About this Article

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Bob Zepp: A Low Band, Low Cost, High Performance Antenna — Part 2

This antenna array provides a switchable, 4-direction, vertically polarized, full-azimuth-coverage high gain antenna for 160 meters and a bidirectional horizontal antenna for 40/75/80 meters. Here are the rest of the construction details.

In Part 1, we presented the first two steps in developing the final version of the Bob-Zepp. This began as a simple center fed horizontal wire antenna for 40/80 meters fed with open wire line. By shorting the open wire line at the base, the array becomes a base-fed vertical for 160 meters. Step two involves adding vertical wires to the ends of the horizontal wires; thus the vertical becomes a mini Bobtail curtain. Placing traps on the wires maintains the horizontal configurations on 40 and 80 meters. On 40 meters the antenna is an extended double Zepp, hence the title Bob-Zepp. Furthermore, Part 1 showed how to derive a bidirectional end-fire pattern on 160 meters, thus providing two switchable bidirectional patterns on 160 meters, with both showing considerable gain over a single vertical element.

In Part 2, we begin by showing how the end-fire pattern can become a switchable dual mono-end-fire directional array, thus increasing the gain in these two directions. After Step 3, the final developments are shown to reveal the complete Bob-Zepp.

Step 3

In this end-fire 160 meter configuration, the relative phasing of the currents in the vertical wires can be changed by placing different inductive values where the vertical wires meet the capacitive boots. In effect, by simply changing these inductive values the array can be switched between two *mono-directional* patterns in either end-fire direction, for example, one for "east" and one for "west," while the broadside base-fed curtain remain bidirectional north-south. Figure 9 illustrates the antenna system.

Photo D shows the bottom end of the west leg. You can see the vertical wire coming down to the box, which houses a fixed inductor and remotely operated shorting switch. You can also see the capacitive boot wire, going off to the right. Photo E is a view inside of that box. Photo F is the east leg tuning box, and Photo G shows the tuning circuit inside that box. The variable capacitors are wired in series with the fixed inductor. The motor driven variable capacitors provide for remote tuning of the east or west pattern. The appropriate capacitor is selected with the small relay just below the inductor. Figure 10 gives the schematic diagrams of the west leg circuit and the east leg circuit. We now have three switchable patterns on 160 meters, covering 360° of azimuth direction.

I use a homebuilt 160 meter tuner in the shack. There is a small tuning difference between the east and west patterns, but is easy to tune out with one variable capacitor. Also, DX on 160 meters is almost always worked on nighttime paths, so switching between east and west is not that frequent, especially near local sunrise and sunset. The

Photo D — The west leg of the driven element: the capacitive boot wire runs to the right.

