

# Modeling the W6NL 40m Moxon

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This note looks at the antenna and antenna model for the 40 meter Moxon Yagi designed by Dave Leeson, W6NL. The performance of the antenna, through the model, will be explored in several typical settings. The antenna is modeled using the EZNEC<sup>1</sup> package, built upon the NEC<sup>2</sup> engine. Best results are obtained with the NEC-4 engine.

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<sup>1</sup> EZNEC, by Roy Lewallen, W7EL, is available from [www.EZNEC.com](http://www.EZNEC.com). EZNEC® is a registered trademark of Roy W. Lewallen.

<sup>2</sup> NEC – Numerical Electromagnetics Code. The Wikipedia page contains additional information.

## Introduction

The antenna which is the topic of this note is described in a document titled: *W6NL Moxon on Cushcraft XM240*. A copy of that document is part of the **.zip** file that contains this note.

The document centers on the construction details and the mechanical conversion of the Cushcraft XM240<sup>3</sup> into the W6NL Moxon.

I was involved with making some performance measurements of a stack of two W6NL Moxon's. As part of that work, some questions arose and it appeared that a model of the antenna would be illuminating – as is most always the case with antennas.

Not finding a model immediately available, I used the information in the W6NL document to create a model. Running the model showed that the NEC-2 engine, even with the *stepped diameter correction* algorithm **available** (but not used), produced results with *differences* that could be confusing in trying to evaluate the overall performance of the antenna. Best results were obtained with the NEC-4 engine.

This note describes what was discovered along the way, and includes modeled results from several installation scenarios.

### ***Model File Included***

If you have discovered this note as part of a **.zip** file, you should find the antenna model in the same archive. The file is named M60.ez. It is a single W6NL Moxon located at a height of 60'. By using the EZNEC Wire manipulation commands, it should take very little additional work to change the height and/or create stacks.

Before rushing off to run the model, please be sure to read through the rest of this note so that you understand the ramifications of using the NEC-2 engine as opposed to the NEC-4 engine.

### ***Tool Flow***

A few words on the software tool flow used in this note.

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<sup>3</sup> <http://www.cushcraftamateur.com/Product.php?productid=XM-240>

The models were run using two versions of the EZNEC package. One is EZNEC Pro/2, based upon the NEC-2 engine. For this antenna, using the standard EZNEC or EZNEC+ packages should provide identical results since they all use the NEC-2 engine, and no special “Pro” features were used.

The model I created used 200 *segments* per antenna. This means that the *free* version of EZNEC, with a 20 segment limit, cannot be used.

The second package is EZNEC Pro/4, which uses the NEC-4 engine.

EZNEC Pro/4 results were provided by Dan Maguire, AC6LA. I would like to thank Dan for running the models and contributing his time to this project. Dan has made other contributions to the Moxon quest, and they will be described later.

Since an important part of the analysis was looking at band sweeps of antenna characteristics, EZNEC was run in *sweep mode*, and the resulting data was post processed with the LBDXView package. LBDXView is available on the Internet, and is also included on the CD included with the 5<sup>th</sup> edition of *ON4UN's Low-Band DXing*.

## ***Antenna Measurements***

This note focuses on the antenna model and the modeled performance. A companion note will look at some field measurements, and how those compare to modeled results.

## ***The Moxon Rectangle***

The Moxon Rectangle, named after Les Moxon, G6XN (SK), is an interesting and valuable design. In its initial form, it amounts to a two element parasitic (Yagi-Uda) array that has the tips bent at a 90 degree angle towards the other element.

One of the things that I've learned over the years about antennas is that there are usually *no free lunches*. Most any improvement in one area comes with a cost in another area. The Moxon Rectangle comes close to challenging that principle because it offers a lot of good news without too much bad. Generally speaking, it's viewed to have:

1. Smaller Physical Footprint (due to the bent elements).
2. Good front to back ratio and gain (compared to other 2 element designs).
3. Direct 50 Ohm feed, with relatively wide bandwidth.

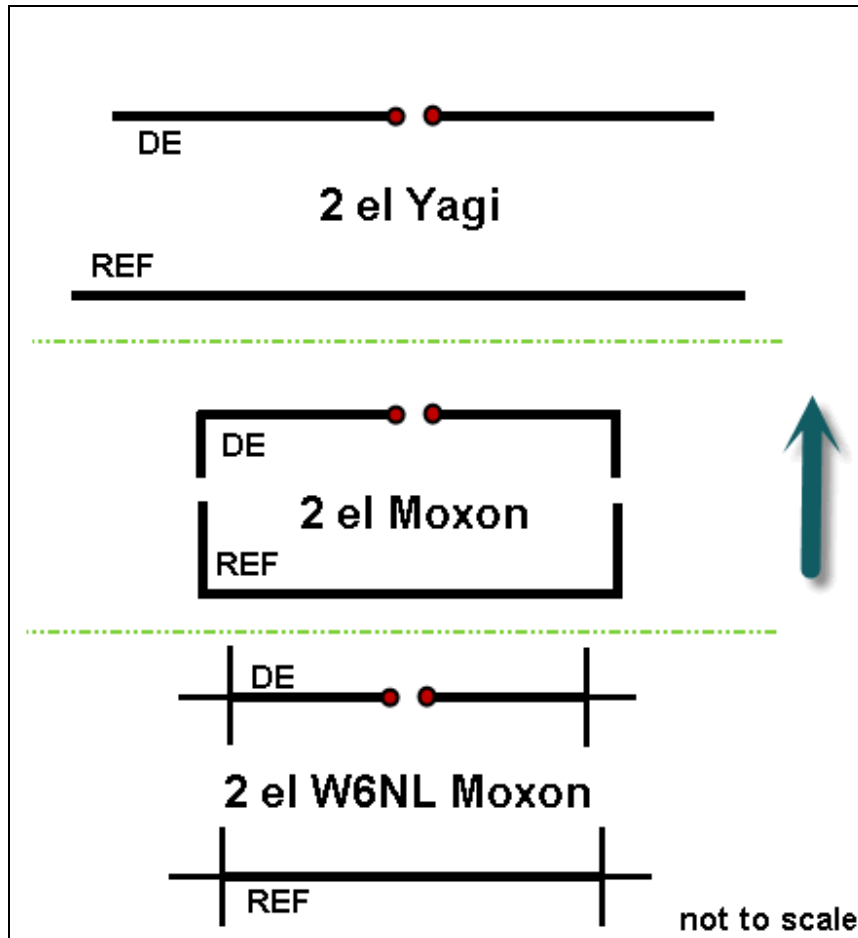


Figure 1 – Moxon Designs

The top design in the figure shows the classic 2 element parasitic Yagi, with a driven element (DE) and reflector (REF). The reflector is longer than the driven element, and both are around  $\frac{1}{2}$  wavelength long.

The initial Moxon, in the middle, shows the tips bent 90 degrees towards the center.

The W6NL variation on this design is shown at the bottom.

Much has been written about the Moxon and the impact of the bends at the ends of the elements. On the Internet, a good source of information is the *Moxon Antenna Project*, at: <http://moxonantennaproject.com>.

The web page archives of L.B. Cebik, W4RNL (SK) have a number of Moxon related articles ([www.cebik.com](http://www.cebik.com)). Dan Maguire, AC6LA, has written a Moxon generator program (<http://www.ac6la.com/moxgen.html>), useful for computing dimensions and even models as a function of frequency.

My first practical experience with a Moxon took place over a dozen years ago. I was involved with a Moxon for 80 meters. It was made of wire, and designed to be bidirectional, using relays to load the reflector with inductors and relays to select the fed element. What made that project interesting was that it was located at the top of an apartment building in India (VU).

## **The W6NL Moxon Antenna Model**

Given a detailed description of the antenna, which was available in this case, creating a model is not hard, but it can be time consuming and tedious. The challenge is getting all of the coordinates correct, as well as the Wire diameters. There are lots of little numbers to get right.

I believe the model matches the description. If it does not, all of the errors are due to my poor transcription. Blame me, not the original design.

As mentioned earlier, a file containing the model, M60.ez, is part of the **.zip** file containing this note. As is common with upper HF self supporting antennas, the model units are inches, since this is most convenient. If you modify the model, perhaps to change the height, be sure that you are working in inches, not feet.

