Standing Wave Ratio — What Does It Really Mean?

Higher SWR means more loss, but more loss can mean lower SWR. Here's how to make sense of this.

Joel R. Hallas, W1ZR
Contributing Editor, *QST*

Standing wave ratio, or SWR, seems to come up in most ham conversations related to antenna systems. SWR is a measure of how closely matched a load is to a nominal impedance — typically the 50 Ω coaxial cable for which most current amateur equipment is designed. An SWR of 1:1 indicates that the load is an exact match to the design impedance, while any other ratio (always greater than 1.0) indicates a mismatch. Some consider it a big deal, while some say it doesn't matter. Can they all be right?

What SWR Is All About

To discuss standing wave ratio, I will start with a discussion of what happens in a real transmission line without standing waves — one with a standing wave ratio of 1:1. Figure 1 shows a typical setup, with an SWR or power meter between the transmitter and the antenna tuner. Of course, for the matched case, we don't need a tuner at all, but sooner or later we will change frequencies and then we likely will.

The Directional Wattmeter

Note that a directional wattmeter that reads forward and reflected power can also tell us about the matched condition — if we read forward power and the reflected power is zero, we have a matched condition, or an SWR of 1:1. If we understand what the power readings mean, the power meter can tell us a bit more — how much power we have at a particular location in the system.

We can determine SWR from forward and reflected power through the following expression:

$$SWR = \frac{1+\sqrt{P_R/P_F}}{1-\sqrt{P_R/P_F}} \qquad \text{Eq 1}$$

Where P_R and P_F are the reflected and forward power in the same units.

You won't need to make this calculation (unless you want to check my work), but it's here if you want to. So, for example, if the reflected power is 1⁄10 the forward power, the SWR, equals

$$SWR = \left(1+\sqrt{1/10}\right)/\left(1-\sqrt{1/10}\right) = (1+0.316)/(1-0.316) = 1.92:1. \qquad \text{Eq 2}$$

This illustrates one weakness of some power meters compared to the usual voltage sensing SWR meter that has a value of 3:1 near mid-scale. The power meter tends to have the values of most interest to us clustered near the bottom end of the reflected power scale, rather than near the middle. Still, the numbers will illustrate our discussion very nicely.

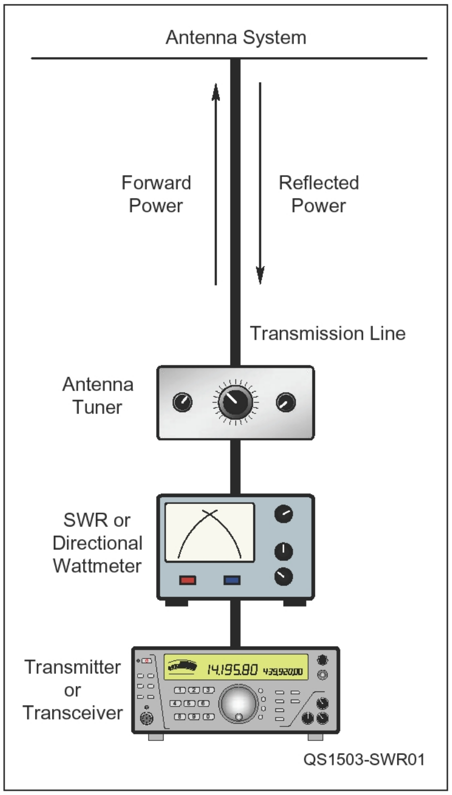

Figure 1 — The usual configuration of an HF amateur station using an antenna tuner to feed an antenna system.

Another important consideration in interpreting a directional wattmeter's readings is that net-delivered power equals the forward power minus the reflected power. Thus, don't be surprised if the meter between a 100 W transmitter and a mismatched load reads 150 W forward and 50 W reflected. It doesn't mean that your transmitter is suddenly putting out more power, it just means that the load has an SWR of 3.7:1.

