Arrays of K9AY Loops:
"Medium-Sized" Low Band RX Antenna Solutions

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With the low bands benefitting from the current sunspot minimum, receive antennas are important for DXers, contesters and other active amateur radio operators. This presentation offers solutions that lie between large antenna systems such as multiple Beverages, and small loops and other compact antennas, including flags, pennants, EWEs, tuned loops and others.

What do I mean by "Medium Sized"?

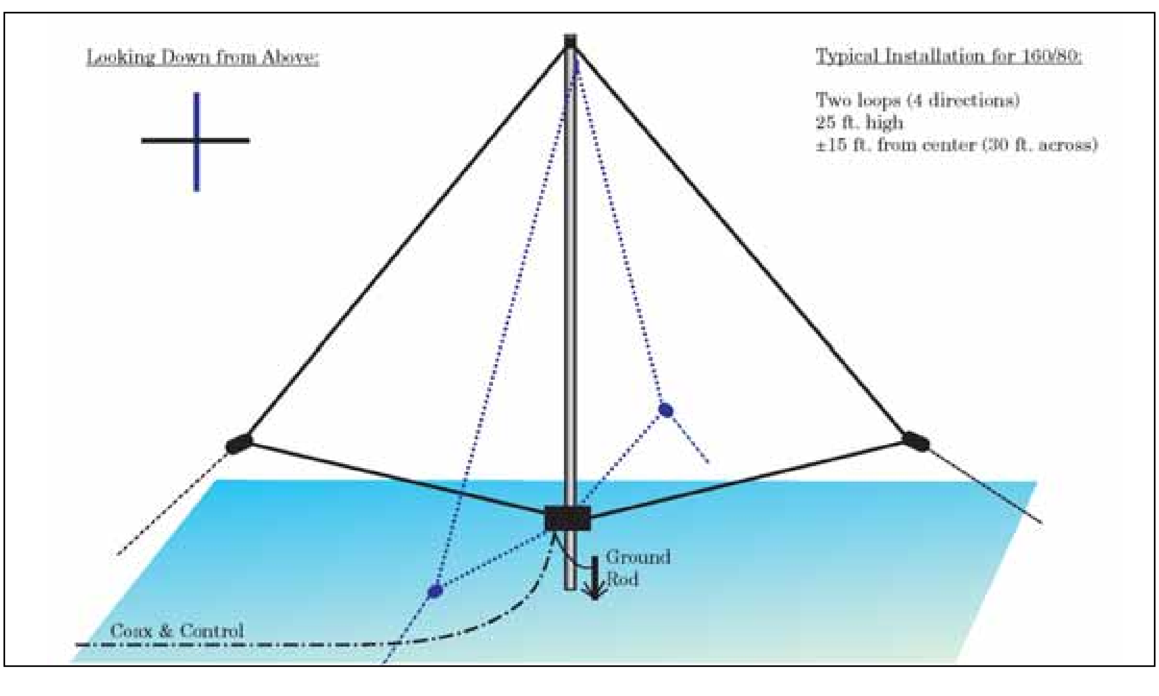
Three scenarios come to mind:

1. You have ample room for towers and antennas, but not enough room for Beverages.
2. You may even have enough room for one or two Beverages, but not for all desired directions.
3. Either of the above, plus seasonal Beverages that must be removed during the warmer months, requiring some other solution for year-round use.

As you can see, this is neither about small city lot operating, nor large antenna farms.

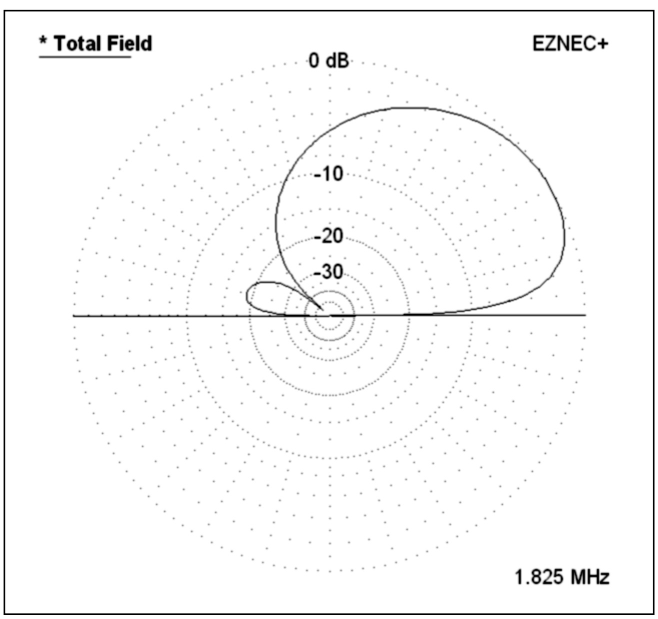
Why Use a K9AY Loop for an Element in an Array?

First let's review this antenna. The sketch below shows the basic design as published in September 1997 *QST*: two crossed loops with connections switched to provide coverage in four directions. The switch box alternately connects the matching transformer and terminating resistor to the selected wires.

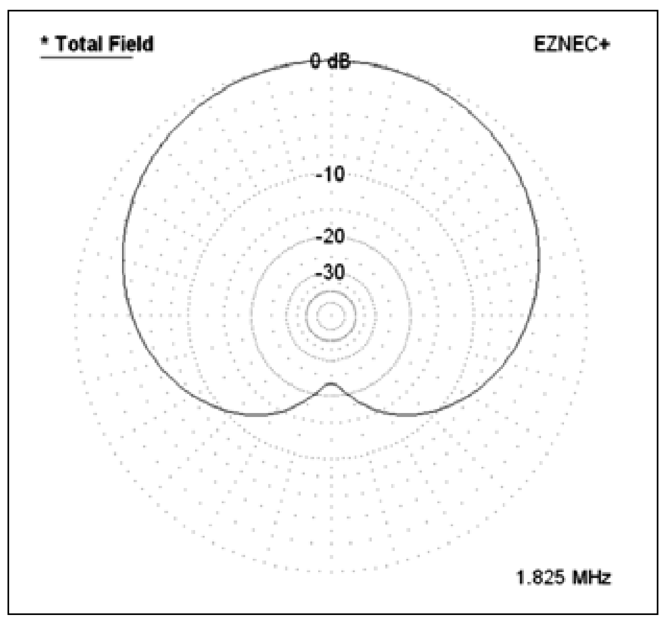


The K9AY Loop at SM6LKM shows how one user implemented construction.
(SM6LKM photo)

The next figure shows the basic pattern plots for the K9AY Loop. Note that there is one deep null off the back, and at least 10 dB front-to-back is maintained over a modest vertical and horizontal angle. With the crossed loops, this pattern can switched to any of four directions, typically NE, SE, SW and NW.



Vertical Pattern



Horizontal Pattern (at 30º elevation angle)

This basic design is used by more than 2,000 hams around the world. It offers a pattern similar to what can be obtained with a EWE, flag or pennant, but with the primary advantage of being switchable. Another small advantage is that it has a few dB higher signal level than a flag or pennant of the same size, since it uses the ground image.

The features that make the K9AY Loop useful as an element in an array include:

· It's well-behaved feedpoint impedance simplfies matching and phasing circuitry.

· There is no need to consider mutual impedances in matching and phasing circuitry. Like all small antennas, it has relatively low efficiency, which means that coupling is low between elements.

· It's switchable pattern enables multi-direction arrays.

· It already has a directional pattern, which is combined with the added directivity achieved with array layout and phasing.

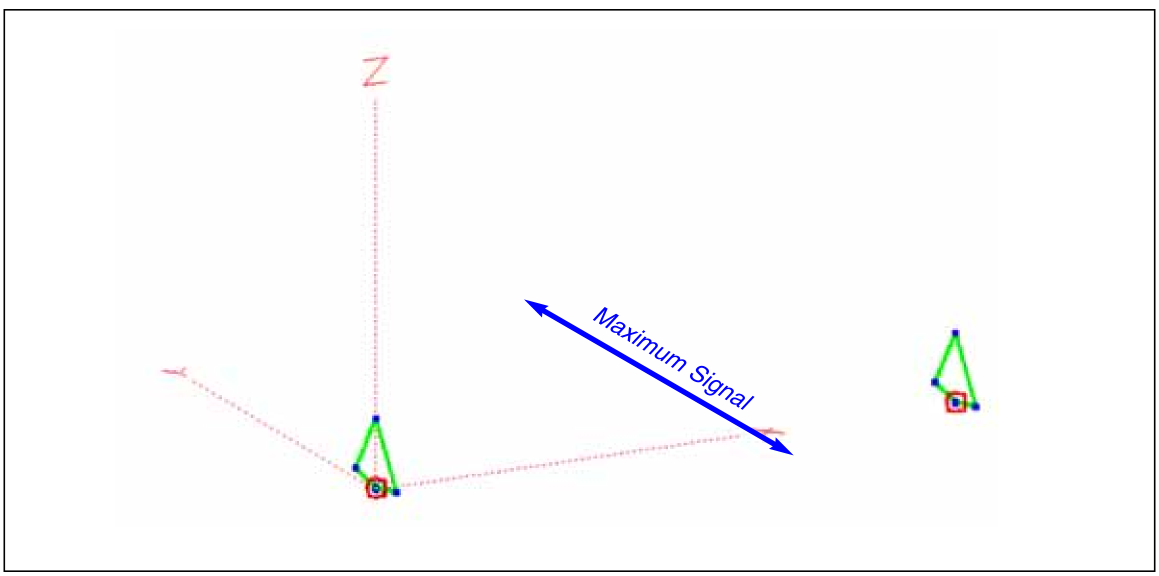
· Of course, it is not the only usable element for an array — short verticals, flag, pennants, EWEs and even Beverages are other options. Each has its own set of characteristics to consider.