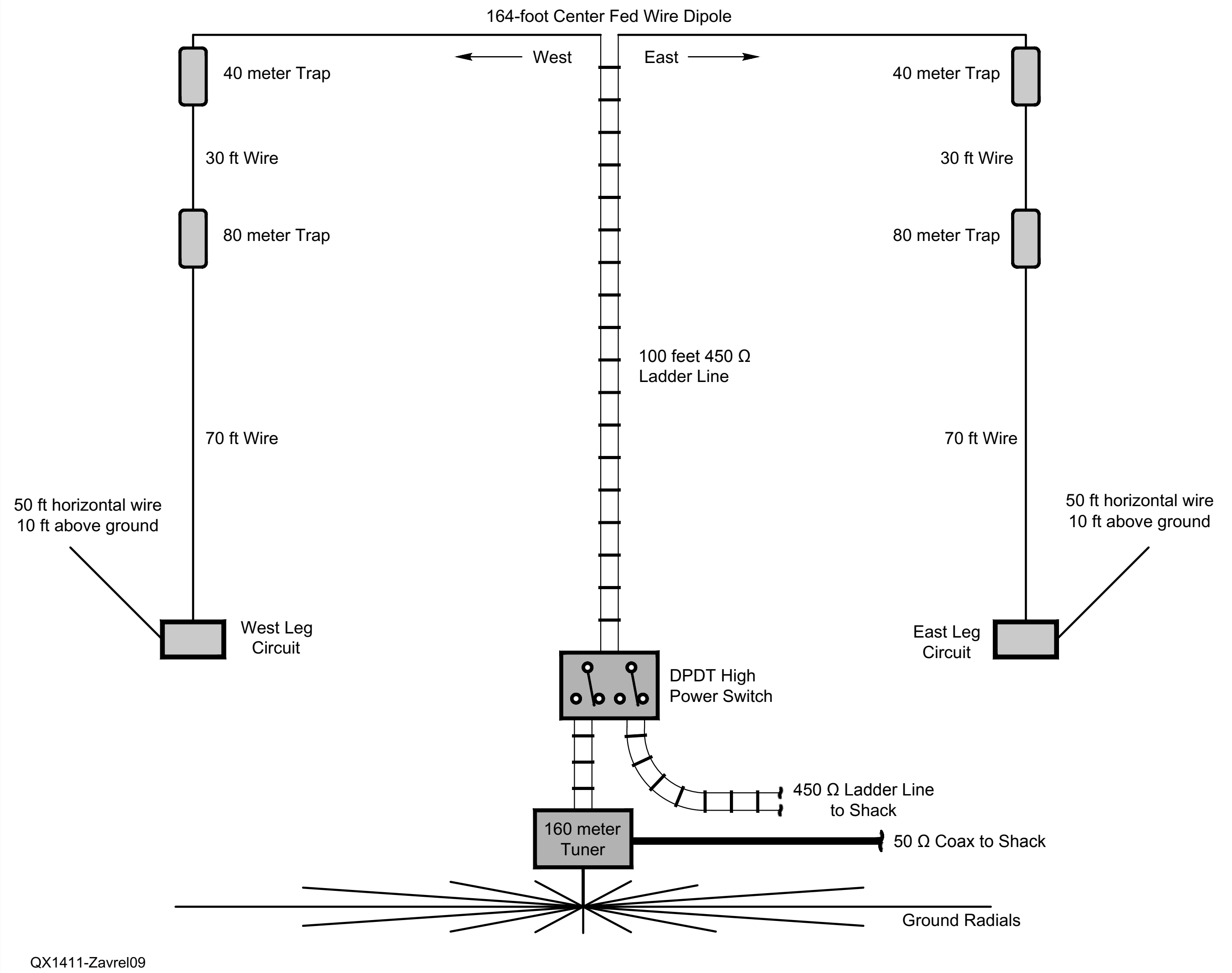

Figure 9 — This diagram illustrates the extended double Zepp antenna on 40 meters, the extended dipole on 75/80 meters and the 160 meter bidirectional north/south curtain plus east and west end-fire antennas.