In the actual antenna, the short perpendicular elements are connected to the bottom side of the main elements with brackets and clamps. This is shown in the following diagram taken from the document:

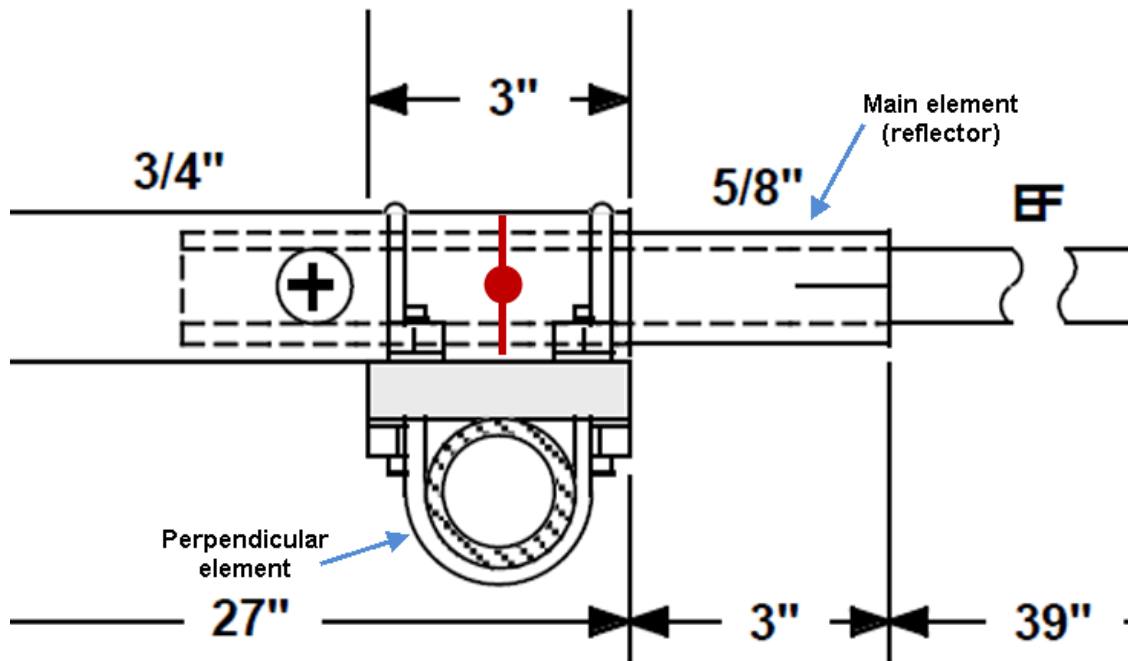


Figure 2 – Perpendicular Element Construction Details

There are four similar junctions on the antenna – one on each end of the driven element and the reflector.

In the model, I have connected the perpendicular element directly to the main element. In effect, it is attached where the red dot is located on the diagram. So that all Wires meet at ends and do not overlap, the model has a Wire junction at that same point. Except for this detail, you should find a 1 to 1 correspondence between *exposed* tubing in the construction plans and modeled Wires.

I manually specified the number of Wire segments in the model. If you run the model you will find a few segment length warnings. These are due to the very short Wires created where the perpendicular elements attach. EZNEC has an *automatic segmentation* feature that was not used, but it was tried. It was unable to get rid of the warnings. I don't believe that any harm comes from these warnings.

There is one important piece of information not contained in the construction article – the spacing between the two elements! That is 21.5 feet (21 feet, 6 inches).

## Stepped Diameter Correction

Now it's finally time to get into what I believe may be a source of confusion over modeled results for this antenna.

A known problem with the NEC-2 engine is its treatment of *stepped diameter Wires*. This condition is inherent in elements constructed from telescoping aluminum tubing. As the next section of tubing is added, we step down in diameter. This is great for mechanical, weight, and cost considerations, but creates a complexity for the electrical model (remember, *no free lunches*).

One way around this problem is to select a modeling engine that does not have a problem with stepped diameters. This would include NEC-4 and MININEC.

The NEC-2 engine, with the problem, however, is perhaps the most popular modeling engine in use, being both powerful and free (well, there's one *free lunch*).

Another way around this problem is to discover a single Wire with a constant diameter that is considered to be electrically equivalent to the stepped diameter element. If we model (in NEC-2) the single Wire with the constant diameter in place of the stepped diameter Wires, we have side-stepped the problem.

An algorithm to convert a set of stepped diameters wires into a single equivalent wire was presented in the book *Physical Design of Yagi Antennas*, by Dave Leeson<sup>4</sup> (ARRL, 1992) (page 8-18).

That algorithm was added to the EZNEC program, and is turned on by default and operates *behind the curtain*, automatically (I'm speaking of NEC-2, it's not needed for NEC-4).

In most cases, the problem is now largely solved, although the NEC-4 engine is considered to provide more accurate results, and should be considered if you are seeking the highest level of accuracy.

The problem with this antenna is that due to the perpendicular elements that are the signature of the Moxon design, the stepped diameter correction algorithm cannot be used. The Wire arrangement does not meet the correction criteria in EZNEC.

The EZNEC documentation describes what can happen if the stepped diameter correction is not used. Here is the text from the manual:

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<sup>4</sup> Yes, that is the same Dave Leeson that designed this 40m Moxon.

The inaccuracy of NEC-2 in the presence of large steps in diameter typically shows up as an incorrect reactance. If you design an antenna with parasitic elements having connected wires with largely differing diameters, **EZNEC** will give an accurate idea of the antenna performance. However, it will show the performance occurring at not quite the correct frequency. When you actually build the antenna, you can expect the predicted performance, but may need to adjust parasitic element lengths slightly to achieve that performance at the desired frequency. For example, if **EZNEC** shows your "X-beam" to have a gain of 6 dBi, front/back ratio of 20 dB, and feedpoint SWR of 1.5:1 at 14 MHz, you might find when you build it that the front/back ratio is much worse than predicted at 14 MHz but is very good at 14.5. In this case, you would need to lengthen the parasitic element until you get the best front/back ratio at 14 MHz. The beam will then have very nearly 6 dBi of gain and 1.5:1 SWR at 14 MHz.

#### EZNEC Manual (Section on Stepped Diameter Correction)

As I read through this description, I came away with the idea that NEC-2 considers stepped Wires to be as if they don't drop (much) in diameter. The modeled Wire is *too long* because it is *too fat*. The modeled results will be slightly lower in frequency than the real antenna results. Said another way, if you build the antenna, expect that you have to make it a little longer than the model suggests. Said yet another way, when you are using NEC-2 without stepped diameter correction, you should move the modeled results up a little in frequency.

As the upcoming examples will show, the result is that a model of the W6NL 40m Moxon run on the NEC-2 engine, without stepped diameter correction, will have about a 200 KHz downward shift in performance.

It should be possible to *massage* a model that would be much closer to the truth with NEC-2. In other words, there is an equivalent antenna without stepped diameter Wires. But, that would take some time and work to create. For this antenna, and any stepped diameter antenna that cannot use the correction, I would strongly suggest using NEC-4. The EZNEC manual describes the circumstances that must exist for it to use the stepped diameter correction algorithm. If you are working on an antenna with telescoping elements, please make sure that the correction is being used (or, use NEC-4). From the examples in this note, it would appear as if **all** Moxons constructed with telescoping tubing would not qualify for stepped diameter correction, and would be best modeled with NEC-4.

While working through this realization about Moxons made from stepped diameter tubing I realized that I could not be the first person to come to this conclusion. My first guess as to who would be on top of this was L.B. Cebik,



W4RNL (SK). I checked some of his material, and on a page titled: *Stepped Diameter Moxon Rectangles for 20 through 10 Meters* I found this quote:

Re-design of a Moxon rectangle that employs a stepped-diameter taper schedule is not a task for NEC-2. Because the stepped-diameter correction of NEC-2 implementations does not operate for non-linear elements, the program will not correctly handle the bent Moxon elements. Re-design should use either NEC-4 or a highly corrected version of MININEC 3.13, such as the one sold as Antenna Model. A MININEC implementation must have at least the frequency-drift correctives if it is to handle the 12 and 10- meter designs adequately.

