Chapter 6

Simulation of Near Field and Far Field Radiation Patterns of a Novel LPDA at VHF Band

6.1 Introduction

In the present chapter the characteristics of the near and far field radiations of the Log Periodic Dipole Array antenna in the VHF range (50 MHz-300 MHz) have been examined and analyzed. The simulations of near as well as far field patterns for an LPDA made up of nine-dipoles are explained and described. The polar radiation patterns in the near and far field areas for various frequencies are computed as a function of angle. In near as well as in far fields the antenna is utilized to identify the radio frequency. The description and uses of near and far field have mainly been contemplated from the antenna measurement techniques. The study of the antenna in free space exhibits that the over estimation just takes place in the major lobe, whereas even underestimation can occur in all other directions. On regarding the consequences of other radiating elements in an array construction, it is seen that the effective near-field pattern of a single slot in the array is practicable. This field will be helpful in deduction of the effective far-field patterns of each and every array element consisting of the consequences of mutual coupling in the existence of other radiators.

These days due to the significance of ultra wideband (UWB) technology the use of ultra wideband antennas have enhanced. An enormous number of innovative UWB antenna designs are demonstrated in literature. In different near-field applications like sensing, product quality assessment, biomedical imaging, etc. such UWB antennas are utilized [1]. The attributes of antennas are described properly and can be estimated by well built measurement methods [1-4] both for the purposes of far-field applications including the line-of-sight applications for instance in radar systems, point-to-point communications, radio telescopes and also for the purpose of multipath environment resembling mobile and indoor communications etc[1]. The radiation plots of antenna are a considerable means for antenna designers and researchers. Antenna arrays have been utilized in numerous electromagnetic radiating systems to accomplish a good radiating effectiveness. As a consequence there is an enormous requirement of electromagnetic tools that can compute effectively the pattern performance of antenna array in a complex atmosphere. A sphere coordinate system (r, θ, φ) can be arranged by incorporating the origin on the middle of the antenna array. In different areas around the antenna, three diverse sorts of propagation models are to be employed. The first area is comparable to the near -field of a single antenna sub-element i.e. a pair of dipoles at r <<λ, the second to the junction between the far -field of each sub-element and the near-field of the whole antenna (r >>λ & r < 2D^2/λ), whereas the last is the far -
field area of the whole antenna \((r > 2D^2/\lambda)\). The formula used normally is \(L = 2D^2/\lambda\) in which \(D\) implies the greatest antenna measurement. The internal radius of the far-field is analogous to the Fraunhofer distance \(2D^2/\lambda\), wherein the antenna’s wavelength in free space and vital dimensions are implied by \(\lambda\) and \(D\). The investigational authentication of the antenna array’s radiation pattern needs the required measures in the far radiation field. Formula \(L = 2D^2/\lambda\) is generally utilized to ascertain the border between the far and near field radiation region. There is a decay of the electric and magnetic fields at an estimation of \(1/r\), where \(r\) denotes distance from the antenna in the far-field elongating to infinity.

Due to a lot of requirements and purposes that necessitate a broad bandwidth to transmit or obtain radio signals, a novel category of antennas were built, which are also acknowledged as “Frequency Independent Antennas” [5]. The LPDA is regarded to be most essential, in the class of frequency independent antennas. This kind of antenna is categorized as frequency independent because the antenna pattern and input impedance alter insignificantly over a range of frequencies in the designed bandwidth [6]. The structure of the LPDA is selected in such a way that the electrical attributes should recur periodically with the logarithm of the frequency. Nowadays logarithmically periodic antennas have been extensively utilized because of their frequency response features, easiness of design and directivity. The log-periodic principle was founded in the late 1950s [7]. The former eminent practical design of LPDA was presented by Carrel in the year 1961 [8]. Techniques of designing and examining essential LPDA geometry have been discussed in detail by Carrel and Peixeiro [6]. For a lengthy period the LPDA arrangement has been employed in VHF and UHF communications [9]. LPDA is an important kind of antenna with a linear polarization with wideband and moderate gain [10]. The LPDA gives a linearly polarized and directive radiation pattern throughout a wide frequency range. LPDAs have many benefits, like directive radiation pattern, linear polarization and low cross polarization ratio over a broad frequency band [11,12]. The fundamental design is founded on Carrel’s conception [8]. Design formulas comprise of two vital factors i.e. \(\tau\) and \(\sigma\), which was established by Peixeiro design curves [6]. The three design parameters necessitated for creating LPDA are geometric ratio \(\tau\), angle factor \(\alpha\) and spacing factor \(\sigma\). The geometric ratio \(\tau\) and spacing factor \(\sigma\) may be simply established according to the needed directivity. The geometric ratio finds out the length and resonant frequency of each dipole element. The spacing factor \(\sigma\) describes the severance between the dipole elements so as to attain required bandwidth and gain. LPDAs [5] not only have wide bandwidth but also reasonable gain and uniform radiation patterns. Recently, LPDA is utilized as the elementary receiving element which almost has a continuous coverage over an enormous range of frequencies. In this design, the spacing and scaling factors \(\sigma\) and \(\tau\) were selected as 0.13 and 0.78.
6.2 Analysis of the Fields