The Matched Case — SWR = 1:1

If a signal is launched down a transmission line that is terminated in its characteristic impedance — a 50 Ω resistive load for many coax types, including the popular RG-213 (modern RG-8), RG-8X, and RG-58A — the power that reaches the far end will be completely absorbed by the load. If it's an antenna, most of it (less any losses in the coax or antenna itself) will be radiated as an electromagnetic wave — just what we want. If we were to measure (without disrupting things) the voltage and current along the matched line, we would observe that they both remain essentially constant amplitude sine waves as we move down the line, except for a reduction over distance due to line loss.

In Table 1, we have tabulated the loss in 100 feet of matched coax of the types we mentioned above on a number of amateur bands. The loss is expressed in decibels, a logarithmic function and the usual unit for such data because system component losses and gains expressed in decibels can be added together to obtain the total system gain or loss. In terms of power,

Table 1
Matched Loss (dB) of 100 Feet of Three Types of 50 Ω Coax

Coax Type	3.7 MHz	14.15 MHz	28.5 MHz	50.1 MHz	144.2 MHz
RG-213 (Belden 8267)	0.375	0.785	1.153	1.573	2.813
RG-8X (Belden 9258)	0.578	1.251	1.870	2.587	4.751
RG-58A (Belden 9259)	0.868	1.890	2.838	3.936	7.267

Table 2
Fraction of Power Lost and Power Remaining for Various Losses

Loss (dB)	Loss Fraction	Remaining Fraction
0.5	0.109	0.891
1	0.206	0.794
2	0.369	0.631
3	0.499	0.501
5	0.684	0.316
10	0.900	0.100
20	0.990	0.010
30	0.999	0.001

the fraction lost is shown in Table 2 for various decibel values. What this means, for example, is if the cable loss is 3 dB, about half of your power is dissipated in the cable instead of being radiated by the antenna. It also means, sometimes more importantly, that half your received signal is lost before it gets to your receiver.

In Figure 2, I have imagined inserting directional wattmeters at each end of the transmission line. We don't generally do this — often the upper one is in the air, for one reason — but the numbers they would provide make good illustrations. In this case, I imagined that the antenna tuner is lossless to simplify the discussion. I selected the attenuation of a 100-foot length of popular RG-8X, 50 Ω coax, and an operating frequency of 14.15 MHz for the calculations. Nothing about the matched numbers should be a big surprise.

The Mismatched Case — SWR > 1:1

If we terminate the end of the line with an impedance other than the transmission line characteristic impedance, the usual situation for many antennas, the situation gets a bit more complicated. At the interface between the transmission line and its mismatched load (the antenna) a reflection occurs, resulting in a wave returning down the transmission line toward the source. This wave is also attenuated as it travels back toward the transmitter, but it exists all along the line. Note that while the antenna tuner is matched to the impedance of the mismatched antenna transformed by the coax, it is not matched to the coax Z_0 and the wave encounters the mismatch on the antenna side of the tuner and is thus re-reflected toward the antenna.

Figure 3 is a repeat of Figure 2, except that now instead of a matched load, we have an antenna with an impedance of 12.5 Ω, a 4:1 SWR. The figure shows the power and SWR readings that we would see at all of the points in our heavily instrumented system. Tables 3 and 4 provide some representative data for other cables and situations. There are a number of key observations that can be gleaned from these results.

First, observe that the loss in the transmission line has increased due to the higher SWR. Instead of the matched loss of 1.25 dB, we now have 2.2 dB of loss. This means that if we start out with 100 W, only 60 W will reach the antenna, rather than the 75 W we had for the matched case.

At the bottom of the transmission line, it looks like a much better situation, even though it really isn't. The reflected power from the mismatched antenna has been attenuated by the mismatched coax on its way back to the transmitter, so the SWR at the bottom looks much better than it really is. Note that if we had a very lossy, very long transmission line, so that the reflected wave was almost gone, we would see an SWR of close to 1:1, even though almost nothing will get to the antenna. This is why we have to look carefully at what our meter readings really mean.