L.B. Cebik from *Stepped Diameter Moxon Rectangles for 20 through 10 Meters*

This certainly agrees with what I have (re)discovered. If you model a stepped diameter Moxon in NEC-2, your results will have an unexpected frequency shift. The next set of examples seeks to develop some intuition into the magnitude of the problem.

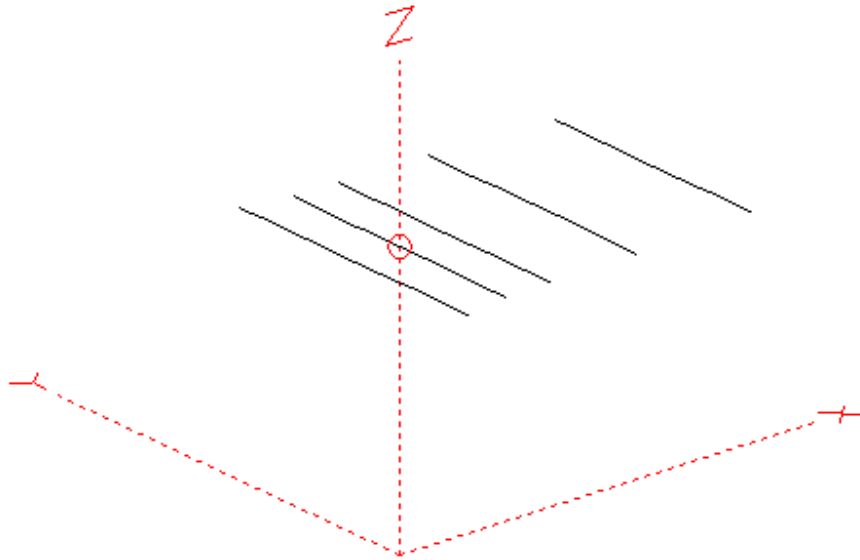
There is a test for the potential of a modeling problem with an antenna called the *Average Gain Test*. I won't describe it here, but, the idea is to see if we have modeled an antenna that has characteristics that challenge the calculation engine. When the model results are reliable, the average gain has a value of 1. Some folks who have worked with this metric claim that you can have confidence in the results of a model when the average gain value is between 0.95 and 1.05. Beyond that range, there is a good chance that the results cannot be trusted.

In this case, for the example W6NL Moxon, I found the average gain to be 1.032, within the trustworthy range. So, this is a case where the results do not reflect the model, but the *Average Gain Test* does not call that out.

The moral of the story is – if you are using NEC-2 and modeling stepped diameters, use a modeling program that provides stepped diameter correction, or, expect there to be differences similar to what are described in this note. Be sure that the correction is actually being used, and not just **available**. I had a recent situation where a typing error caused a wrong digit in a Wire end coordinate. It was a tenth of an inch error. For a 20 meter antenna, a tenth of an inch is not going to make a difference in the performance in either the real world, or, NEC-4. But, with EZNEC/NEC-2, it checks carefully for a centered Source, and my little typing error was enough to disable the stepped diameter correction. If your model needs correction, and you have access to it, be sure it is being used.

## ***An Example: 20m 5 Element Yagi***

I'm going to use an example to develop some insight into the stepped diameter correction issue. The example I picked is a 20 meter 5 element Yagi that is supplied with the EZNEC package. The file is named **20m5elya.ez**.



**Figure 3 – 5 element 20m Yagi**

This model has the property that we can run it three different ways.

1. Using NEC-2, without stepped diameter correction.
2. Using NEC-2, with stepped diameter correction.
3. Using NEC-4, no stepped diameter correction needed.

There is an EZNEC program option that disables the stepped diameter correction. It cannot be forced on, but it can be forced off.

My only modification to the model was to change the ground type to be Real/High Accuracy, and then raise the antenna to 60', approximately 1 wavelength on 20 meters.

## **SWR Comparison**

The SWR comparison is:

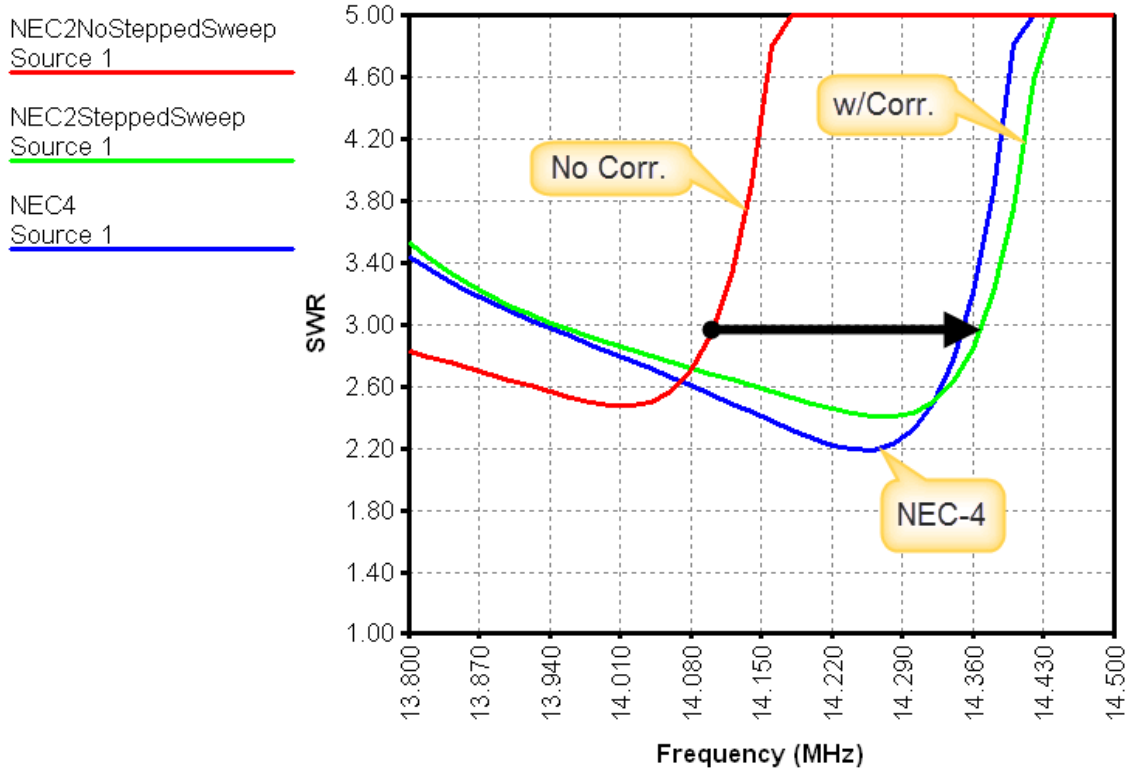


Figure 4 – 20m Yagi SWR Comparison

The corrected NEC-2 (green) and NEC-4 (blue) are largely tracking together. The uncorrected NEC-2 SWR, in red, is about 280 KHz under the corrected. It's clear that if you grabbed the red trace and yanked it right by around 280 KHz you would end up with the corrected data.

