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Near Field UHF RFID Antenna using Dual-Log Periodic Array

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ABSTRACT: To obtain a high gain, directivity and wider bandwidth log periodic antenna is one of the choices. For UHF terrestrial applications it is the most widely used antenna. Near field, RFID has numerous commercial applications like identification and tracking of objects. The compactness and conformability of microstrip patch antenna Due to the compactness and conformability and the ability to operate as a single element, the microstrip patch antenna is preferred.The dual LPDA (Log Periodic Dipole Array) patch antenna is designed that consists of parallel dipole antennas operated in an ultra-high range of frequencies for near-field RFID and terrestrial applications. Initially, a DLPDA was designed in the conventional way of design and later a modified structure of the DLP antenna was proposed to improve the bandwidth characteristics. The challenge in the design of a conventional Log Periodic Antenna is to increase gain, which is attained by the modified design of the LPDA. Highly directional characteristics were obtained using the modified design of DLPA. The same proposed design is implemented using CST studio and HFSS tool and the results were compared, in terms of antenna performance and impedance matching.

Keywords: Area of the antenna, power radiated, antenna impedance, current distribution, RFID, LPDA, CST.

Abbreviations: DLPDA, Dual Log periodic dipole antenna; RFID, Radio Frequency Identification; ODC, Opposite Direct Current.

I. INTRODUCTION

The log-periodic dipole array (LPDA) containsfew dipole elements that progressively reduce in length from the last element to the first element and the maximum radiation direction is from the smaller element.It is a frequency-independent structure and has a strong intensity concentration near the edge of the conductor that results in more reliable and stable characteristics. Radio-Frequency Identification (RFID) systems are widely used in applications like innovative healthcare, controlling road traffic, retail business, supply chain management, library management, factory environment, and many more real-world applications. In the previously available literature, the effect on bandwidth and gain by varying the scaling factor, space constant, and length of the feed is analyzed for a proposed MLPDA [3]. Heon Kwon *et al.*, have discussed applying a meander line to the LPMDA antenna dipole elements thatachieve the reflection phase with AMC [4]. The design of an active LPDA was discussed by Rahim & Gardner [5]. A method of achieving the required frequency band of log periodic antenna by controlling the PIN diode switch was discussed [6]. V band applications with PLPDA were presented by Haraz *et al.*, [7]. To achieve the required bandwidth, using a dual patch microstrip antenna fed by two L-probes was discussed by Tiang *et al.*, [8]. The design of LPDA for VHF and UHF applications was presented by Bugaj *et al.*, [9]. The Near-field characteristics like a magnetic field, impedance bandwidth were achieved by a log-periodic antenna as presented by Li *et al.*, [10].

The paper presents a modified design of the DLPA to obtain better bandwidth characteristics with center feed, for near field RFID applications. The design was simulated using the CST STUDIO SUITEenvironment using the FTDT method and also HFSS using FEM analysis.The results of the proposed antenna structure are compared and analyzed. The basic less gain disadvantage of Log Periodic Antenna has been overcome by altering the spacing factor and substrate width, in the proposed design, with improved results in comparision with the other research papers.

II. ANTENNA DESIGN METHOD

The dipoles arranged in parallel fashion in a Log Periodic Dipole Array (LPDA) antenna offers the impedance and radiation characteristics are repeated periodically as alogarithmic function of frequency and operated in ultra-high range.Nearly situated two oppositely directed currents (ODCs) are proposed to arrive atexquisiteand orderly magnetic fields in the near-field region. The accomplished frequency band of the antenna is 800-1.5GHz. To achieve the opposite currents in adjacent dipoles with a 90-degree phase shift, a two-sided parallel T-junction design is implemented. The LPDA involves a pair of metal rods acting as half wave dipoles. The dipoles are mounted near to each other in a line, in parallel to the excitationline with the alternating phase. Bandwidth and the frequency response can be increased by adding elements to an LPDA.

