Setting the Record Straight: SWR

SWR – does your antenna perform better with a 1:1 SWR than with a 2:1 SWR? Is there a relationship between antenna performance and SWR?

By Eugene Morgan (WB7RLX)

I have thought about writing this article for a very long time. The reason is due to all of the misinformation and misunderstanding about SWR and what it actually means in terms of antenna performance. How many times have we all heard conversations about antennas that seem to always start with SWR and that seem to suggest there is a relationship between SWR and performance. I hope in this article to explain the fallacy in this idea but more importantly help the reader to better understand SWR and what it's actually telling you about your antenna system.

A lot of what I'm going to write about has already been written by many other authors. Consequently it will be hard for me to not appear to be plagiarizing some of them. I will at the end of this article give credit to those whose work I have studied and have helped me to understand the true meaning of SWR. Of course I will not go to the level of detail they have and instead encourage those that want to go deeper into the topic to go directly to the sources I have reference at the end of this article.

Throughout this article you will see paragraphs that start with **Key Takeaway:** If you didn't understand what the ideas being expressed was, focus on the key takeaways. The key takeaways attempt to summarize the points or key ideas of the sections they follow. So with that let's jump in and see if we can get a better understanding of this whole SWR thing and what it all means.

How many of us have heard some of the following ideas expressed in our conversations with other hams:

- "I can't operate on the 80-meter band because I don't have room for an antenna."
- "My SWR is 2.5:1 but if I can get it down to 1:1 my antenna will work much better."
- "My SWR was 3.5:1 but my antenna tuner brings it down to 1.1:1."
- "My antenna works best on this frequency because it is resonant here."
- "My SWR is 2:1, so I lose half of my power by being reflected"
- "I had to put up four dipoles so I can operate on 80, 40, 20 and 17 meters."
- "If my SWR is more than 1.5:1, it's bad."
- "I spent all afternoon trying to get my SWR down to 1.5:1."

These statements and others like them demonstrate the general lack of understanding regarding SWR in spite of all the articles and information that has been published on the topic. Of course

I'll be the first to admit that some of these articles are hard to understand as they often include so many formulas and with funny characters in them few of us non-math majors understand. Here's a perfect example from the ARRL Antenna Handbook:

	Equation	*Valid for:*
ARRL Antenna Book, 24th ed. p. 23.13, eq. (16)	$\frac{1}{\eta} = e^{2\alpha l} \frac{1 - e^{-4\alpha l} \left\|\Gamma_L\right\|^2}{1 - \left\|\Gamma_L\right\|^2} = \frac{\mathrm{a}^2 - \left\|\Gamma_L\right\|^2}{\mathrm{a}\left(1 - \left\|\Gamma_L\right\|^2\right)}$	Z_0 real $X_0 = 0$ $\mathrm{a} = e^{2\alpha l}$ $\Gamma = \frac{Z - Z_0}{Z + Z_0}$

Figure 1: Transmission Line Loss Formula that includes SWR

There's not many hams that can look at the formula in Figure 1 and know what it's actually saying. What it's expressing is the total loss in a transmission line including the loss due to SWR. So it's no wonder why so many misunderstand what SWR actually means. It also doesn't help that over the years the ARRL antenna handbook inconsistently referred to this formula as both the "*Additional Loss"* in one section and "*Total Loss"* in another section of the same handbook. They also used different notation for some of the Greek characters in the formula in several different editions of the handbook[1]. Fortunately this was for the most part corrected by the 18th edition of the Antenna Handbook.

True or False – Test your knowledge

In this next section I'm going to borrow a test that I took a long time ago about SWR. This test is from the book "*Reflection III*" by Walter Maxwell, W2DU[2]. I'm not going to reproduce the entire test here and I've shortened many of the questions and tried to avoid going to the same level of detail he does. However the test I've summarized here will be a good measure of your current understanding of SWR. Hopefully by the end of this article you will have improved your knowledge.

1. Reflected power does not represent lost power. True or False: __
2. Reflected power does not flow back into the transmitter and cause dissipation and other damage. Damage blamed on high SWR is really caused by improper output-coupling adjustment, not by SWR. True or False: __
3. Any effort to reduce an SWR of 2:1 on any coaxial line will be completely wasted from the standpoint of increasing power transfer significantly. True or False: __
4. Low SWR is not proof of a good-quality antenna system or that it is working efficiently. True or False: __

5. The radiator of an antenna system need not be of self-resonant length for maximum resonant current flow and the feed line need not be of any particular length. True or False: __
6. SWR on the line between the antenna and ATU is determined only by the matching conditions at the load and is not changed or "brought down" by the matching device. True or False: __
7. High SWR in a coaxial transmission line caused by a severe mismatch will not produce antenna currents on the line, nor cause the line to radiate. True or False: __
8. SWR in a feed line cannot be adjusted or controlled in any practical manner by varying the line length. True or False: __

In Dr. Maxwell’s test there are a total of 27 questions. I picked only nine because they seem to be the kinds of misunderstanding I hear most often voiced. As has already been stated this is a much shorter list and the nine questions I used were summarized. If you really want to be surprised refer to his book. For the record the answer to all the questions is True.

What is SWR

What is SWR? As simply as can be stated it is the ratio of power being sent to the antenna versus the amount of power being reflected by the antenna. Note that in most articles on SWR the antenna is often referred to as the “load” and the radio or transmitter is often referred to as the “generator.” It’s also at this point the traditional SWR formula is presented. I’m not going to do that here. Instead we are going to focus on the concepts rather than the math.

