Flag Theory IIa

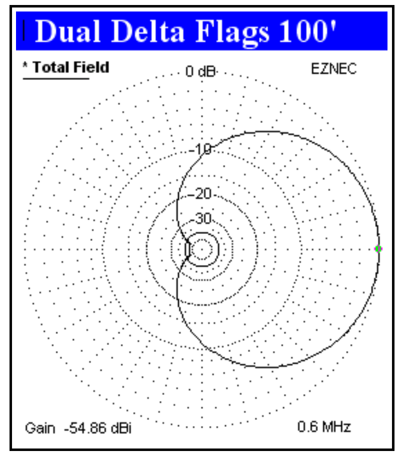
Dallas Lankford, 11/20/2010, rev. 5/14/2012

It has been said that dBi means gain relative to an isotropic radiator. But what does that mean? For example, for a receiving antenna with -50 dBi gain, how much preamp gain will be needed between the antenna and receiver? Some insight into such questions can perhaps sometimes be gotten from a certain not so well known formula.

The formula, which is stated in Field Intensity Units by Anonymous and which can be derived from the antenna factor formulas stated on the web site http://en.wikipedia.org/wiki/Antenna_factor 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 and/or combiners,

where $V_{dB\mu V}$ is the RMS voltage at the receiver antenna input in dB relative to 1 µV, assuming a 50 ohm antenna input, $E_{dB\mu V/m}$ is the field strength RMS voltage in dB relative to 1 µV/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 dBµV and dBµV/m respectively.



The EZNEC plot below is for the dual delta flag array which was tested at Grayland. For a 1 µV/m field at 600 kHz, $V_{\mu V} = 0 - 54.86 + 4.4 + 29.8 = -20.6$ dBµV, or 0.093 µV at the antenna input of a receiver with a 50 ohm antenna input, assuming no other gain or loss.

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 Grayland, which is often a low noise site, with the majority of atmospheric and man made noise sources in the null of the dual delta flag array. This is consistent with my observations at Grayland where at the low end of the MW band 20 dB of preamplification (which was all I took) seemed inadequate.

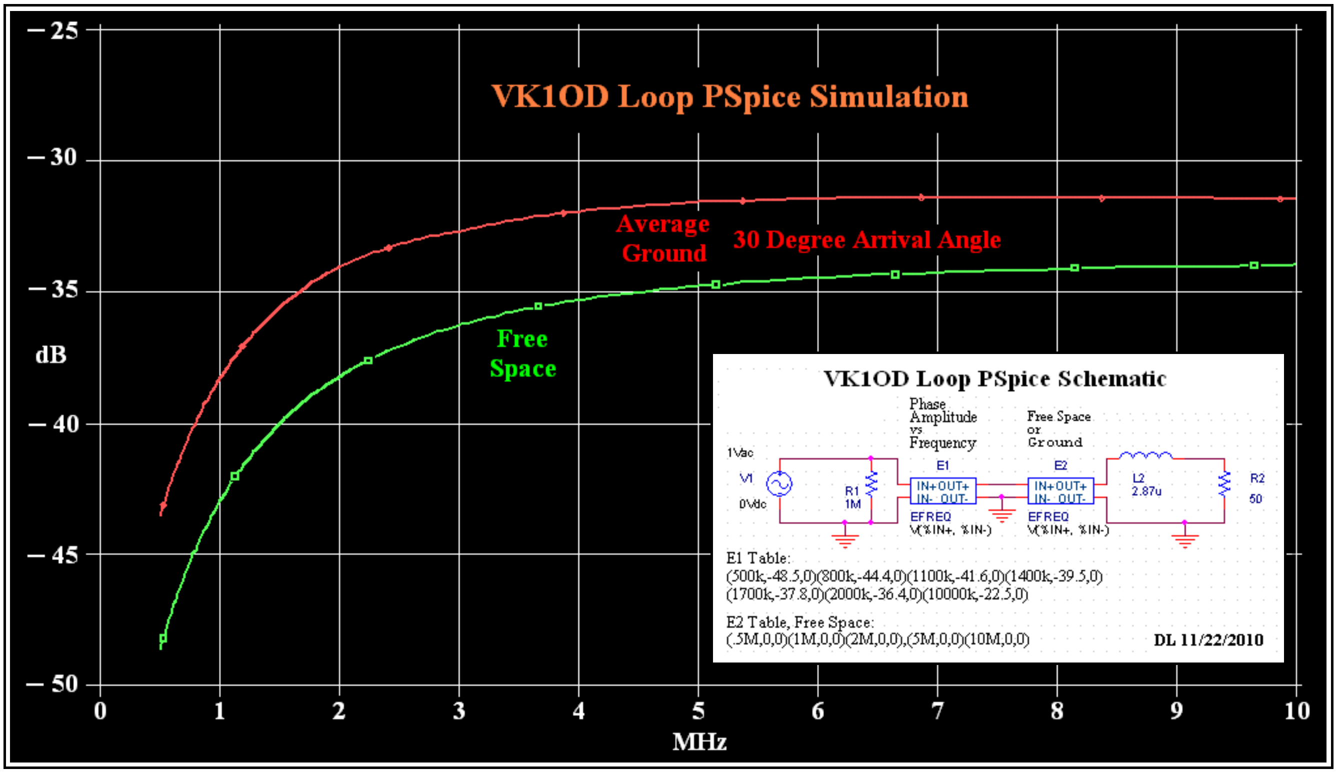
For those who prefer dBm units for receiver antenna inputs, the basic formula can be gotten by adding –107 (or subtracting 107) dBm (1 µV) to (from) the right hand side of the original Anonymous formula above:

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

For antennas and antenna arrays which have no additional loss, the above approach seems entirely satisfactory. However, for antennas and antenna arrays which have substantial additional loss, such as mismatched loops, the above approach does not seem entirely satisfactory because SWR losses must be included, and EZNEC does not give accurate large value SWR losses. I do not know how EZNEC includes combiner loss, so that aspect is unclear to me.

It seemed that if these kinds of antennas could be simulated with PSpice, then high SWR losses might be included in the PSpice simulations.

