

REFLECTIONS AND STANDING WAVE RATIO (SWR)

For a moment, let us consider an infinitely long transmission line whose characteristic impedance is Z_0 . If we apply RF to the transmission line, current will flow down the line and a guided electromagnetic wave, known as a traveling wave, travels along the transmission line. If we measure the current and voltage at the input to the line and calculate the input impedance, we will find it to be equal to Z_0 . From an electrical point of view, an infinite length of transmission line of characteristic impedance Z_0 looks like a resistor whose resistance is Z_0 . This may seem odd at first - there is nothing connected to the other end of the transmission line, which although it is infinitely far away, is still an open circuit, but that is how transmission lines work. A detailed explanation would require lots of physics, and for us, it is the result that is important, not the derivation.

One of the consequences of this behavior is that a finite length of transmission line terminated in its characteristic impedance acts just like the infinite line. RF power goes into the input of the transmission line, travels to the load and is absorbed by the load resistor. The input impedance is Z_0 . A transmission line terminated in its characteristic impedance is known as a nonresonant line.

Things become more interesting when we have a finite length of transmission line that is not terminated in its characteristic impedance. The animation below shows what happens to a current pulse that is sent down an open-circuited transmission line. Notice that the current pulse is reflected at the open circuit and its phase is changed by 180 degrees. This happens because the current through the open circuit must be zero. This can happen only if the current pulse is reflected with a 180 degree phase shift, so that the total current at the open circuit is zero. Be sure to use your browser's "BACK" button to return to this web page.

[Pulses traveling on a transmission line](#)

By analogy, a voltage pulse launched into a short circuited transmission line will undergo complete reflection and a 180 degree phase shift, so that the voltage across the short circuit is zero. The table below shows the behavior of voltage and current at the end of a open circuited or shorted transmission line. It is worth noting that the information in this table is very general - it is not only true for DC pulses, but also AC.

REFLECTION PROPERTIES OF OPEN AND SHORTED TRANSMISSION LINES

Transmission Line Termination	Effect on voltage	Effect on current
open circuit	100% reflection no phase shift	100% reflection 180 deg phase shift
short circuit	100% reflection 180 deg phase shift	100% reflection no phase shift

To express what we know about reflection more concisely, we will define a new quantity, called the reflection coefficient, Γ , defined as follows:

$$\Gamma = \frac{V_{REFLECTED}}{V_{INCIDENT}}$$

Γ ranges in value from -1 to 1. The table below shows the relationship between the impedance of the termination (load) and the reflection coefficient

Impedance of transmission line termination (Z_L)	Reflection Coefficient, Γ
$Z_L = 0$ (short circuit)	$\Gamma = -1$
$0 < Z_L < Z_0$	$-1 < \text{Re}(\Gamma) < 0$
$Z_L = Z_0$	$\Gamma = 0$
$Z_0 < Z_L < \infty$	$0 < \text{Re}(\Gamma) < 1$
$Z_L = \infty$ (open circuit)	$\Gamma = +1$

These observations can be summed up in a mathematical formula:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

where:

Z_0 is the characteristic impedance of the transmission line

Z_L is the load impedance

Although Z_0 is a real number, Z_L can be complex and thus Γ may be a complex number.

When a steady state AC wave is traveling on a transmission line, there is a steady state reflected wave, unless $Z_L = Z_0$. The reflected wave travels in the opposite direction and the voltage and current at the input to the line are the sum of the two oppositely directed waves. The animation below shows how the forward and reflected traveling waves form a standing wave. The blue wave is the forward traveling wave, moving from the source on the left to an open circuit on the right. The reflected traveling wave is green and moves left to right, back towards the source. The standing wave is black. Notice that its amplitude changes, but the position of the zero voltage points (nodes, labeled N on the animation) do not move. Be sure to use your browser's "BACK" button to return to this web page.

Traveling and Standing Wave Animation

The amplitude of the standing wave varies between a minimum and maximum. The ratio of the maximum to minimum value is known as the voltage standing wave ratio (VSWR) or standing wave ratio (SWR).

$$SWR = \frac{V_{MAXIMUM}}{V_{MINIMUM}}$$

where:

$V_{MAXIMUM}$ = maximum amplitude of the standing wave

$V_{MINIMUM}$ = minimum amplitude of the standing wave

The SWR measures the degree of mismatch between the load and the transmission line's characteristic impedance. The SWR can take on any value from 1 to infinity. SWR is much easier to measure than Γ and thus it is more widely used. Unlike Γ , the SWR is always a real positive number greater than or equal to 1.0. The limiting value of 1.0 occurs on transmission lines where there are no reflections, that is lines that are terminated in their characteristic impedance. As the terminating impedance becomes either greater or smaller than the characteristic impedance, the SWR increases. The SWR can be computed from the load and characteristic impedances by using the following formula:

$$SWR = \frac{1 + \left| \frac{Z_L - Z_0}{Z_L + Z_0} \right|}{1 - \left| \frac{Z_L - Z_0}{Z_L + Z_0} \right|}$$

It is also possible to measure the forward and reflected RF power on a transmission line and determine the SWR:

$$SWR = \frac{\sqrt{P_F} + \sqrt{P_R}}{\sqrt{P_F} - \sqrt{P_R}}$$

where

P_F is the forward RF power

P_R is the reflected RF power

This formula is very useful because it is relative simple to measure RF power.

Here are some examples showing how SWR is computed.

Example 1:

A resonant transmission line carries 81 watts in the forward direction and 9 watts in the reverse direction. What is the SWR on the line?

$$SWR = \frac{\sqrt{P_F} + \sqrt{P_R}}{\sqrt{P_F} - \sqrt{P_R}} = \frac{\sqrt{81} + \sqrt{9}}{\sqrt{81} - \sqrt{9}} = \frac{9 + 3}{9 - 3} = \frac{12}{6} = 2$$

Example 2:

A transmission line whose characteristic impedance is 300 ohms is terminated in a load resistance of 100 ohms.

What is the SWR?

$$SWR = \frac{1 + \left| \frac{Z_L - Z_0}{Z_L + Z_0} \right|}{1 - \left| \frac{Z_L - Z_0}{Z_L + Z_0} \right|} = \frac{1 + \left| \frac{100 - 300}{100 + 300} \right|}{1 - \left| \frac{100 - 300}{100 + 300} \right|} = \frac{1 + \left| \frac{-200}{400} \right|}{1 - \left| \frac{-200}{400} \right|} = \frac{1 + |-0.5|}{1 - |-0.5|} = \frac{1 + 0.5}{1 - 0.5} = \frac{1.5}{0.5} = 3.0$$

SWR is encountered frequently in communications work. It is relatively easy to measure and can be used to estimate other quantities such as the magnitude of Γ and Z_L . A knowledge of the SWR can be important because the RF losses in a transmission line increase as the SWR increases. This is especially true in coaxial transmission lines, which are generally not used when the SWR will be above 3.0. Parallel conductor ladder line, whose dielectric is primarily air, can be used at SWR's of as high as 12.0 without problems.



SWR can be measured directly with an SWR meter, or computed from values of forward and reflected power. A particularly useful instrument, shown below, is the crossed-needle SWR meter.