By using a specific example we can better understand what SWR actually is. There are usually four things present in any radio station: a transmitter, a tuner (aka: an ATU), a transmission line, and an antenna. We will discuss what happens when there is no ATU in a moment, let me just say at this point it’s not good.

When I press down on my CW key my radio sends energy of a certain strength (power) and frequency to the ATU. The ATU is adjusted so the transmitter sees a 50 ohm load. Because of that near perfect match all 100 watts is passed through the ATU and to the transmission line and finally to the antenna at the other end of the transmission line. In cases where the antenna is mismatched to the transmission line a portion of that power is sent back toward the transmitter. The power that is sent back toward the radio is called reflected power. The term we use to express what is happening is SWR. SWR is the measure of what is happening to the forward and reverse voltage and how they compare in size. SWR is the “ratio” of forward to reflected energy and is expressed as a ratio such as 1:1 or 2:1 or 4.5:1 and so on. Note that SWR is not expressed in dB, or watts, or volts or anything else for that matter. But if we know what the units are: volts, watts, or even dB we can use the SWR ratio to convert to whatever units we choose to express loss in. This is of course where things get really messy with lots of math and it’s usually at this point we stop reading, so we won’t go there in this article. Let’s skip all that and see if we can work out what this all means and leave the math to the egg head set. My apologies to the egg head set.

So what does this forward power, reflected power and so on actually mean? The best way to understand this from a practical standpoint is to work through an example. Let’s say my radio supplies 100 watts worth of wiggles via a make believe lossless ATU and the ATU pumps 100 watts into a make believe lossless transmission line. At the end of our perfect transmission line is an antenna. When the power hits the antenna there is an impedance mismatch. Oh no! The mismatch is such that 10% of that precious power gets reflected back down the transmission line. So what happened to that 10 watts that gets reflected? Is it lost, I mean truly lost, does it evaporate, does the IRS collect it, where does it go?

Well, 90 watts is radiated into the ether and 10 watts is sent back down the transmission line where it runs smack dab into the ATU. Guess what happens next? That 10 watts is sent right back to the antenna and this time when that 10 watts hits the antenna 9 watts is sent into the antenna to be radiated and 1 watt is sent back to the ATU. And what happens to that 1 watt when it hits the ATU? You guessed it, it’s sent right back to the antenna. Where 90% of the 1 watt is radiated into the ether and the other 10% goes right back to the ATU.

This little back and forth between the ATU and the antenna goes on and on until every microvolt of the radio wave has been radiated. So even with a mismatch there was no loss of power, it all got radiated.

So now let’s get back to the real world where there’s no such thing as a lossless ATU or lossless transmission line. The world where every time a radio wave passed through something there is a tax that must be paid, paid in the form of energy. Like they say, there is no free lunch in spite of what some would have you believe.

Let’s replay the scenario above but this time we recognize the losses as the radio wave passes through each device. In our real world example my radio sends 100 watts to the ATU and the ATU takes a very tiny amount of the power. It varies but as a rule the loss is very small so for now will say it’s a tenth of a watt and sort of ignore it for the sake of simplicity. The ATU passes the nearly 100 watts to the transmission line. Now this is where it starts to get expensive.

As we all know transmission lines all have some level of loss. For example for RG58 the loss is pretty big, so that inexpensive 100 feet of RG58 just took a portion of the power, about 2.8 dB worth at 28 MHz, so much for cheap coax. So as they say, you’re going to pay for it somewhere. Fortunately RG8X isn’t as bad, it will only take 1.4 dB. And the DXE-400 Max coax you paid $1.18 a foot for took only .8 dB.

To get our heads around this let’s put these losses into context. Understand that an S-Unit is 6 dB. Stop here and think about that for a moment, an S-unit is equal to 6 dB..…… So our signal finally arrives at the antenna a bit poorer than when it started. At the antenna 90% of the power that’s left is sent on its way to that DX station in Japan. Guess what happens to the other 10%, it gets sent back to the ATU and it also has to pay a 10% tax on its way back to the ATU. And when it hits the ATU what's left is sent back to the antenna and again it pays another 10% tax on its way back to the antenna. And again 90% of the energy that's left gets radiated and 10% gets sent back to the ATU where it pays another 10% tax and is then sent right back to the antenna losing another 10% as it goes.

This of course goes on and on until not one microvolt of energy is left and with each transit of the transmission line a 10% energy tax is paid. So what happened to all the energy that got lost in the transmission line? Good question, the answer, it was turned into heat. So what can we take away from this? First the higher the SWR the larger is the amount of power that is sent back and forth. So with higher SWR there is a higher loss, but the reflected energy is not totally lost. The other key point that those who like to run a lot of power should be aware of, all that power can create enough heat to melt a hole in the transmission line. So be careful if you're using an amplifier. Running 800 watts into an antenna system with a high SWR on the feed line can damage the feed line by melting little holes in the dielectric and even into the jacket of the coax.

Key Takeaway: In our lossless system all 100 watts of the power was radiated in spite of the mismatch. No power was lost, it was all radiated. In our real world system where there was loss we learned that nothing is wasted. The 100 watts is either converted into RF or into heat. What we also learned is that only a portion of the reflected power is turned into heat but a large majority of the reflected power is actually radiated. Later you will learn just how much power is lost. I think you will be surprised. I'll give you a hint, it's not as bad as you might think.

