Modeling and Measuring the Creative Design CLP5130-2N Log Periodic Antenna

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1. Introduction

A log periodic antenna is an array of dipoles with mathematically related lengths and spacings. A more formal name is *logarithmic periodic dipole array* (LPDA). The Creative Design CLP5130-2N log periodic antenna described here is a popular antenna in solar radio spectrometers such as those used in e-CALLISTO {eCallisto} because it is sturdy, inexpensive and covers a broad frequency range, 105 to 1300 MHz (figure 1). Another very similar and popular antenna is the CLP5130-1N, which also is used in e-CALLISTO and it has a frequency range of 50 to 1300 MHz {Creative}.

Note: Links in braces { } and references in brackets [ ] are provided in **section 7**.

This paper describes an electromagnetic model of the -2N antenna along with field measurements for comparison. The model is based on the Numerical Electromagnetic Code (NEC) implemented in the EZNEC+ v.5.0 software application {EZNEC}.The purpose of this work is to verify the manufacturer's claims of gain, beamwidth and voltage standing wave ratio, VSWR (table 1).

Figure 1-1 ~ Creative Design CLP5130-2N log periodic antenna against a blue Anchorage sky. The antenna shown has a "dragonfly" mount (see text). Log periodic antennas are recognized by their obvious apex (point at which imaginary lines along the element tips meet at the front of the antenna) and progressively shorter elements with progressively smaller spacing.

2. Design and construction

A log periodic antenna is a type of broadband antenna with good directivity. It can be described by two geometric parameters, a scale factor τ that specifies the relative lengths and a spacing factor σ that specifies the relative spacings of the antenna elements (for additional detail, see [Carrel], [Hutira] and [Isbell]) (figure 2-1). A third parameter, α, is one-half the apex angle and is derived from τ and σ. The following values were measured for the CLP5130-2N: $\alpha = 27.3°$, $\tau = 0.84$, $\sigma = 0.193$.The individual antenna elements of the log periodic antenna are interconnected by a transmission line, which often also serves as a structural boom (as in the CLP5130-1N and -2N).

Table 1-1 ~ CLP5130-2N – manufacturer's data. Source: [Creative]

Parameter	Value
Frequency range	105 to 1300 MHz
Number of elements	17
Forward gain	11 to 13 dBi
Front-to-Back ratio	15 dB
Beamwidth – E-plane	70 to 60 degrees
Beamwidth – H-plane	130 to 110 degrees
Impedance	50 ohms
VSWR	≤ 2.0:1
Boom length	1.4 m
Maximum element length	1.3 m
Weight	3 kg

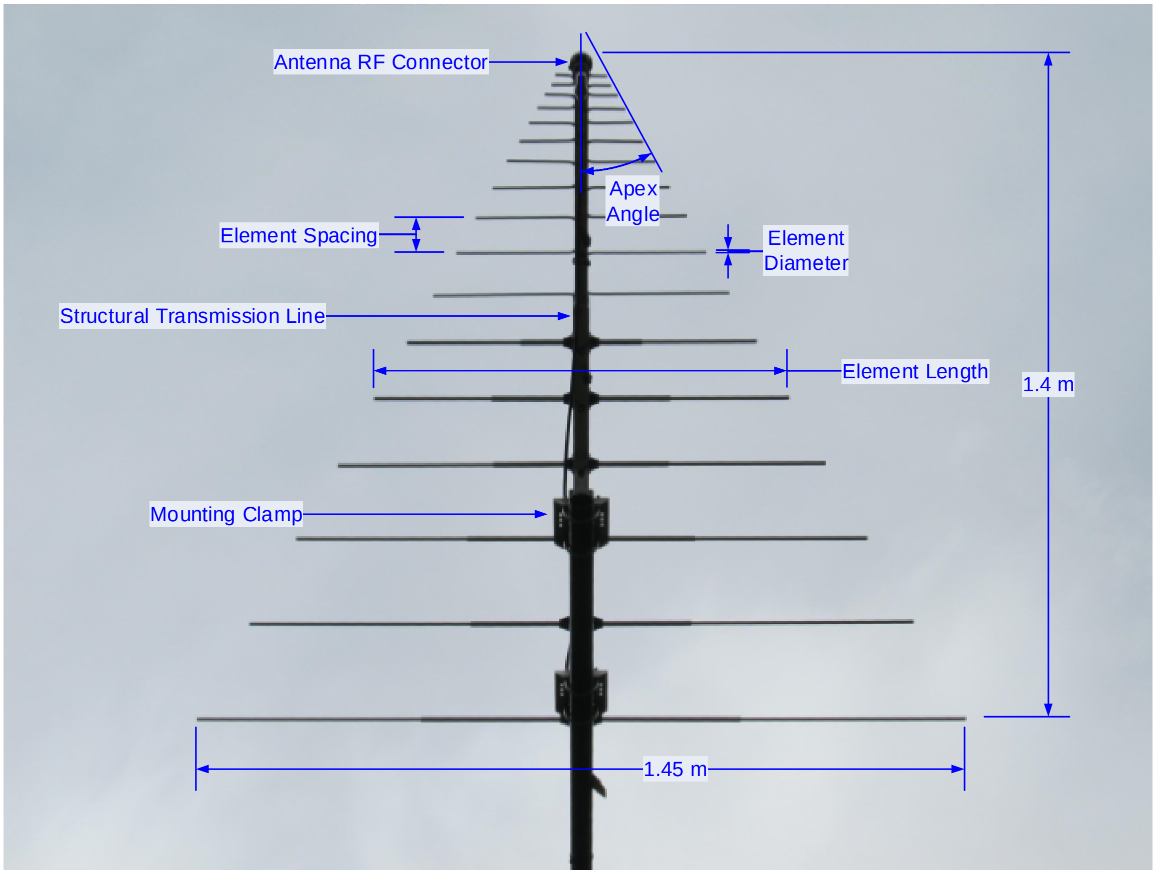


Figure 2-1 ~ Antenna photograph annotated with dimensional characteristics. Note: Actual measured length of the longest element differs from the manufacturer's datasheet.