In the modern days with the discovery of supercomputers as well as properly investigated and precisely examined softwares, theoretical analysis of the fields have been made more practicable. The fields are divided into three classes depending upon their alteration as a function of distance. The electrostatic field is the field which alters as $1/r^3$. As its amplitude diminishes quickly as a function of distance this field is foremost in the close neighbourhood of the dipole [13, 14]. Similarly, the radiation field is that field which changes as $1/r$. The radiation field stretches over the longest distance from the antenna and is liable for the radiation of power from the antenna. The electrostatic field and the frequency are related to each other inversely. As the current’s frequency proceeds to zero, this field also shifts to infinity.

This field is basically because of the gathering of charges on the top of the antenna. The opposite charges are gathered at the apex of the antenna creating a dipole on the flow of the current in the dipole. On the reversal of the current (each half cycle) the dipole reverses its polarity producing an oscillating dipole which creates the electrostatic field. With the reduction in frequency, the gathered charge for specified current increases and so the electrostatic field also enhances. This name is given to the field because it exhibits similar performance like that of a magnetic field achieved from the Biot-Savart law. As the radiation field is proportional to the frequency so the field is almost absent at low frequencies. This field is fundamentally a high frequency event. The electrostatic and the induction fields are together known as the near fields, and the radiation fields are named as the far fields. At a distance of $1/\beta = \lambda/2\pi \approx \lambda/6$ all the three fields mentioned above are equivalent in consequence.

It is seen that the distance within $\lambda/6$ and the distance $\geq \lambda/6$ are identified as the near as well as the far-field zone respectively. To obtain the given outcomes, the process mentioned below is proposed to the designer to comprise the mutual coupling effects in infinite array antenna design.

1. Compute the effective near-field of a sample element in the existence of remaining elements. In the case of finite arrays it should be done for each and every element. It will consist of mutual coupling effect of the elements left behind in the array [15].
2. An effectual far-field pattern of the element which also displays mutual coupling effects can also be obtained by utilizing the results of the near-field pattern.
3. The final pattern can also be determined by utilizing the efficient far-field pattern as well as the array factor of an array set up. This method will effect in total far-field patterns with more resemblance to actual determined patterns of the array.

The near-field values of electric field are calculated all along the identical axes as in the study of free space. Some rules should be accepted for EM near-field estimation, for e.g. in case of the illustrated antenna configuration nulls must be totally ignored in the near-field assessment because it would practically be improbable to correctly examine and investigate each and every possible circumstance. Because of installation
ambiguity, protective envelope may be employed in place of radiation pattern, for electromagnetic field assessment beyond the major lobe. To precisely evaluate an antenna’s far zone performance, the divergence of the phase of the field across its aperture must be limited. As the dimensions must simulate the functioning condition, it is essential to find out the minimum distance between the transmitting antenna and the receiving antenna for a right estimation of the far-field region’s radiation patterns. In order to attain good near-field results, the test method must preserve an internal sampling criterion of $\lambda/2$ and adequate scan area.

6.3 Near Field and Far Field Measurement

The antennas using ultra wide band technology over a broad bandwidth have attracted a huge concern in the discipline of telecommunication. It is observed that throughout the previous decades an extensive amount of effort has been committed in illustrating radiating methods [16]. It is seen that these methods are significantly used in the frequency domain to explain the near and far fields or in computing the radiation pattern at a single frequency employing the near-field data. The radiation pattern of an antenna is one of its most vital differentiating factors. The radiation patterns of an antenna under test are computed by utilizing the techniques such as far-field, compact range, or near-field [17, 18]. The accuracy of an antenna’s working effectually determines the antenna on a near or far-field.