With these features in mind, we'll continue by looking at some array options for a few different scenarios for the space that is available at a ham's QTH.

Scenario #1 **Space available: Linear, around 1/2-wave long**
Possible solution: Broadside/Endfire pairs

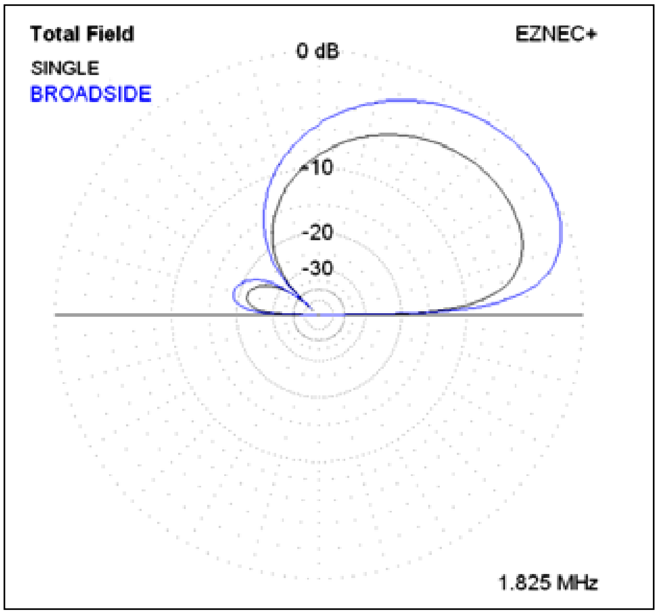
This is for hams who have perhaps 250-300 feet (assuming a 160M antenna) along the back or side of their property. Locating two sets of K9AY Loops roughly 1/2-wave apart offers a classic broadside/endfire arrangement sometimes seen with two transmitting verticals, but enhanced by the intrisnic directional pattern of the loops.

This is not just an antenna modeling exercise — this past July and August, I built and tested 2-element arrays, starting with this broadside/endfire arrangement. I will include my observations in the discussion of their performance. First, here is the layout of two loops in a broadside arrangement:

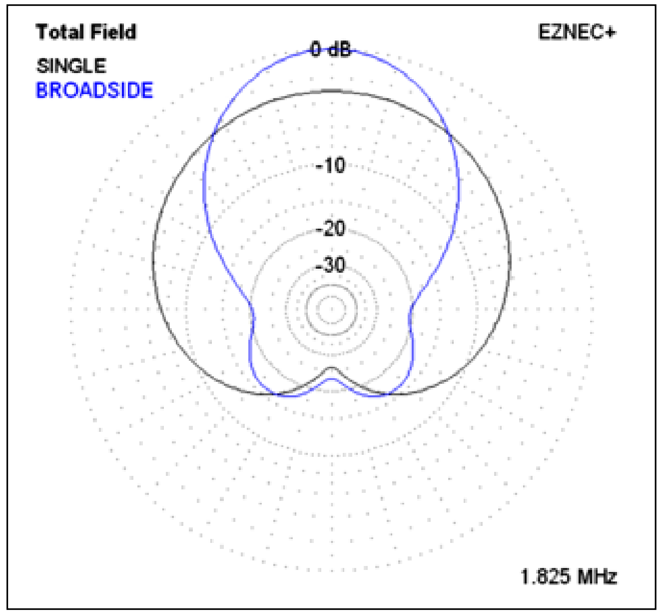


On 160M, 1/2-wave spacing is 270 feet, while on 80M the spacing is 140 feet. The sketch above shows only the two loops that are active in this array — we'll look at the other two loops in the crossed pairs after examining this array.

The next figure shows the patterns for the broadside pair, compared to a single K9AY Loop. As you can see, the vertical pattern is exactly the same shape, although the signal level is increases between 3 and 4 dB due to the gain of the array.



Vertical Pattern

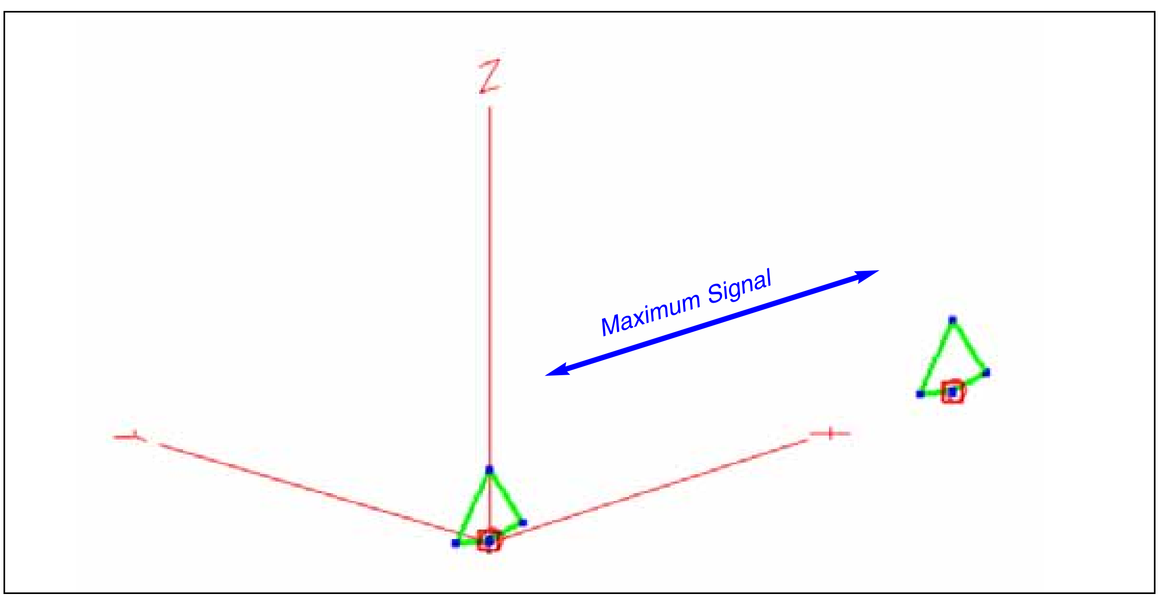


Horizontal Pattern (at 30º elevation angle)

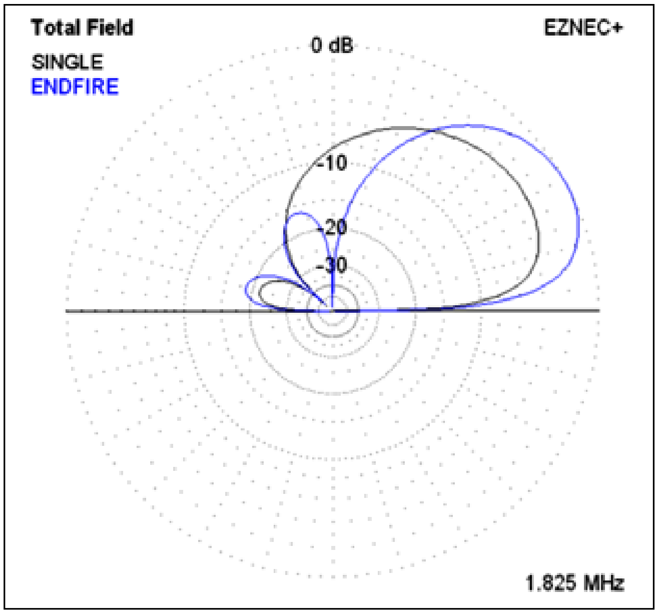
The horizontal pattern is much narrower, with 20 dB front-to-side at the elevation angle shown. With exactly 1/2-wave spacing there will be avery deep null at ground level, which may be useful for local noise rejection. Spacing a little greater than 1/2-wave — somewhere between 1/2- and 5/8-wave — will place the null at a higher angle, which may be better for QRM and distant thunderstorm noise reduction. However, the wider spacing will cause some reduced performance in the endfire directions.

