THE EFFECTS OF VSWR ON TRANSMIITER PERFORMANCE AND RADIATED POWER

by
Mike Durbin Ph. D. E.E.
K5MJD

“Your VSWR should be as close to 1:1 as possible, otherwise " you won't get out very well." Have you heard that one before? A 1:1 VSWR implies a perfect match between the transmitter coax and antenna. The only problem is that it is possible to have a low VSWR and still have a very poorly radiated signal. My dummy load is 1:1 and doesn’t get well at all. VSWR is however an easy concept to understand

Early in electronics you learned that to get maximum power into an antenna required that the impedance match the transmitter impedance, what about handy talkies with NO feedline? (That’s another story I think you will understand better at the end of this article.) The antenna is usually located some distance from the transmitter and requires a feedline to transfer power. If the feedline has no loss, and matches BOTH the transmitter output impedance AND the antenna input impedance, then - and only - then will maximum power be delivered to the antenna. In this case the VSWR will be 1:1 Anything other than a perfect match will cause a "standing wave".

There are a number of ways VSWR, (also known as reflection coefficient, reflected power, transmitter power loss, and return loss) or its effects can be described and measured. The proportion of incident (or forward) power, which is reflected back toward the transmitter by a mismatched antenna is called, reflected power and is determined by the reflection coefficient at the antenna. The reflection coefficient "p" is simply a measure of this mismatch seen at the antenna by the feedline and is equal to:

$$P = (Z1-Zo)/(Z1+Zo)$$

Here Z1 is the antenna impedance and Zo is the feedline impedance. Both Z1 and Zo are complex numbers so "p" is also a complex number. Remember from AC mathematics that a complex number has a "phase angle" associated with it. The phase of the reflected signal will be advanced or delayed depending upon whether the antenna appears inductive or capacitive to the feedline. If the antenna appears inductive the voltage will be advanced in phase, and if the antenna is capacitive, the voltage will be retarded. The reflective signal travels back to the transmitter and adds to the incident signal at that point. As the two travelling waves pass each other in opposite directions, they set up an interference pattern called a "standing wave". At certain places on the feedline the voltages will add producing a voltage maximum, and at others their relative phase difference will cause a voltage minimum to exist on the feedline. These maximum and minimum points occur 1/4 wavelength apart. VSWR measurements on coax are usually made at the transmitter end of the feedline. Therefore you are presented with the VSWR of the entire system which includes all losses associated with the system. This causes us to get readings not necessarily true of the actual antenna performance. Those of you with remote sensing VSWR meters with the sensor mounted at the antenna are the only ones getting a true VSWR measurement.

Many VSWR meters are calibrated to read FORWARD power as well as REFLECTED power. They may actually be measuring voltage, and simply have the scales calibrated in power. The important point is to understand what the meter is actually telling you. Assuming for the moment that the VSWR meter contributes no errors, the FORWARD reading is the SUM of the forward power and the reflected power. As a result, it is greater than your actual power output. The REFLECTED power reading is that amount of power which was not initially absorbed by the antenna and has been sent back down the feedline. At the transmitter end it encounters the transmitter output circuitry and is re-reflected back towards the antenna. This happens because you do, in fact, have a VSWR greater than 1:1 as seen by the transmitter. When the re-reflected power encounters the antenna, a portion of it is absorbed and the whole process starts over again.

The fact that feedlines have losses and, antennas have something called radiation efficiency are what make proper interpretation of VSWR important. Power is lost due to feedline attenuation and this loss goes up as the VSWR goes up. The efficiency of an antenna is determined by the ratio of its "radiation resistance" to its "loss resistance". Antenna efficiency can simply described by the following equation:

$$\%\ Efficiency = [Ra/(Ra+Rloss)] \times 100$$

The radiation resistance is Ra, and Rloss is made up of any associated losses of the antenna such as loading coils and ground systems. How well you "get out" therefore depends more on low losses and efficient antennas than on what your actual VSWR is as the following example will show. Also remember that radiation angle has a lot to do with the actual distance and direction your signal travel. Things like incidence angles of reflection for HF and take off angles for higher frequencies also effect you antennas performance. I.e. Try and use a low angle repeater antenna to talk to a satellite directly overhead and you will see that no matter how good your antenna is for low angles the satellite signal goes away when overhead.

THE EFFECTS OF ATTENUATION ON VSWR

I said in the beginning VSWR may appear to be very low and yet there could be serious things wrong with your antenna system. Dummy loads?

