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DESIGN AND ANALYSIS OF LOG PERIODIC DIPOLE ARRAY ANTENNA

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Abstract

In this paper, Log Periodic Dipole Array Antenna is proposed for frequency range from 800MHz to 6GHz. Frequencies of interest for proposed antenna are CDMA (880MHz), GSM 900 (940MHz), GSM 1800 (1.84GHz), 3G (2.14GHz), 4G (2.35GHz), Wi-Fi (2.45GHz), Wi-Fi (5.1GHz), etc. The above are targeted frequencies because this antenna can be used for CDMA, 2G, 3G, 4G and Wi-Fi frequencies. Wideband log periodic antenna operating from 800MHz to 6GHz with 10 dipoles is designed, simulated on HFSS software and is realized on 1.6 mm Epoxy FR4 substrate. Designed antenna has advantages like wide bandwidth, simple design and the measured results are persistent with theoretical results. Antenna results indicate reflection coefficient below -10dB for whole band from 800MHz to 6GHz. The overall gain obtained is 4dB. This paper discusses complete idea about the LPDA and its design equations. Several parameters of antenna are evaluated and such antennas are used for applications like field strength meter.

Keywords:

LPDA, HFSS, Return Loss, VSWR, Impedance, VNA

1. INTRODUCTION

The rapid development in communication system has increased the necessity of wide bandwidth. Despite of its bulkiness Log Periodic Dipole Array antenna is used to fulfill wide bandwidth and high gain requirement. LPDA is capable of working on High frequency, very high frequency and ultra-high frequency. Log periodic antenna was invented by Dwight E. Isbell and Raymond DuHamel was licensed by University of Illinois at Urbana Champaign. The main invention of this type of antenna was to increase the useful frequency band of UHF and VHF antenna. LPDA antenna is a dipole antenna with longest dipole works as reflector and successive dipoles act as directors. Bandwidth is improved by adding the number of dipoles. All dipoles in LPDA are active elements resonating at its particular center frequency provided that the dipole length should be half of the wavelength. The longest dipole resonates at lowest frequency and shortest dipole resonates at highest frequency. Printed microstrip antennas are low in cost, compact, lightweight and small in size. In microstrip LPDA dipoles are connected to feed line through crisscross connection and phase reversal is present between two dipoles. In crisscross connection the half part of dipole is placed on the upper part of substrate and another half part of dipole is placed on the lower part of the substrate [1]. Phase reversal is obtained by placing alternate dipole on opposite side of substrate. Feed lines and dipoles are printed on both sides of the substrate, due to this ground plane is absent. Microstrip log periodic antenna has feed line on both sides of substrate. The radiation pattern of log periodic antenna is unidirectional and the main lobe is along the axis of the boom [7]. Array of dipole antenna is fed with equal and opposite phase. All dipole elements are fed with successive elements out of phase and radiates in end fire direction.

The aim of this antenna is to achieve the wideband from 800MHz to 6GHz. As this antenna is designed for the application of field strength meter the frequencies of interest are CDMA (880MHz), GSM 900 (940MHz), GSM 1800 (1.84GHz), 3G (2.14GHz), 4G (2.35GHz), Wi-Fi (2.45GHz), Wi-Fi (5.1GHz), etc.

In 2018, 2-18GHz conformal low profile log periodic array on cylindrical conductor is designed. It employs monopoles of different heights for the high band, folded top-hat monopoles for the low band and top-hat monopoles for the middle band. The top hats help to achieve a low profile of the monopoles while the folding is to maintain a good input resistance at the low band. At bottom micro strip line is used to feed the array [1]. A printed log periodic monopole antenna is designed and developed in 2018. 12 monopoles are designed on single side of substrate, working from 8.4 to 14.6GHz frequency range and this antenna is fabricated using standard circuit board process [2]. In 2011, an ultra-wide band log periodic antenna is prepared having many notched bands. This notch antenna is designed for bandwidth 3.1GHz to 10.6GHz. Several antennas were designed for frequencies of 3.5GHz, 5.5GHz, 6.8GHz and 8.5GHz [4]. In 2014, high gain log periodic antenna was designed using Taguchi initialized invasive weed optimization. And this optimization is used to tilt the main lobe slightly from horizontal plane and for null filling under the main lobe [5].

Mistry and Xenos [7] has designed a log periodic antenna which has 12 dipoles. The operating range of these antennas is 0.8GHz to 2.5GHz. The unique thing done in this antenna is that the substrate thickness of epoxy FR4 material is1mm. And normally the thickness of substrate is 1.6 mm. And the feed line used is 1mm. This paper contains CAD (computer aided design) model for the proposed PLPDA in CST. This antenna is proposed for L-Band EMC applications. In this paper for optimization of this antenna TRF algorithm is used. Usually in log periodic antenna the port is connected near the longest dipole side which resonates on lower frequency. But this paper the port is connected from the shortest dipole side and the shortest dipole resonates at highest frequency [7]. In 2014, constant radiation characteristics of log periodic dipole array antennas are measured. And the correct terminal voltages on each element of log periodic dipole array constant radiation characteristics can be achieved for an Omni-directional radiation pattern [8].

