Indian Journal of Pure & Applied Physics
Vol. 58, January 2020, pp. 16-23

Compact printed log-periodic dipole antenna (LPDA) with T-shaped arm for wide band applications

Amit Birwal[a], Nilesh Kumar Manker[b] & Kamlesh Patel[a*]

[a]Department of Electronic Science, University of Delhi, South Campus, New Delhi 110 021, India
[b]Microwave Tube Research and Development Centre, DRDO, BEL Complex, Jalahalli, Bangalore 560 013, India

Received 27 May 2019; accepted 11 September 2019

Compactness of printed log-periodic dipole antenna (LPDA) is an essential requirement in developing low-weight communication system. With this aim, in the present work, we utilized two-step approach to reduce size of this kind of antenna. First, to achieve compactness, a maximum apex angle was taken for the desired gain of 6 dBi, which reduces the boom length to minimum possible value. Secondly, after fully optimizing the width and length of each dipole, a T-shaped arm is introduced in place of straight dipole arms. For comparison, initially printed LPDA is designed with full arm structure of gain 6.5 dBi in 1.5 to 3.5 GHz band using CST Microwave Studio. In T-shaped arm LPDA, the antenna size eventually reduces by 82% compared to full arm structure, which offers a bore sight gain level varies from 2 to 4.5 dBi in the frequency band of 1.8 to 3.5 GHz. Simulation analysis are discussed in detail along-with a size comparison of various printed LPDAs. The measured results of the fabricated LPDA with T-shaped arm are found to closely match with the simulation results.

Keywords: Log-periodic dipole antenna, Compact antenna, Antenna gain, T-shaped arm

1 Introduction

Wireless communication is becoming the fast growing need of today's technology due to its numerous applications. Antenna plays the most important role for any successful wireless communication network. Micro strip antennas are the most preferred for this kind of applications, as these antennas are compact, planar and so can be easily integrated to any RF circuits. However, few drawbacks associated with these antennas are narrow bandwidth, moderate gain, low radiation efficiency, moderate size etc.[1]

For high gain and wide bandwidth, log periodic dipole antennas (LPDAs) are an obvious choice because of their easier design and numerous advantages as compared to other type of antennas[2]. LPDA is an array of driven dipole elements designed to operate in a wide bandwidth with 180° phase shift in the alternating elements of this antenna. The dimensions of LPDA are expressed in terms of wavelengths which vary with frequency. Since it usually displays diverse radiation properties at different frequencies, so it can be designed for any band. LPDA exhibits a relatively low VSWR over a wide band of frequencies. Based on the operating frequency the length of radiating dipole becomes quarter wavelength while the other elements remain passive. So, the active radiating region of the antenna depends on the operating frequency[3]. This type of antenna was introduced using cylindrical wire dipoles by the procedure given by Carrel[4] and Isbel [5], and later the design structure was analyzed by Vito and Stracca[6,7].

As given in literature[2], LPDA has been designed in a gain range of 6-10.5 dB (or dBi) for the wide band applications. Some applications of log-periodic antenna are as a high quality measurement antenna and direction finder. In addition, this antenna is very well suited for WLAN, Wi-Fi and other directional communication applications. So, printed dipole becomes more popular due to compact size and low cost with capability to integrate with planar circuits[3,8].

In recent years, the miniaturization of antennas has gained interest owing to the increasing demand for smaller antennas for the rapid development in wireless communication[8]. To achieve the size reduction, efforts have been made using fractal Koch geometry without compromising the performance of the antenna[9]. Although use of fractal Koch geometry makes design of LPDA more complex, the length of boom remains same. In literature[10], printed log-periodic dipole array (LPDA) antenna fed by tapered microstrip line is proposed for easy integration with

*Corresponding author (E-mail: kpatel@south.du.ac.in)

radio frequency circuits. A dual-band CPW-fed printed LPDA using inkjet-printing technology for wireless communications is presented in literature[11].

On keeping the same goal in this paper, a miniaturization technique has been proposed which results in the size reduction of both length and width of LPDA to achieve possible size reduction. Initially the LPDA is designed for 6.5 dBi gain to operate from 1.5 to 3.5 GHz band. Its dimensions are optimized by using CST microwave studio and the performance has been validated using the fabrication and measurements of final printed LPDA with T-shaped arms.

2 Antenna Design

LPDA are generally the antennas which are frequency independent, the design consists of an array of dipole elements connected alternatively to the first antenna on the upper side and second antenna on the lower side of substrate as shown in Fig. 1. To design the LPDA, basic parameters like scaling factor τ, spacing factor σ and apex angle α are used. These parameters decide the required length and distance between dipole elements. In this design, desired value of gain gives optimum τ and σ using the design graph given by Carrel[4, 7]. To design LPDA, we first need the values of bandwidth of the active region B_{ar}, which is a function of apex angle α and τ as given in the next section 2.1. To obtain the minimum size of boom length, maximum value of apex angle is required.

