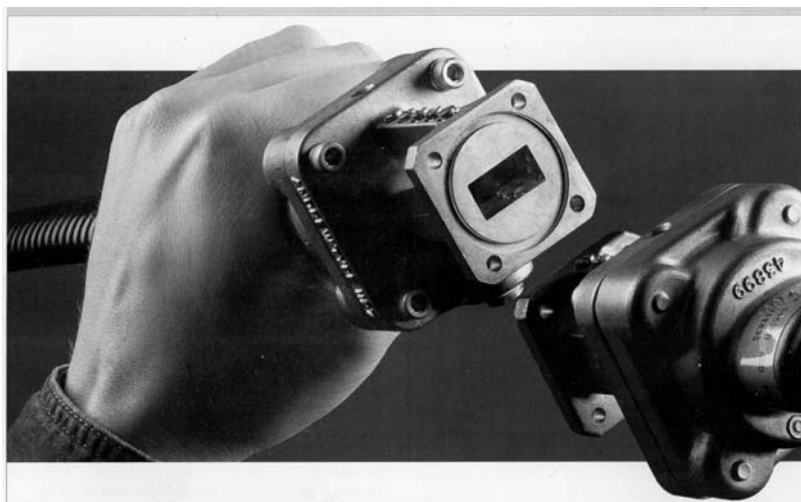


Application Note



Return Loss (VSWR) Measurements in Waveguide Systems



Alternative methods of waveguide return loss (VSWR) measurement using the 6820 series microwave scalar analyzer are discussed and the errors associated with each are analyzed.

Introduction

Antenna feeder systems employing waveguide are commonly used at frequencies above 4 GHz. At lower frequencies the size of the waveguide becomes too large to handle conveniently although it is used for high power applications such as radar. In radar systems, the low trans-

mission loss property of waveguide is essential because high transmitter power is employed.

Modern microwave radio link systems are rarely configured with rigid waveguide because it is relatively difficult and inconvenient to put in place. As a result the most

common waveguide type now in use in these systems is elliptical waveguide which has greater flexibility. Typical system feed runs can be as short as 3 meters at 23 GHz and up to 50 meters or more at 7 GHz. Systems where the radio is mounted directly on the antenna are rarely measured at installation. This would be a production test measurement only.

Like coaxial feeder systems, waveguide feeders are characterized at installation in terms of return loss (VSWR) and insertion loss using a scalar measurement system such as the 6820 series scalar analyzer. During maintenance of operational systems a fault location measurement can be used to reveal faults in the feed line and this application is discussed in Aeroflex publication; "Fault Location on Waveguide Antenna Feeds" (part number 46889/462).

This article describes the available measurement techniques and the measurement errors involved in making return loss (VSWR) measurements on waveguides. The 6820 series scalar analyzer is an ideal tool for performing all of these measurements and examples are used to show the relative merits of each.

Appendix A
Reflection Coefficient Relationships

The fundamental parameter is the scalar reflection coefficient, ρ .
 Note that $\rho = |\Gamma|$, where Γ is the phasor reflection coefficient; i.e. it includes a phase component and is normally written in the form $\rho \angle \theta^\circ$ (where θ° is the phase angle).

The two expressions most commonly used to describe reflection measurements are: Return Loss and VSWR (Voltage Standard Wave Ratio). Mathematically:

$$\text{Return Loss (dB)} = -20 \log_{10} \rho$$

and

$$\text{VSWR} = \frac{1+\rho}{1-\rho}$$

Conversion from return loss to VSWR and vice versa is only possible by first calculating ρ or, as is commonly the case, by use of nomograph.

Choice of Measurement Method

Two scalar measurement methods might be considered for return loss (VSWR) measurements of waveguide feeds:

1. Scalar Network Analyzer with coaxial bridge or auto-tester
2. Scalar Network Analyzer with waveguide directional coupler

Each method requires hardware with specific performance specifications which will be highlighted. The merits of each method will be considered and associated errors discussed.

1. Scalar Analyzer with Coaxial Bridge or Auto-tester

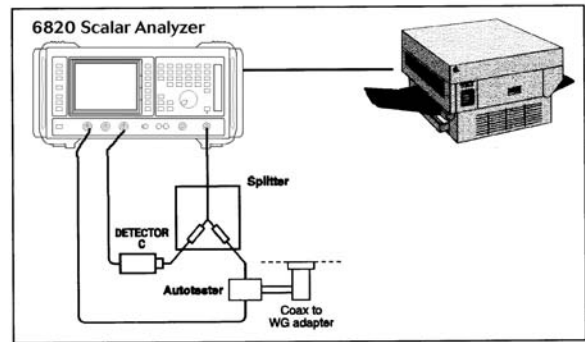


Figure 1: Auto-tester with waveguide adapter.