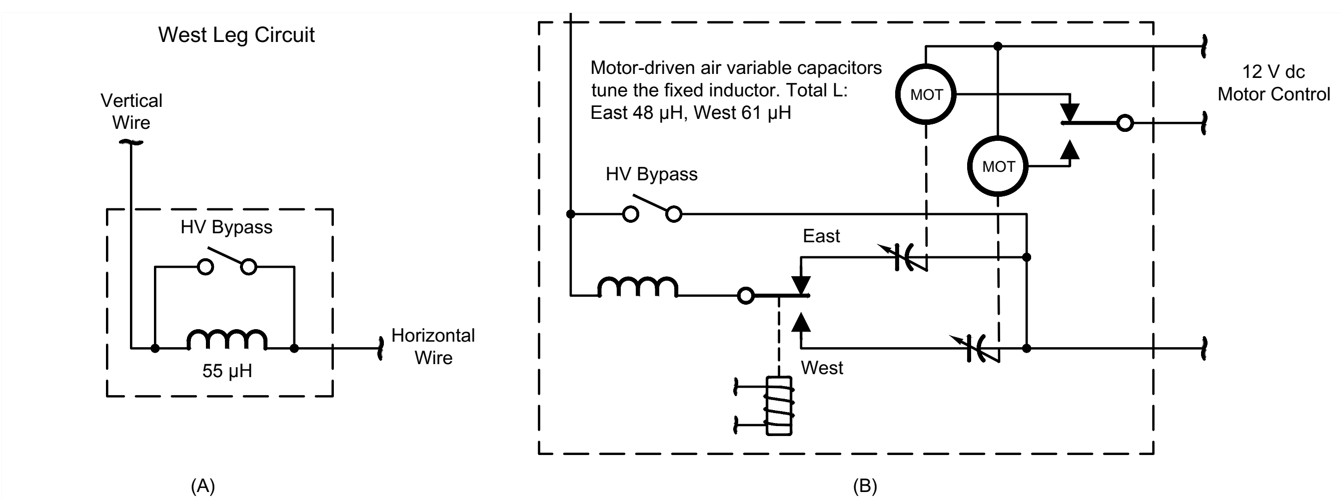

Figure 10 — Here are the schematic diagrams of the tuning circuits at the end of the west and east legs of the antenna. Photo E is the west leg circuit and Photo G is the east leg circuit.

Photo E — The fixed inductor at the west leg. A Russian surplus ceramic switch shorts the inductor out of the circuit when a broadside pattern is desired. The inductor is only used for end-fire patterns.

Photo F — The driven element's east leg tuning box. The heavy cable contains the low-voltage control wires.

same tuner provides complete coverage of the 160 meter band as well, so one tuner in the shack provides full-band coverage *and* tuning out slight differences in the east and west patterns.

The east and west patterns were optimized for forward gain because they are routinely used for transmit only (I have a 4-square receive antenna). By adjusting the inductors, a respectable front to back (F/B) ratio is also possible with some compromise in gain — no surprise there.

To simplify the inductive switching, which creates the directive patterns, a fixed inductor is placed at the base of one end wire while two separate inductive values (through the use of the two series variable capacitors) are available for the respective east and west patterns. This simplification costs only about 0.2 dB gain. The inductors at both driven element legs are completely switched out (shorted) for the north/south curtain pattern, thus only one relay is necessary at the base of the west leg. That also causes the slightly different feed impedances, however.

Step 4

By placing a 1 λ loop reflector in back of the curtain we can create a mono-directional broadside curtain array. In my case, the maximum gain is to the north (actually toward Europe and the Middle East). The actual loop circumference is less than 1 λ, but I can remotely tune the loop from the shack by using another fixed inductor/variable motor driven capacitor from the shack.

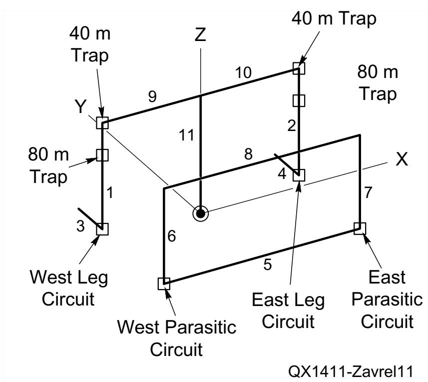

Figure 11 — This drawing is the *EZNEC* model of the complete antenna, including the 1 λ loop reflector.

The following patterns are modeled from *EZNEC* and also bear out through experiment and on-the-air use. All elevation angles were taken at 20° over "average ground." Notice that the gain approaches that of a full-size 4-square.