2.1 Design equations

For designing printed LPDA the steps in sequence are given below[12]:

First desired value of gain and bandwidth of the antenna are decided,

For the desired gain, τ $(0.8 \leq \tau \leq 0.98)$ and σ $(0.05 \leq \sigma \leq \sigma_{opt})$ are selected,

The value of the apex half-angle α is calculated from:

$$\cot\alpha = \frac{4\sigma}{1-\tau} \quad \text{... (1)}$$

We determined B_{ar} from the following equation:

$$B_{ar} = 1.1 + 7.7(1-\tau)^2 \cot\alpha \quad \text{... (2)}$$

It can also be obtained from design graph[10].

The structure (array) bandwidth $B_s = (f_n/f_1)\,B_{ar}$ is obtained, where f_n and f_1 are highest and lowest frequency,

Next the boom length L, number of elements N and length of first dipole L_1 are determined using the below formulas:

$$L_{ft} = \left[\frac{1}{4}\left(1-\frac{1}{B_s}\right)\cot\alpha\right]\lambda_{max} \quad \text{... (3)}$$

$$N = 1 + \frac{\ln(B_s)}{\ln(1/\tau)} \quad \text{... (4)}$$

$$L_{1ft} = \frac{492}{f_1} \quad \text{... (5)}$$

The spacing between dipole (first two dipoles) is calculated using:

$$d_{12} = 1/2(l_1 - l_2)\cot\alpha \quad \text{... (6)}$$

Finally the width W_i of each element is obtained[13]:

$$W_i = \pi a_i \quad \text{... (7)}$$

Where, a_i is the radius of dipole for its half length L_i. For the LPDA, Z_n is the average characteristic impedance, which is set as 25 Ω and is given by:

$$Z_n = \frac{\eta_o}{\pi}\left[\ln\left(\frac{L_i}{a_i}\right) - 2.25\right] \quad \text{... (8)}$$

2.2 Design of printed LPDA

The printed LPDA shown in Fig. 1 is designed to work in the frequency range of 1.5 to 3.5 GHz with the desired gain of 6.5 dBi over the FR4 substrate ($\varepsilon_r = 4.4$) with thickness of 1.5 mm. The length, width and spacing of dipole elements using the Eqs (1-8) are calculated and mentioned in Table 1 and incorporated in CST microwave studio as an initial design. The calculated design parameters are taken as apex angle α of 21.44°, $\tau \approx 0.78$, B_{ar} of 2.012, B_s of

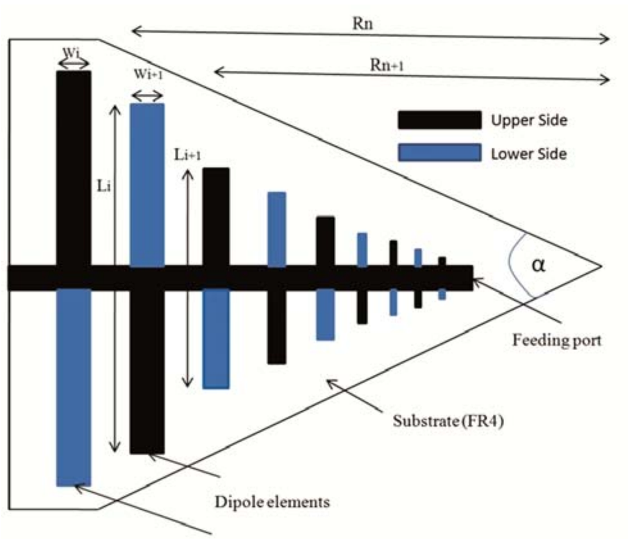

Fig. 1 – Printed log-periodic dipole antenna (LPDA) configuration.

4.69 and boom length of 90.35 mm with 9 elements. The initial LPDA design is then optimized to get compact size and desired performance as shown in Fig. 2.

It can be seen in Fig. 2(b) that S_{11} is lower than -10 dB in a wide frequency range of 1.5 to 3.5 GHz, except four fractional frequency bands, near 1.95 GHz, 2.2-2.4 GHz and 2.95-3.25 GHz. Further optimization needed to obtain the similar or better performance with the minimum boom length.

2.3 Printed LPDA with minimum boom length

With aim to achieve the minimum boom length, we considered the maximum possible apex angle of 35° for the desired gain. Other parameters are modified as $\tau \approx 0.8$, $B_{ar} \approx 1.5$, $B_s \approx 3.5$, and boom length ≈ 51.35 mm with 9 elements. The calculated length, width and spacing of dipole elements are given in Table 2 for this case. The simulated layout and return loss (RL) for this LPDA are shown in Fig. 3.

Compared to Fig. 2(b), we obtained better RL values at 1.5 GHz, ~1.9 GHz and ~ 2.35 GHz in Fig. 3(b). Still there are few frequency ranges in RL

Table 1 – Calculated physical parameters values of the first printed LPDA.

