

Gain and Directivity Analysis of the Log Periodic Antenna

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Abstract: *In telecommunication, a log-periodic antenna is a broadband, multi element, directional, narrow-beam antenna that has impedance and radiation characteristics that are regularly repetitive as a logarithmic function of the excitation frequency. The lengths and spacing of the elements of a log-periodic antenna increase logarithmically from one end to the other. This antenna design is used where a wide range of frequencies is needed while still having moderate gain and directionality. In this paper the directivity, electric field, gain and axial ratio were investigated and analyzed by using twelve elements with spacing factor of 0.7 and wavelength of 6m, where the directivity and its gain were observed to be increasing when the elements of the log periodic antenna were increased at the active region of the RF.*

Keywords: log periodic antenna, directivity, gain, far field, electric field

1. Introduction

Compact, very low-cost printed antennas with both wideband and Omni-directional characteristics are desired in modern communications systems. Dipole antennas have been popular candidates in many systems for their uniform Omni-directional coverage, reasonable gain, and relatively low manufacturing cost. Despite the advantages mentioned above, dipole antennas suffer from relatively narrow bandwidth, about 10% for VSWR < 2:1. This bandwidth problem has limited their application in modern multi-band communication systems. In addition, nearby objects easily detune the dipoles because of the limited bandwidth of operation [1].

In modern telecommunication systems, antennas with wider bandwidth and smaller dimensions than conventional ones are preferred[2]. Log-Periodic antennas are designed for the specific purpose of having a very wide bandwidth. The achievable bandwidth is theoretically infinite; the actual bandwidth achieved is dependent on how large the structure is (to determine the lower frequency limit) and how precise the finer (smaller) features are on the antenna (which determines the upper frequency limit)[3].

In telecommunication, a log-periodic antenna (LP, also known as a log-periodic array or log periodic beam antenna/aerial) is a broadband, multi-element, directional, narrow-beam antenna that has impedance and radiation characteristics that are regularly repetitive as a logarithmic function of the excitation frequency. The individual components are often dipoles, as in a log-periodic dipole array (LPDA). Log-periodic antennas are designed to be self-similar and are thus also fractal antenna arrays [4]. Increasing number of log periodic fractal iteration reduces return loss, especially in higher frequencies, however, increases the antenna bandwidth [5]. The log periodic antenna is used in a number of applications where a wide bandwidth is required

along with directivity and a modest level of gain. It is sometimes used on the HF portion of the spectrum where operation is required on a number of frequencies to enable communication to be maintained. It is also used at VHF and UHF for a variety of applications, including some uses as a television antenna [6].

2. Concepts and Theory of the Log Periodic Antenna

The lengths and spacing of the elements of a log-periodic antenna increase logarithmically from one end to the other. This antenna design is used where a wide range of frequencies is needed while still having moderate gain and directionality[4]. The successive dipoles are connected alternately to a balanced transmission line called feeder. That is to say these closely spaced elements are oppositely connected so that endfire radiation in the direction of the shorter elements is created and broadside radiation tends to cancel. Actually, a coaxial line running through one of the feeders from the longest element to the shortest is used. The center conductor of the coaxial cable is connected to the other feeder so that the antenna has its own balun [7].

Radiation energy, at a given frequency, travels along the feeder until it reaches a section of the structure where the electrical lengths of the elements and phase relationships are such as to produce the radiation. As frequency is varied, the position of the resonant element is moved smoothly from one element to the next. The upper and lower frequency limits will then be determined by lengths of the shortest and longest elements or conversely these lengths must be chosen to satisfy the bandwidth requirement. The longest half-element must be roughly 1/4 wavelength at the lowest frequency of the bandwidth, while the shortest half-element must be about 1/4 wavelength at the highest frequency in the desired operating bandwidth[8]



Figure 1: Diagram showing the log periodic antenna[9]