Would you be happy with 1.65 to 1 VSWR? Well read on to see just how good your antenna really is. Assuming a 3-db loss down the feedline means only 1/2 of your output power reaches the antenna, and if your antenna has significant losses, something less than 1/2 of your power will be radiated depending upon how bad the losses really are. If for instance, the loss resistance equals your radiation resistance, the antenna is only 50% efficient meaning only 1/4 of your output power is actually radiated. Yet that reading of 1.67:1 looks fine. A reflection coefficient of p =0.5 means your antenna is not well matched to the feedline. VSWR can be calculated from the reflection coefficient by the following:

$$VSWR = (1+p)/(1-p)$$

Using this formula your VSWR at the antenna is 3:1. But my VSWR meter reads good so I must be radiating good and therefore the repeater is deaf... HOW MANY TIMES HAVE I HERD THAT. The difference in the input and output VSWR values is due to the loss introduced by the feedline. You can measure VSWR at the antenna end of the feedline, and get a true reading can't you? This is not very practical but there are some meters that allow this.

You can also use 1/2 wavelengths of coax between your VSWR meter and the antenna because a 1/2 wavelength of cable repeats the impedance it sees. This would give you a truer reading, but how many ½ wavelengths are there in 100 feet of coax? Let's assume you have an efficient antenna, fed with a low-loss feedline so that the VSWR meter at the transmitter gives you a true reading of 1.65:1. There is no real reason to try to lower it, in fact the same would hold true if the reading were 2:1. Figure 3 is a chart showing the equivalence of VSWR to RETURN LOSS(dB), REFLECTED POWER(%) and TRANSMISSION LOSS(dB). Return loss is related to reflection coefficient by the equation:

$$\text{Return Loss} = -20\log10(p)$$

It is just another way of measuring VSWR. For example, with a perfect 1:1 VSWR there would be no reflected power consequently the return loss on the feedline would appear to be infinite. A short or open circuit at the antenna is the worst case scenario since the reflection coefficient would be p =1.0. All incident power would be reflected, and with a lossless feedline the return loss would be 0-dB. this is what the RETURN LOSS (dB) column refers to

The most informative columns in Figure 3 are the REFLECTED POWER(%) and the TRANSMISSION LOSS(dB) columns since they provide an answer to our question of whether further reduction of VSWR is worthwhile. Figure 3 shows that for a VSWR of 1.6:1 the reflected power is only 5.5% of the incident power, and the transmission loss is only 0.24 dB. In more familiar terms, if you count an S-unit as 6 dB, then the 0.24 dB loss is only 1/22 of an S-unit. A reduction of the VSWR to 1.5:1 would provide only a 0.09 dB reduction in transmission loss. This is not worth the effort it would take to achieve such a miniscule increase in power.

FIGURE 3.0

VSWR	RETURN L OSS dB	REFLEC T PWR %	TRANS LOSS	VSWR	RETURN LOSS dB	REFLEC T PWR %	TRANS LOSS
1.00	0.0000	0.000	2.5				
1.1	26.4	0.228	0.100	3.0	6.00	24.90	1.25
1.2	20.8	0.816	0.0353	3.5	5.10	31.00	1.61
1.3	17.68	1.71	0.073	4.0	04.4	36.00	1.93
1.4	15.55	2.78	0.122	4.5	03.9	40.60	2.27
1.5	14.0	4.00	0.180	5.0	03.5	44.40	2.56
1.6	12.6	5.50	0.240	6.0	02.9	50.80	3.08
1.7	11.7	6.80	0.310				
1.8	10.9	8.20	0.370				
1.9	10.2	9.60	0.440				
2.0	09.5	11.0	0.500				

Examination of the chart shows that a VSWR of 2.6:1 results in only about 1 dB of transmission loss. A high VSWR of 6:1 shows just a 3 dB transmission loss, but this is 1/2 an S-unit. You will still be getting out but this is becoming a significant loss. Your feedline will be dissipating more power than it should, and there may be other serious things wrong with your antenna system. Not to mention the fact that your nice new solid state radio can not tolerate reflected power and actually turns it’s self down as reflected power goes up.

So my answer is to use the best antenna and feedline you can, and then worry about that antenna tuning. There is an old saying in ham radio that "a dime in the antenna is worth a dollar in the transmitter any day”.

So there you have it for this little article.

Want to try a good experiment put two identical antennas exactly ½ wavelength apart and watch what happens to your radiated signal… Ever heard of phase canceling? Totally different subject but thought I would get you thinking.

73’s for now K5MJD