A small loop for free space was derived by VK1OD directly from physics equations, not from EZNEC, and so it provides a bench mark independent of EZNEC for comparison with the PSpice simulation methods developed here. The VK1OD loop PSpice simulation schematic embedded in the PSpice simulation below provides a simple introduction to the PSpice antenna simulation method for loop antennas which I have developed. The PSpice simulation output is in dBµV units. PSpice antenna simulations are inherently for free space. This means that PSpice simulations are independent of EZNEC only for the free space case. Earth grounds can be included in the PSpice simulations by using EZNEC as will be explained later.

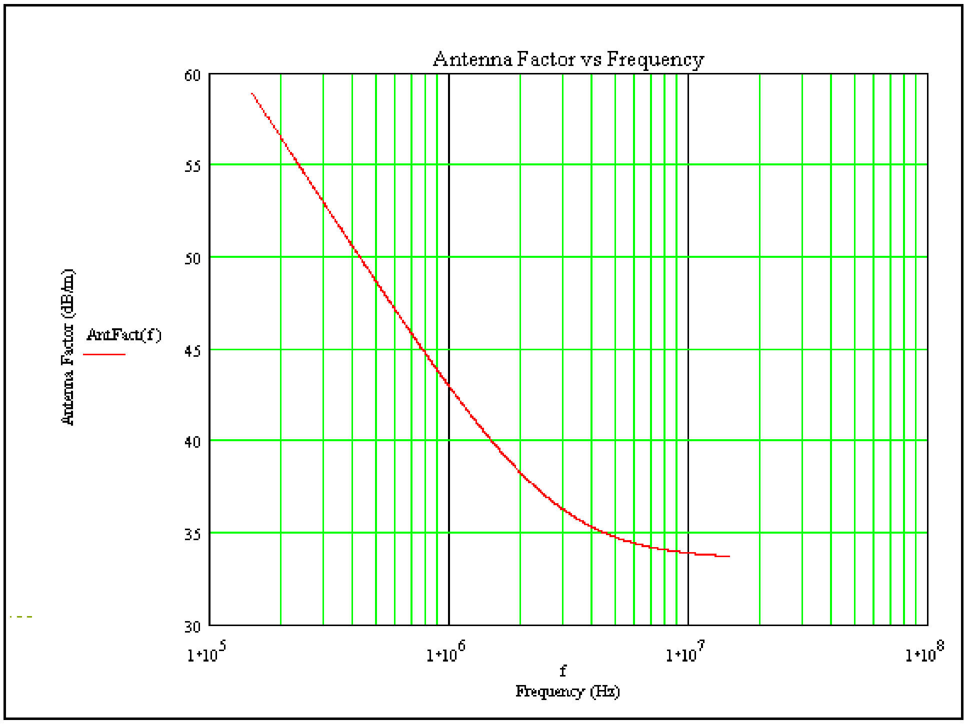


The VK1OD loop was a square single turn loop with area 0.36 square meters. It was connected directly to a 50 ohm antenna input of a receiver, so the loop impedance was not matched. The loop inductance of 2.87 µH was calculated from a formula, not measured. The PSpice schematic models a 2.87 µH inductor in series with a 50 ohm resistor (the receiver input). The open circuit voltage induced in the loop by a passing electromagnetic wave is simulated by a 1 volt RMS sine wave V1 whose amplitude and phase are processed by an PSpice EFREQ part E1 followed by a second PSpice EFREQ part which simulates free space or ground. The 1M resistor R1 is an artifact of PSpice which is required to make PSpice run. Ditto for the three grounds. R1 and the three grounds are not part of the loop antenna simulation, and may be regarded as not being there. In PSpice EFREQ varies an input voltage amplitude and phase with respect to frequency using a linear table of triples (frequency, amplitude, phase). The frequencies of the triples are monotonically increasing; that is, the frequency increases as the points go from left to right. The table need not be depicted as a horizontal line of triples; when the line is broken into several horizontal lines of points, the single linear line of triples is the line gotten by placing the the lines of triples beside each other, beginning with the top line, followed by the second line placed to the right of the top line, and so on. The triples may be regarded as points in 3 dimensional space connected in order by line segments which approximate a curve in 3 dimensional space. PSpice apparently curve fits a curve to the points because the traces on the simulation graphs are curves, not a sequence of straight line segments. The points of EFREQ E1 are: (500k,-48.5,0) (800k,-44.4,0) (1100k,-41.6,0) (1400k,-39.5,0) (1700k,-37.8,0) (2000k,-36.4,0)(10000k,-22.5,0) (20000k,-16.4,0). The frequencies are 500 kHz to 10MHz. Units can be k (for kHz) and M (for MHz). I used k throughout for no particular reason. For table E2 I used M throughout for no particular reason. Because the simulation is for a single loop, the phases were all set to 0. For an array of loops, with phase shifters and combiners, the phases would be varied to simulate the delays among the antenna elements of loop array. The amplitude of the open circuit voltage V(θ) induced in a planar loop antenna with respect to the angle θ between the plane of the loop and a passing electromagnetic wave is

$$V(\theta) = 2\pi E A \cos(\theta) / \lambda ,$$

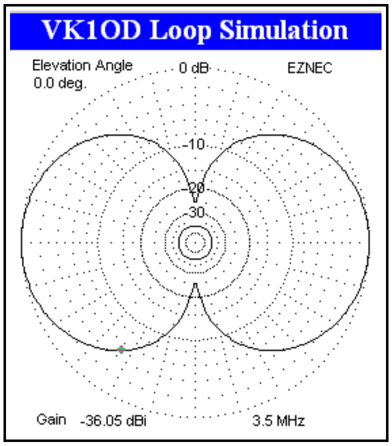
where E is the field strength of the wave in volts per meter, A is the area of the one turn loop in square meters, θ is the angle between the the plane of the loop and the electromagnetic wave, and λ is the wavelength in meters. For example, at 500 kHz, for θ = 0 (maximum loop pickup), V = 2π x 1 x 0.36 x 1 / 600 = 3.77 x 10^– 3, and 20 log(V) = – 48.5 dB. Thus the first triple in the table for EFREQ E1 is (500k,-48.5,0). The table shown for EFREQ E2 is for free space, so all triples have the form (f,0,0); the amplitude change due to ground is 0 because there is no ground, and the phase is 0 for the reason given above. All simulations are for the plane of the loop unless otherwise stated.

