The SWR Obsession

QST April 1994, pp. 70-72

The SWR Obsession

Many hams suffer from a cruel obsessive-compulsive disorder. They're driven to achieve the lowest possible SWR—even when it isn't necessary.

By Steve Ford, WB8IMY
Assistant Technical Editor

There he goes again, scrambling up the ladders to cut another couple of inches from the ends of his antenna. The SWR was at 1.8:1 when he put it up, but that just isn't good enough. He'll run up and down those ladders for hours until he finally achieves the perfect 1:1 reading on his meter. Of course, it's all worthwhile in the end—isn't it?

No.

In this case, our hypothetical ham wasted an afternoon chasing a ghost. Other than burning off a few calories, he achieved nothing. Like many amateurs, this fellow has an unhealthy attachment to his SWR meter. Although they're essential pieces of test equipment, SWR meters have a tendency to dominate our thoughts to an extreme degree. I know hams who swing from elation to depression according to the readings on their meters. ("Oh, happy day! My SWR is 1:1 on 40 meters!")

In the age of instant gratification, I guess it's natural to fall in love with an SWR meter. It tells you all you need to know at a glance—or so many hams believe. It's a bit like an instrument Bones would use in the original *Star Trek* series. He waves it over your chest a few times and declares, "Ah-hah! You have a case of Martian flu!"

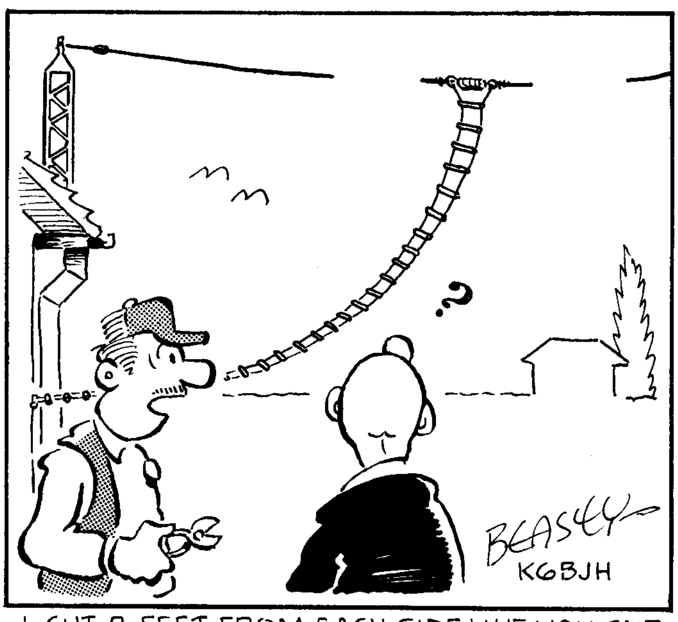
In truth, an SWR meter provides valuable information about your antenna system, but it doesn't tell the whole story. The trick is to regard it as just one tool in your diagnostic arsenal. Your SWR meter should inspire your curiosity, maybe even your deep concern in some instances. Never let it dictate your actions, however. When you look at your SWR meter, make sure you're seeing the complete picture.

Before we continue, I have a warning for those who fancy themselves as antenna and transmission line experts: Stop reading now. You won't find complicated presentations on wave mechanics and other arcane topics in this article. Instead, I'm going to make the complex simple. This means cutting some corners and that's sure to make your blood pressure jump a few notches. If you can't live without a dose of math and minutiae, take a look at the sidebar, "Get Out Your Calculators—or Computers" written by Dean Straw, N6BV, another Assistant Technical Editor (and our resident antenna guru) here at Headquarters.

Bouncing Waves

It's a quiet evening at home and you're itching to get on the air. With microphone in hand, you make your first call. As you press the PTT (push to talk) button and speak, the first syllable of your first word is transformed into RF (radio frequency) energy and sent zipping through the feed line. In a slice of time so small it's beyond human comprehension, that wave of energy arrives at the transmitting antenna. Some of the RF has changed into heat because of losses in the feed line, but most of it arrives at the antenna intact.

