Bob's TechTalk #21
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Impedance (Part VI of X)

More on VSWR:

Last month we talked about VSWR and how, when energy reaches the antenna end of the feedline some of it is reflected back unless the antenna impedance perfectly matches the feedline. The perfect match is a condition that is not often met by antennas used over ham band frequencies. What happens to this reflected energy when it reaches the other end of the feedline and encounters either an antenna tuner, a pi-network circuit (found in most older tube transmitters - see sidebar) or a broadband matching transformer (found in most solid-state radios)?

Is Reflected Energy Lost?

When the energy reflected by the antenna mismatch reaches a properly tuned antenna tuner or pi-network circuit it encounters another large impedance discontinuity and is reflected almost entirely right back up to the antenna. Any energy lost in the tuner or pi-network circuit depends on how well the circuit was designed and adjusted. While normally low, this loss can be high when matching high SWRs, especially if the actual impedance at the tuner is at a very low impedance point. If a broadband matching transformer is encountered instead of an antenna tuner, the situation is different; less energy is reflected and more is dissipated in the transformer and final transistors. In modern transceivers a protection circuit is employed to reduce the output power of the final transistors to protect them in such a case. This obviously results in a significant reduction in power reaching the antenna, should the mismatch be large. A VSWR of up to 2.0:1 can usually be handled by the broadband output circuit without excessive losses; above that an antenna tuner is recommended. Read your product's specifications.

An Experiment:

Look at the setup in figure 1. A transmitter is connected through a directional wattmeter to an antenna tuner; the output of the antenna tuner goes through a second directional wattmeter and along a 50 Ω feedline to to a dummy load. This dummy load can be switched between 50 Ω and 16.7 Ω. These products were all bought at *Radio Lair* in *Diagon Alley* and are lossless.

With the dummy load set to 50 Ω and the antenna tuner switched out of the circuit, adjust the transmitter to produce 100 watts. Both meters should read 100 watts of power towards the antenna and zero watts of power towards the transmitter. Without changing any transmitter adjustments, switch the transmitter to standby. Then switch the dummy load to 16.7 Ω and switch in the antenna tuner. Adjust the antenna tuner so the transmitter again sees a 50 Ω resistive load. With the transmitter on, the wattmeter be-

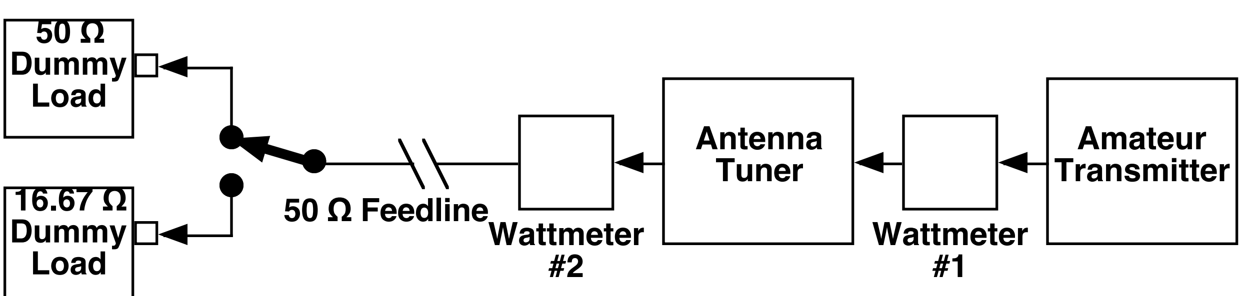

Figure 1: Experiment Setup

tween the transmitter and antenna tuner should still read 100 watts of power towards the antenna and zero watts of power towards the transmitter (If it doesn't, the antenna tuner is misadjusted).

Before looking at the other wattmeter, let's think for a second. The mismatch between the 16.7 Ω dummy load and the 50 Ω feedline results in a VSWR of 3.0 to 1. Here are two simple formulas that relate forward and reflected power to SWR:

$$SWR = \frac{1 + \sqrt{\frac{P_R}{P_F}}}{1 - \sqrt{\frac{P_R}{P_F}}} \qquad \text{eq. 1}$$

$$\frac{P_R}{P_F} = \left(\frac{SWR - 1}{SWR + 1}\right)^2 \qquad \text{eq. 2}$$

where P_F is the forward power and P_R is the reflected power.

Solving equation 2 using an SWR of 3.0 tells us that 25% of the power is reflected when the SWR is 3.0:1. With that information, you may first guess that the second wattmeter will read 100 watts forward and 25 watts reflected. Then you remember that those 25 watts reflected are sent back up the line when they are again reflected by the antenna tuner, so the meter should read 125 watts forward and 25 watts reflected? You're getting closer, but we know the antenna tuner cannot change the SWR on the feedline to the antenna, and if we try these values in equation one, they can only exist if the SWR is 2.6:1, so this answer is not correct either. Let's look at the second wattmeter; it reads 133 watts forward power and 33 watts reflected power. Plugging these values into equation 1 gives the correct 3.0:1 SWR. Many people are shocked to find that the forward power is greater on the feedline than what the transmitter is actually putting out! No this isn't "free" power; if you subtract the reflected power from the forward power you'll see that the net forward power is still the original 100 watts. The reflected power is 33 watts and not 25 watts because when the 25 reflected watts reaches the antenna, a quarter of it is also reflected and on and on. After an infinite amount of reflections that reflected power builds to 33.33... watts as shown in Table 1:

Reflection Number	Power Reflected	Sum (Watts)
1	25.000	25.00
2	6.250	31.25
3	1.563	32.81
4	0.391	33.20
5	0.098	33.30
6	0.024	33.33
7	0.006	33.33

Table One

This is in a lossless system. You can try this experiment at home. You may need to borrow some wattmeters and dummy loads from a friend (Or conduct the experiment as a group.) Parallel three 50 Ω dummy loads for the 16.7 Ω dummy load. You should still see a forward power greater than the transmitter power if you try this experiment yourself, though feedline and antenna tuner losses will reduce the values to an extent that is determined by your system losses. The important thing to remember is that much the power reflected due to SWR is returned to the antenna. It is not all wasted energy.

Next month we'll finally discuss baluns and what they can do and can't do.

73, from AF6C

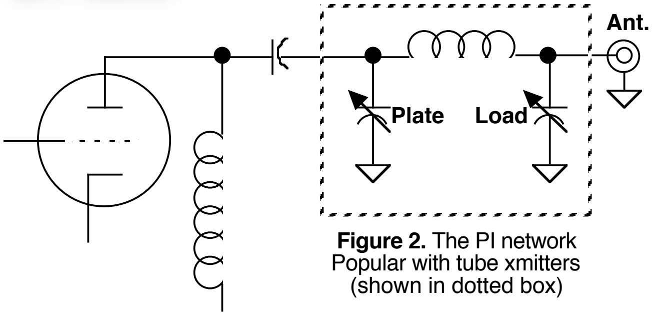

Figure 2. The PI network
Popular with tube xmitters
(shown in dotted box)

Sidebar: – The Pi-Network Circuit:

We've mentioned the pi-network circuit numerous times. Figure 2 shows the basic circuit. It performs a function similar to an antenna tuner except, instead of transforming the impedance of the antenna to 50Ω resistive to match the output of a transmitter, it transforms it to a high impedance (KΩs) to match the plate load the final transmitting tubes want to see for maximum efficiency. The 'Tune' capacitor tunes the circuit to resonance and the 'Load' capacitor adjusts the match. Like an antenna tuner the adjustments are interactive.

Figure 2 – The Pi-Network

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