This method would be the first choice for a coaxial cable but is not ideal for waveguide because the use of any adapter on the test port of the auto-tester will degrade the two key parameters which determine the magnitude of errors in the measurement. These two parameters are directivity and test port match and while each affects the measurement of return loss (VSWR) in a different way, it is predominantly the directivity term which has the greatest effect on devices with inherently good return loss (VSWR).

Usually waveguide feeder systems have very good return loss (VSWR) values and are therefore very susceptible to errors caused by measurement devices with poor directivity. Typical values measured are of the order of 20 dB (1.22:1 VSWR) or better.

In order to use an auto-tester, which is a coaxial device, with a waveguide system it is necessary to use a waveguide to coaxial adapter to interface the coaxial measuring port of the auto-tester to the required waveguide flange. It is the use of this adapter which generates very large errors in the measurement making it inadequate for nearly all waveguide applications. Figure 1 shows the measurement setup described.

Example 1 below shows the error analysis using an auto-tester with adapter.

Appendix B (next page) gives the error analysis equation used for all examples and describes the symbols used for these examples.

Example 1. Measurement of a 23 GHz waveguide system with an actual return loss of 23 dB (VSWR of 1.15:1).

An auto-tester with WSMA connectors is used with a rated directivity of 38 dB at 23 GHz and a test port match of 18.4 dB. The specially tuned coax to waveguide adapter has a return loss of 32 dB.

$$\begin{aligned} \rho_a \text{ (23 dB)} &= 0.071 \\ D_{\text{bridge}} \text{ (38 dB)} &= 0.013 \\ D_{\text{adapter}} \text{ (32 dB)} &= 0.025 \\ \rho_s \text{ (18.4 dB)} &= 0.120 \\ D_{\text{bridge+adapter}} &= 0.038 \\ \rho_m &= 0.071 \pm (0.038 + 0.005 \times 0.12) \\ \rho_m &= 0.071 \pm 0.039 \end{aligned}$$

ρ_m lies between ± 0.11 and 0.032

Converting these to logarithmic terms gives a range of measured values of return loss between 19.2 dB and 29.9 dB for an expected value of 23 dB (error range - 3.8 dB to +6.9 dB).

Appendix B

Error Analysis for Return Loss (VSWR) Measurements.

Error Equation:

$$\rho_m = \rho_a \pm (D + \rho_a^2 \cdot \rho_s)$$

where:

ρ_a is the expected or specified actual value of reflection coefficient.

D is the effective directivity of the measurement device which consists of two elements in these examples: D_{bridge} and D_{adapter} , where $D = \sum (D_b + D_a)$. ρ_s is the effective source match of the auto-tester + adapter combination and ρ_m is the possible range of measured values due to the error terms.

In order to use the error equation the logarithmic values of return loss must be converted to linear terms (reflection coefficient, ρ).

2. Scalar Analyzer with Waveguide Directional Coupler(s)

This is the "industry standard" method of making waveguide return loss (VSWR) measurements. It is well established and, provided the directivity of the waveguide directional coupler is adequate, achieves very good, repeatable results.

Return Loss Measurement

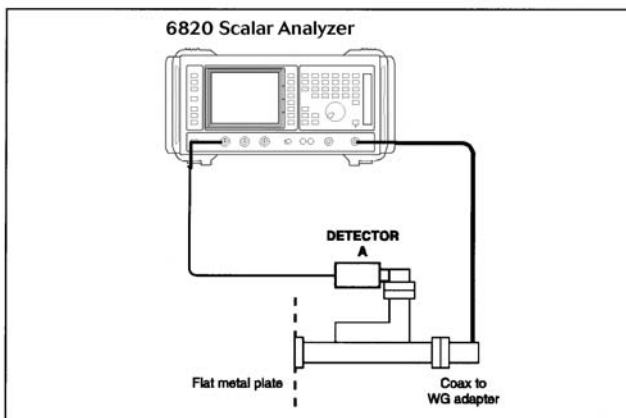


Figure 2: Measurement using a single coupler.

Two configurations of couplers are used, Figures 2 and 3 show these. The benefit of the setup in Figure 2 is simplicity of connection and, provided that a coupler with good directivity (>40 dB) is used, gives accurate results for waveguide systems with specified performance of greater than 20 dB return loss ($<1.2:1$ VSWR). Figure 3 shows a configuration using two directional couplers which is used to provide a better controlled source match. This is

necessary when the expected specification for return loss is <14 dB ($1.5:1$ VSWR) and especially when a long RF cable is used to connect the scalar analyzer source output to the coupler input adapter. The effect is to reduce the large peak to peak ripple which is generated by multiple reflections. A dual-directional coupler can be used instead of the two couplers shown in Figure 3 with the same benefits.