The highest directivity is along the longitudinal axis in the direction of the shortest elements. The longest dipole determines the low frequency and the shortest determines the high frequency. Usually, the low frequency dipole is about 7% longer than 1/2-wavelength at the low design frequency and the high frequency dipole is about 30 to 35% shorter than 1/2-wavelength at the high design frequency. These criteria apparently were used for the CLP5130-2N, whose uncompensated dipole lengths correspond to a frequency range of 98 to 1760 MHz (105 to 1300 MHz working range).

When the antenna is illuminated by an electromagnetic field, currents flow in each dipole. Dipoles with lengths closest to 1/2-wavelength carry the highest currents (figure 2-2). The currents in this *active region* combine on the transmission line according to their phase and work together to form the antenna radiation pattern characteristics. Log periodic antennas are fed from the end nearest the apex (front).

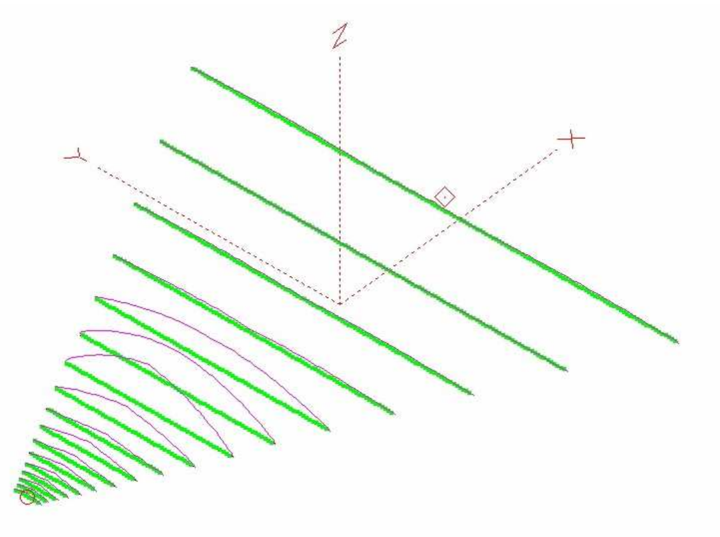


Figure 2-2 ~ Log periodic antenna elements (green) and the current magnitudes in each element (thin violet lines) when the antenna is illuminated with a single-frequency 245 MHz radio wave. Elements 6 and 7 (from the rear) carry the highest currents. Element 6 is 584 mm long and very close to the length of a 1/2-wave dipole at 245 MHz (582 mm). The shorter dipoles carry lower currents, which decrease as their lengths decrease. Dipoles longer than 1/2-wave at 245 MHz carry very little current. The currents in each dipole add or subtract on the transmission line according to their phase to form a total current that depends on the frequency and direction of the incoming radio wave. This image was produced by EZNEC.

An important attribute of log periodic antennas is the use of a transmission line to interconnect the dipole elements. This line can be made from ordinary wires, in which case the dipole elements need to be supported by a separate insulating structure, or the line itself can be made from structural components such as round or square tubes or channels. The CLP5130-2N uses rectangular aluminum channels for the transmission line and support. Half-elements are attached to alternating channels; for example, one-half of element number E2 is attached to the upper channel and the other half is connected to the lower channel. This type of connection provides the phase reversal at adjacent dipoles that is needed for a log periodic antenna.

The transmission line often extends past the rear (longest) dipole element a distance of 1/4 wavelength at the low frequency. This line extension is terminated with a shorting bar or coil. The bar or coil provides a dc short for lightning and static build-up protection and also is required to provide an electrical termination (termination is discussed briefly in the next section). The CLP5130-2N line extends only 33 mm beyond the longest element and uses a coil (inductor) termination that is electrically equivalent to a length extension. At the front of the antenna, the transmission line terminates in an N-type RF connector for connection to 50 ohm coaxial cable.

The CLP5130-2N is made entirely from aluminum except for stainless steel fasteners and plastic brackets that hold the longer elements (figure 2-3). The antenna is broken down for shipment and is assembled on-site using common tools in about 30 minutes.


Figure 2-3 ~ Left: Photograph of the CLP5130-2N showing transmission line channels and plastic brackets that hold the longer elements (black object on lower element). A stainless steel self-threading screw through the channel bonds each half-element to the transmission line. Also seen is a stepped element consisting of two tube diameters and non-stepped elements. Right: Transmission line termination coil at the rear of the antenna.

3. NEC Model

This section describes the model, its limitations and the compromises and simplifications that were necessary during its development. In numerical electromagnetic codes, an antenna or any arbitrary metal structure is modeled as a collection of thin wires. Each wire is divided into a number of segments. The NEC software solves the mathematical equations that describe the impedances and induced currents in these wire segments. Except for a very simple wire dipole antenna, an NEC antenna model is a compromise between physical reality and computational expediency. Several versions of the NEC exist, and EZNEC+ v.5.0 uses version 2 (NEC-2), which is in the public domain.

The EZNEC main window shows a model summary (figure 3-1). Log periodic antennas that are built like the CLP5130-2N are difficult to simulate or model because of the stepped dipole elements and structural boom transmission line. A stepped element consists of two or more tubing diameters along its length. EZNEC has the ability to handle stepped elements but only if the entire antenna uses them. In the case of the CLP5130-2N, only seven of the 17 elements are stepped. The stepped elements consist of two tube diameters, 10 mm and 7 mm. All non-stepped elements are 4.5 mm diameter except the shortest one, which is 4.0 mm diameter.