Now let's take another look at the above scenario and assume there is no ATU in place, however we still have the lossless transmission line in place. What happens in this case? Those of you who don't believe in ATU's pay close attention. The reflected power triggers the mismatch protection circuit of the transmitter, which in turn causes the transmitter to reduce the output power. The power is reduced by the amount of reflection. In this case, the reflected power does not get re-reflected back out the antenna where it could be radiated. The result is that the transmitter throttles back and less power is sent to the antenna. The reflected power does not cause heating in the transmitter but it does result in reducing the amount of available power, which is purposely designed into the radio. Therefore, hams who refuse to use a tuner actually prefer by implication, and perhaps unknowingly, this mode of needless reduced power operation. So it not the reflected power that's lost, it's lost power due to the fold back circuitry being triggered by the reflected power.

Why then is the power reduced when a certain mismatch level exits? The answer is that the reflected impedance (reflected voltage divide by reflected current) going to the transmitter causes the operating voltage or current to increase beyond the design limits established for the final power amplifier transistors and associated components. It is the change in **impedance and NOT the reflected power** that causes the throttle back effect, which is triggered to protect the transistors from being subjected to voltage and/or current values beyond their rated specifications.

The key thing to understand about the ATU, that besides providing the ability to match the transmitter to the transmission line, the ATU provides a gating effect. It's like a one way valve or a better analogy, like a giant diode for radio waves. In the ATU power traveling from the transmitter port of the ATU goes through the ATU and out the antenna port with very little loss. However the reflected power as it comes back to the ATU is totally reflected back to the antenna. So in our lossless transmission line 100% of the power is eventually radiated. With no ATU the transmitter is throttled down to protect the components from operating beyond their design limits which reduces output of the transmitter.

Key Takeaway: Use an ATU whenever the SWR of an antenna is great enough to trigger the mismatch protection circuit (aka: fold-back circuity). For most radios that happens at around 1.5:1 or greater SWR. The rig with an ATU continues to deliver full power to the antenna regardless of the feedline's SWR, assuming the tuner is engaged and properly adjusted. The tuner-less rig does not. So on rigs without tuners one should consider an external tuner be added to the antenna system. An ATU also provides an added benefit, it allows an antenna to be used across a larger portion of the band and even on multiple bands in many cases. This is especially advantageous for the lower HF bands such as 40-160 meters where antennas tend to be a bit narrow banded. It's also critical for the ham who wants to do FT-8 and or CW as well as SSB. CW and FT-8 are always at the lower end of the band and SSB is usually at the higher end of the band. The ATU allows an antenna to be used across a wider frequency range and in some cases allows the antenna to be used across multiple bands.

What's my SWR?

As can be seen in Figure 2, even the best transmission line is not without loss and that loss increases with frequency. What that means is that every time a radio wave transits a transmission line it loses some of its energy to heat regardless of what direction the wave is traveling. This is referred to as attenuation, earlier I referred to it as a kind of a toll tax or energy tax. Each time the radio wave travels traverses the transmission line, either from the ATU toward the antenna or from the antenna toward the ATU, it will be attenuated according to the feedline's attenuation properties, (dB loss in meters or dB loss in feet). These values are found in the spec sheets provided by the cable manufacturer. Before selecting a cable for your station you should take a look at these spec sheets and specifically at the loss numbers for the bands you intend to use the coax for.

This information is essential in determining the initial loss and the extra loss that will be cause by SWR. For example, suppose you are using 100 feet of RG58/A at 7 MHz. The typical total loss for 100 feet of RG58/A at 7 MHz with a perfect 1:1 matched between the antenna and feedline is 1.05 dB. If your SWR happens to be 1:1, then you already know what the feedline loss is. But if the SWR is not 1:1, then there will be additional loss in the line. This additional loss is called the *SWR loss*. To put this another way, ALL the RF energy that is not converted into heat will be radiated by the antenna. That's why even with 10 watts of reflection not all 10 watts will be wasted, only a very small portion will be attenuated. As we saw in our earlier discussion a portion of the energy will be converted into heat as it goes back toward the ATU and then another portion will be converted to heat as it travels back to the antenna and so on until all the energy has been either radiated or converted into heat in the transmission line. The formula I introduced you to at the beginning of this article is one of several formulas used to calculate total loss in a transmission line, some of its key inputs are attenuation and SWR. But not to worry, we are going to try to simplify the calculation by using a couple of tables. Of course our estimates may not be as accurate as might be derived by using a formula only few understand, but our method will be good enough that we can get a rough approximation of the loss in our antenna systems.