Dipoles element (i)	Length (mm)	Width W_i (mm)	Spacing $R_n - R_{n+1}$ (mm)
1	79.5	10.5	0
2	62	8.2	21.2
3	48.4	6.4	16.5
4	37.7	4.9	12.9
5	29.4	3.8	10.1
6	22.9	3	7.9
7	17.9	2.4	6.1
8	13.9	1.9	4.8
9	10.8	1.5	3.7

Table 2 – Calculated length, width and spacing of dipole elements.

Dipoles element (i)	Length (mm)	Width W_i (mm)	Spacing $R_n - R_{n+1}$ (mm)
1	75.4	10	0
2	60.2	8	10.7
3	48.2	6.4	8.6
4	38.7	5.1	6.9
5	30.8	4.1	5.6
6	24.8	3.3	4.5
7	19.8	2.5	3.6
8	15.9	2.0	2.9
9	12.7	1.7	2.3

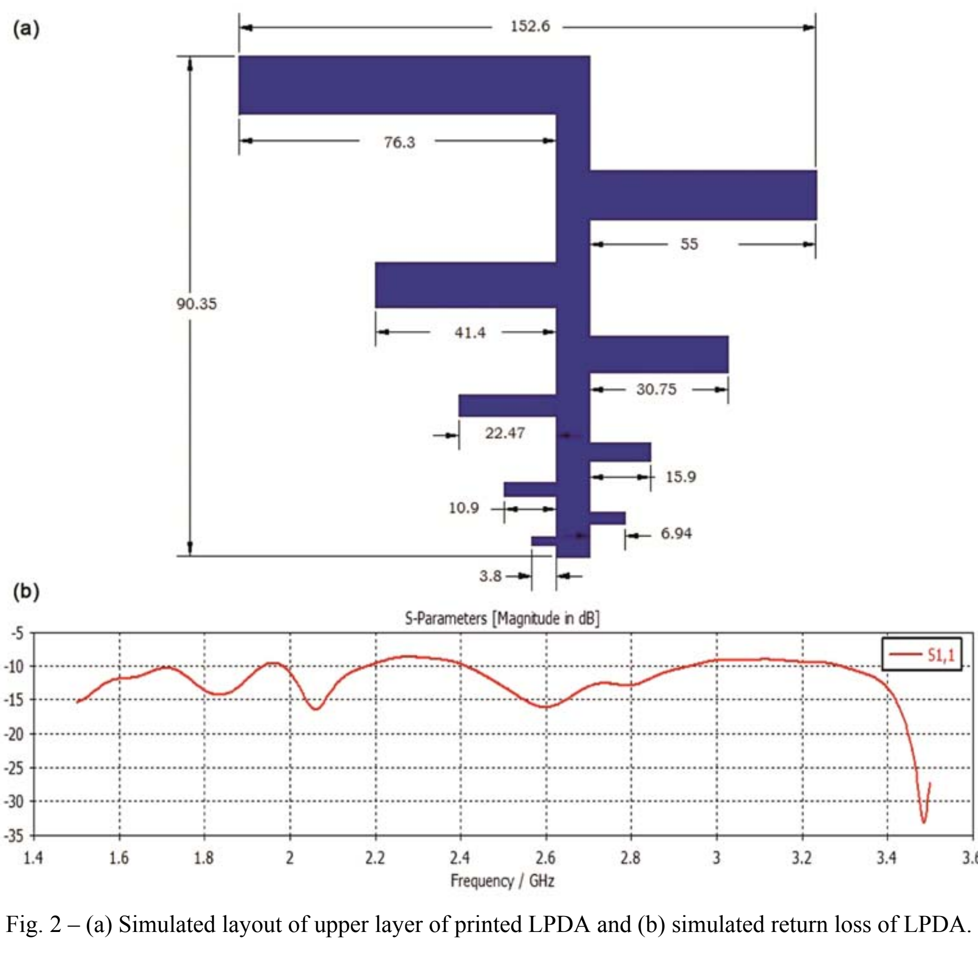

Fig. 2 – (a) Simulated layout of upper layer of printed LPDA and (b) simulated return loss of LPDA.