One of formulas from the references abive is $AF = -G_{dBi} + 20\log(f_{MHz}) - 29.8$ from which it follows that $AF = -V_{dBm}$, when $E_{\mu V/m} = 0$. Thus the antenna factor graph in the VK1OD article should be the negative of my PSpice simulation graph above, and it is to within 1 dB at the high frequency end and to within 2 dB at the low frequency end; compare the VK1OD graph below with the PSpice simulation graph above.

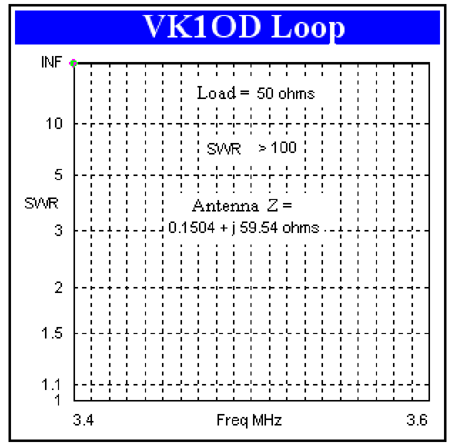


This may be regarded as establishing the validity of the PSpice antenna simulation method for free space.

Earth grounds, good, average, or bad, can often be included in PSpice simulations by using EZNEC as follows. Choose a fixed arrival angle, say 30 degrees. For various frequencies, run EZNEC for free space and for the type of ground desired. Note the difference in EZNEC dBi for each frequency. Construct a EFREQ table based on those differences at those frequencies. In the case of the VK1OD loop, for a 30 degree arrival angle the free space dBi is less than the average ground dBi by about 5.1 dB at 0.5 MHz, 4.7 at 1 MHz, 4.2 at 2 MHz, 3.6 at 3 MHz, 3.2 dB at 5 MHz, and 2.5 dB at 10 MHz. From these values an EFREQ E2 Table for average ground and 30 degree arrival angle is (0.5M, 5.1,0) (1M,4.7,0) (2M,4.2,0) (3M,3.6,0) (5M,3.2,0) (10M,2.5,0). In the case of a loop antenna, no correction is needed for arrival angle when the arriving ray is in the plane of the loop.



At left is an EZNEC simulation for the VK1OD loop for free space. Using Anonymous' formula, V = – 16.15 dBμV at 3.5 MHz. This is very different from the – 35.5 dBμV of the PSpice simulation above at 3.5 MHz and from the 35 antenna factor of the VK1OD graph at 3.5 MHz. At right is an EZNEC SWR simulation for the VK1OD loop attached directly to a receiver with a 50 ohm antenna input impedance. The exact value of the SWR is not stated by EZNEC, only that it is greater than 100. It appears that the SWR loss accounts for the difference of about 19 dB between the EZNEC simulation value and the PSpice value and antenna factor value. In general, EZNEC does not seem to provide a way to adjust for SWR loss when the SWR value is extremely high. Only when the SWR is near 1:1 is it easy to correct for; no SWR correction is required in that case.



As stated above, the amplitude of the open circuit voltage induced in a single turn loop antenna by a passing electromagnetic wave is

$V(\theta) = 2\pi$ E A $COS(\theta) / \lambda$.

Thus the voltage with respect to time and θ is

$V(\theta,t) = [2\pi E A COS(\theta) / \lambda] COS(\omega t)$

where t is time in seconds, $\omega = 2\pi f$, and f is frequency in Hertz.

If a resistor R is added in series with a small (relative to wavelength) loop, then an open circuit voltage voltage

$V_E(t) = k(R) E SIN(\omega t + \varphi)$

is added to the loop open circuit voltage where k(R) is a function of R and φ is the phase between V(θ,t) and V(θ,t). This kind of antenna is called a flag antenna. If $\varphi = \pi /2$ and $k(R) = 2\pi A / \lambda$, then the open circuit voltage induced in the flag antenna due to the addition of R is

$$V_{flag}(\theta,t) = V(\theta,t) + V_E(t)$$

$$= [2\pi E A / \lambda] [(COS(\theta)COS(\omega t) + COS(\omega t)]$$

$$= [2\pi E A / \lambda] [(COS(\theta) + 1] COS(\omega t) .$$

Thus if the pattern of a loop antenna can be adjusted in this way, then the pattern is a cardioid. It is fortuitous that in some cases R can be adjusted so that a cardioid or near cardioid pattern results for a particular arrival angle. This is the basis for flag antennas and flag arrays. For maximum pickup, θ = 0, and the amplitude of the flag antenna is seen to be twice the amplitude of a loop antenna of the same size, namely

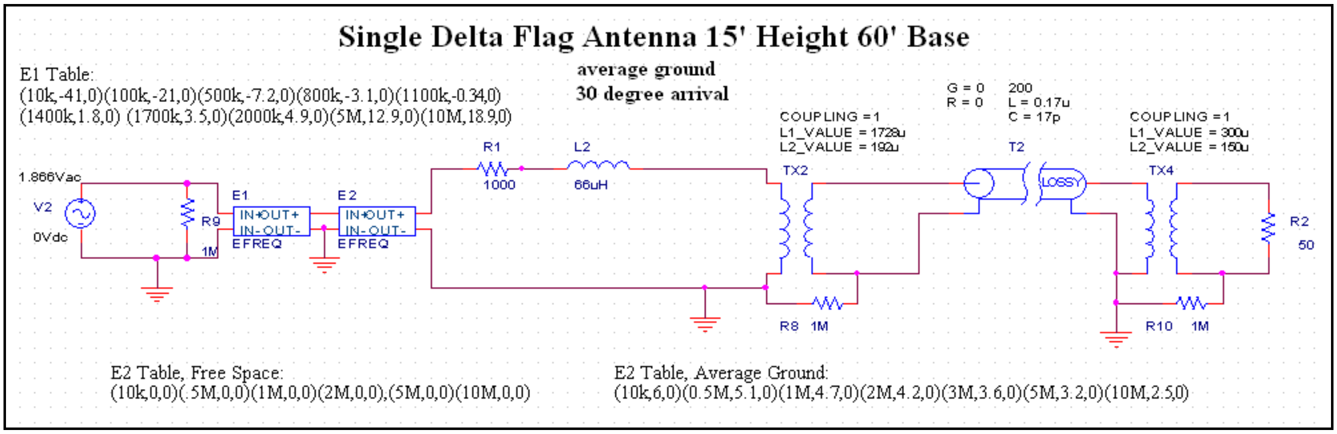
$$V_{flag}(0^o,t) = 2[2\pi E A / \lambda] COS(\omega t)$$

