Bob's TechTalk #16

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Impedance (Part II of X)

Antenna Impedance

Last month we discussed 'impedance'. We know it is made up of two parts, resistance and reactance; both are measured in ohms. The reactance part can be positive (inductive) or negative (capacitive); the resistive part can only be positive

Now let's have some fun with that and examine the impedance at the input of a half-wave dipole in free space, and how it changes as we vary the size of the dipole. We will keep the frequency constant throughout this exercise; however, remember that raising the frequency is the same as lengthening the antenna, and lowering the frequency is the same as shortening the antenna (See Side Bar).

The resonant half-wave dipole we'll start with is made with thin wire and each leg is electrically one quarter wavelength long. At 7 MHz each leg is on the order of 33'5" (using the basic half-wave antenna equation of 468/f, where f is the frequency in MHz.) Since other variables, such as the thickness of the antenna wire, influence the length to some extent you should be able to adjust the length of the legs, usually by slightly shortening them, and reach a point where the impedance at the antenna terminals is purely resistive (the reactive component is 'j0Ω' - Remember the 'j' signifies the reactive, or imaginary part and when you see 'j0Ω' just say "'an imaginary' zero ohms.") The antenna is then resonant at the given frequency.

Figure 1a shows the half-wave dipole. What do we know about the dipole? We know the current at the tip of the dipole is at a minimum because any energy that hasn't been radiated is reflected and the cancels the current moving in the other direction. The curved lines show the current distribution along the dipole legs. At the feed point the current is maximum since it is 1/4 wavelength from a current minimum. When the current is maximum at the feedpoint one can surmise from Ohm's law that the resistance there is low. Now let's extend each leg of the antenna so that it is a half wavelength long, making a full-wave dipole. (Figure 1b). Since each tip is still a current minimum, the feedpoint is now also a current minimum and one can surmise that the resistance there is now high. Next, if we extend each leg to three-quarters of a wavelength the feedpoint will again be a current maximum and the resistance will be low. As the antenna continues to be lengthened by half-wave increments (each leg by a quarter-wavelength) the input resistance varies between low and high. The resistance at these points (especially the high resistance) varies significantly upon wire thickness and any close objects coupling to the antenna. The half-wave dipole has a low resistance around 72 ohms; the full-wave dipole has a high resistance on the order of thousands of ohms; and the one-and-a-half wavelength dipole has a low resistance on the order of 90 to 100 ohms. If you keep increasing the number of half-wavelengths of the antenna the high resistance gets smaller and the low resistance points get larger, converging towards 377 ohms which is the intrinsic impedance of free space.

At each of the multiples of half-wavelength the dipole is at resonance (the reactance is zero), but what happens to the reactance in between? That is shown in figure 2, which represents the feedpoint impedance of a dipole as it is lengthened. Note in figure 2 how the impedance spirals inward and also how radically the reactive part of the impedance changes in even-wavelength dipoles. Also note that the resistance minimums and maximums are not truly at the resonance points, but slightly on the capacitive side.

