APPLICATION NOTE
ANV004

VSWR MEASUREMENT

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Introduction:

VSWR stands for voltage standing wave ratio. The ratio of the reflected power to the incident power of standing waves created due to impedance mismatch between RF source and load.

These standing waves are unwanted as the transmitted energy gets reflected, and travels back to the source it may damage the RF signal source.

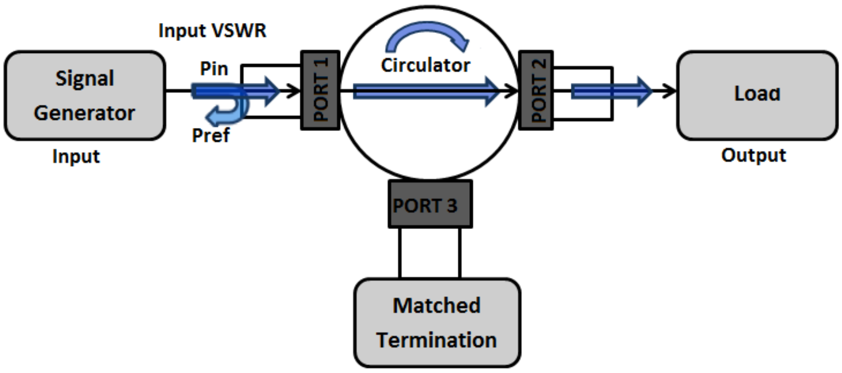

Figure 1: VSWR Measurement

Reflection Coefficient:

Reflections occur as a result of discontinuities, such as imperfections in uniform transmission line, or when a transmission line is terminated with other than its characteristic impedance. The reflection coefficient Γ is defined as a complex number that describes both the magnitude and the phase shift of the reflection.

The simplest cases, of reflection coefficient values are:

- $\Gamma = -1$: maximum negative reflection, when the line is short-circuited
- $\Gamma = 0$: no reflection, when the line is perfectly matched
- $\Gamma = +1$: maximum positive reflection, when the line is open-circuited

The reflective property of a port is characterized by the reflection coefficient magnitude $|\Gamma|$.

$$|\Gamma| = \sqrt{Pref/Pin} = V-/V+ \qquad \text{(Eq. 1)}$$

Where
P_{ref} : reflected power [W]
P_{in} : incident power [W]
$V-$: reflected wave [V]
$V+$: incident wave. [V]

The resulting VSWR is given by:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad \text{(Eq. 2)}$$

The effective input VSWR of an Isolator will vary as a function of the load VSWR. If the output load mismatch is increased, more energy is reflected towards the termination port. After attenuated by the isolation it is then reflected back to the input. Due to which there is increase in total VSWR observed at the input. Therefore, a low VSWR specification is always desirable.

- Poor VSWR: A large fraction of the incident signal is reflectss back towards the source of transmission. This type of VSWR occurs at an open or short circuit in a system, where the impedance match is the worst.

- Better VSWR: Only a fraction of the incident signal reflects back towards the source of transmission. This type of VSWR occurs in a system, where the impedance match is sufficiently well. The relatively higher power efficiency is obtained.

VSWR is expressed in ratio form relative to *1* (example *1.25:1*). Following are two special cases of VSWR:

- VSWR of ∞:*1* is obtained when the load is an open circuit
- VSWR of *1:1* is obtained when the load is perfectly matched to source impedance

VSWR Measurement Principles:

As shown in *Figure 2* the reflection properties of Circulator can be described by S-parameters. An RF vector network analyzer (VNA) can be used to measure the reflection coefficients of the input port (S_{11}) and the output port (S_{22}).

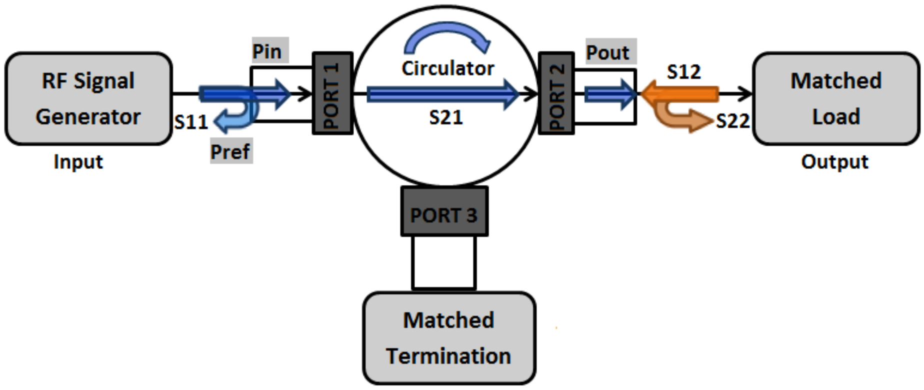

Figure 2: VSWR Measurement Principle

The return loss at the input and output ports can be calculated from the respective reflection coefficients as follows:

Input return loss (RL_{IN}) is a scalar measure of how close the actual input impedance of the network is to the nominal system impedance value and, expressed in logarithmic magnitude, is given by:

$$\text{Input port return loss } (RL_{IN}) = 20\log_{10}|S_{11}| \quad [dB] \qquad (Eq.\ 3)$$

Where,
S_{11} : input port voltage reflection coefficient.

Output return loss (RL_{OUT}) is a scalar measure of how close the actual output impedance of the network is to the nominal system impedance value and, expressed in logarithmic magnitude, is given by:

$$\text{Output port return loss } (RL_{OUT}) = 20\log_{10}|S_{22}| \quad [dB] \qquad (Eq.\ 4)$$

Where,
S_{22} : output port voltage reflection coefficient.

The reflection coefficient can also be expressed in terms of the characteristic impedance of the inner conductor and the matched load impedance as follows:

$$\Gamma = (Z_L - Z_O)/(Z_L + Z_O) \qquad (Eq.\ 5)$$

Where
Z_L is the matched load impedance.
Z_O is the characteristic impedance of the inner conductor.

Substituting *(Eq.5)* into *(Eq.2)*, to obtain VSWR in terms of Z_L and Z_O:

$$VSWR = \frac{\left[1 + \left|\frac{ZL - ZO}{ZL + ZO}\right|\right]}{\left[1 - \left|\frac{ZL - ZO}{ZL + ZO}\right|\right]}$$

$$VSWR = \frac{[ZL + ZO + |ZL - ZO|]}{[ZL + ZO - |ZL - ZO|]} \qquad (Eq.6)$$

Solving *(Eq.6)* for,

Case 1: if $Z_L > Z_O$ then $|Z_L - Z_O| = Z_L - Z_O$

$$\therefore VSWR = \frac{[ZL + ZO + ZL - ZO]}{[ZL + ZO - ZL + ZO]}$$

$$\therefore VSWR = \frac{ZL}{ZO} \qquad (Eq.7)$$

Case 2: if $Z_L < Z_O$ then $|Z_L - Z_O| = Z_O - Z_L$

$$\therefore VSWR = \frac{[ZL + ZO + ZO - ZL]}{[ZL + ZO - ZO + ZL]}$$

$$\therefore VSWR = \frac{ZO}{ZL} \qquad (Eq.8)$$

The proper calibration is the fundamental prerequisite of the accurate *VSWR* measurement. For a given frequency band once these S-parameters in are known, it is possible to perform the *VSWR* measurement of an unknown load.

Reflected Power from Specified VSWR:

From the datasheet specified VSWR values the actual amount of reflected power can be calculated. This helps to determine the reflectivity behavior for different incident power levels.

For example, consider Valvo's Isolator *VFA 852* which has *VSWR = 1.40:1* & P_{in} (CW) = *20 W* (at *f= 48 MHz*). Now, we will determine the amount of power that reflects off in the Isolator *VFA 852*.

VSWR is given by: $VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$

Rearranging the above equation to get reflection coefficient,

$$\therefore\ \Gamma = \frac{VSWR - 1}{VSWR + 1}$$

$$\therefore\ \Gamma = \frac{1.40 - 1}{1.40 + 1}$$

$$\text{Reflection Coefficient: } \Gamma = 0.166 \qquad (Eq.9)$$

Calculating the equivalent return loss,

$$\text{Port return loss } (R.L.) = 20log_{10}|\ \Gamma\ |$$

$$\therefore\ R.L. = 20log_{10}|\ 0.166\ |$$

$$\therefore\ \text{Port return loss } (R.L.) = -15.59 \quad [dB] \quad (Eq.10)$$

(Note: A negative sign indicates that power loss)

As we know that this return loss is the ratio of reflected power to the incident power of the port. Hence it can be expressed as:

$$Port\ return\ loss\ (R.L.) = 10log10\left[\frac{Pref}{Pin}\right] \quad [dB] \quad (Eq.11)$$