Figure 11 is an *EZNEC* plot of the antenna, which also shows the relative current values along the various elements. The separation of the loop and the curtain is 90 feet in this generic example. This is for the north pattern. The horizontal sections of the loop are 164 feet, the same over-all width of the driven curtain. The top wire is 90 feet above ground, while the bottom wire is 10 feet above the ground. Fixed loading inductors of 19.5 µH are positioned at the bottoms of both the loop's vertical wires (wires 6 and 7). The tuning and switching takes place at the base of element 7. The inductors needed for the

Photo G — Inside the east leg box: The high voltage switch at the top inside the box shorts the inductor out for broadside patterns. The lower voltage switch selects one of the two variable capacitors. These capacitors are in series with the fixed inductor, which is wound on a PCV pipe section. These capacitors are connected in series with the inductor and provide motor-driven variable tuning for the east and west end-fire patterns. The small relay at the bottom automatically connects the appropriate motor/capacitor for either the east or west pattern. These capacitors must be mounted on insulators. Notice also the nylon insulators connecting to the motors. The motors are 12 V DC, 6 rpm gear motors. The DC control permits easy direction changing when fine tuning the antenna.

Photo H — Here is the parasitic loop tuning box, which is at the base of the east vertical element. This view is looking west down the low horizontal wire of the loop. The horizontal wire is placed about 15 feet high so delivery trucks and other vehicles can pass under it. The horizontal wire is supported by a tree in back of this view, to achieve the desired height clearance. The insulator is visible in the top left corner of the photograph.

end-fire configuration at the bases of wires 1 and 2 are shorted for bobtail configurations.

The plots of Figures 12, and 13 show the outstanding gain for the end-fire east and west patterns, and Figure 14 shows the north pattern using the parasitic loop.

With both loop inductors at 19.5 μH, the array shows maximum gain to the north. By changing either of the loop inductors from 19.5 μH to 4 μH, the loop becomes a director and the pattern is now to the south. Figure 15 shows the switching arrangement to make this change. Figure 16 is the *EZNEC* radiation pattern plot for the pattern to the south.

Building High Power Remote Control Variable Inductors

With three variable, remote control, and high power inductors needed for all the tuning of this array, a simple and far more

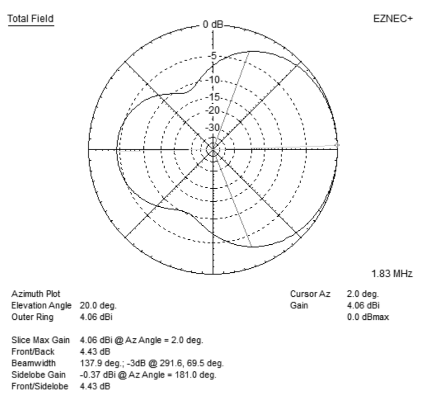

Figure 12 — This *EZNEC* radiation pattern plot shows the end-fire pattern to the east.

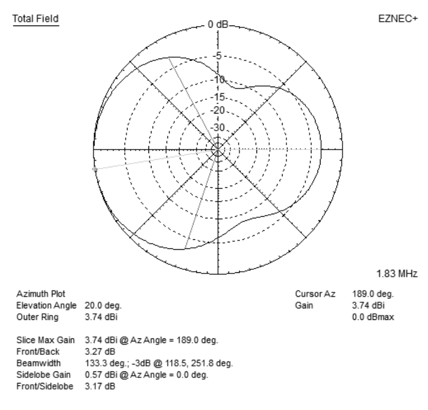

Figure 13 — This *EZNEC* radiation pattern plot shows the end-fire pattern to the west.

Photo I — This is a peek inside the parasitic loop tuning box. The high voltage surplus Russian switch is used to close the loop, thus activating the loop. A remote controlled motor-driven variable capacitor is used in series with the inductor to provide a continuously variable inductance. Thus the array can be adjusted from the shack for maximum forward gain or maximum F/B. A second lower-voltage switch is used to tap the inductor for a director pattern toward New Zealand. The director pattern is a "free feature" but is not very critical, thus fine tuning is not required. The box is an old single-drawer file cabinet with an aluminum sheet access door. The exterior of the box was painted with rust-resistance paint.

