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Printed Log-Periodic Dipole Antenna with Notched Filter at 2.45 GHz Frequency for Wireless Communication Applications

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Abstract: A Printed Log-Periodic Dipole Antenna (PLPDA) with notched filter at the frequency 2.45 GHz is proposed for wireless communication applications. VSWR <2.5:1 is achieved over the band. The notched filter is achieved by integrating U-shaped slot on the transmission line in order to reduce the interference from the various wireless applications operating at 2.45 GHz frequency. The proposed PLPDA is working from 1-6 GHz frequency with gain >5 dB. The band stop filter is designed with notched frequency band from 2.1-2.6 GHz and integrated with the antenna. Finally, the PLPDA is designed, fabricated and measured. The measured results are in good agreement with simulation results.

Key words: Printed Log Periodic Dipole Antenna (PLPDA), Voltage Standing Wave Ratio (VSWR), notched filter, wireless communication, U-shaped slot

INTRODUCTION

Antenna design is the most auspicious area in advanced wireless communications system due to its importance applications in numerous communication fields. Antenna is the ascendant element in every wireless communication system. An ideal antenna is the one which radiates and receives electromagnetic waves in all directions. But in reality it is not possible, it is often taken as a reference for reveal the directive properties of actual antennas. Nowadays advanced wireless communication system requires antennas attaining compact, low profile, high directivity, broadband, unfaltering radiation pattern over the frequency band. So as to achieve low profile, the PLPDA antenna was designed based on the printed Circuit technology, called printed log-periodic dipole arrays antenna (Balanis, 1989). The structure of antenna was utterly itemizing by angle and its performance is distinct of frequency called frequency independent antennas. If a plot is made against the input impedance as a function of frequency the change will be found as repetitive. If the plot is made of the logarithm of frequency instead of frequency the change will be periodic that gives rise to the name "log-periodic" (Madhav *et al*., 2011). The bandwidth of the log-periodic array can be enhanced by the longest and shortest dipole elements. The longest dipole shows the lower cut-off frequency and the shortest dipole shows the highest cut-off frequency. Log periodic antennas are frequency independent antennas which theoretically have no limitation on bandwidths. In these antennas, the linear dimension depends on frequency bands and antennas performance repeats periodically as a function of logarithm of frequency resulting in extremely broad-band antennas. State of the art fabrication techniques like chemical milling and chemical etching have been used to realize the frequency of operation up to 26 GHz. These antennas find extensive use in sector surveillance, RDF, amplitude comparison direction finder, base line interferometer, communication links, etc. And have been configured to suit all the platforms of the services. The log periodic antennas are the most versatile antennas used in communication band for search, monitoring and direction finding. These antennas are used for ionospheric sky wave communication ranging from short to medium and long ranges. The structure alters with some replication by a persistent scaling factor τ so that the structure grows. The length, diameter, their spacing and gap spacing at dipole centres labelled as l, d, R, S of the log-periodic array alters logarithmically as defined by the inverse of the geometric ratio τ, i.e.:

$$\frac{1}{\tau} = \frac{l_{n+1}}{l_n} = \frac{R_{n+1}}{R_n} = \frac{d_{n+1}}{d_n} = \frac{s_{n+1}}{s_n} \quad (1)$$

Another parameter that is generally integrated with a dipole array is the spacing factor σ defined as:

$$\sigma = \frac{R_{n+1}-R_n}{2l_{n+1}} \quad (2)$$

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DESIGN METHODOLOGY OF THE PLPDA

The antenna has been designed and simulated with the help of electromagnetic simulation software High Frequency Structure Simulator (HFSS). The PLPDA is designed to operate between 1-6 GHz. The antenna is printed on RT DUROID 5880™ substrate with dielectric constant 2.2 and thickness of 1.6 mm. The antenna's every successive dipole element printed on reverse side of the substrate in order to achieve 180 degree phase shift (Yu *et al*., 2010; Blake and Long, 2009; Chauloux *et al*., 2014). The antenna is fed with coaxial cable and it is run through one side of the printed transmission line up to the shortest element. And the inner conductor of the cable is soldered and connects to other side of the transmission line (Casula *et al*., 2013). The general configuration of a PLPDA is described in terms of the design parameters τ, α and σ related by:

$$\alpha = \tan^{-1}\left[\frac{1-\tau}{4\sigma}\right] \quad (3)$$

$$\tau = 1-4\sigma[\tan\alpha] \quad (4)$$

Once two of them are specified, the other can be found. In this proposed PLPDA, we have taken $\tau = 0.83$, $\sigma = 0.107$. The width of the active region depends on the specific design. Carrel (1961) has introduced semi empirical equation to calculate the bandwidth of the active region B_{ar} related to α and τ by:

$$B_{ar} = 1.1+7.7(1-\tau)^2\cot\alpha \quad (5)$$

In practice a slightly larger bandwidth (B_s) is usually designed than that which is required then the two are related by:

$$B_s = BB_{ar} = B[1.1+7.7(1-\tau)^2\cot\alpha] \quad (6)$$

Where:

B_s = Designed bandwidth
B = Desired bandwidth
B_{ar} = Active region bandwidth

The total length of the structure is:

$$L = \frac{\lambda_{max}}{4}\left[1-\frac{1}{B_s}\right]\cot\alpha \quad (7)$$

$$\lambda_{max} = 2l_{max} = \frac{\nu}{f_{min}} \quad (8)$$

Table 1: Geometry of the PLPDA

.Dipole	L (mm)	W (mm)	S_{ij} (mm)
1	180.72	7.2	40.9
2	150.00	6.0	34.0
3	124.50	6.0	28.2
4	103.30	4.9	23.4
5	85.70	4.9	19.4
6	71.10	4.1	16.1
7	59.00	4.1	13.3
8	49.00	3.4	11.1
9	40.70	3.4	9.2
10	33.70	2.8	7.6
11	28.00	2.8	6.3
12	23.20	2.3	5.2
13	19.30	2.3	4.3
14	16.00	1.9	3.6
15	13.30	1.9	-

The No. of elements are determined by Balanis (1989):

$$N = 1+\frac{\ln(B_s)}{\ln(1/\tau)} \quad (9)$$

Table 1 shows the optimized values of printed log-periodic dipole antenna which describes the length of the dipoles (L), width of the dipole elements (W) and spacing between the successive dipole elements (S_{ij}).

DESIGN OF THE U-SHAPED SLOT

To realize band-notched characteristic, band-stop filter should be integrated into the antenna design. There are numerous band stop filter designs are available. In this study, U-shaped slots are used to obtain notched band and are shown in Fig. 1. Compared to other slots like L, T and H, U-shaped slots are flexible to design and easily inserted into the design (Kim *et al*., 2006; Chen *et al*., 2006). The location of U-shaped slot should be optimized to in order to obtain desired results. The physical length of the U-shaped slot is about quarter-wavelength at the notched frequency such that the slot radiates and arrests the signal. The U-shaped slot effectively reflects the signal power back to the excitation port, thereby reducing the interference with the other signal at the designed notch frequency. The fabricated PLPDA with notched filter is shown in Fig. 2.

The relationship between the length of the U-shaped slot and the notched frequency can be approximated by Yu *et al*. (2010):

$$L_u = \frac{c}{4f_{notch}\sqrt{\varepsilon_{eff}}} \quad (10)$$

Here:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+\frac{12h}{w}}} \quad (11)$$

