Modified Planar Log Periodic Dipole Array Antenna For IEMI Detection

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***Abstract*—We are interested in designing an antenna in the frequency band of 0.5 GHz to 2 GHz for Intentional Electromagnetic Interference (IEMI) detection application. We modify the conventional planar log-periodic dipole array (CPLPDA) antenna, and design a modified planar log-periodic dipole array (MPLPDA) antenna to achieve better gain over the desired frequency band. The gain improvement in MPLPDA antenna is done by increasing the length of the dipole which is loaded at low frequency. We provide the design of MPLDA antenna and obtain its performance through simulations using Ansys High Frequency Structure Simulator (HFSS) 2019 R3.7 electromagnetic simulation software. Using simulations, we show that MPLPDA antenna achieves an average gain of 4 ±0.5 dB. Also, compared to CPLPDA antenna, the MPLPDA antenna has a better gain performance at low frequencies by around 1.5 dB. The proposed MPLPDA antenna will revolutionise the safety of electronic systems from IEMI attacks.**

***Index Terms*—Broadband antenna, conventional planar log periodic dipole array antenna (CPLPDA), gain, intentional electromagnetic interference (IEMI) detection, modified planar log periodic dipole array antenna (MPLPDA).**

I. INTRODUCTION

Over the last few decades, electronic systems are ubiquitous as in personal communications, industries, military, etc. However, electronic systems are vulnerable to Intentional Electromagnetic Interference (IEMI). The IEMI can cause any malfunction or degradation in system performance. The protection of electrical and electronic systems from IEMI attacks is very important for proper functioning of electronic systems. Thus, IEMI is a point of concern and important research topic in the EMC society. In this regard, the International Electrotechnical Commission (IEC) has been developing standards to protect commercial equipment and systems, which is entitled "EMC: High power transient phenomena." Shielding techniques such as Faraday's cage, shielded room, shielded racks/cabinets, grounding of shielded rooms and cabinets, cable filters [1], are developed to counteract IEMI.

Even though shielding techniques are effective to mitigate IEMI radiation, detection and diagnosis of IEMI radiation is important to secure the system more effectively from IEMI attacks. In [2], a study has been done on susceptibility of electronic devices to high pulse microwave (HPM), which has been carried out by Swedish Defence Research Agency, FOI and Swedish Defence Material Administration, FMV. It has been observed that the interference effects are much more prominent at low frequencies (L and S band) compared to high frequencies. IEMI signals can reach a distance of about a kilometer and are capable of damaging electronic systems permanently [2]. Therefore, as required by various EMC standards, different types of antennas such as biconical antenna [3], horn antenna [4], wired Log Periodic Antenna [5], combilog antenna [6], active loop antenna [7] and sleeve dipole antenna [8] have been used for emissions measurements. The antennas used for emissions measurements are typically of broadband to cover a wide band of frequencies. In emissions measurements, biconical antennas are used for a frequency range between 30 and 300 MHz, and log-periodic dipole array antenna used for frequency range between 300 and 1000 MHz, and beyond [8]. The broadband antennas are large in size and maintaining constant gain over the desired frequency band is difficult to achieve, and hence, the use of such antennas is limited for practical applications.

In [9], triangular shaped dipoles have been designed to achieved reduction in total area of antenna. Also, triangular shaped dipoles achieve nearly constant gain of 7.2 ± 0.5 dB over the frequency band of 570 MHz to 2.75 GHz. A sinusoidal-shaped dipoles printed log periodic antenna using stepped dielectric loaded materials achieve size reduction with width 0.28λ over a frequency band of 200 to 803 MHz [10].

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In [11], a folded planar helix (FPH) dipole shape PLPDA antenna has been introduced to achieve gain improvement at low frequency with miniaturization of PLPDA antenna. The antenna achieve a stable radiation pattern and 5.7 dBi average gain for the operating frequency band of 400 MHz to 800 MHz. A T-shaped dipole element top loadings PLPDA has been studied to reduce the antenna structure to 55% compared to PLPDA antenna. The average gain of 5.1 dBi for the operating frequency band of 0.82 GHz to 2.09 GHz has been reported [12]. In [13], a Hat and T-shaped top loadings dipole element PLPDA has been shown to reduce the antenna size. A meander feedline and a trapezoidal stub were introduced into the antenna structure at low frequency to improve the performance of the antenna. The measured gain achieved from 2.48 to 7.89 dBi for the operating frequency band from 0.55 to 9GHz has been reported.