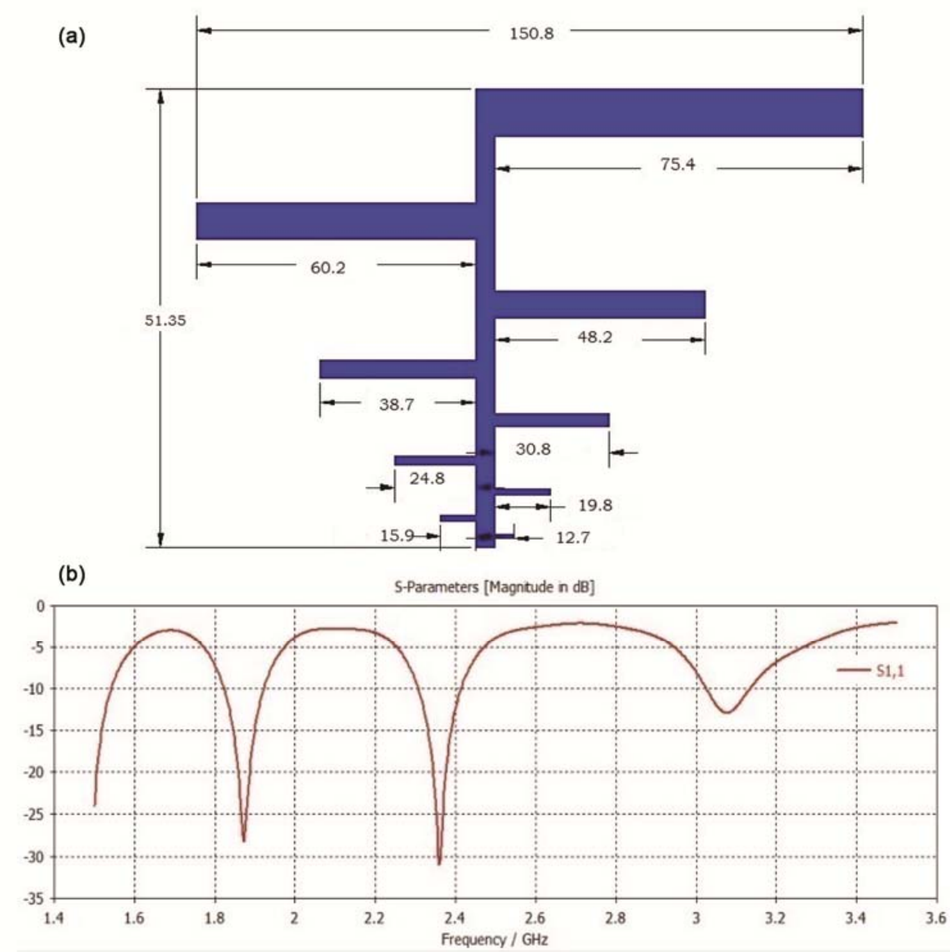

Fig. 3 – (a) Simulated layout of upper layer of printed LPDA with minimum boom length and (b) simulated return loss of LPDA with minimum boom length.

response, where S_{11} is higher than –10 dB and these are 1.6 – 1.75 GHz, 1.95 – 2.25 GHz, 2.5 – 2.9 GHz and 3.3 – 3.5 GHz. We have noticed that design with minimum boom length leads to compromise the antenna bandwidth.

2.4 Printed compact LPDA with minimum width and length

The printed LPDA with minimum boom length as mentioned in the previous section still has a total width of 150.8 mm. So, the structure is further optimized for minimum length and width of each dipole element without impacting the antenna performance. The simulated layout and return loss for this case are shown in Fig. 4. As it can be seen from Fig. 4(b), better performance as S_{11} > -10 dB is observed at 1.5 GHz, ~2.35 GHz, 2.85 – 3.05 GHz and 3.5 GHz. So, the LPDA shown in Fig. 4(b) is comparatively compact LPDA with the optimum performance for broadband radiation.

2.5 Printed LPDA with T-shaped arm

In order to create possibility of further reduction in width, we utilized dipoles of T-shaped as these dipoles are considered to be pressed at the open ends and so forming a T-shaped arm. This new design has a great impact on overall width reduction from 74.6 mm to 49 mm, i.e., compact by ~ 34 % after optimization as shown in Fig. 5(a). Figure 5(b) shows that the return loss performance is improved too in 1.9 to 2.15 GHz and above 2.5 GHz, where S_{11} < -10 dB. Only ranges of 1.5 – 1.9 GHz and 2.2 – 2.5 GHz have higher S_{11}, which may have generated due to reflections from T-shaped ends. The final dimension of each dipole element is mentioned in Table 3.

3 Simulated Results of Printed LPDA with T-shaped Arm

The 3D radiation pattern of final LPDA with T-shaped arms are shown in Fig. 6, at three frequencies 1.9 GHz, 2.5 GHz and 3.5 GHz where directional gain of ~ 3.68 dBi, 4.66 dBi and 4.44 dBi are obtained, respectively. For printed LPDA with T-shaped arms the polar radiation plots for Phi=90° (azimuth) and