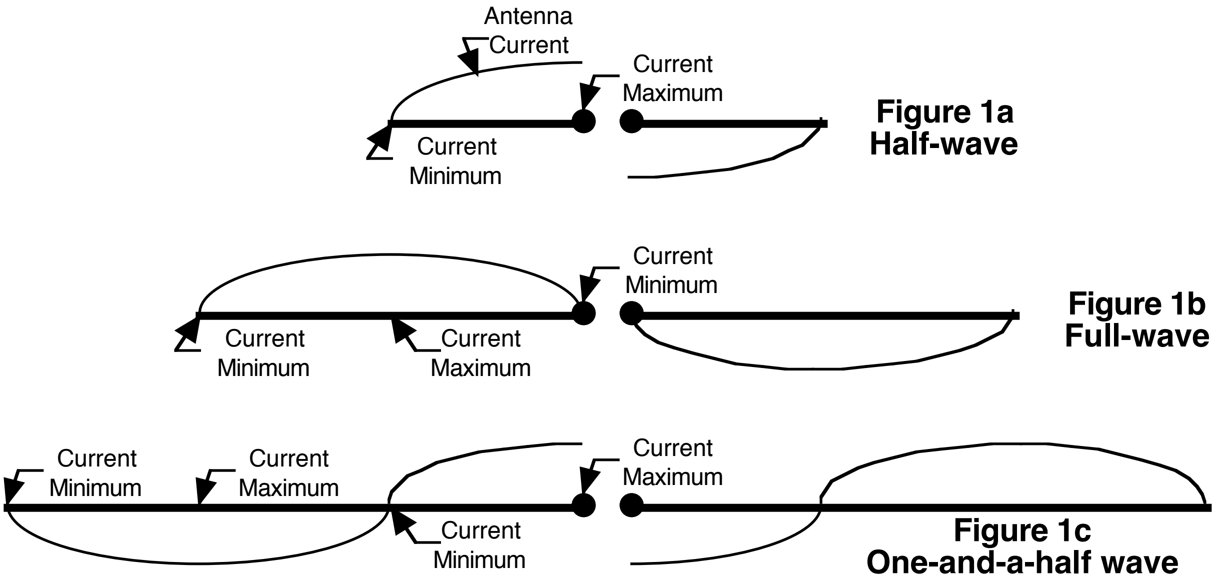

Figure 1: Current distribution on various dipoles

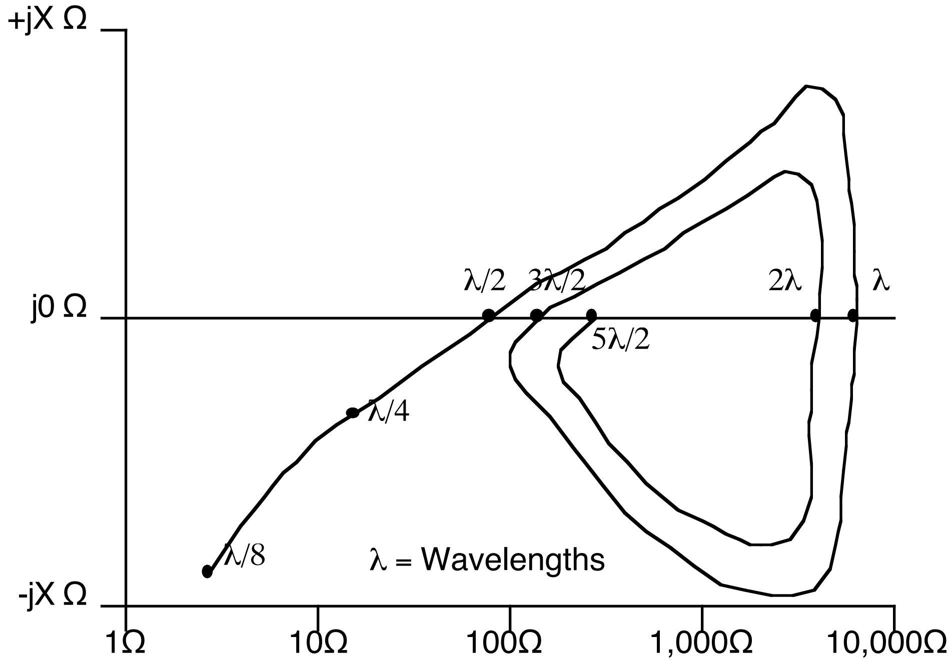

Figure 2: Antenna Feedpoint Impedance vs. Antenna Length

Let's concentrate on a dipole near a half-wavelength in length and shorter since these are more commonly used by hams, especially when space is a restriction. As you slightly lengthen a half-wave dipole from resonance, the feedpoint reactance becomes inductive, and the resistance increases. As you shorten the dipole the feedpoint reactance becomes capacitive. That is why a coil is often used on shortened antennas; it cancels out the capacitive reactance of the shortened antenna. Not only does the capacitive reactance increase, the feedpoint resistance decreases rapidly. At an eighth wavelength the resistance is just a few ohms.