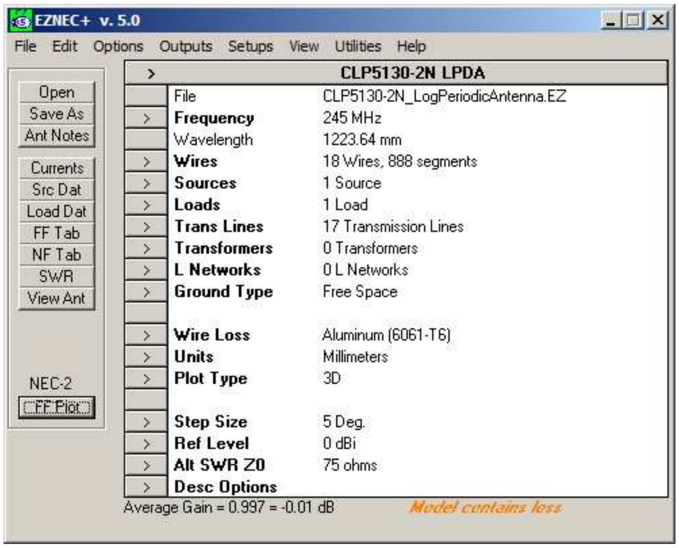


Figure 3-1 ~ EZNEC main window showing a summary of the CLP5130-2N antenna model. This particular setup modeled the antenna in free space but it is simple to change to any height above ground.

To resolve the problem of stepped elements, I used EZNEC to separately calculate an equivalent length and single (non-stepped) diameter for each stepped element and then substituted the equivalent dipoles in the log periodic antenna model. EZNEC uses the calculation method described by [Leeson] for the stepped element conversion (or correction). The equivalent dipole has the same resonance and Q as the original stepped dipole. Its length is slightly less than the original and its diameter falls between the two original diameters (figure 3-2).

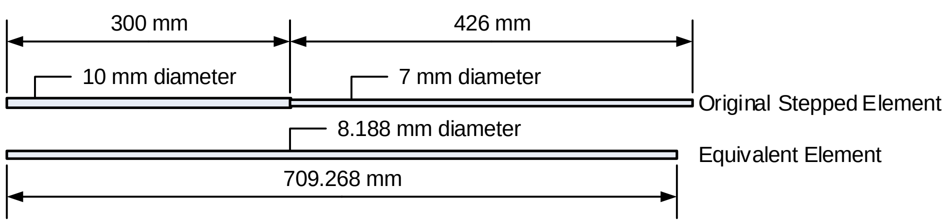


Figure 3-2 ~ Example of one-half of a stepped element (upper) converted to electrically equivalent non-stepped element. The conversion is done on the entire dipole but only one-half is shown here.

As a practical matter, the structural transmission line cannot be physically modeled in EZNEC. Therefore, the dipole elements in the model were interconnected with an ideal transmission line setup to provide the phase reversal between the elements that is required for log periodic antennas. Because the actual CLP5130-2N transmission line is made from channels (figure3-3), determining its characteristic impedance is a problem in electromagnetics. With the help of a colleague and fellow Dane, Kurt Poulsen, I found an arbitrary transmission line calculator {ATLC2} that could handle the calculations. This calculator yielded 111 ohms characteristic impedance.

The actual transmission line impedance used in the model has no effect on the antenna radiation pattern but does affect the calculated impedance and VSWR. Substituting an ideal transmission line for a real physical structure leads to idealistic results that most probably deviate from the antenna's actual performance. A question arises as to the amount of deviation, so I briefly address this in the next section. It is an interesting characteristic of many commercial log periodic antennas that no provision is made for impedance matching or balanced-to-unbalanced conversion between the antenna transmission line (111 ohms), which is inherently balanced, and the unbalanced coaxial cable feedline (50 ohms). Some antennas do use a so-called "choke balun" but none is provided or called for with the CLP5130-2N. Nevertheless, as seen in **section 4**, the voltage standing wave ratio (VSWR) does not seem to suffer by this crime of technicality.

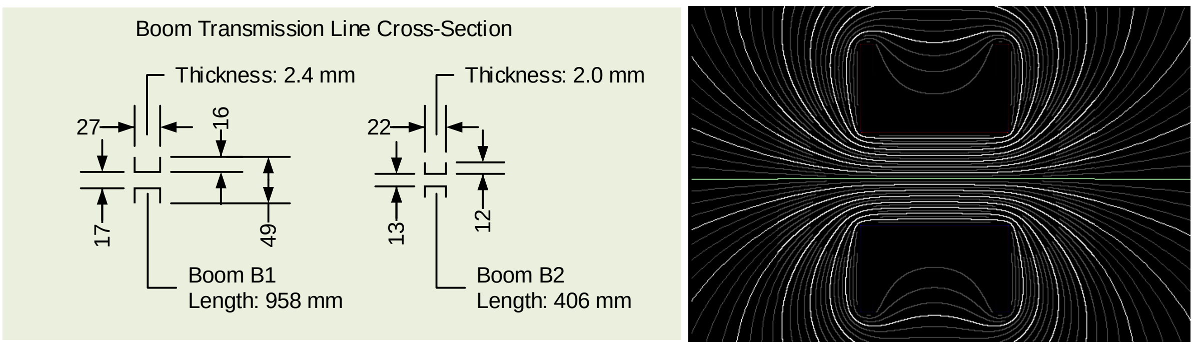


Figure 3-3 ~ Left: Dimensions of transmission line channel cross-sections. The larger set of channels (B1) is about 1 m long. Nested at the high frequency end of the larger channels is the set of smaller channels (B2) that extend another 0.4 m. Right: Electric field around the channels as calculated by the ATLC2 software tool.

The CLP5130-2N can be obtained with a "standard" or "dragonfly" mounting arrangement. The standard mount is a U-shaped aluminum bracket below the transmission line boom that is clamped to a mast. This mount usually is used with a vertical mast to hold the antenna in a horizontal configuration. The dragonfly mount includes an aluminum tube section that projects slightly more than 1 m behind the antenna. This tube is clamped to a mast and allows both horizontal and vertical configurations. These mounting arrangements probably affect the antenna patterns and impedances, but I made no attempt to include the antenna mounting structure in the antenna model.

