Research on Miniaturization of Log-periodic Dipole Arrays Using Folded Dipole

Fulin Du\textsuperscript{a}, Long Jin\textsuperscript{b}
University of Electronic Science and Technology of China, Chengdu 610000, China
\textsuperscript{a}sdrxdl@163.com, \textsuperscript{b}jinlong@uestc.edu.cn

Abstract. Log-Periodic Dipole Array (LPDA) is an ultra-wideband antenna with frequency-independent properties. It is widely used in radar, electronic warfare and other fields. Through summarizing the predecessors’ LPDA design theory, A LPDA operating in 1GHz – 10GHz was proposed in this paper. A miniaturization method was presented by folding the dipole of low frequency. Compared with the original antenna, the miniaturized antenna reduced the lateral size by 25%. Meanwhile, the $S_{11}$ parameter is less than -10dB in the operating band. And gain about 5 dB can be obtained in the same frequency band.

1. Introduction

Log-periodic dipole antenna [1] (LPDA) was proposed for the first time at the University of Illinois in the 1950s. Now it has a huge impact on commercial and military applications around the world. Miniaturization and high performance have become the inevitable trend of the development of UWB antennas. This requires that in the premise of meeting the antenna performance, the space occupied by the antenna needs to be reduced as much as possible.

The lateral size of the LPDA is determined by the lowest operating frequency. In some practical applications, due to space limitations, the antenna size should be reduced. LPDA miniaturization methods are mainly focused on low-frequency dipoles. In order to reduce the length of the dipole unit, many methods, including meandering line technology [2], fractal technology [3-5], loading technology etc. have been taken to reduce the size of antenna.

In this paper, a wideband, covering 1 GHz – 10 GHz, log periodic dipole antenna (LPDA) with small size is proposed. The arms of the low-frequency dipoles are bent, making the size of the antenna reduced to 75% of the conventional LPDA without reducing the antenna’s performance.

2. Antenna Design

The radiating elements of the LPDA antenna are printed on both sides of the insulating substrate. The antenna feeds the end of the shortest component. The LPDA consists of $N$ antenna elements arranged in parallel and symmetrical to each other, and the structure is shown in Fig. 1. This paper chooses the parameters $L_1 = 132$ mm, $R_1 = 198$ mm, $d_1 = 23.8$ mm. After determining the size $L_1$, $R_1$, $d_1$ of the longest antenna element of the antenna, the dimensions of the other antenna elements can be sequentially determined by the $\tau$, according to the following Eq. (1).

$$\tau = \frac{L_{n+1}}{L_n} = \frac{R_{n+1}}{R_n} = \frac{d_{n+1}}{d_n} \tag{1}$$
According to the above formula, the lengths \( L_1, L_2, L_3, ..., L_n \) and the horizontal distances \( R_1, R_2, R_3, ..., R_n \) and the distances between the two adjacent antenna elements \( d_1, d_2, d_3, d_n \) can be obtained. \( \alpha \) is the angle between the connecting line of the end points of each dipole of the antenna and the center line. It can be shown in Eq. (2).

\[
\alpha = \tan^{-1} \frac{L_n}{2R_n} \tag{2}
\]

\( \sigma \), another important parameter to LPDA, is defined by Eq. (3).

\[
\sigma = \frac{d_n}{2L_n} = \frac{R_n + R_{n+1} - R_n}{2L_n} = \frac{1-\tau}{4\tan \theta/2} \tag{3}
\]

This equation shows that as long as the \( \tau \) and \( \sigma \) are determined, the antenna structure is also determined. So according to the parameter calculation equation of LPDA operating 1 GHz ~ 10 GHz, the horizontal length is 204 mm and the vertical length is 132 mm. In this paper, the scale factor \( \tau = 0.83 \) and space factor \( \sigma = 0.14 \) is chosen. The number of dipole elements \( N \) is 22, radius of feeding line is 1.4 mm, the width of the longest dipole is 2 mm and the width of shortest is 0.2 mm. The structure of the traditional LPDA is shown in Fig. 1.

![Figure 1. The structure of the traditional LPDA.](image)

After the dipole is bent, the input impedance of the entire antenna will change, which will affect \( S_{11} \). First of all, theoretical analysis and calculation of LPDA input impedance will be conducted. In the design of LPDA, the input impedance of antenna feeding point \( Z_{in} = 50 \Omega \) is usually given first, and then \( Z_0 \) can be calculated. The formula is shown as Eq. (4) [6].

\[
Z_0 = Z_{in} \left( \frac{1}{Z_a} \right) + \left( \frac{1}{Z_a^{\frac{1}{2}}} \right)^2 + 1 \tag{4}
\]

In the above formula, \( Z_a \) is the characteristic impedance of the dipole, and can be defined by Eq. (5).

\[
Z_a = 120 \left[ \ln \left( \frac{L}{\lambda} \right) - 2.25 \right] \tag{5}
\]
In Eq. (5), or is the width of the antenna element and L is the length of that. After determining the values of \( Z_a \) and \( Z_{in} \), the characteristic impedance of the distribution feeder \( Z_0 \) can be calculated according to Eq. (4). The input impedance of the LPDA \( Z_c \) is shown as Eq. (6).