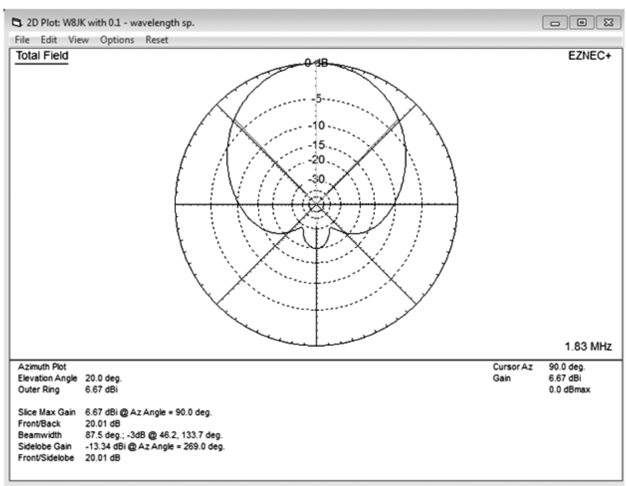

Figure 14 — This *EZNEC* radiation pattern plot shows the pattern to the north, with the loop switched in as a reflector.

economical solution is used rather than very expensive and hard-to-find motor-driven rotary inductors. For the inductive values typically needed for low band tuning, large gauge wire inductors (wound on PVC or ABS conduit) can serve nicely. To make it "variable" simply use a variable capacitor in series with the inductor. Small gear motors are available from numerous surplus supplies (I use **www.surpluscenter.com**). You want one that is geared down to 1 to 2 rpm, and that has a ¼ inch shaft. Low voltage DC control allows for reversing the direction. I even found a small surplus motor speed controller that I use for fine tuning! Then place an *insulated* shaft coupler between the capacitor shaft and the gear motor, since *both* sides of the capacitor are at high RF potential — BE CAREFUL! This is a nice technique to know when any type of remote tuning is needed or desired.

For a series LC circuit, selection of component values to form an equivalent variable inductor is simple. The capacitive and inductive reactances simply cancel. If the capacitive reactance is greater than the inductive reactance (smaller capacitor value), the equivalent is a capacitor, if the capacitive reactance is less than the inductive reactance, the result is an inductor. If they are equal, the result is a short circuit (except for a small resistive value). The vital equations are:

$$X = X_L - X_C \qquad \text{[Eq 1]}$$

and:

$$X_L = \omega L \qquad \text{[Eq 2]}$$

$$X_C = 1/\omega C \qquad \text{[Eq 3]}$$

$$\omega = 2\pi f \qquad \text{[Eq 4]}$$

where:

L is inductance in henrys, *C* is capacitance in farads, and *f* is the frequency in hertz.

For example, if we have a 100 µH inductor (about 1131 Ω inductive at 1.8 MHz) and a 78 to 500 pF variable capacitor connected in series, this would provide the equivalent of a 0 to 84 µH variable inductor at 1.8 MHz, where 78 pF is about 1130 Ω capacitive reactance and 500 pF is about 177 Ω capacitive reactance at 1.8 MHz. So, the greater the series capacitance, the greater the equivalent series inductance will be. If we tune the capacitor below 78 µF, the circuit begins to present a capacitive reactance.

Taking Gain Measurements

I developed a simple method of measuring the antenna gain, to make the tuning ad-

