equipment such as a logarithmic amplifier is available, measurements can be made over RF power levels of -40 to +20 dBm because of the dc gain provided by the instrument.

## 3-4. EFFECTS OF ADAPTERS ON RETURN LOSS MEASUREMENT ACCURACY

When an adapter is used to adapt the test port of an SWR Autotester or bridge to a different connector sex or type, measurement inaccuracies result. These inaccuracies are manifested through a reduction in the effective directivity of the SWR Autotester or bridge and a degradation in its test port match.

The reduction in effective directivity occurs because even if the test port were terminated in a perfect impedance match (no reflections), the adapter would still reflect part of the incident signal. Consequently, since the definition of directivity is the ratio, in dB, of power at the output port when the bridge is terminated in an open (full reflection) divided by power at the output port when the test port is terminated in a perfect impedance (no reflection), the reflection from the adapter is an error signal that reduces the effective directivity of the instrument (refer to paragraph 3-2.1 for an explanation of directivity).

The degradation in the test port match occurs because the reflection from the device under test (Zx in Figure 3-6) is re-reflected from the mismatch of the adapter, as well as being re-reflected from the mismatch at the test port (refer to paragraph 3-2.2 for an explanation of test port match re-reflections). When these two re-reflected signals are added in phase, they degrade the effective test port match of the SWR Autotester or bridge.

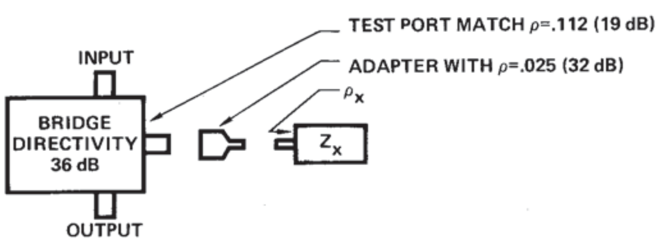
The examples in Figure 3-6 show how to calculate the reduction in directivity and the degradation to the test port match. As shown, the dB values for directivity, adapter return loss, and test port match are converted to reflection coefficient values (see Table 4-1) and are added together in simple addition. This is a fast and easy method for effectively adding in dB.

In the examples of Figure 3-6, an adapter with a return loss of 32 dB (.025 reflection coefficient), and a bridge with a directivity of 36 dB and test port match of 19 dB (.016 and .112 reflection coefficients respectively) are used. Their effect on directivity is shown under the heading "EFFECTIVE DIRECTIVITY," where the reflection from the adapter (.025 reflection coefficient) is added to the bridge directivity (.016 reflection coefficient). The results of this addition show that the effective directivity is only 27.74 dB. This is 8.26 dB down from the original 36 dB directivity value! The degradation in test port match is shown under the heading "TEST PORT MATCH." Here, the reflection coefficient of the adapter is added to the reflection coefficient of the test port to produce a test port reflection coefficient of 0.137 or a return loss of 17 dB--2 dB worse than before.

It is informative to examine the error limits with and without the adapter for a 20 dB return loss measurement; this is shown in the box of Figure 3-6. In this box, the measurement is shown to be 20 dB, and the error limits of the bridge alone, without the adapter, are shown to have a range of 2.8 dB (from -1.3 dB to +1.5 dB). These error limits are obtained from the Microwave Measurement Chart, Table 4-1, and they represent the error that is caused by the directivity being only 16 dB greater than the measured signal (36 dB directivity minus 20 dB measurement). Under the "ADAPTER ADDED" column in the box of Figure 3-6, the error limits jump from an overall 2.8 dB range to a 7.3 dB range. This jump is caused by the directivity being only 7.74 dB greater than the measured signal (27.74 effective directivity minus 20 dB). As shown by Table 4-1, this 7.74 dB (approximately 8 dB) difference correlates to an error range of 7.3 dB, from -2.9 dB to +4.4 dB.

## 3-5. OPEN/SHORT REFERENCE-REFLECTION AVERAGING: A TECHNIQUE FOR REDUCING ERRORS DUE TO TEST PORT MATCH

Open/short reference-reflection averaging describes a technique that can be used to compensate for errors due to test port match. In a typical measurement system the reference, or calibration, reflection is the 100% reflected signal from the unconnected (open) test port of an SWR Autotester or bridge. As described in paragraph 3-2.2 (Test Port Match), when the reflected signal is 100% the test port match error is large. Since return loss is a measurement of the ratio of incident to reflected power (incident power




EFFECTIVE DIRECTIVITY:

BRIDGE ⇒ .016 REFLECTION COEFFICIENT
ADAPTER ⇒ .025 REFLECTION COEFFICIENT
.041 ⇒ 27.74 dB

TEST PORT MATCH

BRIDGE ⇒ .112 REFLECTION COEFFICIENT
ADAPTER ⇒ .025 REFLECTION COEFFICIENT
.137 ⇒ 17 dB

ERROR LIMITS OF A 20 dB MEASUREMENT

| MEASUREMENT | BRIDGE ONLY | ADAPTER ADDED |
| --- | --- | --- |
| 20 dB | 18.7/21.5 dB<br>−1.3 TO + 1.5 dB<br>△ 2.8 dB | 16.9/24.9 dB<br>−2.9 TO + 4.4 dB<br>△ 7.3 dB |

Figure 3-6. Adapter Error Effects on Return Loss Measurements

is represented by the reference reflection), if this error in the reference reflection is not compensated, the accuracy of all future measurements using that reference reflection will be affected.

