Learning Unit 5

HF Wire Antennas with Gain

Objectives and Overview:

Take the student to the next step beyond the half-wave dipole and introduce wire antennas with enhanced directivity and gain. The concept of creating and aligning antenna currents is introduced. The student will construct an extended double Zepp for 12-meters. Along with the EDZ, the bi-square and W8JK designs are reviewed and the alignment of currents will be related to the resulting patterns.

Student Preparation and Materials Required:

Read the article "An extended double Zepp Antenna for 12 Meters" in Chapter 10(page 10.6) of the reference text. Also, read the section "Bidirectional Antennas" in Chapter 12 (page 12.14.)

Background:

Gain! Oh, boy! No word evokes as much interest in the antenna designer. An antenna with gain seems to give its user something for nothing--more signal with no extra electricity required. Even better, when the antenna is a simple combination of wires. Back in the Old Days before beams and rotators, clever wire antennas ruled the airwaves. Today those same antenna designs are found in many backyards as low-cost, efficient antennas. A favorite wire antenna is often a Big Gun's cherished secret weapon! In this lesson, we will build one of the best--the extended double Zepp.

First, let us go into more detail about gain and how it is achieved. In Lesson 1, we learned that "gain is the amount by which an antenna manages to concentrate its radiated energy in desired directions." In Lesson 3, the dipole's donut-shaped antenna pattern shows that it is concentrating its energy in the direction at right angles to it is axis. Does a dipole have gain? Yes, because little energy is radiated off the ends of the dipole, the dipole's broadside signal will be 2.1 dB stronger (not quite twice as strong) than that from an isotropic radiator. Gain with respect to the isotropic radiator (whose radiation pattern is a circle in every plane) is written specially, as *dBi*--the 'i' alerts the reader that the reference antenna is isotropic. If a dipole's maximum gain is used as the reference, the abbreviation "*dBd*" is used.

How can the dipole's gain be improved upon? What happens if we just make the dipole longer? Figure 1 shows the effect of lengthening a half-wave dipole in several steps--to ¾, 1, and 1-1/2 wavelengths.

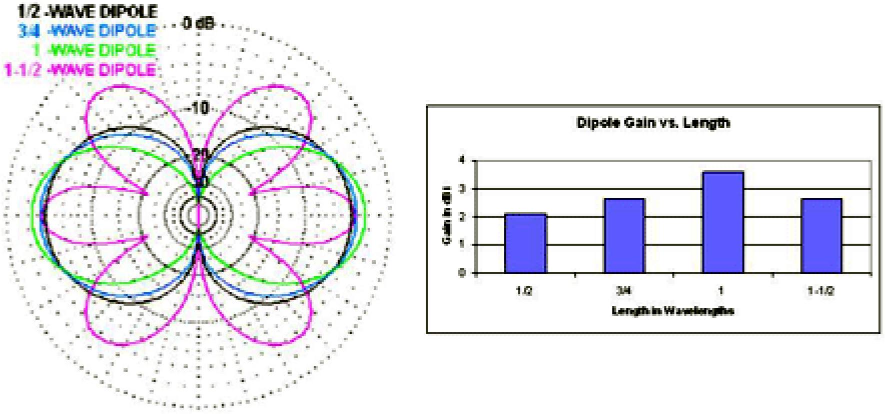

Figure 1

Figure 1 -- Dipole Gain versus Length

As the figure shows, increasing the length of our dipole to ¾ and then to 1 wavelength does increase its gain, but by 1-1/2 wavelengths our gain has dropped. Not only has the gain dropped, the radiation pattern has split into three lobes and the strongest main lobe is now about 50 degrees from broadside! How did that happen?

The radiation pattern of an antenna shows what signal strength would be received by a distant observer moving around the antenna. The signal strength depends on how all the signals radiated by the antenna's electrons add up in the observer's antenna--some of the signals will add and others cancel. How much adding and canceling depends on the phase of the received signals and their relative amplitudes. For example, for two signals to completely cancel each other, they must be of equal strengths.