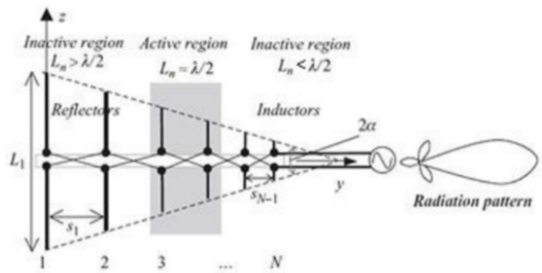

Fig. 1. Log Periodic Dipole Array Antenna

The structure of LPDA is shown in Fig. 1. For an N number dipole log periodic antenna, the relation between the length of Nth dipole and region of radiation is also shown. Each element in the LPDA antenna is a driven element. As the size of the antenna increases the bandwidth offered by the LPDA also increases. In LPDA the driven element with smaller size plays a major role at high frequencies and the driven element with a bigger size plays a dominant role at low frequencies.

A. Conventional LPDA design

The length of the dipole in the array of LPDA and the distance between the dipoles in the array are dependent on the scaling factor (τ) and the spacing factor (σ).

L_n=Length of the nth element

S_n= The spacingbetween n and (n+1)elements

τ=scaling factor

σ=spacing factor

α=apex angle of the log-periodic antenna

STEP1: $\tau = \frac{L_{n+1}}{L_n}$

STEP 2: $\sigma = \frac{S_n}{2*L_n}$

STEP 3: $\alpha = \tan^{-1}\frac{L_n - L_{n+1}}{2*S_n} = \tan^{-1}\frac{L_n(n\tau)}{2*S_n} = \tan^{-1}\frac{t\tau}{4*\sigma}$

Step 4: The mathematical expression for maximum frequency and minimum frequency that can be applied to LPDA is given as

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

$$L_N = \tau L_{N-1} \leq \frac{\lambda_{min}}{2} = \frac{c}{f_{max}}$$

L_1 =Length of the first dipole

L_n =Length of the nth dipole

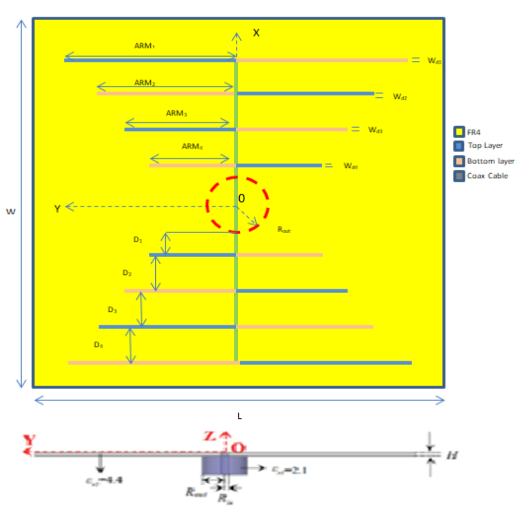

Fig. 2. Structure of Log Periodic Dipole Array Antenna.

The design of a typical LPDA is shown in Fig. 2, with coaxial probe feed.

ARM_n is designated as the length of the nth dipolearm, and W_{dn} is the width of the ntharm. The D_n is the distance between the nth dipole and the (n+1)th dipoles. From the design equations of LPDA, the length of thearm of the first dipole ARM_1 is calibrated as follow:

$$ARM_1 = \frac{\lambda_1}{4\sqrt{\epsilon_{eff}}}$$

$$\lambda_1 = \frac{c}{f_1}$$

$$\varepsilon_{eff} = 1 + F(\varepsilon_{eff} - 1), 0 \leq F \geq 1$$

f_1 = lowest operating frequency of LPDA

λ_1 = free-space wavelength and ε_{eff} is the effective dielectric permittivity.