The broadside patterns shown are reversible, covering the two directions that are a right angles to the line between the loops.

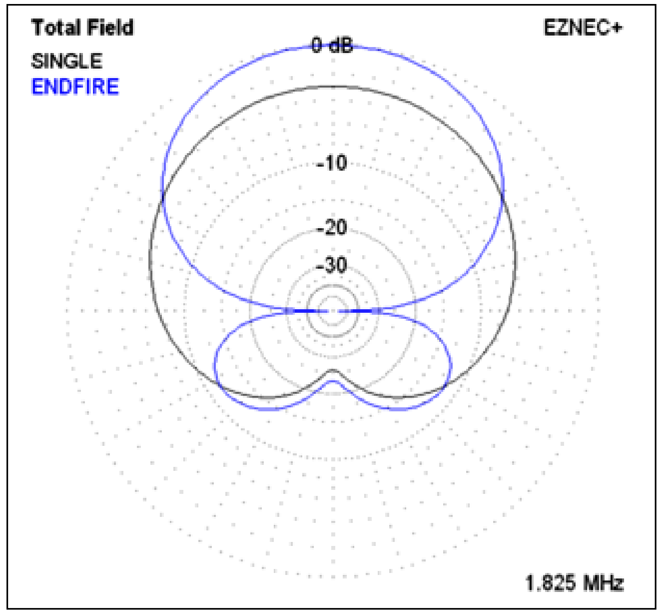
Next, we look at the layout of the loops as a 2-element endfire array, with the same spacing. This configuration uses the other two loops of the crossed pairs:



The maximum signal is along the line of the two loops. In this case, I'll just show 180º phasing, since it is the simplest possible phasing for endfire. With this phasing, the pattern can be reversed by simply reversing the loops themselves — no phase shift networks need to switched. The patterns are shown here:



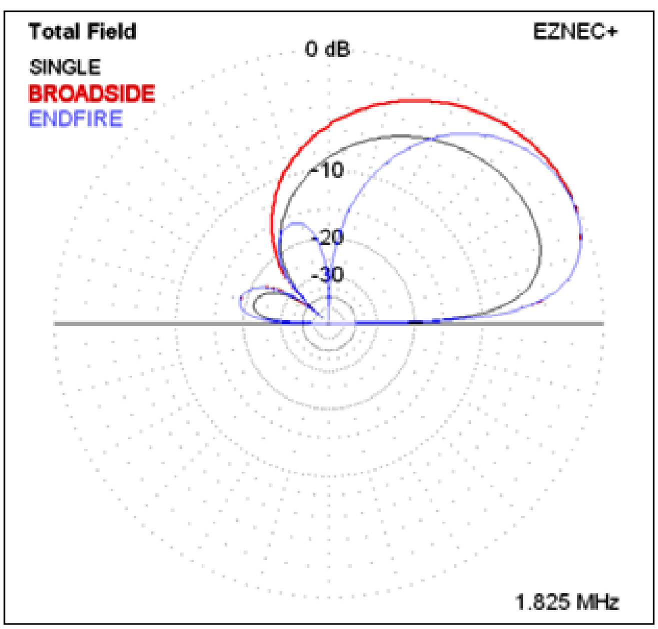
Vertical Pattern



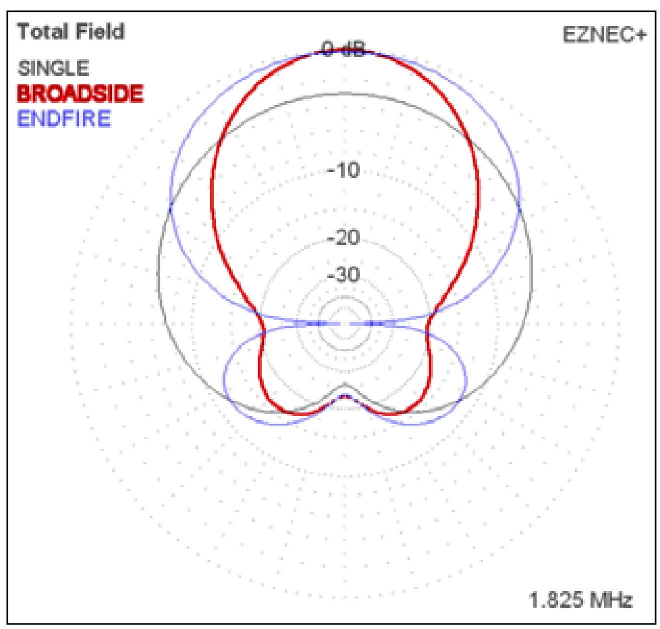
Horizontal Pattern (at 30º elevation angle)

Analyzing these patterns, we can see that the endfire pattern is much different than the broadside pattern. First, both patterns show the 3 dB gain due to combining the signal capture of two antennas. Next, the vertical pattern is improved over a single loop, with greatly reduced response at very high angles. This will reduce sky noise a bit, but more important, will reduce "short skip" signals from close-in stations. The horizontal pattern adds two deep, but narrow, nulls off the sides. It is still very wide in the main direction — certainly better than a single loop, but not as narrow as the broadside pair.

To summarize, the broadside pattern is narrow, but tall, while the endfire pattern is wide but flat. The endfire array also has the side nulls. The figures below combine the patterns into one plot for comparison.



Vertical Pattern



Horizontal Pattern (at 30º elevation angle)

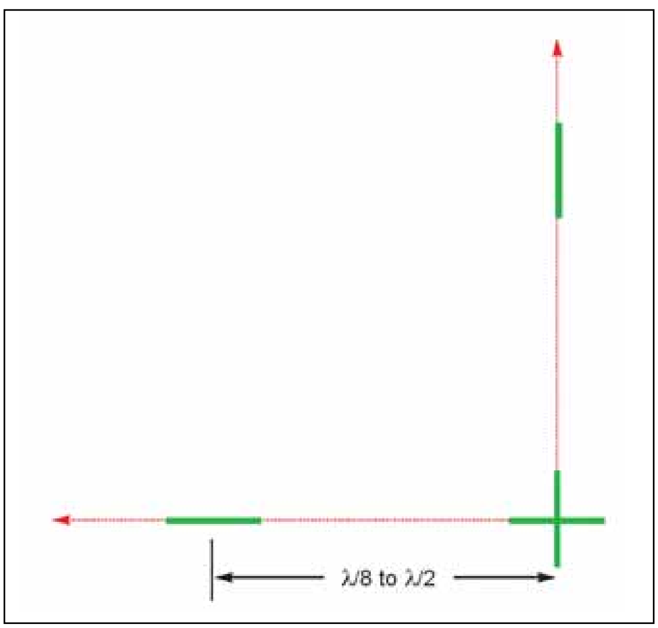
Extensive listening tests confirmed that these patterns are readily achieved with two K9AY Loop crossed pairs, constructed to be as identical as possible, and with no special "tweaking." To get the required 180º phasing, I modified the standard K9AY Loop switch unit so that one loop had reversed phase when either endfire direction was selected. This was done quite simply by adding a relay to reverse the connections to the matching transformer. Control of the array was just like a single loop, with four directions, and the beamwidth of the patterns still allowed coverage in all directions.

My overall reponse was that the endfire pattern was generally more useful than the broadside pattern because it could be used at frequencies where the spacing was not 1/2-wave. The broadside pattern is great for single-band operation, but the endfire pattern was useful over a wide range of frequencies. My test setup had the two loops spaced 140 feet, or 1/2-wave on 80M. The best broadside performance was a bit higher in frequency, where the spacing was closer to 5/8- or 3/4-wave, placing the side nulls at angles that reduced skywave signals.