### Gain Comparison

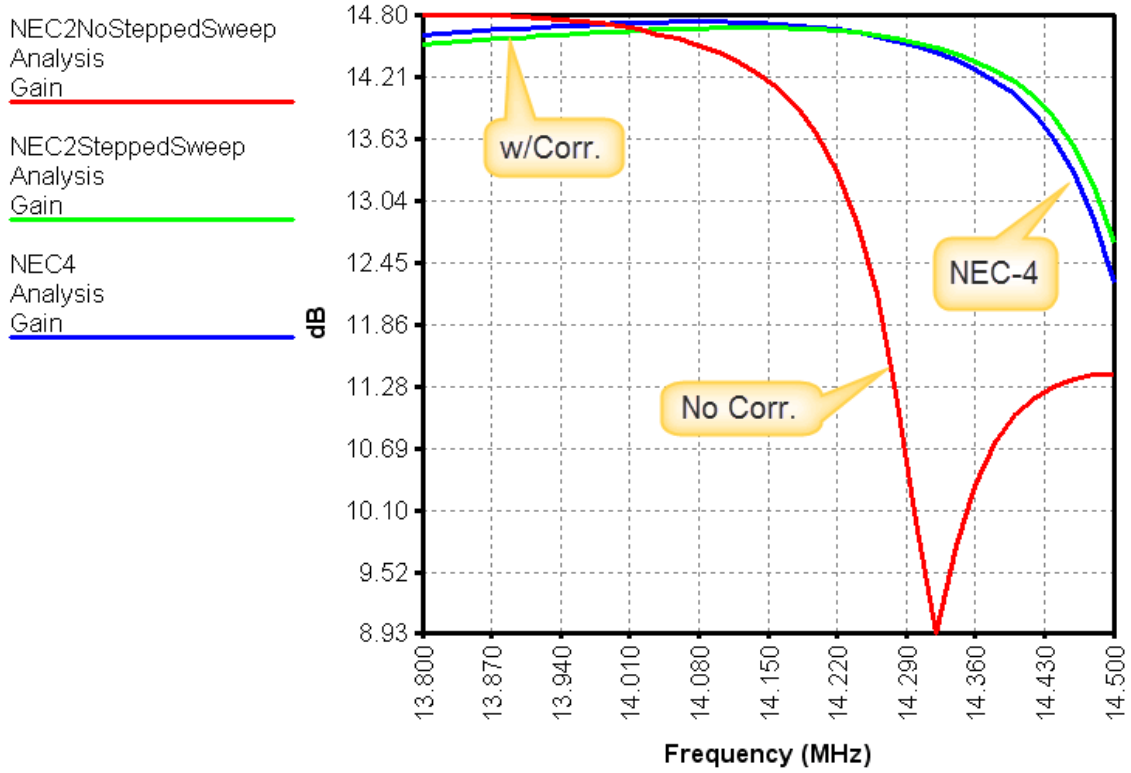
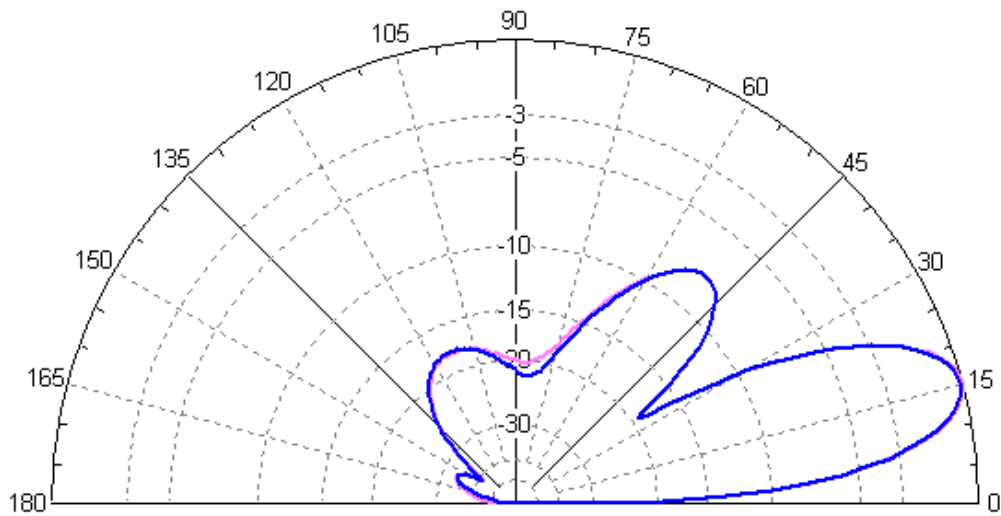


Figure 5 - 20m Yagi Gain Comparison

As with the SWR, the uncorrected NEC-2 data (red) is shifted down in frequency from the corrected NEC-2 data, which tracks the NEC-4 (blue) data.

### Elevation Pattern

The elevation pattern for the corrected NEC-2 and NEC-4 data at 14.1 MHz is:



Main Lobe:  
 BW: 16.66°  
 Freq: 14.100 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 14.69 dB @ 15°  
 Outer Ring Gain: 14.75 dB (+0.06 dB)

NEC2SteppedSweep  
 NEC4

**Figure 6 - Corrected NEC-2 and NEC-4 Elevation Pattern**

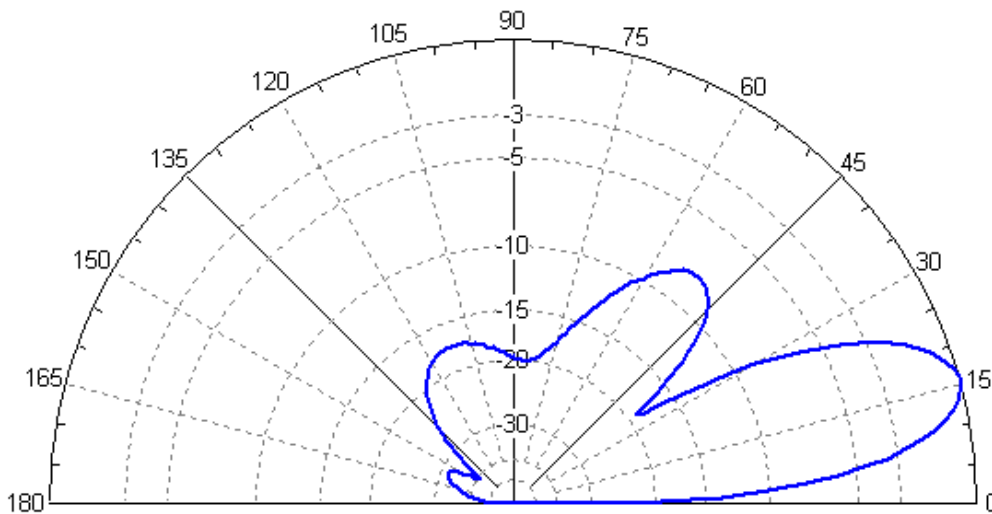
The patterns are nearly identical, indicating that the correction to NEC-2 (blue) yields close to the NEC-4 (pink) results.

Given the trend we have seen so far, the uncorrected NEC-2 pattern that matches the other two at 14.1 MHz should be down in frequency about 250 KHz.

I examined the uncorrected patterns, and selected this one from 13.860 MHz<sup>5</sup>.

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<sup>5</sup> The pattern drawing software I was using demands that the frequency be the same for all data, so, it's not possible to mix frequencies for a direct visual comparison. Two separate patterns are created, and they must be visually compared.



Main Lobe:  
 BW: 16.94°  
 Freq: 13.860 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 14.80 dB @ 16°  
 Outer Ring Gain: 14.80 dB (+0.00 dB)

**Figure 7 - Uncorrected NEC-2 Elevation Pattern**

Although it is necessary to make a visual comparison, I believe that the patterns are very similar; suggesting that the same frequency shift is present in the pattern as well as other characteristics such as SWR and gain.

## Summary

As suggested by the EZNEC manual, without stepped diameter correction the antenna characteristics were shifted down in frequency. The corrected NEC-2 and NEC-4 characteristics were much closer together. Without the stepped diameter correction the antenna elements would appear to be slightly too long.

## Example Moxon Antenna Performance

When an antenna design is presented it's common to include performance information such as gain and pattern shape. In many cases, the performance and characteristics will be a function of the antenna height above ground.

This antenna is probably a good example of height playing a larger role in performance. That's simply because at 40 meters, most horizontal antennas are located within  $\frac{1}{2}$  to 1 wavelength above ground. Typically, you need to be moving above 1 wavelength in height to see the effect of ground diminish. This might

also be a source of confusion since the characteristics of the antenna will change if it's moved from let's say 50' to 150' off of the ground. You might say that the antenna and ground *work as a team*, and it's incomplete to just describe the antenna without at least making a quick mention of the ground conditions used.

The remainder of this note places the W6NL 40m Moxon antenna at various heights, and even looks at a stack of two. The *Ground Description* in EZNEC is *Average, Pastoral* (0.005, 13).

