

EZNEC Simulations Of Antennas And Dual And Quad Antenna Arrays

Dallas Lankford, 11/23/2014

This article discusses how I have used EZNEC to design single antennas and dual and quad antenna arrays. A few of the antenna arrays discussed in this article have been constructed and used on DXpeditions to Quoddy Head and Grayland. Many of the others have been constructed in my yard near my house here in Ruston at one time or another and used for my DXing here.

EZNEC is antenna simulation software written by Roy Lewallen, W7EL. Version 5.0, which I use, costs about \$89. There are other versions with more elaborate features (which, naturally, cost more), but I have found version 5.0 to be completely satisfactory for my needs. W7EL did not write the antenna simulation software. He wrote a very well done graphical user interface for the antenna simulation software NEC 2; the result is EZNEC. There is a free EZNEC 5.0 demo that you can download from the EZNEC web site. But it is limited to antennas with 20 segments, so you can accurately model only very simple antennas. It can not be used to simulate my dual and quad arrays accurately. Nevertheless, it allows you to get a feel for how EZNEC works.

To apply EZNEC to dual and quad arrays I needed to specify not only the sizes of and distances between the antennas, but also the phase relations between and among the antennas of the arrays. When modeling antenna arrays, EZNEC does not permit the time delay between and among the antennas to be used for pattern and gain simulation. Instead of time delay, phase delay must be used for EZNEC simulations. Thus I begin with some of the derivations from my article Discrete LC Delay Line Phasers which are needed to calculate the phases between and among antennas for dual and quad arrays.

The basic facts about the delay distance between two antennas are given in the figure at right. The delay distance is $d = s \cos(\theta)$ for an arrival angle θ , where s is the horizontal spacing between the centers of the individual antennas. For $s = 100'$ and $\theta = 30^\circ$, $d = 100 \cos(30^\circ) = 86.6'$. There are 3.28 feet per meter, so $d = 86.6/3.28 = 26.4$ meters. The angle θ is chosen as 30° for these examples because I have taken 30° as the optimal arrival angle for the very wide 30 dB null apertures of the arrays that I use. Of course, there is no single arrival angle for undesirable signals.

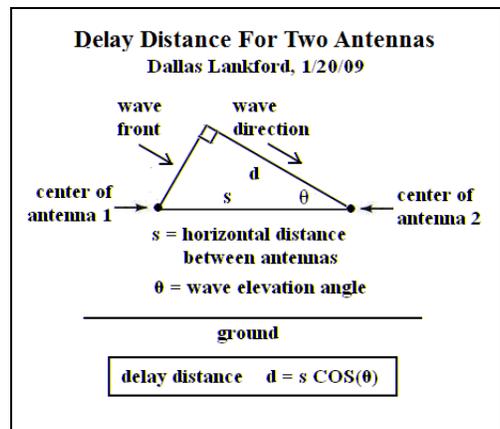
The time delay T is the time difference between the arrival of a wave front at antenna 1 and the arrival of that same wave front at antenna 2. The speed of electromagnetic radiation is approximately 2.99×10^8 meters per second in air, so the time delay per meter in air is $1/(2.99 \times 10^8) = 3.34$ nS/m. Thus the time delay $T = 3.34 \times 26.4 = 88.3$ nS.

To convert time to degree delay at a particular frequency, say 1 MHz, do the following. 1 MHz is 10^6 cycles/sec, or $1/10^6$ sec/cycle, or $10^9/10^6$ nS/cycle, or 10^3 nS/cycle, or $1000/360$ nS/degree, or 0.36 degree/nS. Thus at 1 MHz the 88.3 nS delay is $(0.36)(88.3)$ degrees = 31.8 degrees. In view of the previous, the phase delay of 88.3 nS can be converted to degree delay at other frequencies by simple ratios. For example, at 600 kHz the degree delay is $(0.6)(31.8) = 19.1$ degrees, and at 1.6 MHz $(1.6)(31.8) = 50.9$ degrees.

