

SWR myths and mysteries.

By Andrew Barron ZL3DW – September 2012

This article will explain some of the often misunderstood facts about antenna SWR at HF and uncover some popular misconceptions. The questions are; what really happens in a mismatched antenna system, how much power is radiated and what happens to the rest? Is high SWR always bad? Will high SWR blow up your transmitter and how does an antenna tuner really work?

There are many books written about transmission lines and antennas and the mathematics dealing with complex antenna impedance and transmission line behaviour are fairly complex, I will attempt to explain the basics while keeping the article a 'maths free zone'. If you want to get into the details there is a lot of information on the Internet and also the ARRL and RSGB handbooks.

So what happens in the real world?

Step 1: RF energy from your transceiver travels down your feeder cable (usually coax cable these days) towards the antenna. On the way some of the energy is lost as heat due to the cable loss of the coax cable. Better coax types have less loss. Coax cable loss is measured in decibels (dB) and is greater at higher frequencies. So a coax cable that is OK for HF 1-30MHz may be poor at VHF or UHF frequencies.

Step 2: When the energy reaches the antenna, some of the energy is radiated, a very, very, small amount is absorbed by antenna components and dissipated as heat, and the rest is reflected back down the feeder cable towards the transmitter again. There is no loss due to the reflection; 99.9+% of the system losses are due to the coax. If the antenna is a good match for the feeder and transmitter i.e. has an impedance of around 50 Ohms then most of the power will be radiated, which is good.

Step 3: The voltage of the RF energy travelling back towards the transceiver is not in the same phase as the RF voltage travelling towards the antenna. The addition of the two voltages causes high voltage (low current) and low voltage (high current) nodes at regular distances along the feeder cable. In extreme cases with high power transmitters this can cause voltage breakdowns or hot spots along the feeder. This regular pattern of voltage nodes is called a 'Voltage Standing Wave'. The ratio of the peak voltage to the minimum voltage is the 'Voltage Standing Wave Ratio' or VSWR usually shortened to SWR.

Step 4: Some of the RF energy reflected back towards the transceiver is lost as heat due to the cable loss of the coax cable.

Step 5: When the RF reaches the antenna tuner or the transceiver final stage, some energy is absorbed as heat but almost all of the energy is reflected back towards the antenna again! Contrary to popular opinion the RF power reflected back even from a very bad match such as an open or shorted feeder will NOT damage the final of your transceiver. I will explain what can cause your rig serious damage later, so keep reading.

Step 6: The energy reflected back towards the antenna joins the energy generated by your transmitter and the energy being reflected from the antenna, but again the phase is different and this affects the standing wave. The effect is small because having lost energy on the way to the antenna, and then on the way back to the transmitter the RF power of the now twice reflected wave is quite small. When the energy finally reaches the antenna (for the second time) it has been attenuated by the cable loss again. Again some of the energy is radiated and some is reflected... go to step 3 and repeat until all of the energy has either been lost as heat in feeder loss or radiated by the antenna.

Here is an example using approximate values for a typical feeder loss of 1dB and an antenna with an SWR of 2:1. 100W is sent out from the transceiver. Just over 20W is lost due to the 1dB feeder cable loss so 80W reaches the antenna where due to the mismatch causing the 2:1 SWR around 70W is radiated and 10W is reflected back. By the time the 10W reflected signal reaches the transceiver through the 1dB feeder cable loss it has reduced to around 8W which is reflected back towards the antenna. When the 8W reaches the antenna it is down to around 6W. 5.6W of that is radiated and the remaining 0.4W is reflected back towards the transceiver again. So out of the 100W you originally put

into the antenna feeder, about 75.6W is radiated, the rest is lost as heat, in the coax. Because of these multiple reflections, high SWR causes the feed line losses to be multiplied, so low loss feed line causes less power to be lost in a mismatched system than high loss feed lines.