Everything seems normal so far, but serious strangeness is just around the corner. All it takes is a slight "disagreement" between your antenna and your feed line. This disagreement usually takes the form of an *impedance* mismatch. When the impedance of your antenna and your feed line are not the same, most of the energy is still radiated by the antenna, but the rest is *reflected back to your radio.* When the reflected wave reaches your radio, another odd thing happens: it's reflected right back to your antenna. The wave reaches your antenna and some of it is radiated. The rest—you guessed it!—is reflected back to your radio again.



I CUT 2 FEET FROM EACH SIDE LIKE YOU SAID, BUT MY SWR WENT THROUGH THE ROOF!

While this reflected energy is bouncing back and forth like lightspeed Ping-Pong balls, your radio is still generating power. Now we have the energy created at the radio (the *forward power*) combining with the *reflected power.* This is a complex combination of waves, not like 1 apple + 1 apple = 2 apples. Without going knee deep into math—and I promised you I wouldn't—it's sufficient to say that this combination of forward and reflected power creates what are known as *standing waves.*

Get Out Your Calculators or Computers

"The Lure of the Ladder Line"[1] must have struck a responsive chord (or a nerve) out there—both Steve and I received many letters, telephone calls and Internet e-mail messages as soon as *QST* hit the streets in late December. Despite the snow and ice, some brave hams even went outside to change their feed lines from coax to ladder line. They excitedly reported that their signals were greatly improved—in fact, several just couldn't stop making happy noises to us!

There were some adverse reactions too, ranging from mild surprise to outright disbelief. Table 1 in the article caused the most shock—why should good-quality coax have so much loss? And why should even ladder line be so lossy at 1.8 MHz? Unfortunately, due to space limitations, a more detailed table of values had to be cut from the original article, leaving some of our more technically inclined brethren scratching their heads. So here are some details on how the loss figures were derived.

Just to spice things up a bit, this time I computed losses for a slightly different antenna—I used the same total amount of wire, 66 feet, but assumed that it was in the shape of a typical inverted-V, rather than a horizontal dipole.

I used *NEC2*, a mainframe computer program now available for use on high-end PCs, to analyze this antenna, rather than a *MININEC*-derived program. *MININEC* programs lose accuracy rapidly when the antenna is less than about 0.2 wavelength above ground. I specified "average" ground, having a conductivity of 5 mS/m (millisiemens per meter) and a dielectric constant of 13.

Once I had determined the feedpoint impedances for the multiband inverted **V**, I explored the feed-line loss for two types of transmission line—450-Ω "window" ladder line, which Steve had used for his antenna, and RG-213 type coax, which he had used before he discovered ladder line. In this illustration, each line was to be 100 feet long, a number I thought representative for a typical amateur installation (50 feet up the tree, 50 feet back to the shack).

By the way, this is a good point to digress just a bit. The wave mechanics in a transmission line can be a little mystifying to a novice (or even an old-timer like me). Books on transmission-line theory usually start out by analyzing a "theoretically perfect, lossless line." They look at such a line when it is matched, and then when it is mismatched. At this point they launch into detailed descriptions of forward and reflected waves, and all the complicated interactions they create. Sorry, but my eyes usually begin to glaze over by the second page.

There is a much simpler way to look at a practical (that is, lossy) transmission line that is not terminated in its characteristic impedance—*at any point on that lossy line a unique impedance exists.* If we insert an SWR meter (also called, more accurately, an *SWR bridge*) in the line, what we are measuring is the difference between the characteristic impedance of the line and the unique impedance at that point.

The value of the unique impedance at any one point on the line is determined by lots of factors—for the line itself, we have the characteristic impedance, physical length, velocity factor, and loss characteristics. Then we throw in the frequency and the terminating impedance (usually an antenna) at the end of the line. All these factors are elegantly and succinctly described by the Transmission Line Equation.[2]

[1] S. Ford, "The Lure of the Ladder Line," *QST*, Dec 1993, pp 70-71.
[2] *The ARRL Antenna Book*, 16th Edition, pp 27-29 to 27-30. See Eq 18.

We don't have enough room in this sidebar to get into the gory mathematical details, but we can let the personal computer simplify our lives. Some years ago I wrote a program called *TL*, short for *Tranmission Line*, using this equation to compute the input impedance for any length of lossy transmission line, terminated in any desired impedance. *TL* is a versatile program and can compute other useful line parameters also. You can download *TL.EXE* by modem from the ARRL BBS by dialing 203-666-0578.

