DESIGN CONSIDERATION OF ARRAYS FOR THE STUDIES OF RADIATION PATTERN OF LOG PERIODIC DIPOLE ARRAY ANTENNA AT DIFFERENT FREQUENCIES

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Abstract

Log Periodic Dipole Array (LPDA), as the name suggests, comprised of two crossed logarithmic periodic dipole antennas, one arranged in north-south direction and the other in east-west direction. In this paper we have presented the analysis and simulation of Azimuth and Elevation patterns, with some significant antenna parameters (input impedance, VSWR, antenna gain, front to back ratio) of our simulated LPDAs (50-300 MHz and 50-500 MHz). We can conclude that LPDA antenna is the simplest antenna with reliable bandwidth and gain estimates, with precise directivity.

Keywords: LPDA, azimuth & elevation pattern, VSWR, design constants.

1. INTRODUCTION

In this paper we have look over the design consideration of antenna arrays for the study of radiation pattern of the antenna. For this it is required to specify the coordinate system and the related electromagnetic fields. The most normal coordinate system is the spherical coordinate system, comprised of a radial distance; an elevation angle and an azimuth angle because at a considerable distance from an antenna, the electromagnetic fields must inversely decay with radial distance from the antenna. The elevation angle, expressed as Θ, is the angle between a line drawn from the origin to the point and the z axis while the azimuthal angle, expressed as Φ, is considered as the angle between the projection of this line in the x-y plane and the x axis. For our analysis we choose two LPDAs with operating frequencies 50-300 MHz and 50-500 MHz.

2. LOG PERIODIC DIPOLE ARRAY

Log Periodic Dipole Array (LPDA) antennas are utilized in broadband communication in the VHF and UHF range and are usually used in case of wide band applications. LPDA antennas fall under the class of frequency independent antennas giving bandwidth more than 10:1. If the input impedance of a LPDA antenna is plotted as a function of frequency, it will be repetitive, even if it is plotted as a function of the logarithm of the frequency, it will be periodic with every cycle being exactly same to the previous one. Therefore the name log-periodic is given as the alterations are periodic with respect to the logarithm of the frequency. As the essential features of the antenna, i.e., the input impedance, the gain, etc., alter periodically in the logarithm of the frequency domain, this antenna is called as log-periodic array. For a specified frequency, the elements with lengths near to half wavelength resonate. The longest dipole resonates at the lowest frequency (fL) of operation and the shortest dipole resonates at the highest frequency (fH) of operation. To feed the LPDA, two wire transmission lines can be utilized. The terminals of the smallest dipole from the input point of the array and the two-wire transmission line joins all the other dipoles. It has been seen that maximum radiation along the direction of the smallest dipole as well as a good input match is attained if the feed line is criss-crossed between every dipole. This is shown in Figure 1. The spacing between the two wires changes all along the length of the feed line because of the criss-crossing and therefore the characteristic impedance of the feed line does not remain steady. At a specified frequency of operation in the LPDA, the dipole with length nearest to λ/2 becomes resonant. The longer dipole acts as a reflector whereas the shortest dipole acts as directors [1]-[4]. Moreover the phase reversal of currents in adjoining elements, finally results in highly directive broadside beam pattern appearing from the direction of the smallest element in the array. LPDA is of high directivity and high front-to-back ratio over a very wide frequency range. Front-to-Back (FB) ratio is the ratio of maximum forward to minimum rearward radiation and is normally measured in dB.
The LPDA is a coplanar linear array of progressively spaced dipoles of irregular heights. These dipoles are fed by a distorted balanced transmission line of distinctive impedance $Z_0$, which is loaded by termination impedance. The bandwidth of a LPDA is restricted by the size and figure accuracy of the elements and by the feed which combines concentrated radiation to the receiver. Only 2 or 3 are active at any specified frequency in the operating range though an LPDA consists of a huge number of dipole elements [5]-[8]. The electromagnetic fields created by these active elements add up to make a unidirectional radiation pattern, in which maximum radiation is off the small end of the array. The radiation in the reverse direction is usually 15 - 20 dB below the maximum. Figure 2 shows how the design constant $\tau$ varies with the relative spacing $\sigma$ between the dipole elements in a LPDA antenna [9]-[11].

