how important is low SWR?

This controversy is put to rest once and for all

What, exactly, is the meaning of SWR? What significance does SWR have in Amateur Radio applications? Is a low SWR important?

This subject has always been a popular topic for discussion, and one ham may tell you something completely different from another. This article is written to tell you the facts about SWR. Then, you should be able to determine whether or not you should try to improve the SWR of your antenna system, or perhaps change to a better feed line. (Chances are quite good that you won't have to do anything at all to your present system!)

definition of SWR

When asked exactly what SWR is, many people will answer with something like, "Well, SWR is what you get a reading of when you hook up an SWR meter to your feed line." Then, although they have just admitted they don't know what SWR is, they'll probably add, "If it's more than 1.5:1, it's bad."

SWR is the relationship, or ratio, between the maximum and minimum currents and voltages along a transmission line; hence its name: standing-wave ratio. Ideally, the current and voltage are constant all along a transmission line. This ideal condition occurs when, and only when, the load (antenna) and the line have *equal impedances*. However, this ideal situation is seldom the case in this imperfect world of ours. More often than not, the load and line have impedances that are different — sometimes by quite a lot.

When the load and the line have different impedances, the current and voltage distribution along the line is not uniform. In some places the voltage will be high, and in other places it will be low; the same is true of the current. The VSWR (voltage standing-wave ratio) is the ratio of the highest voltage on the line to the lowest voltage on the line. When talking about SWR, it is generally understood that we are talking about VSWR, although the current standing-wave ratio is theoretically the same.

The SWR is also the relationship between the antenna, or load, impedance, Z_L, and the characteristic impedance of the line, Z_O. Mathematically it gets rather complicated, but if the load is resistive, SWR is the ratio Z_L/Z_O or Z_O/Z_L (whichever is greater than 1).

Often, you'll see SWR given as a ratio, such as 3:1. However, since 3:1 simply means 3/1, mathematically we might just as well do away with the "1" and say that the SWR is 3. (Any number divided by 1 is just the number, right?)

reflected power

Nowhere is the SWR misconception more widespread than with respect to "reflected power."[1] To understand what this really is, we must first know what power is. Power is defined as the rate at which energy is expended. Direction has nothing to do with power. Power is just dissipated someplace or places. In an antenna system, most of the power is dissipat-

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ed, one hopes, as radiation. Some power is dissipated as heat in the transmitter final-amplifier tank coil, some is dissipated in the feed line, and some is dissipated in objects surrounding the antenna.

Reflected power is, literally, what a directional wattmeter reads when put in the reflected power mode! Reflected power is *not* a force (expended energy) moving toward your rig from your antenna.

Even though reflected power is somewhat fictitious, being caused as a wattmeter reading only because of certain phase relationships and ratios between feed-line currents and voltages,[1] it is very useful in certain antenna calculations. That is, *if* it is properly interpreted.

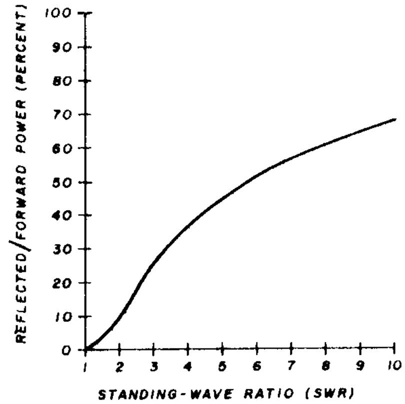

fig. 1. Relationship between SWR and the percentage of "forward power" that is "reflected."

forward power

If reflected power is a fictitious invention because power has no direction, the same is true of "forward power." The reading on a directional wattmeter in the forward-power mode is the sum of the actual transmitter output power and the "reflected power."

If you have ever used a directional wattmeter and observed that your transmitter was putting out 170 watts for a dc plate input of 200 watts, did you conclude that your rig was 85 percent efficient? If you did, you were probably wrong. (You know, of course, that 85-percent efficiency is virtually unheard of, even with class-C amplifiers.) Most likely, your SWR was high, causing an inflated "forward-power" reading. The actual output of the transmitter is the difference between the "forward power" and the "reflected power." (Think about it!)*

The relationship between the forward and reflected readings on a directional wattmeter is a function of the SWR. **Fig. 1** illustrates this function.

problems a high SWR may cause

A high SWR can, and sometimes does, cause certain problems. These problems include damage to the feed line, damage to transmitter components, reduced transmitter power output, and increased harmonic output. Let's discuss these one at a time.