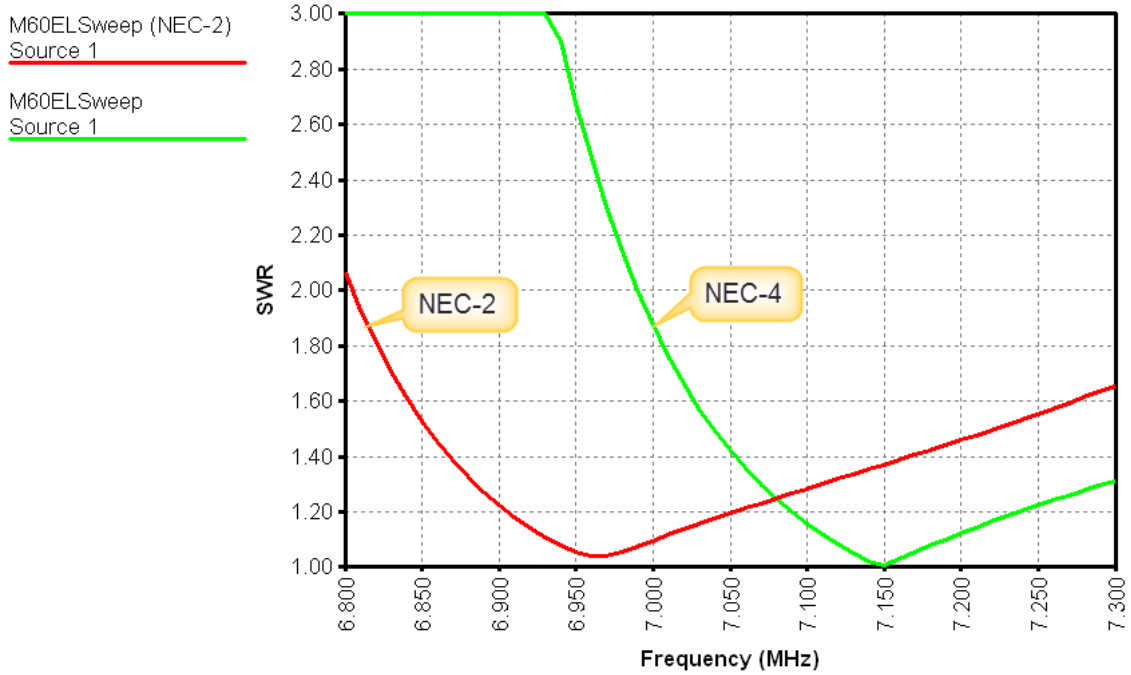
For the first example, the uncorrected NEC-2 and NEC-4 data will be compared. Once it is established that the uncorrected NEC-2 data is shifted down in frequency, the emphasis will shift towards examining the NEC-4 results, on the theory that they are the most accurate.

For some characteristics that can be compared on a single graph, the comparison will be presented at the end.

## **Single Moxon at 60'**

The first example places a single Moxon at 60'. The first goal is to look for the difference between NEC-2 without stepped diameter correction, and NEC-4. Since this is the actual W6NL Moxon antenna, we do not have the choice of NEC-2 with stepped diameter correction.

Here is the SWR comparison.

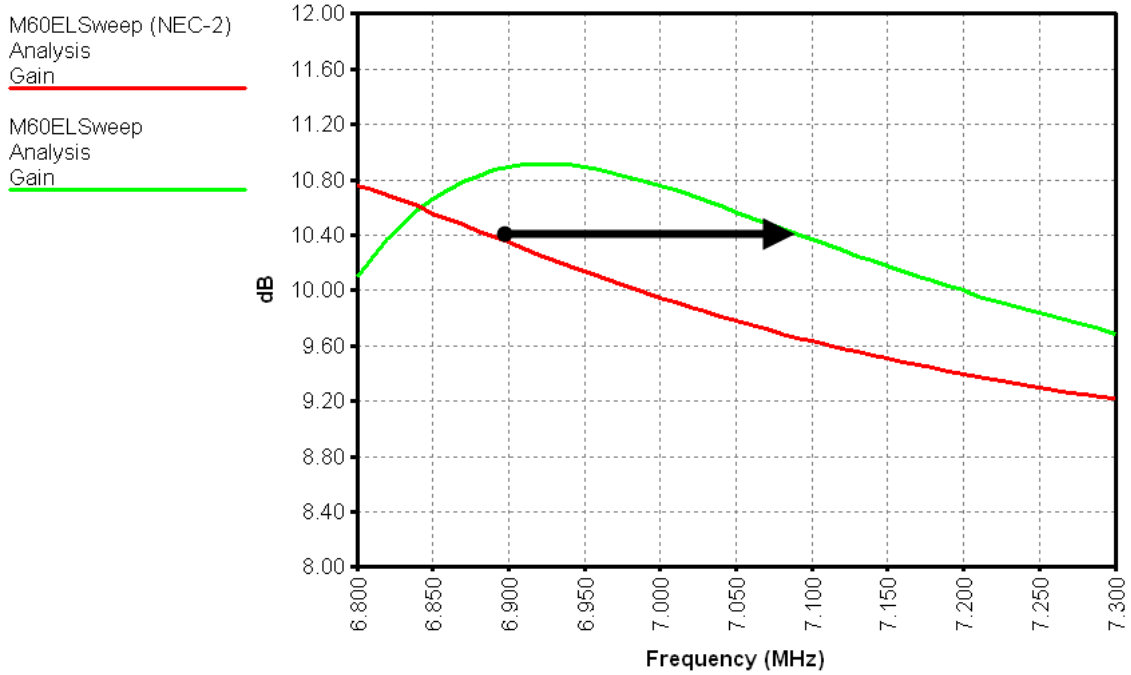


**Figure 8 – NEC-2 and NEC-4 SWR Comparison**

As was seen in the case of the 5 element 20 meter Yagi, the NEC-2 engine without stepped diameter correction has a response that is lower in frequency than NEC-4. In this case, about 200 KHz.

The gain comparison is:





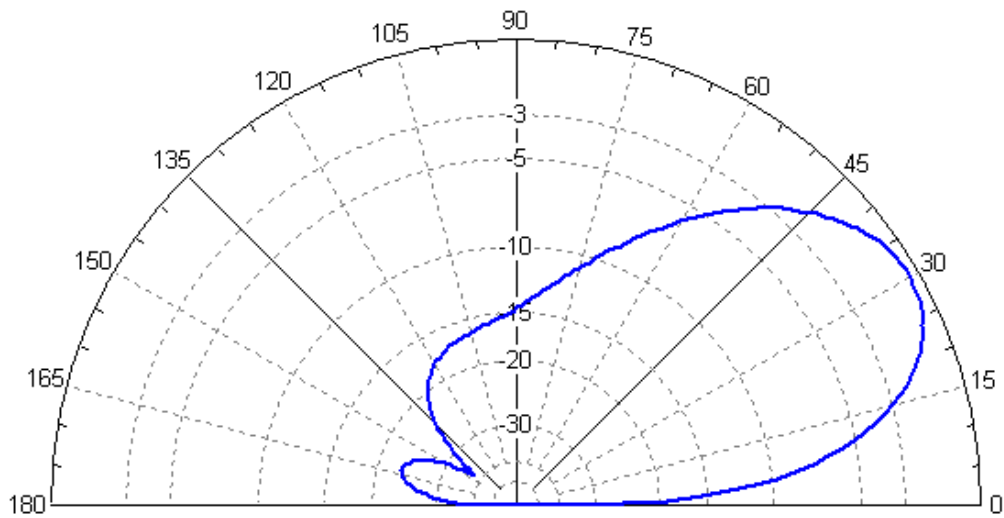
**Figure 9 – NEC-2 and NEC-4 Gain Comparison**

As before, if we grab the uncorrected NEC-2 response and drag it up in frequency, we arrive at the NEC-4 response.

So, my own conclusion from these two models is that the stepped diameter correction, when it can be applied, does a good job of making NEC-2 respond like NEC-4. Without it, the frequency shift described in the EZNEC manual will be present.

All results from this point to the end of the note were obtained from NEC-4.

Here is the 60' Moxon elevation pattern at 7.050 MHz.