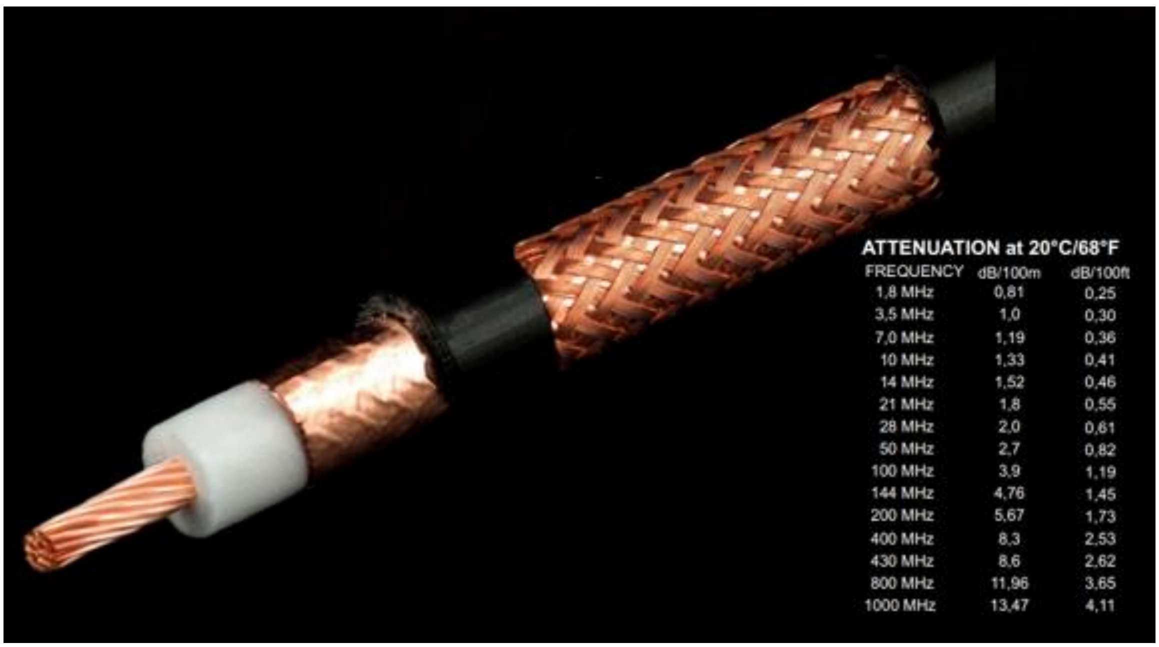

Figure 2: Loss numbers for M&P UltraFlex 10

Now that you understand what happens as your signal travels back and forth across the transmission line, let's try to quantify the real impact of SWR. In short what does it mean, how much power or rather signal do I actually lose to SWR, and should I be worried?

What's My REAL SWR?

The first step to understanding the potential loss in your antenna system is understanding what your real SWR is, here's a hint, it is not what you measured from the comfort of your shack which is generally where the measurement is taken. Measuring it at that point does not give an accurate reading due to the attenuation that is occurring on the feed line. To get the actual SWR, the measurement should be taken at the antenna feed point. The reading you get in your shack is the apparent SWR and is always less than the actual SWR. Sometimes the difference is considerable if the feedline is long and/or has high loss such as in the case of RG58A and RG8X.

However, putting an SWR meter at the antenna feed point is not easily done, especially when it's at the top of your 60' tower or in a tall tree, or suspended in midair by two thin wires. But there are ways to find out what your real SWR is. There is software out there that can make the calculation for you, one I recommend is TLW[4] which is included with the ARRL antenna handbook. There is another way of doing it that I will present here. I should note that the results using the tables will be an estimate and will vary from reality. Actual loss in a given antenna system can truly only be measured using a VNA and while having access to both ends of the transmission line.

SWR at the Transmitter

dB Loss	1.0	1.2	1.4	1.6	1.8	2.0	2.5	3.0	4.0	5.0	6.0	7.0
0.2	1.0	1.2	1.4	1.6	1.9	2.1	2.6	3.1	4.2	5.5	6.8	8.0
0.4	1.0	1.2	1.4	1.7	1.9	2.1	2.7	3.4	4.7	6.3	8.0	9.5
0.6	1.0	1.2	1.5	1.7	2.0	2.2	2.9	3.7	5.2	7.8	10.0	
0.8	1.0	1.2	1.5	1.7	2.0	2.3	3.1	4.0	6.0	9.0		
1.0	1.0	1.2	1.5	1.8	2.1	2.4	3.3	4.3	7.0			
1.2	1.0	1.3	1.5	1.9	2.2	2.6	3.6	4.8	7.0			
1.4	1.0	1.3	1.6	1.9	2.3	2.8	4.0	5.5	9.9			
1.7	1.0	1.3	1.6	2.0	2.5	3.0	4.3	6.5				
2.0	1.0	1.3	1.7	2.1	2.8	3.3	5.3	8.4				
2.5	1.0	1.4	1.8	2.4	3.2	4.0	8.0					
3.0	1.0	1.4	1.9	2.7	3.7	4.9	9.8					
3.5	1.0	1.4	2.1	3.1	4.6	6.9						
4.0	1.0	1.5	2.3	3.7	6.0	6.9						
4.5	1.0	1.6	2.6	4.7	7.9							
5.0	1.0	1.8	3.0	6.0								
5.5	1.0	2.0	3.4	8.5								

Table 1: Actual SWR at the Antenna

The key output of this first exercise is to establish the true SWR, the SWR as if we were to take it at the feed point of the antenna. The true SWR will be one of the numbers from the table above using your cable's attenuation values which is represented by the left most column. The left column is what we call the *Match Loss* and is expressed in dB. Think of it as the toll tax or energy tax that is charged every time a radio wave crosses the coax from one end to the other regardless of direction. The top row of numbers is the measured SWR at your radio and is expressed as the first half of an SWR ratio, the second half is always a 1. Example 1:1 or 2.5:1 and so on. All of the other numbers in the table represent the *Real SWR* values based on measured SWR in the shack (top row) and *Match Loss* in dB (left most column). To better understand let's do an example.