It is possible to explain the operation of a log periodic array in straightforward terms. The feeder polarity is reversed between successive elements. Take the condition when this RF antenna is approximately in the middle of its operating range. When the signal meets the first few elements it will be found that they are spaced quite close together in terms of the operating wavelength. This means that the fields from these elements will cancel one another out as the feeder sense is reversed between the elements. Then as the signal progresses down the antenna a point is reached where the feeder reversal and the distance between the elements gives a total phase shift of about 360 degrees. At this point the effect which is seen is that of two phased dipoles. The region in which this occurs is called the active region of the RF antenna. Although the example of only two dipoles is given, in reality the active region can consist of more elements. The actual number depends upon the angle α and a design constant. The elements outside the active region receive little direct power. Despite this it is found that the larger elements are resonant below the operational frequency and appear inductive. Those in front resonate above the operational frequency and are capacitive. These are exactly the same criteria that are found in the Yagi. Accordingly the element immediately behind the active region acts as a reflector and those in front act as directors. This means that the direction of maximum radiation is towards the feed point[6].

Consider the figure below showing the schematics of the logarithmic periodic dipole antenna with The lengths of the dipole elements, the spacing from the virtual apex to the dipole elements, the wire radius of the dipole elements, the spacing between the quarter wave-length dipoles are proportional with the geometric scale factor, τ , which is always smaller than 1.[10]

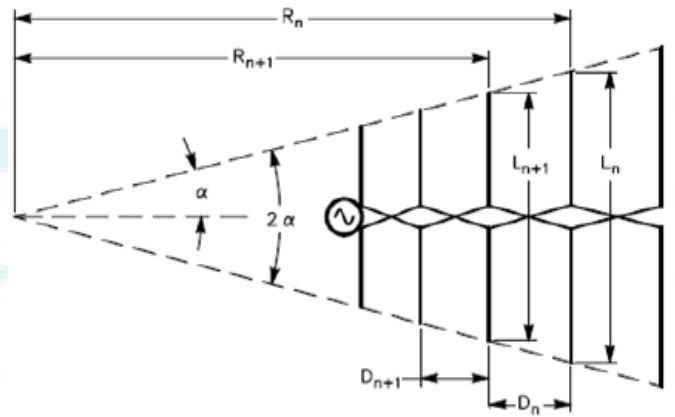


Figure 2: Showing the schematic of the log periodic dipole antenna with its dimensions [10]

$$\tau = \frac{R_{n+1}}{R_n} = \frac{D_{n+1}}{D_n} = \frac{L_{n+1}}{L_n} \quad (1)$$

$$\sigma = \frac{1-\tau}{4 \tan \alpha} = \frac{D_n}{2L_n} \quad (2)$$

$$\alpha = \tan^{-1} \left[\frac{1-\tau}{4\sigma} \right] \quad (3)$$

Where:

τ = Geometric scale factor < 1

σ = Spacing factor, which relates distance between two adjacent elements with the length of the larger element

L = Length of the dipole

D = Spacing between the dipoles elements

R = Distance from apex to the dipole elements

α = Half of the apex angle

It is called logarithm periodic dipole antenna because of the ratio of the frequency as frequency (f) is the reciprocal of period (T) and from the following relation:

$$\frac{f_{n+1}}{f_n} = \frac{D_{n+1}}{D_n} = \frac{R_{n+1}}{R_n} = \frac{L_{n+1}}{L_n} = \tau ;$$

Taking logarithm base 10 both sides it will become:

$$\log\left(\frac{f_{n+1}}{f_n}\right) = \log\left(\frac{D_{n+1}}{D_n}\right) = \log\left(\frac{R_{n+1}}{R_n}\right) = \log\left(\frac{L_{n+1}}{L_n}\right) = \log(\tau) \quad (4)$$

For electric and magnetic field intensities, the following equations serves for the purpose of reaching the directivity and the gain of the log periodic antenna:

The electric field intensity:

$$E_{\theta} \approx \frac{jnI_0 e^{j\beta r}}{2\pi r} \left(\frac{\cos(\beta l \cos\theta) - \cos(\beta l)}{\sin\theta} \right) \quad (5)$$

Where:

E_{θ} = Electric field intensity

$$n = \text{Intrinsic impedance} = \sqrt{\frac{\mu}{\epsilon}} = 120\pi \sqrt{\frac{\mu_0}{\epsilon_0}}$$

β = phase constant or wave number = $2\pi/\text{wavelength}$

r = radius

I_0 = Maximum possible current

l = length of the monopole antenna

Magnetic field intensity of the antenna is given by:

$$H_{\theta} = \frac{E_{\theta}}{n} = \frac{jI_0 e^{j\beta r}}{2\pi r} \left(\frac{\cos(\beta l \cos\theta) - \cos(\beta l)}{\sin\theta} \right) \quad (6)$$

The average power density also known as Poynting vector is given by:

$$S_{av} = \frac{1}{2} \hat{r} \times R_e \left(E_{\theta} \times H_{\theta}^* \right) = \hat{r} \frac{nI_0^2}{8\pi^2 r^2} \left(\frac{\cos(\beta l \cos\theta) - \cos(\beta l)}{\sin\theta} \right)^2 \quad (7)$$

Finally the radiation intensity is found from the following relation:

$$U = r^2 \times S_{av} = \frac{nI_0^2}{8\pi^2 r^2} \left(\frac{\cos(\beta l \cos\theta) - \cos(\beta l)}{\sin\theta} \right)^2 \quad (8)$$

Directivity is found by

$$D = \frac{4\pi U(\theta, \phi)}{\int_0^{2\pi} \int_0^{\pi} U \sin\theta \, d\theta \, d\phi} \quad (9)$$

Where U= radiation intensity found on equation (8) above.

3. Methodology

A log periodic antenna was constructed by using FEKO simulator software with the number of elements being twelve and an operating frequency of 50MHz and the geometric scale factor of 0.93 with the spacing factor of 0.7, the wavelength of 6m and these parameters together with others were simulated in FEKO software and the element during construction looks like in the following figure were twelve elements are clearly seen in the blue and red color and placed in the x-plane.

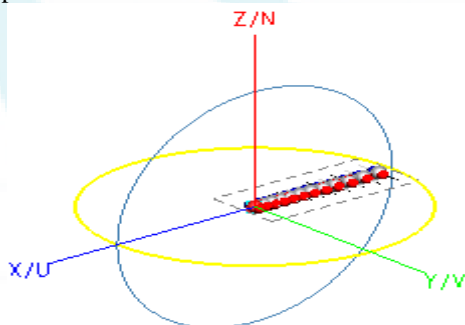
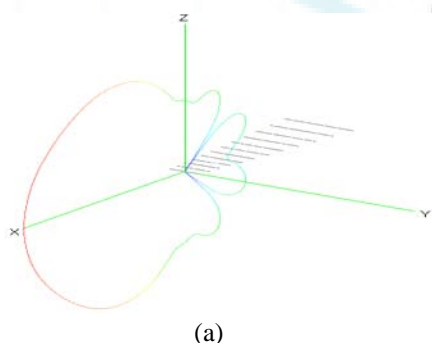


Figure 3: Diagram of the log periodic dipole antenna after being meshed



(a)

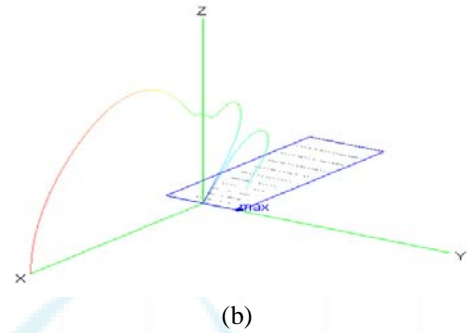


Figure 4: (a) 3D full (b) 3D Cut plane Diagrams of the directivity with the elements in the X-plane

As it can be seen in those diagrams under this section of methodology the directivity vary according to the number of elements the log periodic antenna have, so the more number of the elements at an operating frequency of 50MHz, the greater the directivity is which eventually causes an increase in the appreciable gain.