EZNEC specifies antenna gain in dBi, which means gain relative to an isotropic radiator. But what does that mean? Before we discuss an EZNEC example in detail, we give formulas to convert dBi to $V_{dB\mu V}$ and to convert $V_{dB\mu V}$ to dBm.

The first formula, which is stated in [SoftWright](#), is: $V_{dB\mu V} = E_{dB\mu V/m} + G_{dBi} - 20 \log(f_{MHz}) + 29.8$ - any additional loss, due to, say, SWR mismatch and/or combiners,

where $V_{dB\mu V}$ is the RMS voltage at the receiver antenna input in dB relative to 1 μV , $E_{dB\mu V/m}$ is the field strength RMS voltage in dB relative to 1 $\mu V/m$, G_{dBi} is the antenna gain in dBi, and f_{MHz} is the frequency in MHz. In other words, $V_{\mu V}$ and $E_{\mu V/m}$ are in dB μV and dB $\mu V/m$ respectively. The formula assumes that the



antenna impedance is 50 ohms, but is accurate for antennas of other impedances if you include mismatch attenuation.

The EZNEC example below of a dual delta flag array provides an example to illustrate the formula above.

Dual Delta Flag With – 54.33 dBi Gain: For a 1 $\mu\text{V}/\text{m}$ field at 600 kHz, $V_{\mu\text{V}} = 0 - 54.33 + 4.4 + 29.8 = -20.13 \text{ dB}\mu\text{V}$, or 0.099 μV at the antenna input of a receiver with a 50 ohm antenna input, assuming no other gain or loss. It is also assumed that the flag antennas use step down transformers to give 50 ohms output impedances.

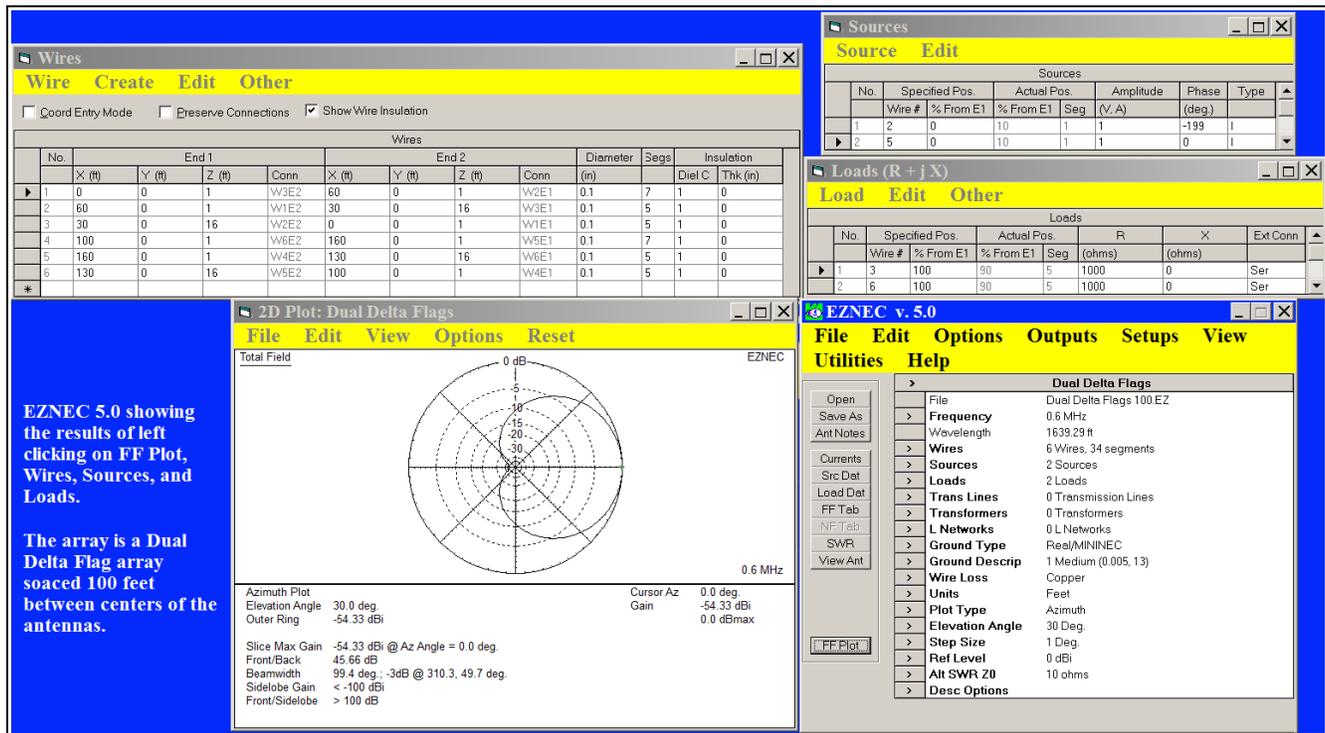
For a Perseus receiver having a 1.8 μV sensitivity for 6 kHz bandwidth 10 dB (S + N)/N AM (MW DX), about 26 dB of preamplification would be in order for a man made noise floor of 1 μV , say at Quoddy Head or Grayland, which are often low noise sites, with most man made noise sources in the null of the dual delta flag array.