If your transmission line is UltraFlex 10 and is 100 feet long and your target frequency is the 10 meter band (28 MHz) then your match loss would be .61 dB, refer to Figure 2. If the measured SWR in the shack is 2:1 then the actual SWR at the antenna would be around 2.2:1. How did we get that number? Look at the left side of the table and locate the row where you see .6 (row 3). Now look along the top row and locate the column closest to the SWR of 2:1 (column 6). Now find the intersection of column 6 and row 3. There you will find 2.2. 2.2:1 is your *Real SWR*, the SWR we would most likely find at the antenna if we measured it at 28 MHz. Write that down. We will use it again. Label it *Real SWR*. Also write down the *Match Loss,* which is .61 dB. In case you were wondering where the .61 dB figure came from look at the manufactures spec sheet, see Figure 2.

Just in case you were wondering what if my transmission line were shorter say 50 feet long, then the match loss would be estimated at .3 dB. This would infer that your actual SWR at the antenna would be around 2.1:1.

Now let's estimate what the actual impact of your *Real SWR* is in relation to how much you lose in the signal. I think you may be surprised by the answer so hang in there. We are almost done.

How Much Does *Real SWR* Affect My Signal?

To really understand let's continue on with our example. Okay, we've establish we have a *Real SWR* of 2.2:1. Now we want to know how much our signal is affected in dB. Why dB? Because that's the easiest reference we have that we can relate to. Think about your S-meter. On your S-meter one S-unit is equal to 6 dB. So if we can relate our signal loss to our S-meter we can get a real sense of the impact of that loss. Consider that the difference between an S3 signal and an S4 signal is 6 dB. Between an S4 signal and an S9 the difference is 30 dB. Let's keep going, what you will find by working through this exercise will be beneficial and maybe even surprising. Ready?

Now let's turn our attention to table 2. Table 2 looks a lot like table 1. It's set up the same way. The green column on the left represent the known dB loss for a given transmission line, the *Match loss*. The dark blue row across the top is the *Real SWR* instead of the apparent SWR. All of the values in the table represent SWR loss in dB. We are going to use the intersection of the *Match Loss* column with the *Real SWR* row to calculate our signal loss due to SWR in dB.

Let's now use the numbers we got from the first exercise. Locate the *Real SWR*, which is 2.2 on the top row of table 2 (hint, column 3 is the closest, we will split the difference in a moment.) Now locate the row closest to the *Match Loss* (hint, row 3). Now find the intersection of column 3 and row 3. The number you find there is .1 dB. But because our

Real SWR was between 2:1 and 2.5:1 let's split the difference and call it .15 dB. Now let's do some real simple addition, you will not need your calculator for this.

The formula for total loss is Match Loss + SWR Loss = Total Loss in dB. So let's plug in some numbers: .61+.15=.76 dB. So our total estimated loss for a 2:1 SWR as measured from the shack is a whopping .76 dB? What! Only .76 dB? Not even one sixth of an S-unit, really? Yes, really. I told you that you would be surprised. Not even a flicker of the needle on the S-meter. So about now you must be asking yourself if it's really worth it to pull the antenna down for the fourth time and snip a bit more off or add a bit more back on in an effort to get the SWR to 1:1 or even 1.2:1. Reflect on that for a minute, pun intended.

Another point I'd like to make. In our example we used 28 MHz. Loss increases as frequency increases. Likewise, loss decreases as frequency decreases. So let's take this same example but instead of 10 meters let's consider 20 meters or 40 meters. The losses we could expect to see on our 40 meter dipole with a 2:1 SWR would be hardly measurable. On our 20 meter vertical the change from a 2:1 to a 1.2:1 SWR wouldn't be noticed by the guy a block away. So killing yourself for the holy grail of a 1:1 SWR is just not productive. Instead, be happy with the 2:1 and get on the air an make some contacts. Or better still read *Reflection III* and find out about low SWR for the right reasons and the wrong reasons. Yes those really are chapters in Dr. Maxwell's book.

Real SWR - SWR at the Antenna

dB Loss	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
0.2	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.7
0.4	0.0	0.0	0.1	0.2	0.2	0.4	0.5	0.7	0.8	1.0	1.1	1.3
0.6	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7
0.8	0.0	0.0	0.2	0.3	0.4	0.7	0.9	1.2	1.5	1.7	1.9	2.1
1.0	0.0	0.0	0.2	0.3	0.5	0.8	1.2	1.5	1.7	1.9	2.2	2.5
1.2	0.0	0.0	0.2	0.4	0.6	1.0	1.3	1.7	1.9	2.2	2.5	2.8
1.4	0.0	0.0	0.2	0.4	0.6	1.1	1.5	1.8	2.1	2.4	2.7	3.0
1.7	0.0	0.0	0.3	0.5	0.7	1.3	1.7	2.0	2.3	2.6	3.0	3.3
2.0	0.0	0.1	0.3	0.5	0.8	1.3	1.8	2,1	2.5	2.8	3.2	3.6
2.5	0.0	0.1	0.3	0.6	0.9	1.5	1.9	2.3	2.8	3.1	3.5	3.7
3.0	0.0	0.1	0.3	0.6	1.0	1.5	2.0	2.5	2.9	3.2	3.7	4.0
3.5	0.0	0.1	0.4	0.7	1.1	1.6	2.1	2.6	3.1	3.4	3.8	4.1
4.0	0.0	0.1	0.4	0.7	1.1	1.7	2.2	2.7	3.2	3.5	3.9	4.2
4.5	0.0	0.1	0.4	0.7	1.1	1.7	2.3	2.8	3.2	3.6	4.0	4.3
5.0	0.0	0.1	0.4	0.8	1.2	1.8	2.3	2.9	3.2	3.7	4.1	4.4
5.5	0.0	0.1	0.5	0.8	1.2	1.8	2.4	2.9	3.2	3.8	4.2	4.5

