Bob's TechTalk #19
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Impedance (Part IV of X)

The Antenna Tuner:

Last month we saw how the impedance present on a feedline changes as it is measured at different points along that feedline from the antenna to the transmitter. Only when the antenna terminal and the coax impedance are the same, is the impedance constant along the feedline; this is the ideal condition, but is difficult to meet and is lost as soon as the frequency is varied. In practice, one must expect some mismatch and deal with it. A mismatch, when properly handled, won't result in a significant degradation of your signal. This month we'll look at the interface between the radio and the feedline. An antenna tuner is often used here to match the feedline impedance to the transmitter (and cancel out any reactance from the antenna). While the antenna tuner is normally located in the shack, some hams claim that it should be placed at the antenna instead for much superior performance. Later in the article we'll look at the pros and cons of doing this. Please read it before you haul your Johnson Matchbox to the top of your tower!

A Bit of History:

Older tube transmitters and amplifiers usually had a pi-network output tuning stage that was able to compensate for mismatches that resulted in SWRs up to about 3:1. The pi-network could easily handle the mismatch that occurred across the band on 10, 15 or 20 meters or much of 40 meters when using a properly designed resonant antenna (triband beam, dipole, multiband vertical, etc.) The antenna tuner was only found in shacks where non-resonant antennas (longwires, etc.) or resonant antennas on 80 and 160 meters were used. Why do resonant antennas require an antenna tuner on 160 and 80 meters and not on the higher bands? It's a simple question of antenna bandwidth. Let's say a particular design of an antenna has an SWR of 1.2:1 at its resonant point and remains below 2:1 as you move in frequency ± 1% from the resonant point. On 15 meters the whole 450 KHz segment of the band is only about 2% of the frequency, so if the antenna is cut somewhere near the middle it should be usable with an SWR never much greater than 2:1 across the band. However, on 80 meters that 2% is only about 70 KHz of the 500 KHz width of the band. Therefore only a small part of the band can be used with an SWR below 2:1. As long as you stay within that 70 KHz area no antenna tuner is required. But hams like to use their available spectrum!

Today's solid-state transmitters commonly use broadband output. When they were first introduced there was a lot of hype about "no tuning needed". While that was true for load impedances very close to the $50 + j0\Omega$ design impedance, larger mismatches often resulted in damage to the expensive final transistors. Protective circuits were quickly developed that lower the power output when a significant SWR is detected to prevent transistor damage. Hams found their power dropping off as they moved around the band away from the antenna resonant point with their new solid state radios. The solution was to add an external antenna tuner to bring the impedance back in line and allow the radio to develop full power. Of course the tuner needed to be tuned so the benefit of "no tuning needed" vanished. Manufacturers quickly compensated by adding "automatic" antenna tuners that could tune at the touch of a switch. These tuners work well but are limited due to size and have matching capabilities on par with the range pi-networks could tune. (It's a credit to the manufacturers design skill that they are able to make them as small as they have!) The Kenwood TS-440SAT antenna tuner is specified to match between 20 and 150 ohms, an SWR of around 3:1. Solid state transmitter have resulted in internal or external antenna tuners once again becoming popular in ham shacks.

A Look at Power Transfer:

The antenna tuner helps in the process of getting power from the radio to the antenna where it can be radiated. So, what is the most efficient way to transfer power from one point to another along a wire? Forget RF, forget even AC, we'll do this in as simple a way as we can by using DC - just volts, ohms and amperes! Figure 1 shows a simple DC circuit.

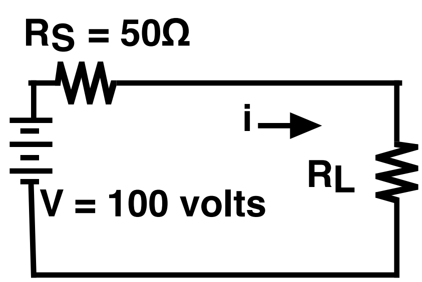

Figure 1

The battery produces 100 volts. R_S is the source resistance and represents the internal resistance of the battery and the wire. R_L is the load. This is the resistor we want to absorb the most wattage. With the battery voltage set at 100 volts and R_S set at 50 ohms, the question is: What is the resistance of R_L that will allow it to absorb the most power from the battery? This can easily be solved using calculus, but let's keep it simple and use algebra. R_L is a load resistance. I is the current flowing through R_L and is determined by dividing the voltage by the sum of R_S and R_L (Ohms Law!):

$$I = \frac{E}{\left(R_S + R_L\right)} = \frac{100}{\left(50 + R_L\right)}$$

The power dissipated by R_L is then calculated by:

$$W_L = I^2 R_L$$

Look at Table 1. It solves the preceding equations for various values of R_L. From table 1, it's evident that the most power is transferred when $R_L = R_S$. But even more interesting is how the power transfer falls off away from this point. When the resistance changes by ± 25% the power drops by only about 2%. As long as we're in the vicinity of the 50 ohm resistance the loss will be minimal.

