App-Note: 007 - VSWR Conversion to Reflected Power

VSWR:

- **VSWR** represents the ratio of the maximum to minimum voltage on a **loss-less transmission line**.
- It's often expressed as a ratio (e.g., 3.0:1, 2.0:1).
- In dB terms, VSWR is equivalent to **return loss**.

Return Loss:

- **Return loss** quantifies how much of the signal is reflected back in a transmission line.
- It's measured in **decibels (dB)**.
- Higher return loss indicates better impedance matching.

Reflection Coefficient (Γ):

- The reflection coefficient, denoted by **Γ**, is related to VSWR and return loss.
- It's a complex quantity that characterizes the reflection of electromagnetic waves at an interface.
- The magnitude of Γ is directly related to VSWR and return loss.

Mismatch Loss:

- Mismatch loss occurs due to impedance mismatches in connectors or transmission lines.
- It's the power lost due to reflections.
- Lower VSWR results in reduced mismatch loss.

Reflected Power (%):

- Reflected power is the portion of the incident power that gets reflected back.
- It's expressed as a percentage.
- Lower VSWR corresponds to less reflected power.

Thru Power (%):

- Thru-power is the portion of the incident power that is delivered to the load.
- It's also expressed as a percentage.

Formulas:

$$r = \frac{VSWR - 1}{VSWR + 1}$$

$$r = 10^{\frac{-RL}{20}}$$

$$RL = -20\text{Log}_{10}(r) \quad \text{Where } r = \frac{VSWR-1}{VSWR+1}$$

$$VSWR = \frac{1+r}{1-r} \quad \text{Where} \quad r = 10^{\frac{-RL}{20}}$$

$$ML = -10\text{Log}_{10}(1-r^2) \quad \text{Where } r = \frac{VSWR-1}{VSWR+1}$$

$$ML = -10\text{Log}_{10}(1-r^2) \quad \text{Where} \quad r = 10^{\frac{-RL}{20}}$$

What is VSWR?

VSWR (Voltage Standing Wave Ratio) is the measure of how efficiently RF power is transmitted into a load. For example, if a power amplifier is connected to an antenna through a transmission line - ideally there will be no reflections and all the signal from the power amplifier will be transmitted to the antenna. However, in the real world, there will be some mismatches which will cause some of the signal to get reflected into the transmission line. VSWR is the measure of how much signal get reflected into the system. It is the ratio between transmitted and reflected waves. A high VSWR indicates poor transmission-line efficiency and reflected energy.

What is return loss (RL)?

Return Loss is the ratio of FWD Power to RFL Power in dB. The Higher the Return Loss the more power is absorbed into load with less Reflected Power.

For Example, 100 Watts of Forward Power and 11 Watts Reflected Power is a 9.5 dB Return Loss.
100 Watt of Forward Power and 1 Watt of Reflected Power is a 29 dB Return Loss.

What is reflection coefficient (Γ)?

Reflection Coefficient indicates how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium. It is a ratio of the amplitude of the reflected wave to the wave incident at the junction. The reflection coefficient is denoted by the symbol gamma. The magnitude of the reflection coefficient does not depend on the length of the line, only the load impedance and the impedance of the transmission line.

What is mismatch loss (ML)?

Impedance mismatch/discontinuity between the transmission line/cable to the connected load/component leads to a small amount of incident signal power reflected back to the source. In transmission line theory, the mismatch loss (ML) is the ratio of incident power (Pi) to the difference between incident and reflected power (Pr). High mismatch loss means high reflected power, so high mismatch loss is not good for a system. The mismatch loss is expressed in dB as follows.

$$ML_{\text{dB}} = 10\log_{10}\left(\frac{P_i}{P_i - P_r}\right)$$

For an ideal system, there is no impedance mismatch between the transmission line & load, hence no reflection, so no reflected power. The mismatch loss is zero. So, all the incident power is delivered to the load. But, for a practical system, there will always be a small impedance mismatch; significant reflection will be there, so the significant reflected power will be there. For a practical system, the mismatch loss is higher than the ideal system.

How Much Do You Really Need?

RF power amplifiers are often the least understood and poorly treated asset in a laboratory. Systems are sometimes underpowered creating situations where the amplifiers need to be driven harder into the varying VSWR load conditions. The tables on page three (3) illustrate delivered power due to the changing effects of VSWR. From antennas, to cables, to bulkhead connections, waveguide and your equipment under test, these all contribute to understanding the power needed for the test applications.

Although most amplifiers can withstand less than perfect environments, proper planning for your applications will enable smooth testing when your tests become more demanding due to VSWR.

VSWR, Reflection Coefficient and Delivered Power Mis-Match Table Examples

Table 1 Examples - shows delivered power at 10W due to VSWR.

Table-1, 10W forward/Reflected Power examples with VSWR				
VSWR	**% of reflected power**	**Forward Power in Watts**	**Delivered Power**	**Reflected Power in Watts**
1.0	0.0	10.0	10.0	0.0
1.5	4.0	10.0	9.6	0.4
2.0	11.1	10.0	8.9	1.1
3.0	25.0	10.0	7.5	2.5
4.0	36.0	10.0	6.4	3.6
5.0	44.0	10.0	5.6	4.4
6.0	51.0	10.0	4.9	5.1
7.0	56.3	10.0	4.4	5.6
8.0	60.5	10.0	4.0	6.0
9.0	64.0	10.0	3.6	6.4
10.0	66.9	10.0	3.3	6.7

Table 2 Examples - shows delivered power at 100W due to VSWR.

Table-2, 100W forward/Reflected Power examples with VSWR				
VSWR	**% of reflected power**	**Forward Power in Watts**	**Delivered Power**	**Reflected Power in Watts**
1.0	0.0	100	100	0
1.5	4.0	100	96	4
2.0	11.1	100	89	11
3.0	25.0	100	75	25
4.0	36.0	100	64	36
5.0	44.0	100	56	44
6.0	51.0	100	49	51
7.0	56.3	100	44	56
8.0	60.5	100	40	60
9.0	64.0	100	36	64
10.0	66.9	100	33	67

Table 3 Examples - shows delivered power at 250W due to VSWR.

Table-3, 250W forward/Reflected Power examples with VSWR				
VSWR	**% of reflected power**	**Forward Power in Watts**	**Delivered Power**	**Reflected Power in Watts**
1.0	0.0	250	250	0
1.5	4.0	250	240	10
2.0	11.1	250	222	28
3.0	25.0	250	188	62
4.0	36.0	250	160	90
5.0	44.0	250	140	110
6.0	51.0	250	123	127
7.0	56.3	250	109	141
8.0	60.5	250	99	151
9.0	64.0	250	90	160
10.0	66.9	250	83	167

Table 4 Examples - shows delivered power at 1000W due to VSWR.

Table-4, 1000W forward/Reflected Power examples with VSWR				
VSWR	**% of reflected power**	**Forward Power in Watts**	**Delivered Power**	**Reflected Power in Watts**
1.0	0.0	1000	1000	0
1.5	4.0	1000	960	40
2.0	11.1	1000	890	110
3.0	25.0	1000	750	250
4.0	36.0	1000	640	360
5.0	44.0	1000	560	440
6.0	51.0	1000	490	510
7.0	56.3	1000	440	560
8.0	60.5	1000	400	600
9.0	64.0	1000	360	640
10.0	66.9	1000	330	670