ANTENNAS FROM THE GROUND UP

20. SWeaRing
or Some Facts and Fantasies About Standing Wave Ratios

L. B. Cebik, W4RNL

We have all read dozens of articles about SWR. So we all know that the Voltage Standing Wave Ratio is a complex function of the relationship between the feedpoint impedance of our antenna and the characteristic impedance of our transmission line. When the antenna feedpoint impedance is a pure resistance, the relationship is simple: SWR equals the larger of the two divided by the smaller of the two. If the antenna feedpoint exhibits reactance in addition to resistance, then the SWR is usually higher by a somewhat more complex calculation.

We also all know that generally, the better the match between the load, the transmission line, and the source (our transmitter outputs), the more power is consumed by the load. Hence, it is generally wise to strive for a well- matched antenna-feedline-transmitter system. So we place an SWR meter in the line at or near the transmitter and monitor the SWR at that point.

And, unfortunately, that is where most of us stop in our efforts to understand SWR and its place in antenna work. The first thing we want to notice is that we can measure SWR. More correctly, we measure Voltage Standing Wave Ratio (VSWR), because we are measuring the ratio of the maximum voltage along a transmission line to the minimum voltage along the line. Since the ratio of maximum current to minimum current along that same line (ISWR) has the same value, we have gotten in the habit of referring simply to SWR.

SWR is directly related to the impedance of the load and the impedance of the feedline connected to it. It has become, because we can measure it, the standard measure of a match or mismatch between the load (usually an antenna, for our purposes) and the feedline. Transmission lines are almost (but not quite) purely resistive, which simplifies the arithmetic a lot. We can call their characteristic impedance Zo and treat it as a resistance. However, the relationship is still not absolutely simple, since the load impedance may have both resistive (RL) and reactive (XL) components.

To calculate SWR, let's define two arbitrary terms, A and B.

$$A = \sqrt{(R_L + Z_O)^2 + X_L^2} \qquad (1)$$

and

$$B=\sqrt{(R_L-Z_O)^2+X_L^2} \qquad (2)$$

The only difference (although it is a big difference) is the + vs. - at the resistive ends of the expressions.

$$SWR=\frac{A+B}{A-B} \qquad (3)$$

From these expressions, we can already figure a lot of things. Here is a quick sampling of a few.

1. When we have a load that matches the transmission line, it will first of all have to have XL = 0, since the line is presumed to be resistive. Second, RL and Zo will have to be equal. These two facts make the B-equation equal zero, and A/A=1 for our SWR value. So a perfect match has an SWR value of 1.

2. It does not matter if the load resistance is higher or lower than the transmission line Zo. Whether the difference comes out positive or negative, its square will be positive. Hence, all SWR values will be positive values.

3. There is no direct connection between the overall load impedance and the SWR. The only time SWR equals ZL/Zo or Zo/ZL is the very special case where the load has no reactance. Never assume your antenna feedpoint presents no reactance to your transmission line. Even as you change frequency within a band, your antenna can be resonant at only one specific frequency and at all others presents at least some reactance to the feedline. So even if your antenna's resistive component remained unchanged (which it does not, but may only change by a very little bit), you would still encounter increases in SWR as you move away from the specific frequency of resonance. (And that assumes a perfect match at resonance, which might not be the case.)

4. We traditionally express SWR as a ratio rather than as a single value. Do not be fooled by that practice into thinking that the ratio is telling you something more than the output of the calculation. Every calculated number can be expressed as a ratio to 1, and that adds nothing to our knowledge.

5. From the form of the expressions, you can tell that even though we can calculate SWR from a knowledge of the transmission line Zo and the feedpoint impedance values of RL and XL, we cannot go the other way around. There are innumerable combinations of RL and XL that will give the same SWR value.

Where do you find all these other values of R and X that yield the same SWR? Right along your transmission line. As we have noted in past installments, a transmission line is an impedance transformer. If the value of SWR at the load end is higher than 1, then everywhere along the line there are different values of R and X that yield the same SWR. (This, of course, assumes a lossless line, which is not quite precise. Every line has at least a little loss. But the assumption is no more a problem for this discussion than our other assumption that feedlines are purely resistive.)