For those who prefer dBm units for receiver antenna inputs, the basic formula can be gotten by adding –107 (or subtracting 107) dBm (1 μV) to (from) the right hand side of the first formula above:

$$V_{\text{dBm}} = E_{\text{dB}\mu\text{V}/\text{m}} + G_{\text{dBi}} - 20 \log(f_{\text{MHz}}) - 77.2 - \text{any additional loss.}$$

Thus the Dual Delta Flag example value above is –127.1 dBm.

Below is an EZNEC 5.0 simulation of a the Dual Delta Flag array wwith –54.33 dBi gain mentioned above.



When you click on EZNEC.EXE, the window with heading EZNEC 5.0 pops up on your desktop. As you can see, there are many options that you can left click on, those in the yellow header, those in the EZNEC box (Frequency, WIRES, Sources, Loads, Trans Lines, Transformers, etc.), and those in the buttons on the left side of the EZNEC box (Open, Save As, Ant Notes, Currents, Src Dat, etc.). Some of those options will not concern us because it is not my intention to give a complete explanation of how EZNEC works.

When EZNEC 5.0 pops up, it pops up with the antenna file LAST.EZ, which is the last antenna that EZNEC 5.0 worked on. The .EZ extension is the extension of all antenna descriptions. When you (left) click on Open, a window opens with a list of antenna descriptions. The figure below right shows a partial list of the antenna

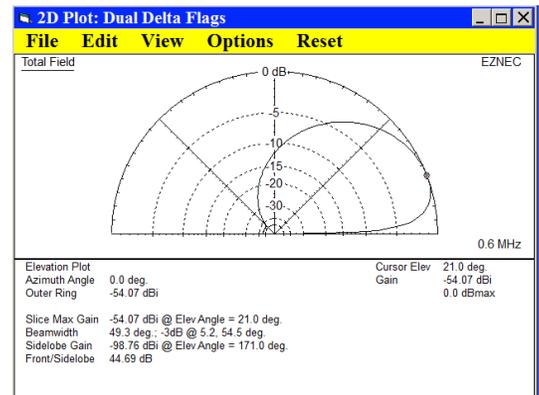
descriptions that came with EZNEC 5.0. As I recall, I clicked on Last.ez, then clicked on Wires, and changed the description of the wires to describe a dual delta flag array with 100 foot spacing between centers of the antennas. The individual antennas I constructed had 60 foot bases, and 15 foot altitudes, with the bases of the deltas one foot above the ground. If you examine the Wires box (window) in the figure above you will see that the wires of that example describe the dual delta flag array just mentioned above. The load box describes where the flag terminating resistors are placed, and the resistor values (1000 ohms). The source box (window) describes the phase of each antenna. The right most antenna has 0 phase, while the left most antenna has phase -199 degrees, that is $-180 - 19$. Recall that the 88.3 nS time delay for antennas with distance between centers of 100 feet and 30 degree arrival was earlier (above) converted -19 degrees delay. Thus the entries in the Source window were selected to give a null for that dual flag array. When doing EZNEC simulations I usually round of the degree values to the nearest degree (thus 19.1 becomes 19).