Figure 2 illustrates the process. Figure 2a shows a single isotropic source radiating signals that spread out into space like ripples, appearing as sine waves as they pass an observer's antenna. Figure 2b shows two such radiators one wavelength apart sending out signals that add and cancel along the labeled lines as shown in the radiation pattern. Finally, Figure 2c shows the resulting radiation pattern with the nulls of the pattern corresponding to the directions in which the radiated signals cancel.

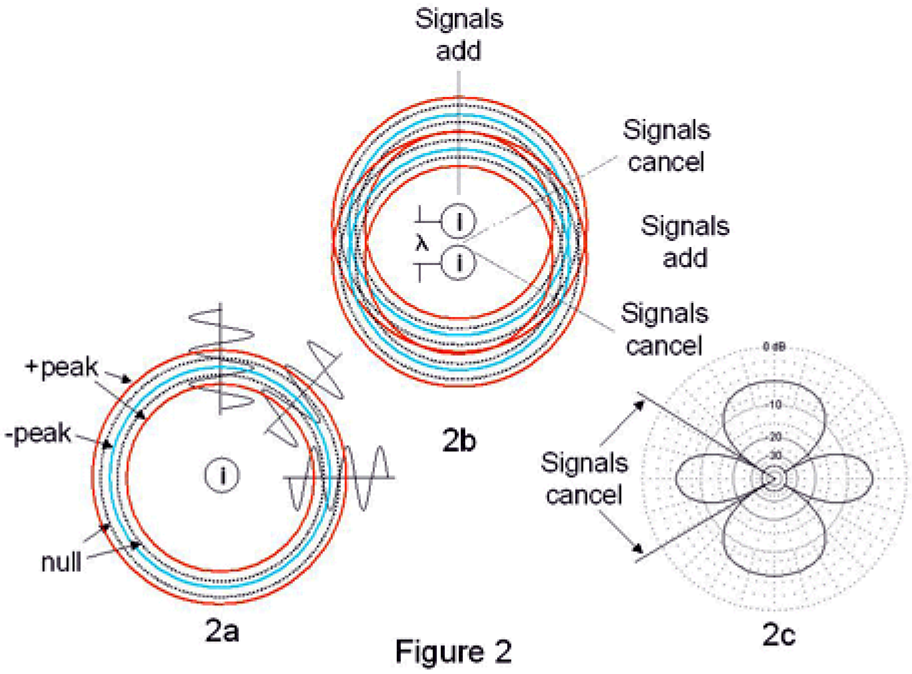

Figure 2 -- Signals Adding and Cancelling to Form Nulls and Lobes

Recall from Lesson 3 that the current on a long dipole forms a repeating pattern of peaks--one peak flowing towards one end of the dipole and then a half-wavelength later another peak flowing the other way. The 1-1/2 wavelength dipole has three such peaks. The two end peaks flowing in the same direction are *in phase*, while the one in the middle, flowing in the opposite direction, is *out of phase*. To create the multi-lobed radiation pattern of the 1-1/2 wavelength dipole in Figure 1, replace the isotropic radiators with the three half-wave dipoles in a line.

This is how gain is created--by arranging the currents in an antenna so that the fields they radiate sum together in a few directions and cancel elsewhere. High-gain antennas focus all of their radiated energy in just a few directions. Omnidirectional antennas may try to focus their energy in a single plane, like the ground-plane antenna of Lesson 2, which radiated equally at all directions around the antenna and much less outside that plane.

The Extended Double Zepp (EDZ)

Taking another look at Figure 1, the graph seems to be telling us that there is a dipole length somewhere between ¾ and 1-1/2 wavelengths where gain is at a peak. The radiation patterns indicate that somewhere around 1 wavelength, the pattern starts to "break up" into the multiple lobes. Is there a "magic" length that has the best gain but without the multiple lobes? Yes, and it is the extended double Zepp as shown in Figure 10-11 of the reference text.