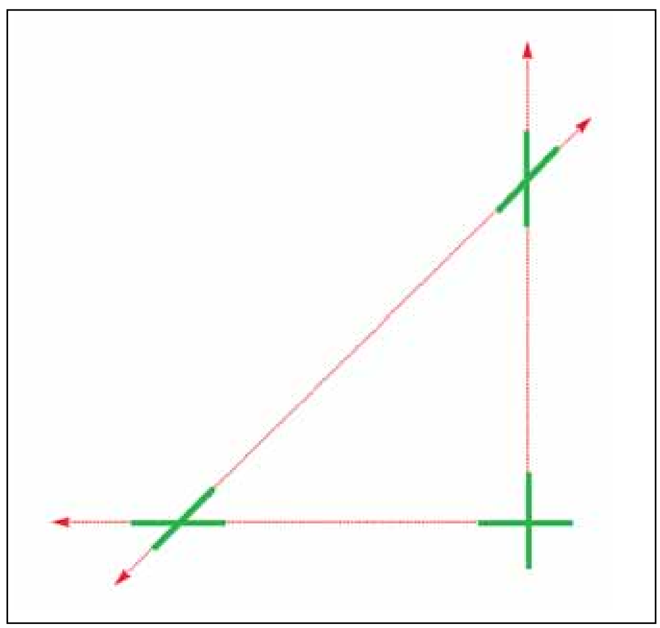
With 140-foot spacing, I could get useful performance from the endfire pairs from the AM broadcast band through 5 MHz. The reduced high angle response was clearly observed at these frequencies. At the lower frequencies, the closer spacing alters the exact shape of the pattern, but the side nulls are always present, as is the K9AY Loop's intrinsic F/B behavior. I'll have more on this subject in the next section.

Scenario #2 **Space available: Corner, with less than 1/2-wave along either line**
Possible solution: Endfire combinations

This is another arrangement that is not uncommon. Many hams can find a corner of the property where receiving antennas will not intrude too much into the yard. The space might also be available around the end of a garden plot or other feature of the property. With this arrangement, it is possible to fit two or three sets of loops into a relatively compact area:



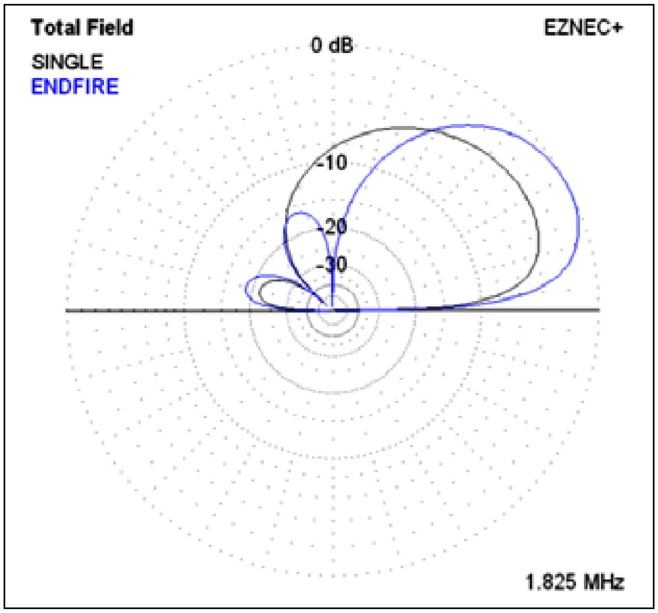
Crossed Loop + Single Loops



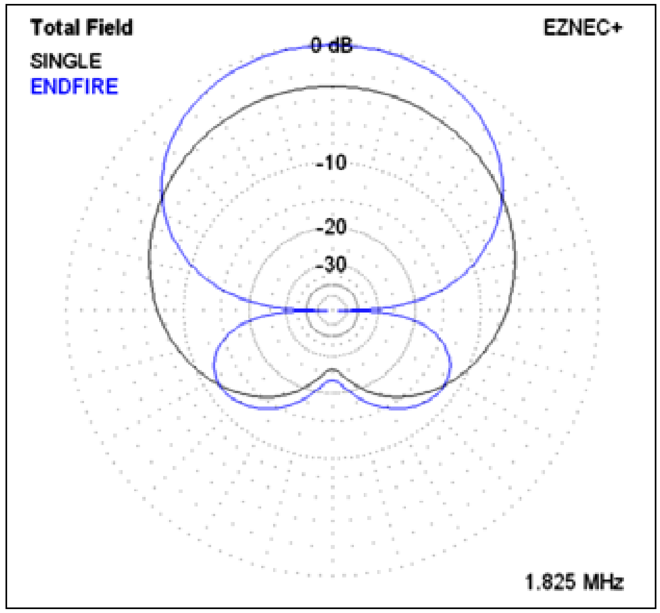
3 Crossed loops, at different angles

The combination on the left permits four direction coverage with the endfire pattern. The layout on the right adds additional loops if the user wants to have two more direction options for both the main beam and the nulls of the array. In practice, the minimum recommended spacing for both 160M and 80M use is 100 feet each way. I should note that the distances shown are center-to-center, and some added space is needed to accommodate the 30-foot total width of the loops.

With the simple 180º phasing and patterns shown earlier, these pairs will be usable, but there are options for enhancing their performance. First, I'll repeat those earlier patterns as a reminder:



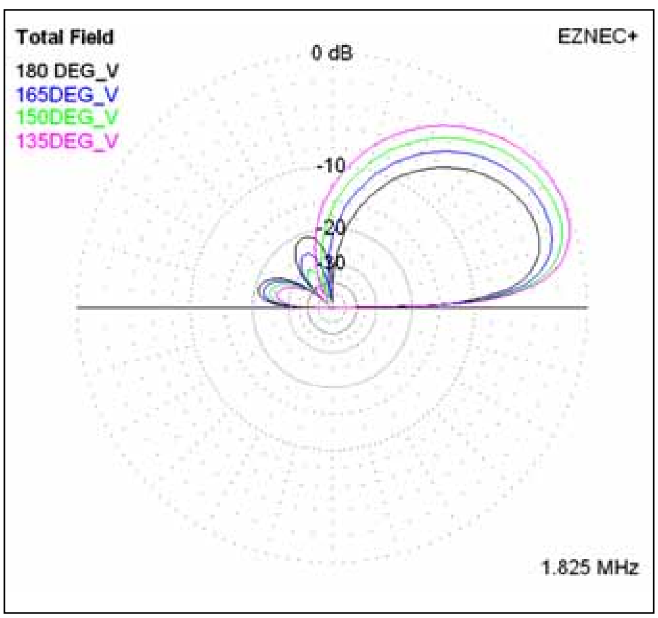
Vertical Pattern



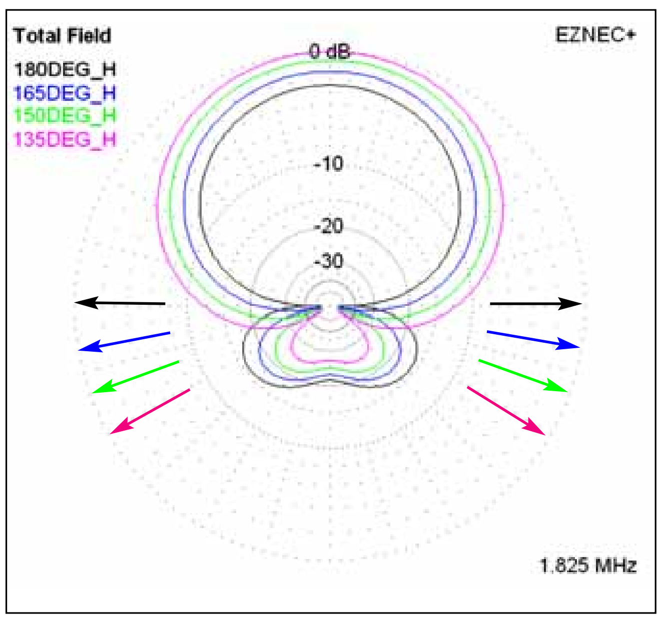
Horizontal Pattern (at 30º elevation angle)

You may already have considered that a change in phasing would move the side nulls. This is indeed the case, and is an effective way to steer the nulls to get maximum rejection of a particular noise or QRM source. The width of the null region is relatively narrow, but the depth of the null is good enough to virtually eliminate signals from that specific direction.

The following figure is somewhat complicated, but shows a series of patterns that are obtained when the phasing is changed in 15-degreeincrements. The colored arrows in the right figure shows the azimuth of the side nulls (again at a 30º elevation angle) of the. The steps in phase shift can be accomplished in a straightforward manner with sections of coax that are switched in or out to change the length of the feedlines, and thus, the phase.