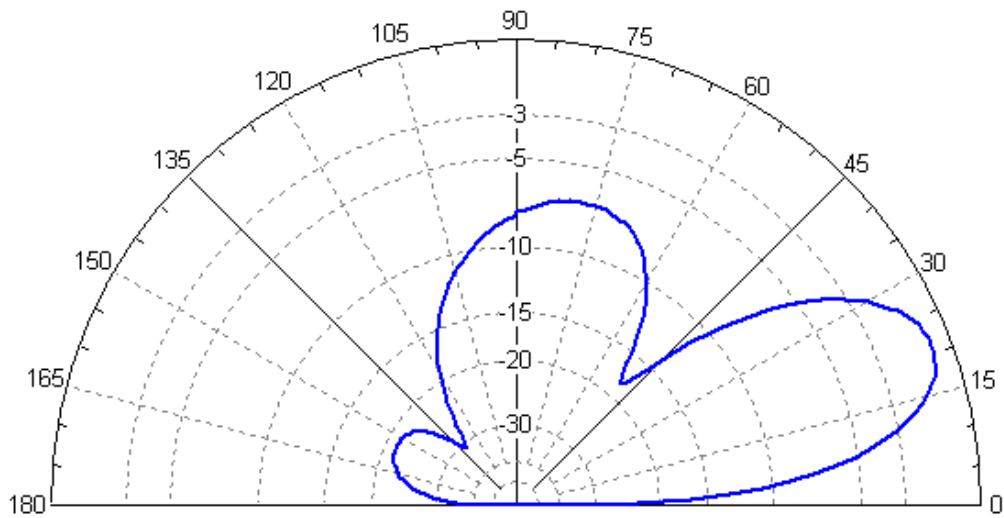


Main Lobe:  
 BW: 36.84°  
 Freq: 7.050 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 10.57 dB @ 31°  
 Outer Ring Gain: 10.91 dB (+0.34 dB)

**Figure 10 - 60' Moxon Elevation Pattern**

## Single Moxon at 90'

Here is the 90' Moxon elevation pattern at 7.050 MHz.

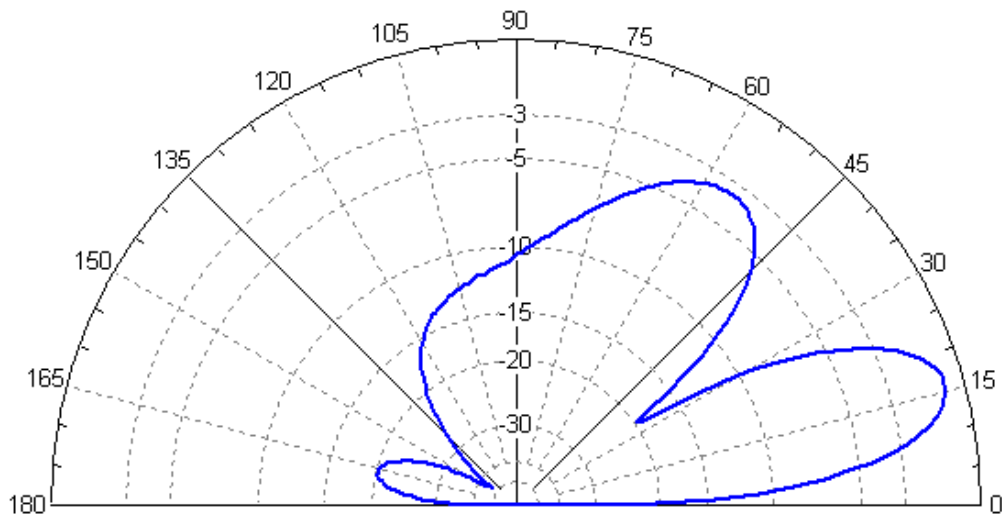


Main Lobe:  
 BW: 23.28°  
 Freq: 7.050 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 11.49 dB @ 21°  
 Outer Ring Gain: 12.19 dB (+0.70 dB)

**Figure 11– 90' Moxon Elevation Pattern**

## Single Moxon at 120'

Here is the 120' Moxon elevation pattern at 7.050 MHz.

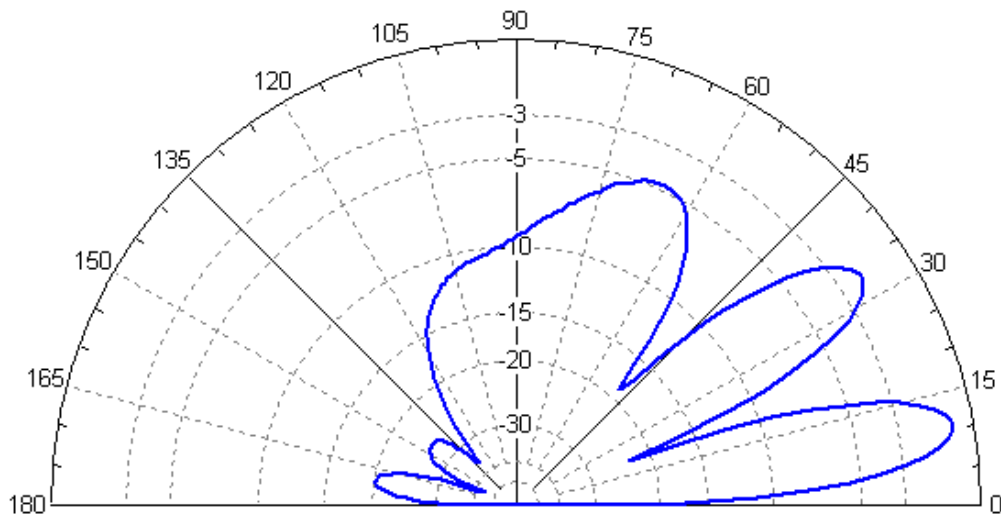


Main Lobe:  
 BW: 16.97°  
 Freq: 7.050 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 11.47 dB @ 16°  
 Outer Ring Gain: 12.16 dB (+0.69 dB)

**Figure 12 – 120' Moxon Elevation Pattern**

## Single Moxon at 185'

Here is the 185' Moxon elevation pattern at 7.050 MHz.



Main Lobe:  
 BW: 10.86°  
 Freq: 7.050 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 11.74 dB @ 11°  
 Outer Ring Gain: 12.53 dB (+0.79 dB)

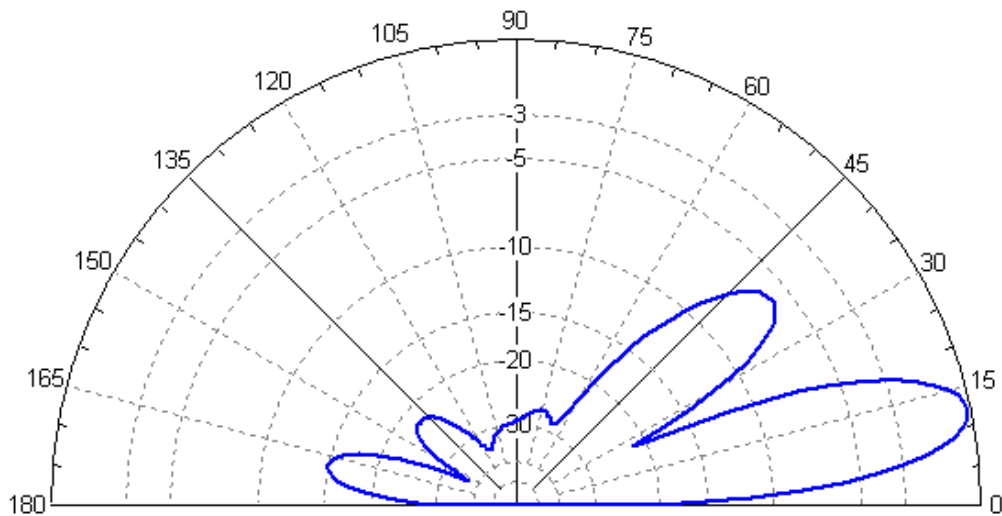
**Figure 13 – 185' Moxon Elevation Pattern**

## Moxon Stack, BIP

**BIP** is an array stacking term that means *both in phase*. There is a stack of two antennas, and they are fed in phase. Depending upon the height separation, whether we are talking voltage or current phase can matter. In this case, I mean the phase of the current. This can be accomplished by using odd multiple  $\frac{1}{4}$  wavelength lines from the common feed point, creating the *current forcing* condition driven from a common voltage junction.

The BIP and BOP configurations presented in this note have the top Moxon at 185' and the bottom Moxon at 120'. In other words, the highest two single Moxon heights.

Here is the BIP elevation pattern at 7.050 MHz.