Table 2: Additional Loss Caused by SWR

Following is the 6 step process we followed to arrive at our estimated loss due to SWR. You can use this 6 step process and plug in your own numbers. You might be surprised at the results.

a. We know the cable run is 100’ of UltraFlex 10. It has a loss at 28 MHz of around .61 dB when measured across 100’ of coax. We know that by looking at the manufacture’s spec, see, Figure 2. It happens that our cable run is also 100’

b. We have measured the SWR in the shack for our 10 meter vertical which is 2:1 at 28 MHz

c. Next we estimate the actual SWR at the antenna. Refer to table 1. Look down the left side until you come to .6 then we look across the top row of the table until you come to the apparent SWR of 2.0. Now look at the intersection of the apparent SWR and the Match Line Loss. In our example at that intersection we find an SWR value of 2.2. Our *Real SWR* = 2.2:1 and our Match Loss is .61 dB

d. Now refer to table 2. Again we go down the left side until we find the match loss of .6 dB. Look across the top row until you come closest to our Real SWR of 2.2. That would be column with 2.0 at the top. Now find the intersection of the *Match Loss* row and the *Real SWR* column. At the intersection of those two we see that actual estimated loss is .2 dB. But we are going to fudge it a bit because our actual SWR of 2.2 is between 2,0 and 2.5. So let’s assume the loss is somewhere between .1 and .2 dB. Let’s estimate it at .15 dB.

e. Now let’s make the calculation: Match loss + SWR loss = Total loss.

    a. Match loss = .61 dB
    b. SWR Loss = .15 dB
    c. .61 dB + .15 dB = .76 dB.
    d. Total loss = .76 dB

In general, when the SWR loss is less than 1 or 2 dB then you are wasting your time by striving for a perfect match. A change in signal strength of 1 dB is recognized as the smallest detectable change. Therefore in practice, anything less amounts to practically nothing. A loss of 1 dB will not be detected by the other station under the best of conditions or for that matter the worst of conditions. Also note that having an SWR loss of less than 1 dB does not mean you have a great antenna or a poor antenna. It simply means there is no point in trying to get a better match with the existing feedline. We will look into that fallacy in a minute.

Key Take Away: At HF frequencies trying to get your SWR down under even 3:1 is often a waste of effort. You are better served to look for other deficiencies in your antenna system in order to minimize loss. For example, do you have a good ATU, are you using a good low loss cable? Can you get your antenna any higher? Do you have enough radials under your vertical? Is there another antenna type that might serve you better? Is my transmission line longer than it needs to be? Consider your options and don't waste time on things that have little return on investment.

Key Take Away: There is another more subtle takeaway from the above example. There is an advantage to lowering the SWR on the antenna if the antenna is one that by its very nature present a high impedance to the feedline. There are several examples: The OCF dipole, the half wave wire, and the long wire, are just three examples. That is one of the reasons these antennas have an impedance transformer at the feed point of the antenna. This is also a case where it might make sense to locate a remote antenna tuner at the feed point of the antenna. By doing so you remove any extra loss due to SWR. If the cable run is short and the cable has good low loss numbers, then there's really no advantage to doing this. But if the cable run is long in terms of wave lengths at the highest frequency used, say 3 or 4 wave lengths or more, and the SWR on the antenna is high, as is often the case with antennas like the G5RV, the OCF dipole, the half wave wire and the long wire antenna, then it might make sense to invest in a remote tuner. But again only when these two conditions are meant: a long transmission line and a high SWR >3:1.

Another antenna that might benefit by having the tuner at its base is the vertical. The vertical, unlike the antennas mentioned above, has the opposite problem, it presents a very low impedance at the feed point, sometimes as low as a few ohms so there can be a significant mismatch at the feed point. In that situation it might make good sense to place a remote tuner at the base of the vertical, especially if the feed line is long in terms of wave lengths for the highest frequency used.

A Note about VHF, UHF and SWR

Throughout this article I have been focused on HF where losses due to SWR are generally so small as to not make a difference in overall signal strength. The same rules do apply to VHF and UHF, however things are much more complicated. First off at VHF and UHF attenuation in the transmission line is going to be considerably greater. Second, at HF UHF fittings like PL-259's, SO-239's, male to male and female to female couplers have very little loss. So little that it has no measurable effect on power measurements. But at VHF and above that's no longer the case. This is one of the key reasons why for UHF and above the use of Type-N fittings is always recommended. With N-Type and BNC fittings loss is minimal and there is no impedance bump as we see in UHF fittings[3].

The other reason is at VHF and above even small losses matter. The loss of a dB can make a difference in modes such as Earth Moon Earth (EME), meteor scatter, and other weak signal communication modes that depend on line of sight propagation. This also includes modes that depend on tropospheric ducting, which usually take place a 50 MHz and above. At HF the loss of a few dB is not critical, at VHF and above, it can be much more impactful. This is why in VHF and UHF systems much more attention is paid to using very low loss transmission lines such as hardline and Heliax and in keeping transmission lines as short as possible or eliminating them altogether.

