A Compact Wide band Printed LPDA Antenna for WLAN Applications in 5 GHz Band

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ABSTRACT
A compact wide band Printed LPDA (Log Periodic Dipole Array) antenna is proposed for WLAN applications in 5-6 GHz range. The antenna having dimensions of 36.58 mm x 24.37 mm x1.6 mm is designed and simulated using HFSS 13. The prototype of proposed antenna is developed using simple FR4 substrate. The proposed antenna works well in the desired operating bandwidth from 5-6 GHz and covers dual bands of IEEE 802.11a (5.15-5.35 GHz and 5.725-5.825 GHz) with VSWR effectively less than 2. The antenna shows a wide impedance bandwidth of 1.643 GHz from 4.869 GHz – 6.512 GHz, with bandwidth efficiency of 28.87 %. The antenna gain is > 6 dB throughout the operating band, with max gain of 7.6 dB at 5.6 GHz and stable radiation pattern in end fire direction. Measured results for S_{11} parameter are in good agreement with simulated one, which validates the proposed antenna design.

Keywords
PLPDA (Printed Log Periodic Dipole Array), WLAN, FR-4, Wide band

1. INTRODUCTION
Nowadays WLAN applications are very popular with IEEE standards working in 2.4 GHz and 5 GHz band. IEEE 802.11a operating at 5 GHz band (5.15-5.35 GHz and 5.725-5.825 GHz) facilitates relatively higher data rate than the 802.11 b/g which operates at 2.4 GHz band. So the design of a printed LPDA antenna operates over this band is presented in this work. The evolution of conventional antenna design has started from 1960, when Isbell [1] first introduces the traditional LPDA antenna in free space [1]-[6].The concept of conventional LPDA antenna is then applied to develop printed LPDA antenna [7]-[10].

There is a lot of work reported regarding the WLAN antenna design in 5 GHz band using printed technology [11]-[18]. In [11] a wideband /dual band packaged antenna is proposed for WLAN applications in 5 GHz band, using FR4 substrate. In spite of having facility of using as a wide band or as a dual band antenna, the peak gain obtained was very low (1.8 dbi at 5.25 GHz). In [12] a wide band patch antenna for 2.4/5 GHz WLAN applications is designed using simple probe feed and air gap (capacitive gap) to improve the bandwidth. Reference [13] presents a compact and simple design of a CPW (Co-Planar Waveguide) fed planar antenna for UWB applications with dual band notch at 3.5/5.5GHz. In [14] a stacked triangular dielectric resonator antenna (DRA) fed by a conformal patch is proposed for WLAN applications in the frequency range of 4 - 6.02 GHz. To improve the gain, BW and radiation performances of DRA, triangular shaped resonators with same dielectric constant and different sizes are stacked together. In [15] a compact triple band microstrip slot antenna applied to WLAN /WiMax applications is proposed. In spite of its simpler structure, peak gain achieved was low (4.32 dbi at 5.5 GHz). In [16] a compact printed planar UWB (Ultra Wide Band) antenna with dual band notched is proposed. Two rectangular parasitic strips are placed below the substrate to achieve dual band notched characteristic at 3.3-3.8 and 5.1-5.6 GHz bands. Reference [17], presents a simple 2.45/3.5/5.8 GHz triple band circularly polarized printed monopole antenna with enhanced bandwidth. In [18] a compact dual band polarized LPDA with dimensions of 160 x160 x60 mm for MIMO WLAN applications is proposed. The proposed array exhibits the characteristics of high isolation and, good F/B ratios and average gain of 5 and 6 dbi over 2.4 and 5 GHz band respectively.

This paper presents a simple design of a compact printed LPDA antenna for WLAN applications in 5 GHz band. The antenna is designed using Carrels theory and then optimized using HFSS 13, a high frequency structure simulator based on FEM (Finite Element Method). The antenna is simulated on a simple FR4 epoxy substrate with dielectric constant of 4.4 and thickness of 1.6 mm. The various design parameters like return loss, working bandwidth, radiation pattern and overall gain are used as indicators in the evaluation of performance enhancement. The proposed antenna works well in the desired frequency range with good return loss curve and satisfactory radiation pattern in end fire direction and maximum gain of 7.6 dbi at 5.6 GHz.