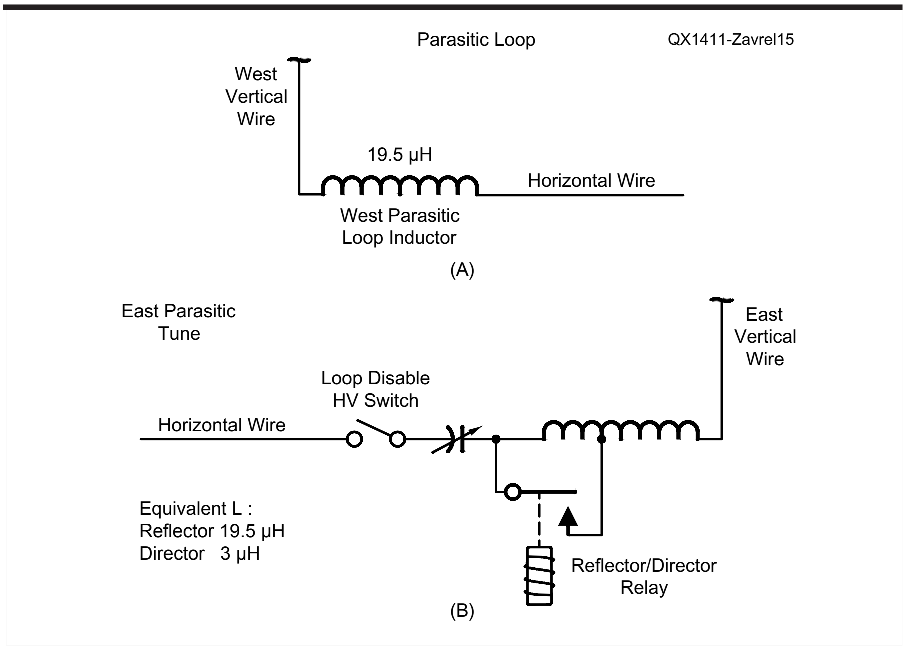

Figure 15 — This drawing shows the switching arrangement to enable or disable the loop, along with the relay to change the inductance value to switch between the loop serving as a reflector and a director for the north and south patterns.

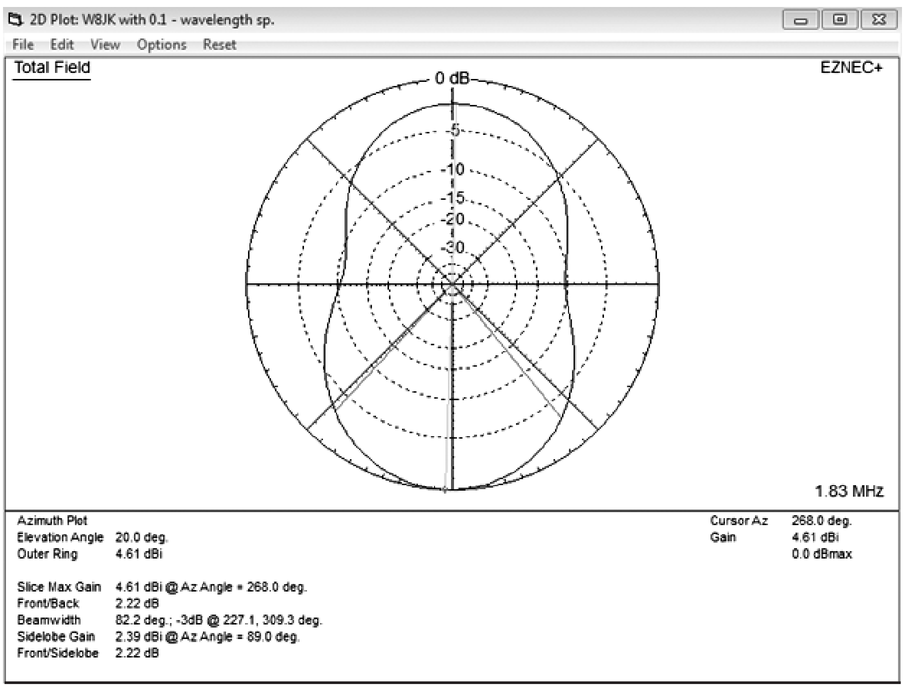

Figure 16 — This *EZNEC* radiation pattern plot shows the pattern to the south, with the loop switched in as a director.