In this paper, we introduce conventional planar log-periodic dipole array (CPLPDA) antenna for Intentional Electromagnetic Interference (IEMI) detection on a critical network. We propose a modified planar log-periodic dipole array (MPLPDA) antenna to overcome the drawbacks of broadband antenna. MPLPDA antenna is a modified version of CPLPDA antenna. CPLPDA antenna and MPLPDA antenna provide desired band coverage for detection of IEMI signals. The CPLPDA antenna and MPLPDA antenna operating from 0.5 GHz to 2 GHz is designed to be implemented in a device for detection of IEMI on a critical network. CPLPDA antenna and MPLPDA antenna is a type of broadband antenna. Different applications of broadband antennas are emission measurements [8], RF energy harvesting system [9], airborne applications [10], direction finding of radio wave [11], 5G communication, radar and mobile imaging applications [12]. The MPLPDA antenna and the CPLPDA antenna are compared to other state-of-the-art antennas. It is observed that the MPLPDA antenna provide nearly constant gain of 4 ±0.5 dB and also both MPLPDA antenna and CPLPDA antenna antenna achieve stable radiation patterns for the desired frequency band.

The rest of the paper is organized as follows. Section 2 discusses the CPLPDA antenna design and the proposed modified PLPDA antenna design is described in Section 3. In Section 4, we provide simulation results of the proposed MPLPDA antenna and compare its performance with that of CPLPDA antenna. In Section 5. we conclude the paper.

II. Conventional Planar Log-Periodic Dipole Array Antenna Design

The CPLPDA antenna for the frequency range 0.5 GHz to 2 GHz is designed. The basic step to design CPLPDA antenna has been obtained from the Carrel design procedure given in [13]. The conventional PLPDA antenna is shown in Figure 1. The CPLPDA antenna has been carried out on a FR4 substrate having thickness h = 0.16 cm with dielectric constant $\in_r$ = 4.4 and loss tangent $\tan_d$ = 0.02. From equation 1 we have calculated the apex half angle $\alpha = 34°$. The approximate number of dipole elements 'N' required for the CPLPDA antenna design is given by Eqn. (2). 16 dipole elements are

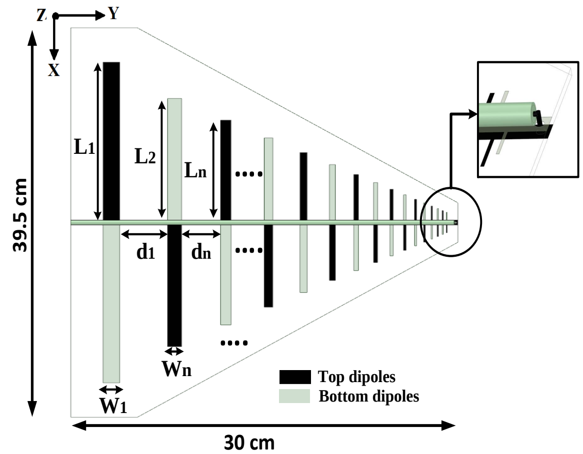


Fig. 1. Conventional PLPDA antenna.

used in CPLPDA antenna with a scaling factor τ of 0.822 and spacing factor σ = 0.149.

$$\alpha = 2\tan^{-1}\left\{\frac{1-\tau}{4\sigma}\right\}, \tag{1}$$

$$N = 1+\frac{\log_{10}(B_s)}{\log_{10}\left(\frac{1}{\tau}\right)} = 1+\frac{\ln(B_s)}{\ln\left(\frac{1}{\tau}\right)}, \tag{2}$$

where, B_s is relative bandwidth of the antenna structure given by Eqn. (3).

$$B_s = B \cdot B_{ar} \tag{3}$$

B and B_{ar} are relative operating bandwidth and the bandwidth of the active region, and are given by

$$B = \frac{f_{high}}{f_{low}}, \tag{4}$$

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

The lengths of the largest dipole element and smallest dipole element have been calculated depending on the smallest and the largest frequency. The lengths of other dipoles have been obtained using the scaling factor as shown in Eqn. 6.

$$\frac{1}{\tau} = \frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n} = \frac{W_{n+1}}{W_n}, \tag{6}$$

where $n = 1, 2, \cdots, N$. W_n is the width of the dipole and it is determined from Eqn. (6).