Programs that use numerical electromagnetic codes require wires to be divided into short straight segments. These segments are required to comply with certain dimensional rules in relation to the wavelength. A conservative segmentation requires at least 20 segments per wavelength at the highest design frequency (segment length ≤ λ/20). In the case of the CLP5130-2N, the highest frequency is 1300 MHz and the corresponding wavelength is 231 mm. This results in a minimum segment length of 11.5 mm. I reduced this slightly and used segment length ≤ 10 mm, leading to a total segment count of 888 for the whole antenna. I experimented with different segment lengths and found that 10 mm is conservative.

More segments require longer computation times. The longer times were readily apparent when the antenna was analyzed over a wide frequency range with high resolution. For example, analyzing the impedance characteristics with 1 MHz resolution over a range of 50 to 1000 MHz required several minutes on my Windows 7 x64 laptop. Running the same analysis with 50 MHz resolution required a few seconds.

In the next section I discuss some model calculations at 50 MHz, below the antenna design frequency range. The segmentation that I used is adequate for the range 100 to 1000 MHz; however, at 50 MHz EZNEC issued a segmentation warning indicating the model calculation accuracy could be compromised. Since I investigated 50 MHz out of curiosity, I made no attempt to adjust segmentation. Another check available for NEC models is the *average gain test*, and I used this to check the model over its design frequency range. The average gain is the ratio of total power in the far field to the power delivered to the antenna by the sources. A very good model has a value of 1 ± 0.05. For the model described here, the value is 0.995 from 100 to 1000 MHz but falls to 0.942 at 50 MHz. Although the value at 50 MHz is not particularly bad, it could indicate compromised accuracy of the patterns and gain at that frequency (but the antenna is not designed for this frequency, anyway).

The termination at the rear of the antenna significantly affects its low frequency characteristics, and it must be placed in the NEC model as a load to yield useful results. The actual CLP5130-2N uses a 6-turn, 23 mm diameter coil with a calculated inductance of 0.276 μH. I placed the inductive load in the model at the actual physical distance (with zero dc resistance), but I found that varying the value of the inductance had little effect.

4. Modeling results and measurements

<u>General considerations</u>: This section describes the EZNEC model simulation results over a frequency range of 50 to 1000 MHz, the lower limit being below the lower design frequency of 105 MHz and the upper limit not reaching the upper design frequency of 1300 MHz. I used a lower frequency of 50 MHz to investigate performance below the antenna's design frequency range out of curiosity, and I limited the upper frequency because I was not interested in antenna performance above 1000 MHz.

Model simulations and measurements have two main components: Antenna radiation patterns and impedance. Antenna gains, beamwidths and front-to-back ratios are derived from the patterns. The maximum available gain, beamwidth and front-to-back ratio at each frequency as calculated by EZNEC are tabulated for comparison (table 4-1) and explained below. Impedance includes VSWR for a 50 ohm reference and is shown separately.

As already mentioned, the NEC model is a simplified electrical model of physical reality. The two aluminum channels that make up the transmission line boom have physical dimensions that are significant fractions of the wavelengths at the high end of the antenna's design frequency range. There is little question electrical currents on the antenna elements and boom interact with each other, and this probably is the reason the dipole elements at the high frequency end are much shorter than 1/2-wavelength at 1300 MHz. On the other hand, effects on the impedance up to 1000 MHz appear to be very small because field measurements and the model calculations agree very well.

<u>Radiation patterns</u>: Antenna patterns for a receive antenna indicate its response in azimuth and elevation and are used to determine the directions from which reception is the best or sidelobe response is the lowest. All patterns in this article are based on a horizontally polarized antenna, thus the E-plane (electric) corresponds to azimuth and H-plane (magnetic) to elevation. The antenna elevation angle is 0° in all simulations.

Antenna patterns depend on the height of the antenna above ground surface and the electrical characteristics of the earth in the vicinity of the antenna. The elevation patterns for an antenna above ground and in free space are different (figure 4-1), but the azimuth patterns are similar (figure 4-2).

Gains: The antenna gain is relative to an isotropic antenna (an isotropic antenna has equal response in all directions and often is used as a reference in antenna engineering work). When the antenna is above ground, the maximum gains calculated by EZNEC are a few degrees above the horizon, and when in free space the maximum gains are at 0° elevation angle. Antenna gains usually are given in datasheets as maximum values. In this regard, the modeled antenna shows good agreement with the manufacturer's data only when the model includes the influence of ground reflections.

The peak gains for the antenna above ground are approximately 5 to 6 dB higher than for free space. When the antenna is above ground, the patterns are affected by ground reflections that add or subtract depending on the electromagnetic field phase and amplitude at each dipole element. The resulting peaks and nulls are obvious in the elevation patterns and, as the antenna height changes, the peaks and nulls change. However, in free space, the antenna elevation patterns are symmetrical about an elevation angle of 0° and there are no reflections and no peaks or nulls in the patterns.