As air is the dielectric interface of dipoles, an effective filling factor*F*is defined. For free space, where (ε_{eff}=1) F = 0 and for dielectric substrate space ($\varepsilon_{eff} = \varepsilon_{r2}$), F = 1. The other parameters of the antenna, like the width of the arm and distance between the arms, can be conceived from the scaling factor and the spacing factor: Using the design equations of LPDA, the antenna parameters are as shown in Table 1.

$$\tau = \frac{ARM_n}{ARM_{n-1}} = \frac{W_{dn}}{W_{dn-1}}$$

$$\sigma = \frac{D_n}{4ARM_n}$$

Due to ODC on adjacent poles, steady magnetic field distribution in the near field is generated. The current vectors on the conducting surfaces are shown in Fig. 3. The magnetic field intensity between the 2nd and 3rd dipoles regions can be made stronger by a pair of ODCs generated by the pairs of first, third dipoles and second, fourth dipoles.

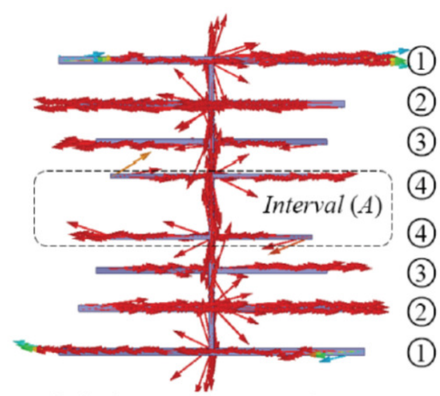

Fig. 3. Current flow across the antenna before modifying the antenna design parameters.

The magnetic field in the gap of the two LPDAs is also strengthened by ODCs generated by the 4th dipole of the two LPDAs. The feed structure using one coaxial cable and feed lines with equal width gives an unbalanced current distribution as in Fig. 3. Therefore the radiation pattern performance is a function of frequency. A printed log-periodic dipole antenna (PLDPA) with a balanced feeding structure is achieved by varying the width of feeder lines.

Table 1: Design parameters of the antenna.

Parameter	Value
Scaling Factor τ	0.87mm
Spacing Factor σ	0.06 mm
Filling Factor F	0.29 mm
Leastoperating frequency $f1$	830 MHz
Length of ARM_1	64 mm
Length of ARM_2	55.68 mm
Length of ARM_3	48.44 mm
Length of ARM_4	42.14 mm
Width of ARM_1 (W_1)	3.5 mm
Width of ARM_2(W_2)	3.05 mm
Width of ARM_3(W_3)	2.65 mm
Width of ARM_4(W_4)	2.3 mm
Height of each dipole arm	0.035 mm
Distance between 1 and 2 ARMs (D_1)	15.2 mm
Distance between 2 and 3 ARMs (D_2)	13.22 mm
Distance between 3 and 4 ARMs (D_3)	11.5 mm
Distance between 4^{th}ARM and center feed (D_4)	10 mm
Relative permittivity ε_r	4.4
Dissipation Factor	0.02
Patch Length (L)	170 mm
Patch Width (W)	170 mm
R_{in} (Radius of the inner circle of the feed)	0.5 mm
R_{out} (Radius of the outer circle of the feed)	1.6 mm
Feedline width (W_f)	2 mm

Table 2: Design parameters of the modified DLP antenna.

Parameter	Value
Scaling Factor τ	0.87
Spacing Factor σ	0.04 mm
Filling Factor F	0.29
Least Operating Frequency $f1$	830 MHz
Length of ARM_1	64 mm
Length of ARM_2	55.68 mm
Length of ARM_3	48.44 mm
Length of ARM_4	42.14 mm
Width of ARM_1	3.5 mm
Width of ARM_2	3.05 mm
Width of ARM_3	2.65 mm
Width of ARM_4	2.3 mm
Distance between 1 and 2 ARMs (D_1)	12.8 mm
Distance between 2 and 3 ARMs (D_2)	11.14 mm
Distance between 3 and 4 ARMs (D_3)	9.689 mm
Distance between 4^{th} ARM and center feed (D_4)	8.428 mm
Patch length (L)	150 mm
Patch width (W)	150 mm
Substrate Height (H)	1.6 mm
R_{in} (Inner cylinder radius of coax feed))	0.5 mm
R_{out} (Outer cylinder radius of coax feed)	1.6 mm
Feed Line Width (W_f)	2 mm

B. Modified antenna design

The bandwidth of a log-periodic dipole array antenna depends on the substrate width and the spacing factor. To obtain wider bandwidth, the substrate width is increased and the spacing factor is decreased. For the increase of bandwidth, the spacing factor is reduced to 0.04mm from 0.06mm to the width of the substrate is increased. The length of the patch antenna should be longer than one wavelength of the least working frequency of the design. An increase in length provides a wider bandwidth. These requirements of the Patch antenna guarantee excellent performance in terms of gain, directivity, and beamwidth. The width of the Patch antenna should be longer than half wavelength of the least working frequency. A decrease in antenna width provides a wider bandwidth.