- Vert1.ez
- Nbsyagi.ez
- N4pcoop.ez
- Logpert.ez
- Logper.ez
- Last.ez
- K5rp.ez
- Fdsp.ez
- Elevrad2.ez
- Elevrad1.ez
- Diptl.ez
- Dipole1.ez
- Cardtl.ez
- Cardioid.ez

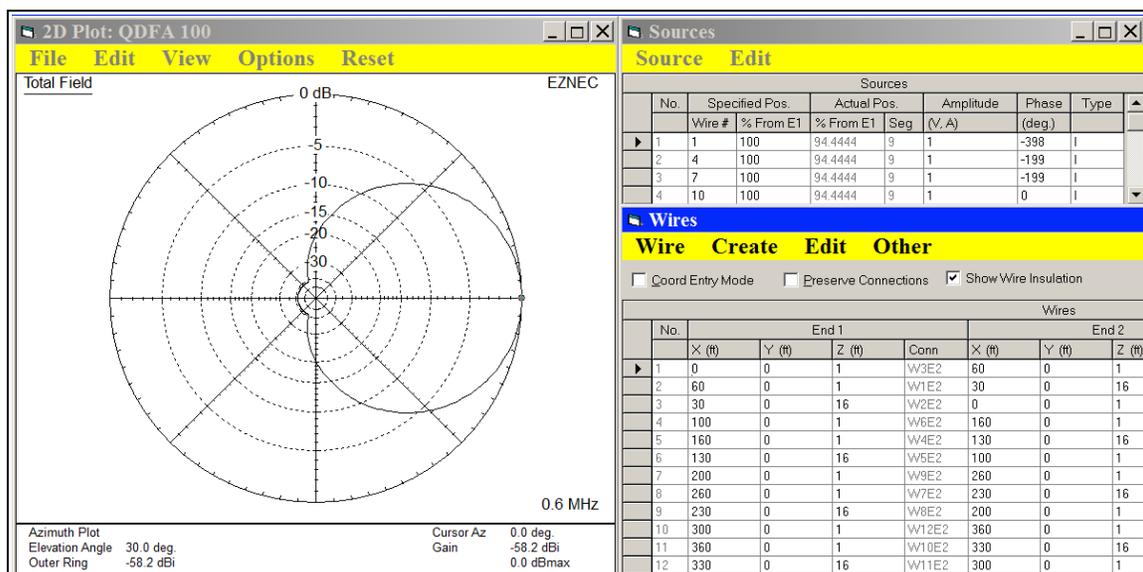
The 30 degree arrival angle was selected in the EZNEC 5.0 box (window) by clicking on Elevation Angle and then entering 30. Any elevation angle between 0 and 90 degrees can be entered. Notice that the value of the Elevation Angle, Gain, and other information is shown in the Plot box (window).

Clicking on Plot Types gives you the options of Azimuth, Elevation, and 3 Dimensional. The Azimuth plot box is labeled 2D Plot, but this is a misnomer because the Azimuth plot is actually 3 dimensional... it is on the surface of a cone.

In the figure at right is an Elevation plot for the dual delta flag array. This is the pattern of the dual flag array in a plane perpendicular to the ground and passing through the planes of the antennas. As can be seen from the vertical plot the vertical 30 dB null aperture is about 50 degrees, which seems very good to me.