2. ANTENNA DESIGN

In LPDA all the dipoles are active elements, the longest dipole works as reflector and successive dipoles act as directors. The Fig.1 shows the structure of log periodic dipole array antenna. This antenna is directive and shows end fire radiation pattern. In LPDA, it is observed that from longest dipole to shortest dipole, the length, width and spacing between the dipoles decreases gradually. The spacing of the dipoles is the logarithmic function of frequency represented by spacing factor. The radiation pattern shown in Fig.1 is endfire radiation pattern with minimum side lobes and back lobes. Side lobes and back lobes indicate the losses. S represents the spacing between the dipoles, L is the length of dipoles and the radiation pattern is along Y-axis. LPDA antenna is characterized with the active region and inactive region. The inactive part is also called as passive region. The elements near the half wave length dipole will radiate so the region where radiating elements are present is called as active region. The shortest elements are too capacitive to radiate properly. And the dipoles longer than the half wavelength dipole will also not radiate properly. So the longer and shorter dipoles than the half wavelength dipoles are included in inactive region.

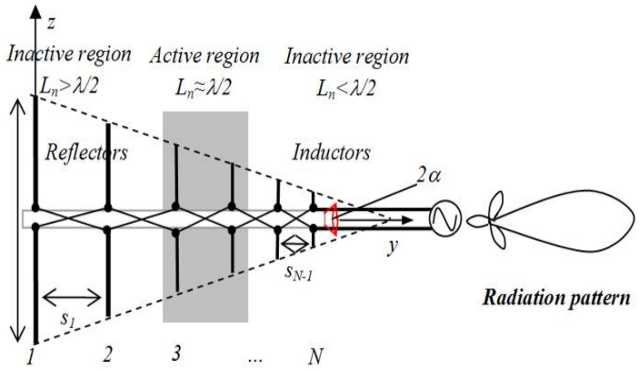

Fig.1. Structure of Log Periodic Antenna

Length of the longest dipole

$$L_1 \geq \frac{\lambda_{\max}}{2} = \frac{c}{f_{\min}} \tag{1}$$

Length of the shortest dipole

$$L_n \leq \frac{\lambda_{\min}}{2} = \frac{c}{f_{\max}} \tag{2}$$

Length of the consecutive dipoles

$$L_{n+1} = \tau . L_n \tag{3}$$

The scaling factor

$$\tau = \frac{L_2}{L_1} = \frac{L_{n+1}}{L_n} = \frac{S_{n+1}}{S_n} < 1 \tag{4}$$

The spacing factor

$$\sigma = \frac{S_1}{2L_1} = \frac{S_n}{2L_n} < 1 \tag{5}$$

The spacing between the longest dipole and the consecutive dipoles:

$$S_1 - S_2 = \left[\frac{L_1 - L_2}{2}\right]\left[\frac{4\sigma}{1-\tau}\right] \tag{6}$$

The spacing between the successive dipoles

$$S_{n+1} = \tau \cdot S_n \tag{7}$$

Number of Dipoles

$$B_{ar} = 1.1 + 7.7\left(1-\tau^2\right)\left[\frac{4\sigma}{1-\tau}\right] \tag{8}$$

$$B_s = \left[\frac{f_{upper}}{f_{lower}}\right] B_{ar} \tag{9}$$

$$N = 1 + \frac{\log B_s}{\log\left(\frac{1}{\tau}\right)} \tag{10}$$

Width of the dipoles,

$$W_{n+1} = \tau . W_n \tag{11}$$

Directivity is calculated from the following equation:

$$\text{Directivity} = \left(\frac{41,000}{\text{HPBW}\left(\text{Eplane}\right) \times \text{HPBW}\left(\text{HPlane}\right)}\right) \tag{12}$$

where, W is width of dipoles and N is number of dipoles. The above equations are used to calculate the dimensions of log periodic antenna. Carrels graph as shown in Fig.2 plays important role in calculation of the log periodic antenna dimensions. It shows dB lines which are from 6dB to 10.5dB. Scaling factor values are present on X-axis and the spacing factor values are present on Y-axis. The optimum line cuts the dB line at particular point and at that point the value of scaling and spacing factor is noted. During calculations, we assume a gain value and according to that value the scaling and spacing factors are obtained from carrels graph. At particular gain line, and at particular point where optimum line cuts the gain line, the value of scaling and spacing factor according to that point is decided. Hence from these parameters, the dimensions of log periodic antenna are calculated [7].

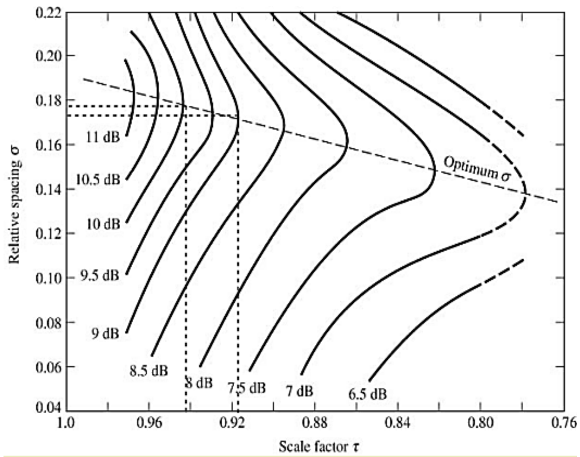

Fig.2. Carrels Graph

The spacing factor and scaling factor is decided from carrels graph. Scaling factor is denoted by τ and spacing factor is denoted by σ. The point of intersection between gain line and optimum line decides the value of scaling and spacing factor. Highest and lowest frequency value is responsible for length of the longest and shortest dipole respectively. The proposed LPDA is designed for τ = 0.82, σ = 0.15, f_{min} = 800MHz, f_{max} = 6GHz and N = 10.