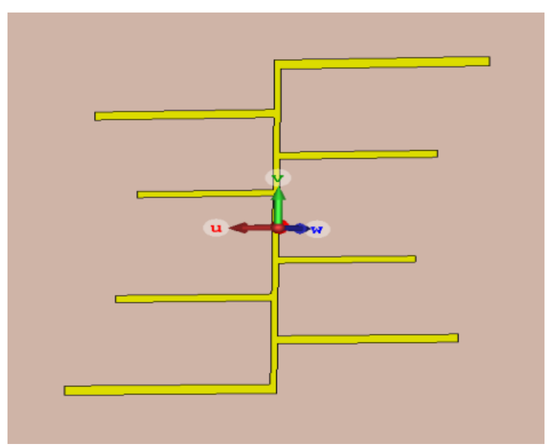

Fig. 4. Structural Design of modified Log Periodic Dipole Array Antenna.

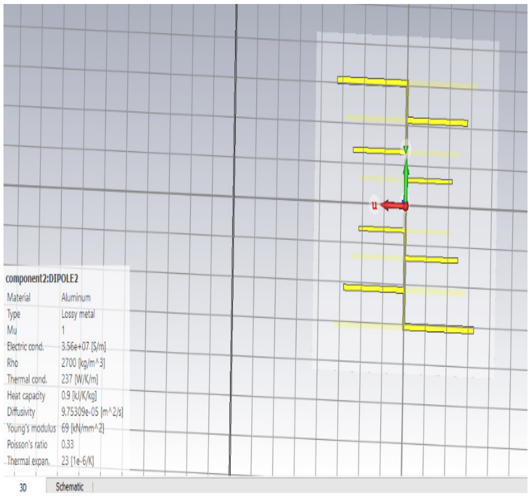

Fig. 5. Front view of modified Log Periodic Dipole Array Antenna (using CST)

The proposed and modifies structure of DLPDA is shown in Fig. 4. After changing the spacing factor, length, and width of the patch, the dimensions of the antenna are as shown in Table 2. The front view of the design using CST simulation tool, shows the parallel feeding to diploes as in Fig. 5, while the back view of the design shows that the arms of each diploe in LPDAs are printed on both sides of the surface of the dielectric substrate, as in Fig. 6, designed using CST software. By changing the area of the antenna, the properties like the center frequency, bandwidth, output power, and reading rate of the antenna can be varied.

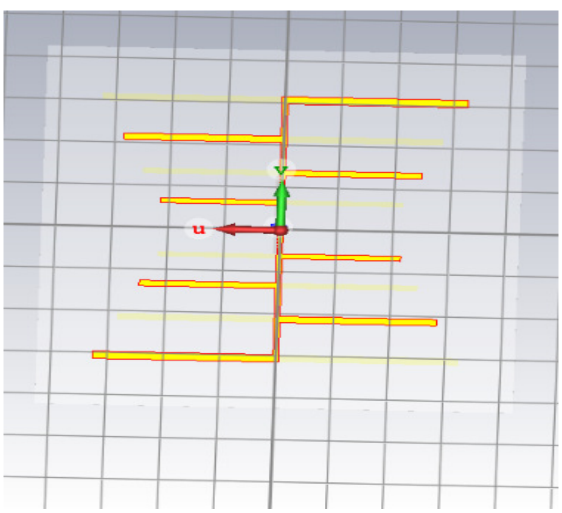

Fig. 6. Back view of Log Periodic Dipole Array Antenna (using CST).