3. PROPOSED ANTENNA SYSTEM

The design dimensions of the proposed LPDA antennas have been shown in Figure 3 and 4. It consists of a pair of pair of dipole elements connected in zigzag fashion and thus acts as a transmission line.
4. Design Steps

The LPDA comprises a system of driven elements, but only some elements in the system are active in a single frequency of operation. It can be operated over a range of frequencies depending upon its design parameters. The apex angle, \( \alpha \), including length and spacing factors \( \tau \) and \( \sigma \), give much of what one requires to design an LPDA. The scaling factor \( \tau \) is one of the most important parameter that expresses the LPDAs. The space between the elements decreases with increase in frequency. Moreover we should be cautious with the parameter \( \alpha \) because if it is set to a value which is too small or too large it will cause destruction of the impedance bandwidth of the antenna.

The design of the LPDA antenna is based on this characteristic and this feature allows alterations in frequency to be made without immensely affecting the electrical operation. Although \( \sigma \) can be used smaller than the optimum value of the \( \sigma \), \( \sigma_{opt} \), it should not be lesser than 0.05 as the front to back ratio diminishes and the directivity falls down quickly. If we choose \( \sigma \) greater than \( \sigma_{opt} \), side lobes are seen. The longest and the shortest dipole elements can be computed after determining \( \sigma \), \( \tau \) and \( \alpha \), bandwidth of the system . The lengths of the shortest and longest elements will then determine the upper and lower frequency limits. The characteristics of the LPDA antenna such as impedance, pattern, directivity, beamwidth, side lobe level at frequency \( f \) will be recurring at all frequencies given by \( \frac{f}{f_n} \) where \( n \) is integer. The variations between these frequencies are moderately small if \( \tau \) is not very far away from unity. When the frequencies (f, \( f_1 \), \( f_2 \), \( f_3 \)) are plotted on a logarithmic scale, they are uniformly spaced. Compared to the currents on the other elements the currents on the active elements are huge. As the elements with dimensions roughly half-wave lengths provide most of the radiation so the region where these elements take place is called “active region”. The active region moves from one group of elements to the next as the frequency alters from \( f_{min} \) to \( f_{max} \). The elements outside the active region do not contribute much radiation and moreover they act as parasitic elements [3, 4].

The specifications of the LPDA for calculating the length of the dipole from apex and element separation distance are presented in Table 1 while some of its physical properties are shown in Table 2.