Table.1. Dimensions of LPDA Antenna

Length of Dipoles in mm	**Spacing between dipoles in mm**	**Width of dipoles in mm**
L_1 = 170.45	$S_{(0-1)}$ = 3.0000	W_1 = 5.940
L_2 = 139.769	$S_{(1-2)}$ = 51.135	W_2 = 4.878
L_3 = 114.61	$S_{(2-3)}$ = 41.889	W_3 = 4.004
L_4 = 93.980	$S_{(3-4)}$ = 34.348	W_4 = 3.284
L_5 = 77.063	$S_{(4-5)}$ = 28.166	W_5 = 2.693
L_6 = 63.191	$S_{(5-6)}$ = 23.096	W_6 = 2.209
L_7 = 51.816	$S_{(6-7)}$ = 18.939	W_7 = 1.812
L_8 = 42.489	$S_{(7-8)}$ = 15.529	W_8 = 1.486
L_9 = 34.840	$S_{(8-9)}$ = 12.735	W_9 = 1.219
L_{10} = 28.568	$S_{(9-10)}$ = 10.440	W_{10} = 1.100

The Fig.3 shows the LPDA antenna designed in HFSS software. Ansoft HFSS 13.0 is used to simulate the LPDA antenna. HFSS uses (FEM) Finite Element Method (FEM) to compute the electrical behavior of components. A finite element method in HFSS uses tetrahedral collection and this entire collection of tetrahedral is called as mesh. HFSS is not only used for preparing antenna, but it is also used for designing filers, transmission lines, waveguides, connectors, package modelling etc. It has dielectric constant ε_r of 4.4 and loss tangent of 0.017. Top view and bottom view of antenna is same and the dipoles are connected in crisscross manner. The SMA connector is connected to the feed line from the shortest dipole side.

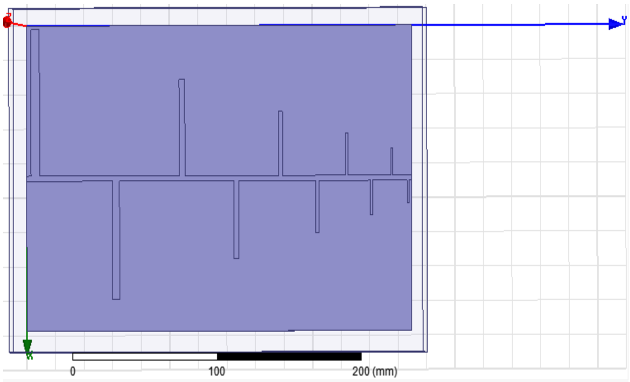

Fig.3. Designed Antenna in HFSS

The fabricated log periodic dipole array antenna with 10 dipoles is shown in Fig.4. A two holed SMA connector is connected from the shortest dipole end. Epoxy FR4 substrate is used having thickness 1.6 mm. The dimension of designed LPDA antenna is 177.5mm × 269.8mm × 1.6mm. The width of both the feed lines is 3mm respectively.

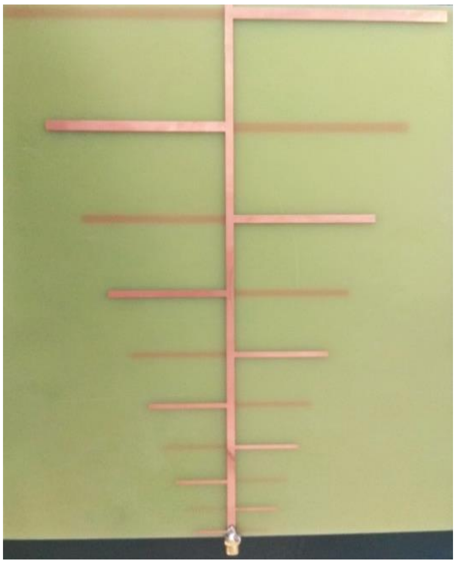

Fig.4. Fabricated Antenna

3. SOFTWARE SIMULATION RESULTS

The Fig.5 shows the return loss of antenna operating from 800MHz to 6GHz. For whole wideband from 800MHz to 6GHz, the return loss is below -10dB. Return loss shows how well the transmission lines or devices are matched. For CDMA return loss is -13.75, for GSM 900 return loss is -13.94, for GSM 1800 return loss is -28.54, for 4G return loss is -17.17, for Wi-Fi return loss is -17.20 and for 5.1GHz Wi-Fi frequency return loss is -22.08.