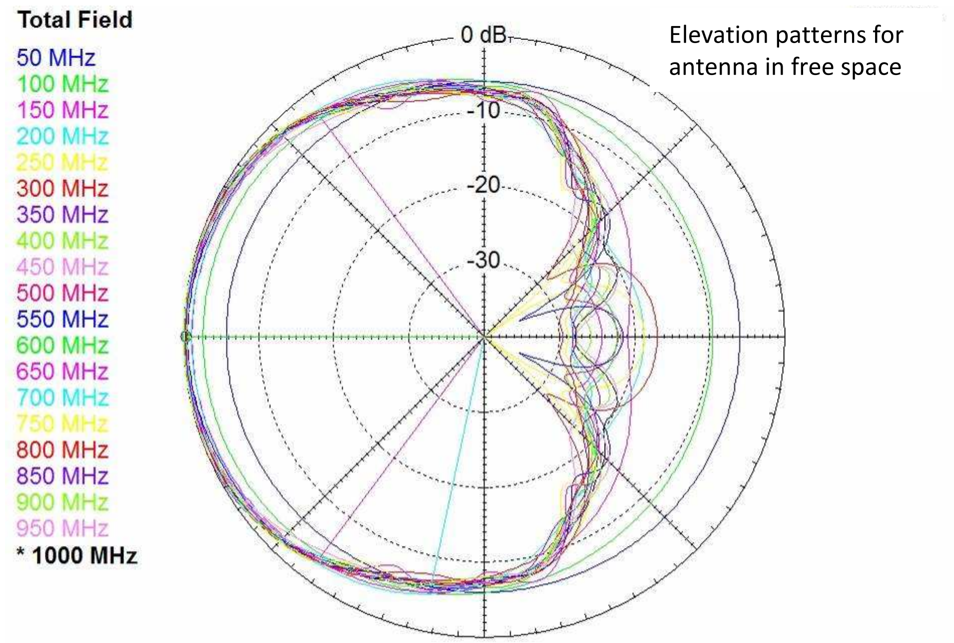
A limitation of the model is that if an earth ground is present, the simulation shows no downward response in the vertical antenna pattern. Even if the antenna is modeled at a height of 100 000 km, the patterns show no downward response (that is, no response at negative elevation angles). However, practical experience shows there is, in fact, downward response and that as height is increased, peak gains decrease to free space values and the pattern peaks and nulls smooth out. Therefore, it is appropriate to use the lower gains calculated for free space when the antenna is, say, 10 wavelengths or more above ground (height > 10λ). For UHF, this height is 10 m or more.

Table 4-1 ~ CLP5130-2N antenna pattern characteristics for free space from the EZNEC simulation

Frequency (MHz)	**Peak Gain (dBi)**	**3 dB Horizontal Beamwidth (°) (note 1)**	**3 dB Vertical Beamwidth (°) (note 2)**	**Front/Back Ratio (dB)**	**Front/Sidelobe Ratio (dB)**
100	4.93	72.6	170.4	6.94	6.94
150	6.39	69.2	135.6	19.77	17.59
200	6.50	70.6	140.6	17.67	17.67
250	7.45	59.2	100.4	17.89	17.89
300	7.35	55.8	110.8	16.33	13.89
350	6.91	62.4	117.4	28.66	14.88
400	7.08	63.6	115.4	25.14	18.19
450	7.26	69.6	88.4	20.87	9.40
500	7.53	55.0	101.2	21.64	9.51
550	6.97	67.6	111.6	19.99	14.74
600	7.51	53.8	100.4	21.64	9.05
650	7.08	66.0	114.2	23.33	11.26
700	7.33	58.6	101.6	27.94	9.60
750	7.57	59.0	105.4	28.59	10.00
800	7.25	64.0	113.6	29.02	10.97
850	7.30	61.0	106.0	27.91	8.47
900	7.11	62.6	111.4	27.37	10.81
950	7.18	63.0	117.8	27.72	10.06

1000	7.08	59.8	105.6	27.82	9.73

Table notes:
1. Horizontal beamwidth at 0° elevation angle.
2. Vertical beamwidth at 0° azimuth angle.



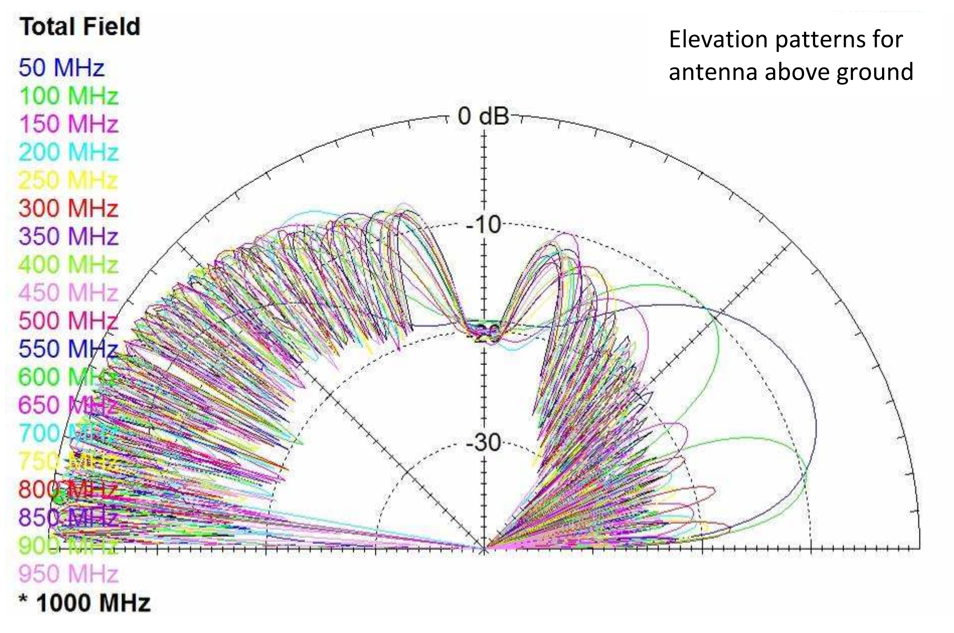
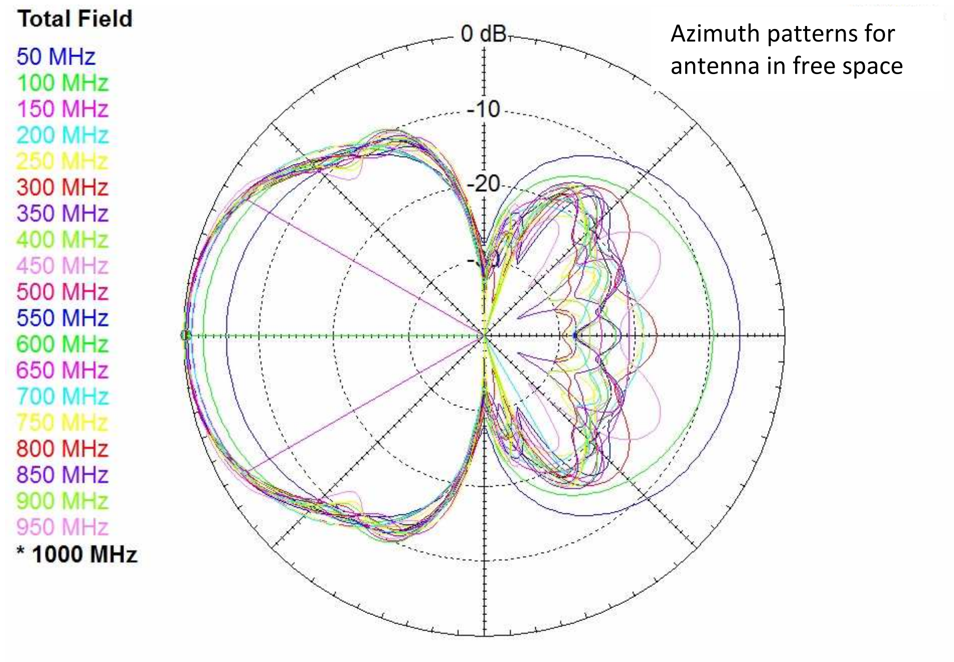


