Bob's TechTalk #20
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Impedance (Part V of X)

Standing Wave Ratio (SWR)

Introductory Review:
Before we begin discussing SWR, let's review what was discussed in the past several articles: When the impedance of an antenna matches the nominal impedance of the feedline, the impedance is constant along the feedline and has no reactive component. This "ideal" condition is difficult to achieve and really means very little to the efficiency of the antenna/feedline system. What is usually the case, though, is that the antenna presents a mismatched impedance to the feedline that consists of a resistive component between half and twice the nominal feedline impedance and a reactive component that is either inductive or capacitive, depending on whether you're operating frequency is above or below the antenna's resonant point. The impedance presented by the antenna is transformed along the feedline in a cyclic manner that repeats every half-wavelength. If the reactive component is inductive at a given point, it will be capacitive a quarter-wavelength away; and if the resistive component is above the nominal feedline impedance at a given point, it will be below it a quarter-wavelength away. If your coax was lossless, the impedance at any given point would repeat every half-wavelength. Loss in the feedline causes the reactive component to slowly approach zero, and the resistive component to slowly approach the nominal feedline impedance with each half-wavelength cycle away from the antenna. The higher the loss of the feedline, the faster the approach.

Last month we saw that the job of the antenna tuner is to transform the resistive component of the impedance present at that end of the feedline to the nominal output impedance that the transmitter is designed for (usually 50Ω). The tuner also provides a reactive component that is opposite in reactance to the value present at that end of the feedline. This reactance is transformed up the feedline and cancels the reactive component of the antenna.

Last Month's Quiz:
No one emailed me by the meeting with the answers to the question I asked in last month's article. However, Bob, WB6IXN did email his answer after the meeting. The correct answers are: For 37.6Ω: 1.14 A and 49 W, and for 66.5Ω : 0.86 A and also 49 W.

SWR:
When energy flows along a lossless feedline that is terminated at the nominal impedance of the feedline, all the energy is absorbed by the terminating load. If you measure the RF voltage at any point along the feedline it will be identical with every other point. The maximum, average and minimum RF voltages are identical. The same is true of the RF current; see Figure 1. However, if there is a

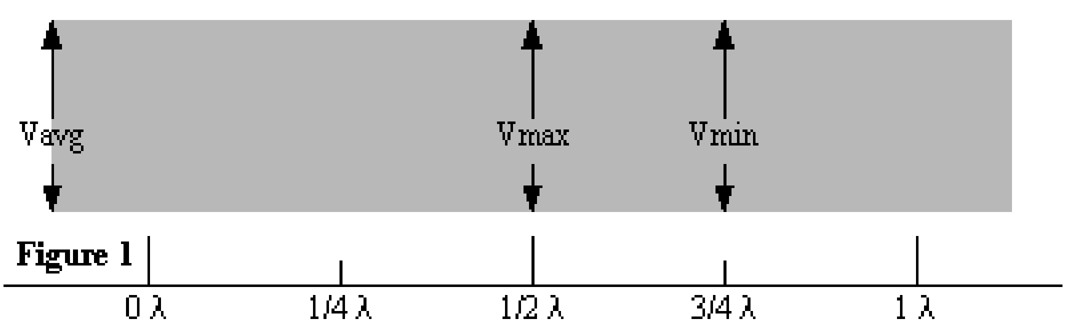


Figure 1

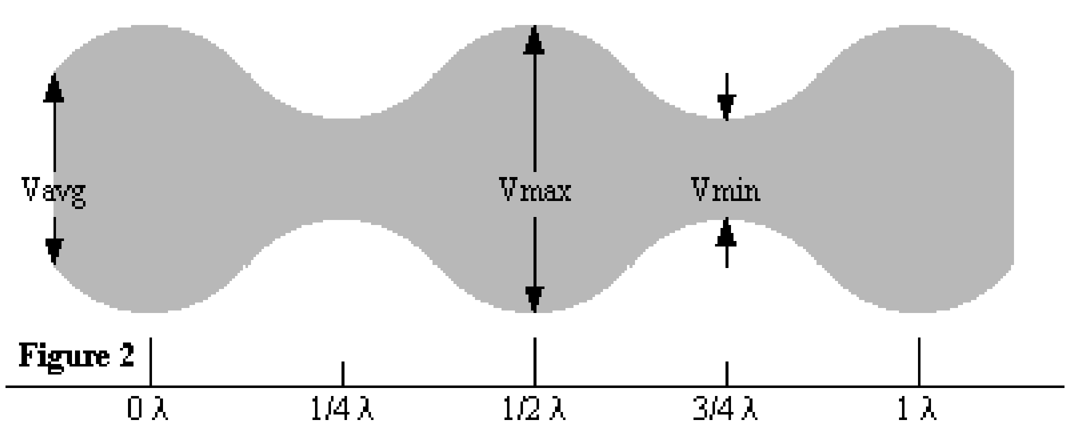
mismatch of impedances at the terminating load, some of the energy is reflected back along the feedline to the transmitter. As the reflected energy travels back along the feedline, its energy adds algebraically with the energy moving forward. At points where the two RF voltages are in phase, their voltages add, and at points where they are out of phase, their RF voltages subtract. The amount depends upon the phase angle between the two RF voltages at the point of measurement; they are maximum when the phase difference is 0° and minimum when it is 180°; see Figure 2. Remember that since energy is traveling in both directions, their relative speeds are twice as fast and thus these peaks and voltages repeat every half-wavelength.