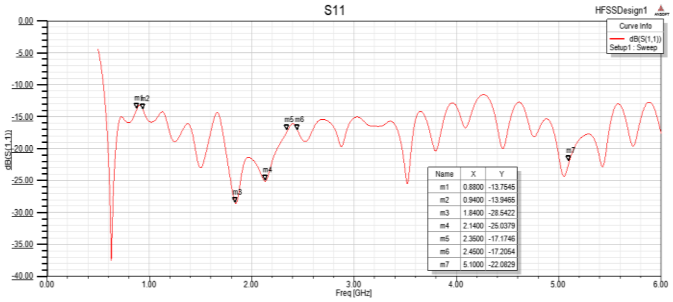

Fig.5. Return Loss of Simulated Antenna Operating from 800MHz to 6GHz

The VSWR of antenna is shown in Fig.6. The obtained VSWR is below 2 for whole bandwidth from 800MHz to 6GHz. If VSWR is not below 2, there is mismatch between the transmission line impedance and antenna impedance, the wave gets reflected from destination end to source end. The incident wave gets mixed with reflected wave and voltage standing wave is created. Ideally VSWR should be 1. The obtained VSWR is accurate and below 2.

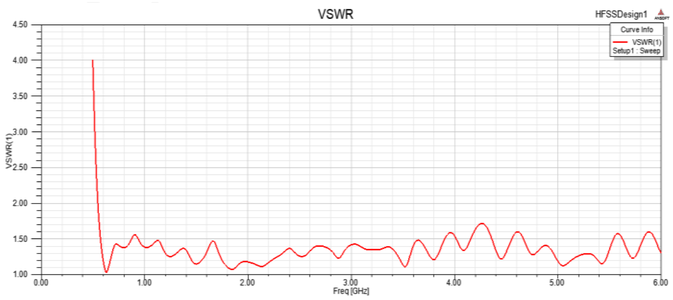

Fig.6. VSWR of Simulated Antenna Operating from 800MHz to 6GHz

The gain of antenna from 800MHz to 6GHz is shown in Fig.7. Gain of antenna shows how directive the antenna is. At 1.84GHz, the gain is 4.17 at 2.14GHz, the gain is 4.08 at 2.35GHz gain is 4.53 and at 2.45GHz gain is 4.51.

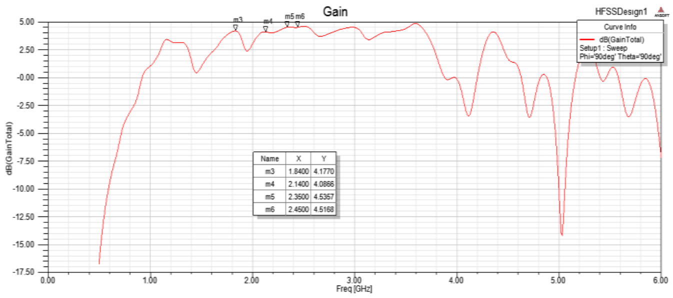

Fig.7. Gain of Simulated Antenna Operating From 800MHz to 6GHz

For 880MHz, the radiation pattern is shown in Fig.8. The red part indicates the amount of power and its direction of radiation. Directivity and gain of antenna at 880MHz is shown in Fig.9 and Fig.10 respectively. 880MHz frequency is used for CDMA application.

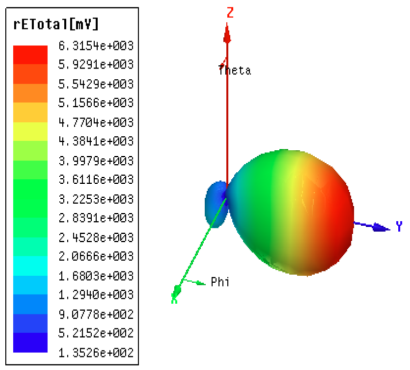

Fig.8. Radiation Pattern of LPDA Antenna for 880MHz

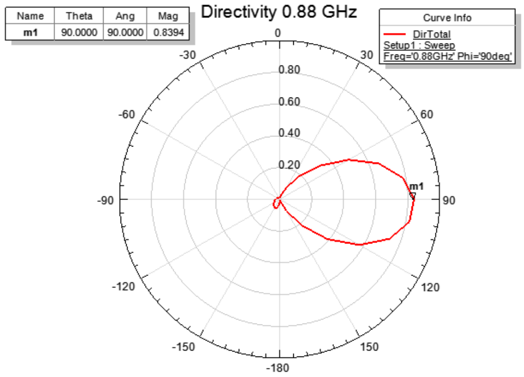

Fig.9. Directivity of LPDA Antenna for 880MHz

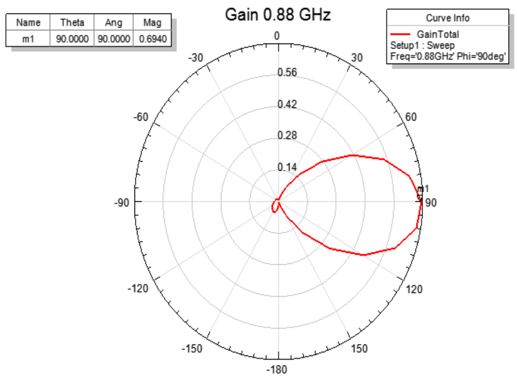

Fig.10. Gain of LPDA Antenna for 880MHz

For 940MHz, the radiation pattern is shown in Fig.11. The red part indicates the amount of power and its direction of radiation. Directivity and gain of antenna at 940MHz is shown in Fig.12 and Fig.13 respectively. Frequency 940MHz is used for GSM 900 (2G) application.