Moreover it is also observed that it is possible in a far-field region to determine directly the radiation pattern of the antenna. By means of a near-field to far-field transformation [19] of determined near-field information it is probable for anyone to acquire the radiation pattern. Though it is known that near-field ranges usually need additional calculation and correct amplitude and phase measurements, near-field ranges are often favoured to a far-field range as they are packed and less susceptible to matters of multipath. It is seen that in many instances far-field ranges are desired for antennas with lower frequency as well as in those cases in which simple pattern measurements are needed. On the other hand, near-field ranges are a good preference for higher frequency antennas and where entire pattern and polarization dimensions are necessitated. In recent times near-field methods are extensively applied for the examination of modern generation radiating techniques, as they make it probable to achieve minute information on the attributes of antennas with high performance. The near-field measurements give a speedy and precise method of ascertaining the antenna gain, radiation pattern, polarization, beam pointing and so on [20].

The near-field estimation method which is useful in transforming those measurements into the far-field result with the assistance of a Fourier transform is utilized in determining the energy in the near-field region which is seen to radiate [21]. The true far field can be acquired with the help of the fact that antenna radiation can be expressed forever in terms of expansion of spherical wave functions which fulfils Maxwell's equations. So as to completely describe the far-field radiation characteristics
of antennas, one of the two diverse Spherical Near-Field (SNF) configurations may be utilized. The method of phi-over-theta SNF technique permits us to describe antennas over a full sphere utilizing an incorporation of theta, phi and polarization axes. A second SNF configuration is obtainable in the chamber to permit assessment of larger antennas, antennas possessing gravitational susceptibilities and antennas performing at smaller than 1 GHz frequency. In our times near-field measurement methods in association with near-field to far-field conversion algorithms are seen to be utilized extensively. The degree of accuracy attained and the duration of measurement are the two most significant matters for the near-field measurements of antenna.

6.4 Analysis of Field Pattern

On each dipole element in the LPDA antenna the feed point current $I_{n,f}$ is induced. Here $n$ represents the $n^{th}$ dipole and $f$ indicates the frequency. The expression [10] given below determines every current $I_{n,f}$ in the electric fields of the far zone

$$E_\theta = \frac{j\eta I_{n,f}}{4\pi x_n} \left[ \frac{\cos\left(\frac{kL_n}{2}\cos \theta\right) - \cos \frac{kL_n}{2}}{\sin \theta} \right] \times \left[ \frac{1}{\sin \left(\frac{kl_n}{2}\right)} \right]$$

(6.1)

The length of the $n^{th}$ dipole and the physical distance between the $n^{th}$ dipole and the view point are represented by $L_n$ and $x_n$ respectively. By the help of this expression the far zone electric field which is obtained from every distinctive element in the array is acquired at a specific view point for a particular frequency value. The entire far zone electric field is subsequently acquired as the superposition of each far zone electric field [22]. To acquire the time domain signal monitored at that particular far-field point, this frequency domain determination is reiterated for sufficient frequency points to find out the frequency interval and to get the outcomes an inverse Fourier transform is beneficial [23]. It is also noticed that the $n^{th}$ radiating element having length $L_n$, component $E_\theta$ in the electric field at the frequency $f$ is influenced by $I_{n,f}$ and also $f$. The frequency $f_n$ is selected where $E_\theta$ is made maximum at the significant and predominant frequency of the $n^{th}$ element.
6.5 Far Field Patterns of Log Periodic Antenna

![Figure 6.1 Finite dipole geometry](image)

The above Figure 6.1 illustrates the distribution of current on the dipole elements, which are presumed to be center-fed and we can write it as in equation (6.2). In equation (6.2), $I_m$ and $k$ signify the amplitude of the current distribution and a constant. This constant $k$ equals to the free space propagation constant.

\[
I\left(x = 0, y = 0, z'\right) = \begin{cases}
\hat{\alpha}_z \cdot I_m \sin \left( k \left( \frac{L}{2} - z' \right) \right) & 0 \leq z' \leq \frac{L}{2} \\
\hat{\alpha}_z \cdot I_m \sin \left( k \left( \frac{L}{2} + z' \right) \right) & -\frac{L}{2} \leq z' \leq 0
\end{cases}
\]