Substituting (*Eq.10*) into (*Eq.11*),

$$\therefore\ -15.59 = 10log10\left[\frac{Pref}{Pin}\right]$$

$$\therefore\ \left[\frac{Pref}{Pin}\right] = 10^{\frac{-15.59}{10}}$$

$$\therefore\ Pref = (10^{\frac{-15.59}{10}}) * (Pin)$$

$$\therefore\ Pref = (10^{\frac{-15.59}{10}}) * (20)\ \ (from\ datasheet\ \ Pin = 20\ W)$$

$$\therefore\ Pref = (0.027) * (20)$$

$$\therefore\ Pref = 0.54\ [W] \qquad (Eq.12)$$

Now we know, *0.54 Watts* of power is reflected from the Isolator *VFA 852* when it is used in *20 Watts* input power application. Similarly, one can calculate the reflected power in any Circulator / Isolator depending on input power ratings of the application.

The dependency of *VSWR* and Γ as a function of the percentage reflected power P_{ref} [%] is shown in *Figure 3* below:

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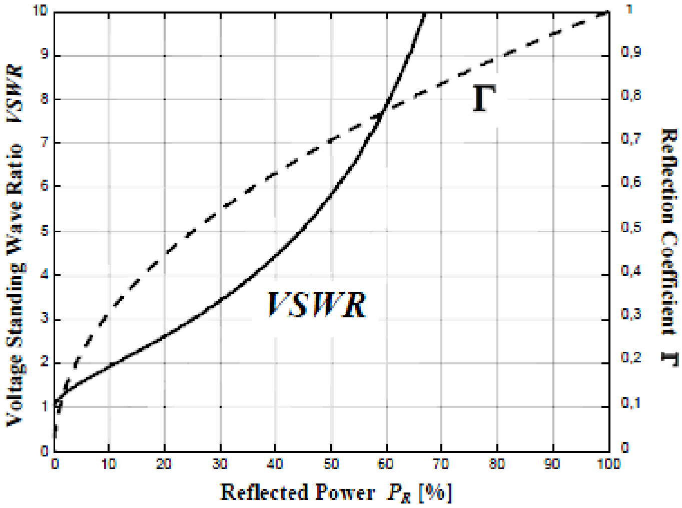

Figure 3: VSWR v/s Reflected Power

Power Rating v/s VSWR:

The VSWR value on terminated Circulator port represents the absolute maximum amount of reflected power (P_{ref}) that will reflect off from the port when a *50 Ω* load is connected on it. In order to dissipate this reflected power safely, Circulator termination power ratings must be equal to or higher than VSWR value for a given bandwidth.

VSWR Extreme Values:

The input reflection of the ports of a Circulator is often measured by directional couplers. For low level measurements network analyzers, bridges and slotted lines can be used too. On the ports not being measured we put matched loads, and the port being measured is connected to the directional coupler, bridge, slotted line or network analyzer. If the loads used have an input VSWR lower than *1.1* we can neglect their influence on the measurement of the input reflection.

When using a directional coupler or bridge the main source of failures in this measurement is the directivity D_C of the directional coupler or bridge measured in *dB*. The signal resulting from the directivity combines with the signal returning from the Circulator and measured VSWR lies between a maximum value $VSWR_{Max}$ when both signals add and a minimum value $VSWR_{Min}$ when the signals subtract one from the other. We can calculate these limits in the following way.

The directivity of directional coupler D_C is converted into equivalent VSWR value $VSWR_C$.

$$VSWR_C = \frac{1+\frac{1}{10^{\left[\frac{Dc}{20}\right]}}}{1-\frac{1}{10^{\left[\frac{Dc}{20}\right]}}} \qquad (Eq.13)$$

To calculate the minimum and maximum values we combine the equivalent VSWR of directional coupler $VSWR_C$ with VSWR of the Circulator $VSWR_{Circulator}$.