What is Return Loss? Engineers usually use Return Loss instead of SWR. Return loss is the difference, in dB, between forward and reflected power measured at any given point in an RF system and, like SWR, it does not vary with the power level at which it is measured. Return Loss has a fixed relationship to SWR but is expressed in dB which makes it easier to use in calculations. For the same reason, Engineers often refer to RF power in dB relative a fixed level usually a milliwatt (dBm) or Watt (dBW), rather than using Watts. The lower the SWR is, the higher the Return Loss. For example an SWR of 2:1 is equivalent to 9.5dB RL and an SWR of 1.1:1 is equivalent to 26dB RL. A perfect (but unachievable) 1:1 SWR is equivalent to a Return Loss of infinity. In the real world an SWR better than 1.5:1 (RL=14dB) is acceptable and an SWR better than 1.2:1 (RL =21dB) is pretty good.

Most SWR meters do not actually measure the voltage maximum and minimum nodes along the transmission line. They actually measure the forward and reflected power, normally by rectifying the voltage across load resistors on a directional coupler, so in reality they are measuring the return loss. But as there is a known relationship between return loss and SWR the meter can be calibrated to display SWR. Cross needle SWR meters read forward power on one meter and reverse power on the other meter. The intersection of the two meters (where the pointers cross) is calibrated to show SWR or Return Loss, or both.



All antenna loads have either capacitive or inductive reactance in addition to resistance. The combination of the resistive load and the reactive load is the antenna (complex) impedance. This means that the load as seen at the transmitter looks like a combination of a resistance and an inductance or capacitance. In a 'good' well matched antenna the resistance will be close to 50 Ohms and the inductance or capacitance will be near zero. This is called resonance and is usually arranged to be in the centre of the band or may be offset slightly towards the CW or SSB portions on the band. At the band edges the SWR is typically slightly higher, the resistance is slightly higher or lower than 50 Ohms and there may be a small amount of either capacitive or inductive reactance.

You can see from the earlier example that the 8W of reflected power that gets back to the transmitter will not cause any major problems so what can cause damage to your transceiver if you have high SWR? The problem is not the power reflected back from the mismatched load or antenna. In fact transmitting after failing to connect an antenna to your transceiver would cause 100% reflections but would probably not damage the transmitter finals (don't try this at home). But running the transceiver into a length of coax cable with a short circuit on the end, or a faulty antenna, non resonant antenna, or no antenna (open circuit) is exceptionally dangerous. The culprits are the standing wave and the complex impedance. Remember I said that the standing wave results in high voltage nodes at regular distances along the coax feeder? The voltage at these nodes is the (vector) sum of all of the signals being sent and reflected back and forwards along the cable. The voltage peaks could be very high. If due to the particular load impedance, RF frequency, and length of the transmission line (coax feeder cable), one of the voltage peaks happens to occur right at the transmitter end of the cable, there could be excessive RF voltage appearing at the transmitter output stage. This could cause flash over or RF breakdown across final transistors, inductors or capacitors. The risk of this is unpredictable you could get away with it 100 times on one frequency and then blow the rig at a different frequency. A voltage null at the transmitter end of the cable would cause high current to flow which could also damage the rig, but this situation is less dangerous than the high voltage event because it would probably trip the SWR protection in the rig.

Standing wave voltage is not the real baddy though; the other nasty is the complex impedance. As I said earlier all antenna loads have either capacitive or inductive reactance in addition to resistance. In a well matched antenna the capacitive or inductive reactance is balanced out leaving a mostly resistive load. But in a poorly matched system such as short circuit, faulty antenna, non-resonant, or no antenna there will be a lot of capacitive or inductive reactance. This is transformed by the transmission line (feeder cable) and appears to the transmitter as if you have connected an inductor or capacitor plus the

resistive component across the output. Note that due to the length of the transmission line a capacitive reactance at the antenna may look inductive at the transmitter and vice versa. The effect of adding capacitance or inductance at the transmit output stage is to de-tune the final. In a valve output stage like a linear amp this can cause the same sort of flash over events as a voltage standing wave peak. In a transistor final it can cause excessive current and burnout the transistors. Less severe detuning will cause mismatch between the transmitter output and the coax feeder, resulting in mismatch loss and reduced output power being delivered to the antenna.