Note the meter readings between the transmitter and the antenna tuner — these are usually the only ones we actually see! If the antenna tuner is properly adjusted, the SWR here will be 1:1 and we will be

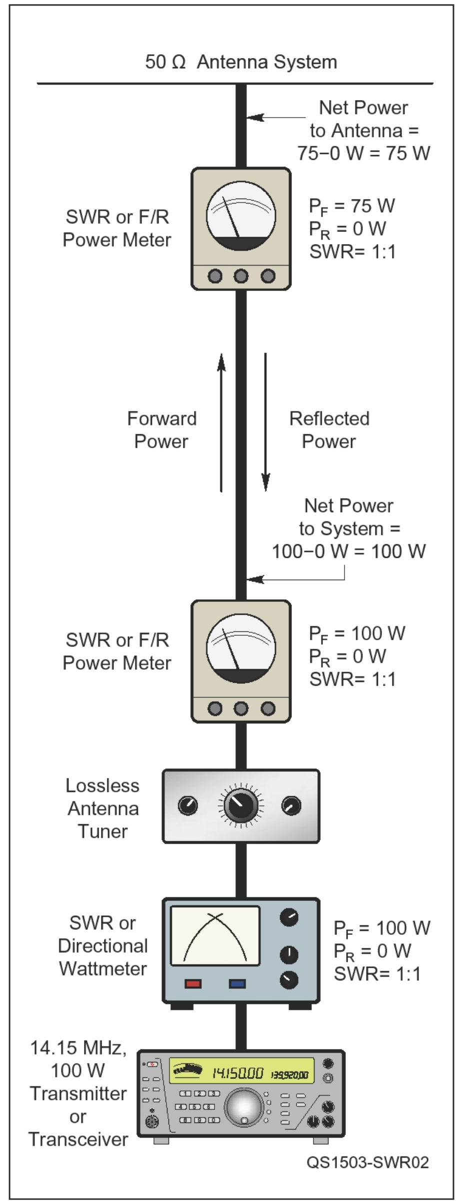

Figure 2 — The configuration of Figure 1, showing expanded instrumentation. While this would not typically be used, the numbers that would be obtained will assist in the discussion. For this example, we use 100 feet of the popular RG-8X coaxial cable to connect our radio to a perfectly matched antenna system on 14.15 MHz.

sending the full 100 W toward the antenna system, but as we now know, the results are quite different.

What To Do About It

While the SWR meter that we observe to tune our antenna tuner is crucial in order to adjust the tuner, its readings with the tuner in-line do not tell us much about what's really happening in the antenna system. We can, however, make use of it to get a good idea of what's happening in the following way:

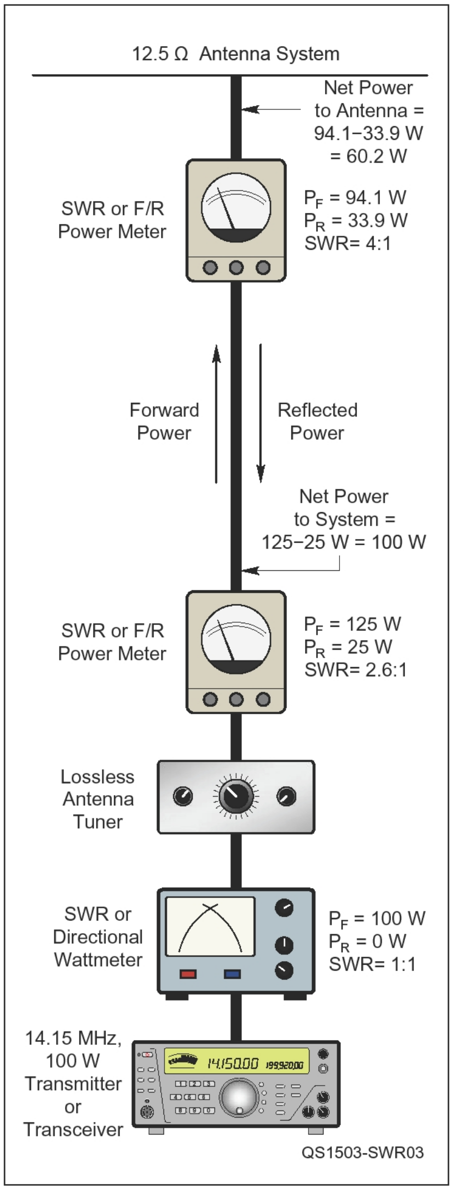

Figure 3 — This is the same situation as Figure 2, except that the antenna has an impedance of 12.5 Ω, a 4:1 SWR. Note that due to the loss in the transmission line going up to the antenna, and in the reflected signal coming back, it looks at the radio end as if the SWR is just 2.6:1. Even more confusing is the meter at the radio, showing 100 W out going to a perfectly matched system.

Table 3
Loss (dB) of 100 Feet of Three Types of 50 Ω Coax Feeding 12.5 Ω Load (4:1 SWR)

Coax Type	3.7 MHz	14.15 MHz	28.5 MHz	50.1 MHz	144.2 MHz
RG-213 (Belden 8267)	0.810	1.501	2.035	2.687	4.305
SWR at Transmitter End	3.45	3.01	2.70	2.43	1.92
RG-8X (Belden 9258)	1.041	2.203	3.107	4.033	6.501
SWR at Transmitter End	3.21	2.64	2.28	1.99	1.50
RG-58A (Belden 9259)	1.672	3.166	4.296	5.62	9.153
SWR at Transmitter End	2.95	2.27	1.91	1.64	1.25

Table 4
SWR Seen at Transmitter End of 100 Feet of Cable Feeding a 12.5 Ω Load (4:1 SWR)

Coax Type	3.7 MHz	14.15 MHz	28.5 MHz	50.1 MHz	144.2 MHz
RG-213 (Belden 8267)	3.45	3.01	2.70	2.43	1.92
RG-8X (Belden 9258)	3.21	2.64	2.28	1.99	1.50
RG-58A (Belden 9259)	2.95	2.27	1.91	1.64	1.25

First, take and record an SWR reading of your antenna(s) with the antenna tuner bypassed (or, if need be, removed and replaced with a jumper) on all bands that you use them. For the large percentage bandwidth bands such as 80 meters, take a number of readings across the band, since they will likely be quite different. Having this data recorded and in your station log is the first step in making sure that your antennas haven't changed. Based on the discussion above, if the SWR improves over time, it is almost never good news.

Next, use *Transmission Line for Windows* (*TLW*) software to determine the actual situation on the line.[1] This is discussed briefly in the caption to Figure 1 of a recent article describing an update of *TLW*.[2] Take the measured impedance value of your antenna system at the shack end and enter it into *TLW*, but click the INPUT button, rather than the default LOAD button. If you just have SWR data and no detailed impedance information, just divide your characteristic impedance by the measured SWR and use that for the RESISTANCE value and put 0 in the REACTANCE window. Then enter the frequency, cable type, and length. The results will be very close and you will have the SWR and loss data that you would read if you measured it at the antenna. This was described in more detail in an earlier article.[3]

The data provided by *TLW* shows the actual SWR at the antenna end of the coax, as well as the total cable loss and how much is a result of any mismatch. With this information in hand, you are in a good position to understand what's really happening throughout your antenna system.

Notes

[1] *Transmission Line for Windows* (*TLW*) software is included on the CD-ROM that is supplied with *The ARRL Antenna Book*. See *The ARRL Antenna Book,* 22nd Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 6948. Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

[2] J. Hallas, W1ZR, "Introducing an Improved Version of *Transmission Line for Windows* Software," *QST*, June 2014, pp 38 – 40.

[3] J. Hallas, W1ZR, "I Know What's Happening at the Shack — What's Happening at the Other End of my Feed Line?," *QST*, Feb 2007, p 63.

Joel R. Hallas, W1ZR, is a Contributing Editor of *QST*. You can reach him at **w1zr@arrl.org**.

For updates to this article, see the *QST* Feedback page at www.arrl.org/feedback.