Fortunately, the values of R and X along a transmission line, where the load is a mismatch to the line (another way of saying that the load impedance is not identical to the line impedance), transition smoothly through the range of values that yield the same SWR all along the line. In fact, from a knowledge of the load RL and XL and the line impedance Zo, we can calculate those values all along the line.

Before you wear out your hand calculator, remember that virtually all of these equations have been placed into one or more of the programs of HAMCALC, that handy collection made available by VE3ERP.

So what can the SWR value tell me that is useful. First, it tells you in very broad terms how closely your load is matched to your transmission line. That is useful information if in advance you know that by some simple adjustment you can bring the load (which is changeable) into alignment with the Zo of the transmission line (which is not changeable by any simple adjustment). For example, when you prune a dipole for lowest SWR, you are assuming from statements made by authorities that the impedance at resonance is close to the impedance of your coaxial feedline.

For many other situations, knowing broadly that you have a big or small degree of mismatch is fairly useless. Knowing the degree of mismatch between the 135' antenna feedpoint and the transmission line on 30 meters gives us no useful instructions for making antenna changes.

But that leads us to the second thing that knowing the SWR can do for us. It provides a means of calculating what happens all along the line so that we can introduce other methods of matching. But, again, most of them have already been put to use in HAMCALC. And, if you know how to use a Smith Chart, you are using mechanical geometrics to do the algebra for you. Either way, you can calculate where to place matching components along the line, how much to trim a line to let the ATU find more efficient settings, and numerous other jobs.

I shall not pretend that this is a particularly complete story about SWR. In fact, most books start with a related concept called reflection coefficient and then define SWR in terms of it, which helps keep SWR a little more of a mystery for those not inclined to do all the algebra involved in bringing the ideas together. Here, we started with SWR simply because most hams own SWR meters and almost no one has a well-calibrated reflection coefficient meter. (It is possible to make a scale face for an SWR meter for this factor.)

Some Misconceptions About SWR

Despite all this available knowledge, I still encounter some interesting misunderstandings about SWR. Of course, they come from "outside," so each of you can claim, "Well, I knew better than that." Even so, it may be useful to review a few of them.

1. "My SWR is low, so my transmitter is safe." In olden days when tube-type rigs had adjustable output circuits, folks worried about burning out tubes and other components "because" of SWR. Actually, the combination of resistance and reactance seen by the transmitter output circuit would sometimes permit only a small RF transferral. However, operators continued to load their finals to full DC plate input power. What is not RF in a final is heat, and that excess conversion of DC power to heat is what destroyed tubes and stuff around the tubes.

Today's transistor rigs have feedback circuits that sample the reverse voltage at the output and automatically reduce drive to the finals in the event of a high SWR. Thus, it is pretty difficult to hurt a rig by connecting it to a high SWR output load. SWR is NOT the modern way to hurt a rig. Overdrive, with or without SSB compression, is a source of major stresses on a rig's circuitry. However, the chief modern rig killer seems to be voltage surges coming from the antenna, the power line, or the ground. And that is a matter of safety that calls for measures outside the rig-- like disconnecting the antenna, power cord, and system ground to totally isolate the rig when not in use.

2. "My antenna system is fine, because the SWR is better today than when I put it up three years ago." The fact of a lower SWR over time is often true. However, the conclusion drawn is false. If the SWR is lower than it used to be, the chief reason is an increase in losses in the system. Losses represent that portion of energy converted to heat along the line and at the antenna terminals, energy that is no longer available as energy to radiate. As systems age, cables become "lossier," terminals become corroded, and a variety of other things contribute to the problem.

Yes, a lowering of SWR can indicate problems, not improvements. It is not impossible, but it is exceedingly rare for an antenna system to change its feedpoint impedance to match the transmission line. It is so rare that the lowering of SWR with time should always be taken as a sign that it is time for antenna system maintenance. Clean, deoxidize, tighten, and seal, as appropriate. If things do not improve, replace the outdoor coax with new stock (but save the old stuff for noncritical uses, if it has any life left in it).

3. "My antenna is operating very well because my SWR is a perfect 1:1 match." Unfortunately, my dummy load gives a nearly perfect 1:1 match, and I cannot hear anyone when it is in the line. SWR is one measure of impedance match, but it is not an indicator of the quality of antenna performance as an antenna. Antennas convert radio frequency energy--a form of AC voltage and current--into electro-magnetic radiation (and also the reverse for reception); and they also manage to focus that radiation in various patterns. How well an antenna does this job is only indirectly connected with the impedance match to the transmission line carrying the energy to be converted and directed.