**Table 1: Length of the dipole from apex and element separation distance**

<table>
<thead>
<tr>
<th>Length of the Dipole from Apex(cm)</th>
<th>Element Separation Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( D_{n,n+1} ) = Spacing between the nth and (n+1)th element</td>
</tr>
<tr>
<td>R1 61.36</td>
<td>D_{1,2} 17.31</td>
</tr>
<tr>
<td>R2 78.67</td>
<td>D_{2,3} 22.19</td>
</tr>
<tr>
<td>R3 100.86</td>
<td>D_{3,4} 28.45</td>
</tr>
<tr>
<td>R4 129.31</td>
<td>D_{4,5} 36.47</td>
</tr>
<tr>
<td>R5 165.78</td>
<td>D_{5,6} 46.76</td>
</tr>
<tr>
<td>R6 212.54</td>
<td>D_{6,7} 59.95</td>
</tr>
<tr>
<td>R7 272.49</td>
<td>D_{7,8} 76.85</td>
</tr>
<tr>
<td>R8 349.34</td>
<td>D_{8,9} 98.53</td>
</tr>
<tr>
<td>R9 447.87</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Length of the Dipole from Apex(cm)</th>
<th>Element Separation Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( D_{n,n+1} ) = Spacing between the nth and (n+1)th element</td>
</tr>
<tr>
<td>R1 33.14</td>
<td>D_{1,2} 7.31</td>
</tr>
<tr>
<td>R2 40.45</td>
<td>D_{2,3} 9.13</td>
</tr>
<tr>
<td>R3 49.58</td>
<td>D_{3,4} 11.42</td>
</tr>
<tr>
<td>R4 61</td>
<td>D_{4,5} 14.27</td>
</tr>
<tr>
<td>R5 75.27</td>
<td>D_{5,6} 17.8</td>
</tr>
<tr>
<td>R6 93.07</td>
<td>D_{6,7} 22.5</td>
</tr>
<tr>
<td>R7 115.57</td>
<td>D_{7,8} 27.8</td>
</tr>
<tr>
<td>R8 143.37</td>
<td>D_{8,9} 34.85</td>
</tr>
<tr>
<td>R9 178.22</td>
<td>D_{9,10} 43.57</td>
</tr>
<tr>
<td>R10 221.79</td>
<td>D_{10,11} 54.47</td>
</tr>
<tr>
<td>R11 276.26</td>
<td>D_{11,12} 68.07</td>
</tr>
<tr>
<td>R12 344.32</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2: Physical properties of the LPDAs**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Particulars</th>
<th>Specifications</th>
<th>Particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>50-300MHz</td>
<td>Frequency Range</td>
<td>50-500MHz</td>
</tr>
<tr>
<td>Polarization</td>
<td>linear</td>
<td>Polarization</td>
<td>linear</td>
</tr>
<tr>
<td>Number of dipoles</td>
<td>nine</td>
<td>Number of dipoles</td>
<td>twelve</td>
</tr>
<tr>
<td>half of the apex angle</td>
<td>22°</td>
<td>half of the apex angle</td>
<td>22.16°</td>
</tr>
<tr>
<td>Height</td>
<td>447.87cm</td>
<td>Height</td>
<td>344.32 cm</td>
</tr>
<tr>
<td>Width</td>
<td>364.94cm</td>
<td>Width</td>
<td>349.24 cm</td>
</tr>
</tbody>
</table>
5. Simulation Results

Figure 5 gives the illustration of our simulated LPDA antennas at 300 MHz and 500 MHz respectively. The antennas were simulated using EZNEC software and it was considered under free space. The simulated radiation pattern (electric and magnetic), VSWR, input impedance, gain and front to back ratio are illustrated in the Figures. The performance properties of the LPDA antenna were acquired with MATLAB simulations and it was regarded under free space. The inputs for the program are Tau, sigma, characteristic impedance of the feeder element, length of the dipoles and the spacing between the dipoles. The outputs of the program are the Currents at the bases of the dipoles and E and H-plane patterns of the antenna which are obtained by the currents of the dipoles. Figure 6 shows respectively the variation of E-field pattern, H-field pattern, vertical azimuth pattern and horizontal azimuth pattern at 300MHz. Figure 7 shows the variation of input impedance at Source with frequency indicating that it lies between 40 to 75 ohm. Figure 8 shows the variation of VSWR with frequency indicating that it lies between 1.03 to 1.19. Figure 9 shows the variation of antenna gain with frequency indicating that it lies between 5.5 to 7 dB. Figure 10 shows the variation of Front to Back ratio with frequency indicating that it lies between 25 to 50 dB.

Figure 5 Simulated Antennas

Figure 6 a) Variation of E-field pattern, b) Variation of H-field pattern, c) Variation of Vertical Azimuth pattern and d) Variation of Horizontal Azimuth pattern at 300MHz
6. COMPARATIVE STUDY

Here we compare some parameters of the two constructed LPDA at different frequency range (50-300MHz and 50-500MHz). Figure 11 and Figure 12 gives a Comparison of Azimuth and Elevation plot of two LPDA. Figure 13 and Figure 14 respectively illustrates FF plot for Elevation Pattern for 300MHz LPDA and 500 MHz LPDA, while Figure 15 and Figure 16 respectively illustrates FF plot for Azimuth Pattern for 300MHz LPDA and 500 MHz LPDA. Figure 17 shows Magnitude and phase plot of current for 300MHz LPDA and 500 MHz LPDA.
Figure 11 Azimuth Plot of 300 MHz LPDA for Elevation Angle
a) 0deg to 90deg (300MHz LPDA) b) 0deg to 90deg (500MHz LPDA),
c) 0deg to -90deg (300MHz LPDA) and d) 0deg to -90deg (500MHz LPDA)