Compensation for test port match error can be achieved by averaging the reflections from a precision open and short such as the WILTRON Series 22 Open/Short, and using this average for the reference reflection. This averaging technique is effective because the reflection from a precision open is exactly 180° out of phase from the reflection from a precision short. With this phase difference, the test port match error component in the open is offset by the test port match error component in the short; the average is equal to the true value of a 100% reflected signal.

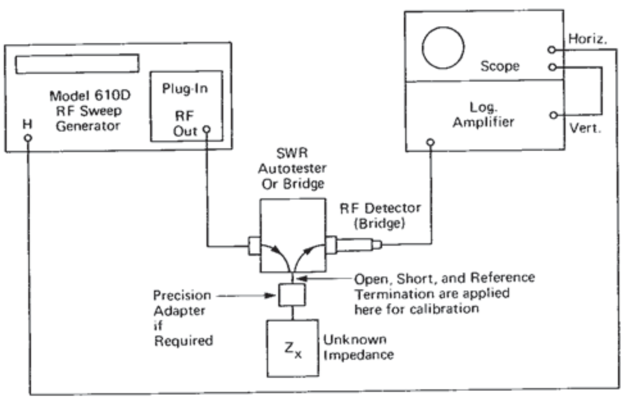



Figure 3-7. Basic Test Setup for Return Loss Measurements

For typical return loss measurement systems, such as the one shown in Figure 3-7, open/short averaging is accomplished as follows:

a. Connect the open termination to the test port of the SWR Autotester or bridge.

b. Adjust the oscilloscope controls to obtain a waveform similar to solid line A of Figure 3-8; lightly trace the outlines of this waveform on the face of the oscilloscope.

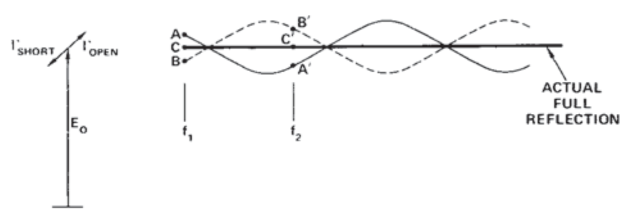



Figure 3-8. Signal Averaging With Open/Short Terminations

c. Remove the open-termination from the test port and install the short-termination in its place.

d. Observe the oscilloscope; the display should resemble dotted line B of Figure 3-8. (Do not touch the oscilloscope controls.)

e. Lightly trace the outlines of this waveform on the face of the oscilloscope.

NOTE

The magnitude of the worst-case (fully-reflected) signal, which includes the vector sum of the test port match signal, is now known.

f. On the face of the oscilloscope, trace a third waveform that represents the average between the first two waveforms.

g. Erase the first two waveforms from the oscilloscope face.

NOTE

The waveform that is drawn on the face of the oscilloscope represents a close approximation of the fully-reflected signal minus the effects of the test port match error signal.

h. The reference reflection for future return loss measurements has now been established. When the reflectometer is used for actual measurements, the reflected signal is then measured relative to this reference reflection.

As described above, this technique is simple and effective; however it has limitations. Confusing factors, such as slope in the frequency response and harmonics in the input frequency, limit the technique's ability to locate a true signal average. These limitations, however, become negligible when the technique is used with network analyzers or other instruments having a logarithmic display, such as the WILTRON Model 560 Scalar Network Analyzer.

When used with the WILTRON Model 560, the Open/Short Calibration Technique is considerably simplified. The Model 560 contains a built-in memory; consequently, instead of tracing the waveforms on the display face and manually taking their average, the waveforms can be entered into memory and their average taken automatically.

## 3-6. PRECISION TYPE N and WSMA CONNECTORS

Center-pin dimensions for precision Type N connectors and technical information for the improved WILTRON SMA (WSMA) connector are provided in the following paragraphs.

### 3-6.1 Center-Pin Dimensions for Precision Type N Connectors

The WILTRON SWR Autotesters and bridges that contain the letter "N" in their model numbers (63N75, 67N50, 97N50, etc.) are equipped with a Type N test port connector. For SWR Autotesters and bridges that operate above 2 GHz, these Type N connectors have precision center-pin dimensions, as shown in Figure 3-9. For accurate return loss measurements, it is recommended that the mating Type N connector have the same nominal dimensions. These connectors are available with either 50Ω or 75Ω impedance. And while it is not the recommended mode of operation, the 75Ω N female connectors will withstand occasional mating with 50Ω male connectors without damage.

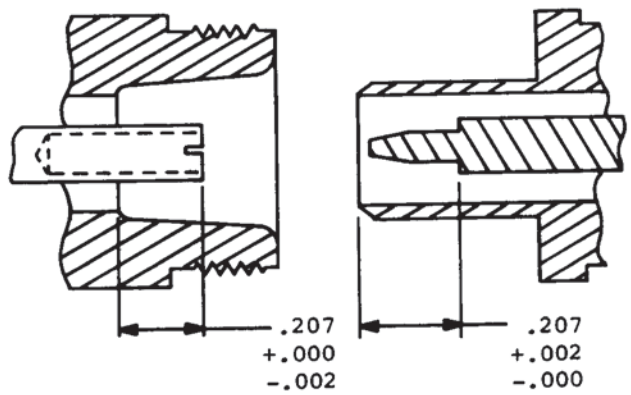



Figure 3-9. Precision Type N Connector Dimensions (Inches)

### 3-6.2 Improved SMA Connector: WSMA

SMA connectors are widely used throughout the industry because of their small size and broadband characteristics. However, their low reliability in applications requiring frequent reconnects has discouraged their use on test components and instruments. To meet the need for a connector with longer life and greater accuracy in instrumentation applications, WILTRON has developed a new SMA-compatible connector: the WSMA. When used as the test port on reflection-measuring components, the new connector provides a 20-fold improvement in life expectancy and a 10 dB improvement in return loss measurement accuracy.