Before proceeding, a bit of history. "Zepp" comes from the name "Zeppelin," the very same German nobleman that developed the famous airships known as Zeppelins. In those early days of radio, when long wavelength signals were used, long antennas were necessary to communicate. This was not a problem on the ground where a center-fed dipole could easily be supported between trees or masts. Airborne, it was a big problem since the supports for a dipole either were not sufficiently far apart, or were difficult to place on the airframe of the Zeppelin.

As we learned in Lesson 3, the dipole can be fed anywhere along its length if one is willing to work with the higher feed point impedances away from the center of the antenna. This is just what the zeppelin radiomen did, feeding a one-half wavelength wire at its end and letting the remainder trail out towards the ground. This became a popular antenna in the days of open-wire, high-impedance transmission lines and was quickly dubbed the "Zepp." If you place two Zepps back-to-back and feed them in the middle, you have a double Zepp.

If you lengthen each side slightly to about 5/8-wavelength, you get a triple bonus. First, the feed point impedance drops dramatically because it is no longer at a current minimum. This makes it easier to adapt to low-impedance transmission lines. Second, the main lobe gain is at the maximum value for single-wire antennas of this general size, approximately 5 dBi (gain over an isotropic source) and 3 dBd (gain over a dipole.) Third, the pattern has only small sidelobes, nearly 7.5 dB below the main lobe. This is an excellent set of tradeoffs!

While the feed point impedance has definitely dropped below the several thousand ohms present at the end of a half-wavelength antenna, it is still quite a bit higher than that of 50-ohm coaxial cable. Because the 5/8-wavelength antenna is no longer resonant, the impedance has both resistive and reactive components. For example, the 12-meter version's feed point impedance is predicted to be 142 -- j555 ohms. Some method of *impedance transformation* is necessary to change this to 50 ohms.

The 5' 5" section of 450-ohm *open-wire* or *ladder line* connected at the feed point presents nearly 50 ohms at the other end, for a good match to coaxial cable. You can think of the transmission line as extending the wires of the antenna an extra 1/8-wavelength to the point at which the current again reaches a maximum. The wires in this case are brought together in a transmission line. The feed line thinks it is feeding the midpoint of a dipole!

This trick only occurs at the design frequency because the line must be a specific *electrical length*, about 1/8th of a wavelength, to the RF flowing along it. As frequency is changed, so does the wavelength and the line is no longer the correct length. Luckily, 12-meters is narrow, so operation at reasonably low SWR is possible across the whole band.

Once the impedance has been changed to 50 ohms, a coaxial cable should not be connected directly to the open-wire line. Because the outside of the coax braid is a fine conductor, current making the transition between the open-wire line and coax is just as likely to flow on the outside of the coax as it is on the inside. This would upset the antenna's radiation pattern (currents on the outside of coax braid radiate RF just like on an antenna) and mess up the impedance at the transition from coax to open-wire by giving the RF current an undesired path. These unwanted currents can be prevented by using a *balun*, short for *balanced-to-unbalanced* transformer.

A balun is an RF transformer that can not only transfer RF energy between symmetric *balanced* items (like dipoles) and *unbalanced* items (like coaxial cable), but also perform impedance transformations at the same time. Some baluns are referred to as "4:1" or "9:1" or "2:1" and the ratios specify how much impedance is changed between primary and secondary connections of the balun. In the case of the EDZ, we only need a 1:1 balun which leaves the impedance unmodified while preventing the unwanted current flow.

The Bi-square and W8JK

Now that you understand how currents of different phases on an antenna can cause the antenna to radiate better in some directions compared to others, you will enjoy learning about another pair of Old-Timers--the Bi-square and the W8JK.