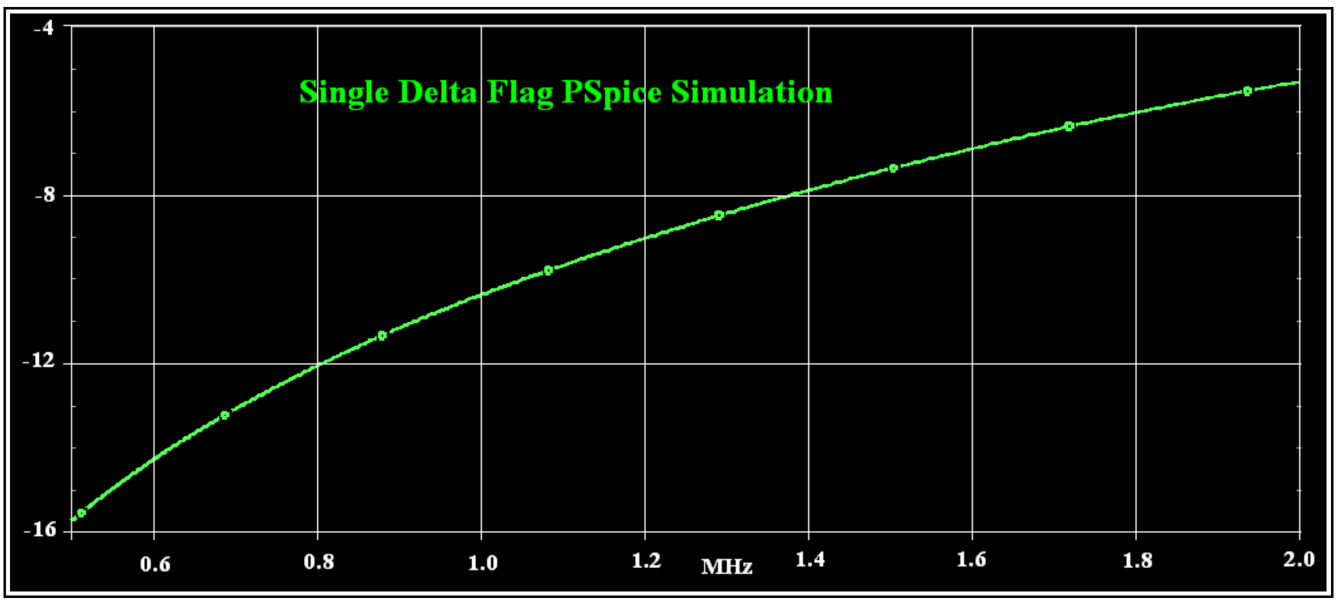
for free space. For a 30 degree arrival angle, θ = 30 degrees, so

$$V_{flag}(30^o,t) = 1.866[2\pi E A / \lambda] COS(\omega t)$$

the coefficient is COS(30) + 1 = 1.866 in free space. For average ground, EZNEC simulation indicates the coefficient is about the same.

The following is a PSpice schematic for a single delta flag antenna with base 60' and height 15', namely 41.8 square meters, close to average ground, and with a 30 degree arrival angle, followed by a PSpice simulation of this schematic. The 1.866 factor of $V_{flag}(30^{o},t)$ is used at the input (so that the input voltage V2 is 1.866 volts) and the E1 table entries are calculated from $2\pi A / \lambda$. So, for example, the E1 table entry for 500 kHz is 20 log(2π x 41.8 / 600) = – 7.18 which is rounded off to – 7.2 .