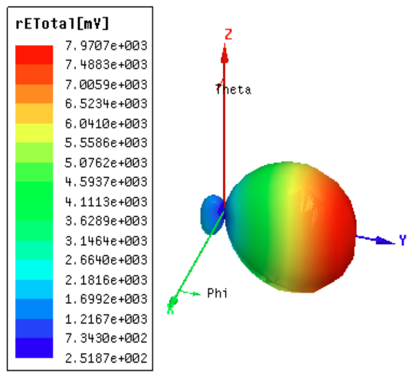

Fig.11. Radiation Pattern of LPDA Antenna FOR 940MHz

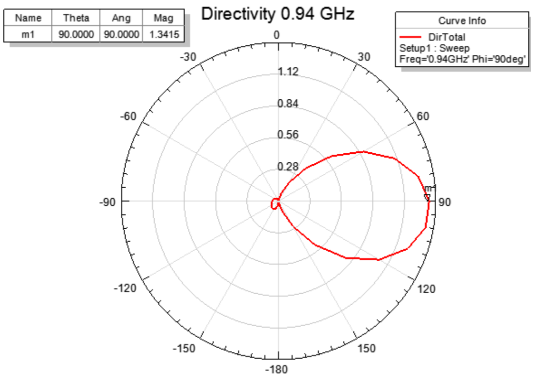

Fig.12. Directivity of LPDA Antenna for 940MHz

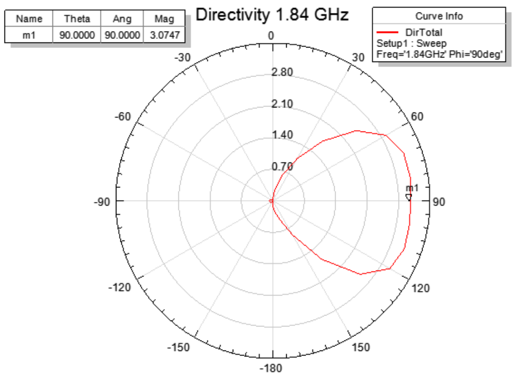

Fig.15. Directivity of LPDA Antenna for 1.84GHz

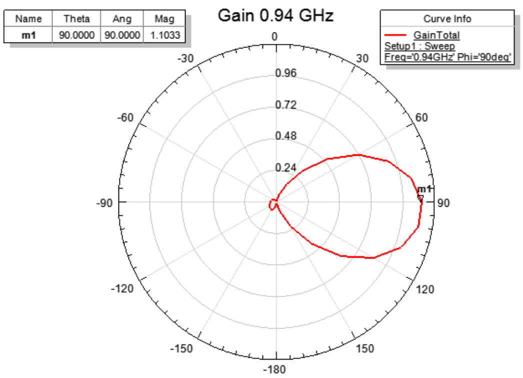

Fig.13. Gain of LPDA Antenna for 940MHz

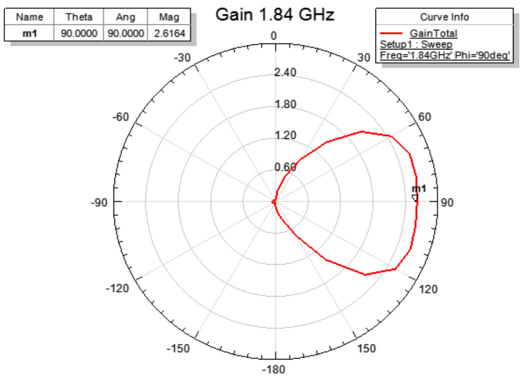

Fig.16. Gain of LPDA Antenna for 1.84GHz

For 1.84GHz, the radiation pattern is shown in Fig.14. The red part indicates the amount of power and its direction of radiation. Directivity and gain of antenna at 1.84GHz is shown in Fig.15 and Fig.16 respectively. The frequency 1.84GHz is used for GSM 1900 (3G) application.

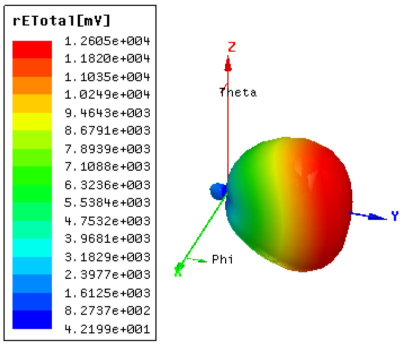

Fig.14. Radiation Pattern of LPDA Antenna for 1.84GHz

For 2.14GHz, the radiation pattern is shown in Fig.17. The red part indicates the amount of power and its direction of radiation. Directivity and gain of antenna at 2.14GHz is shown in Fig.18 and Fig.19 respectively. The frequency 2.14GHz is used for 3G application.