2. ANTENNA DESIGN
The structure is very close to a standard (wire) LPDA and therefore the standard strategy to design an LPDA can be used [2], along with some modifications (Fig. 1).The property of antenna is mainly determined by 3 parameters the scale factor τ, spacing factor σ and number of diploes N. To achieve better radiation property, low return loss and high gain, we decide $\tau = 0.9$ and $\sigma = 0.15$. All the adjacent dipoles elements are printed on two sides of micro strip substrate in an alternate way and are fed with coaxial cable at lower end using SMA connector. All the elements of antenna are fed by a paired strip to match the resistance of 50 Ω. For calculating the width of parallel strip feed line to match the required impedance of 50 Ω, a 25 Ω standard micro strip with width of h/2 is designed using calculations given in [19] and optimized through HFSS 13.The resulting width of parallel strip obtained ;W=4.185 mm. Then effective dielectric constant is calculated by using relation;

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{W}\right)^{-1/2} \quad (1)$$

Now, starting with required bandwidth of 5-6 GHz, and following the rules given in [20], first the length of largest dipole L_{max} is determined as:

$$L_{max} = K_1 \lambda_{max} \quad (2)$$

Where λ_{max} is the largest effective wavelength at the lowest operating frequency 5 GHz. K_1 is a constant depends on Scaling factor τ [20].Then length of shortest dipole element can be calculated by using equation;

$$L_{min} = K_2 \lambda_{min} \quad (3)$$

Where λ_{min} is the shortest effective wavelength at highest operating frequency 6 GHz and K_2 is lower truncation constant calculated using formula given in [20]. Now to cover the desired frequency range from 5-6 GHz, number of dipoles required are calculated as N = 8.33 ≈ 8 from equation;

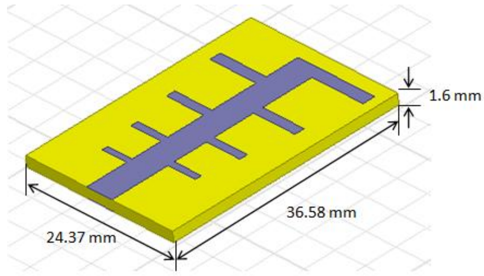
$$N = 1 + \frac{\log\left(K_2/K_1\right) + \log\left(f_l/f_u\right)}{\log \tau} \quad (4)$$

Where f_l is lowest operating frequency = 5 GHz and f_u is highest operating frequency = 6 GHz. From equation (2) length of largest dipole element L_{max} = 16.943 mm. Then width W_1 of largest dipole can be determined by using the expression of characteristic impedance Z_0 of cylindrical dipole [2] by using equation;

$$Z_0 = \frac{\eta_0}{\pi}\left[\ln\left(\frac{L_n}{a_n}\right) - 2.25\right] \quad (5)$$

Where a_n = radius of dipole, and L_n its half length. Now width of largest dipole is calculated as in [21] by using formula;

$$W_n = \pi a_n \quad (6)$$



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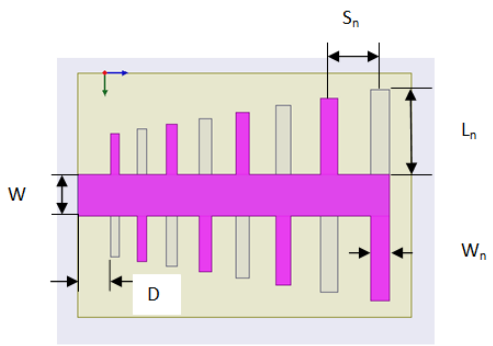


(b)

Fig. 1. Schematic layout of Printed LPDA antenna (a) Outer dimensions (b)Inner dimensions (Solid lines for front face while blanked lines for back face of the substrate)

to match the impedance of 50 Ω. The length and width of other dipoles can be calculated by using well known expressions of LPDA;

$$\frac{L_n+1}{L_n} = \frac{1}{\tau} \quad (7)$$

$$\frac{W_n+1}{W_n} = \frac{1}{\tau} \quad (8)$$

The spacing between two elements is also depends on the scaling factor τ, as given in eq. (9)

$$\frac{S_n+1}{S_n} = \frac{1}{\tau} \quad (9)$$

Key design parameters and geometry of antenna are listed in Table 1 and Table 2 respectively.