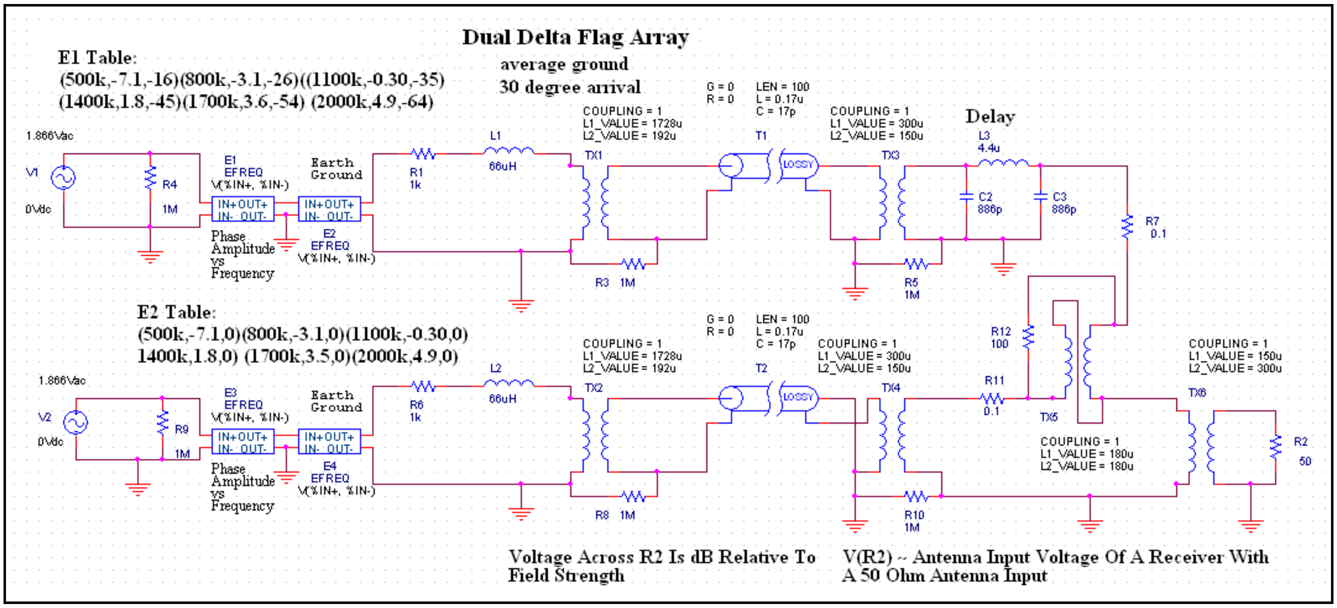


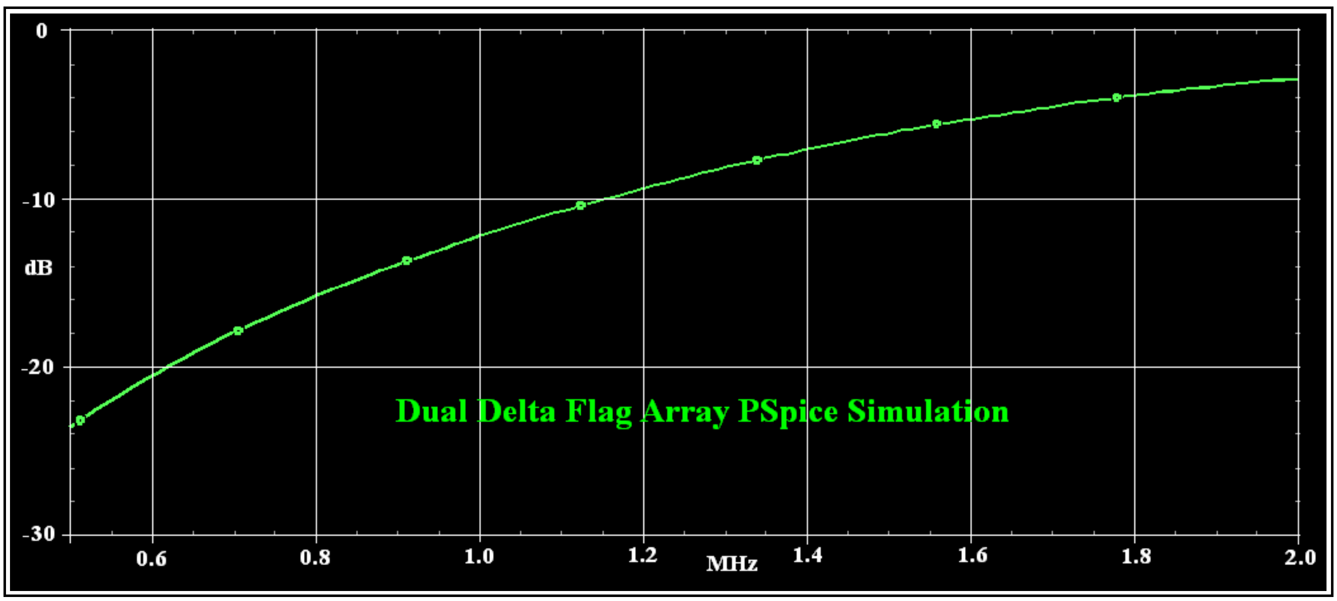


The simulation agrees with EZNEC to within 1 dB, assuming that the single flag antenna which EZNEC models is impedance matched to the receiver (which can easily be done with a broadband transformer). The PSpice schematic already includes impedance matching. This may be regarded as establishing the validity of the PSpice antenna simulation method for average ground and arrival angles in the neighborhood of 30 degrees.

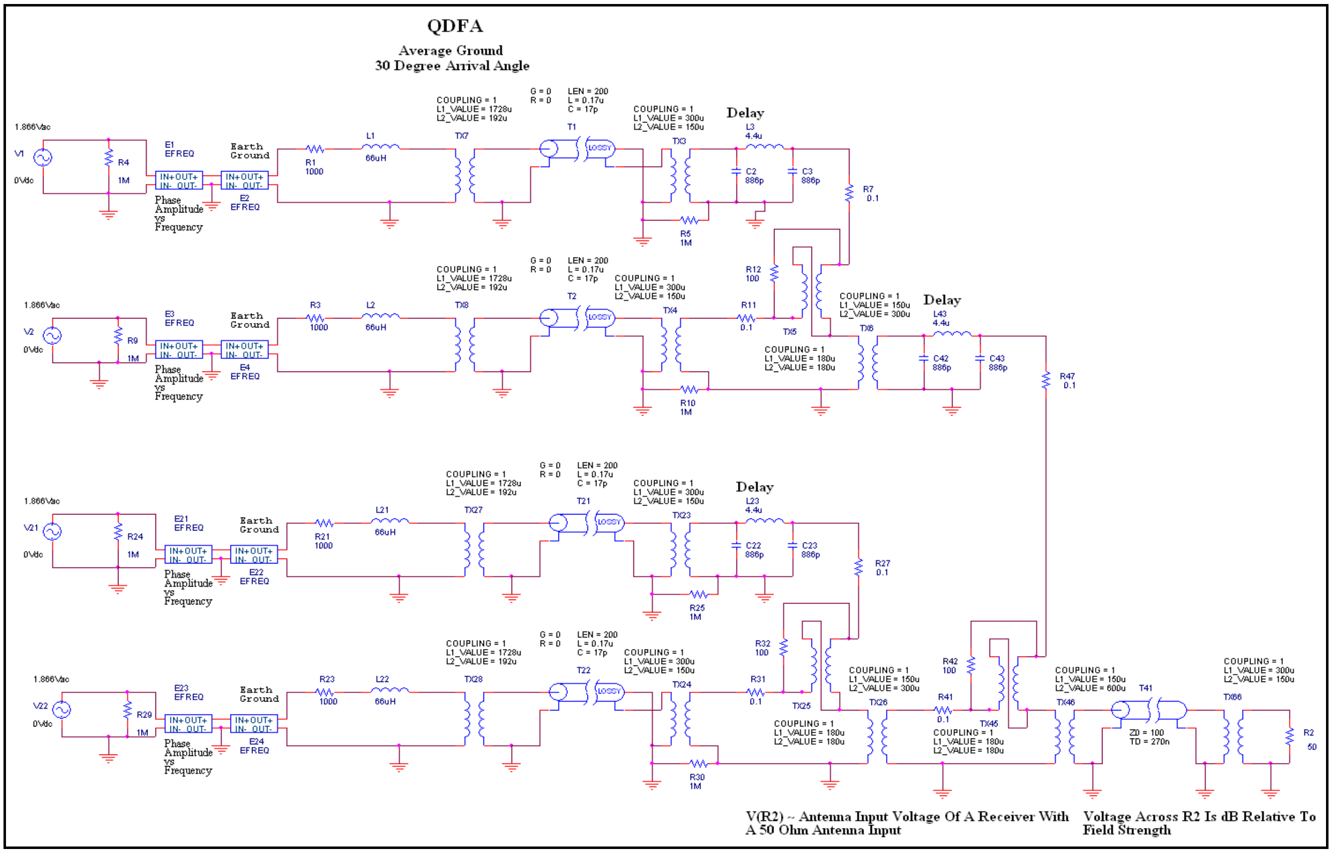
Below is a PSpice schematic of my 60' x 15' dual delta flag array with 100 foot spacing between centers and 30 degree arrival followed by a PSpice simulation. The third coordinate of the triples of E1 are the phase delays in degrees.