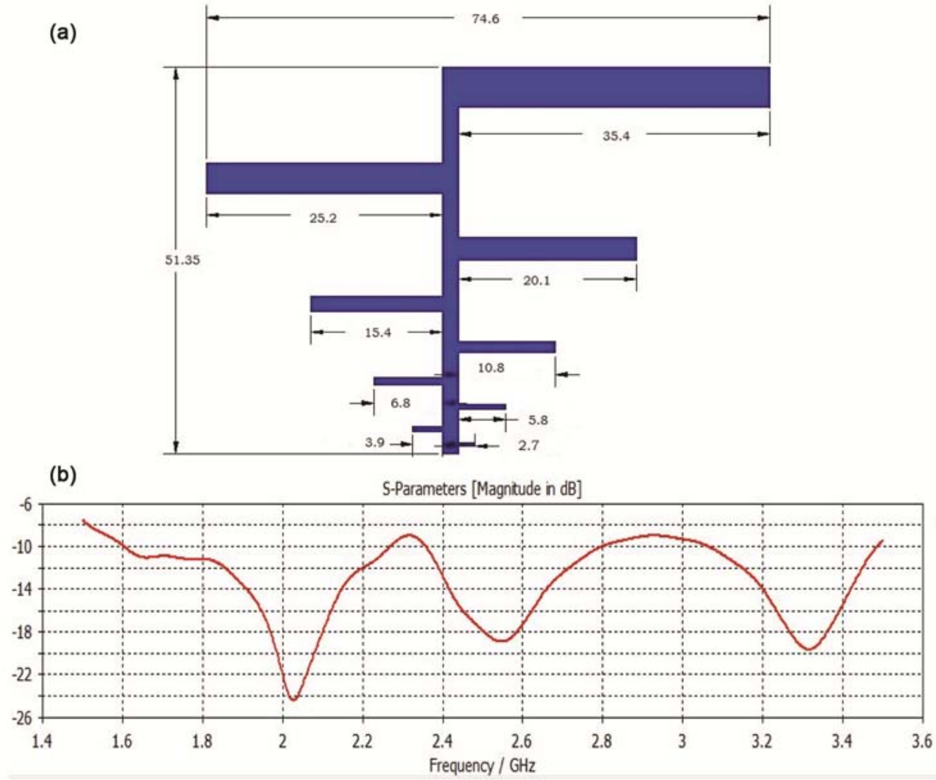

Fig. 4 – (a) Layout of upper layer of printed LPDA with optimized width and length and (b) simulated return loss of LPDA with minimum width and length.

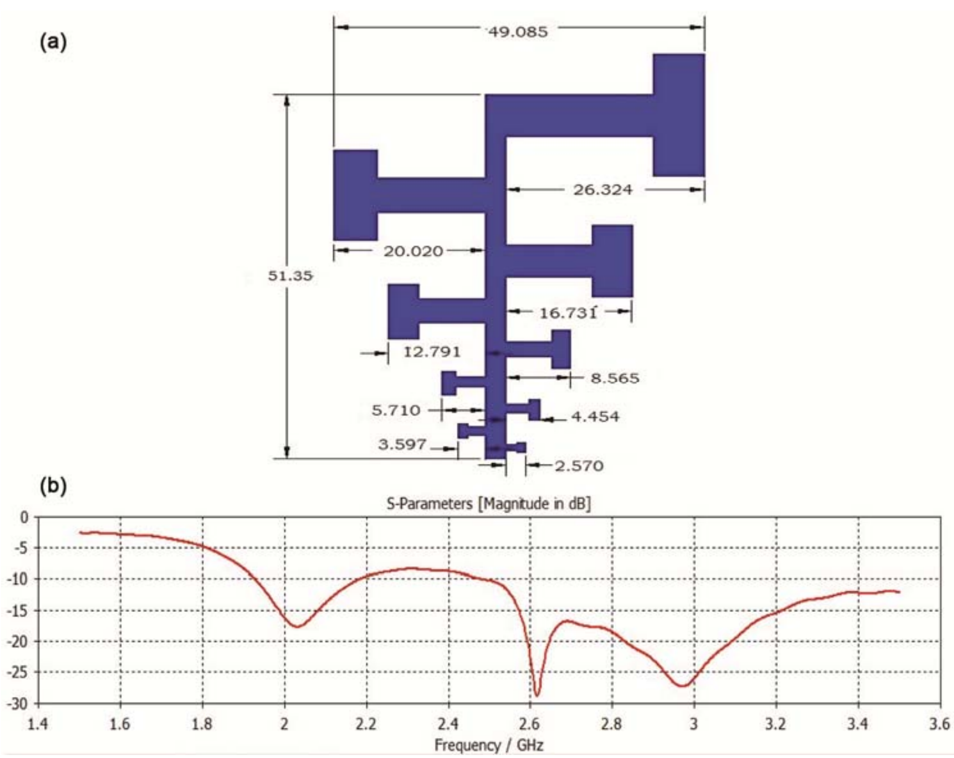

Table 3 – Optimized dimension of T-shaped dipole elements.

Dipoles elements (i)	Length (mm)	Width W_i (mm)	Spacing $R_n - R_{n+1}$ (mm)
1	26.32	6	0
2	20.02	5	11.2
3	16.73	4.6	9.2
4	12.79	3.7	7.1
5	8.56	2.1	5.3
6	5.71	1.8	4.7
7	4.45	1.5	3.8
8	3.59	1.2	1.2
9	2.57	0.9	2.3

Fig. 5 – (a) Layout of upper layer of printed LPDA with T-shaped arm and (b) simulated return loss of LPDA with T-shaped arm.

Phi=0° (elevation) at frequencies 1.9 and 2.5 GHz are shown in Fig. 7 and Fig. 8, respectively. It can be seen that the major lobe represents the radiated energy in a particular direction and very low side/back lobes which can be helpful in any communication system.