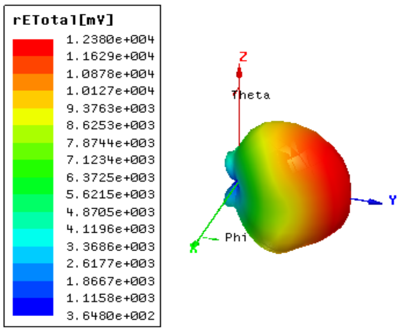

Fig.17. Radiation Pattern of LPDA Antenna for 2.14GHz

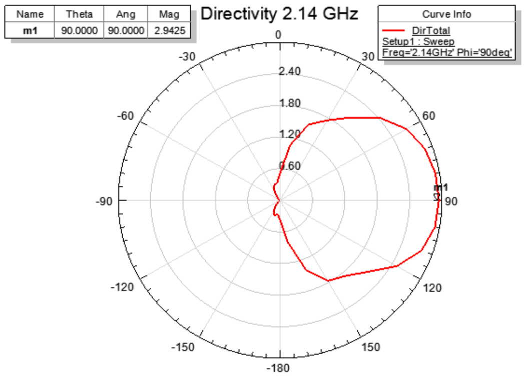

Fig.18. Directivity of LPDA Antenna for 2.14GHz

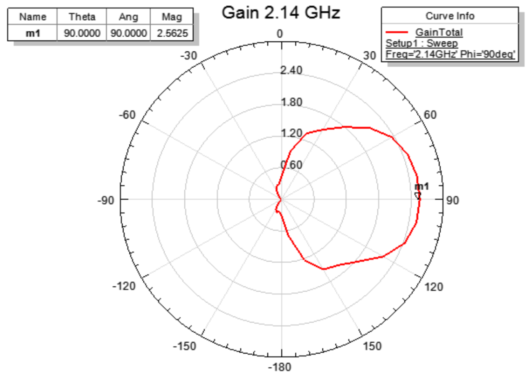

Fig.19. Gain of LPDA Antenna for 2.14GHz

For 2.35GHz, the radiation pattern is shown in Fig.20. The red part indicates the amount of power and its direction of radiation. Directivity and gain of antenna at 2.35GHz is shown in Fig.21 and Fig.22 respectively. The frequency 2.35GHz is used for 4G application.

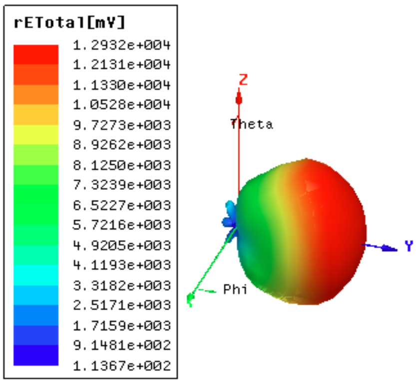

Fig.20. Radiation Pattern of LPDA Antenna for 2.35GHz

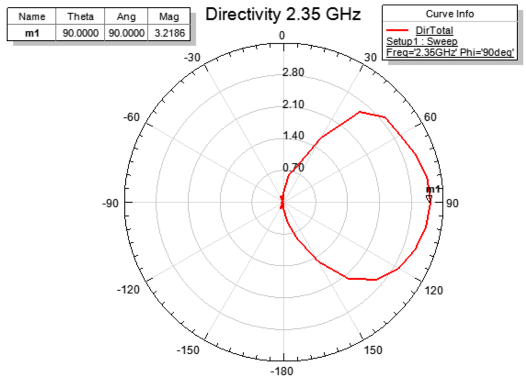

Fig.21. Directivity of LPDA Antenna for 2.35GHz

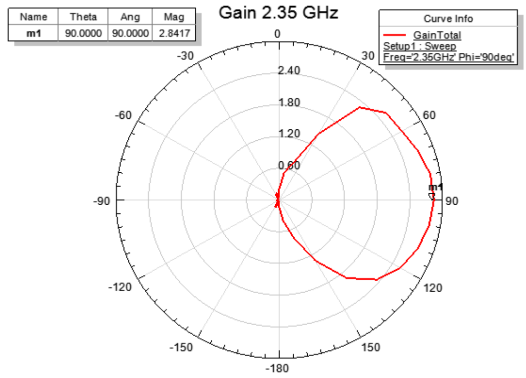

Fig.22. Gain of LPDA Antenna for 2.35GHz

For 2.45GHz, the radiation pattern is shown in Fig.23. The red part indicates the amount of power and its direction of radiation. Directivity and gain of antenna at 2.45GHz is shown in Fig.24 and Fig.25 respectively. The frequency 2.45GHz is used for Wi-Fi application.