\[
Z_c = \frac{Z_0}{\sqrt{1 + \frac{Z_{0}^{2}}{Z_{a}^{2} + \sigma^2}}}
\]  (6)

According to Eq. (6), the input impedance of the LPDA is related to \( Z_0 \), \( Z_a \), \( \tau \), and \( \sigma \). By adjusting the length of the dipole after bending, it can get a lower reflection coefficient \( S_{11} \). Bending dipole structure is shown in Figure 2(a). In the structure of the antenna, length \( a_1 = 0.75 \times L_1 \), \( b_1 = 0.5 \times d_1 \), \( c_1 = 0.07 \times L_1 \), \( a_2 = 0.8 \times L_2 \), \( b_2 = 0.5 \times d_2 \), \( c_2 = 0.07 \times L_2 \). Figure 2(b) shows the structure of the folded LPDA on a substrate of 202 mm * 101 mm * 1 mm.

![Figure 2. (a) Structure of the folded dipole. (b) Structure of folded LPDA.](image)

LPDA is a balanced antenna, and the commonly used 50Ω coaxial line is unbalanced transmission line, so a balun (balance-unbalance transformer) is needed. A balun in the form of exponential gradient microstrip line is designed and shown in Figure 3.

![Figure 3. Structure of index gradient line microstrip balun.](image)

On the unbalanced side, the width of the ground plane is 11.4 mm, the width of the microstrip line is 1.8 mm, and the width of the microstrip at the balanced end is 1.4 mm. The size of balun is 30 mm * 12 mm * 1 mm.

3. Results And Analysis

Figure 4 (a) and (b) show the reflection coefficient \( S_{11} \) and gain curves of the two antennas. Between 1 GHz and 10 GHz, the \( S_{11} \) is less than -10 dB, the gain is 7 dB in the high frequency band and 5 dB in the low frequency band.
Figure 4. (a) Simulated S11 of the folded LPDA and traditional LPDA. (b) Simulated gain of the folded LPDA and traditional LPDA.

Fig. 5 shows the simulated radiation pattern of the XOZ plane of the folded antenna at 1GHz, 4GHz and 7GHz. According to the radiation pattern (Fig. 5), with the increase of frequency, the back lobe of the antenna radiation pattern decreases. This is because long dipoles reflect the higher frequencies radiation. The pattern is stable over the entire bandwidth.
Fig. 5 shows the simulated radiation patterns for the folded LPDA in XOZ (E) plane at: (a) 1 GHz, (b) 4 GHz, (c) 7 GHz.

Fig. 6 shows the photograph of the fabricated folded LPDA with a balun. The measured reflection coefficient $S_{11}$ of the antennas with the port connected directly to a 50 $\Omega$ SMA connector is shown in Fig. 7. It can be observed that the reflection coefficient $S_{11}$ is less than -10 dB in the frequency band of 1 GHz to 10 GHz. The measured far-field radiation patterns of the antenna are given in Fig. 8. The measured results have good similarity with the simulation results.

Fig. 6. Physical structure of the folded LPDA with a balun.
Figure 7. Measured S11 of the folded LPDA.

Figure 8. Measured radiation patterns for the folded LPDA in XOZ (E) plane at: (a) 1 GHz, (b) 4 GHz, (c) 7 GHz.
4. Conclusion

In this research, a folded LPDA, with a balun, is proposed, fabricated and measured. According to the measured results, the folded LPDA has the desired return loss and directivity. Compared to the traditional LPDA, the antenna's lateral size is reduced by 25% without sacrificing the performance of the antenna.

References

[1] D Isbell. Log periodic dipole arrays [C].Ire Transactions on Antennas & Propagation, 260 - 267, 1960.
[2] S Luan, X Liu, J Qiu, A novel miniaturized ultra wideband log-periodic antenna [C]. International Conference on Ultrawideband & Ultrashort Impulse Signals, 246 - 248, 2010.
[3] A Moallemizadeh, HR Hassani, SMA Nezhad. Wide Bandwidth and Small Size LPDA Antenna [C]. European Conference on Antennas Propagation, 1-3, 2012.
[4] Longdan Tan, Zengrui Li, Qingxin Guo, Hui Zhang, lie Wang, Guosheng Liu and Xueqin Zhang. A Small and Wideband Second order Koch-Fractal Log-Periodic Antenna[C].Cross Strait Quad-Regional Radio Science And Wireless Technology Conference (CSQRWC), 2013. IEEE, 273-275, 2013.
[5] AA Gheethan, DE Anagnostou. Reduced Size Planar Log-Periodic Dipole Arrays (LPDAs) Using Rectangular Meander Line Elements [C]. IEEE Antennas & Propagation Society International Symposium, 1 - 4, 2008.
[6] GD Vito, G Stracca. Further comments on the design of log-periodic dipole antennas [C]. IEEE Transactions on Antennas & Propagation, 714 - 718, 1973.