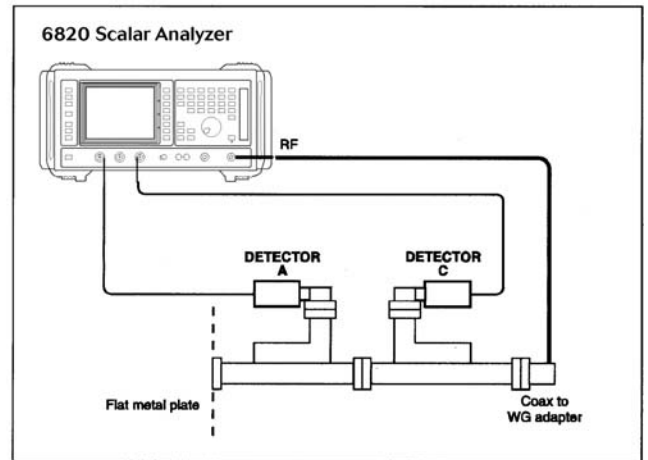


Figure 3: Measurement using twin or dual-couplers

The setups shown in Figures 2 and 3 both require waveguide to coax adapters to allow connection of the scalar analyzer RF output and the 6230A series scalar detectors to the waveguide flanges of the coupler. In each case a 6230A series detector is connected to the coupler measurement port to detect the reflected signal. In Figure 3 the second coupler or second arm of a dual-coupler is used to sample the incident signal from the scalar analyzer RF output to provide a ratio measurement.

Note: In this case the use of a waveguide adapter with the 6230A series scalar detector does not degrade the measurement because connections to the coupled arm do not affect directivity or test port match.

Scalar Analyzer Setup

The following section describes the setup and return loss (VSWR) measurement of a 23 GHz elliptical waveguide feed and antenna using a 6820 series scalar analyzer. The waveguide feed consists of approximately 20 meters of elliptical waveguide with an antenna which operates between 21.2 GHz and 23.6 GHz

Conventions

The following conventions are used within this article to indicate scalar analyzer key presses.

[BOLD] Hardkey press, i.e. a dedicated front panel function key.

[italic] Softkey press, i.e. a software menu key.

- 'toggle function' enabled.
- o 'toggle function' disabled.

Numeric entries are made using either the keypad or the rotary control. Keypad entries must be followed by a terminator key.

From the **[PRESET]** condition all instrument settings are at default

values and the scalar analyzer is operating in scalar mode. (A full listing of default settings is available in the scalar analyzer Operating Manual, Appendix A).

The source is set to sweep over an operating range of 21.2 GHz to 23.6 GHz with an output power of 0 dBm. The key presses are:

[PRESET] *[Default Settings]*

[SOURCE]

[Set Start Frequency] 21.2 **[Gn]**

[Set Stop Frequency] 23.6 **[Gn]**

[SOURCE ON/OFF •]

Figures 2 and 3 require different measurement setups for the scalar analyzer. For Figure 3 a ratio is required and is shown as the ratio of A/C. The key presses are:

[SCALAR] *[Input Selection]* *[A/C]*

Figure 2 only requires a single detector on input A and the key presses are:

[SCALAR] *[Input Selection]* *[A]*

The two alternatives should be followed by:

[Return to Scalar]

and since the measurement is of a system connected to an antenna select:

[SCALAR] *[More]* *[AC Detection]* It is essential that AC detection is used to eliminate the effect of interference from other transmitters on the same site.

All measurements of this type require a calibration process to be performed which characterizes the losses in the couplers, etc. Calibration is performed by placing a short circuit or shorting plate across the open end of the waveguide coupler and selecting the appropriate "short only" calibration on the scalar analyzer. With the short in place the display is normalized to a straight line at 0 dB (∞ VSWR). The short is then removed and the measuring point connected to the waveguide under test.

A variation of the calibration procedure is to perform a "short/open" calibration as is the case with an auto-tester. In the case of waveguide an open circuit waveguide flange provides a relatively good match to free space - typically around 10 dB where coax systems are close to 0 dB.

The key presses required for the above examples are:

[CAL] *[Zero Detectors]* *[Short OR Open]* *[Continue]*

The scalar analyzer will then perform the calibration and display a normalized response at the reference level of 0 dB. The system is now calibrated and the coupler can be connected to the flange of the elliptical waveguide.

The default display of the scalar analyzer is of return loss in dB, but VSWR format can be selected by pressing:

[SCALE/FORMAT] *[VSWR]*

The scale values of the display can be adjusted, for example, to

set 5 dB/division select:

[SCALE/FORMAT] *[Set Scale]* **[5]** **[ENTER/=MKR]**

Markers can be positioned on the measurement trace using the **[MARKERS]** menu. The active marker is placed at the required frequency either using the rotary control or using the marker functions, e.g. maximum or minimum. Additionally marker tracking of the marker max. or min. functions can be used to find the worst case for each sweep.