But back to our story—The feedpoint impedances generated by *NEC2* were used in *TL* to generate Table 1. There are several things worth noting in this table. First, the feedpoint impedance varies quite considerably with frequency for a multiband dipole. At 7.1 MHz, where the antenna is nominally resonant, the SWR on a 50-Ω coax is a reasonable 2 to 1, but that same coax would see a phenomenally high 63,761 to 1 SWR at 1.83 MHz, where the 40-meter antenna is only an eighth-wave long! Due to the *extremely* high SWR at 1.83 MHz, the loss in 100 feet of RG-213 coax is 32.5 dB. If 100 W were fed into this line, only 0.06 W would appear at the antenna end. That's right—60 *milli*watts—instant QRP!

When trying to feed an extremely short antenna like this at 1.83 MHz, even low-loss 450-Ω ladder line would see a huge SWR of 7,355 to 1. Ladder line loses 11.2 dB, even though the matched-line loss at this frequency is a miniscule 0.01 dB per 100 feet. Another very nasty thing makes its presence known when extremely high SWRs are encountered for 1500 W of power at 1.83 MHz, *TL* computes that the maximum RF rms voltage is almost 40,000 V! That will fry most antenna tuners, or at least cause them to arc over internally. Steve was not kidding when he stated that his kW antenna tuner was not a happy camper on 160 meters, even when he had backed the power down to less than 20 W!

So the moral of this tale is simple—as versatile as multiband dipoles may be, especially to a ham who can't put up separate antennas for all the HF bands, they do have limitations. If they are electrically very short, for example on 160 meters, there will be losses in whatever transmission line feeds it. Using coax cable to feed a simple multiband antenna will result in far greater losses than for open-wire feeders, on all frequencies.—*N6BV*

Table 1
Inverted-V Dipole, 50 feet high, 66 feet long, fed with 100 feet of 450-Ω "window" ladder line, or 100 feet of RG-213 coax.

Frequency (MHz)	*Antenna feedpoint impedance*	*SWR for ladder line*	*Total loss (in dB) for ladder line*	*SWR for RG-213*	*Total loss (in dB) for RG-213*
1.83	1.6 – *j*2256.6	7355	11.2	63761	32.5
3.80	10.3 – *j*878.8	210	2.2	1505	18.1
7.10	64.8 – *j*40.6	7	0.2	2	0.7
10.10	21.6 + *j*648.4	64	1.8	392	14.9
14.10	5287.1 – *j*1309.5	13	0.5	112	9.7
18.10	198.2 – *j*819.9	10	0.6	72	9.4
21.20	102.9 – *j*181.2	5	0.3	9	3.2
24.90	269.3 + *j*569.6	5	0.4	30	6.9
28.40	3088.9 + *j*774.0	7	0.6	66	10.1

When you place a *standing-wave ratio* (SWR) meter in the line at your transceiver, it measures the result of this complex combination of waves and shows it as a function of forward and reflected power. That's why you get readings like 1.5:1, 2:1 and so on. The higher the SWR, the more power is being reflected back to your radio.

SWR and Feed Lines

Common sense tells you that having any amount of reflected power is a bad thing, right? Well...it depends. High SWR is more of a problem—and obsession—for hams today than in the past.

Prior to World War II, most amateur transmitters were designed for *open-wire* feed lines. Open-wire lines consist of two wires in parallel separated by an insulating material, mostly air. The impedance of the line is primarily determined by the spacing of the wires. Since much of the RF loss in feed lines is caused by the resistance of the wires and the nature of the material that separates them, open-wire lines have very low losses indeed! (Air is a good insulator for RF energy.)

With open-wire feed lines, little power is lost between the transmitter and the antenna. Even with a high SWR, the loss is usually minimal. The reflected power bounces back and forth, but most of it is eventually radiated at the antenna. As you can probably guess, few hams concerned themselves with SWR in the days when open-wire line was king.