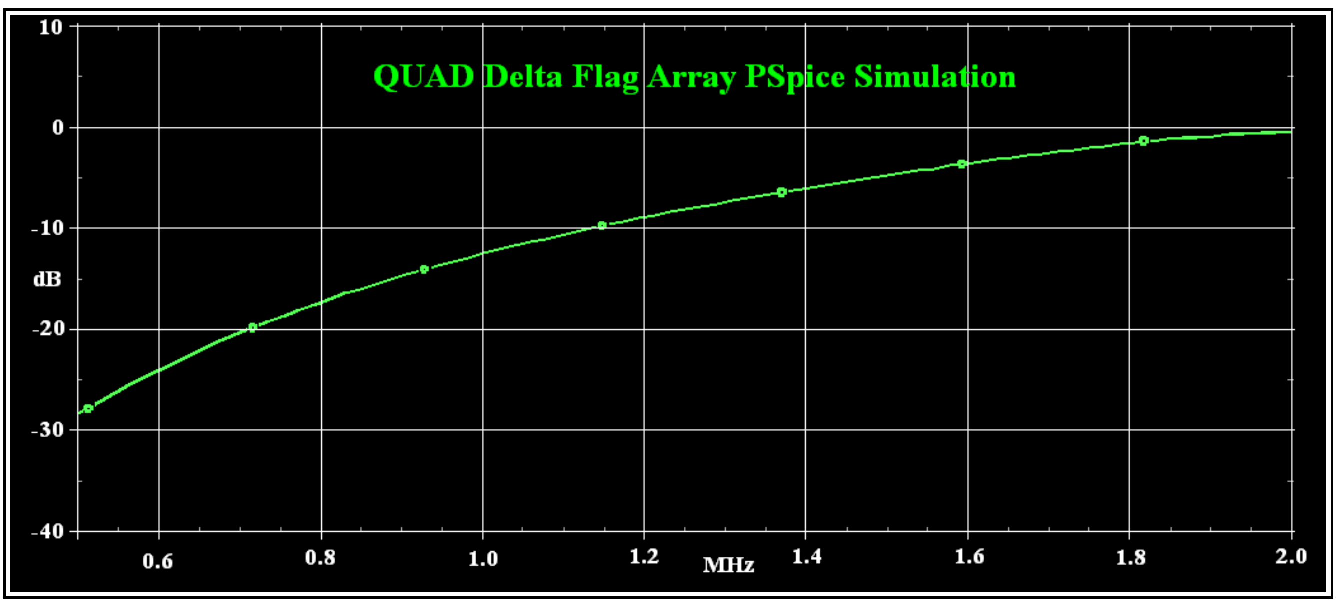
The PSpice simulation agrees with the EZNEC simulation to within 1.5 dB at 600 kHz and within 0.5 dB at 1500 kHz.   This may be regarded as establishing the validity of the PSpice antenna simulation method for dual delta flag array with 30 degree arrival angle and average ground.



