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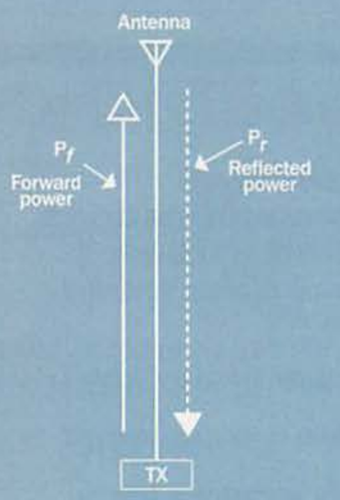
Understanding standing wave ratios

Be careful, as transmission line loss can profoundly impact your calculations

The term standing wave ratio, or SWR—sometimes called voltage standing wave ratio, or VSWR—frequently is a subject of discussions/arguments among communication technicians, hams and others involved in the radio communications field. The easiest way to explain SWR is through an example.

Figure 1

An in-line directional wattmeter is used to measure the forward and reflected power at the transmitter. The results may be quite misleading—especially if the normal matched-line loss of the transmission line is significant. See text for details.



In Figure 1, a transmitter is connected to an antenna through a 100-foot length of transmission line. Let's suppose in this instance that the transmission line is loss-less (though no such circumstance exists in the real world.) Further suppose that the antenna is not properly matched to the 50 ohm system and that 25% of the RF power is reflected back down the line from the antenna toward the transmitter. With the in-line directional wattmeter connected between the transmitter and the transmission line, the wattmeter indicates 100 W forward power and 25 W reflected power. In Figure 1, P_f represents the forward traveling wave (forward power) and P_r represents the reflected traveling wave (reflected power).

The voltages of the forward and reflected waves will combine at different phase angles along the length of the transmission line. A phasor analysis will reveal that voltage maxima (anti-nodes) and voltage minima (nodes) exist along the length of the transmission line. Figure 2 shows the representation of the standing wave pattern on the transmission line. The VSWR figure is derived from the ratio of the voltage at the maxima to the voltage at the minima. So all we have to do is calculate the voltage of the forward wave and the voltage of the reflected wave and express the sum and difference of these two voltages as a ratio. This is the standing wave ratio. The calculations are as follows:

Equation 1

$$V = \sqrt{PZ}$$

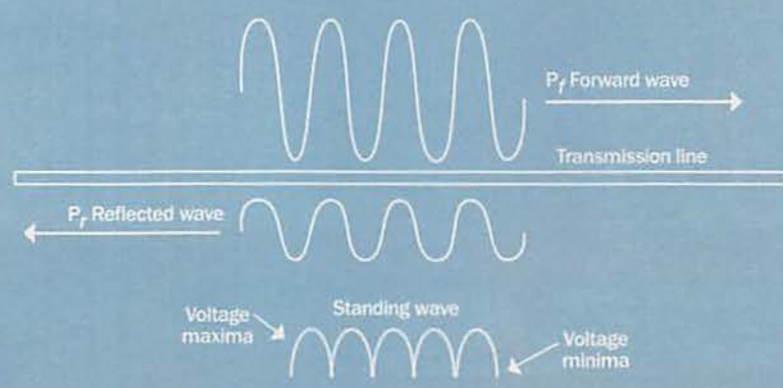
First, from the power and impedance we can calculate the voltage using Equation 1. Since the impedance is 50 Ω and the power in the forward wave is 100 W, the voltage of the for-

Equation 2

$$V = \sqrt{PZ} = \sqrt{100 \times 50} = \sqrt{5000} = 70.71$$

Figure 2

Forward and reflected traveling waves on a transmission line produce a resultant standing wave with voltage maxima and minima. The standing wave ratio is the ratio of the voltage maxima to the voltage minima.



Equation 3

$$VSWR = \left[\frac{70.71+35.35}{70.71-35.35}\right] = \left[\frac{106.06}{35.35}\right] = 3.00:1$$

Equation 4

$$SWR = \frac{1+\sqrt{r}}{1-\sqrt{r}}$$

Equation 5

$$SWR = \frac{1+\sqrt{.25}}{1-\sqrt{.25}} = \frac{1+.5}{1-.5} = \frac{1.5}{.5} = 3:1$$

ward wave is 70.71 (see Equation 2). The voltage of the reflected wave is calculated in the same manner, and the result is 35.35 V. The VSWR is computed as the ratio of the sum (maxima) to the difference (minima) of the two voltages, or 3:1, as shown in Equation 3.