To obtain additional information concerning the WSMA connector, contact your local representative or write WILTRON directly for a copy of the technical paper "New WILTRON Connector Relieves Nagging SMA Measurement Problems," November, 1978.

# SECTION IV

# MICROWAVE MEASUREMENT CHART

## 4-1. INTRODUCTION

This section contains the WILTRON Microwave Measurement Chart, plus a description and two examples of its application.

## 4-2. DESCRIPTION

The Microwave Measurement Chart, Table 4-1, is a product of the WILTRON Microwave Laboratory. This chart was designed primarily to be used with the magnified reflection technique described in paragraph 2-4.3. It can also be used (1) to provide easy conversion from any one microwave measurement value to any other (i.e, return loss, SWR, and reflection coefficient), (2) to define the limits of the test port match error signal, and (3) to define the limits of the directivity error signal. Application information and examples showing how to use the chart are provided in paragraph 4-3.

This chart replaces the SWR nomographs previously supplied.

## 4-3. APPLICATIONS

The Microwave Measurement Chart is a very useful tool for microwave measurement applications. The chart may be used several ways, but it is mainly used for the magnified-reflection technique, described in paragraph 2-4.3. In this application, the chart is used to convert a ripple value measured on a logarithmic display to a value, in dB, below the reference reflection. The technique for analyzing the ripple waveform and using the chart to extract the needed information is described in paragraph 2-4.5. The following examples show how the chart may be used to define measurement-uncertainty limits caused by directivity and test port match.

### 4-3.1 Defining Measurement-Uncertainty Limits Due to Directivity

A device with a 20 dB return loss is measured using an SWR Autotester or bridge that has a directivity of 35 dB. The difference between these two values is 15 dB. Refer to Table 4-1 and the column headed "x dB Below Reference." The difference value of 15 dB correlates to values of 1.4216 and -1.7007 in the columns headed "REF + x dB" and "REF - x dB" respectively. These values represent the uncertainty limits of the measurement. Since the measurement is in -dB, the uncertainty limits are 20 dB minus 1.4216 and 20 dB plus 1.7007 dB. Consequently, a measured return loss of 20 dB will, in actuality, fall somewhere between -18.78 and -21.70 dB.

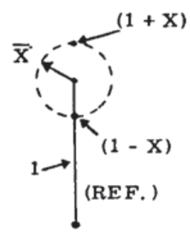
## 4-3.2 Defining Measurement-Uncertainty Limits Due to Test Port Match

An SWR Autotester or bridge with a test port match of $\pm .11\rho^2$ is used to measure a return loss of 3 dB. The first step in defining the measurement-uncertainty limits due to test port match is to translate the return loss value, 3 dB, into a reflection coefficient value. Refer to Table 4-1 and the column headed "Return Loss, dB." From this table it can be seen that 3 dB correlates to a reflection coefficient of .7079. To determine uncertainty limits, the reflection coefficient of the device under test is squared ($\rho^2$) and multiplied by the reflection coefficient of the test port (.11). The result of this multiplication is .0551. Again, by using Table 4-1 it can be seen that the nearest value to .0551, in the column headed "Reflection Coefficient," is .0562. This number, .0562, correlates to .4752 and -.5027 in the columns headed "REF + dB" and "REF - dB" respectively. Since the measurement is return loss (-dB), the measurement-uncertainties due to test port match can result in measurement errors of approximately -.48 and +.5 dB--an error range of approximately 1 dB.

## Table 4-1. Microwave Measurement Chart

**Conversion tables for Return Loss, Reflection Coefficient, and SWR with tabular values for interactions of a small phasor x with a large phasor (unity reference) expressed in dB related to reference.**