With the degree delays for 1 MHz and 1.6 MHz calculated above, namely 31.8 degrees for 1 MHz and 50.9 degrees for 1.6 MHz, it is easy to generate antenna array patterns at those frequencies. As it turns out, the patterns for those frequencies have the same shapes as the pattern for 600 kHz. The only differences for those new patterns are their gains, which are -41.7 dBi and -30.8 dBi respectively. So as frequency increases, the gains of the dual delta flag arrays increase.



It is also easy to use EZNEC to generate patterns for the Quad Delta Flag Array (QDFA) once you have the antenna file for the dual delta flag array. Above is such a pattern. The wires can be generated from the dual delta flag wires by using the copy command in the Wires options. When you copy wires, you can select which wires to copy, and how much to change the x, y, and z distances. So if you copy all 6 wires of the dual delta flag wire box (window), and change the x amount by 200 feet (y and z amounts not changed), then you get the wires in the box of the above figure. The sources and loads are automatically copied with the phase values unchanged but correctly assigned to the new wires. So the new load box with 4 loads is set up as desired. The new source box has wires 1 and 2 assigned degrees 0 and -199 respectively as they were in the dual delta flag source box. To make the QDFA source correct, all that is required is to change the 1 and 2 sources - 199 and - 389 respectively (add an additional delay of - 199 the wire 1 value and use that as the new wire 1 value). So it takes very little work to make the .EZ antenna file for the QDFA. Once it is made in this manner from the DDFA.EZ antenna file, merely save it as QDFA.EZ (remember the Save As button in the EZNEC 5.0 box (window)?).

Once you have made a few .EZ antenna files, it does not take long to make a lot more. Below are the antenna files that I currently play with.

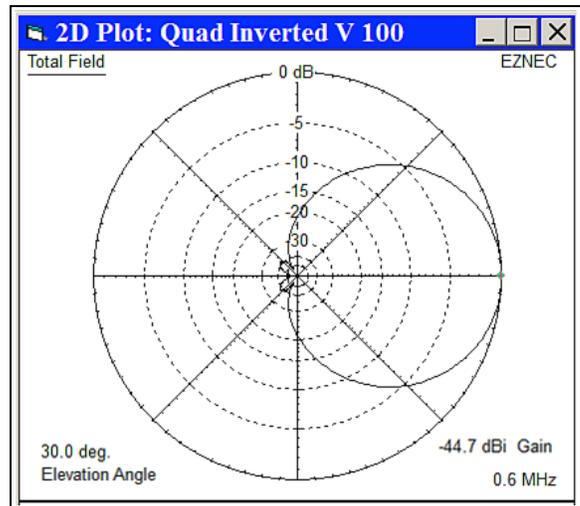
• Beverage 500 .EZ	• One K9AY.EZ
• Beverage 1000 .EZ	• One LDF.EZ
• Beverage 1650 .EZ	• One Loop 10' x 10'.EZ
• Beverage 3000 .EZ	• One Loop.EZ
• Beverage Houlton ME 55 kHz.EZ	• One Vertical.EZ
• Dual ALA-100 Array.EZ	• One WOG.EZ
• Dual Delta Flags 100.EZ	• Q45 1ft Elevation.EZ
• Dual Delta Flags Long 100.EZ	• Q45.EZ
• Dual Double Delta.EZ	• Q95 2ft Elevation.EZ
• Dual Grounded Delta Flags 100.EZ	• Q95 Unterminated #14.EZ
• Dual Grounded Long Delta Flags 100.EZ	• Q95 Unterminated #18.EZ
• Dual Inverted V 100.EZ	• QDFA 100.EZ
• Dual K9AY Array.EZ	• QDFA Big 100.EZ
• FM Yagi 8 Element 5 Driven.EZ	• QDFA Big Tall 100.EZ
• Half Size Dual Delta Flag array.EZ	• Quad Inverted V 100.EZ
• LAST.EZ	• Quad K9AY.EZ
• One Delta Flag.EZ	• Stacked FM Yagi 8 Element 5 Driven.EZ
• One EWE.EZ	• VE1ZAC Small DADFA.EZ
• One Flag.EZ	• VK1OD Loop.EZ
• One Hi Z Delta Flag.EZ	• WF Giant.EZ
• One Inverted V.EZ	• WF.EZ

