VSWR, Reflection coefficient, Return loss, s11/s22.

VSWR:

The SWR is usually defined as a voltage ratio called the **VSWR**, for *voltage standing wave ratio*. For example, the VSWR value 1.2:1 denotes a maximum standing wave amplitude that is 1.2 times greater than the minimum standing wave value. It is also possible to define the SWR in terms of current, resulting in the ISWR, which has the same numerical value. The *power standing wave ratio* (PSWR) is defined as the square of the VSWR.

The VSWR is related to the reflection coefficient as:

$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1+\rho}{1-\rho}.$$

where ρ = the magnitude of the reflection coefficinet.

Refelection coefficient:

Reflections occur as a result of discontinuities, such as an imperfection in an otherwise uniform transmission line, or when a transmission line is terminated with other than its characteristic impedance. The reflection coefficient Γ is defined thus:

$$\Gamma = \frac{V_r}{V_f}.$$

Γ is a complex number that describes both the magnitude and the phase shift of the reflection. The simplest cases, when the imaginary part of Γ is zero, 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.

For the calculation of VSWR, only the magnitude of Γ, denoted by ρ, is of interest. Therefore, we define

$$\rho = |\Gamma|.$$

Return loss:

Return loss or **Reflection loss** is the reflection of signal power resulting from the insertion of a device in a transmission line or optical fiber. It is usually expressed as a ratio in dB relative to the transmitted signal power.

If the power transmitted by the source is P_T and the power reflected is P_R, then the return loss in dB is given by

$$RL(dB) = 10 \log_{10} \frac{P_T}{P_R}$$

Optical Return Loss is a positive number, historically ORL has also been referred to as a negative number. Within the industry expect to see ORL referred to variably as a positive or negative number.

This ORL sign ambiguity can lead to confusion when referring to a circuit as having high or low return loss; so remember:- High Return Loss = lower reflected power = large ORL number = generally good. Low Return Loss = higher reflected power = small ORL number = generally bad.

In metallic conductor systems, reflections of a signal traveling down a conductor can occur at a discontinuity or impedance mismatch. The ratio of the amplitude of the reflected wave V_r to the amplitude of the incident wave V_i is known as the reflection coefficient Γ.

$$\Gamma = \frac{V_r}{V_i}$$

When the source and load impedances are known values, the reflection coefficient is given by

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

where Z_S is the impedance toward the source and Z_L is the impedance toward the load.

Return loss is simply the magnitude of the reflection coefficient in dB. Since power is proportional to the square of the voltage, then return loss is given by

$$RL(dB) = -20\log_{10}|\Gamma|$$

where the vertical bars indicate magnitude. Thus, a large positive return loss indicates the reflected power is small relative to the incident power, which indicates good impedance match from source to load.

When the actual transmitted (incident) power and the reflected power are known (i.e. through measurements and/or calculations), then the return loss in dB can be calculated as the difference between the incident power P_i (in dBm) and the reflected power P_r (in dBm).

$$RL(dB) = P_i(dBm) - P_r(dBm)$$

s11/s22 relationship to impedance matching:

Input return loss

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

$$RL_{\mathrm{in}} = |20\log_{10}|S_{11}|| \text{dB}.$$

By definition, return loss is a positive scalar quantity implying the 2 pairs of magnitude (|) symbols. The linear part, $|S_{11}|$ is equivalent to the reflected voltage magnitude divided by the incident voltage magnitude.

Output return loss

The output return loss (RL_{out}) has a similar definition to the input return loss but applies to the output port (port 2) instead of the input port. It is given by

$$RL_{\mathrm{out}} = |20\log_{10}|S_{22}|| \text{ dB}.$$

Voltage reflection coefficient

The voltage reflection coefficient at the input port (ρ_{in}) or at the output port (ρ_{out}) are equivalent to S_{11} and S_{22} respectively, so

$\rho_{\text{in}} = S_{11}$ and $\rho_{\text{out}} = S_{22}$.

As S_{11} and S_{22} are complex quantities, so are ρ_{in} and ρ_{out}.

Voltage reflection coefficients are complex quantities and may be graphically represented on polar diagrams or Smith Charts

Voltage standing wave ratio

The voltage standing wave ratio (VSWR) at a port, represented by the lower case 's', is a similar measure of port match to return loss but is a scalar linear quantity, the ratio of the standing wave maximum voltage to the standing wave minimum voltage. It therefore relates to the magnitude of the voltage reflection coefficient and hence to the magnitude of either S_{11} for the input port or S_{22} for the output port.

At the input port, the VSWR (s_{in}) is given by

$$s_{\text{in}} = \frac{1 + |S_{11}|}{1 - |S_{11}|}$$

At the output port, the VSWR (s_{out}) is given by

$$s_{\text{out}} = \frac{1 + |S_{22}|}{1 - |S_{22}|}$$

Mismatch loss:

Mismatch loss in transmission line theory is the amount of power expressed in decibels that will **not be available** on the output due to impedance mismatches and reflections.

Mismatch loss (ML) is the ratio of incident power to the difference between incident and reflected power:

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

where

P_i = incident power
P_r = reflected power
P_d = delivered power

The amount of incident power not reaching the load due to mismatching is

$$\frac{P_d}{P_i} = 1 - \rho^2$$

where ρ is the reflection coefficient

If the reflection coefficient is known, mismatch can be calculated by

$$ML_{\mathrm{dB}} = 10\log_{10}\left(1 - \rho^2\right)$$

In terms of the voltage standing wave ratio (VSWR):

$$ML_{\mathrm{dB}} = 10\log_{10}\left(1 - \left(\frac{VSWR - 1}{VSWR + 1}\right)^2\right)$$