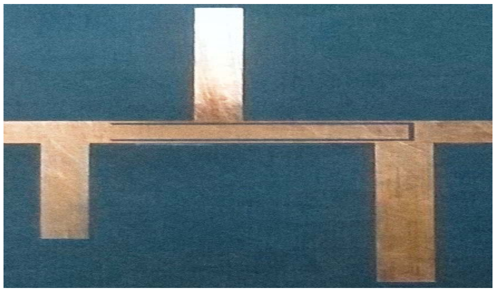

Fig. 1: U-shaped slot in PLPDA

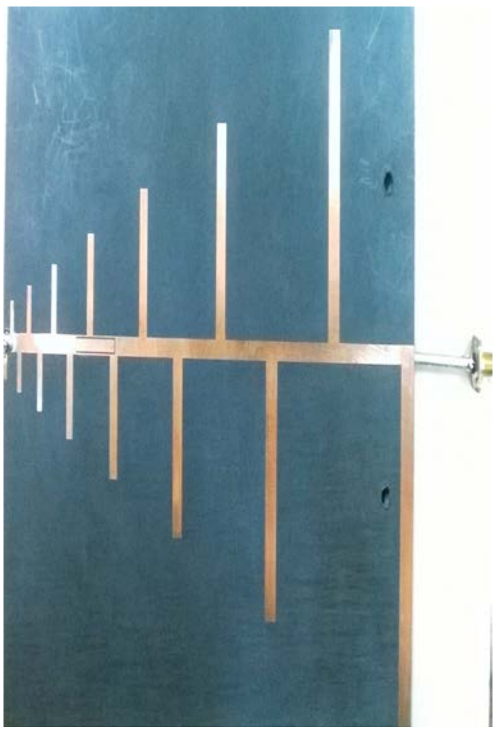

Fig. 2: Fabricated PLPDA with notched filter

Where:

ε_r = Relative permittivity of the substrate
H = Thickness of the substrate
w = Width of the longest dipole
f_{notch} = Notched frequency

SIMULATED AND MEASUREMENT RESULTS

The numerical simulation and measurements of PLPDA have been done for the frequency band of 1-6 GHz. The performance of PLPDA does not improve monotonically as the parameters of the antenna changes. It must be optimized through analysis during simulation to get the optimum parameters.

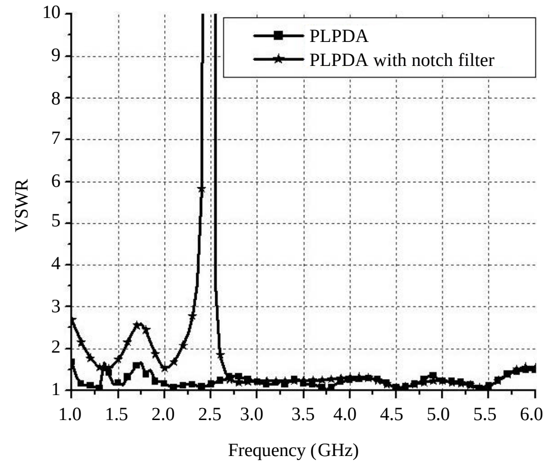

Fig. 3: Simulated VSWR of proposed PLPDA

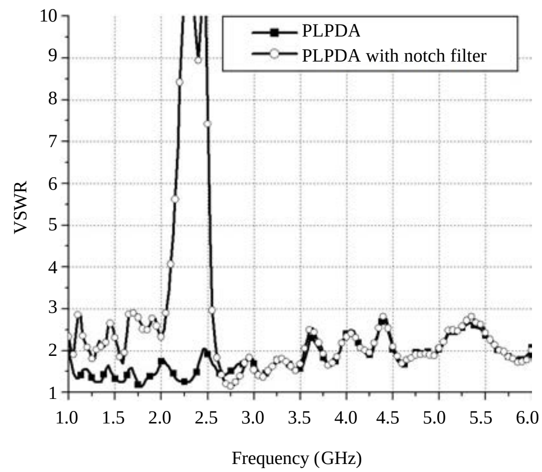

Fig. 4: Measured VSWR of proposed PLPDA

Voltage Standing Wave Ratio (VSWR) measurement: Figure 3 shows the simulated VSWR of proposed PLPDA with and without notch filter. From the Fig. 3, it is seen that the simulated VSWR of PLPDA is <2:1 over the band. Using notch filter (Blake and Long, 2009) the VSWR is >10:1 at the desired notch frequency. Figure 4 shows the measured VSWR of proposed PLPDA with and without notch filter (Blake and Long, 2009). From the Fig. 4, it is seen that the measured VSWR of PLPDA is <3:1 over the band except at the notched frequency band (Blake and Long, 2009) which is in agreement with simulated results.