Main Lobe:  
 BW: 12.91°  
 Freq: 7.050 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 14.19 dB @ 12°  
 Outer Ring Gain: 14.29 dB (+0.10 dB)

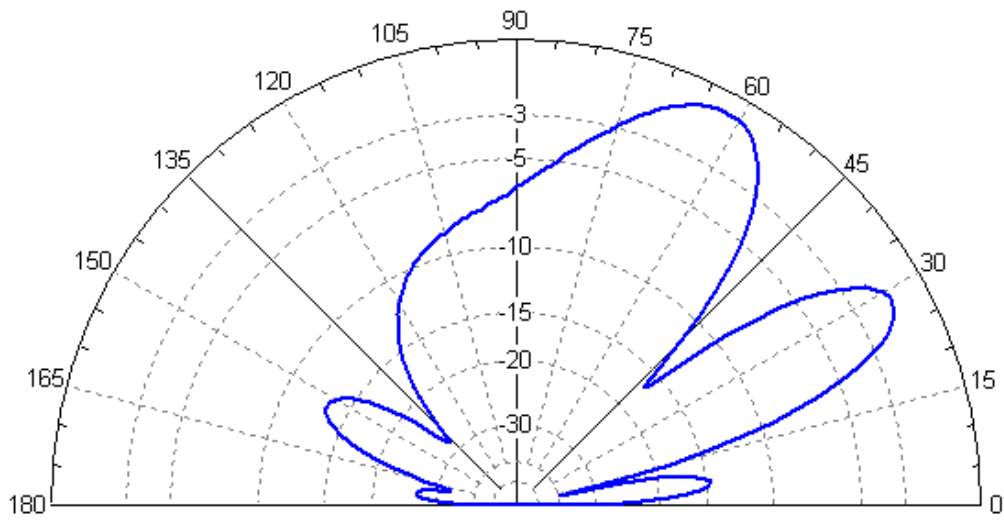
**Figure 14 – BIP Elevation Pattern**

In order to create the BIP and BOP stack configurations, the two antennas must be fed either in phase or out of phase. This is usually done with coaxial cable, since these are monoband antennas. There will be additional loss in those cables, and these models do not take that loss into account.

## **Moxon Stack, BOP**

BOP is the companion of BIP, and means *both out of phase*. While you might think that two antennas pointing in the same direction but out of phase would result in nothing, that's not the case. What you end up with is a change in the take off angle of the main lobe. With BOP, the main lobe take off angle increases. This can be very helpful for more local contacts, where the take off angle is often higher. You might say that BIP is for DX and BOP is for local.

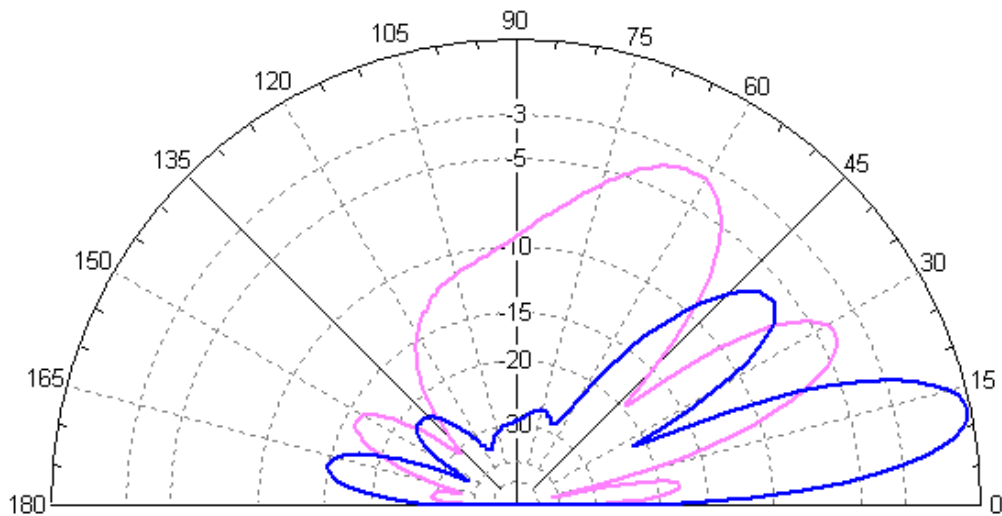
Here is the BOP elevation pattern at 7.050 MHz.



Main Lobe:  
 BW: 27.25°  
 Freq: 7.050 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 10.76 dB @ 62°  
 Outer Ring Gain: 11.45 dB (+0.69 dB)

**Figure 15 – BOP Elevation Pattern**

Here is a comparison of BIP versus BOP at 7.050 MHz.



Main Lobe:  
 BW: 12.91°  
 Freq: 7.050 MHz  
 Azimuth Angle: 0°  
 Lobe Gain: 14.19 dB @ 12°  
 Outer Ring Gain: 14.29 dB (+0.10 dB)

MBIPELsweep  
 MBOPELSweep

**Figure 16 – BIP & BOP Elevation Patterns**

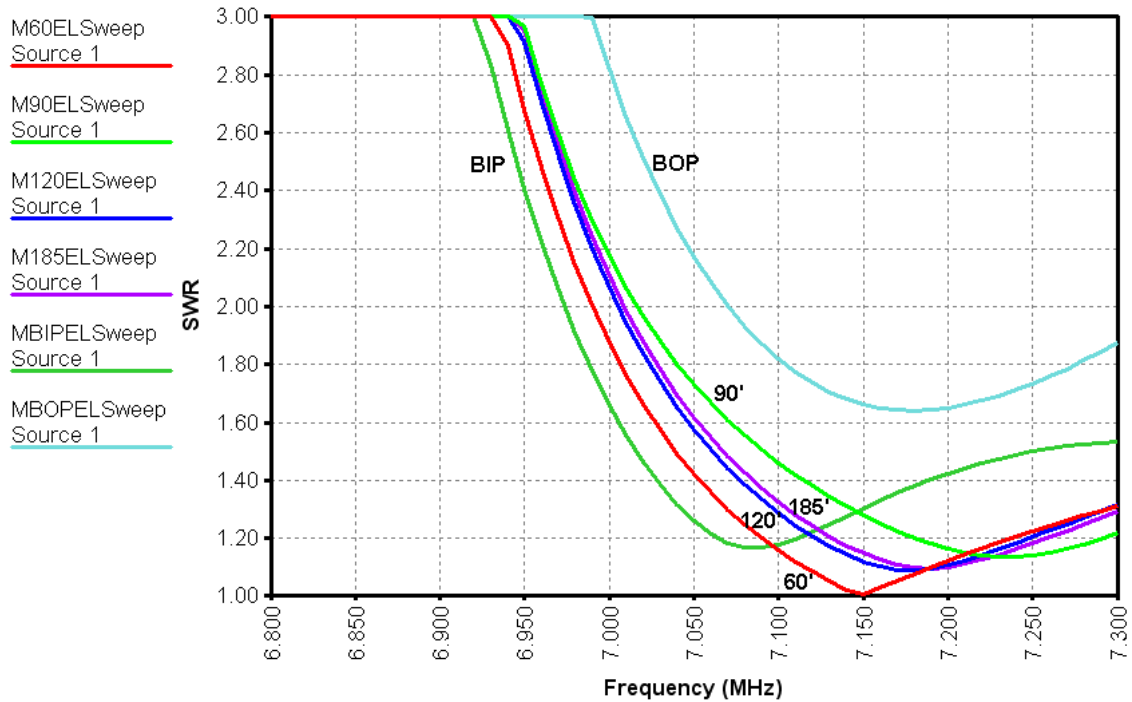
Between the two choices, a deep null (such as at around 25 degrees in blue BIP) is avoided. There is a more uniform gain coverage as a function of take off angle when you have BIP and BOP available on your stack.

## Comparison Across Moxon Examples

This section compares parameters across the Moxon examples.

### ***SWR Comparison***





**Figure 17 – Moxon SWR Comparison**

To identify the data, you can either match up colors with the legend on the left, or, use the height/array labels on the traces.

Between 60, 90, and 120 feet, the SWR curve is changing, but there is little difference between the 120' and 185' Moxon's. 120' and 185' are around 1 wavelength and higher, so the effect of ground is diminishing.

Please note that this and other plots start at 6.8 MHz, well under the band.

The BIP and BOP stack examples do not include loss in the feed system.