Equation (6.3) expresses the $E$ field of a single dipole element as

\[
E_{em} = j\eta \frac{(I_m)_n e^{-jkn}}{2\pi r_n \sin \left( k \frac{L_n}{2} \right)} \left[ \cos \left( \frac{kL_n}{2} \cos \theta \right) - \cos \left( \frac{kL_n}{2} \right) \right]
\]

In equation (6.3), the numerator, $r_n \approx r - R_n \sin \theta$, states the far-field for phase terms and the denominator $r_n \approx r$, roughly illustrates the far-field for amplitude terms. By replacing the equality and approximation in equation (6.3), we obtain equation (6.4).
\[ E_{tn} = \frac{e^{-jkr}}{r} \cdot \frac{j\eta}{2\pi \sin(k\frac{L_a}{2})} \left( I_m \right)_n e^{jkRn\sin\theta} F_n(\theta) \]  

(6.4)

In the above equation (6.4), \( F_n(\theta) \) can be written as

\[
F_n(\theta) = \left[ \frac{\cos \left( \frac{kL_a \cos \theta}{2} \right) - \cos \left( \frac{kL_a}{2} \right)}{\sin \theta} \right]
\]

Figure 6.2 A larger view of Figure 6.1 where dipoles are plotted in XZ plane

Equation (6.4) represents \( E_{\theta n} \) of a single dipole. Figure 6.2 exhibits a larger view of Figure 6.1 where dipoles are plotted in XZ plane. The entire E-plane pattern of LPDA comprising of \( N \) dipoles is described in equation (6.5).

\[ E_{\theta} = \frac{e^{-jkr}}{r} \cdot \frac{j\eta}{2\pi \sin(k\frac{L_a}{2})} \sum_{n=1}^{N} \left( I_m \right)_n e^{jkRn\sin\theta} F_n(\theta) \]  

(6.5)

E-plane is the XZ plane where \( \phi \) is equivalent to zero considered in Figure 6.1. The plane where electric field lines take place is called the E-plane of an antenna.

6.5.1 Generalization for the Far-Fields of the Antenna

Figure 6.3 Illustration of the direction of LPDA on the cartesian coordinate system
Figure 6.3 illustrates the direction of LPDA on the cartesian coordinate system. With reference to Figure 6.3, we can write the following equations:

\[
F_{\text{ant}(\theta, \phi)} = \frac{j\eta}{2\pi \sin(k \frac{L_n}{2})} e^{-jk r} \sum_{n=1}^{N} (I_m)_n e^{+jk r} F_n(\theta, \phi) \tag{6.6}
\]

\[
F_n(\theta, \phi) = \left[ \cos\left(\frac{kl_n \cos \theta}{2}\right) - \cos\left(\frac{kl_n}{2}\right) \right] \sin \theta
\]

Taking \(\mathbf{n}' = R_n \hat{a}_x\) and according to the principle of rectangular to spherical transformation we get, \(\mathbf{r} = \sin \theta \cos \phi \hat{a}_x + \sin \theta \sin \phi \hat{a}_y + \cos \theta \hat{a}_z\).

Finally, \(F_{\text{ant}(\theta, \phi)} = \frac{j\eta}{2\pi \sin(k \frac{L_n}{2})} e^{-jk r} \sum_{n=1}^{N} (I_m)_n e^{+jk R_n \sin \theta \cos \phi} F_n(\theta, \phi) \tag{6.7}\)

E and H plane patterns are got by equation (6.7). It has been stated before that the E-plane in which the electric field lines are seen is the XZ plane where \(\phi\) is equal to zero. H-plane stands for XY plane wherein \(\theta\) equals zero. Figure 6.4 can be employed to get the far-field approximation for finding out the H plane pattern of the LPDA. In the numerator, \(r_n \approx r - R_n \sin \phi\), expresses the far-field approximation for phase terms and in the denominator, \(r_n \approx r\), illustrates the far-field approximation for amplitude terms [24]. Thus equation (6.8) given below signifies the H-plane pattern

\[
E_\phi = \frac{e^{-jk r}}{r} \frac{j\eta}{2\pi \sin(k \frac{L_n}{2})} \sum_{n=1}^{N} (I_m)_n e^{+jk R_n \cos \phi} F_n(\theta, \phi) \bigg|_{0=90^\circ} \tag{6.8}
\]