3. SIMULATION AND MEASURED RESULTS

The PLPDA antenna designed in previous section then simulated and optimized using HFSS 13 to obtain various key parameters like return loss, gain and radiation pattern. Antenna is differentially fed at lower end using lumped port

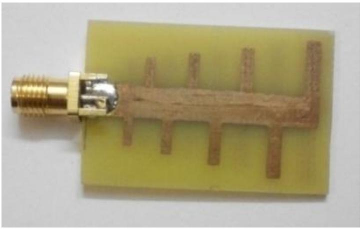
Table 1. Key Design Parameters

Parameters	Value
Width of parallel strip line (W)	4.185 mm
Feed length (D)	6.5 mm
Scaling factor (τ)	0.9
Spacing factor (σ)	0.15
Length of largest dipole (L_{max})	16.943 mm
Effective dielectric constant (ε_{eff})	3.6962

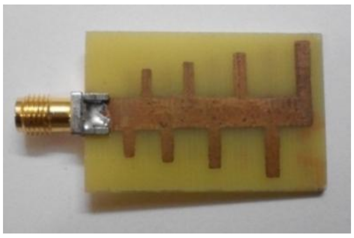
Table 2. Geometry of designed PLPDA

Dipole	*Ln* [mm]	*Wn* [mm]	*Sn* [mm]
1	4.05	0.88	-
2	4.501	0.98	2.70
3	5.002	1.09	3.00
4	5.557	1.21	3.33
5	6.175	1.34	3.70
6	6.861	1.49	4.11
7	7.623	1.66	4.57
8	8.471	1.85	5.08

for simulation purpose. The feed length of antenna (length from smallest dipole = D) plays an important role in deciding better impedance matching and return loss curve, so the feed length of antenna is properly calculated and optimized to get best return loss curve and impedance matching. The whole antenna structure is then simulated for a feed length of 6.5 mm. To check the validity of simulation, prototype of proposed antenna is developed on FR-4 Substrate (Fig. 2), and S_{11} parameter measurement is performed using Agilent N9923A Vector Network Analyzer. It is observed (Fig. 3) that antenna works effectively in the desired operating band, with satisfactory matching between simulated and measured results. The differences may be due to effect of SMA connector and mismatching tolerance. The measured results show that antenna covers a wide frequency range of 1.643 GHz from 4.869 GHz – 6.512 GHz, with bandwidth efficiency of 28.87 %, which effectively follow the IEEE 802.11a WLAN standard operating at 5 GHz band (5.15-5.35 GHz and 5.725-5.825 GHz). Further, Fig. 4 shows the gain of the antenna remains positive (>6 dB) throughout the operating band, with maximum gain of 7.6 dB at 5.6 GHz. Fig. 5,6 and 7 show E plane and H plane radiation pattern of the



(a) Front side



(b) Back side

Fig. 2. Hard ware of proposed antenna design (a), (b)