Limit lines can be used to compare the measured values to a specification limit for the system. This will usually be a single value over the whole of the frequency range being measured and a straight line or flat limit is required. A limit specification table is first produced by entering the table editor via:

[SCALAR] *[Limit checking]* *[Edit specification]* *[Upper Limit Only]* *[Return to Limit Editor]* *[Edit Segments]* *[Flat]*

If the waveguide system in the example above has a specified limit of 21 dB selecting

[Flat] gives the opportunity to specify:

21.2 **[Gn]** ⇒ 21 **[Enter/=MKR]** ⇒ 23.6 **[Gn]**

The edit specification screen is exited by selecting:

[Return to Limit Editor] *[Save As]* *[New Store Name]* *[filename...]* *[Done]* *[Save]* *[Exit]*

The limit line is now switched on by selecting:

[Assign Spec] *[filename...]* *[Select]* *[Limit Checking •]*

This sets a straight line upper limit across the frequency range, the lower limit is disabled and therefore does not appear on the scalar analyzer display since it has no meaning for this particular measurement. Alternatively, a VSWR display requires a limit line at 1.2:1 (21 dB return loss) and can be set by selecting:

21.2 **[Gn]** ⇒ 1.2 **[ENTER/MKR]** ⇒ 23.6 **[Gn]**

in the edit segment menu. When limit checking is applied the limit lines are displayed with the measurement and a PASS or FAIL test indicator is shown.

Limit checking has been applied to the trace of figure 4 and shows that the waveguide feed and antenna meets a 21 dB specification over its operating band of 21.2 GHz to 23.6 GHz.

Hard copies of measurements can be obtained by using the **[PRINT]** menu.

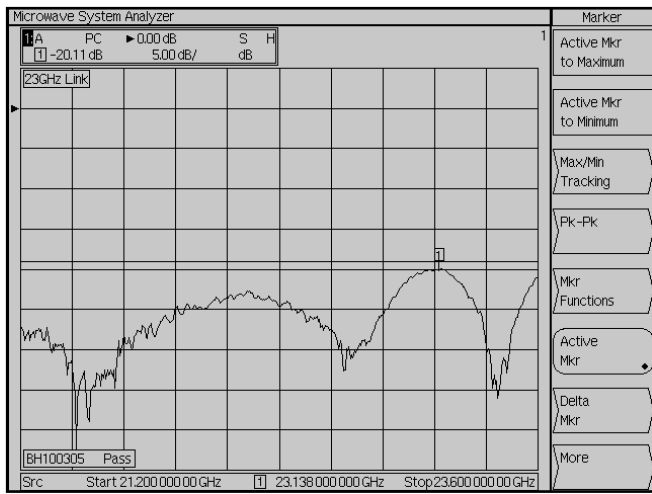


Figure 4: Plot of coupler measurement

Figure 4 shows the measurement of the 23 GHz elliptical waveguide system described above. Data can be output graphically to either a plotter or printer and, by pressing:

[PRINT], *[Print Options]* the instrument setup conditions can be displayed on the plot. The copy menu also allows for selection of alternative printers using the *[Select Printer]* key within the menu.

All of the above scalar analyzer settings can be stored for future use in a settings store which is selected from within the **[SAVE/RECALL]** menu by pressing:

[SAVE/RECALL] *[Save Settings]* *[New Store Name]* *[filename..]*
[Done] *[Save]*

Additionally, by pressing *[Save Settings as User Default]* the settings can be accessed directly after pressing **[PRESET]** and selecting *[User]*.

Example 2 below shows the error analysis of a waveguide coupler measurement.

Example 2. Measurement of a 23 GHz waveguide system with an expected value of return loss of 23 dB using a single waveguide directional coupler with a rated directivity of 40 dB and an effective source match of 19 dB.

Conversion to linear terms:

$$\rho_a (23\text{dB}) = 0.071$$

$$D_{\text{coupler}} (40 \text{ dB}) = 0.01$$

$$\rho_s (19\text{dB}) = 0.11$$

$$\rho_m = 0.071 \pm (0.01 + 0.005 \times 0.11)$$

$$\rho_m = 0.071 \pm (0.0106)$$

ρ_m lies between 0.082 and 0.060

Converting these to logarithmic terms gives a range of measured values of return loss between 21.8 dB and 24.4 dB for an expected value of 23 dB (error range +1.4 dB, - 1.2 dB).

Summary

Analysis of the errors shows that, for most waveguide measurements, only one of the two methods presented is viable for accurate measurement of return loss (VSWR).

Since many of these measurements are made in the field, a portable measurement tool such as the IFR 6820 series scalar analyzer with its large range of accessories can provide a fast, accurate system to gather the required data.

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