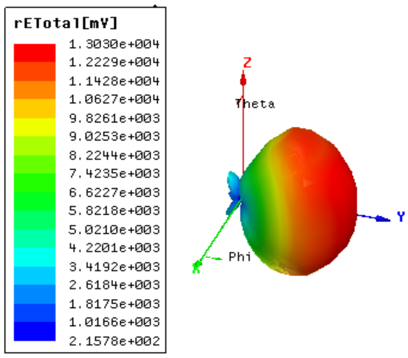

Fig.23. Radiation Pattern of LPDA Antenna for 2.45GHz

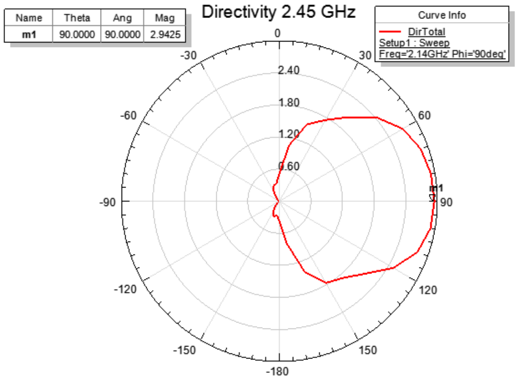

Fig.24. Directivity of LPDA Antenna for 2.45GHz

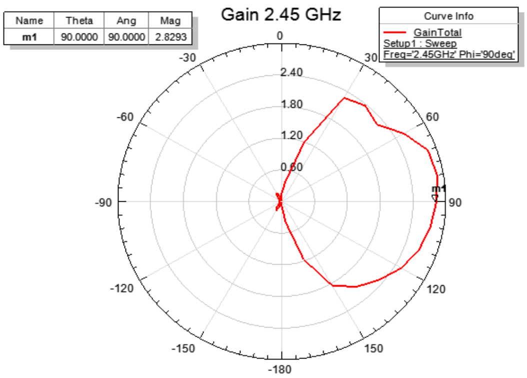

Fig.25. Gain of LPDA Antenna for 2.45GHz

4. HARDWARE RESULTS

To observe hardware antenna results, the ROHDE & SCHWARZ Vector Network Analyzer is used ranging from 9 KHz to 13.6GHz. The return loss, VSWR and impedance is measured on VNA.

Return loss of fabricated antenna is shown in Fig.26. For the whole bandwidth from 800MHz to 6GHz the return loss is below -10dB. The frequencies which are targeted are CDMA, GSM 900, GSM 1800, 3G, 4G, and Wi-Fi. The return loss obtained for CDMA (880MHz) is -16.30dB, GSM 900 (940MHz) is -16.04dB, GSM 1900 (1.84GHz) is -15.72dB, 3G (2.14GHz) is -19.12dB, 4G (2.35GHz) is -15.18dB and for Wi-Fi (2.45GHz) return loss is -16.96dB.

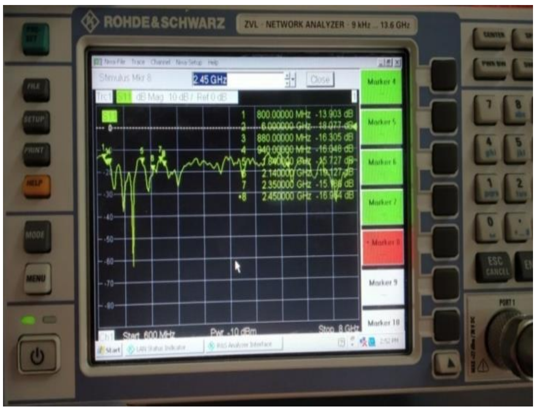

Fig.26. Return Loss of Fabricated Antenna Operating from 800MHz to 6GHz

VSWR of fabricated antenna is shown in Fig.27. For the whole wide band from 800MHz to 6GHz, the VSWR of fabricated antenna obtained is below 2. Voltage standing wave ratio indicates how well the transmission line impedance is matched with the antenna impedance. VSWR describes the power reflected from antenna due to impedance mismatch. For better performance of system, the VSWR value should be below 2.

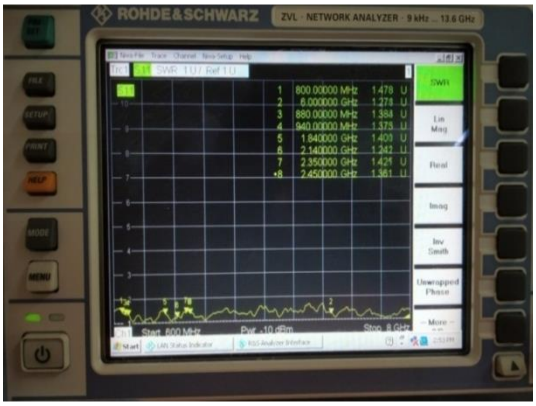

Fig.27. VSWR of Fabricated Antenna Operating from 800MHz to 6GHz

Smith chart of fabricated antenna is shown in Fig.28. Smith chart indicates the antenna behavior at particular frequency. At some frequencies, the antenna shows capacitive behavior and at some frequencies, antenna shows inductive behavior.

Fig.28. Smith Chart of Fabricated Antenna Operating from 800MHz to 6GHz

The radiation pattern of the fabricated antenna is observed for 940MHz frequency. For testing the radiation pattern of fabricated antenna an antenna trainer kit is used. E-plane and H-plane radiation pattern of antenna is observed.

The E-plane radiation pattern at 940MHz is shown in Fig.29. The half power beam width of H-plane is 90°.