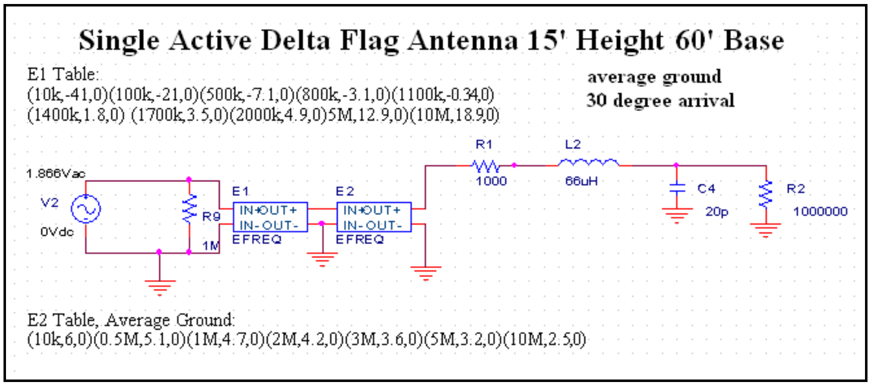


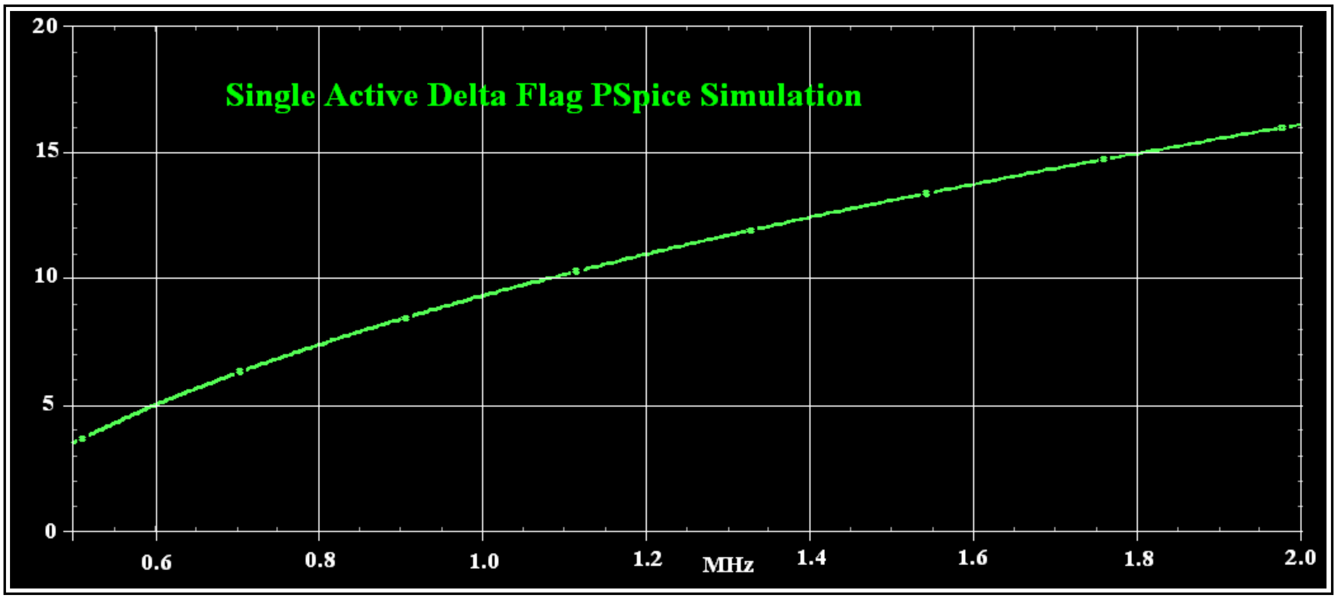
Below is a PSpice schematic of my quad delta flag array. You may magnify it in Adobe Reader for better viewing. Following the PSpice schematics is a figure with PSpice simulations of the QDFA. The QDFA PSpice simulation agrees with an EZNEC simulation of a QDFA with the same dimensions and same 1000 ohm terminating resistors to within 0.5 dB at the high end and to within 2.0 dB at the low end of the MW band. This may be regarded as establishing the validity of the PSpice antenna simulation method for a quad delta flag array with 30 degree arrival angle and average ground.





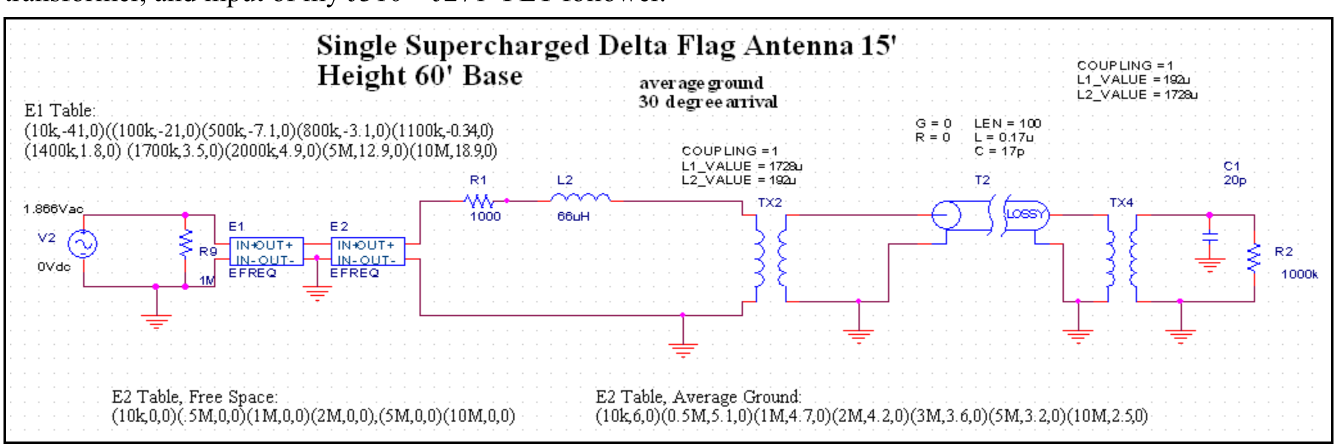
In January of 2011 I invented active delta flag antennas which solved the low MW band insensitivity. Below is a PSpice schematic and PSpice simulation of a single active delta flag antenna element with loop area equal to the size used by the QDFA. The model is for an active flag with FET follower having 0 dB gain (the J310 – J271 FET follower I use has about – 0.3 dB gain). For other active head gains signal output levels can be adjusted accordingly. An active DDFA or QDFA need not be simulated because at a given frequency the increase of its signal output compared to the original DDFA or QDFA is the same as the increase of the signal output of a single active delta flag element compared to an original (not active) delta flag element.