If you are using non resonant antennas or antennas designed to present a higher or lower impedance than 50 Ohms, you should ALWAYS use an Antenna Tuner. Actually an antenna tuner in the shack does not tune the antenna it is really an antenna matching unit. It is not capable of altering the impedance or resonant point of the antenna. To actually 'tune' an antenna you must change its physical or electrical length or other parameters, for example the Steppir antenna controller adjusts the length of the elements and so the Steppir controller could legitimately be called an antenna tuner. The same would apply to a screwdriver antenna controller or the remote tuned capacitor on a magnetic loop.

There is great controversy about whether antenna tuners do actually 'tune' the antenna. Some very experienced PHD qualified experts insist that they do. I think that the issue is whether we are referring to the radiating part of the antenna or the total antenna system including the (hopefully) non-radiating feed line, tuner, and transmitter. I believe that the experts who state that the tuner makes the antenna resonant are assuming the tuner or matching arrangement is at the antenna end of the feeder coax and in that case it is true that the tuner matching capacitor(s) and inductor(s) affect the electrical length of the antenna to bring it to resonance in much the same way as the gamma match, loading coil, or other matching hardware on the antenna itself. But that resonant point may not be a 50 Ohm match although the inductive or capacitive reactance will be balanced out at resonance. If the resonant point is not a 50 Ohm match the tuner may tune away from the resonance point slightly to better match the transmitter and feeder to the antenna.

A tuner located at the shack sees a complex impedance that been transformed by the transmission line. This is dependent on the length and impedance of the transmission line and will normally be completely different to the complex impedance at the antenna. The tuner in the shack matches the complex impedance on its input to the transmitter and this does not necessarily bring the antenna to resonance. You can prove this by placing an SWR meter between the tuner and the antenna. When 'tuned' you can have a good match to the transmitter but there may still be higher SWR on the antenna side of the tuner. This would not be the case if the antenna was resonant.

If you can't match an antenna using the tuner in your shack, you can use the transmission line transformation to your advantage. Add a few metres of additional feeder cable and the complex impedance seen at the tuner will be different which may allow you to find a match within the range of your tuner. Sometimes this trick can be used to allow you to use a non-resonant antenna or an antenna cut for a particular band such as 10m, 20m, 40m or 80m on a non-harmonically related band such as 12m, 17m or 30m.

The antenna matching unit in your rig or the shack (usually known as a tuner) uses inductors and capacitors to transform the complex impedance of the feeder and antenna so that the transceiver sees a mostly resistive (not capacitive or inductive) load at around 50 Ohms. The section of feeder coax between the radio and the tuner has no standing wave so there is no risk to your transceiver. The section of coax between the tuner and the antenna may still have a standing wave because the coax feeder is a different impedance to the complex impedance of the antenna load, however high SWR does not necessarily mean a lot less signal is being radiated.