As America entered World War II, open-wire feed line proved to be a problem for the military. It wasn't shielded from the effects of nearby metal objects, for example. If too much metal was too close to an open-wire feed line, it created an imbalance. This caused an impedance "bump" in the line. Power reflected from this point just like it reflected from a mismatched antenna. Open-wire line didn't take kindly to being wrapped around corners, either. (Open-wire line takes corners well enough, but the curve must be *gradual.*)

The military needed a feed line that was rugged, highly flexible and shielded. So-called *concentric line* already existed, but it wasn't very flexible. (A metal shield entirely surrounded a central wire used to conduct RF energy.) To solve the flexibility problem, manufacturers replaced the solid shield with a braided wire. Flexible insulation ensured that the braid was kept at a uniform distance from the center so that the impedance could be maintained. Before you knew it, *coaxial cable* (coax) was born!

Coax solved the installation problem. You could place coax right up against a large piece of metal and it didn't care. Better yet, you could easily bend and shape it—within reason. After the war, surplus coaxial cable flooded the market and invaded Amateur Radio with a vengeance. Within a few years it became the dominant feed line for all amateur applications.

Coaxial cable has a serious flaw, however. Unlike open-wire line, many types of coax have significant loss. Remember: The air insulation is gone and plastic has taken its place. Plastic isn't nearly as invisible to RF energy as air. You have to spend big money and invest in air-insulated *Hardline* coaxial cable before you have loss figures that rival open-wire lines.

Do you recall what we said about mismatches and reflected power? The greater the mismatch, the more reflected power is bouncing between your antenna and your radio (resulting in a higher SWR reading on your meter). This isn't a serious problem with open-wire line because of its low loss. Coax, on the other hand, may be burning up a significant amount of the power that's traveling up and down the cable. So, if you're feeding an antenna with coaxial cable, a little SWR paranoia may be warranted—depending on the situation.

Is it Okay to be Obsessive about SWR?

Sometimes a little obsession is a good thing. At other times you're just spinning your wheels. The pursuit of the "perfect" 1:1 SWR has the potential for plenty of wasted effort. Let's take a look at a few hypothetical examples and see what we have to gain or lose. The results were calculated using standard transmission line formulas.

Example 1: You've installed a 40-meter wire dipole antenna and you're feeding it with 50 feet of RG-58 coaxial cable. The SWR at the input to the coax is 1.5:1. (This is what you're reading on your SWR meter.)

In this example you're losing about 0.62 dB in total cable attenuation as a portion of your power travels back and forth. This means that only a tiny fraction of your power is being lost. You'd have to lose more than 1 dB before anyone would be able to hear the difference in your signal! If you trim and tweak your antenna to get it down to a 1:1 SWR, you'll gain nothing except the false satisfaction of seeing the result on your meter. (Your power loss will only drop from 0.62 dB to 0.57 dB!)

Example 2: You're still using the 40-meter dipole with 50 feet of RG-58 coaxial cable, but now you're trying to operate the antenna on 20 meters. The SWR on your meter is reading an astonishing 67:1. (Most SWR meters won't really read this high and most transceivers without antenna tuners would shut down.) When the SWR is high, the loss in the coax becomes *very* significant. In this situation, you're losing about 7 dB of your power in the cable. If you were transmitting 100 W, less than *25 W* would actually be radiated by the antenna.

Example 3: You're determined to use your 40-meter antenna on 20 meters, so there's only one thing to do: replace that 50 feet of RG-58 coax with open-wire line. In this case we'll assume that you're using common 450-Ω ladder line. Because the impedance of the open-wire line is different from that of your RG-58, the resulting SWR is different, too. Now you're dealing with an SWR of 7.5:1. That's better than 67:1, but it's still high. Even so, the open-wire line loses only *0.17 dB* of your power! With an antenna tuner to match the open-wire line to your transceiver, you can use your 40-meter antenna on 20 meters with little difficulty—or loss.

I should point out that the term "antenna tuner" is a misnomer. An antenna tuner doesn't tune the antenna at all. You can only do that at the antenna itself. Instead, an antenna tuner acts as a resonator and an impedance transformer. It matches the impedance at the shack end of the feed line to a value (usually 50 Ω) that will make your transceiver happy. That's why many amateurs prefer to call them *transmatches.*

Example 4: Let's head up to the 2-meter band. Here we have a beam antenna fed with 100 feet of RG-58 coaxial cable. Unfortunately, something is wrong at the antenna and the SWR is 4:1. If you thought that RG-58 was lossy on the HF bands when the SWR was high, wait until you see what happens on 2 meters. The result is a loss of 8.45 dB. If you were running 25 W, your antenna would be radiating only about *3 W*—and you wouldn't hear very well either! (It's not only the transmitted energy that's lost in the line, received signals are attenuated, too.)