The transmission line. Coaxial feed line in particular, and also certain other types such as TV ribbon line, can withstand only so much current and voltage. If the current becomes too high, the conductors will get so hot that they melt the dielectric material. If the voltage gets too high, arcing may occur between the conductors, again damaging the dielectric. This kind of problem rarely happens with power input levels of under 200 watts; but if you plan on using a kilowatt, you had better consider this possibility. For a given power level, the higher the SWR, the higher the observed current and voltage will be. If you're using RG-58/U or TV-type twin lead, *don't* use a power input over 200 watts. If you're using RG-8U with a kilowatt, beware if the SWR is more than 5.

Depending on the exact length of the transmission line, you might have a current or voltage maximum at your transmitter. Excessive current can cause the transmitter tank coil to overheat and become damaged. Excessive voltage can cause arcing in the output loading capacitor. Usually this problem occurs only with transmitters that have wide-range pi networks with components that aren't sufficiently rugged. It's also quite rare for SWR values of less than about 4; but it can still happen.

Components. Solid-state transmitters are often designed to work into a 50-ohm nonreactive load and have no matching circuits to compensate for other loads. With some of these rigs, there is an "SWR pro-

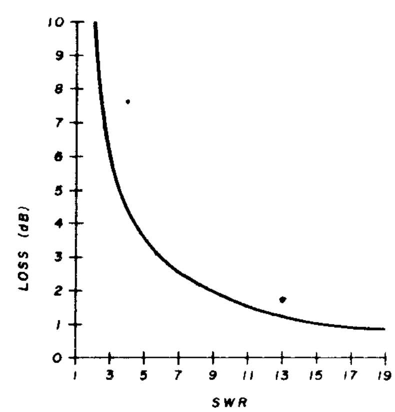

fig. 2. Determining the matched-line loss for old transmission line. Short circuit the far end of the line and measure the SWR at the input. The graph shows the relationship between SWR and matched-line loss.

*The power from the transmitter into the line is the sum of a) the power lost in and from the line and in any additional matching or other devices inserted into the line and b) the power delivered to the antenna (from reference 1) table 1. Loss per foot, under perfectly matched conditions (SWR = 1), of various types of transmission lines commonly used by Amateurs. Accuracy is to two significant digits. (*1 foot = 3.05 meters.*)

cable type	characteristic impedance (ohms)	loss per foot, (dB) frequency (MHz) 3.5	7	14	21	28
RG-58/U*	52	0.0070	0.0100	0.0150	0.0190	0.0230
RG-59/U*	75	0.0065	0.0090	0.0130	0.0160	0.0180
RG-62/U*	93	0.0050	0.0072	0.0100	0.0130	0.0150
RG-11/U*	75	0.0038	0.0055	0.0080	0.0100	0.0120
RG-8/U*	52	0.0031	0.0045	0.0065	0.0081	0.0095
TV ribbon lead	300	0.0020	0.0030	0.0042	0.0054	0.0061

*Values are nominal since there are no set standards for commercial coax.

tection" circuit built in, but with many solid-state final amplifiers, damage can occur with an antenna system that presents a high SWR. If you have a solid-state rig, check your instruction manual to see if the final is "SWR protected." If it is not, check to see how high the SWR can be without risking damage to the output transistor(s), and be sure the SWR *is not above this limit*!

Output. Most commercially manufactured rigs will function all right if the SWR is less than 2 or 3. Some, with no output loading network, may tolerate an SWR of only 1.5 before power output is degraded. Certain of the older-vintage radios will compensate for SWR levels up to 5 or even 10. The radio's instruction manual should tell you how high the SWR can get before power output is degraded. If the SWR is beyond this limit, the final amplifier will not operate at full efficiency because the impedance mismatch will be too severe. If your loading control must be set to one extreme or the other to get a semblance of proper final-amplifier tuning, the SWR is too high for the circuit.

Harmonics. If the loading capacitor must be set all the way to maximum and you still can't get the transmitter to tune to the required power input level, you're being forced to under-load the transmitter. This can cause increased harmonic output, because under-loading causes nonlinearity in the final amplifier.

Of these problems, three can be eliminated by using a transmatch at the transmitter output. A "perfect" impedance match will then be presented to the transmitter. The transmatch will normalize the currents and voltages in the transmitter tank circuit, thus maximizing energy transfer and preventing under loading. The possibility of feed-line damage still remains, however, (as explained previously) unless the transmatch is placed at the point where the line feeds the antenna. This is generally not very convenient.

problems a high SWR doesn't cause

A high SWR, by itself, will *not* make a feed line radiate, and will *not* make an antenna less efficient. A perfectly matched feed line may radiate, and may be terminated by a grossly inefficient antenna (for example, a dummy load!). These problems are *not* related to SWR. If the transmitter can be properly loaded, a high SWR will *not* cause radio-frequency interference (RFI) that would not otherwise occur.