Figure 12 Elevation Plot for a) 300MHz LPDA and b) 500 MHz LPDA for azimuth angle 0-300 deg

Figure 13 FF plot for Elevation Pattern (300MHz)
Figure 14 FF plot for Elevation Pattern (500MHz)

Figure 15 FF plot for Azimuth Pattern (300MHz)

Figure 16 FF plot for Azimuth Pattern (500MHz)

Figure 17 a) Magnitude plot of current for 300MHz Antenna, b) Phase plot of current for 300MHz Antenna, c) Magnitude plot of current for 500MHz Antenna, d) Phase plot of current for 500MHz Antenna
Table 3 gives a comparison of different parameters of both 300 and 500 MHz Antenna.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>300 MHz</th>
<th>500 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of the antenna in m</td>
<td>4.48</td>
<td>3.44</td>
</tr>
<tr>
<td>Power in W</td>
<td>129.271</td>
<td>117.433</td>
</tr>
<tr>
<td>$E_x$ Mag</td>
<td>6.7947E-5</td>
<td>1.3168E-5</td>
</tr>
<tr>
<td>$E_y$ Mag</td>
<td>2.471E-15</td>
<td>4.284E-15</td>
</tr>
<tr>
<td>$E_z$ Mag</td>
<td>2.471E-15</td>
<td>4.284E-15</td>
</tr>
<tr>
<td>$E_{tot}$</td>
<td>6.7947E-15</td>
<td>1.3168E-5</td>
</tr>
<tr>
<td>Voltage in V</td>
<td>131.8 at 11.18 deg</td>
<td>123.7 at 1803 deg</td>
</tr>
<tr>
<td>Current in A</td>
<td>1 at 0.0 deg</td>
<td>1 at 0.0 deg</td>
</tr>
<tr>
<td>Impedance in ohm</td>
<td>129.3+j25.55</td>
<td>117.4+j38.84</td>
</tr>
<tr>
<td>SWR 50 ohm</td>
<td>2.703</td>
<td>2.655</td>
</tr>
<tr>
<td>75 ohm</td>
<td>1.822</td>
<td>1.829</td>
</tr>
</tbody>
</table>

7. CONCLUSION

The LPDA consists of a system of driven elements; but not all of them in the system are active on a single frequency of operation. Depending on its design parameters, the LPDA can be operated over a range of frequencies having a ratio of 2:1 or higher. Over this range its electrical behaviors like gain, feed-point-impedance, front-to-back ratio, etc. remain more or less constant. With the variation of the operating frequency, there is a smooth transition along the array of the elements to comprise the active region. We have presented here the design and simulated performance analysis of radiation pattern, Gain, and VSWR of LPDA antenna at 50MHz – 300MHz and compare some radiation characteristics for 50-300 MHz LPDA and 50-500 MHz LPDA. The LPDAs we have designed is appropriate for high forward gain, good front-to-back ratio, and low VSWR.

The research of Space Weather utilizing the nature of low-frequency solar radio bursts and their potential is enormous [3]. In Space Weather researches Solar radio monitoring will continue to play an indispensable task as they are susceptible to the regions of the solar atmosphere where many Space Weather phenomena commence. They can also acquire characteristics that are invisible at other wavelengths and so complement other amenities. Moreover, Space Weather is the study of the circumstances in the solar wind that can influence life on the surface of the Earth, especially the increasing technologically advanced devices that are part of today’s life. Solar radio observations are important to such phenomena as they normally initiate as events in the solar atmosphere, comprising flares, coronal mass ejections and shocks which generate electromagnetic and particle radiations that influence the Earth. LPDA antenna can be predominantly used for all this purposes very accurately.

In planar antenna designs, the antenna parameters are directly related to the dielectric characteristics and thickness of the substrate material used. Therefore, in the future other substrate materials could be used to improve the results. In order to reduce the backward radiation from the antenna, PMC (perfect magnetic conductor) surfaces can be developed and used as ground plane with the antenna which will result in enhancement of the antenna efficiency as well as directivity [4].

References


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