### ***Gain Comparison***

The follow graph compares the gain. These are maximum gain values for each height/array. The take off angle will vary from height to height (but dropping with more height). The take off angles used for the azimuth slices were taken from the elevation patterns that show the angle of the maximum gain forward lobe. Those angles are:

1. 60' = 30 degrees.
2. 90' = 22 degrees.
3. 120' = 16 degrees.
4. 185' = 12 degrees.

5. BIP = 12 degrees.
6. BOP = 30 degrees.

Measuring gain and F/B at the take off angle of maximum gain is a common convention, although not always the best way to evaluate performance.

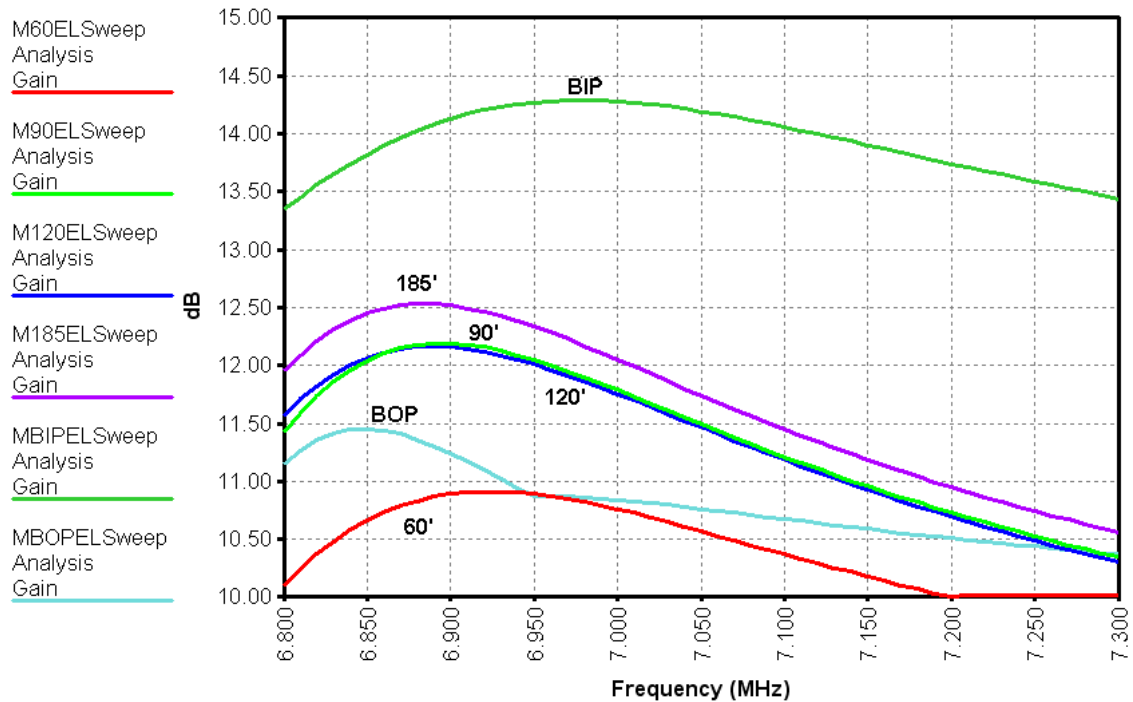


Figure 18 – Moxon Gain Comparison

The big jump up in gain for the BIP configuration is one reason why we stack antennas. In addition to the absolute gain, the BIP main lobe take off angle is very low – good for DX.

The BOP maximum gain is not that exciting in absolute terms, but the take off angle is so high that if you need a high angle lobe, BOP has the highest gain by far.

### ***F/B Comparison***

Front to back data is obtained from azimuth pattern plots. The plots are made at the take off angles of maximum gain in the front lobe. Those angles were listed in the previous section.

The F/B comparison is:

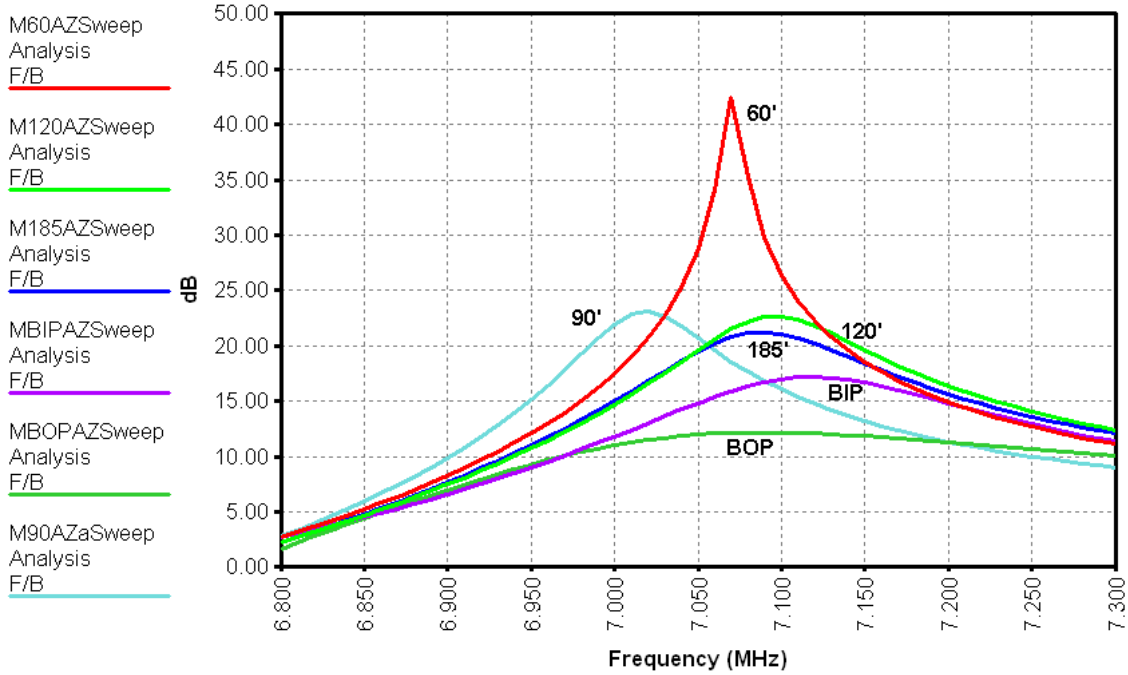


Figure 19 – Moxon F/B Comparison

To end with a little bit of color, here is a 3D wire frame drawing of the 90' Moxon pattern.

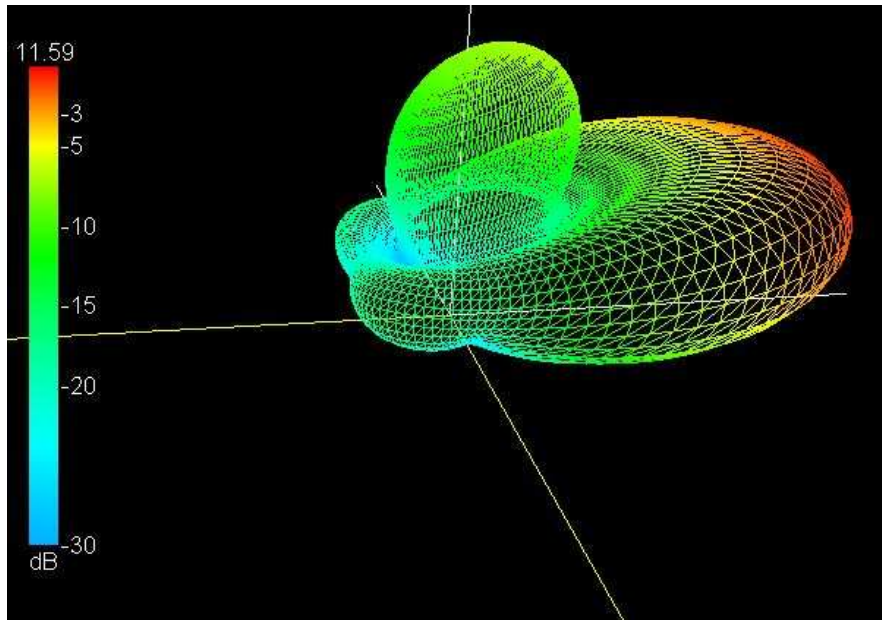


Figure 20 – 90' Moxon 3D Pattern