In CPLPDA antenna design, scaling factor (τ), spacing factor (σ), and aperture angle (α) are important and their values affect the antenna geometry. The largest element (L_1) has been calculated depending on the smallest frequency, and can be determined using the following equations

$$L_1 = \frac{\lambda_L}{2} \tag{7}$$

where,

$$\lambda_L = \frac{c}{f_{\min} \times \sqrt{\varepsilon_r}}. \tag{8}$$

The lengths of other dipoles (L_n for n = 2 to 16) are computed using

$$L_{n+1} = \tau L_n. \tag{9}$$

The centre to centre spacing between the longest dipole element and its adjacent dipole element is calculated using Eqn. (10). The other dipole elements spacing of d_n for $n = 2$ to 16 are computed using Eqn. (11).

$$d_n = 2\sigma . L_n, \tag{10}$$

$$d_{n+1} = \tau d_n. \tag{11}$$

The boom width is 0.5 cm which is the feed line of the antenna having 50 Ω line characteristic impedance. It is observed after a parametric study that the length of the longest dipole L_1 is 16.0 cm, width of the dipole W_1 is 1.3 cm, and centre to centre spacing between the first two longest dipoles d_1 is 3.7 cm. The feed to the CPLPDA antenna has been done through coaxial cable feed at the shortest dipole side while placing the coaxial cable connector at the longest dipole side. The coaxial cable inner conductor is attached to feed line at the bottom of the antenna through a via-hole in the substrate. The optimization and gain improvement of LPDA antenna through mode converter balun is described in [19, 20].

III. Modified Planar Log-Periodic Dipole Array Antenna Design

The MPLPDA antenna for the frequency range 0.5 GHz to 2 GHz is designed. The MPLPDA antenna has been designed using the Carrel design procedure [13]. The main objective of MPLPDA antenna is to achieve a nearly flat gain over the desired frequency band. Figure 2 shows the schematic of the proposed MPLPDA antenna.

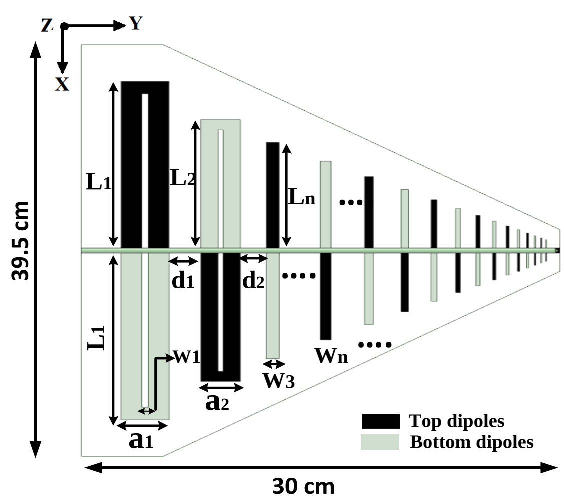


Fig. 2. Modified planar log periodic dipole array antenna.

The MPLPDA antenna has been carried out on a FR4 substrate having thickness h= 0.16 cm, dielectric constant $\in_r$ = 4.4, and loss tangent $\tan_d$ = 0.02. The approximate number of dipole elements 'N' required for the MPLPDA antenna design is given by Eqn. (2). 16 dipole elements are used in MPLPDA antenna with a scaling factor $\tau = 0.822$ and a spacing factor σ = 0.149.

The lengths of the largest and the smallest dipole elements have been calculated depending on the smallest frequency ($f_{\min}$) and the largest frequency ($f_{\max}$). The largest dipole element (L_1) has been determined as follows.

$$L_1 = \frac{\lambda_L}{2}, \tag{12}$$

where

$$\lambda_L = \frac{c}{f_{\min} \times \sqrt{\varepsilon_r}}. \tag{13}$$

In MPLPDA antenna, the length of the longest dipole and its adjacent dipole at low frequency is considered as double the length 'L_1' and folded length of dipole. Since, the CPLPDA antenna dipole length is λ/2, the MPLPDA antenna introduced bending of λ/4 dipole length. The bending of the dipole enhance the gain of the antenna [14]. In MPLPDA antenna we have considered 90° bending of λ/4 dipole at low frequency to increase the gain. The bending of the dipole increase the resonating capabilities of dipole antenna at low frequency. The total length of the longest dipole and adjacent dipole of MPLPDA antenna is

$$\text{Length}_1 = 2L_1 + a_1, \tag{14}$$

$$\text{Length}_2 = 2L_2 + a_2, \tag{15}$$

where Length_1 and Length_2 are the total lengths of first and second dipoles, and a_1 and a_2 are width of the dipoles as mentioned below

$$a_1 = W_1 * 2 + w_1, \tag{16}$$

$$a_2 = W_2 * 2 + w_2, \tag{17}$$

where w_1 and w_2 are the width of the dipole bend, W_1 and W_2 is the width of the dipole, and they are determined from Eqn. (6). The lengths of other dipoles (L_n for $n = 2$ to 16) has been obtained using Eqn. (18).