justments on this antenna. I attach an HP AC voltmeter to the speaker output of my Elecraft K3, with the AGC turned off. To create a very simple 160 meter battery operated signal source, I used a common 1.843 MHz digital clock module running on three 1.5 V AA batteries. I mounted the entire assembly in a piece of PVC tubing and added a PVC cap on the bottom end. A four foot wire provides the antenna, and also doubles as a way to hang the signal source from tree branches. To make my gain measurements, I place the signal generator several hundred feet from the array. While tuning the inductors remotely, the AC voltmeter records the response. The HP meter also provides a dB scale, so dB differences can be read directly. If maximum forward gain is desired, the inductances are adjusted for maximum audio output. The signal generator is then moved and the applicable pattern also adjusted, making sure the antenna is properly matched. This makes for a very convenient method of fine tuning the array from the comfort of my shack!

Optimizing Loop Parasitic Elements

Most amateurs are familiar with the Cubical Quad antenna. The quad uses slightly longer or shorter than 1 λ loops for the parasitic elements (reflector and directors), and a resonant 1 λ loop for the driven element. A properly tuned (cut) near-square loop will be equally effective as either a vertical or horizontally polarized parasitic element. For the desired vertical polarization on 160 meters, a simple vertical can be made to provide respectable gain by placing a reflector loop in back of the vertical. Placing a reflector in back of a bidirectional vertical array, such as the Bob-Zepp, outstanding forward gain can be realized. Indeed, over 6 dBi is realized at a 20° take-off angle in the north direction, comparable to a full-size 8-circle array!

Parasitic loops are obviously advantageous for creating substantial gain in low-band systems. Using a fixed loop (non-rotatable array), the loop will always act as a reflector distorting or ruining patterns in other dictions. Also, it can adversely affect receive arrays, like 4-squares or 8-circles operating within several hundred feet of the loop. The solution is to de-tune the loop, effectively taking it out of the "circuit" to avoid the problem, particularly when using a directional receive antenna.

One solution is to break the wire with a switch. Unfortunately, if you place the switch at the wrong location in the loop, it will not eliminate its effect upon the desired pattern. Indeed, it is possible to place a switch at a location where it has no effect whatsoever (at the maximum voltage point). The following two examples show how critical switch placement is. The open switch, by default, defines a zero-current point (no current is possible across an open circuit). This will also define the high voltage point. As mentioned before, a square loop will affect either a vertically or horizontally polarized signal (unlike a Yagi's parasitic element, which will function on only one polarization effectively). Breaking the loop half way along a vertical section, however, will force the element to be *only* horizontally polarized and visa-versa.

A second effective solution is to break the loop in two locations, but this requires two high voltage switches and considerably more mounting and wiring. Using this solution, make sure the two remaining section lengths are far removed from multiples of ½ λ.

A third solution uses only one switch and provides other advantages as well. A loop at or less than about 0.93 λ total length, open at the *base* of one (single switch) of the vertical elements results in an insignificant parasitic effect with little effect on forward gain compared to a full-sized loop. The addition of two inductors can create either a reflector or a director element, or a north or south pattern. Furthermore, the use of inductors provides "fine tuning" of the parasitic element for maximum gain or F/B. I maximize F/B since this array's gain becomes an outstanding receive antenna in the north direction.

When using odd-shaped loops, the use of two inductors can help "force" the loop to be optimized for vertical polarization. I found it most effective to model the array using *EZNEC*, use the results as a starting point, and then optimize gain or Front to Back Ratio by fine tuning. For the loop dimensions shown, a 0 Ω inductive reactance value at the bottom inductor will result in near-maximum gain to the south. The difference between gains using the loop as a reflector versus as a director is evident in the plots shown in Figures 14 and 16. Using the loop as a director for the south pattern, however, provides an extra 1 dB over the loop "out" configuration, at the expense of a second switch in the loop control box. Now the parasitic element can be switched north, south or "out" for a bidirectional pattern.

As with the east/west pattern tuning, a similar capacitor-inductor combination provides for remote inductive tuning from the shack. Photo H shows the parasitic loop tuning box and Photo I gives us a peek inside the box. Photo J shows the west corner of the parasitic loop.