III. RESULTS AND DISCUSSION

S-parameters describe the relationship between the input-output ports of a system or network. S11 representsthe value of reflected power from the antenna, and it is called as the *reflection coefficient or return loss*. If S_{11}=0 dB, which represents that all the power is reflected from the antenna and no power gets radiated. The simulated results of LPDA design as in Fig. 2 are presented below, in Fig. 7.

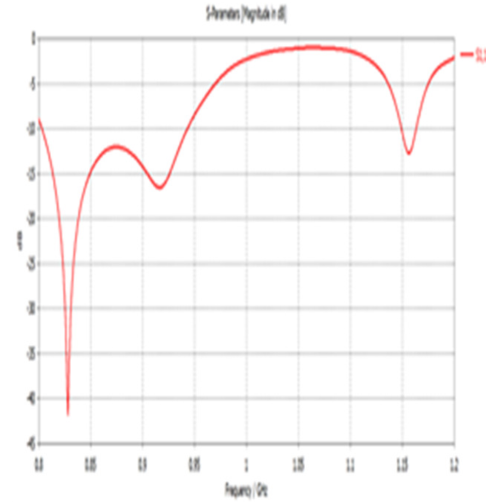

Fig. 7. The reflection coefficient of the antenna before modifying the antenna design using CST.

The LPDA shows better S_{11} characteristics at 830MHz frequency with S_{11}= -42dB with 14.5% impedance bandwidth as shown in Fig. 6. This shows that the antenna has quite an attractive signal radiating capability, better reflection coefficient can be achieved if there is good impedance matching. The input Impedance of antenna relates the current to the voltage at the input section. From the simulation result, as shown in Fig. 8, it can be observed thatthe maximum overall impedance of LPDA about 83Ω is achieved at a higher frequency of about 1.16 GHz. In a Log Periodic Antenna, as the impedance of the antenna is a logarithmic function of frequency, the below plot is considered to be important.

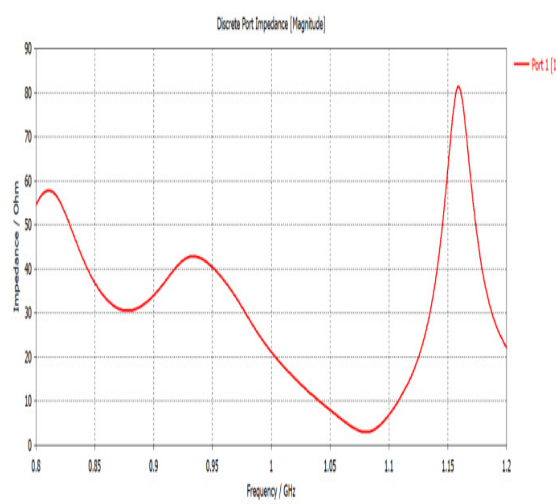

Fig. 8. The measured impedance of the antenna before modifying the antenna design using CST.

The radiated power is a measure of power radiated from the antenna when it is exciting. From the simulation result of Fig. 9, it is observed that the designed antenna will produce the maximum power about 0. 3W at 0.8 GHz.

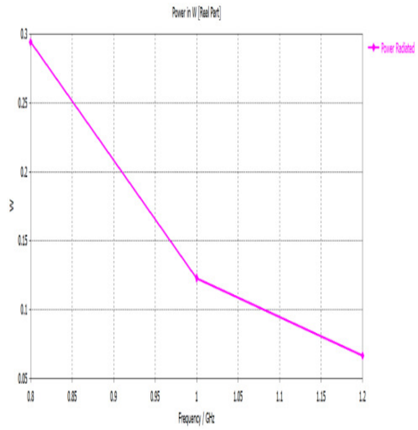

Fig. 9. The radiated power of the typical structure of DLPA, before implementing the modification, using CST.