The bi-square, shown in Figure 12-24 and 12-25 of the reference text, looks like a simple full-wavelength loop antenna, but it is not. It's a square, like a loop, but the top corner of the antenna is open. Instead of the sides being ¼-wavelength long, they are ½-wavelength, just like a dipole. In fact, you can think of the bi-square as four dipoles in two pairs connected end-to-end and fed at the end of one of the dipoles.

The middle of each side is pulled out to make a square. Figure 3 shows the current distribution on the antenna with a single current peak on each half-wavelength section, just like the simple dipole in Lesson 3. In this case, the current is moving diagonally. Each current can be thought of as the sum of two smaller currents at right angles to each other, one vertical and one horizontal. Looking at the antenna horizontally through its center, you can see that there is an equal amount of upward and downward vertical current--the radiation from these currents cancels out. However, all of the horizontal currents are flowing in the same direction and so create the effect of a pair of horizontal current peaks at the same height as the centers of the upper diagonals.

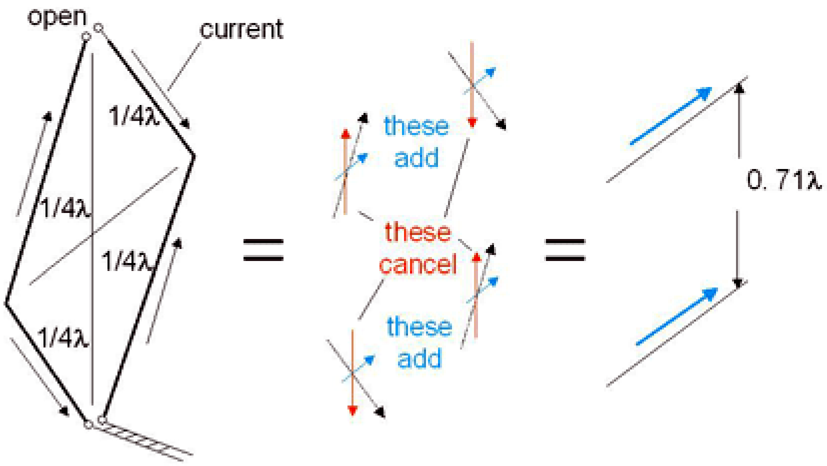

Figure 3

Figure 3 -- Analyzing the Bi-square Antenna

Electrically, the bi-square looks very much like a pair of dipoles, one above the other, with currents in-phase. This results in the radiated fields adding together broadside to the bi-square and mostly canceling overhead. The radiation pattern in Figure 12-26 of the reference text includes the effects of the ground, and you can see that the fields are concentrated at low vertical angles, just right for DX and long-haul domestic QSOs in both directions, and all with a single vertical support.

The W8JK antenna is named for its inventor, Dr. John Kraus of Ohio State University. This antenna, as seen in Figure 12-29 of the reference text, also uses current phasing to create a bi-directional, low-angle pattern by driving the two dipole elements with opposite phase currents.

With the two dipole currents out-of-phase, it should be clear that the radiated fields would cancel overhead, creating a deep null in the radiation pattern. Similarly, because the dipoles radiate little off their ends, there is another deep null in the pattern to either side. Think of a balloon with a string tied tightly around it is middle and you will have a pretty good idea of what the W8JK radiation pattern looks like. Because nearby signals often arrive at high vertical angles, this is a good antenna for rejecting them in favor of low-angle, DX signals. While the W8JK offers another dB of gain and the deeper overhead null than a bi-square, it also requires an additional support.

Your head is probably spinning with ideas for wire antennas! They're inexpensive, generally do not require extremely high supports, and provide excellent gain. You can have plenty of fun and get a lot of satisfaction out of backyard experimentation with them. For more information on these antennas, read more in the reference text or browse to the ARRL Technical Information Services Web page (http://www.arrl.org/tis/tismenu.html), which also has many links to interesting articles on antennas.