Does my Tuner (ATU) Change the SWR on the Transmission Line?

Here again the short answer is no. This is another common misconception. The ATU only changes the impedance your transmitter sees. The tuners job is to make sure your radio sees a 50 ohm load. The key reason for that is to stop the transmitter from throttling back the output in order to protect the finals from seeing a high impedance. That's all it does.

You can test this yourself. If you insert an SWR meter between your radio and the ATU and adjust the ATU appropriately the SWR meter will show a good match, usually something very near to a 1:1. But if you change nothing and move the SWR meter between the ATU and the antenna you will see the SWR as it really is. If you move the SWR meter to another place in the transmission line closer to the antenna you may notice the SWR is only slightly higher. This is because there will be less attenuation as you get closer to the antenna.

Key Take Away: The ATU does NOT change the real SWR on the transmission line. If the SWR as measured at the radio is say 2:1 for example without the ATU, it will remain 2:1 with the ATU engaged and adjusted for a low SWR. The 1:1 match would be between the radio and the ATU, not between the ATU and the antenna. Also what you would find if you could move the SWR meter closer to the antenna, is the SWR would increase ever so slightly. Attenuation in the feed line is the reason for the small change in SWR. If the SWR is considerably higher that is a good indication there is something very wrong in the system, possibly a bad length of coax or water has seeped into the coax, or you have a bad fitting somewhere in the system.

In extreme cases of a high SWR coupled with a long transmission line it would make sense to put a tuner at the feed point of the antenna in an effort to lower the SWR on the transmission line. But multiple ATU's should NEVER be put in line. If you still can't get the SWR in range using your ATU you could use an ATU extender like the MFJ-914 tuner extender. However you should never put two ATU's in series. That means if you have both an ATU in your radio and an external ATU, they should never be used together at the same time, use one or the other but not both at the same time.

What Does SWR Have To Do With Antenna Performance

The short answer to the question, nothing. Here again is another often misunderstood concept. SWR is only a measure of the ratio of forward power to reflected power and nothing more. SWR says nothing about how well you’re antenna is performing. If SWR really mattered as a performance indicator then we would all put dummy loads on our roofs and be done with it. The dummy load after all has a very low SWR across the entire HF spectrum. But as should be apparent by using this extreme example it should be obvious that SWR has nothing to do with antenna performance. What matters when it comes to antenna performance is height and size, at least that’s what the physics tells us and there is no way to cheat the physics as we currently understand it. Maybe someday when we have quantum physics figured out and the nature of dark matter and energy are understood, maybe then we will discover something new, like the quantum gravity dark energy antenna, or the QGDE antenna as I like to call it.

There are many examples of antennas that are good performers that have high feed point impedance by their very nature. I have already mentioned several of them, the cast of characters includes: G5RV (when installed correctly) which uses 450 ohm window line attached to 50 Ohm coax usually through a 1:1 balun. The long wire and the half wave long wire. Both of these antennas have a very high feed point impedance and require a 9:1 unun and a 49:1 unun respectively. Then there is the off center fed dipole (OCFD). This antenna requires a 4:1 balun to achieve a good match to 50 ohm coaxial. And let’s not forget the good old loop. Its feed point impedance is anywhere from 75 ohms to 150 ohms and often needs to be tamed with a 2:1 balun. These are all examples of very good antennas that are capable of working a lot of DX. They all operate with a high feed point impedance and usually require some type of a matching transformer at the feed point in order to establish a reasonable match to a 50 ohm feed line.

The key to using any of these antennas is to find a way to transform the high impedance at the feed point to a reasonable level so that SWR can be minimized on the feed line. That is often done using impedance transformers, better known as baluns and ununs. And in some cases you can actually locate a remote tuner at the base of the antenna. This helps to reduce SWR on the transmission line, which allows all the energy to be radiated in the antenna rather than turned into heat in the transmission line.

Key Takeaway: SWR is not an indicator of antenna performance or efficiency. Don’t focus all your energy on trying for the 1:1 SWR. Instead focus on the elements of your antenna system that matters. Use good feed line, waterproof the connectors. Get your antenna as high as possible and clear of obstacles in the near field as best you can. If you are using a ground mounted vertical, ensure you have laid out an adequate radial field. Deploy the best antenna you can for your given set of constraints. Use baluns and/or chokes to minimize common mode current on the feed line. And finally make sure your station and your antennas are well grounded.

There's always kind of a funny irony when I see a station whose owner boasts of his low SWR but has no balun on his dipole and can't figure out why his computer mouse suddenly goes a little crazy or his internet router reboots when he calls CQ.

Add or Subtracting Coax Changes My SWR

One of the other misconceptions that I often hear is the idea that changing the length of your transmission line will change your SWR. This again is another misunderstood idea. Theoretically, the SWR should not change with line length except for a barely perceptible change because of the corresponding change in line attenuation. If you recall in our previous example, moving the SWR meter from the shack all the way to the antenna resulted in the SWR going from a mere 2:1 to 2.2:1. This is a very small change after moving the SWR meter a hundred feet. If the SWR changes significantly that's an indication there's something else going on. And whatever that something else is, it is generally not good.

If you're reading this and remembering the time when you changed the length of your feed line and your SWR seemed to improve, then I'm sure your wondering why the conflicting perspective. Or the other time your friend related his experience of lowering his SWR by removing a few feet from his transmission line. How come, why did the SWR change? Great question and an important one.