Surprisingly enough, at high frequency, a high SWR will generally not cause very much loss of signal. With several hundred feet of RG-58/U at 28 MHz and an SWR of, say 20, there will admittedly be a lot of loss because of the SWR. But this is an extreme case. In ordinary applications, the SWR can be surprisingly high before serious signal loss occurs.*

We will now investigate this phenomenon quantitatively. With the following information, you will be able to:

1. Determine how much signal loss your SWR is causing.

2. Find out whether or not it is significant.

3. Tell whether changing the feed line type, such as from RG-58/U to RG-8/U, is worth it, and perhaps

4. Save a lot of time, energy, money, and grief.

matched-line loss

Table 1 shows the loss in dB per foot for the most common types of transmission lines used by Amateurs. The numbers in **table 1** are based on perfectly matched systems; thus the antenna must have a pure resistance of 52 ohms for RG-8/U and RG-58/U, 75 ohms for RG-59/U, and 300 ohms for TV ribbon, for these data to be correct. However, the

*Consider the end-fed Zepp antenna of 50 years ago. These antennas were efficient even with an SWR of 10 or more. **Editor**

table 2. Actual SWR as a function of matched-line loss (vertical) and the apparent SWR (horizontal). SWR values greater than 10 are indicated by x. SWR values above 6 are accurate to about ± 0.5.

line loss matched (dB)	apparent SWR (at transmitter) 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	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	7.6	10.0	x
0.8	1.0	1.2	1.5	1.7	2.0	2.3	3.1	4.0	6.0	9.0	x	x
1.0	1.0	1.2	1.5	1.8	2.1	2.4	3.3	4.3	7.0	x	x	x
1.2	1.0	1.3	1.5	1.9	2.2	2.6	3.6	4.8	8.3	x	x	x
1.4	1.0	1.3	1.6	1.9	2.3	2.8	4.0	5.5	9.9	x	x	x
1.7	1.0	1.3	1.6	2.0	2.5	3.0	4.3	6.5	x	x	x	x
2.0	1.0	1.3	1.7	2.1	2.8	3.3	5.3	8.4	x	x	x	x
2.5	1.0	1.4	1.8	2.4	3.2	4.0	8.0	x	x	x	x	x
3.0	1.0	1.4	1.9	2.7	3.7	4.9	9.8	x	x	x	x	x
3.5	1.0	1.4	2.1	3.1	4.6	6.9	x	x	x	x	x	x
4.0	1.0	1.5	2.3	3.7	6.0	10.0	x	x	x	x	x	x
4.5	1.0	1.6	2.6	4.7	7.9	x	x	x	x	x	x	x
5.0	1.0	1.8	3.0	6.0	x	x	x	x	x	x	x	x
5.5	1.0	2.0	3.4	8.5	x	x	x	x	x	x	x	x

information in **table 1** is essential for determining the SWR loss in your system — so get it down.

For example, suppose you are using 60 feet of RG-58/U at 7 MHz. The loss is 0.01 dB per foot, so the total loss under perfectly matched conditions is 0.01 x 60 or 0.60 dB.

If your SWR happens to be 1, then you already know what the feed line loss is. You thus have no use for **tables 2** and **3**. But if the SWR is not 1, there will be additional loss in the line. This additional loss is sometimes called "SWR loss."

Incidentally, the data in **table 1** are for brand-new cable. Coaxial cable gets lossier with age. Some types are better in this regard than others. Generally the foam dielectric type deteriorates faster than the solid dielectric type. There is a way to check old transmission line to find out what the loss really is. Short-circuit the far end of the line and place an SWR

table 3. Additional loss caused by standing waves. Find the line loss when perfectly matched in the vertical column; read across for the actual SWR. Find the figures that are closest to yours if yours are not exactly represented. Conditions above and to the left of the heavy line indicate an SWR loss of less than 1 dB.

line loss matched (dB)	actual SWR (at antenna) 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	0	0	0	0	0	0	0	0	0	0	0	.0
0.2	0	0	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.7
0.4	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	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7
0.8	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	0.2	0.3	0.5	0.8	1.2	1.4	1.7	1.9	2.2	2.5
1.2	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	0.3	0.4	0.6	1.1	1.5	1.8	2.1	2.4	2.7	3.0
1.7	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	0.1	0.3	0.5	0.8	1.3	1.8	2.1	2.5	2.8	3.2	3.6
2.5	0	0.1	0.3	0.6	0.9	1.5	1.9	2.3	2.8	3.1	3.5	3.7
3.0	0	0.1	0.4	0.6	1.0	1.5	2.0	2.5	2.9	3.2	3.7	4.0
3.5	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	0.1	0.4	0.7	1.1	1.7	2.2	2.7	3.2	3.5	3.9	4.2
4.5	0	0.1	0.4	0.7	1.1	1.7	2.3	2.8	3.2	3.6	4.0	4.3
5.0	0	0.1	0.4	0.8	1.2	1.8	2.3	2.9	3.3	3.7	4.1	4.4
5.5	0	0.1	0.5	0.8	1.2	1.8	2.4	2.9	3.3	3.8	4.2	4.5

meter at the transmitter output. Measure the SWR with a small amount of power. **Fig. 2** shows the relationship between SWR and perfectly matched line loss for this method.