This last point is important! We've learned that the impedance cycles every half-wavelength, but why this is so has never been discussed. Remember that impedance is made up of two components, resistance and reactance; and that reactance relates to the phase shift between the current and voltage. Since the energy traveling along the feedline is constant, high voltage points must mean higher impedance with lower current and low voltage points must mean lower impedance and higher current. Remember Ohm's law! This is what causes the impedance to change along a mismatched feedline.

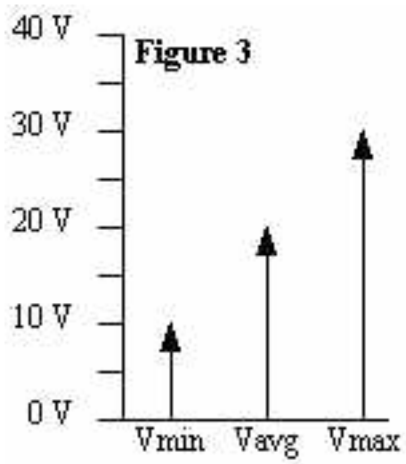
As long as the frequency is constant, these voltage (and current) peaks remain physically at the same places along the feedline; that is, the wave doesn't move but *stands* still. Thus they are called *standing waves*! The ratio of the maximum voltage to the minimum voltage is referred to as the *Voltage Standing Wave Ratio* or VSWR. If the current ratios were used the result would be the same; often the 'V' is dropped and just SWR is used.

Since the maximum and minimum RF voltages of Figure 1 are identical, the VSWR represented is one to one (or 1.0 : 1). Figure 3 represents the voltages of Figure 2. Here the VSWR is 30 to 10 or 3 to 1 (or 3.0 : 1). Note that since the minimum voltage can never exceed the maximum voltage, the SWR can never be less than 1.0 : 1. If the guy you're talking to is claiming an SWR of zero (I've heard it!) consider zero as his "credibility factor".

From what we've learned today the reason is obvious. The forward RF voltage is higher at the transmitter end than at the antenna end after it's traveled along the feedline with its loss. Also, the reflected voltage is higher at the antenna where it has just been reflected than it is when it travels to the transmitter end along the feedline with its loss. At the transmitter end you have higher forward



voltage and lower reflected voltage than at the antenna, and thus the VSWR is lower at the transmitter end.



Where Do You Measure SWR?

I've heard hams say that the best place to measure SWR is right at the antenna. My response is; "What do you really want to measure?" If you place the SWR sensor right at the antenna you measure the SWR of the antenna at the frequency you are currently using. Unless you like running outside and possibly climbing towers, or poles or onto your roof, you need a remote indicating SWR meter (hence the word sensor - the indicator would still be in the shack). You can also notice feedline and transmitter/tuner problems, but only if the meter can measure forward power. When the SWR meter is in the shack at the output of the radio (or antenna tuner) you get a composite picture of the feedline and the antenna. If you make careful measurements when you first install your antenna and feedline, you can get a good idea of any changes that are occurring as your antenna system ages. Your SWR meter is now reading the VSWR that your radio or antenna tuner is actually seeing. If problems do arise, then perhaps a measurement at the antenna would be an appropriate way to troubleshoot the root cause.

VSWR Meters:

There are numerous SWR/Wattmeters meters available. QST does a good job of reviewing them if you're in the market. Probably the most widely used meter for commercial and top-end amateur use is the Bird 43 Wattmeter. While it has become expensive in recent years, it can still be found on the used market at reasonable prices. This meter uses plug-in elements for different power levels and frequency bands. A modification kit is available to convert the Bird 43 to a peak reading wattmeter. The Bird 43 doesn't read VSWR directly. Instead it reads forward and reflected power. A nomogram is included to convert the two wattages into SWR.

Reflection Coefficient and Return Loss:

If you get involved in RF design, you will probably come across the sister terms of SWR: *reflection coefficient* and *return loss*. The reflection coefficient is the reflected voltage divided by the forward voltage and is often symbolized by ρ (rho). Since the voltages are complex and have phase as well as magnitude, ρ is a complex value. However, when you assume the nominal impedance of the feedline is purely resistive (which is a valid assumption at HF frequencies), the magnitude of ρ (expressed as $|\rho|$) is easily calculated. The reflection coefficient ranges between zero and one; zero being no reflection (1.0 : 1 VSWR), and one being total reflection (infinite VSWR). Here are a couple of simple equations to allow you to convert between VSWR and reflection coefficient:

$$|\rho| = \frac{SWR - 1}{SWR + 1} \quad \text{or} \quad SWR = \frac{1 + |\rho|}{1 - |\rho|}$$

The *return loss* is just the reciprocal of the reflection coefficient expressed in dB. It is often found in filter measurements. We won't go into detail on these other forms of VSWR.

The handbook covers them well; but you should be familiar with their existence.

Next month we'll finish our journey along the feedline taking a look at where all that reflected energy goes as well as a look at baluns. In future columns we'll discuss the noise bridge and ways to make measurements on your feedline.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the August 2003 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.