I have had dual and quad arrays of many kinds of antennas at one time or another. None of them measured up to the dual and quad arrays shown, and so they have not survived. A few of them, like the dual inverted V array, are intermediate steps for quad arrays that I have kept in my antenna files to simplify making quad variants of those kinds of antennas.

The quad inverted V (with 100 foot separation between antenna centers) is a good example of this. A single inverted V is terminated with a resistor (510 ohms), but has almost no null, compared to a single flag which has a nice cardioid pattern. A dual inverted V array has a cardioid pattern, but its 30 dB null aperture is about 45 degrees compared to the dual delta flag array with 30 dB null aperture of about 90 degrees. So one might expect that a quad inverted V array would have not nearly as good pattern as a QDFA. I think that was my opinion for several months, perhaps years. In any case, I had a single inverted V antenna or dual inverted V array for some time before I got around to simulating a quad inverted V array.

You can imagine my surprise when a quad inverted V array turned out to have a pattern as good as a QDFA, and gain at 600 kHz (- 44.7 dBi) about 14 dB greater than the QDFA. An EZNEC simulation of a quad inverted V

array is shown in the figure at right right. The output impedance of each of the 4 antennas in the array is about 512 ohms (with 510 ohms terminating resistors), and the output impedance is very nearly real, so the array can be matched well to 50 or 100 ohm lead ins. The EZNEC simulation in the above right figure is for inverted V antennas with 16 foot heights and 90 foot bases. If the deltas of the QDFA are enlarged to 90 foot bases, then the enlarged QDFA array has 3 dB more gain, and the quad inverted V array has only 11 dB greater gain at the low end of the MW band. The quad inverted V array is still much better than the enlarged QDFA because of its 11 dB greater low band gain.



At the high end of the MW band the quad inverted V array has about 8 dB greater gain than the enlarged QDFA. So the quad inverted V array is a much better array than the QDFA throughout the entire MW band because of its greater gain than the QDFA.

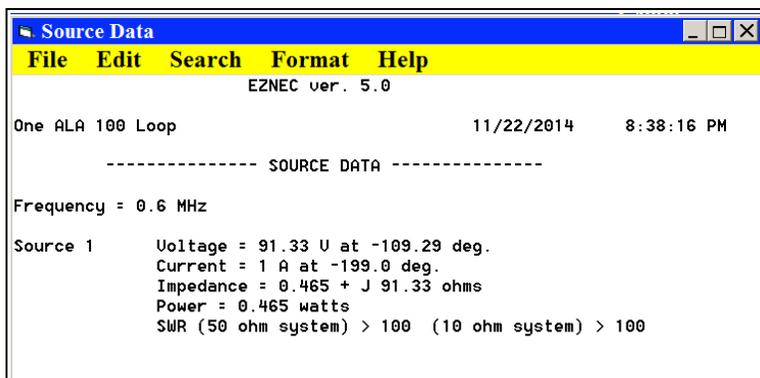
The quad inverted V array also has almost the same amount of gain increase compared to the dual delta flag array. This suggests that using FET followers at the antennas like I did for the dual delta flag array at Quoddy Head 2011 would not be necessary for the quad inverted V to exceed the performance of a 1000 foot terminated beverage antenna. Of course this would need to be verified with tests at Quoddy Head.

I use the online calculator developed by [Chemandy Electronics](http://chemandy.com). If you click on the underlined word Chemandy in the previous sentence their on line calculator, shown in the following figure, will pop up on your display.