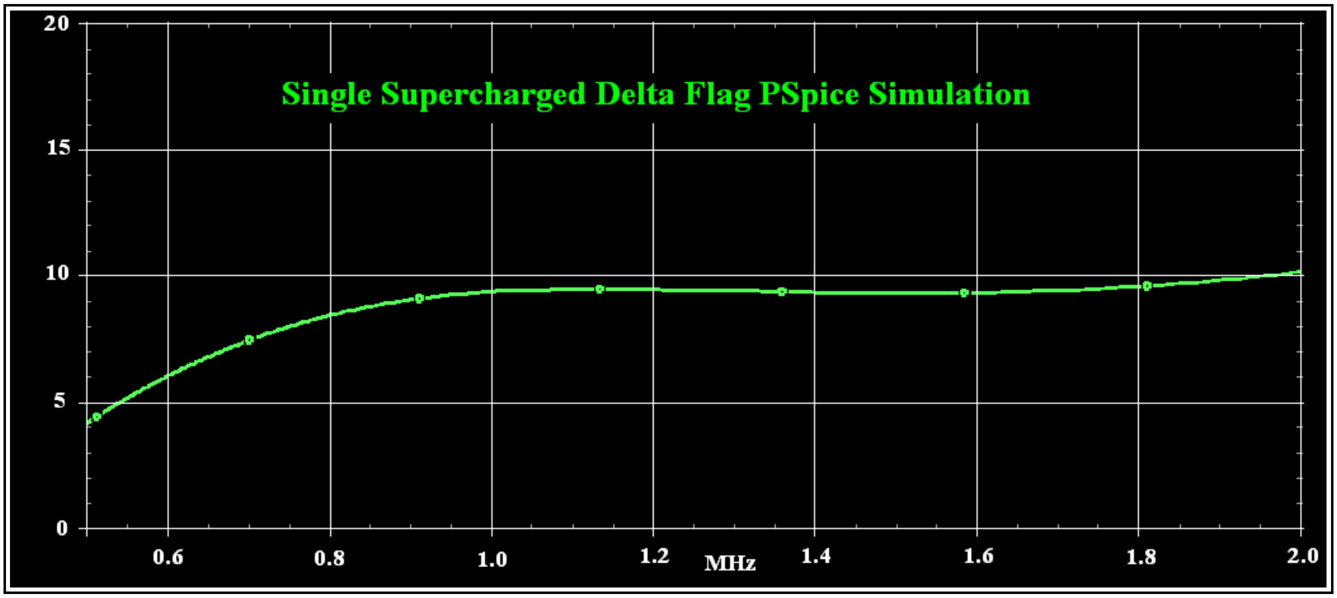




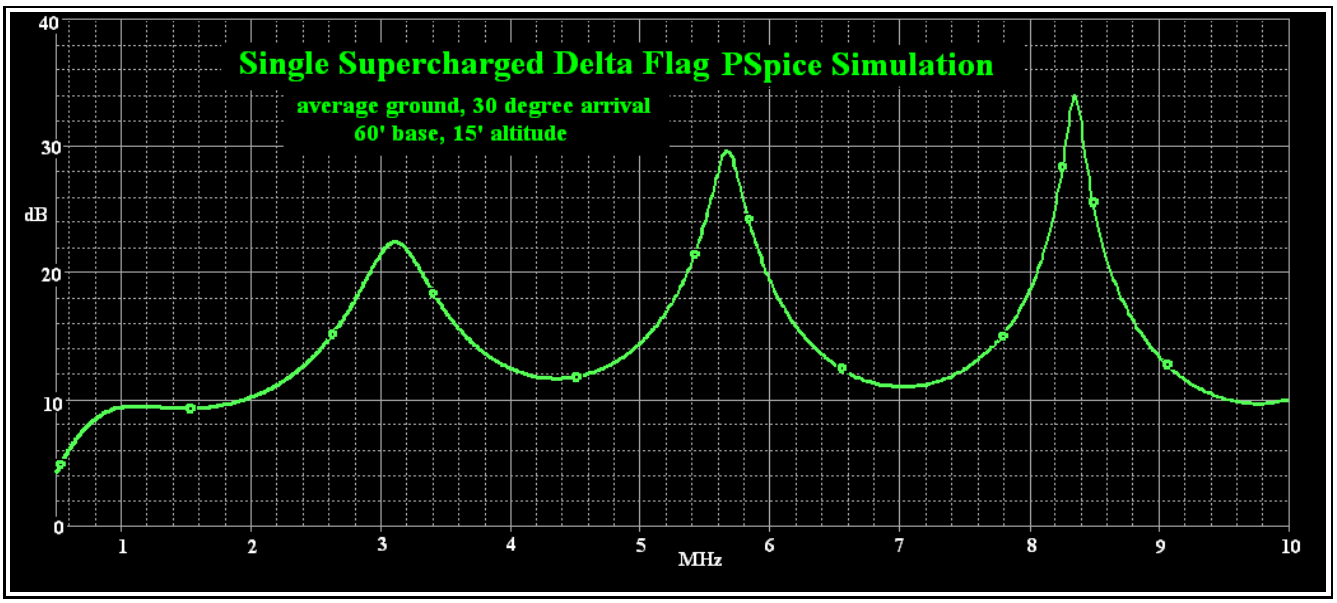
Of course, EZNEC can not accurately simulate an active delta flag antenna element. However, measurements of an active delta flag antenna element and a dual active delta array were compared to an original (not active) antenna element and original array for daytime ground wave signals and the measured increase in signal outputs was about 20 dB from one end of the MW band to the other, which agrees with the simulation above (cf. the not active single delta flag PSpice simulation near the beginning of this article).

The following are the PSpice schematic and PSpice simulations of a single supercharged delta flag antenna (step down transformer, lead in (in this case coax, although twin lead is used for implementations), step up transformer, and input of my J310 – J271 FET follower.





As can be seen, the gain of the single supercharged delta flag is about 4 dB less than the gain of the active delta flag at 1600 kHz, and about 1 dB greater at 600 kHz. The gain differences are so small that accurately verifying the gain differences will likely be impossible. Furthermore, the PSpice supercharger model is not accurate because it used coax instead of twin lead (PSpice does not have twin lead) and because the transformers are ideal (high Q) instead of low Q transformers wound on high permeability ferrite toroids. The slight loss of gain at the high end of the MW band may be due to resonances at higher frequencies as shown in the wider span below.



The length of the coax for these simulations is 100 feet. As the coax length is increased, the frequencies of the resonances decrease, and for 200 feet length the first resonance is about 1600 kHz.

Concluding Remarks

The PSpice methods developed here are satisfactory for modeling the forward gain for original (not active) flag and delta flag arrays as well as for active flag and delta flag arrays. The methods can also be used to model unterminated loop arrays and active unterminated loop arrays.