At anywhere along the feedline the SWR should be practically the same value from end to end. If you can cause the SWR to change significantly by changing the length of the transmission line, there is definitely something amiss. There are several possibilities, the SWR meter you bought at the swap meet has a problem. Or it's possible the feedline is bad. Or, and this is the more likely reason, you have current flowing on the outside of the coax shield, yes you have the dreaded "Common Mode Current gremlin" at work.

Here's the reason why the SWR of the antenna changes when there is common mode current present on the outside of the coaxial. Ask yourself what happens when you change the length of an antenna? It changes the resonance of the antenna, which in turn changes the SWR. If you cut the antenna shorter in raises the resonance. If you add length to the antenna it lowers the resonance. When common mode currents are present on the outside of the coax shield the shield becomes a part of the antenna. So much so that it actually radiates like an antenna and picks up RF like an antenna. And what happens when you change the length of an antenna? It changes the SWR. So there's the reason.

When common mode currents are present on your coax your coax becomes a part of your antenna. What's happening is the antenna is attempting to balance the current on the antenna. The unbalanced current attaches itself to the outside of the coax shield, thereby making the shield a part of the antenna. Antennas are funny that way, they need balance and to achieve it they will flow current down the outside of the coax shield. That means that when you're in receive mode the shield of the transmission line is picking up RF, unfortunately a good portion of that RF is bad RF, aka: RFI. During the transmit cycle the shield radiates RF in some of the very places you don't want it to radiate, like the TV, your computer, and maybe even your internet router.

Common Mode Current can be responsible for what I call the poltergeist effect, the TV mysteriously turns on, the washing machine develops a mind of its own, the computer reboots, and so on. The issue with having your coax act as a part of your antenna is it can pick up stuff you don't want it to and it can radiate where you don't want it to. What this also means is you're wasting precious RF. Common mode current does not add to your signal in a beneficial way. You need to eliminate it or at the very least minimize it and direct it to ground.

How do you do that? Start by using baluns and ununs on your antenna. In the case of the balun it must be of the type that provides some level of choking. In the case of the unun a choke should also be included in the antenna system.

This is the reason I always recommend a choking balun be used on all balanced antennas and an unun on all unbalanced antennas. Balance antennas are usually in the dipole family. This includes: Yagi's, dipoles, G5RV's, OCFD's and so on. I also recommend them for all loop antennas as well. For unbalanced antennas like the end fed wire antennas you should always use an unun in conjunctions with a choke.

Grounding also plays a key role in managing common mode currents. All antennas should be grounded at some point before their respective transmission lines enter the shack. In addition, the equipment in the shack should also be well ground.

Key Takeaway: If changing the feedline length changes the SWR start looking for issues with your antenna and feedline. If the feedline checks out then make sure you're doing all you can to control and minimize common mode current. This infers the use of baluns, ununs, and chokes. It also requires implementing a good grounding solution.

Summary

If you have hung in there to this point then I want to thank you. I know it was a long read so I hope you got something out of it. But more importantly I hope there was something that clicked for you that might help you improved your antenna system. I also hope that this article will help in a small way to slow the SWR myths, although I know they will persist.

SWR is one of the most misunderstood concepts in ham radio. My hope is this article helped you to better understand what SWR is, what it means and what it doesn't mean. I also want to invite you to do two things. First, if you have any questions or if there are any points I have raised that you disagree with please drop me an email. I always enjoy talking about antennas especially if I will learn from the conversation. Second if you want to know more about SWR read Dr. Maxwell's book. When it comes to SWR, in my opinion, his book is the bible on the topic. Unfortunately the book is out of print at this time and may be hard to get and a bit expensive at that. I saw a copy on Amazon that was selling for $147.00. It's also available from CQ Magazine but it has been out of stock for some time.

Dr. Maxwell's book started out as a seven part QST series "*Another Look at Reflections*." This series appeared in the April 1973, June 1973, August, 1973, October, 1973, April 1974, December 1974, and the August 1976 issues of QST magazine. These earlier articles were written specifically to expose and correct the then prevalent misconceptions concerning the mechanics of transmission lines and in particular the facts regarding SWR. These articles can be download from the ARRL Web site if you're a current subscriber to QST. This series was later completed and published as the book "*Reflections*", by the ARRL in 1990. In 2010 "*Reflections III*" was published by CQ Magazine. The 2010 edition included a lot of new material. I purchased a copy when it came out in 2010 and it has become one of the most referred to books in my antenna book collection.

I have tried to do justice to Dr. Maxwell's book but with limited space and time I only scratched the surface. That is why I encourage any of you who what to know more download what you can from the ARRL web site.

One final item before I close. I would like to extend a big thanks to Neil Klagge, W0YSE. Neil helped with the editing and made several great suggestions. His input made the article better than I could have ever done on my own, however any errors you find are all mine. Thank You Neil!

73,

Gene (WB7RLX)

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End Notes

[1] S Stearns, K6OIK, "*Loss Formulas for General Uniform Transmission Lines and Paradox 5*", QEX, Sept/Oct 2021, page 19.

[2] W Maxwell, W2DUD, "*Reflection III: Transmission Lines and Antennas*", CQ Magazine, Section 2-3.

[3] J Hallas, W1ZR, "*The Care and Feeding of Transmission Lines*", ARRL, Chapter 6.

[4] TLW, **T**ransmission **L**ine Program for **W**indows software is provided with the ARRL *Antenna Hand Book*.