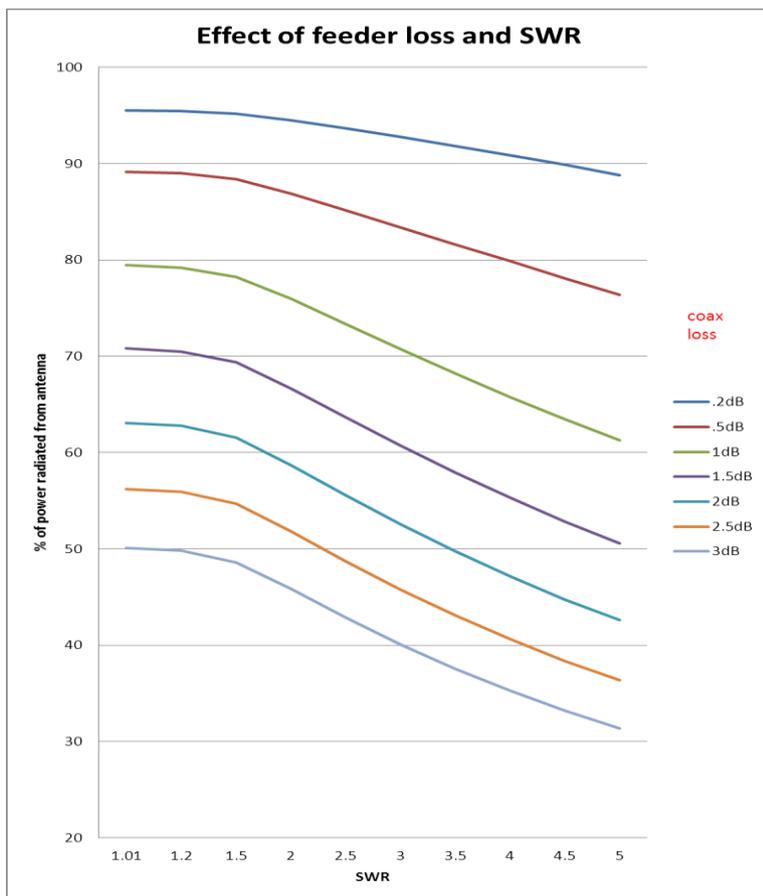
Where the tuner is located is a balance between convenience and performance. If the tuner is placed at the antenna end of the feeder, the whole feed cable is matched so there are no multiple reflections causing increased feed line loss. In other words in a high SWR situation more power will be radiated if the tuner is at the antenna end. But a tuner at the antenna is not very convenient to adjust unless it is a fixed match for a mono-band antenna, a remote tuned matching arrangement, or an auto tuner. A manual or auto tuner at the transceiver end or internal to the transceiver allows you to adjust the SWR match more easily without worrying about remote power feed and control lines, weatherproofing and temperature issues.

While researching this article I came across a rather funny posting on a web blog which pointed out how misunderstood this subject often is. The ham stated that he had a tuner in the shack with a built in SWR meter followed by another SWR meter and that most often the two meters did not agree. On some occasions the tuner read an SWR of 1:1 and the meter on the coax between the tuner and the antenna read more than 2:1. There were many uninformed and confusing replies to this posting until someone pointed out that this is entirely normal and exactly what you should see. Of course if he had placed the meter on the coax between the rig and the tuner then both meters would agree.