| | | | Relative to Unity Reference | | | |
|---|---|---|---|---|---|---|
| SWR | Reflection Coefficient | Return Loss dB | x dB Below Reference | REF + x dB | REF - x dB | REF ± x Peak to Peak Ripple dB |
| 17.3910 | .8913 | 1 | 1 | 5.5350 | -19.2715 | 24.8065 |
| 8.7242 | .7943 | 2 | 2 | 5.0780 | -13.7365 | 18.8145 |
| 5.8480 | .7079 | 3 | 3 | 4.6495 | -10.6907 | 15.3402 |
| 4.4194 | .6310 | 4 | 4 | 4.2489 | -8.6585 | 12.9073 |
| 3.5698 | .5623 | 5 | 5 | 3.8755 | -7.1773 | 11.0528 |
| 3.0095 | .5012 | 6 | 6 | 3.5287 | -6.0412 | 9.5699 |
| 2.6146 | .4467 | 7 | 7 | 3.2075 | -5.1405 | 8.3480 |
| 2.3229 | .3981 | 8 | 8 | 2.9108 | -4.4096 | 7.3204 |
| 2.0999 | .3548 | 9 | 9 | 2.6376 | -3.8063 | 6.4439 |
| 1.9250 | .3162 | 10 | 10 | 2.3866 | -3.3018 | 5.6884 |
| 1.7849 | .2818 | 11 | 11 | 2.1567 | -2.8756 | 5.0322 |
| 1.6709 | .2512 | 12 | 12 | 1.9465 | -2.5126 | 4.4590 |
| 1.5769 | .2239 | 13 | 13 | 1.7547 | -2.2013 | 3.9561 |
| 1.4985 | .1995 | 14 | 14 | 1.5802 | -1.9331 | 3.5133 |
| 1.4326 | .1778 | 15 | 15 | 1.4216 | -1.7007 | 3.1224 |
| 1.3767 | .1585 | 16 | 16 | 1.2778 | -1.4988 | 2.7766 |
| 1.3290 | .1413 | 17 | 17 | 1.1476 | -1.3227 | 2.4703 |
| 1.2880 | .1259 | 18 | 18 | 1.0299 | -1.1687 | 2.1986 |
| 1.2528 | .1122 | 19 | 19 | .9237 | -1.0337 | 1.9574 |
| 1.2222 | .1000 | 20 | 20 | .8279 | -.9151 | 1.7430 |
| 1.1957 | .0891 | 21 | 21 | .7416 | -.8108 | 1.5524 |
| 1.1726 | .0794 | 22 | 22 | .6639 | -.7189 | 1.3828 |
| 1.1524 | .0708 | 23 | 23 | .5941 | -.6378 | 1.2319 |
| 1.1347 | .0631 | 24 | 24 | .5314 | -.5661 | 1.0975 |
| 1.1192 | .0562 | 25 | 25 | .4752 | -.5027 | .9779 |
| 1.1055 | .0501 | 26 | 26 | .4248 | -.4466 | .8714 |
| 1.0935 | .0447 | 27 | 27 | .3796 | -.3969 | .7765 |
| 1.0829 | .0398 | 28 | 28 | .3391 | -.3529 | .6919 |
| 1.0736 | .0355 | 29 | 29 | .3028 | -.3138 | .6166 |
| 1.0653 | .0316 | 30 | 30 | .2704 | -.2791 | .5495 |
| 1.0580 | .0282 | 31 | 31 | .2414 | -.2483 | .4897 |
| 1.0515 | .0251 | 32 | 32 | .2155 | -.2210 | .4365 |
| 1.0458 | .0224 | 33 | 33 | .1923 | -.1967 | .3890 |
| 1.0407 | .0200 | 34 | 34 | .1716 | -.1751 | .3467 |
| 1.0362 | .0178 | 35 | 35 | .1531 | -.1558 | .3090 |
| 1.0322 | .0158 | 36 | 36 | .1366 | -.1388 | .2753 |
| 1.0287 | .0141 | 37 | 37 | .1218 | -.1236 | .2454 |
| 1.0255 | .0126 | 38 | 38 | .1087 | -.1100 | .2187 |
| 1.0227 | .0112 | 39 | 39 | .0969 | -.0980 | .1949 |
| 1.0202 | .0100 | 40 | 40 | .0864 | -.0873 | .1737 |
| 1.0180 | .0089 | 41 | 41 | .0771 | -.0778 | .1548 |
| 1.0160 | .0079 | 42 | 42 | .0687 | -.0693 | .1380 |
| 1.0143 | .0071 | 43 | 43 | .0613 | -.0617 | .1230 |
| 1.0127 | .0063 | 44 | 44 | .0546 | -.0550 | .1096 |
| 1.0113 | .0056 | 45 | 45 | .0487 | -.0490 | .0977 |
| 1.0101 | .0050 | 46 | 46 | .0434 | -.0436 | .0871 |
| 1.0090 | .0045 | 47 | 47 | .0387 | -.0389 | .0776 |
| 1.0080 | .0040 | 48 | 48 | .0345 | -.0346 | .0692 |
| 1.0071 | .0035 | 49 | 49 | .0308 | -.0309 | .0616 |
| 1.0063 | .0032 | 50 | 50 | .0274 | -.0275 | .0549 |
| 1.0057 | .0028 | 51 | 51 | .0244 | -.0245 | .0490 |
| 1.0050 | .0025 | 52 | 52 | .0218 | -.0218 | .0436 |
| 1.0045 | .0022 | 53 | 53 | .0194 | -.0195 | .0389 |
| 1.0040 | .0020 | 54 | 54 | .0173 | -.0173 | .0347 |
| 1.0036 | .0018 | 55 | 55 | .0154 | -.0155 | .0309 |
| 1.0032 | .0016 | 56 | 56 | .0138 | -.0138 | .0275 |
| 1.0028 | .0014 | 57 | 57 | .0123 | -.0123 | .0245 |
| 1.0025 | .0013 | 58 | 58 | .0109 | -.0109 | .0219 |
| 1.0022 | .0011 | 59 | 59 | .0097 | -.0098 | .0195 |
| 1.0020 | .0010 | 60 | 60 | .0087 | -.0087 | .0174 |




PHASOR INTERACTION

# SECTION V
# THEORY OF OPERATION

## 5-1. INTRODUCTION

This section of the manual describes how the SWR Autotesters and bridges operate. The following discussion is intended only to acquaint the user with the measurement concept employed, and therefore does not include a mathematical analysis.