Radiation pattern and gain measurement: Figure 5 shows the measured E plane patterns of the PLPDA and Fig. 6 shows the measured H plane patterns

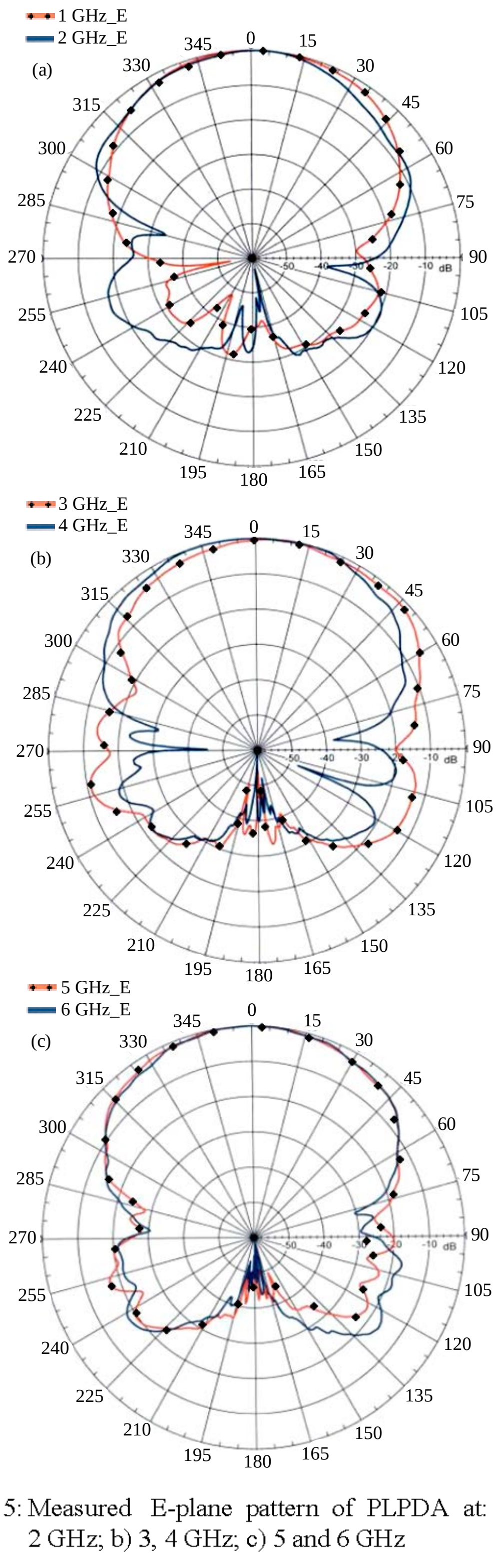

Fig. 5: Measured E-plane pattern of PLPDA at: a) 1, 2 GHz; b) 3, 4 GHz; c) 5 and 6 GHz