Vertical Patterns



Horizontal Patterns

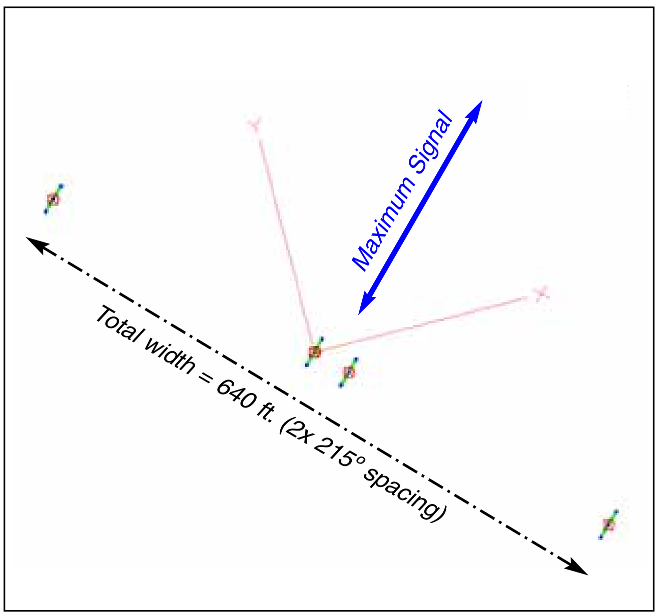
This null-steering capability is quite useful. With my test array, I was able to selectively null several AM broadcast stations, allowing me to hear otherwise inaudible stations on the same frequency. This type of array would be an excellent choice for an avid BCB DXer!

Although I was able to verify that the 'real' patterns matched the modeled patterns, summertime listening is difficult for a good evaluation of low band performance. Atmospheric noise is usually high, and activity is low. I was not able to get a good feeling for the value of these 2-element patterns during crowded band conditions, and with comparisons of near and far stations with different arrival angles. It seemed that the combination of steerable nulls and rejection of very high angle signals made the endfire array more useful than the broadside array noted earlier. However, I had limited opportunities to ascertain the value of the narrow beam of the broadside array.

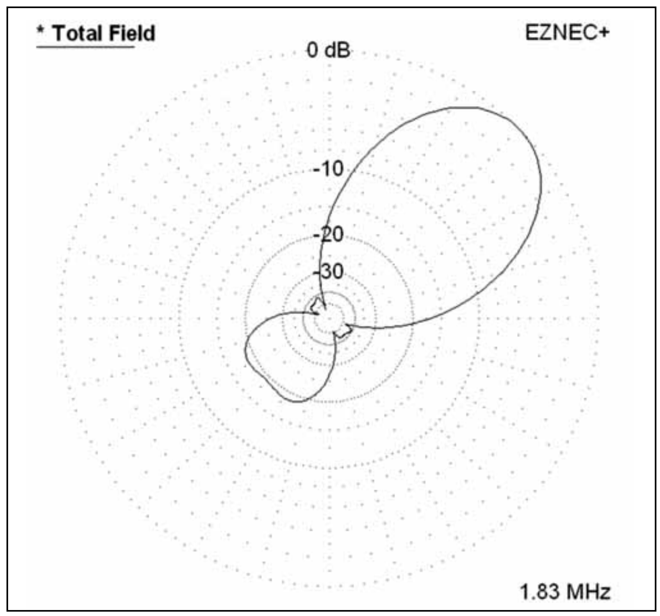
Scenario #3 **Space available: Linear—lots of space along a line**
Possible solutions: Larger broadside and inline arrays

Now we'll move up to larger-sized possibilities. Here are two possible solutions for a station that has as much as a wavelength or more in length, but little width. First, a large broadside array.

While a Beverage can provide good reception along the line of such a long area, there is no way to get high performance off the sides. One interesting possibility is adding a 3rd element to the broadside pair we looked at earlier:



Array Layout

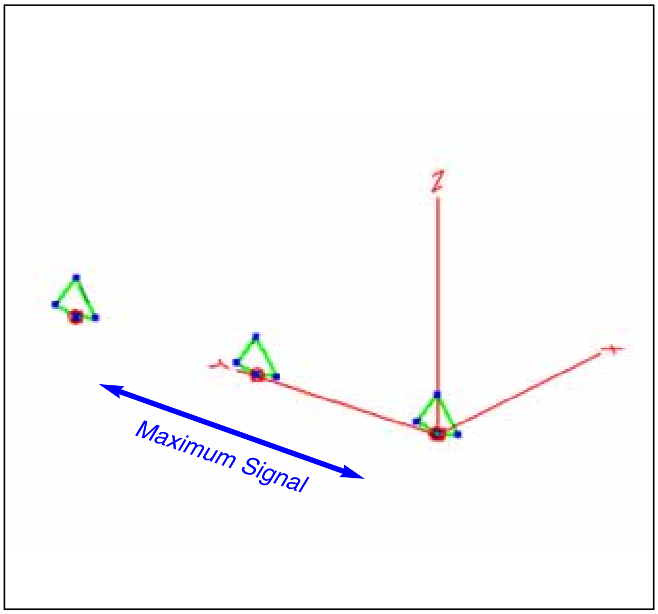


Horizontal Pattern

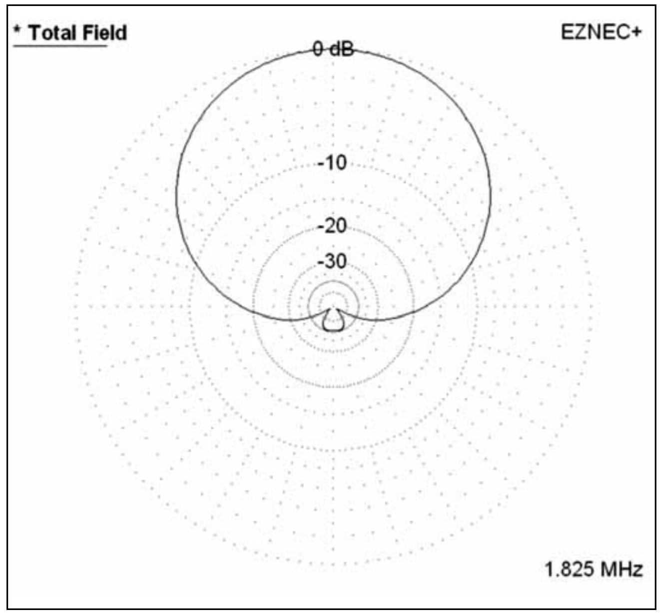
Yes, this is a 3-element array, not 4 — a 3-element broadside array, including the familiar Bobtail Curtain, requires two times as much current in the center element, compared to each outer element. In my design, this is accomplished by placing two loops close together at the center and feeding them separately. All four loops are fed with equal currents, so in effect, the center two work as a single element with twice the current. The reason behind this choice is that 4-way equal-power dividers are easy to build, versus a 3-way power divider with unequal outputs. The minimal coupling between the loops makes it possible to simply place the two center loops close together without interaction.

As you can see from the pattern plot, this array has a very narrow beamwidth! The vertical pattern is identical to that of a single loop, so this array has a very narrow, but tall radiation pattern.

The next option for our long, narrow space is a 3-element version of the endfire array. For this example, I used an array with 1/4-wave (90°) spacing between elements.