You enter the source impedance (purely resistive) and the load impedance (real part R and imaginary part J), click on Calculate (bottom right) and you get the SWR and Mismatch Attenuation (plus a few other things). The

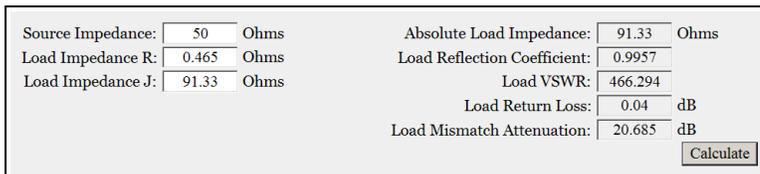
Chemandy calculator is set up for transmitting antennas. But when receiving antennas are used, because of the reciprocity theorem for antennas, for receiving antennas the source in the Chemandy calculator becomes the load (the impedance of the amplifier or lead in that the antenna is connected to) and the load becomes the source (the antenna impedance). So the Mismatch Attenuation in the Chemandy window is the source mismatch when analyzing receiving antennas, not the load mismatch.

Loops have “very” complex impedances, small real part and much larger imaginary part. So it is not possible to impedance match a loop using a step down or step up broadband transformer (like is done for flag arrays and the quad inverted V array). After an EZNEC pattern simulation is done, the antenna impedance (and other info) is placed in the Source Data file. Clicking on the Src Dat button in the EZNEC 5.0 box (window) pops up the window in the figure at right.



The impedance in the Source Data window, $0.465 + j 91.33$ ohms, is for an ALA 100 loop with three 20 foot sides. When that impedance is entered in the Chemandy Mismatch Calculator we get the results in the figure at right.

The Impedance Mismatch Attenuation is -21.7 dB (the SWR is 466.3). That is a hefty amount of attenuation and a whopping SWR. If you do an EZNEC pattern simulation you will find that the gain of this ALA 100 loop is -30 dBi, so when the impedance mismatch attenuation is included, the gain of the ALA 100 loop when connected to a 50 ohm input impedance amplifier or 50 ohm transmission line it is -51.7 dBi. This is about 4 dB less at 600 kHz than my standard size (60 foot base 15 foot altitude) delta flag terminated with a 1000 ohm resistor. The impedance mismatch attenuation of my delta flag when my delta flag is matched with a step down transformer is 0.1 dB, which is negligible.



If an ALA 100 loop is enlarged to the same size as my standard delta flag, the impedance mismatch of the larger ALA 100 is -23.5 dB and the gain is -24.2 dBi for total of -47.7 dBi which is almost exactly the same as my delta flag. The 30 dB null aperture of the loop is considerably less than the 30 dB null aperture of the delta flag, which is why flag arrays are better than loop arrays.

In the case of the quad inverted V array, the impedance of the first antenna at 600 kHz is $513 + j 5.49$ ohms, and the impedance mismatch given by the calculator is 0 dB. Apparently the calculator rounds off its answers because there is actually a very small amount of attenuation. The other three antennas of the quad array have slightly different impedances, and their impedance mismatch attenuations are also rounded off to 0. At 1.6 MHz the impedances of the antennas of the quad array vary slightly and the impedance mismatch attenuations of the antennas of the quad array are about -0.001 dB.

In the case of the QDFA, the antenna impedances at 600 kHz vary from $983.1 - j 64.38$ ohms to $983.3 - j 64.15$ ohms and the impedance mismatch attenuations calculated by the Chemandy impedance mismatch calculator, are all -0.005 dB. At 1.6 MHz the antenna impedances of the quad array vary slightly about $909.6 - j 119.3$ ohms and their calculated impedance mismatch attenuations are all -0.027 dB.

So it follows that both the inverted V array antennas and QDFA antennas can be impedance matched to 50 ohm coax or 100 ohm twinax with broadband step down transformers and when that is done the the resulting arrays have negligible impedance mismatch attenuation. They are great quad arrays.