Figure 4-1 ~ Upper: Modeled free space elevation patterns at 50 MHz intervals from 50 to 1000 MHz for horizontally polarized CLP5130-2N antenna. Lower: Same antenna mounted 3 m above ground level showing that ground reflections add and subtract to the radio waves directly received by the antenna elements. The patterns are based on “average” ground characteristics, conductivity = 0.005 S/m and relative dielectric constant = 13.



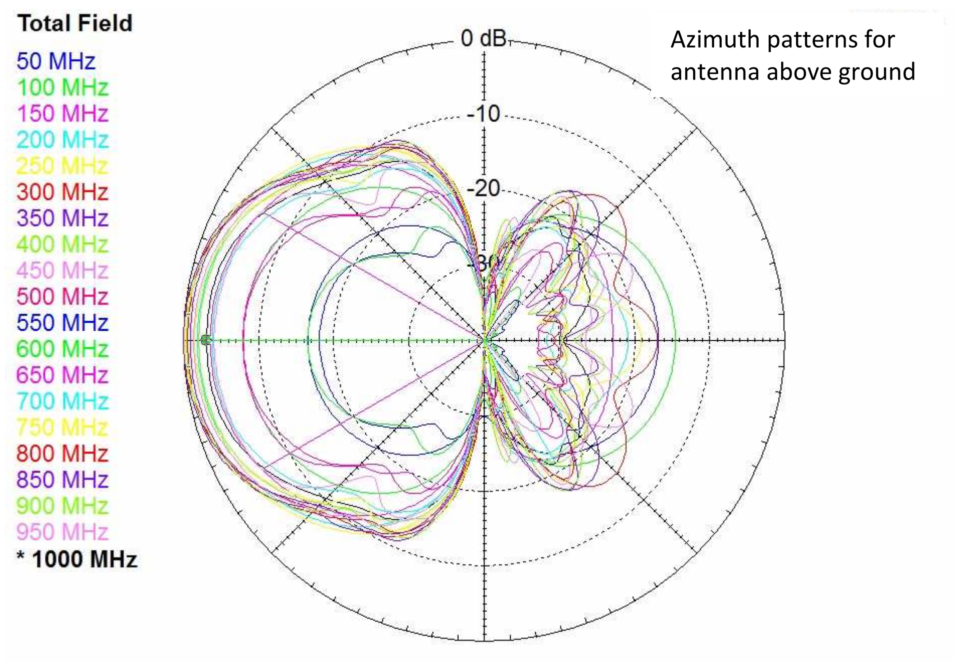


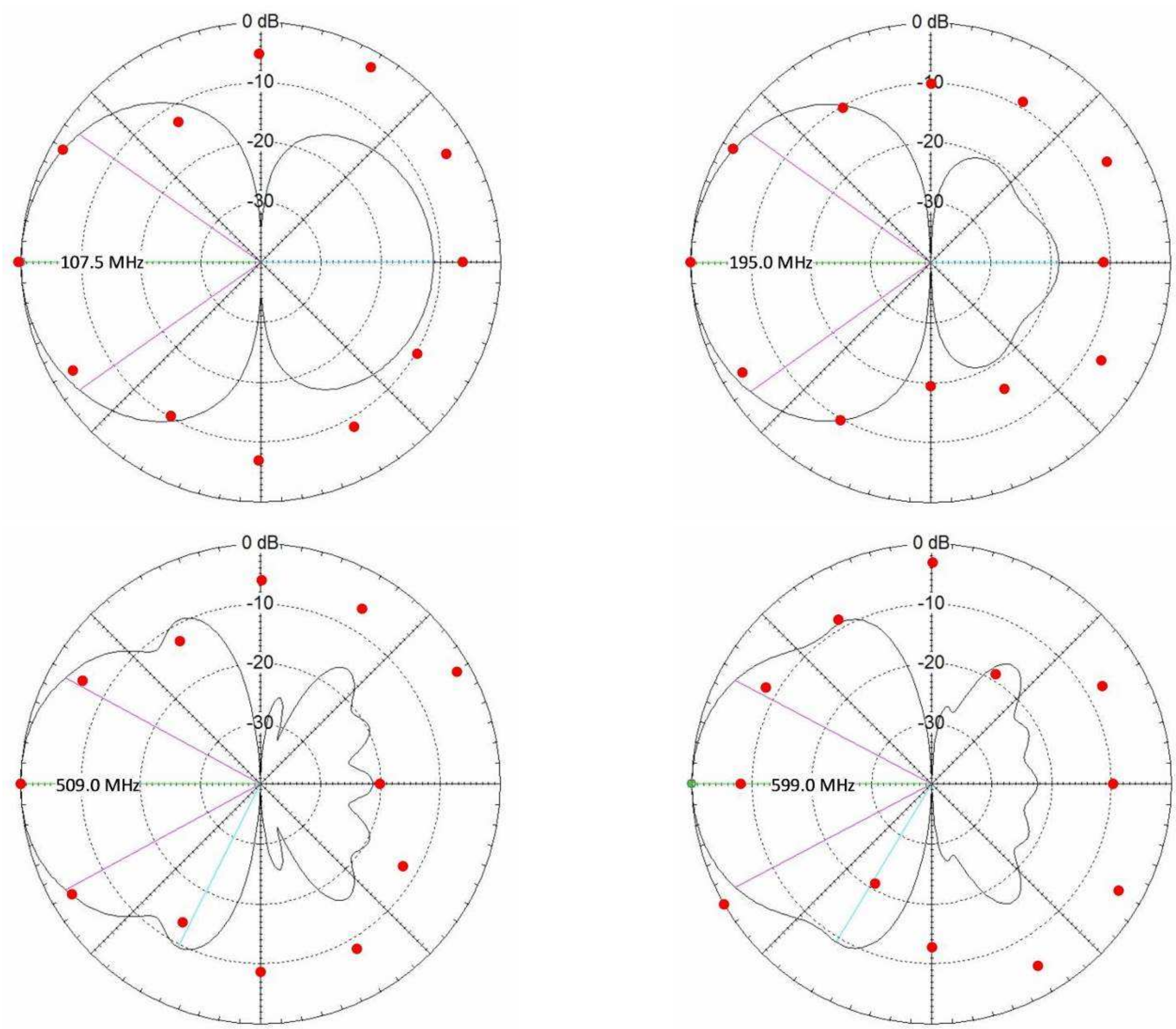
Figure 4-2 ~ Upper: Modeled CLP5130-2N azimuth patterns for installation in free space. Lower: Azimuth pattern at 5 degrees elevation for the same antenna mounted 3 m above ground level. The wide variations in gains are due to reflections from the ground.