4 Fabrication and Measurement of Printed LPDA with T-shaped Arm

With the dimensions given in Table 3, the optimized printed LPDA with T-shaped arm is

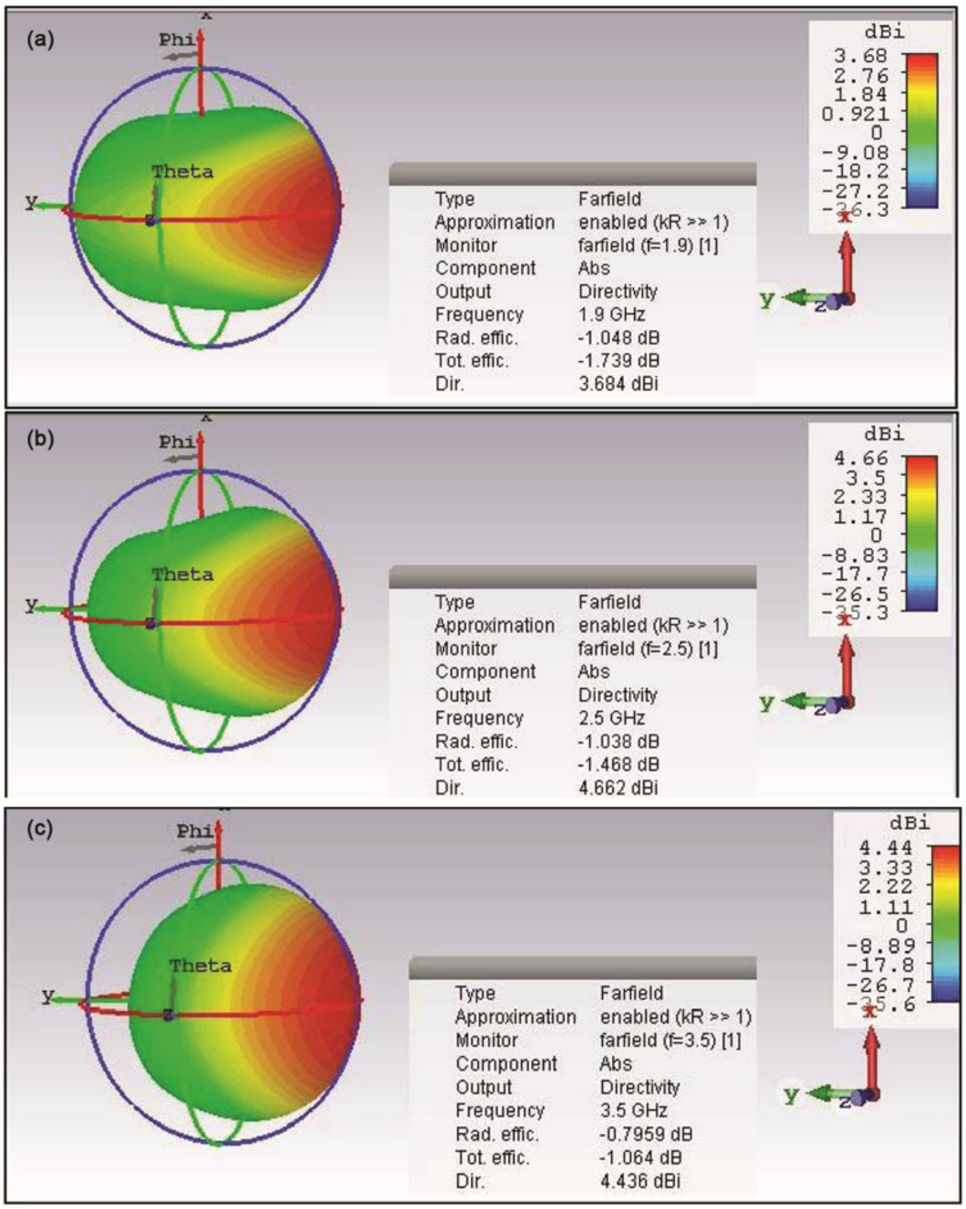

Fig. 6 – (a) Radiation pattern at 1.9 GHz, (b) radiation pattern at 2.5 GHz, and (c) Radiation pattern at 3.5 GHz.

fabricated on FR4 substrate (ε_r = 4.5, height h =1.5 mm and Cu thickness of 18 μm) to verify the simulation results. The return loss of this LPDA is