$$L_{n+1} = \tau L_n. \tag{18}$$

Due to bending of the longest dipole and adjacent dipole at low frequency, the dipole element spacing d_1 and d_2 is reduced. The value of d_1 and d_2 achieved is equal to 2 cm and 1.62 cm. The other dipole element spacing d_n for n = 3 to 16 are same as CPLPDA antenna. The boom width is 0.5 cm which is known as the feed line of the antenna having 50 Ω line characteristic impedance. It was observed after a parametric study that the length of the longest dipole L_1 obtained is 16.0 cm, width of the dipole a_1 is 3.1 cm. The feed to the MPLPDA antenna have been done through coaxial cable feed at the shortest dipole while placing connector of the coaxial cable at the longest dipole end. The coaxial cable inner conductor is attached to feed line at the bottom of the antenna through a via-hole in the substrate.

The CPLPDA antenna and MPLPDA antenna possess low quality factor (Q factor). The characteristics of the Q factor is to estimate the bandwidth of the antenna and also to identify the electrically small antennas. The Q factor is given by [15]

$$Q = \frac{(f_{min} + f_{max})/2}{f_{max} - f_{min}}. \tag{19}$$

From Eqn. (19), we achieve Q factor of approximately 0.83. So, Eqn. (19) is not accurate for Q<2 [15]. Therefore, McLean corrected the Q factor which is valid for all Q<2 [16]. The antenna with low Q factor achieve wide band whereas the antenna with high Q achieve narrowband. The input impedance is very sensitive to small changes in frequency at high Q value. Therefore, the proposed MPLPDA antenna and CPLPDA antenna achieved wide bandwidth.

IV. Simulation Results

In this Section, we perform various simulations of CPLPDA antenna and MPLPDA antenna, and analyse their performance. The simulated reflection coefficient is shown in Figure 3. We observe from the simulation result that $|S_{11}| \leq$ -10 dB from 0.5 GHz to 2 GHz. Hence, the CPLPDA antenna and MPLPDA antenna achieve impedance matching for the desired frequency band. The gain obtained by CPLPDA is between 1.8 to 5.2 dB whereas the proposed MPLPDA antenna has an average gain of 4±0.5 dB which is nearly constant across the entire desired frequency band as shown in Figure 4. The proposed MPLPDA antenna is superior to the CPLPDA antenna with respect to the gain of the antenna as the bending of the dipoles increases the gain at low frequency. The gain of the CPLPDA antenna at 0.5 GHz is 1.8 dB whereas the gain of the MPLPDA antenna at 0.5 GHz is 3.5 dB.

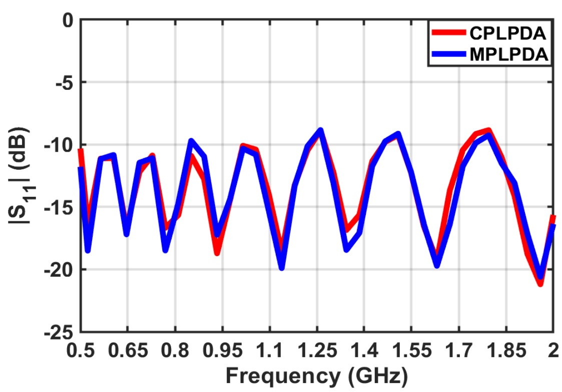


Fig. 3. Reflection Coefficient.

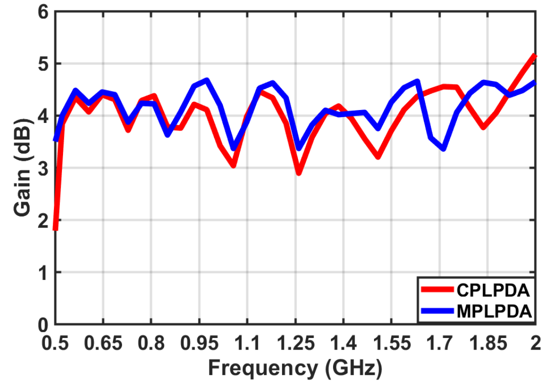


Fig. 4. Gain (dB).