The maximum value of VSWR can be calculated as:

$$VSWR_{Max} = VSWR_{Circulator} * VSWR_{load} \qquad (Eq.\ 14)$$

The minimum value of VSWR can be calculated as:

Case 1: If $VSWR_C / VSWR_{Circulator} \geq 1$

$$VSWR_{Min} = VSWR_C / VSWR_{Circulator} \qquad (Eq.\ 15)$$

Case 2: If $VSWR_C / VSWR_{Circulator} < 1$

$$VSWR_{Min} = VSWR_C / VSWR_{Circulator} \qquad (Eq.16)$$

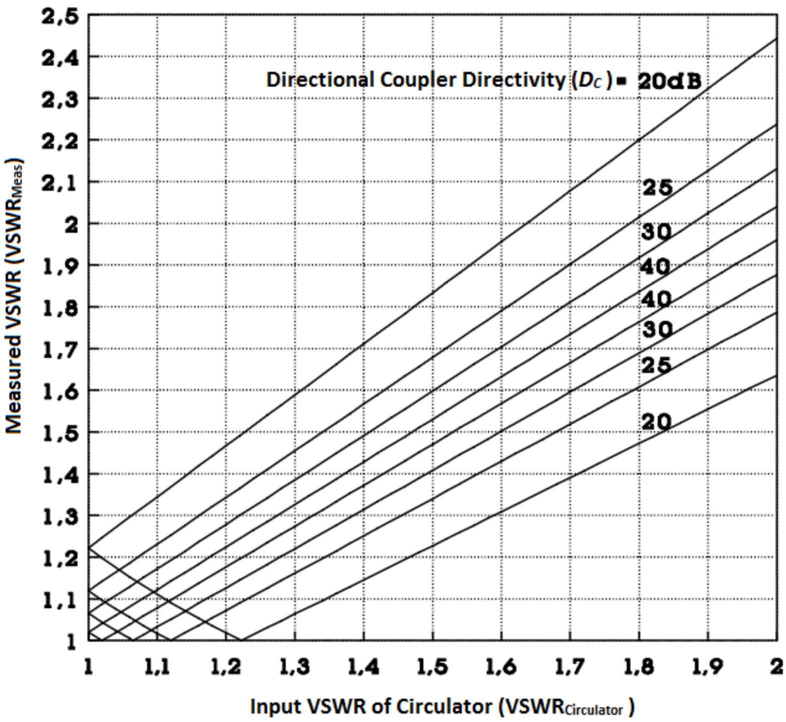

Figure 4: Measured VSWR v/s Circulator VSWR

From the *Figure 4* we can see, that a circulator with an actual input VSWR of *1.25* will have extreme values between $VSWR_{Min} = 1.22$ and $VSWR_{Max} = 1.28$ if measured with a directional coupler or bridge having a directivity of *40 dB*.

These VSWR extreme values are with pure input signal. In presence of harmonics of the input signal, which happens very often when measuring with power, comparatively large deviations in VSWR values are obtained. A normal Circulator represents a more or less good match in its operating band, but reflects nearly all harmonics or other spurious frequencies far outside the operating band. Therefore these harmonic frequencies have to be removed by suitable filters.

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VSWR Conversion Chart:

VSWR	Voltage Reflection Coefficient (Γ)	Return Loss (dB)
1.065	0.032	-30
1.074	0.035	-29
1.083	0.040	-28
1.094	0.045	-27
1.105	0.050	-26
1.119	0.056	-25
1.135	0.063	-24
1.152	0.071	-23
1.173	0.079	-22
1.196	0.089	-21
1.222	0.100	-20
1.253	0.112	-19
1.288	0.126	-18
1.329	0.141	-17
1.377	0.158	-16
1.433	0.178	-15
1.499	0.200	-14
1.577	0.224	-13
1.671	0.251	-12
1.785	0.282	-11
1.925	0.316	-10
2.100	0.355	-9
2.323	0.398	-8
2.615	0.447	-7
3.010	0.501	-6
3.570	0.562	-5
4.419	0.631	-4
5.848	0.708	-3
8.724	0.794	-2
17.391	0.891	-1

Table 1: VSWR Conversion Chart

ABOUT VALVO

Valvo Bauelemente GmbH is a Germany based company specializing in design and developments of standard as well as special RF and microwave ferrite components. Valvo Bauelemente GmbH has more than 30 years of experience in providing well-rounded expertise solutions, technologies and design techniques.

The core of the company is a highly experienced team of respected technologists with developments of performance specific, high reliability complex products. The company has delivered excellent performance in several International R&D projects.

All products are controlled to the highest standards for guaranteed delivery and customer satisfaction.

PRODUCTS

Valvo Bauelemente GmbH is focused on 50 MHz to 18 GHz Circulators, Isolators, Waveguides, and microwave ferrite devices. We offer narrow and broad band devices in coaxial, waveguide, drop-in constructions which are ideally suited for integration into compact systems.

Our highly skilled staff has a strong working knowledge and experience on a variety of ferrite devices with over 2,000 existing designs. This makes us possible to offer custom product solutions in addition to wide range standard product solutions.

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