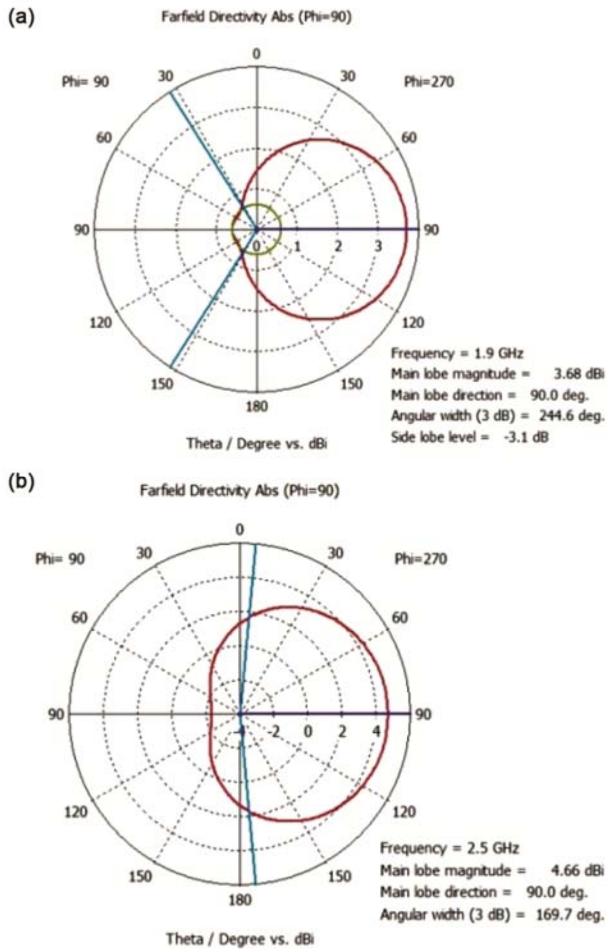

Fig. 7 – (a) Azimuth pattern at 1.9 GHz and (b) Azimuth pattern at 2.5 GHz.

measured using a vector network analyzer model N5227A of Keysight Technologies, USA. Figure 9 shows comparison of simulated and measured return loss of this antenna and the both have a good agreement. The little differences in the simulated and measured results are observed due to the losses in the SMA connector soldering and fabrication tolerances[14].

This final antenna offers a wide bandwidth of (1.7–3.5 GHz) which meets the bandwidth requirements of WLAN/WiMAX bands. To further analyze the gain performance of this final LPDA, gain vs frequency plot is shown in Fig. 10 to verify its broadband response. We have observed that although the simulated response of first printed LPDA is not satisfactory, our optimization of width and length led to increase the overall response and maximum gain of around 6 dBi was found at 2.2 and 2.4 GHz. With T-shaped arm dipoles, the gain was reduced and a

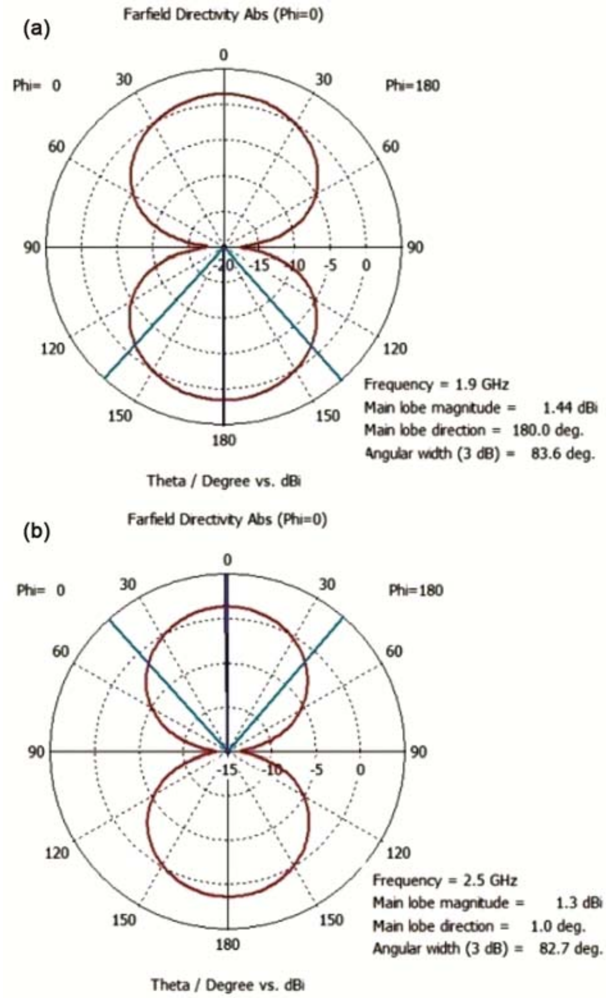

Fig. 8 – (a) Elevation pattern at 1.9 GHz and (b) Elevation pattern at 2.5 GHz.

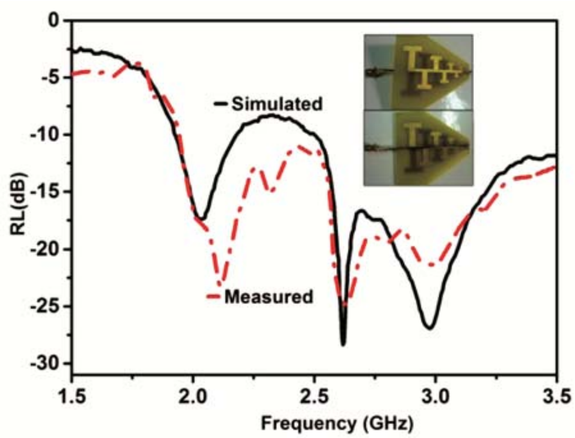

Table 4 – Size comparison of various printed LPDA.