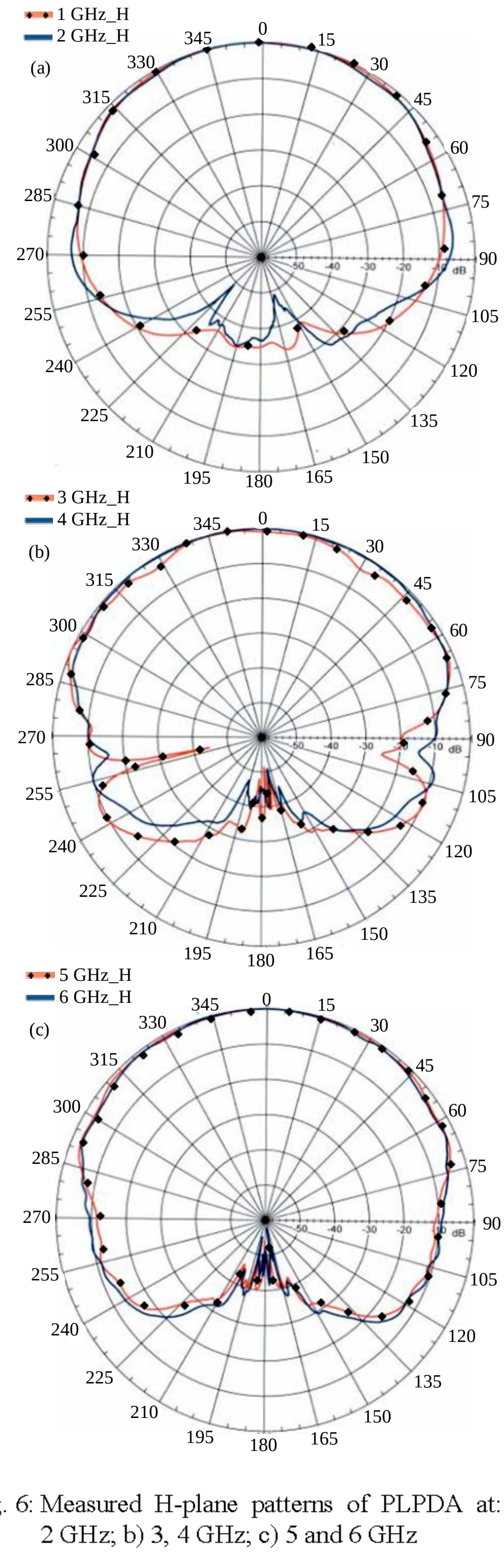

Fig. 6: Measured H-plane patterns of PLPDA at: a) 1, 2 GHz; b) 3, 4 GHz; c) 5 and 6 GHz

of the PLPDA. From the Fig. 6, it is seen that the beam width of the H-plane patterns are more than E-plane patterns due to omni direction property of individual dipole elements. The 3 dB beam width of E-plane and H-plane patterns varies from 55.6°-85.7° and 102°-137.9° over the frequency band.

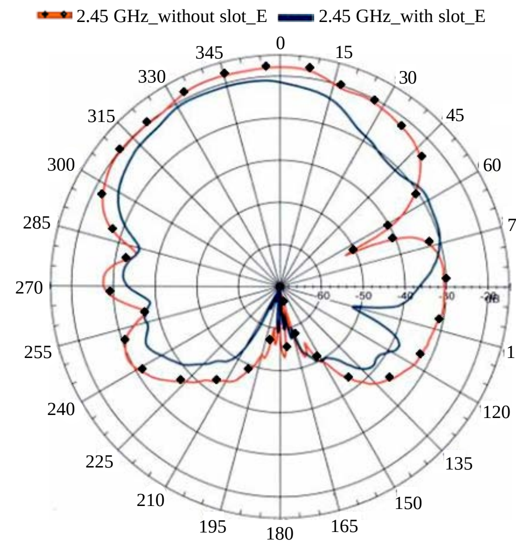

Fig. 7: Measured E-plane pattern of PLPDA at 2.45 GHz with and without U-shaped slot

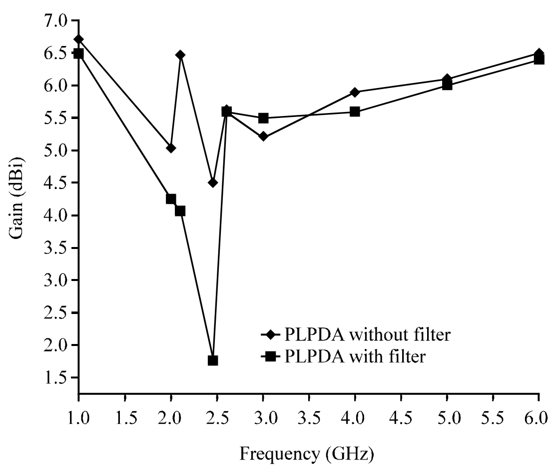

Fig. 8: Measured gain comparison of LPDA without slot and with slot

Figure 7 shows the gain comparison results of the antenna with slot and without slot (Yu *et al.*, 2010) at 2.45 GHz. From Fig. 8, it is seen that there is 3 dB suppression in gain by using notch filter.

CONCLUSION

The simulated and measured results show a good agreement. The measured VSWR is 2.5:1 over the band except at the notched band. At the notched centre frequency of 2.45 GHz, the VSWR is 11:1 which is required to reject the unwanted interference signals. The antenna gain is quite stable over the required frequency range with an average value equal to 5.5 dBi. This optimum performance is achieved by the parametric analysis of the PLPDA using EM simulation software. The spacing between the dipole elements is limited to 34 mm and the scaling factor has been taken as 0.83. The proposed PLPDA find wide applications in wideband communication system where minimum signal interference are desired in particular frequency band.

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