4. Results and Discussion

The following results were obtained after careful simulations using FEKO software in which the number of dipole elements were clearly defined and spaced carefully and the whole antenna was operating at the frequency of 50MHz and the far field pattern is requested in the vertical plane ($\phi=0$ degrees, θ between -180 and 180 degrees in 2 degree increments).

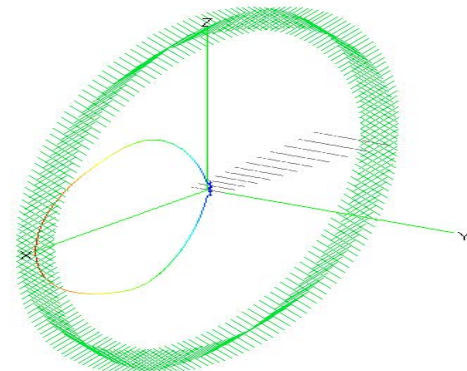


Figure 5: 3D Diagram of the requested far field of the electric field

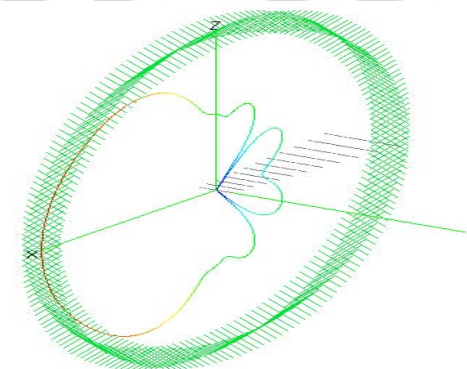


Figure 6: Requested far field 3D diagram of the gain

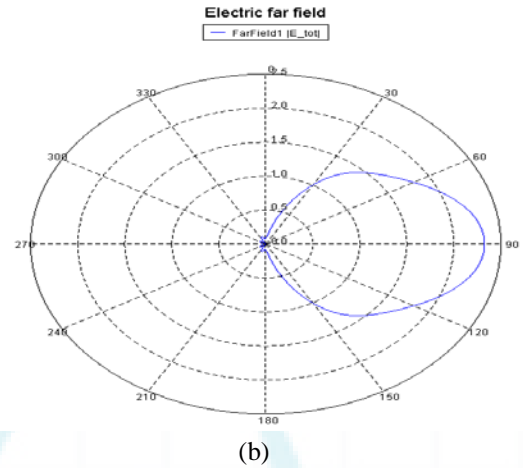
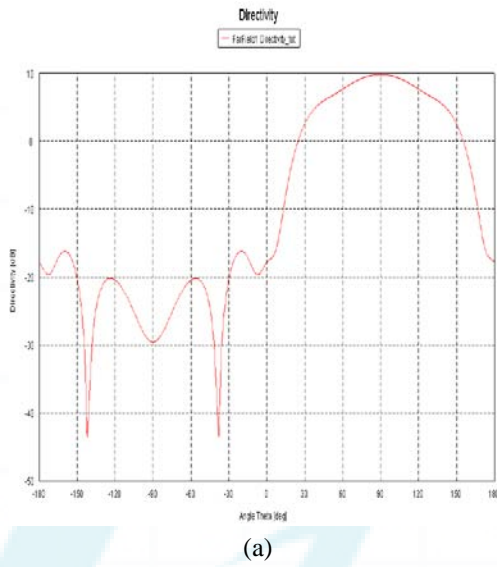


Figure 8: (a) Cartesian plot of the Electric field (b) Polar plot of the electric far field