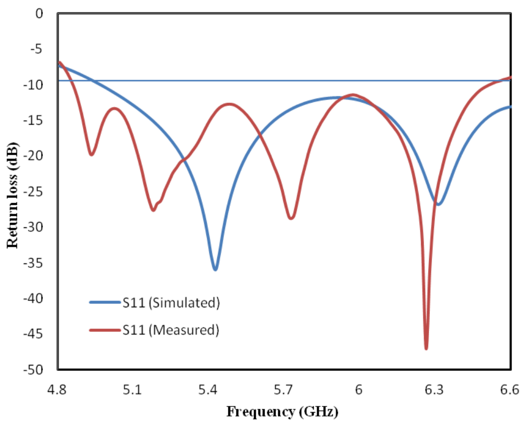


Fig. 3. Simulated S_{11} vs frequency

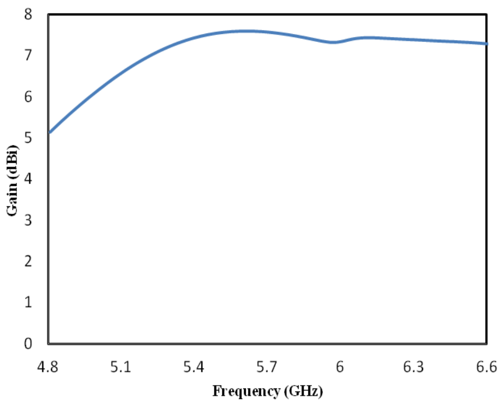
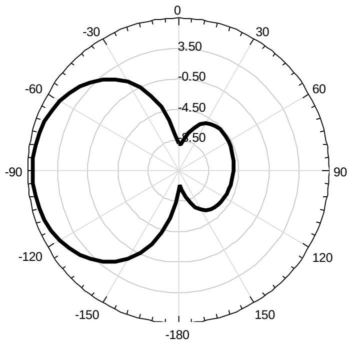


Fig. 4. Gain vs frequency



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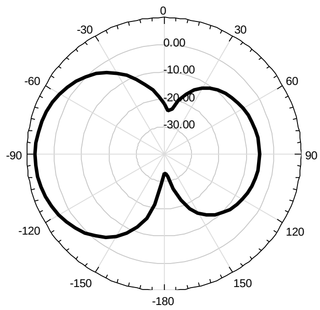
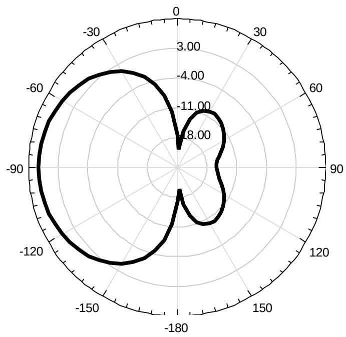


(b)

Fig. 5. Radiation pattern at f = 5.1 GHz (a) E plane (b) H plane



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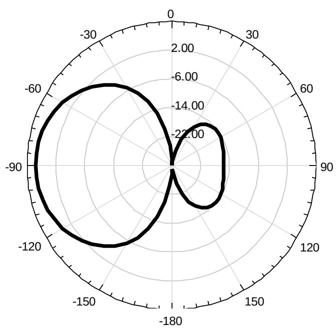
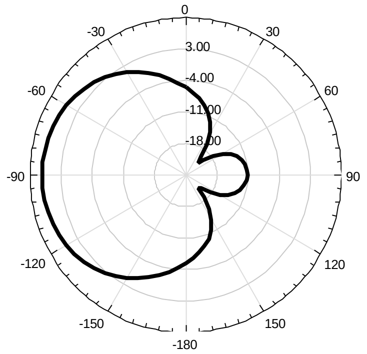
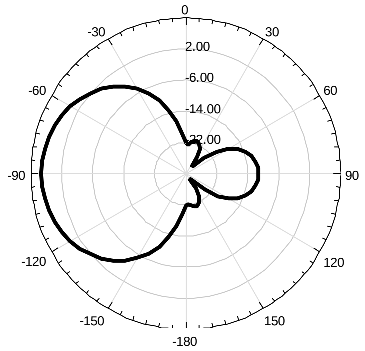


(b)

Fig. 6. Radiation pattern at f = 5.5 GHz (a) E plane (b) H plane



(a)



(b)

Fig. 7. Radiation pattern at f = 6.3 GHz (a) E plane (b) H plane

proposed antenna at 5.1 GHz, 5.5 GHz and 6.3 GHz respectively. It shows an end fire behavior within the desired frequency band.

4. CONCLUSION

This paper analyzes the design procedure of a compact printed LPDA antenna for WLAN applications in 5 GHz band. The S_{11} parameter shows good impedance bandwidth of 1.643 GHz from 4.869 GHz – 6.512 GHz, with bandwidth efficiency of 28.87 %. Also the gain of antenna is > 6dB throughout the operating band ,with maximum gain of 7.6 dB at 5.6 GHz. Antenna shows stable radiation pattern in end fire direction for whole operating band. The dimensions of antenna are 36.58 mm x 24.37 mm x 1.6 mm, shows compactness of the structure. The measured result for S_{11} parameter validates the proposed antenna design. Hence the proposed antenna is well suited in present scenario of wireless communication systems to compete the demand of wide bandwidth, high gain and stable radiation pattern. Further the size of antenna can be reduced by using fractal geometries like Koch and tree dipole structures in future. The main challenge is to achieve the same bandwidth and gain, while using these geometries.

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