## 5-2. DESCRIPTION

A simplified diagram of a typical SWR bridge is shown in Figure 5-1. The Autotester is identical to the bridge, except that the Autotester has a built-in RF detector. The output of an RF generator is applied to the bridge circuit formed by Ra, Rb, Rc, and Zx. Zdet is the input impedance of the RF detector and Zo is the output impedance of the RF generator. Resistances Ra, Rb, and Rc are precision resistors of a value equal to the specified bridge impedance (usually 50 or 75 ohms). When the impedance of the device under test, Zx, is exactly equal to the bridge impedance, the voltage across the RF detector is zero. This occurs because equal voltages are present across Ra, Rb, Rc, and Zx.

When the impedance of the device under test is either higher or lower than the bridge impedance, a voltage is applied to the RF detector that is proportional to the impedance ratio of Zx to Zbridge. Since

$$SWR = \frac{Z_x}{Z_{bridge}} \text{ or } \frac{Z_{bridge}}{Z_x}$$

(whichever is greater), the detected RF output is proportional to the SWR of the device under test.

SWR is related to other transmission line measurements such as reflection coefficient, return loss in dB, etc., as shown in the Microwave Measurement Chart, Table 4-1.

The DC output voltage from the RF detector may be applied to a suitable test instrument such as an oscilloscope or network analyzer. If a sweep generator is used for the RF source, the oscilloscope displays the SWR of the device under test as a function of frequency.

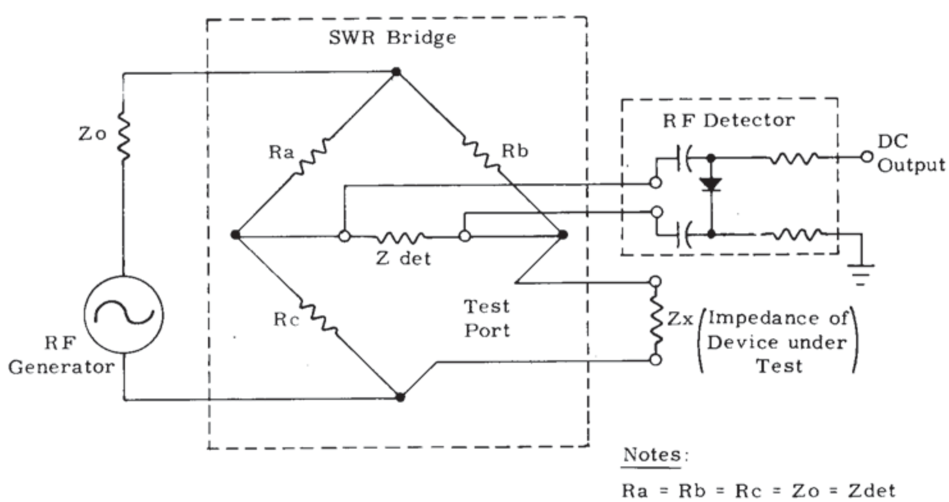



Figure 5-1. SWR Bridge, Simplified Schematic Diagram

# SECTION VI

# PERFORMANCE CHECKS AND MAINTENANCE

## 6-1. INTRODUCTION

This section contains information needed for checking the performance of SWR Autotesters and bridges. The overall performance of these two instruments can be evaluated by measuring directivity and, on the SWR Autotester, checking waveform fidelity at the detector output port. If the directivity is within specification and if the instrument exhibits the correct waveform patterns when the Open/Short Reference-Reflection Averaging Technique (paragraph 3-5) is performed, the instrument is functioning properly.

## 6-2. DIRECTIVITY MEASUREMENTS

The techniques used to measure directivity are variations of the techniques used to measure return loss described in Section II. And, like those techniques, the techniques used to measure directivity are frequency-limited. Above approximately 2 GHz, the air line technique is used; below 2 GHz, a direct method is employed. The cross-over frequency of 2 GHz has been selected to provide a means of categorizing the two measurement methods. Actually, between 1 GHz and 2 GHz either technique may be used satisfactorily.

Measurement methods using the air line are low-frequency limited primarily because of the air line characteristics. For example, below 2 GHz:

the RF wavelength becomes long with respect to the air line length, and the peaks and troughs of the ripple are spaced too far apart to permit effective averaging (ripple frequency too low).

any bow or sag in either the center or outer conductor looks like a lumped-impedance change and causes an impedance mismatch. A bow or sag above 2 GHz also creates an impedance change, but at the higher frequencies, the change acts like an impedance transformer. The effective impedance change is tapered, rather than lumped.

The two methods of measuring directivity are discussed in the following paragraphs. The test equipment and microwave components recommended for use in making these measurements are listed in Tables 6-1 thru 6-4 (opposite page).

### 6-2.1 Measuring Directivity Above 2 GHz

Figure 6-1 shows a test setup and Table 6-5 presents a procedure for measuring the directivity of an SWR Bridge above 2 GHz. The test setup is similar to the ripple-averaging setup in Figure 2-4, except for the following differences:

a. The beadless end of the air line is connected to the test port of the bridge instead of to the device under test. This is because the bridge itself is the object of measurement.

b. A 20 dB offset termination replaces the device under test on the end of the air line opposite the bridge. Using a 20 dB offset provides a reflected signal with a known return loss value.