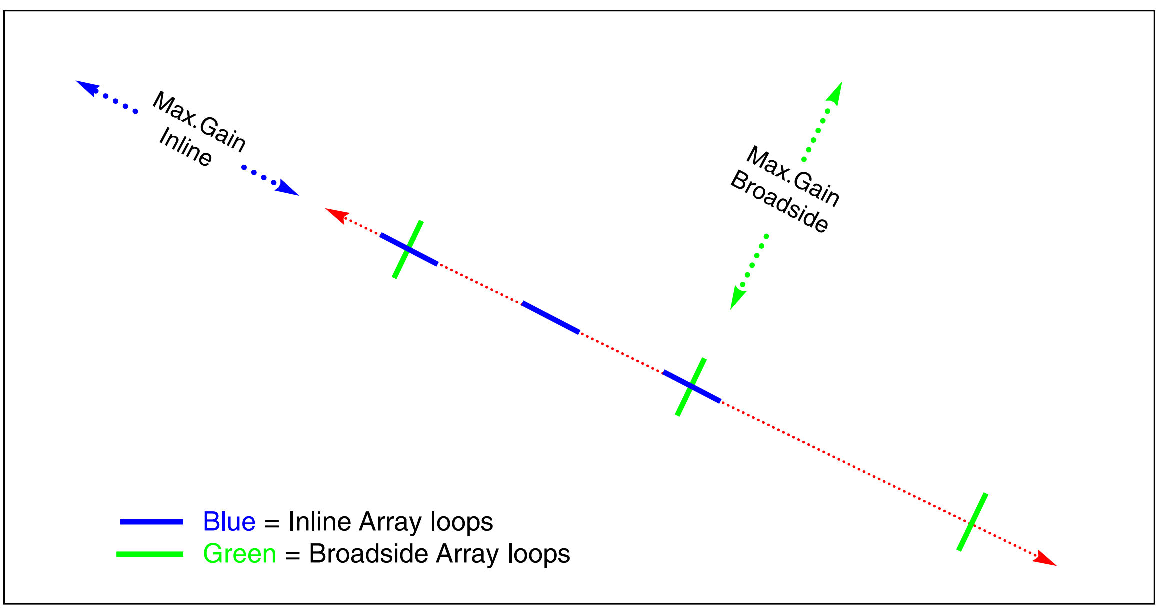
Array Layout



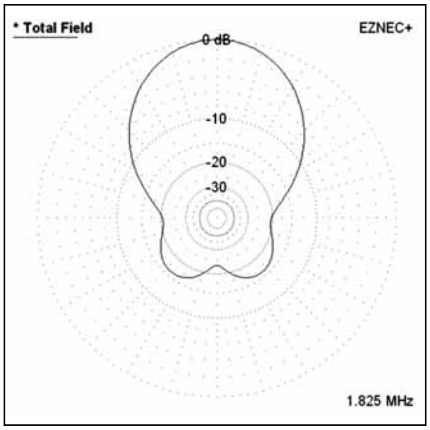
Horizontal Pattern

Using three elements results in a much cleaner pattern than a 2-element endfire array, as evidenced by the plot on the right. Although not shown, the vertical pattern is similar to that of the 2-element array, but with even better front-to-back and high angle rejection. The greatest advantage of adding a 3rd element is that the tradeoffs between forward beamwidth, vertical rejection and front-to-back are controlled by phasing. Any of the three can be emphasized, depending on you preferences. I might also note that a 3-element inline array will have a pattern similar to the familiar 4-square array.

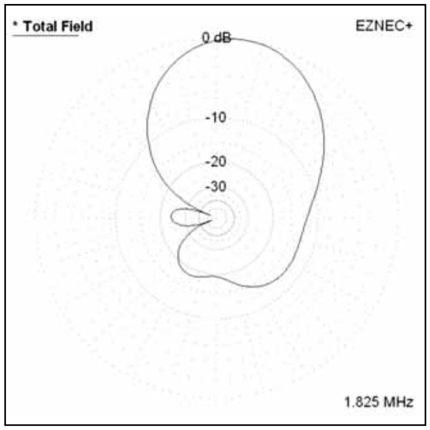
There are many other options for a long, narrow space, including additional elements in either broadside or inline configurations, as well as combination arrays like the one below. This type of arrangement will let you cover four directions from a linear arrangement of loops.



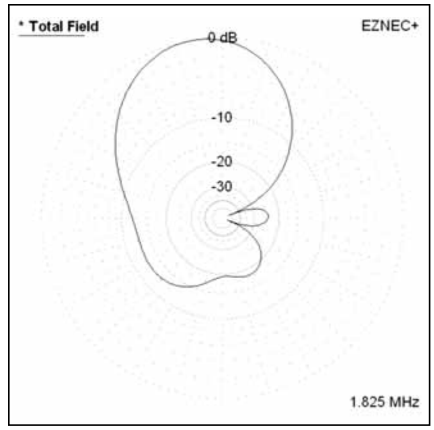
Let's take a closer look at the left part of the array — a 3-element inline array, combined with a broadside pair. As you recall, we can steer arrays with different phasing, which is the case with a broadside array as well as an endfire array. The figures below show this for the broadside pair:



0º Phase Shift



+30º Phase Shift



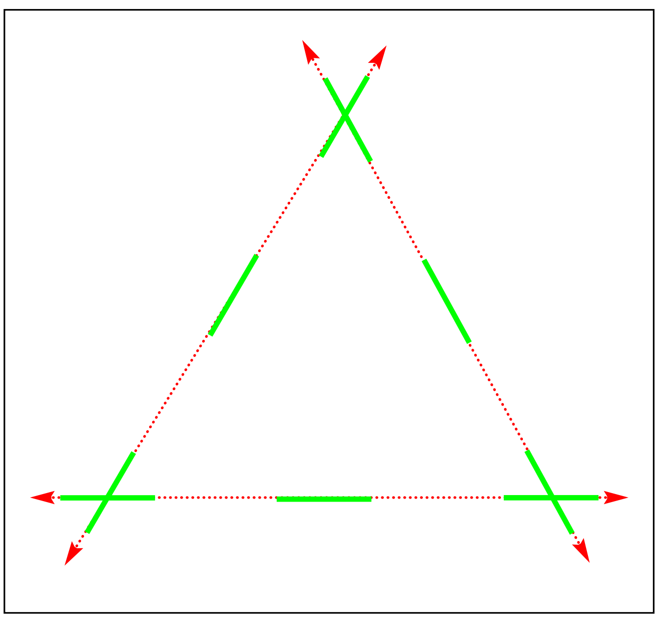
–30º Phase Shift

The plot on the left is the broadside pair, with both elements fed in-phase. A 30-degree phase shift will "push" the main lobe ten degrees to one side, while expanding the front-to-side rejection area on the other side. Of course, if the phase shift is applied to the opposite element, the pattern is pushed the other way. I did this with my experiemental 2-element arrays, and the result was deemed very beneficial if your desire is to enhance rejection off one side of the array.

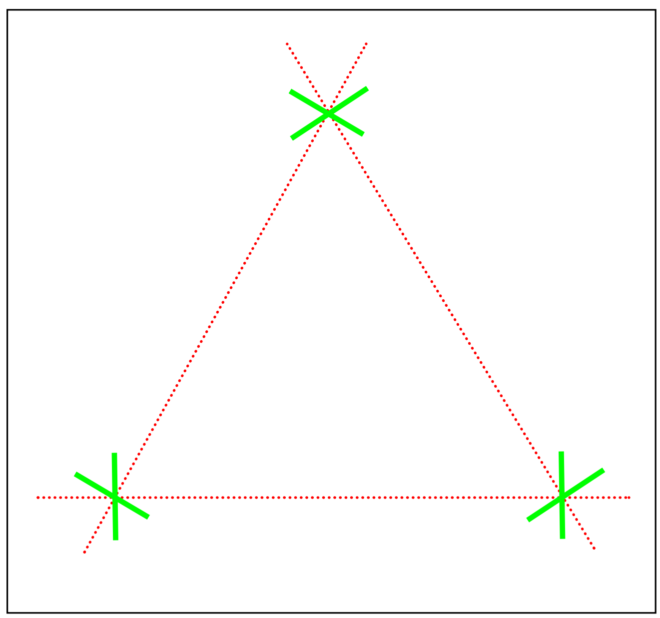
Scenario #4 **Space available: Plenty of space (but not enough for many Beverages)**

Possible solutions:
- **Triangle Array**
- **Rectangle Array**
- **Circle Array**
- **4-Square**

Finally, we'll examine some much bigger arrays with higher performance. This section is intended to get you thinking big—but not quite as big as a whole farm of multiple Beverage antennas. Here are the first options:



Inline Array Triangle



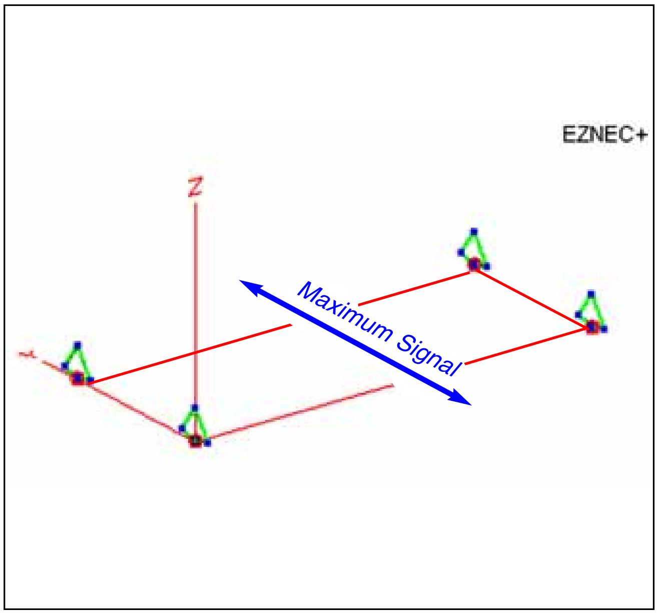
Broadside Pair Triangle

(corner-to-corner dimension of both arrays is 1/2 to 5/8 λ)

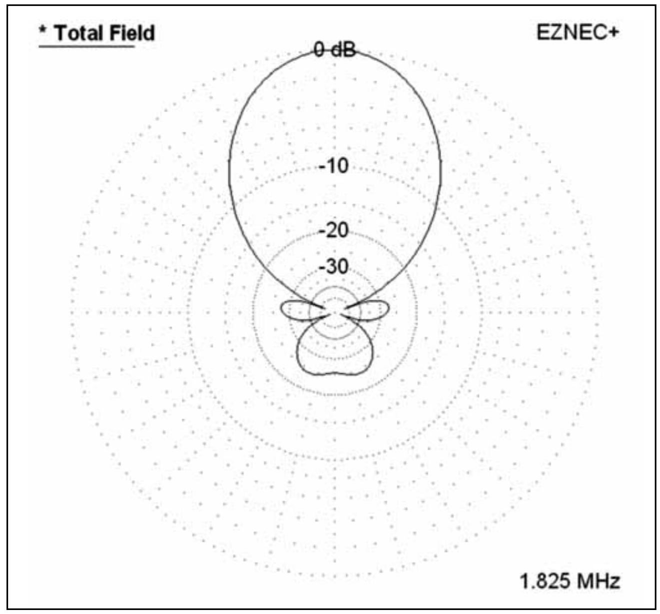
OK, why triangles? A triangle is the smallest arrangement that will provide coverage in all directions with full performance. Both the inline and broadside arrays have horizontal patterns that are narrower than 90º and if only four directions were available, there would be areas between them where signals would be "off the side" and weaker. But those horizontal patterns are wide enough that 6-way switching (60º increments) has no gaps in the coverage.