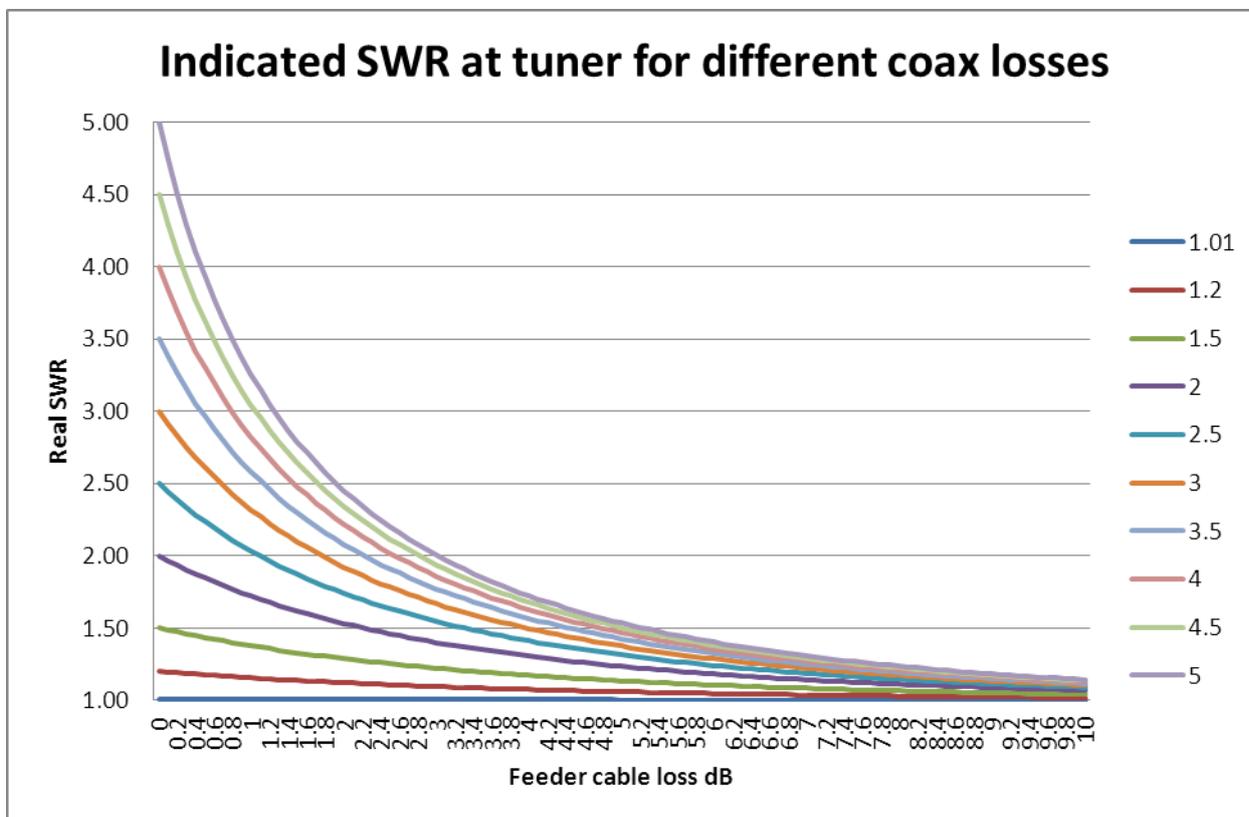
It is possible for your SWR meter to be showing a good SWR but for the antenna to perform poorly. Here are two common complaints. 'I upgraded my feeder to a better type of coax but my SWR got worse, what happened?' and 'I added more radials on my vertical antenna but my SWR got worse, what happened?' The answer is either high coax loss or often in the case of short vertical antennas high ground loss. If the coax loss is high the amount of reflected energy arriving back at the tuner or transceiver is low, so the antenna looks like a better match than it really is. Changing to a low loss coax exposes the poor antenna. For a 3dB feeder loss in a system with a real SWR of 5:1 the indicated SWR at the tuner in the shack is 1.97:1. In a system with a real SWR of 100:1 (a really bad termination like an open or shorted feeder) the indicated SWR of 2.93:1 at the tuner in the shack still does not look too bad. The cable loss is effectively hiding the problem. Another classic example is the $\frac{1}{4}$ wave vertical antenna with insufficient radials which may present a good SWR. Adding more radials will dramatically improve the antenna performance but the reduced impedance at the antenna feed point due to the improved earth plane will cause the SWR to increase. A basic $\frac{1}{4}$ wave antenna with a good earth plane should be around 36 Ohms. I have seen commercial antennas advertised that require 'a minimum of 40 feet of coax feed'. The manufacturer is using coax loss to hide poor antenna design and matching. In the case of the $\frac{1}{4}$ wave vertical it hides the mismatch caused by having either a good earth system or a poor earth system.

The final word is;

- High SWR at the transmitter can damage your rig because the final amplifier will be de-tuned possibly causing a high voltage or current situation in the final stage of the transmitter. Using an antenna tuner will protect the rig by transforming the antenna and feeder complex impedance back to where it should be.
- High SWR will not significantly reduce your power, provided you are using an antenna tuner to protect your transceiver, and your coax loss is low.
- High loss coax can really reduce your output power. Even in a well matched antenna system a coax with a 3 dB loss will waste half of your transmitter power as heat, allowing the antenna to radiate the other half.
- High feeder loss and high SWR multiplies the coax loss, causing very little power to be radiated. For example, if you have a low loss feeder of 0.2dB, the radiated power from a 100W transmitter reduces from 95.5W at an SWR of 1.01:1 to 88.8W at an SWR of 5:1. That is only an additional 0.3dB loss due to the poor SWR. Compare that to a feeder loss of 3dB. You have already lost half your power in feeder loss and the poor SWR costs you an additional 2dB leaving you with a measly 31.3W being radiated from the antenna.



High feeder loss makes the effect of high SWR worse



High feeder loss masks the effect of high SWR by indicating a better SWR than really exists.