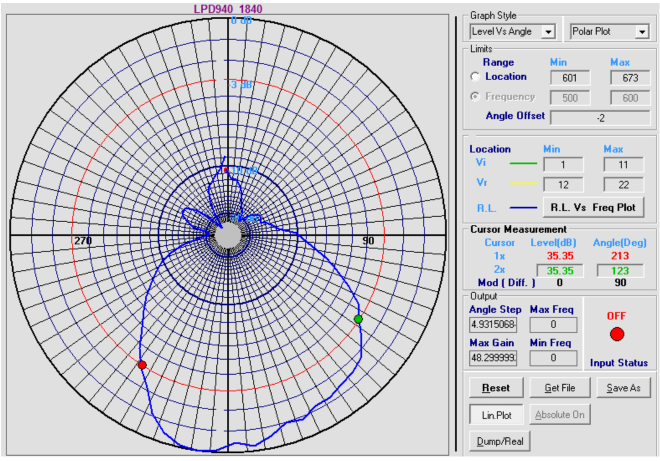

Fig.29. E-Plane Radiation Pattern of Antenna at 940MHz

The H-plane radiation pattern at 940MHz is shown in Fig.30. And the H-plane half power beam width is 60°. Stepper motor mode of antenna trainer kit is used to measure the radiation pattern of fabricated antenna at 940MHz. By using the half power beam width of both E-plane and H-plane radiation pattern, the directivity of antenna is measured. The directivity of antenna at 940MHz is 4.745.

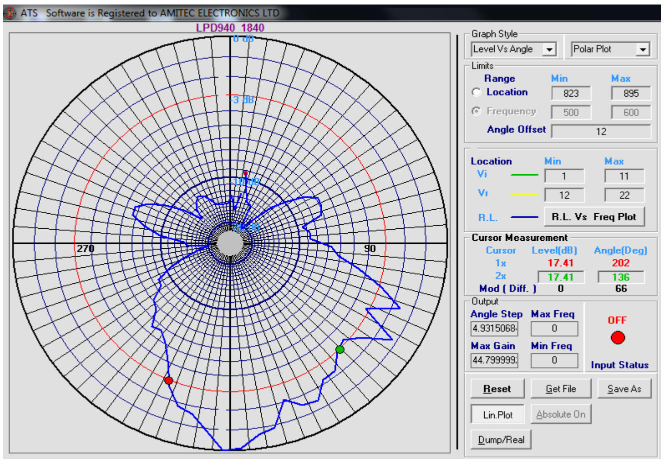

Fig.30. H-Plane Radiation Pattern of Antenna at 940MHz

5. RESULTS AND DISCUSSIONS

In 2018, the conformal log periodic dipole array antenna is designed with cylindrical conductors, and for frequency range 2GHz to 18GHz [1]. A printed log periodic monopole antenna is designed and developed in 2018. 12 monopoles are designed on single side of substrate, working from 8.4 to 14.6GHz frequency range and this antenna is fabricated using standard circuit board process [2]. An ultra-wideband antenna is designed working from 3.1GHz to 10.6GHz. This antenna has multiple notch bands designed [4]. A log periodic antenna which has 12 dipoles is designed for operating range 800MHz to 2.5GHz. The substrate used for this antenna fabrication is epoxy FR4 material of thickness 1mm. And the feed line used is 1mm. This paper contains CAD (computer aided design) model for the proposed PLPDA in CST. This antenna is proposed for L-Band EMC applications. In this paper for optimization of this antenna TRF algorithm is used. Usually in log periodic antenna the port is connected near the longest dipole side which resonates on lower frequency. But this paper the port is connected from the shortest dipole side and the shortest dipole resonates at highest frequency [7].

The proposed antenna in this paper is 10 dipole log periodic antenna working for 800MHz to 6GHz. The overall gain obtained is 4dB. The dipoles are connected in criss cross manner having two feedlines of 3mm each. This antenna structure is simple and easy to implement as compared to the above mentioned antennas. And this antenna works for the frequencies used for 2G, 3G, Wi-Fi, etc. The proposed antenna is compact and works for wider band as compared to above antenna.

6. CONCLUSIONS

This paper presents detailed record on log periodic dipole array antenna. The proposed antenna is printed on both sides of Epoxy FR4 substrate along with the crisscross connections of dipoles. The designed 10 dipoles LPDA antenna provides wideband from 800MHz to 6GHz. Fabricated LPDA antenna performances is evaluated on Vector network analyzer and VNA results are alike with the software results. Form 800MHz to 6GHz the return loss of simulated and fabricated antenna is below -10dB. The obtained VSWR of simulated and fabricated antenna is below 2 and this antenna offers throughout gain upto 4. Smith chart indicates the inductive as well as capacitive behavior at different frequencies. The radiation pattern of fabricated antenna is observed using antenna trainer kit. At 940MHz the half power beam width of E-plane radiation pattern is 90° and H-plane half power beam width is 60°. And the directivity obtained at 940MHz is 4.745. With its simple, cost effective structure and wide bandwidth with high gain it would be reasonable to use this antenna for different applications such as field strength meter.

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