The practical consequences of this fact are pretty basic. First, before committing to an antenna, try to determine what kind of operating you want to do and select an antenna that will enhance that operation--within the limits of what you can handle in terms of finances, maintenance, and home site restrictions. Second, maintain your antenna regularly--even more regularly than most folks change automobile oil. Preventive maintenance will keep your antenna operating to its maximum ability. Third, if you build your own antenna for a long-term installation, use sensible quality materials. Stainless steel hardware is a must. Tubing and wire made for antennas or equally strong and conductive materials are necessary. Applying No-Ox or similar antioxidation conductive materials at connections of dissimilar metals is always a good idea.

4. "My antenna has a feedpoint impedance of 100 ohms. Surely 50- ohm coax will give me lower losses than the more highly mismatched 450-ohm parallel feedline." This misconceptions stems from the belief that SWR is a direct measure of the ability of an antenna to "absorb" energy and convert it into radiation. SWR is only part of the story.

Every transmission line displays two kinds of losses: first is a basic loss based on two significant factors: the ability of the wires to handle RF currents and the leakage between wires through the insulation. Because any coax we can afford compromises cost vs. effectiveness, all common coaxial cables have a higher basic loss per 100 feet than parallel feedline, whether 300- ohm or 450-ohm. In fact, for the HF bands, most parallel feedline has a minuscule loss compared to coax.

The second loss source is a result of SWR--or rather the mismatch that SWR indicates. Since peak voltages climb, leakage increases. Since peak currents climb, heat conversion losses are higher. In effect, SWR puts a multiplier on the transmission line's basic loss. Since coax begins with significant basic losses, additional losses due to SWR are that much more significant. Parallel transmission lines begin with almost insignificant losses, and the same or higher multipliers usually mean that losses are still insignificant. Under some common conditions, a parallel transmission line with a 10:1 SWR may have lower power losses than a coax cable with a 3:1 SWR. Parallel transmission line is almost always the best bet for multiband wire antennas that require an antenna tuner.

But remember that even at 3:1 SWR on the lower bands, like 80 meters, coax losses may still be too low to worry about. If your 80 meter dipole shows an SWR at the high end of 75 within the limits of your rig's built-in antenna tuner to handle and you would like to work a little SSB, go for it.

5. "My meter shows the reflected power to be 25 watts. I'm worried about losing that power at the antenna and what it must be doing to my rig." Most folks who see these kinds of readings have never looked seriously at their forward power under the same conditions. Suppose you set your rig to exactly 100 watts output. Your reflect power reads 25 watts on a decent meter. Your forward power will read at least 125 watts--perhaps a couple of watts more to account for the cable losses just described (and your rig will be putting out about 102 watts). The difference is 100 watts. Where is it--and where did the extra forward power come from?

The reflected power simply returns to the forward direction and adds to the rig's power along the line. No need to worry about the rig, since it is not affected by the reflected power (except as the reverse voltage may activate a power reduction circuit). The antenna is receiving and converting 100 watts of power (less only the very small amount changed to heat due to cable losses). A receiving station cannot tell the difference in signal strength between an exactly matched dipole and one running a 10:1 SWR to a parallel feedline and ATU system. The received signal strengths will be the same, assuming the antennas occupied the same transmitting positions with the same propagation conditions. Both antennas converted just about 100 watts of RF energy into radiation. It may take about a dozen cycles for the high SWR system to build to full power and an equal number to return to zero, but when you have millions of cycles per second to use, those few make no difference to the signal intelligence.

I hope these notes help all those "other" folks approach SWR and antennas a little more intelligently. WorldRadio's Kurt N. Sterba occasionally runs into SWR misconceptions, and I assure you that his treatment is far more entertaining than mine--except to the sources of those misconceptions, who are technical writers who ought to know better. He is a good incentive for writers to keep things right and sensible. The best extended treatment of SWR and medicine for SWR misconceptions is still Walt Maxwell's book, Reflections. Unfortunately, it appears to be out of print. You may want to petition ARRL to reprint it. Hopefully your library has a copy. Mine is too dog-eared to be borrowed. Anything right in these notes belongs to Walt. Anything wrong is likely to be noted by Kurt.