The triangles solve the problem of gaps in coverage with narrower beamwidths, however, these arrays do not add any performance over the previously discussed array options.

A rectangle of K9AY Loops is a significant step up in performance. This array combines the narrow beam of a broadside pair with the improved nulls and high angle rejection of an endfire pair. And because the broadside pair has good side nulls, the endfire nulls can be steered toward the rear for improved front-to-back.



5/8λ × 1/4λ Rectangle Array



Horizontal Pattern (narrowest beam)

The rectangle clearly focuses maximum performance in one direction (and the reverse when switched). The pattern plot shown is for the narrowest beam. The endfire phasing can be changed to emphasize front-to-back, if desired.

A rectangle is limited to two directions, but there are several options for achieving coverage in the other directions, fitting into the same area:

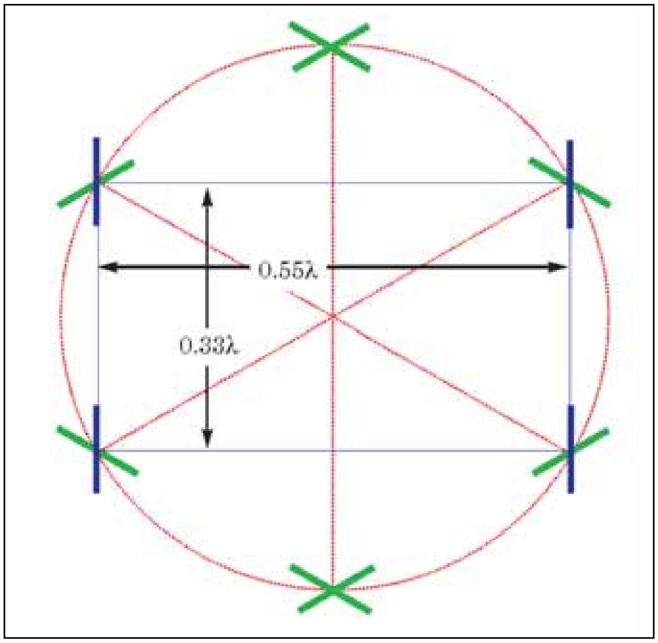
- An inline array can be installed along one of the long sides of the rectangle
- Two inline arrays can be installed from corner-to-corner for added coverage directions
- If lower performance is acceptable, the two loops along a short side can be crossed loops, with the two added loops acting as a short-spaced broadside pair

Circle Arrays

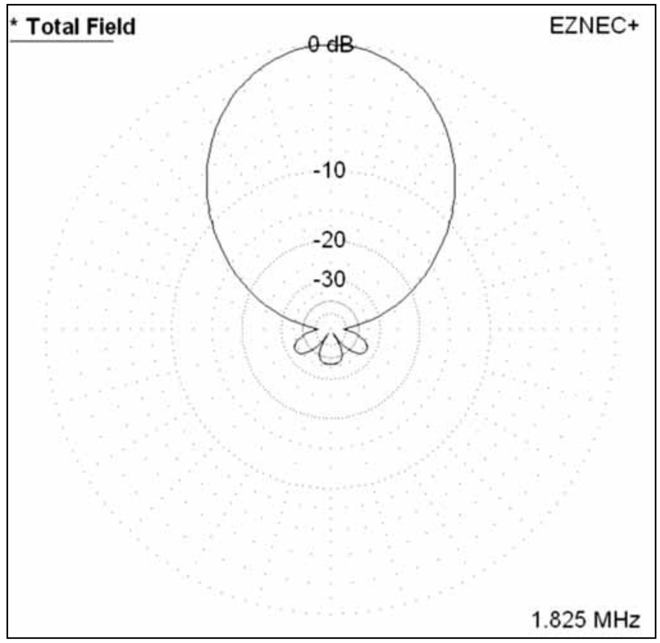
Another option to get coverage at all points fo the compass is to interlace several high performance arrays so that the same pattern can be switched to multiple directions.

Perhaps you have read about transmit arrays with names like 5-square, 6-circle, 8-circle or 9-circle. The same concepts can be appled to receive-only antennas, as we will see next.

The rectangle array has a beamwidth that will allow coverage of all directions with six crossed loops arrange in a circular layout. The individual loops are used four at a time to make three rectangles, each of which is reversible with switching. Thus, the array can be focused in six different directions, like the triangle array described above.



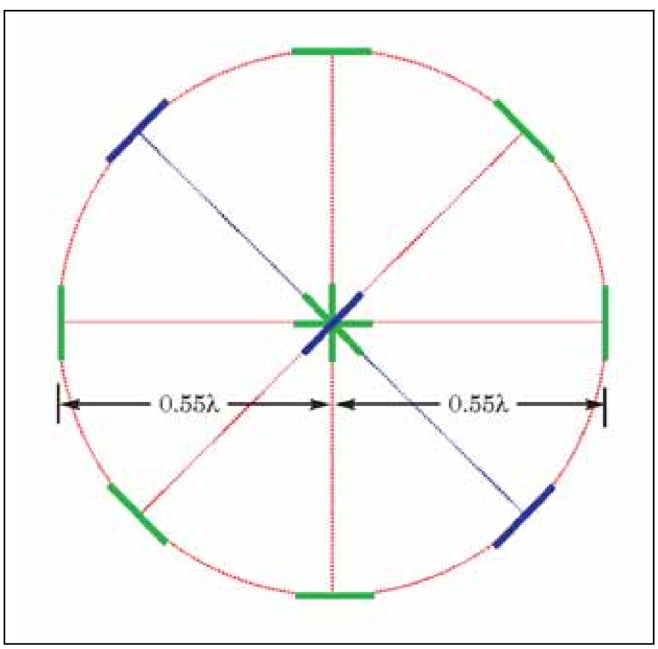
5/8λ × 1/4λ Rectangle Array



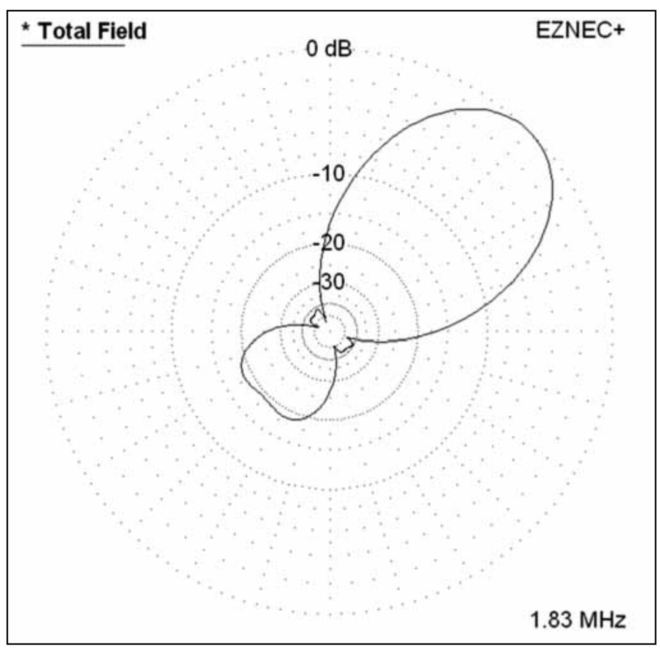
Horizontal Pattern (narrowest beam)

In the layout drawing on the left, the four active loops (blue) make up a rectangle, which can be repeated three times using the other (green) loops. With this type configuration, the “endfire” spacing is about 1/3 wavelength when the broadside spacing is between 1/2 and 5/8 wavelength (about 200 electrical degrees). For the above example, I optimized the rectangle phasing for maximum front-to-back at the selected 30 degree elevation angle.

