More Reflections on Standing Waves Fact and Fiction

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Over the years much misleading information has been published regarding the behavior of antennas that are not self-resonant and also feed-line performance in the presence of standing waves when mismatched at the antenna. The readings given by our SWR meter are often not well understood. Evaluating the efficiency of an antenna system based only on feed-line SWR is usually quite erroneous.

For many Amateurs low SWR has become the Holy Grail, however there appears to be widespread misunderstanding about actual reflection mechanics.

I wish to challenge the reader to question their own understanding of reflection principals.

For those of us who have studied electrical engineering we are very familiar with maximum power transfer theorem. Maximum power will be delivered to the load when the generator output impedance is matched to the impedance of the load. I do not dispute this fact. It is however unfortunate that there is more to be told in the story when standing waves are involved on a transmission line between a generator and a load.

When we pick up our microphone and speak into it our voice is converted to a radio frequency signal that sends a wave of RF energy down our transmission line towards our antenna at nearly the speed of light. Some of the energy of the wave is converted into heat due to losses in our transmission line but most arrives at the antenna. In a perfect world the antenna would radiate all this power, however as none of my antennas are perfect some of this power is reflected back up the transmission line to the transmitter.

If for example we are using a transmitter with an output impedance of 50Ω and a 50Ω coax transmission line terminated with an antenna with an impedance of 100Ω at some places on the transmission line the reflected wave will add to the incident voltage to 133 percent and at other places it will subtract to 66 percent; a voltage ratio of 133/66 or 2.0 this voltage ratio defines the SWR.

Here comes the first bit of fiction; all reflected power is lost. In the above example our SWR meter will show 11 percent reflected power, many of us have been led to believe that if we subtract 11 percent from our transmitter output power we have the useful radiated power. This is simply not true. When the reflected wave reaches the transmitter end of the cable it is reflected back down the line towards the antenna. Where you guessed it some gets radiated and some gets reflected back down the line. The energy will bounce back and forth up and down the line until it is all radiated or lost in heat. Here is the part that many amateur find hard to believe; in a lossless transmission line regardless of the SWR all the power will be radiated. These reflections bouncing up and down a line will be very familiar to anyone that has worked in the field of analogue TV. If a video signal is sent down a piece of coax to a vision monitor that is not terminated correctly we see multiple ghosts as the signal is bounced back and forth.

Reflected power does not therefore return to the output stage of our transmitter and get dissipated, our transmitter may get hot and bothered but it is not the reflected power that is the problem it is actually the impedance that the transmitter is presented with that is causing all the bother, resulting in excessive voltages or currents that can cause damage.

See figure 1. this is a graph taken from the ARRL antenna handbook that lets you calculate the loss due to SWR. You will notice that at even quite high values of SWR if the line loss is low the overall loss due to SWR is quite small.
Another misconception, Low SWR is proof of a good antenna system that is working efficiently. Low SWR over a broad frequency range for a dipole or vertical over ground is actually an indication of problems such as lossy transmission line poor ground or bad connections. For example a quarter wave vertical radiator with 100 or more radials will have a radiation resistance of around 30 or so ohms an SWR for a 50 ohm system of about 1.6:1 if we were to reduce the number of radials down to just a few the impedance of the system may look more like 50 ohms giving a low SWR reading, however the efficiency will have dropped by at least 3dB due to the added ground loss resistance, half of the power is now being dissipated in the ground.
Operators that simply insist on low SWR and find 2:1 unbearable have obviously failed to understand the real relationship between reflected and dissipated power.
In fact the difference in power transferred through any coaxial line with an SWR of 2:1 will be totally imperceptible compared to a matched 1:1 load.
Please note I am talking about the standing waves on the transmission line and I am not talking about the load the transmitter sees. Most modern transceivers object violently to any impedance that is not close to 50Ω. With a system having high SWR on the transmission line we can use a transmatch to keep our transmitter happy. Adjusting the transmatch for maximum line current will create a perfect mirror termination for the reflected wave causing it to be totally reflected as it arrives back at the input end of the line, this total reflection is the reason for it not being dissipated in the transmitter and why it is conserved and not lost. Please note the SWR on the line between the antenna and transmatch is only determined by the matching condition at the load it is in no way changed by the transmatch. A low SWR reading on a meter between the transmitter and transmatch is only an indication of the mismatch between the transmitter and input of the transmatch. There seems to be a great deal of misunderstanding about this fact and many amateurs believe because their SWR meter is reading a low value into their transmatch thay have somehow managed to cancel the standing waves on their transmission line, this simply does not happen. The G5RV antenna that many amateurs use is a particularly good example of an open wire line feed with very high levels of standing waves on many frequencies.
Looking back at figure 1. I am now in a position to make the claim that an SWR on the line of as high as 5:1 using good quality coax cable of reasonable length will not be an issue and in fact particularly on the lower bands give much grater usable bandwidth. Remember you will need a transmatch to keep your modern radio happy in regard to impedance, however if you are still using an old timer like myself with Valves in the final and a PI coupler output they can be quite happy operating into several hundred ohms without a transmatch.
The main reason we should be concerned about SWR as already stated is in relation to line input impedance for the transmitter not lost power. The most widespread misconception is that there is a one to one relationship between reflected power and the resulting reduction in radiated power. The large number of amateurs that believe this totally unscientific notion is quite staggering.

The other common misconception is that standing waves caused by a mismatch at the antenna cause the feed-line to become part of the radiator allowing radiation from the feed-line. The line voltages and standing waves are contained in and between the inner and outer conductors inside the coax. Any radiation from the feed-line will be due to imbalance caused by closer proximity to one of the radiators or not using a balun but nothing to do with SWR.

It seems quite strange that so many amateurs have been mislead regarding SWR as some of our most trusted publications such as the ARRL Handbook and the ARRL Antenna Handbook are very clear on this subject.

A practical example: A 40 meter dipole being fed with 15 meters of RG-213 cable with a measured SWR at the input of 1.5:1. You will be losing about 0.62 dB in cable attenuation as the signal ping pongs up and down. To be able to actually hear any difference you would have to lose at lest 1dB. Now if you spend the afternoon adjusting your antenna, up and down the ladder or on the roof you eventually get the SWR down to 1:1 your power loss will drop from 0.62 dB down to 0.57dB the only thing you gain is sunburn and some sort of false satisfaction of seeing that 1:1 on the meter.

There are many good publications on this subject one excellent article is by M Walter Maxwell W2DU **Another Look at Reflections** available on the ARRL website for ARRL members.

References:

ARRL handbook
ARRL Antenna Handbook
Another look at Reflections W2DU