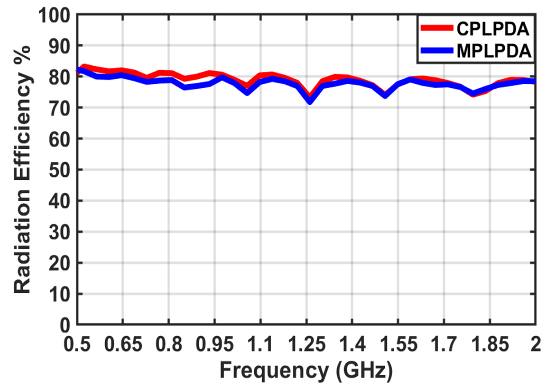
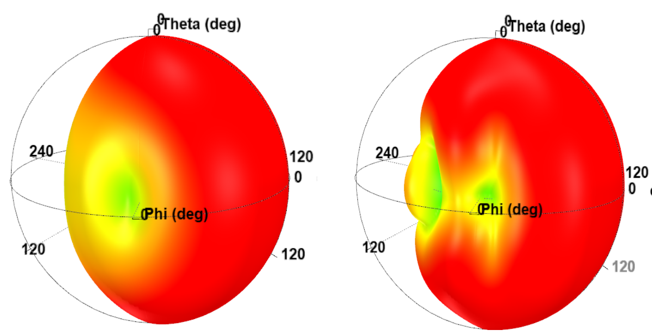


Fig. 5. Radiation efficiency (%).



(a) (b)

Fig. 6. 3D Radiation Pattern of CPLPDA antenna (a) 0.5 GHz (b) 2 GHz

Figure 5 shows the radiation efficiency of the CPLPDA antenna and MPLPDA antenna. We achieve more than 70% radiation efficiency for the desired frequency range for both antennas. Figure 6 shows the simulated 3D radiation patterns of CPLPDA antenna at frequencies 0.5 GHz and 2 GHz. Figure 7 shows the simulated 3D radiation patterns of MPLPDA antenna at frequencies 0.5 GHz and 2 GHz. It shows the CPLPDA antenna and proposed MPLPDA antenna radiates in endfire direction, i.e., the direction of maximum radiation is along the horizontal Y-axis. The E-plane and H-plane at frequencies 0.5 GHz, 0.7 GHz, 0.8 GHz, 1.25 GHz, 1.5 GHz, and 2 GHz are shown in Figure 7. The stable radiation pattern is achieved across the entire bandwidth. Also, we achieve better front-back ratio due to bending of $\lambda/4$ dipole at low frequency. The uniform radiation pattern shows that the MPLPDA antenna is a frequency independent antenna. The CPLPDA antenna and the proposed MPLPDA antenna achieve an average 3dB beamwidth of 75° for the desired frequency band.

Table 1 shows the comparison of the proposed MPLPDA antenna with the existing state-of-the-art PLPDA antenna. It is observed that the MPLPDA antenna achieves high gain at low frequency with nearly constant gain as compared to