E	Rs	RL	I	WL
Volts	Ohms	Ohms	Amps	Watts
100	50	0.0	2.00	0.00
100	50	5.0	1.82	16.53
100	50	10.0	1.67	27.78
100	50	20.0	1.43	40.82
100	50	35.0	1.18	48.44
100	50	37.6	1.14	49.00
100	50	40.0	1.11	49.38
100	50	45.0	1.05	49.86
100	50	48.0	1.02	49.98
100	50	50.0	1.00	50.00
100	50	52.0	0.98	49.98
100	50	55.0	0.95	49.89
100	50	60.0	0.91	49.59
100	50	65.0	0.87	49.15
100	50	66.5	0.86	49.00
100	50	100.0	0.67	44.44
100	50	200.0	0.40	32.00

Table 1

We can now expand our model above to consider AC and include reactances. Remember that a true reactance doesn't dissipate any power. Instead, it cause a phase shift between the voltage and current flowing in the feedline. Maximum power can only be delivered when the voltage and current are in phase. Thus to get the maximun power transfer the source and load reactances must be equal in magnitude but have opposite signs. If the source has 10 ohms inductive reactance (+ j10Ω) then the load must have 10 ohms capacitive reactance to (– j10Ω) to cancel and bring the phase shift back to zero. Remember here we are talking about short lead lengths.

The Antenna Tuner:

Let's assume at the transmitter end of the feedline the impedance is 40 - j42.5 Ω (an SWR of 2.5:1.) Your solid state rig probably won't handle this load efficiently. By placing a properly adjusted antenna tuner between the rig and the feedline a more efficient match may be obtained. What the antenna tuner must do is present an impedance to the transmitter of 50 + 0j ohms and an impedance to the feedline of 40 + 42.5j ohms. The plus sign is not a typo! We want to match the resistive component of the impedance but instead of matching the reactive component we want an equal but opposite reactance. In mathematics a number such as 40 - j42.5 is called a "complex number"; and every complex number has a "conjugate" which is identical except the sign of the "j" (reactive) term is reversed. The conjugate of 40 - j42.5 is 40 +j42.5.

Why is the opposite reactance required? Remember last month we discussed how impedance varies along a transmission line. At the antenna, the transformed conjugate reactive part of the impedance is equal but opposite to the reactive component at the antenna terminals. Since these reactance add, the reactive component becomes zero. Is this tuning the antenna? Well, the SWR along the coaxial line is still the same, but the antenna is operating efficiently because the reactance is canceled. I'll leave the debate as to whether an antenna tuner really tunes the antenna to others, but what is tuned is the whole antenna system (antenna, feedline and the antenna tuner in combination.) The antenna tuner, when properly adjusted, transforms the complex impedance of the antenna and feedline to the 50 ohms resistive that the transmitter needs to put out its maximum energy. It also provides a conjugate component that allows the antenna to operate efficiently.

Real Antenna Tuners:

There is one caveat; an improperly adjusted antenna tuner can result is a large loss of power to the antenna. Two or more different sets of adjustments can result in a proper match, but with significantly different efficiencies. The loss will take on the form of heat or arcing in the antenna tuner and can result in damaged coils, capacitors, and switch contacts. It is best to follow the recommendations of the antenna tuner manufacturer to obtain the most efficient match. Unfortunately, the versatility of an antenna tuner that can match a wide range of impedances also increases the possibilities of misadjustment. For further information you might want to read part one of W8ZR's ***The EZ-Tuner*** in the April 2002 issue of QST (pages 40 through 44.) The author does a good job of discussing the trade-offs of the modern antenna tuner as well as giving some interesting history.

Antenna Tuners at the Antenna:

Some amateurs advocate putting the antenna tuner at the other end of the feedline, so it is located right at the antenna. This does have an advantage and also lots of disadvantages. The advantage is that when the tuner is properly adjusted, the impedance along the feedline will be match the feedline impedance and the SWR will be the ideal 1:1. This means that the additional loss in the feedline due to SWR will be eliminated. Unless the SWR is very large (in which case you should think about using a twin lead type of feedline) this loss is small. For example if your feedline has a nominal loss of 1.0 dB the added loss due to an SWR of 5:1 would be only about another 1 dB.

The disadvantages are obvious. Weather-proofing, remote control or automatic adjusting systems, remote indicators, electrical power to the tuner all have to be coped with. The *"Law of Vanishing Returns"* should be studied carefully before considering placing the antenna tuner at the antenna. There are some remote tuners that are available commercially that can do the job. I've had a good experience with an SGC unit, but read the specifications carefully before you buy.

The antenna matching circuit, often used right at the feedpoint on an antenna, is a form of antenna tuner! The idea of the antenna matching circuit is to convert the impedance of an antenna to an impedance that is close to that desired to match the feedline. Of course, these devices are usually impracticable to adjust once the antenna is installed; but they do present a better impedance to the feedline to lower the SWR and make the antenna tuner's job easier.

Next month we'll take a look at baluns and RF Chokes and, space permitting, we'll begin a discussion of SWR and its more professional equivalent: Reflection Coefficient.

73, from AF6C

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