In a situation like this, your SWR meter down in the shack can fool you about what's happening at the antenna. The loss in a feed line can hide a bad mismatch, making it look much better than it really is. In this case, the SWR meter would show a 1.7:1 SWR—even though the SWR at the antenna is really much higher!

Example 5: We fixed the 2-meter antenna and replaced the lossy RG-58 coax with a superior feed line (Belden 9913 or equivalent). The SWR at the antenna is now down to 1.5:1. With our 100 feet of 9913 cable, the total loss is 1.68 dB and we can trust the SWR meter again! We can rest assured that most of our 25 W output is being radiated by the antenna.

I'll bet some of you are saying, "If the SWR is down to 1.5:1, we can go back to using the RG-58 coax, right?" Sorry. Feed-line loss increases as you go higher in frequency. Even with a low SWR, the loss at 2 meters with 100 feet of RG-58 is still an appalling 6.58 dB. That's why you should never use RG-58 cable at VHF or UHF unless the length is *very* short (mobile applications, for instance).

What Have We Learned?

All five examples have one thing in common: They show that power loss in feed lines is a function of the type (and length) of feed line you're using, the frequency of the signal *and* the SWR. All of these factors act together in complex ways. The bottom line on SWR is that it isn't the evil beast it's cracked up to be. A high SWR isn't necessarily a bad thing at all—*if your cable isn't eating up your power.*

Taking this idea to extremes, imagine

(continued on page 74)

The SWR Obsession

(continued from page 72)

10,000 feet of totally *lossless* feed line. (Maybe 10-inch diameter Hardline bathed in liquid helium?) At one end of the line you have the mother of all antenna tuners, able to match virtually any impedance to 50 Ω for your transceiver. At the other end, you have a hideously mismatched antenna with an SWR of 99,999:1 at 3.8 MHz. Will this ridiculous setup work? The answer is "yes." Despite two miles of cable and an SWR the likes of which God has never seen, the vast majority of your transceiver's power will be radiated at the antenna.

Remember what we said about the bouncing waves. The power that isn't lost in the feed line or at other points in the system has to go somewhere. That "somewhere" is out your antenna! So, when you see the SWR reading on your meter, think carefully and take all the other factors into account *before* you get out your ladder!

When to Worry about SWR—and When Not to Worry

❑ Don't worry if you're feeding an HF antenna with 50-Ω coaxial cable and the SWR is 3:1 or less. If the length of your feed line is within reason (100 feet or less), the difference between an SWR of 3:1 and 1:1 isn't worth your trouble. You can even run as high as 5:1 SWR with good-quality coax and suffer relatively little loss. If your radio is cutting back its output because of an elevated SWR, use an antenna tuner to provide the 50-Ω impedance it needs.

If you're running over 500 W output, achieving a lower SWR may be in your best interest. Feed line, filter or antenna tuner damage may result if you try to run too much power with an elevated SWR.

❑ Don't worry if you're feeding an HF antenna with open-wire line and an antenna tuner. SWR has little meaning in this situation until you start talking about SWRs in the range of several *thousand* to one. Simply adjust the tuner for a 1:1 match at your radio and enjoy yourself.

❑ *Worry* if you're operating at VHF or UHF and the SWR is higher than 2:1 at the antenna. Even high-quality coax has substantial loss at these frequencies when the SWR starts creeping up. Adjust the antenna to bring it down to something less than 2:1. *DO NOT* use a so-called VHF/UHF antenna tuner! The tuner will provide a 1:1 SWR for your radio, but you're living in a fool's paradise. The SWR is still unacceptable on the *antenna side* of the tuner and that's where you're losing power.

❑ *Worry* if the SWR on your antenna system changes substantially (up or down) for no apparent reason. Some fluctuation is normal, such as when ice coats open-wire lines, but big changes are a warning. Your antenna system may have a problem and you'd better check it out.