The concept of reflected power is useful for obtaining the data for **fig. 2**. With a short circuit at the antenna end of the line, we may assume that 100 percent of the power is reflected, since a short circuit cannot dissipate power. Then, based on the SWR versus reflected power function, we can figure out what proportion of the power "came back" to the SWR meter to be registered as reflected power. The remainder was dissipated as heat in the line.

actual and apparent SWR

Most hams measure their SWR in the station at the transmitter output. However, measuring it at this point does not give an accurate reading. The *actual* SWR, the quality of the match between the antenna and the feed line, must be measured at the antenna if an SWR indicator is to give accurate results. The reading you get in the station is the *apparent* SWR, and is always less than the actual SWR. Sometimes the difference is considerable.

To accurately determine the SWR loss in your feed line, you need to know the actual SWR. This can be found out, of course, by climbing your tower or renting a "cherry picker" and physically placing an SWR indicator at the proper point. But there is an easier way.

If you know the line loss under perfectly matched conditions (from **table 1** or **fig. 2**), **table 2** will give you the actual SWR as a function of the apparent SWR.

Once you know the actual SWR as well as the line loss under perfectly matched conditions, you are ready to find the SWR *loss* — the extra feed line loss caused by standing waves on the line.

is it significant?

Use **table 3** to determine the SWR loss in your feed line. Does the result surprise you? How do you know whether or not it is significant?

In general, if the SWR loss is less than 1 dB, 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 is nothing. A gain of less than 1 dB will not be detected by the other station under any conditions. In **table 3**, the heavy black line differentiates between significant SWR losses (lower right) and those that are not significant (upper left).

Just because you have an SWR loss of less than 1 dB does not mean that you have a good antenna. It simply means there is no point in trying to get a better match with the existing feed line. A 2000-foot (*1 foot = 0.305 meter*) run of RG-58/U at 21 MHz will be very lossy even if the SWR is 1. A 3-foot loaded vertical without radials at 3.5 MHz will have a lot of inductor and ground losses, even if it displays an SWR of 1. A small SWR loss does not make up for a poor antenna or feed line system.

The data here can be used to determine whether or not it is a good idea to change your feed line. Suppose, for example, that you are using 300 feet of RG-59/U with an antenna having a pure resistive impedance of 75 ohms, so the SWR is 1. At 21 MHz there will be 4.8-dB loss in the line (**table 1**), although none of it is attributable to the SWR. Would it be worthwhile to change to RG-8/U, which has a 52-ohm characteristic impedance?

Using **table 1**, note that 300 feet of RG-8/U has 2.4 dB loss at 21 MHz. The SWR using this cable will be 1.5 (75/52), so there will be some SWR loss. How much? **Table 3** tells us it will be only 0.1 dB, giving an overall feed-line loss of 2.5 dB. This is an improvement of 2.3 dB over the perfectly matched run of RG-59/U! A change of 2.3 dB is fairly significant. If money is no object, this change would be worthwhile.

The above is a rather unusual example, but in addition to showing you how to use these data, it illustrates another point as well: feed line loss is not a simple direct function of SWR.

conclusion

For all practical purposes, an actual SWR of 2.5 or better is just as good as a perfect match, as far as loss is concerned. This is apparent from examining **table 3**. So next time you try out a new antenna, don't throw your hands up in dismay and declare that it is no good just because your SWR meter reads 1.7!

The data presented here are primarily intended for the DXer or contester, since optimum antenna performance is especially important for them. Actually, a good antenna is important in any ham station. Of course we should try to optimize antenna systems. But there is a point of diminishing returns. The fear of an SWR that's not perfect or near perfect can take the fun out of hamming — not because there is anything actually wrong, but because you *think* there is. Now you know the real story. If your SWR loss is less than 1 dB and you're using the best grade of feed line you can, you have no more excuse not to get on the air and start operating!

reference

1. For a detailed discussion of reflected power, see: Hubert Woods, "Power in Reflected Waves," *ham radio*, October, 1971, page 49. Also see "Comments," *ham radio*, December, 1972, page 76.

ham radio