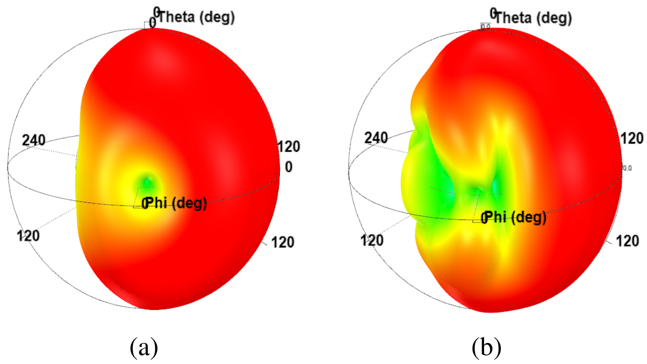


Fig. 7. 3D Radiation Pattern of MPLPDA antenna (a) 0.5 GHz (b) 2 GHz

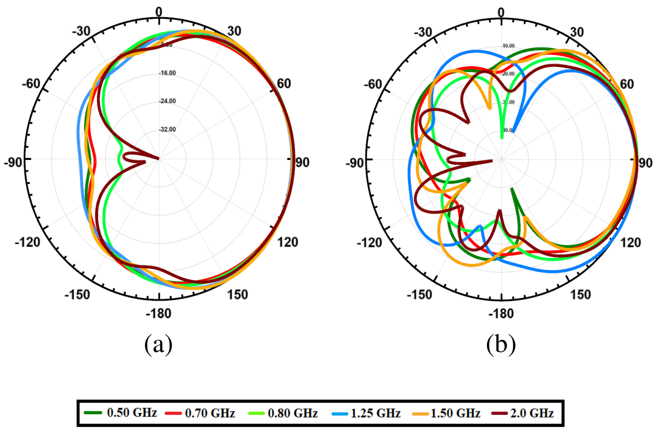


Fig. 8. 2D Radiation Pattern of CPLPDA antenna(a)E-Plane (b)H-Plane

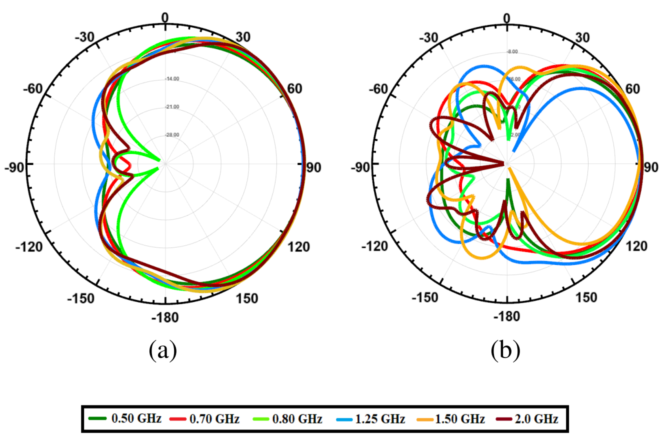


Fig. 9. 2D Radiation Pattern of MPLPDA antenna(a)E-Plane (b)H-Plane

CPLPDA antenna, Hat and T top-loaded approach [18], T top-loaded approach [17] and dielectric loaded LPDA [10]. In comparison with [9], we achieve a nearly stable gain for the desired frequency band. Compared to [21], we achieve a better average gain for the desired frequency band.

The CPLPDA and MPLPDA antennas have been proposed to detect Intentional Electromagnetic Interference (IEMI) attacks on critical networks. The proposed antennas provide safety from IEMI to most of the mobile operating frequency bands like CDMA, GSM900, GSM1800, 3G, and 4G.

TABLE I
COMPARISON OF EXISTING STATE-OF-THE-ART DIPOLE SHAPES OF PLPDA ANTENNA WITH PROPOSED MPLPDA ANTENNA

Dipole Shape	Substrate, ϵ_r	Bandwidth ($S_{11} \leq$ -10 dB)	Gain (dB)
Triangular [9]	FR4, 4.4	0.57–2.75 GHz	7.2 $\pm$ 0.5
dielectric-loaded LPDA [10]	Polyflon, 2.55	0.2–0.803 GHz	3.2-5.5
Folded Planar Helix [11]	FR4, 4.5	0.4–0.8 GHz	5.7
T-shaped top-loaded [17]	styrofoam, 1.06	0.85-2.2 GHz	2.3-6.1
Hat and T top-loaded [18]	RO4003C, 3.55	0.5-8.5 GHz	2.4-7.8
Tapered [21]	RO4003C, 3.55	0.06–0.233 GHz	4.5
CPLPDA	**FR4, 4.4**	**0.5–2 GHz**	**1.8 - 5.2**
Modified PLPDA	**FR4, 4.4**	**0.5–2 GHz**	**4 $\pm$ 0.5**

V. CONCLUSION

The CPLPDA antenna and MPLPDA antenna have been designed to be implemented in a device for detection of Intentional Electromagnetic Interference (IEMI) on a critical network. The length and width of MPLPDA antenna is the same as a conventional PLPDA antenna. In the MPLPDA antenna, the changes are done at the low frequency end dipole. We introduced the bending of the dipole on the MPLPDA antenna structure. It has been observed that the MPLPDA antenna is superior to CPLPDA antenna as MPLPDA antenna achieves higher gain at lower frequency, and also gain of 4 $\pm$ 0.5 dB for the desired frequency band. The CPLPDA antenna and MPLPDA antenna achieve stable radiation pattern in the endfire direction with radiation efficiency more than 70 % for the desired frequency band. The advantage of CPLPDA antenna and MPLPDA antenna is that the antennas can be embedded in any portable device. The application of CPLPDA antenna and MPLPDA antenna is to detect IEMI signals on a critical network.

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