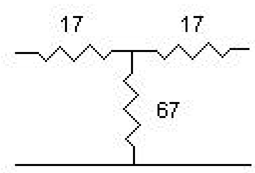
VSWR, or Voltage Standing Wave Ratio.

When a transmission line (cable) is terminated by an impedance that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected back down the transmission line. The forward (or incident) signal mixes with the reverse (or reflected) signal to cause a voltage standing wave pattern on the transmission line. The ratio of the maximum to minimum voltage is known as VSWR, or Voltage Standing Wave Ratio.

A VSWR of 1:1 means that there is no power being reflected back to the source. This is an ideal situation that rarely, if ever, is seen. In the real world, a VSWR of 1.2:1 (or simply 1.2) is considered excellent in most cases. In an EMC lab where many of the tests are very broadband in nature, a VSWR of 2.0 or higher is not uncommon. At a VSWR of 2.0, approximately 10% of the power is reflected back to the source. Not only does a high VSWR mean that power is being wasted, the reflected power can cause problems such as heating cables or causing amplifiers to fold-back.

There are ways to improve the VSWR of a system. One way is to use impedance matching devices where a change in impedance occurs. Baluns are used extensively in antennas to not only convert from balanced to unbalanced signals but also to match the impedance of the source to the antenna. It is common practice in EMC testing to include attenuators at any point where there is an impedance mismatch. One emissions standard, for instance, specifies using an attenuator at the connector of a biconical antenna since it has a high VSWR at some frequencies. One of the conducted immunity standards suggests using a 6dB pad at the input of the coupling device, which is commonly 150 ohms. Attenuators obviously cause power loss, but they reduce VSWR by providing an apparently better termination to a signal.

For example, lets look at a 6dB attenuator and its affect on circuit impedance. Following is a schematic for a 50 ohm 6dB attenuator:



6dB Attenuator

If a 50 ohm termination is added to the output of this attenuator, the source will see a 50 ohm load. Two extremes for terminating a transmission line are open and short circuits. In a completely open circuit, the impedance would be infinite. Adding this 6dB pad to the output of a signal source, without terminating the output of the attenuator, would cause the source to see an 84 ohm termination (17 ohms in series with 67 ohms). Shorting the output of the attenuator would cause the signal source to see a 30.5 ohm termination. In each case, the VSWR would be approximately 1.65:1. (The math will be covered later).

There are various ways of measuring and/or calculating VSWR. In the old days of open transmission lines, the voltage could be measured along the length of the line until the maximum and minimum values were found (which were ¼ wavelength apart) hence the reference to Voltage Standing Wave Ratio. Thus, VSWR would be calculated by the following formula:

$$\text{VSWR} = \frac{E_{max}}{E_{min}} = \frac{E_i + E_r}{E_i - E_r}$$

Where E_{max} = maximum measured voltage
E_{min} = minimum measured voltage
E_i = incident wave amplitude, volts
E_r = reflected wave amplitude, volts

With the use of coax cables, measuring voltage along the cable is impractical. Dual-directional couplers can be used to measure the forward and reverse power, and these values can then be used to compute VSWR.

$$\text{VSWR} = \frac{1+\sqrt{\frac{P_{rev}}{P_{fwd}}}}{1-\sqrt{\frac{P_{rev}}{P_{fwd}}}}$$

Where P_{rev} = reverse power
P_{fwd} = forward power

VSWR can also be represented other ways, such as Return Loss, Mismatch Loss and Reflection Coefficient. Reflection Coefficient is common, can be calculated several ways, and ultimately used to calculate VSWR. Here are some formulae for determining Reflection Coefficient (Ψ):

$$\rho = \frac{E_r}{E_i}$$ Where Er = reflected voltage, Ei = incident voltage

$$\rho = \left|\frac{Z_1 - Z_2}{Z_1 + Z_2}\right|$$ Where Z1 and Z2 are the mismatched impedances in ohms

$$\rho = \sqrt{\frac{P_{ref}}{P_{fwd}}}$$ Where P_{ref} = reverse power, P_{fwd} = forward power

Once the reflection coefficient has been calculated, it can be used to determine VSWR by the following formula:

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

Another way to describe the affect of VSWR is Return Loss. Return Loss is the measure in dB of the ratio of forward and reverse power. If the return loss is 10dB, then 1/10 of the forward power is reflected back. Return Loss can be calculated by the following formulae:

$$\text{Ret Loss} = 10\log\left[\frac{P_{fwd}}{P_{rev}}\right] = -20\log\left[\frac{E_r}{E_i}\right] = -20\log\left[\frac{\text{VSWR} - 1}{\text{VSWR} + 1}\right] = -20\log\rho$$

Yet another way to reference reflected power is Mismatch Loss (or Transmission Loss). This is a dB ratio between the incident power and the power actually absorbed by the termination. Following are formulae for computing Mismatch Loss:

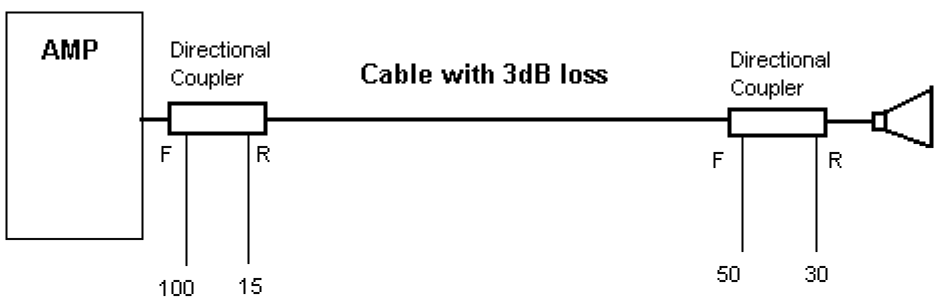
$$\text{Mismatch Loss} = -10\log(1-\rho^2) = 10\log\left(\frac{P_{fwd}}{P_{fwd} - P_{rev}}\right)$$

For instance, if 100 watts forward power is delivered into a load and 15 watts is reflected, 85 watts is absorbed by the load. This gives a reflection coefficient of 0.387, a VSWR of 2.26, a return loss of 8.2dB and a mismatch loss of 0.7 dB. In other words, the power actually absorbed (or not reflected) by the termination is 0.7 dB less than the forward power delivered to the termination. Keep in mind that the terminating device may have its own internal losses and therefore may not utilize all of the absorbed power in the intended fashion. Such is the case with an antenna that may have some losses associated with its balun.

Where to Measure

It is important to know that for accurate VSWR measurements of devices, the VSWR should be measured at the input of the device in question (antenna, CDN, etc). Any cable loss, or attenuation, will make the VSWR at the input of the cable appear much better than at the load or termination. The reason is that the cable loss or attenuation increases the return loss.

For example, (see diagram below) let's say that there is 3 dB of attenuation along the length of a cable. If we send 100 watts forward power into the cable, only 50 watts makes it to the termination. Let's say that the termination reflects 30 watts back. When the reflected signal makes it back to the amp, the same 3dB of cable loss will reduce the reflected power to 15 watts. The amp would see a VSWR of 2.26. However, using 50 watts forward power and 30 watts reverse power to calculate VSWR, we end up with a VSWR of 7.9! The amp sees a return loss of 8.2dB, but at the termination the return loss is 2.2dB, or exactly 6dB difference.



While the cable loss can be added into the measurement, it is more accurate to make the measurement at the input of the device in question. The reason is that every connection or device along the way can have its own VSWR.

Evaluating a device for VSWR properties should be done in a laboratory with something like a VSWR or impedance bridge, measured at the input of the device. However, in the real world it is not often safe or practical to monitor VSWR at the device input during normal operations.

Earlier it was mentioned that inserting an attenuator would improve VSWR. Keep in mind that it does not change the VSWR of the terminating device -- that remains constant. However, it does improve the VSWR seen at the other end of the cable. It does this at the expense of wasting power, however. Some amplifiers are not very happy when they see a mismatch in impedance, and may have reduced power output, a distorted waveform, or even be damaged. Using an attenuator may allow continued operation of the amp without fear of damage or shutdown due to the mismatch.