AN100
What SWR Does Not Show

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Abstract:

This application note explains the advantage of measuring vector impedance vs. measuring SWR (network analyzer vs. SWR meter). Return loss and SWR express the same property (mismatch) using two different scales. All advantages and disadvantages of an SWR reading also apply to return loss readings.

Introduction:

The Standing Wave Ratio (SWR) of an antenna and its feedline has long been used to measure an antenna's transmit efficiency. SWR is a simple concept, you send a unit of RF energy into the feedline, and measure the amount of energy that reflects back. We assume the portion of energy not reflected back transmits out the antenna. The limitations of this measurement usually cause the transmit efficiency to be lower than what SWR predicts. Using a network analyzer to measure vector impedance during antenna alignment improves transmitted efficiency compared to a simple SWR alignment.

SWR meters have been around a long time, and many people are reluctant to change because SWR is an easy concept to understand. In the past, SWR meters were less expensive than vector impedance analyzers (aka network analyzers) which has been a determining factor in the SWR popularity. However, as costs in components continue to drop, the vector analyzers have become less expensive than they used to be.

Since transmitters are rated in power, we will use the term "power", not energy, for the remainder of this paper. These two quantities are closely related: Energy = Power * Time.

SWR expresses impedance mismatch using the following formula:

$$SWR = Z0/ZL \text{ or } ZL/Z0 \text{ and}$$
$$\text{Return Loss} = 20 \cdot \log(SWR)$$

Use the SWR answer that equals or exceeds 1.0. Z0 is the characteristic impedance of the antenna/feedline, usually 50 ohms. ZL is the total impedance of the antenna/feedline. When SWR is 1.0 there is a perfect match, but this rarely occurs on a real antenna.

Vector impedance separates the reactive and resistive components of the impedance. This separation allows the technician or engineer to "see" the impedance in a greater level of detail. Using vector impedance allows one to measure for both match and resonance.

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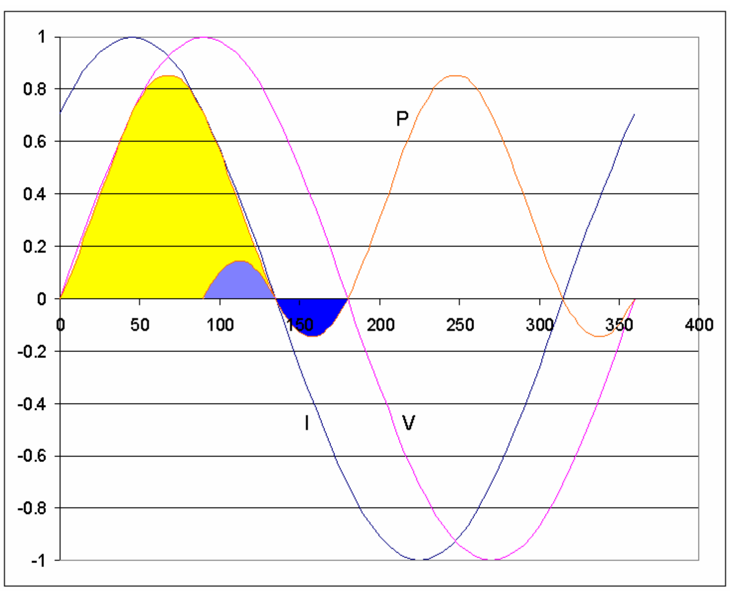
Discussion:

The first question one might ask about the limitations of SWR: "If the power is not reflected back, where does it go?" The answer: the antenna emits less RF power when non resonant due to cancellation of RF power. Thus the expected transmitted power level is not produced. Vector impedance allows you to see resonant frequency during alignment (SWR doesn't), so transmitted power can be improved.

Now we ask "What is resonance, and how does it improve power?" Resonance in an antenna occurs when its impedance has no reactance, i.e. it is purely resistive. Reactance causes the voltage and current waveforms to shift out of phase with respect to each other (remember ELI the ICE man?). Since power equals voltage times current (P=V*I), the power factor drops below a perfect 1.0 when the V and I waveforms go out of phase and power cancellation occurs. Figure 1 shows an example of power cancellation due to a non resonant load. In this example, a capacitive load causes a 30 degree phase shift. The power produced is shown by the filled in areas, we see that a portion of the power produced went "negative" (blue area). This portion of the power curve is actually out of phase, and cancels out an equal portion (purple area) from the positive region. What is left over (yellow portion) is the actual power available for transmission.

Figure 1. Power Cancellation Illustration



With a purely reactive load, the power factor goes to 0. This happens because half the transmitted power cancels out the other half. Using a resonant antenna (power factor = 1.0) allows all of the transmitter's RF power to radiate from the antenna.

Table 1. Power Factor vs. Vector Impedance Angle

Impedance Angle	0	15	30	45	60	75	90
Power Factor	1.000	0.965	0.866	0.707	0.500	0.259	0.000

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The power factor shows the loss that occurs with a reactive load. Depending upon the design, a transmitter may generate even less power when connected to a reactive load. Reactive loads often cause an undesirable increase in the final tube or transistor power dissipation, resulting in degraded transmitter lifetime.

Other limitations of SWR meters eliminated by network analyzers:

1. Designed for 50 ohm systems, SWR meters give misleading information for non 50 ohm antenna/feedlines. One case using a 30 ohm antenna had higher transmit efficiencies with the SWR of 1.6 (set resonant at 30 ohms) vs. when (de)tuned to an SWR of 1.2 (reactive load). Using vector impedance solved the "mystery".
2. There is no method to remove feedline effects from SWR readings. Vector impedance analyzers usually have a cable null feature (open-short-load), so the antenna can be measured with cable effects removed.
3. Cannot produce a Smith Chart plot with SWR data.
4. Most SWR meters use wideband detectors, and are highly susceptible to interfering signals entering the antenna. Network analyzers usually involve some form of signal filtering and offer improved performance in such an environment.

Conclusion:

To align an antenna for the best efficiency, use vector impedance readings from a network analyzer; do not use an SWR meter or return loss reading.

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