In the above expression of equation (6.8), \(F_n(\theta, \phi)\) is denoted by the following equation

\[
F_n(\theta, \phi) \bigg|_{0=90^\circ} = \left[ 1 - \cos\left(\frac{kl_n}{2}\right) \right]
\]

Figure 6.4 A larger view of Figure 6.1 where dipoles are plotted in XZ plane.
6.6 Simulation Results

The time-shared LPDA has been constructed in the Department of Physics of Kalyani University, Kalyani (22.98°N, 88.46°E) situated in the state of West Bengal [25]. The important advantage of LPDA is that in the frequency range its functioning may be efficiently independent of frequency with radiation pattern and therefore the gain. The LPDA has excessive front-to-back ratio and directivity throughout an extensive range of frequencies [26]. Steady radiation patterns are ascertained by performing experiments in the total operational frequency ranges [27]. In this chapter the analysis of simulated performance of the near and far field patterns as well as the alteration of electric field of LPDA within 50MHz -300MHz are noted [28]. Similarly the total field radiation patterns along with the alteration of gain of the LPDA between 50MHz -300MHz are also studied. Figure 6.5 and Figure 6.6 show the alteration of the near-field as well as the far-field radiation patterns at various frequencies. Figures 6.7 and 6.8 illustrate the alteration of electric field with azimuth angle at diverse frequencies for near and far field pattern analysis respectively. It is seen that Figure 6.9 shows the alteration of total field radiation patterns at different frequencies while Figure 6.10 presents a few fascinating characteristics which describes the variation of gain with azimuth angle.
Figure 6.5 The variation of near field pattern at frequencies of: (a) 50 MHz (b) 100 MHz (c) 150 MHz (d) 200 MHz (e) 250 MHz (f) 300 MHz, respectively
Figure 6.6 The variation of far field pattern at frequencies of: (a) 50 MHz (b) 100 MHz (c) 150 MHz (d) 200 MHz (e) 250 MHz (f) 300 MHz, respectively
Figure 6.7 The variation of electric field with azimuth angle corresponding to: (a) 50 MHz (b) 100 MHz (c) 150 MHz (d) 200 MHz (e) 250 MHz (f) 300 MHz for near field pattern analysis
Figure 6.8 The variation of electric field with azimuth angle corresponding to: (a) 50 MHz (b) 100 MHz (c) 150 MHz (d) 200 MHz (e) 250 MHz (f) 300 MHz for far field pattern analysis
Figure 6.9 The variation of total field pattern at frequency of: (a) 50 MHz (b) 100 MHz (c) 150 MHz (d) 200 MHz (e) 250 MHz (f) 300 MHz, respectively
Figure 6.10 The variation of gain with azimuth angle corresponding to: (a) 50 MHz (b) 100 MHz (c) 150 MHz (d) 200 MHz (e) 250 MHz (f) 300 MHz for total field pattern analysis

6.7 Conclusion

The EZNEC software is very effectual in optimizing the length of the dipole elements and also in examining the performances of the antenna like radiation patterns and gain. The major beam points out the Z direction towards the apex of the antenna because of
the backfire radiation. So as to explain the facts of the radiation patterns the plots of the antenna are plotted in logarithm scale. It is observed that the radiation pattern of the LPDA appears to be almost frequency-independent in case of low frequencies whereas its radiation pattern depreciates in the way of greater frequency. In this chapter the simulation outcomes for radiation patterns in the far-field region are compared with the simulation results for radiation patterns in the near-field and an excellent uniformity between the two results is achieved. The authentication of the experiment regarding the radiation patterns of an antenna array needs the essential measurement in the far-field zone. The excellent accuracy acquired together in the reconstruction of the near-field and the far-field sets up the effectiveness of the methodology. The description of antenna radiation patterns by measurements in the near-field and a subsequent near-field far-field conversion needs correct amplitude and phase data. The far-field outlook can present a noticeable sort of important data for an antenna engineer or researcher. The built antenna attains excellent impedance matching and consistent magnetic field distribution in the area close to the antenna. The constructed antenna has accurate near-field and far-field performance for monitoring the solar activities. This antenna would be indispensable for recording solar radio observations due to its wideband operation, minimized cost, simple fabrication, and excellent radiation patterns. Here it is noticed that the consistency to the edge in reality gives further negative results in case of the side lobes.

References