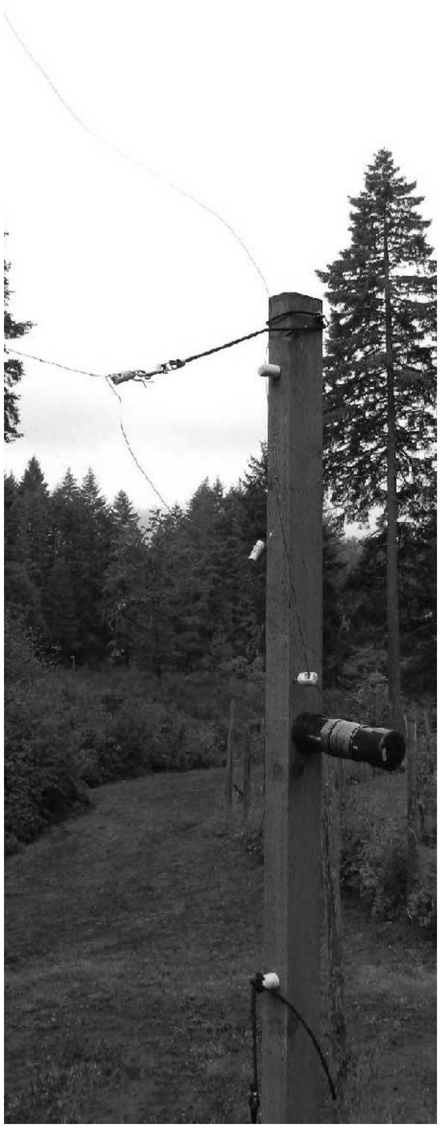

Photo J — Here is the west corner of the parasitic loop: A fixed inductor wound on a 3 inch ABS plastic pipe section with insulated #12 electrical wire solves the problem. ABS end connectors are used to close the pipe and provide a convenient mounting scheme on the post. Note the west anchor for the horizontal wire at the top of the pole using a bungee cord for stress relief. The vertical wire is fed through a ceramic electric fence insulator near the top of the post and with stress relief provided by another bungee cord. My pinot noir vineyard is in the background.

When using low-band parasitic loops, best performance (for a given reduced size <1 λ), can be optimized by making the vertical elements as "vertical" as possible. Inductive loading is placed at the base of the two vertical elements. More important than the different vertical heights, is to keep the horizontal parts of the loop as close to identical in length. This will assure that the current maximums will be placed half way up both vertical elements, and thus provide the best gain and/or F/B ratios possible for the given size. Placement of the loading inductors at the bases of the vertical sections makes them accessible from ground level and prevents additional weight up on the suspended wires.

Results

The gain figures speak for themselves. Running full power, this array can hold its own with full-size 4-square arrays even on the most difficult paths.

Bob Zavrel, W7SX, is an ARRL Life Member, Technical Advisor and Amateur Extra class licensee. He has been licensed since 1966. His primary interest in Amateur Radio is low band DXing and designing and building antennas, tuners, and amplifiers. Bob holds 5BDXCC, 5BWAZ (200), has 334 mixed, and 324 CW entities confirmed. Bob is on the DXCC Honor Roll and the CW DXCC Honor Roll, all using only tree-supported wire antennas. He also hold 9 Band DXCC on 160 through 10 meters. Previous call signs include WN9RAT, WA9RAT, WA9RAT/HR2 and SV1/W7SX.

Bob has a BS in Physics from the University of Oregon and has worked in RF engineering for over 30 years. He has five patents, and has published over 50 papers in professional and Amateur Radio publications, including the first block diagram of an SDR receiver in 1987. He was involved with the first generation of RF integrated circuits for cellular phones, and worked extensively with DDS, WLAN and passive mixer development. Bob is currently an RF Research and Development Engineer for Trimble Navigation with a primary focus on high precision GPS, down to mm accuracy.