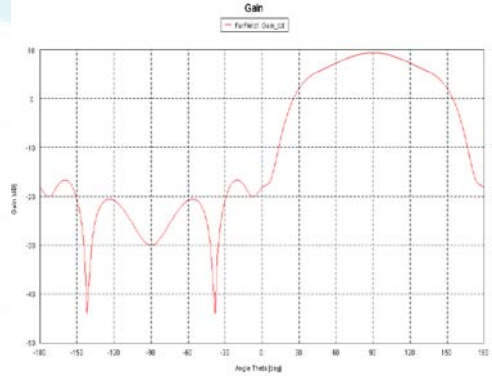
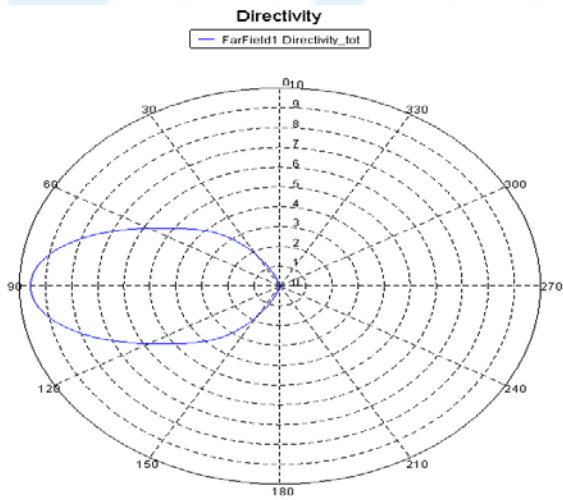


Figure 7: (a) A Cartesian graph of Directivity (b) Polar plot of Directivity

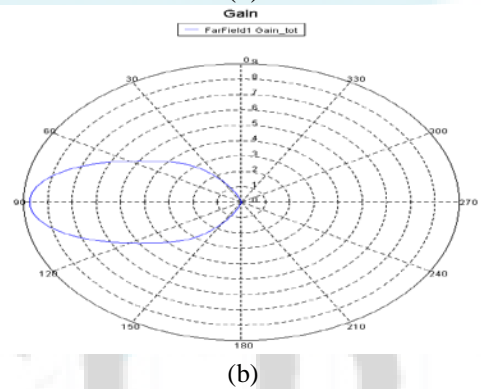
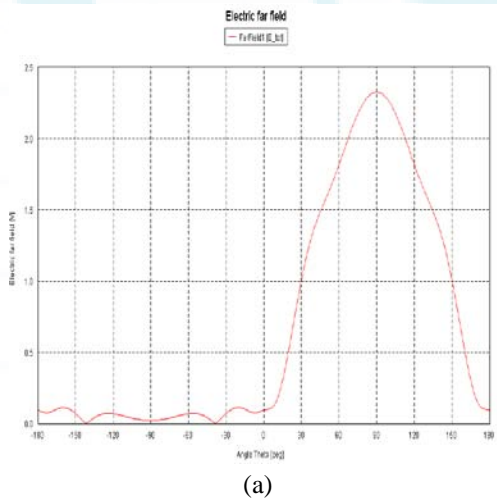


Figure 9: (a) Cartesian graph of the gain (b) Polar plot of the gain

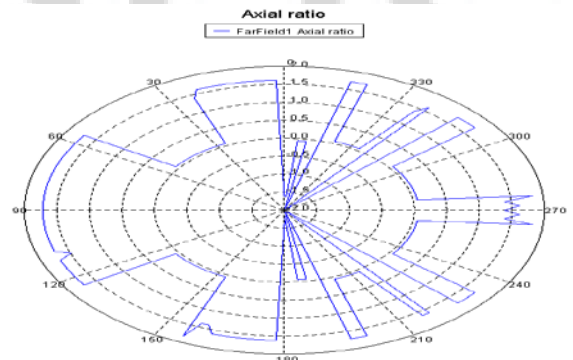


Figure 10: Far field axial ratio of the log periodic antenna

5. Conclusion

As observed in the results above, the active region occupied the twelve elements defined from the apex and that means that the direction of maximum radiation is towards the feed point where the maximum directivity and hence gain are observed. So the more number of elements towards the feed point of the active region of the RF, then the maximum directivity and hence gain are obtained. Also it is observed that the actual number of elements in the active region of the RF depends solely on the angle of apex, the number of elements outside the active region (which means they are defined independently of the apex angle) receive low direct power and hence decreases its gain

6. Future Work

In the future; log periodic antenna must be designed in such a way that the apex angle should cover the maximum active region of the RF for many number of log periodic elements so as to improve its gain and have maximum directivity.

7. Acknowledgement

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