The procedure in Table 6-5 uses the ripple-averaging technique (paragraph 2-4.2) to measure bridge directivity. The difference between the directivity measurement and a standard ripple-averaging measurement lies in ripple pattern interpretation. In ripple-averaging measurements, the average of the waveform is extracted to provide measurement data. In directivity measurements, however, the average value of the ripple pattern is the value of the offset: approximately 20 dB. What has to be measured is the peak-to-peak value of the ripple itself. When the Microwave Measurement Chart (Table 4-1) is used, the peak-to-peak value of the ripple can be used to find the bridge directivity figure. This is accomplished in the same manner as was described for the magnified reflection technique in paragraph 2-5.4

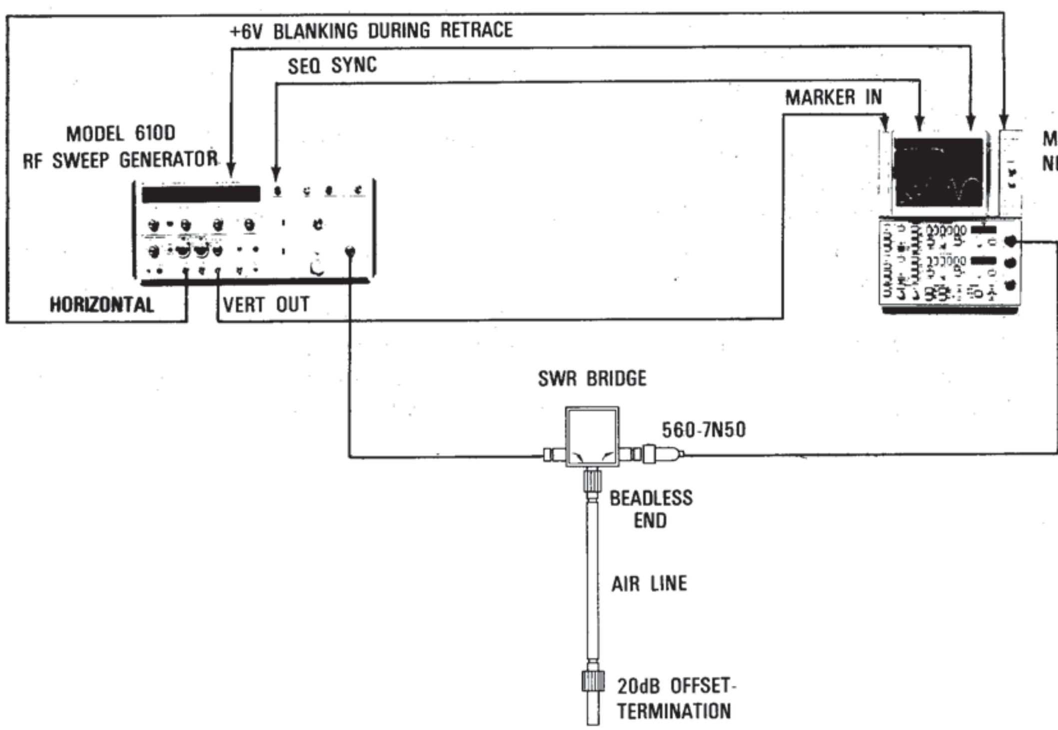



Figure 6-1. Test Setup for Measuring Directivity Above 2 GHz (Air Line Method)

Table 6-5. Air Line Method of Measuring Directivity

1. Connect equipment as shown in Figure 6-1, but do not connect the offset to the beaded end of the air line.

2. Set front panel controls:

   Model 610D Mainframe:

   VAR FREQ MARKER: INTENSITY
   AMPLITUDE: Fully CCW
   SWEEP MODE: LINE SYNC
   SWEEP TIME (SEC): 1 - .1
   SWEEP TIME VERNIER: CAL
   FREQ SELECTOR: F1 TO F2
   RETRACE RF: OFF
   F1: Low frequency of interest
   F2: High frequency of interest
   VAR FREQ MKR: Midrange
   LEVELING: INT
   POWER: ON

   RF Plug-In:

   RF: ON
   RF POWER LEVEL: Fully CW
   FREQ RANGE (same models): Full

   Model 560:

   CHANNEL A: ON
   INPUT: A
   MEMORY: OFF
   dB PER DIVISION: 10
   REFERENCE: Depress to light dB lamp
   CHANNEL B: OFF
   DISPLAY MODE: REFRESH
   SMOOTING: OFF
   POWER: ON

3. Calibrate Channel A and store return loss 0 dB reference data in memory. Proceed as follows:

   a. Connect open to beaded end of air line.

   b. On Model 560, Channel A:

      (1) Adjust OFFSET control for 00.0 dB, as indicated on OFFSET dB display.

      (2) Adjust ZERO dB SET control to center trace on display.

      NOTE

      The horizontal line that is selected to display the 0 dB reference is arbitrary. This line is a point of personal preference. For this procedure, the centerline will be used as the reference point.

      (3) Decrease dB PER DIVISION setting to obtain a maximum vertical deflection.

      (4) On RF Plug-In, adjust SLOPE control to provide a level waveform.

      (5) Depress MEMORY-STORE TRACE pushbutton.

   c. Remove open; connect short in its place.

   d. On Model 560, Channel A MEMORY:

      (1) Depress AVG pushbutton:

      NOTE

      In the following step, do not depress the STORE TRACE pushbutton more than once. If depressed more than once, the correct calibration data will be erased from memory, and erroneous data will be stored in its place.