The next example is an 8-way circle using the large 3-element broadside array described earlier:



8-way, 3-element broadside



Horizontal Pattern

Like the 6-way example, the active loops are shown in blue, with the corresponding pattern shown on the right. This array would occupy a large area, since it is approx. 600 feet across (at 160M), but this may be a good time to note another difference versus Beverages. Beverages are continuous, stretching a wire along its entire length. Loops, on the other hand, are discrete assemblies, and if the coax and control wires are buried, the intrusion into the landscape can be much less than a set of Beverages.

There are many more possible ways to arrange loops in circles. For example, the above arrays can have aditional loops in place that have optimum spacing for 80M coverage. One array that intrigues me is a rectangle array set up for 8-way switching rather than the 6-way arrangement shown above. This place the endfire loops somewhat closer in spacing, which is better than the 1/3 wave of the 6-way design. Thus, an array with a narrow beamwidth and excellent front-to-back can fit into a circle with a diameter of 5/8 wavelength. This is far less acreage than an equivalent-performing set of Beverages would require.

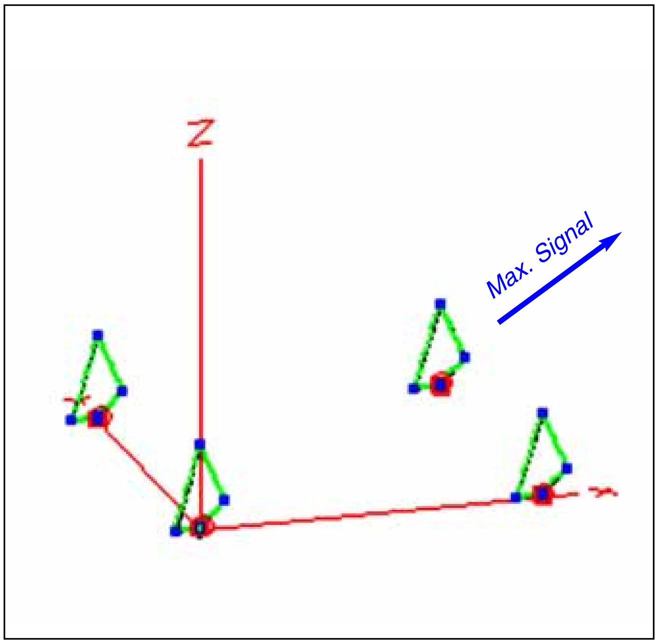
All these circle arrays are fascinating — maybe there is some primal attraction to the circular form...????

Maybe there will be time in the future for me to build my own version of “Loophenge” !

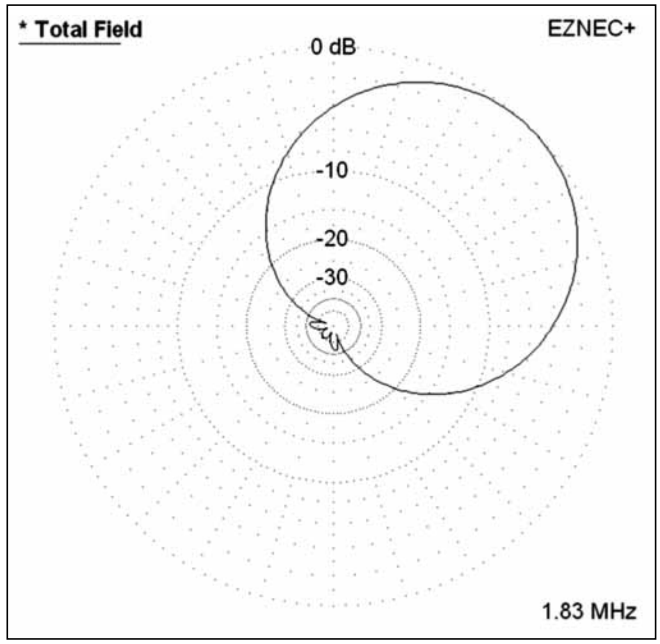
One Final Example

Well, after this little diversion, there is one more array to examine. I saved it until last because, in my estimation, it has the most performance for the space it requires...

The 4-Square of K9AY Loops



Layout



Horizontal Pattern

Not only does the 4-square provide a good, clean pattern on the computer, it does so in practice. There are several 4-squares of K9AY Loops operating in Poland, both on 80M and 160M. Two are shown below.

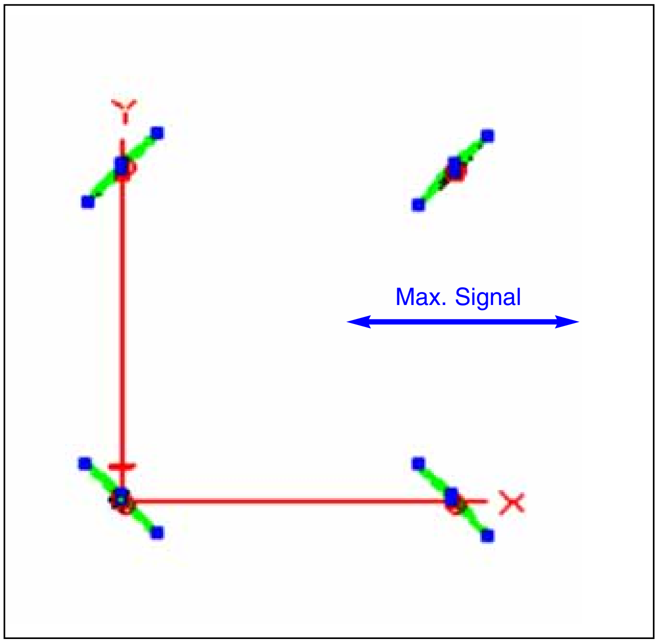
4-Square at SN3A (SP3GEM)

80M 4-Square at SQ3GHMM

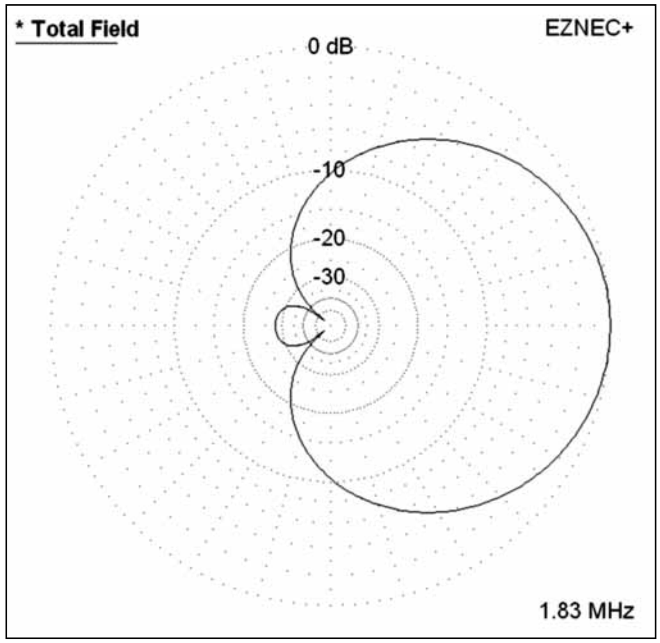
More info is available at — www.sp3key.com/klub/k9ay_160_en/index.html, and www.sp3key.com/klub/k9ay_pro/index_en.html

Although offering a lot of performance in a relatively small occupied area, the 4-square has one limitation—when optimized, it has a beamwidth less than 90 degrees, which leaves the in-between areas with lesser performance.

It is possible to fill those areas with a useful main beam and good front-to-back by adding more options to the 4-square switching/phasing system. First, remember that the loops are oriented along the diagonals of the array, and we want a pattern that lies along the sides. One way to accomplish this is with the arrangement shown below:



Layout



Horizontal Pattern

Although the optimum pattern of the individual K9AY Loops is in line with the plane of the loop, we can get acceptable array performance by arranging four loops symmetrically about the line of our desired direction. most of the front-to-back is achieved through phasing of the individual elements, although there is some contribution by the intrinsic F/B of the loops.

The forward pattern is broader than the normal 4-square pattern because the spacing is a compromise. However, it certainly provides useful performance for those "in between" directions.

Summary

This presentation was meant to show you what can be done with arrays of small receiving antennas. Although I used K9AY Loops for the array elements, many of these (and other) arrays can be implemented with similar performance using other types of elements.

Hopefully, you will gain an appreciation of the power of controlled behavior in an array, using spacing, current distribution and phase shifts to obtain the kind of pattern we want.

Certainly, phasing, switching and impedance matching can be complex, but that is the tradeoff for the performance that can be obtained. Some of these arrays are relatively simple in their implementation and may offer a nice step up in performance versus a single element RX antenna.