Front-to-back ratios: Front-to-back ratio is the ratio of forward gain to rearward gain (180° azimuth). An antenna with high front-to-back ratio is useful for limiting interference that comes from behind the antenna. However, often the interference comes from other directions. A more useful indication of antenna response from directions other than directly in front of the antenna is the front-to-sidelobe ratio. Front-to-sidelobe ratio is the ratio of the peak mainlobe gain to the gain of the lobe with the second highest gain. Sidelobes are easily seen by examining the patterns.

Field measurements: The ideal results from antenna modeling can be verified only by field measurements. However, because of trees and buildings, the site I used for pattern measurements has too much multipath interference and foliage attenuation to be of any real use for measurement purposes (figure 4-3). Nevertheless, I made the measurements anyway to get an idea of how bad the site really is. For comparison, I also measured the pattern of a similar antenna (the CLP5130-1N) that is much higher and the results were much better. The CLP5130-1N model and measurements will be reported in a future paper.

For the pattern measurements described here, I used FM and television broadcast stations and cellular base stations as far-field sources in the 105 to 870 MHz frequency range. All power measurements were made with a Callisto solar radio spectrometer and the NF software tool (this tool was developed by Christian Monstein and I use it during manufacturer of Callisto instruments). I measured the received power at 30° intervals for a fixed elevation angle of 0° (figure 4-4).

Figure 4-3 ~ Antenna pattern measurement setup at an inadequate test site having a lot of foliage loss and multipath interference. The antenna was installed on a tripod and mast 5.3 m above ground level, and a compass was used to point the antenna to the station. The tripod was held down by a 23 kg lead weight. The mast was then rotated in 30° increments determined from a paper scale taped to the mast (inset at upper-left).



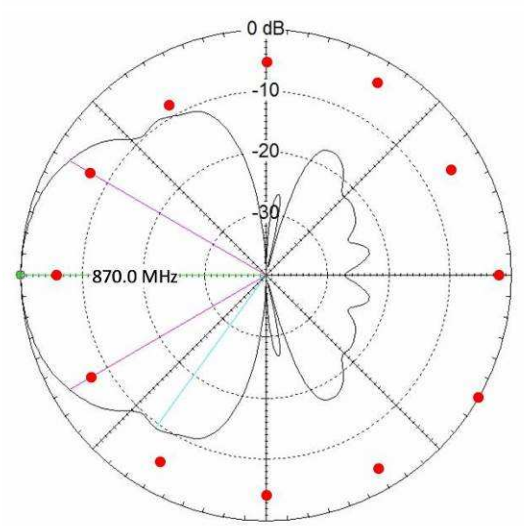
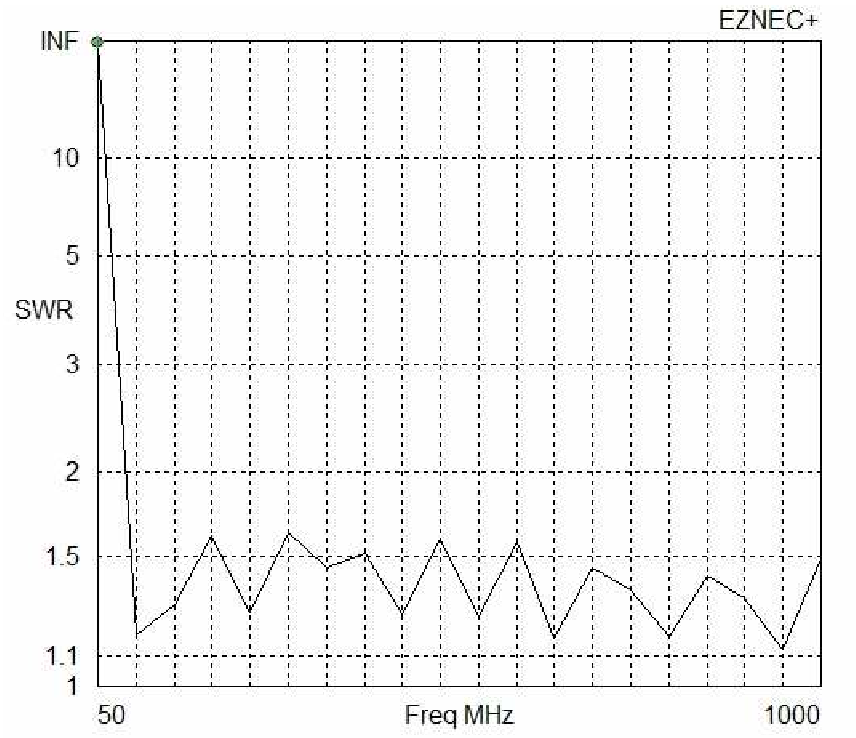
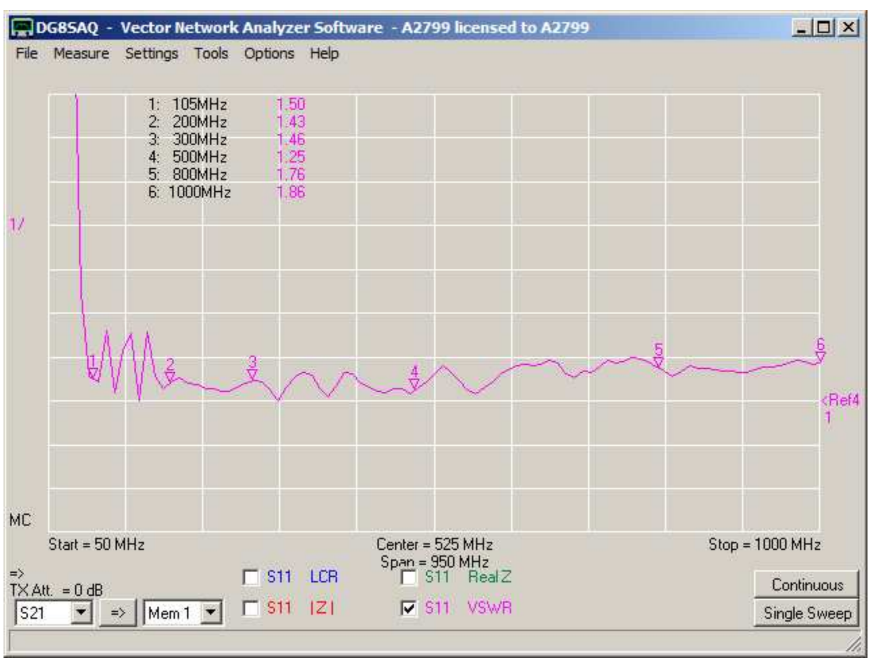