      (2) Depress STORE TRACE pushbutton once.

Table 6-5. Air Line Method of Measuring Directivity (Continued)

(3) Depress SUBTRACT pushbutton.

e. Remove short.

4. Perform directivity measurement as follows:

a. Connect offset to beaded end of air line.

b. On Model 560:

(1) Adjust Channel A OFFSET control to bring waveform pattern onto display.

(2) Depress the required Channel A dB PER DIVISION pushbutton to provide a ripple pattern with good resolution.

NOTE

Insure that SMOOTHING control is off (OFF indicator is lit).

(3) Observe the displayed waveform and note the point where the peak-to-peak ripple has the greatest amplitude.

(4) Adjust Channel A OFFSET to align the average value of the maximum peak-to-peak ripple on the reference (centerline).

(5) Note the value of the OFFSET dB display; this is the actual value of the offset-termination that is connected to the air line.

(6) Measure the peak-to-peak value of maximum ripple (the point noted in step (3) above). Using the process described in paragraph 2-4.5, convert this value into the SWR bridge's directivity value.

### 6-2.2 Measuring Directivity Below 2 GHz

At frequencies below 2 GHz, directivity is measured using a direct rather than an air line method. Two techniques employing the direct method are presented in this manual. Both techniques require the use of a precision termination that will produce a return loss signal at least 10 dB greater than the signal caused by directivity. The terminations listed in Table 6-4 have a return loss that is typically 50 dB.

The recommended procedure for directly measuring directivity is the low-level measurement procedure discussed in paragraph 2-6. This procedure employs the WILTRON Model 501B Logarithmic Level Meter in a precision measurement of the directivity signal. The Model 501B is recommended for the directivity measurement for the following two reasons: (1) it provides approximately 40 dB of gain to allow the extremely low-level (approximately -40 dBm) signal to be measured at a convenient level of oscilloscope amplification, and (2) it provides a logarithmic input for the oscilloscope. The oscilloscope display that this input provides, when the Model 501B front panel controls are properly set, allows the bridge directivity, in dB, to be read directly from the OFFSET control indicator of the Model 501B.

Figure 6-2 shows a test setup that uses an alternate method for measuring directivity below 2 GHz; the procedure using this test setup is presented in Table 6-6.

This procedure is applicable to both SWR Autotesters and bridges. In this procedure, the vertical amplifier of the oscilloscope is calibrated for an input power level equal to the specified directivity of the SWR Autotester or bridge. The measured directivity of the SWR Autotester or bridge is then compared with that of the reference to determine if directivity is within specification.

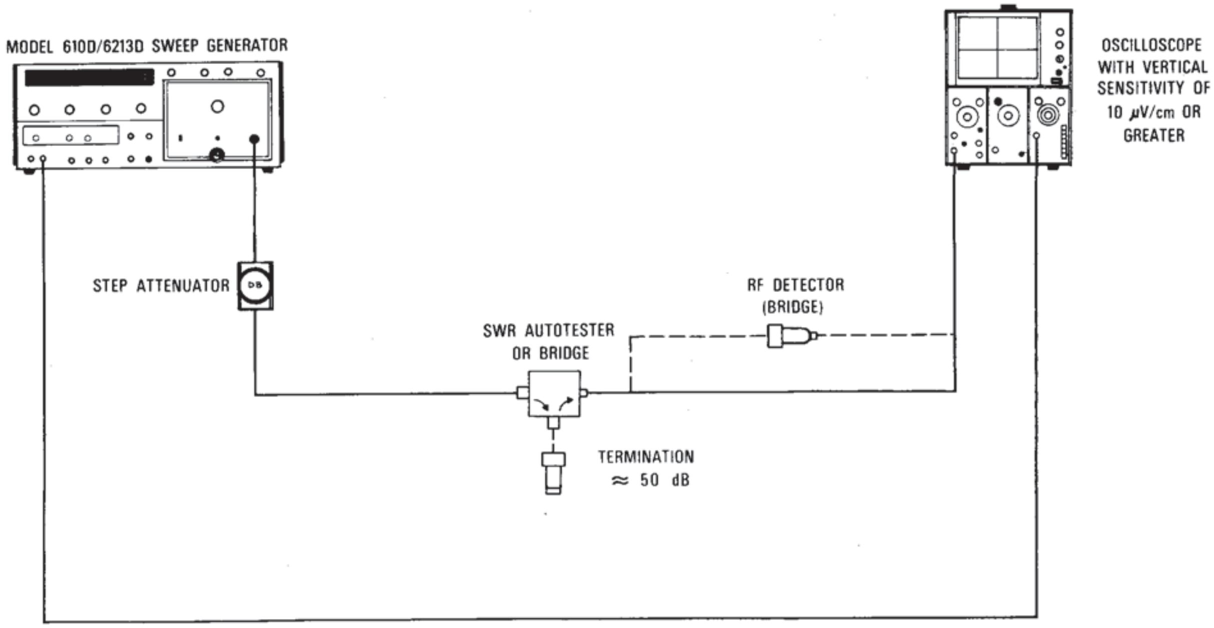



Figure 6-2. Equipment Setup for Direct, Go/No-Go Method

Table 6-6. Direct, Go/No-Go Method of Measuring Directivity

1. Connect equipment as shown in Figure 6-2, but do not connect termination to test port.

2. Position front panel controls:

   Model 610D Mainframe:

   VAR FREQ MARKER: INTENSITY
   AMPLITUDE: Fully CCW
   SWEEP MODE: LINE SYNC
   SWEEP TIME (SEC): .1 - .01
   SWEEP TIME VERNIER: CAL
   FREQ SELECTOR: F1 TO F2
   F1: Low frequency of interest
   F2: High frequency of interest
   VAR FREQ MKR: Midrange
   LEVELING: INT
   POWER: ON

   RF Plug-In:

   FREQUENCY RANGE: 10 MHz to 4.2 GHz
   RF POWER LEVEL: MAX
   RF: ON

   Oscilloscope:

   Vertical Input: DC
   Vertical Input Polarity: Positive (+)
   Vertical Sensitivity: 10μV/division
   Horizontal Input: External (sweep off)
   Horizontal Sensitivity: 1V/division
   Power: On

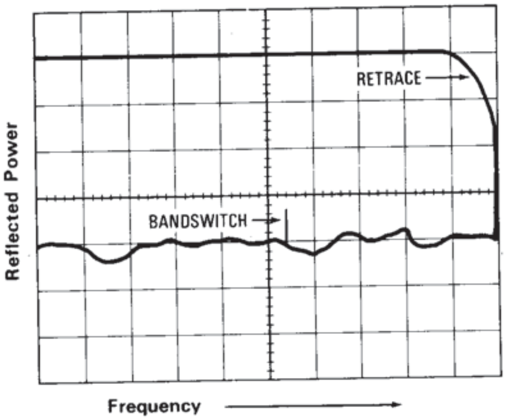
   Step Attenuator:

   0 dB

3. On Step Attenuator, position control to a dB setting equal to the SWR Autotester or bridge directivity specified in specification sheet, i.e., if specified directivity is 42 dB, position attenuation control to 42 dB.

Table 6-6. Direct, Go/No-Go Method of Measuring Directivity (Continued)

4. On oscilloscope, adjust vertical control(s) to position the frequency plot (see below) on a convenient reference line.




5. Connect termination to the test port of the SWR Autotester or bridge.

6. On Step Attenuator, position control to 0 dB.

7. Observe the display on the oscilloscope. If the measured directivity signal is above the reference line, the directivity exceeds the specified value. Conversely, if the measured directivity signal is below the reference line, the directivity measurement is not within specification.

## 6-3. MAINTENANCE

### 6-3.1 Adjustments

It is recommended that no adjustments or maintenance other than cleaning be attempted by the customer. The instrument should be returned to WILTRON for repair and/or service when needed.

### 6-3.2 Cleaning

Connector interfaces--especially the outer conductors on the GPC-7, GR900, and SMA connectors--should be kept clean and free of dirt and other debris. Alcohol is the recommended cleaning agent, and a clean, damp cotton swab is the recommended applicator.

**CAUTION**

On some models of SWR Autotesters and bridges, the test port connector has small plastic rings located on the center conductor. These rings are compensating washers and their position on the center conductor must not be disturbed. Any movement of these washers will degrade the directivity of the instrument.

Table 6-1. Recommended Test Equipment for Directivity Measurements Above 2 GHz

| INSTRUMENT | REQUIRED CHARACTERISTICS | RECOMMENDED MANUFACTURER |
|---|---|---|
| SWEEP GENERATOR | Leveled Output<br>Frequency Range: 2 to 18 GHz | WILTRON Model 610D with Model 6237D RF Plug-In |
| LOGARITHMIC DISPLAY | Vertical Sensitivity: 0.5 dB per division<br>Variable Offset Control | WILTRON Model 560 Scalar Network Analyzer |

Table 6-2. Recommended Microwave Components for Directivity Measurements Above 2 GHz

| TEST PORT CONNECTOR TYPE | AIR LINE | OFFSET |
|---|---|---|
| GPC-7 | 18A50 | 29A50-20 |
| Type N (50Ω) | 18N50 | 29A50-20 |
| SMA | 19S50 | 29S50-20 |

Table 6-3. Recommended Test Equipment for Directivity Measurements Below 2 GHz

| INSTRUMENT | REQUIRED CHARACTERISTICS | RECOMMENDED MANUFACTURER |
|---|---|---|
| SWEEP GENERATOR | Leveled Output<br>Frequency Range: 10 MHz to 4.2 GHz | WILTRON Model 610D with Model 6213D RF Plug-In |
| LOGARITHMIC AMPLIFIER* | 50 dB Gain<br>Calibrated Offset | WILTRON Model 501B Logarithmic Level Meter |
| OSCILLOSCOPE* | Vertical Sensitivity: 10μV/div | Tektronix 5110 with 5A22N Differential Amplifier |
| STEP ATTENUATOR | 0 to 50 dB in 1 dB steps | Weinschel, Model AC-117A-69-43 |

*An Oscilloscope may be used instead of a Logarithmic Amplifier.

Table 6-4. Recommended Microwave Components for Directivity Measurements Below 2 GHz

| TEST PORT CONNECTOR | TERMINATION |
|---|---|
| GPC-7 | 28A50-1 |
| Type N (50Ω) | 26N50 |
| SMA | 28S50-1 or 28SF50-1 |
| GR900 (50Ω) | 26G50 |
| Type N (75Ω) | 26N75 |
| GR900 (75Ω) | 26G75 |
| BNC (75Ω) | 26G75 |