Most technicians use a directional in-line wattmeter to make forward and reflected power measurements in order to determine transmitter output power and reflected power. With some experience, the technician can get a quick mental evaluation of the degree of match or mismatch by comparing the forward and reflected power levels. Basically, the technician is comparing the percentage of reflected power to forward power.

In the example illustrated in Figure 1, the forward power is 100 W and the reflected power is 25 W. Thus, the percentage of reflected-to-forward power is 25%. Experienced technicians know that a reflected power of 25% translates to an SWR of 3:1. If we let *r* represent the ratio of reflected power to the forward power, we can use Equation 4 to calculate the SWR. Using the example in Figure 1, we find that SWR also is 3:1 (see Equation 5).

The term return loss often is used to indicate the degree of match or mismatch instead of the term SWR. To understand return loss, refer back to Figure 1. The forward power is 100 W, and the reflected power is 25 W. The return loss is simply the expression in decibels of the ratio of the forward power to the reflected power and is calculated by the formula in Equation 6.

Thus, a return loss of 6 dB is equivalent to an SWR of 3:1. It also is possible to convert SWR directly to return loss using Equation 7 on page 60. Table 1 provides conversions between SWR and return loss for several SWR ratios.

In the example of Figure 1, the line loss was theoretically zero—but this never happens in the real world. Let's look back at Figure 1 and see what happens if the transmission line loss is 3 dB at the given length and frequency of operation. This changes things quite a bit. The power output from the transmitter (P_f) is still 100 W. However, since the line loss is 3 dB, the forward power arriving at the antenna is only 50 W (down 3 dB). Now the mismatch at the antenna causes 25% of the forward power to be reflected back toward the transmitter. Thus, 12.5 W of power

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Table 1

Return Loss (dB)	VSWR
10	1.92
12	1.67
14	1.5
16	1.37
18	1.28
20	1.2

Equation 6

$$RL = 10 \log \frac{P_f}{P_r} = 10 \log \frac{100}{25} = 10 \log(4) = 10(0.602) = 6.02\ dB$$

Equation 7

$$RL = 10\log\left[\frac{1}{\left(\frac{S-1}{S+1}\right)^2}\right]$$

Where RL is return loss and S is SWR

Equation 8

$$L_A = 10\log\left[\frac{1-r}{1-r\left(10^{\frac{L}{5}}\right)}\right]$$

Where L_A is additional line loss, r is reflected/forward power ratio at transmitter and L is normal matched-line loss of transmission line

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is reflected back down the line. In traveling back down the line, this reflected power is attenuated by 3 dB. This means that the reflected power measured at the transmitter is only 6.25 W.

Using all of this information, we can analyze the results in the following manner. First, the difference between the forward and reflected power readings at the transmitter is 100 W minus 6.25 W for a net power of 93.75 W. The SWR at the transmitter is 1.67:1, and the SWR at the antenna is still 3:1. Thus, the loss of the transmission line makes the SWR measured at the transmitter look much better than it really is at the antenna.

Remember, too, that the actual power delivered to the load is the difference between the forward power and reflected power readings on the wattmeter. Now, at the transmitter, the difference between the two readings is 93.75 W, while at the antenna it is 37.5 W.

Because the line loss was 3 dB (representing a 50% loss), the net power delivered to the antenna should be 50% of the net power delivered into the transmission line at the transmitter. Calculations indicate that the net power delivered to the antenna is only 40% of the net power input to the transmission line. Thus, the loss in the transmission line is 60%, or approximately 4 dB. The normal (matched-line) loss of the transmission line is 3 dB. The additional 1 dB of loss is caused by the mismatch at the antenna. Equation 8 can be used to determine the additional line loss caused by a mismatch at the antenna.

When you measure the SWR (reflected and forward power readings) at the transmitter, remember that the line loss between the transmitter and antenna will mask the true SWR that exists at the antenna. The greater the transmission line loss, the greater this masking effect.

In fact, if the normal matched-line loss of the transmission line is 3 dB, the maximum SWR seen at the transmitter would be just slightly more than 3:1—even for a worst-case mismatch at the antenna. SWR increases the line loss above the nominal matched-line conditions. When choosing a transmission line, use the best (read minimum loss) cable that your budget and other practical considerations will allow.

Until next time—stay tuned! ■