Shortened antennas are always a compromise. A half-wave dipole is a very efficient antenna; properly built and adjusted, and away from interfering structures, it radiates well over 95% of the energy it receives. The feedpoint resistance consists of the antenna’s radiation resistance and any DC ohmic resistance, such as the resistance of the wires. Energy dissipated in the radiation resistance is radiated (good), and energy dissipated by the ohmic resistance is dissipated as heat (bad). Since the wire resistance is small compared with the approximately 72 ohm radiation resistance, the efficiency is high. When the antenna is shortened and inductance is added to compensate for the capacitive reactance at the feedpoint the radiation resistance goes down and the ohmic resistance (because of the coil resistance) goes up; both work to reduce efficiency.

The Vertical Antenna:

A dipole may be turned so that its axis is vertical and used very successfully. It is important that the ends of the vertical dipole (half-wave vertical) be kept clear of close objects such as the ground for best performance. A big drawback of a full-size half wave vertical is its height. The quarter-wave dipole is only half as tall for a given band and is very popular. Here the lower part of the dipole is replaced with a counterpoise often consisting of radials or the ground. Over “perfect ground” the quarter-wave vertical has a radiation resistance half that of the dipole, or about 36Ω. As the ground becomes less perfect the antennas efficiency drops because the ground resistance increases and it is in series with the radiation resistance. This presents an interesting point:

Is Lower SWR Always Better?

We haven’t talked much about Standing Wave Ratio (SWR) yet. But let’s take a look at the quarter-wave vertical mentioned above. At resonance over perfect ground it has an SWR, assuming 50 ohm coax, of 50/36 or 1.4:1. Now lets put that vertical over a poorer ground with 14 ohms of ground resistance; the SWR would then be 50/(36 +14) or the “ideal” 1:1. However, now 28% of the energy is being dissipated in the ground resistance as heat – good for the earthworms, but not for your DXCC. Shortened quarter-wave verticals using coils have even lower radiation resistance and a good counterpoise becomes even more important.

More On Resonance:

Why does a dipole (or any antenna) have to be resonant? This is a good question and the answer may surprise you: It doesn’t! Resonance is not a requirement for an antenna to be efficient. In the early days of radio antennas were fed with open-wire feed and link coupling, and resonance was of little concern. It was only with the development of the pi-network output and coaxial cable that resonant antennas became widespread. The typical pi-network output circuit used on later tube transmitters and amplifiers could match impedances with resistive and inductive parts that resulted in an SWR up to about 3:1 when feeding 50 or 75 ohm coaxial cable. Antennas such as resonant dipoles, inverted vees, beams, and verticals could easily be matched through a length of coax, and the pi-network could correct for a fair degree of variance as one moved away from the resonant point of the antenna; antenna tuners were not often used with these setups except on the lowest bands where frequency excursions were the greatest (percentage wise.). The pi-network and coaxial cable made installation and operation easier than with link coupling and open-wire feeders. Today's solid-state transmitters use broadband output circuits that are much less tolerant of a mismatch and have protective circuits that reduce power when the transmitter sees excessive SWR. That is why antenna tuners are once again found in many shacks - to tune out this mismatch.

Next month we'll move closer to the transmitter as we examine what happens to the impedance as signals travel through the feedline.

Side Bar: Is This Right?

At first "raising the frequency is the same as lengthening the antenna" may seem backwards. After all, as the frequency increases a half-wave becomes smaller. However, if you start with a resonant half-wave antenna and lengthen it, while keeping the frequency constant, the antenna becomes too long and the reactance becomes inductive. Also, if you keep the length of the resonant half-wave antenna constant and raise the frequency, the antenna again becomes too long, and the reactance becomes inductive. Thus, raising the frequency is the same as lengthening the antenna.

73, from AF6C

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