Figure 4-4 ~ Modeled and measured antenna patterns in the frequency range 105.7 to 870 MHz. The red dots are the measurement points. In all plots, the antenna azimuth is normalized to the direction of the radio source. The results are useless because of multipath and foliage loss.

VSWR: Voltage standing wave ratio indicates the degree of matching to a 50 ohm reference impedance. In practical work, a well-matched antenna provides 2:1 VSWR or better. VSWR measurements are easier than pattern measurements, and for these I used a vector network analyzer (VNA). The VNA was calibrated with a short interconnecting cable in-place to remove its effects from the measurements, and I pointed the antenna away from interference sources to reduce their influence on the VNA.

The VSWR calculated by the model followed very closely the measurements and also the VSWR chart provided in the antenna manufacturer's datasheet (figure 4-5). As with the patterns shown previously, the VSWR was calculated at 50 MHz to see how it looked. It is seen that the VSWR increases sharply at 50 MHz.





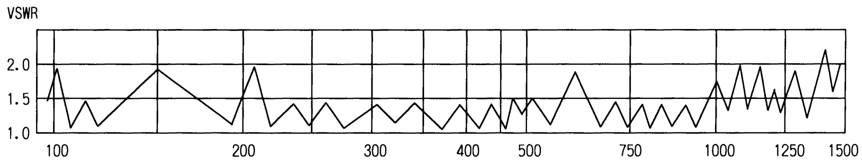


Figure 4-5 ~ Modeled (upper), measured (middle) and datasheet (lower) antenna VSWR relative to 50 ohms impedance from 50 to 1000 MHz. The model indicates the antenna VSWR ≤ 1.7:1. A DG8SAQ VNWA-3E vector network analyzer was used for VSWR measurements with the antenna mounted 5.3 m above ground level. The vertical scale on the VNWA-3E measurement plot is interpreted as follows: The reference position for 1:1 VSWR is shown on the right at the 3rd division from the bottom, and the 4th division is 2:1 VSWR. Markers tabulated at the top of the plot show the VSWR readings at various frequencies.

5. Conclusions

Log periodic antennas that use a structural boom transmission line and stepped elements are difficult to model and any model is a compromise. For the CLP5130-2N antenna described here, the structural transmission line is replaced by an ideal transmission line for modeling purposes. The model uses actual physical dimensions for the non-stepped dipole elements and adjusted (“corrected”) dimensions for the stepped elements.

The modeled VSWR, and thus the impedance, shows reasonably good agreement with measurements and manufacturer’s data. On the other hand, because of severe multipath and foliage at the test site, the measured antenna patterns show only casual agreement with the modeled patterns, but this is the fault of the test site and not the model. The modeled patterns, including front-to-back ratios, generally agree with the manufacturer’s data.

The antenna gains given in the manufacturer’s specifications apparently are peak values for an antenna within the influence of ground reflections. For heights greater than about 10λ, free space gain values about 5 to 6 dB lower are more appropriate but not given in the manufacturer’s data.

6. Ordering information

The CLP5130-1N (50 to 1300 MHz) and CLP5130-2N (105 to 1300 MHz) may be ordered at {Order}. .

7. References [ ] and internet links { }

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{ATLC2} http://www.hdtvprimer.com/KQ6QV/atlc2.html
{Creative Design} http://www.cd-corp.com/english/
{eCallisto} http://www.e-callisto.org/
{EZNEC} http://www.eznec.com/
{Order} http://www.reeve.com/Solar/e-CALLISTO/e-callistoOrderInfo.htm

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Document information

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