Antenna size	Printed LPDA	Printed LPDA with minimum boom length	Printed LPDA with minimum width and length	Printed LPDA with T- shaped arm
Boom length (mm)	90.35	51.25	51.35	51.35
Width (mm)	152.6	150.8	74.6	49.08
Max gain (dBi)	5.5	5.6	5.9	5.1
Size reduction (%)	-	43.9	72.2	81.7

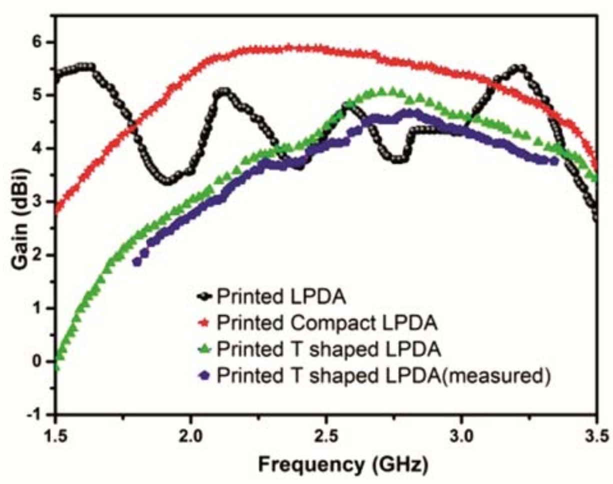

Fig. 10 – Gain vs frequency plot of all printed LPDA.

Fig. 9 – Return loss vs frequency plot of T- shaped printed LPDA.

maximum of 5 dBi@2.7 GHz is obtained. The gain was measured in anechoic chamber as shown by the blue color line for 1.7-3.25 GHz, which found to be in agreement with the simulated results in green color. The fabricated T-shaped antenna exhibits 3 dBi@2.1 GHz, 4.5 dBi@2.7 GHz and 3.6 dBi@3.1 GHz. Table 4 shows the size comparison of optimized printed LPDA for the four cases presented in this work. In literature[15], use of T-shaped elements and double T-shaped elements in LPDA has reduced size by some 50 % and 54 %, respectively, while keeping the average gain of 5 dBi in the frequency range of 2 to 8 GHz. In this work, we achieved about 82 % size reduction in final LPDA (Fig. 9) for comparatively less bandwidth.

5 Conclusions

The design, simulation and fabrication of the printed LPDA with T-shaped arm are presented in the wide frequency range from 1.5 to 3.5 GHz. It has been found that the printed LPDA gain is ~ 6 dBi and return loss is better than 10 dB in the large frequency band. As the operating frequency of LPDA depends on the length of each dipole elements, the rear most dipole is replaced with a slightly longer dipole so that the optimized LPDA should radiate at the minimum frequency of 1.9 GHz. This gives the overall size reduction of approx. 82 % from printed LPDA with straight dipoles to printed LPDA with T-shaped arm dipoles on little compromise on the gain.

Acknowledgment

The authors would like to thank the Research & Development scheme 2015-2016 of the University of Delhi and UGC 12th Plan for the financial support. Authors express thanks for S-parameter measurements to Ms Sandhya M Patel, CSIR-National Physical Laboratory, New Delhi.

References

1 Mutiara A B, Refianti R & Raghmansyah, *J Theor Appl Inform Technol*, 33 (2011) 184.
2 Balanis C A, *Antenna Theory: Analysis and Design*, 3rd Edn, (John Wiley & Sons Inc: New Jersey), 1997.
3 Casula G A, *IEEE Antennas Wireless Propag Lett*, 12 (2013) 1232.
4 Carrel R, *Analysis and design of the log-periodic dipole antenna*, University of Illinois, 1961.
5 Isbell D E, *IRE Trans Antennas Propag*, AP-8 (1960) 260.
6 Vito G D & Stracca G B, *IEEE Trans Antennas Propag*, AP-21 (1973) 303.
7 Vito G D & Stracca G B, *IEEE Trans Antennas Propagat*, AP-22 (1974) 714.
8 Campbell C K, Traboulay I, Suthers M S & Kneve H, *IEEE Trans Antennas Propag*, 25 (1977) 718.
9 Anagnostou D E, , *IEEE Antennas Wireless Propag Lett*, 7 (2008) 456.
10 Yang Z, Jingjian H, Weiwei W & Naichang Y, *Int J Antennas Propag*, 2017 (2017) 6259682.
11 Casula G A, Montisci G, Maxia P, Valente G, Fanti A & Mazzarella G, *IEEE Antennas Wireless Propag Lett*, 15 (2015) 1333.
12 Dean Straw R & Severns R, *The ARRL Antenna Book*, (The American Radio Relay League, Inc. Newington), 1997.
13 Casula G A, Maxia P, Mazzarella G & Montisci G, *Prog Electromagn Res C*, 38 (2013) 15.
14 Gautam A K, Bisht A & Kanaujia B K, *Int J Electron Commun (AEÜ)*, 70 (2016) 354.
15 Pirai M & Hassani H R, *IEICE Electron Exp*, 6 (2009) 1528.