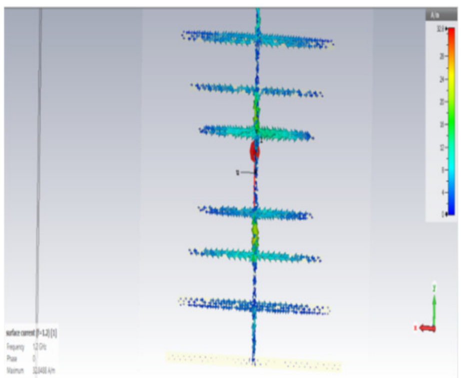

Fig. 10. The current distribution of the typical LPD antenna, without modification.

Fig. 10 shows the vectors of current on the conducting surface of the typical LPD antenna. The adjacent diploescurrents flow in the opposite direction. This will result in increased the steady magnetic field in the near field region.

To improve the bandwidth characteristics, antenna design parameters are modified as in Fig. 5 and 6. In the paper written by Pawar *et al.,* similar design changes were proposed but for the C band [3]. This paper presents the improved results of the modified design at L band frequency range.

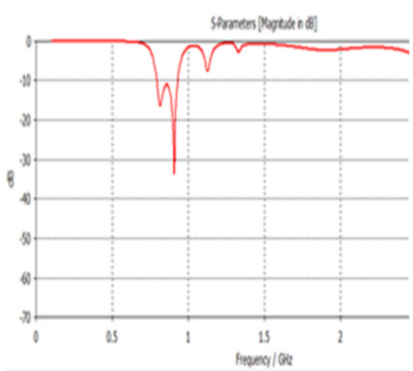

Fig. 11. The reflection coefficient of LPDA with modifications using CST simulator.

Fig. 11 shows that the reflection coefficient value is about -35dB at 906MHz frequency, with an increased impedance bandwidth percentage of 15.88%.

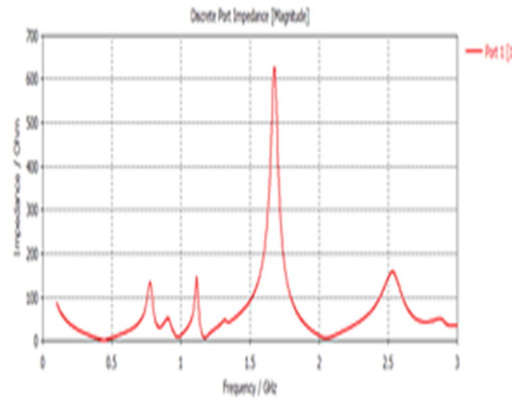

Fig. 12. Impedance characteristics of modified design using CST simulator.

Considering the impedance of the antenna, the modified antenna impedance characteristics shown in Fig. 12 are similar to the shifting version of proposed antenna impedance characteristics. This means the modified antenna will provide greater impedance about 630Ω at very high frequencies compared totypical LPD antenna.

Fig. 13 shows that the radiated power characteristics are improved in terms of directivity to 24dBm compared to the regular LPD antenna.

The current distribution as shown in Fig. 14 of the proposed antenna shows satisfactory radiation properties. The antenna design with modified parameters is also implemented with HFSS software and almost similar results as in CST simulation studio were observed.

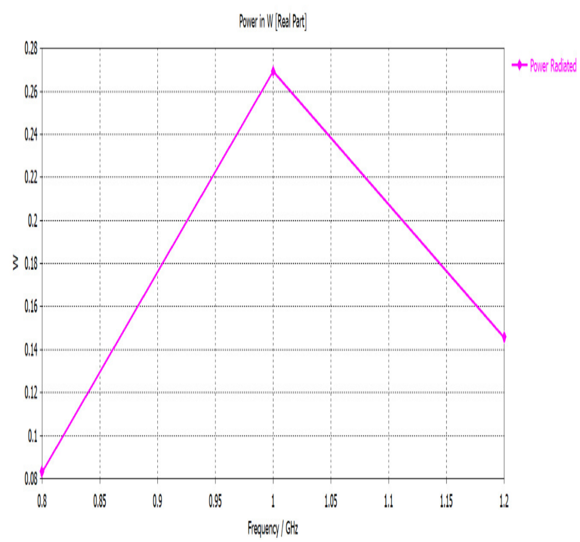

Fig. 13. Improved power radiated characteristics of modified design using CST simulator.

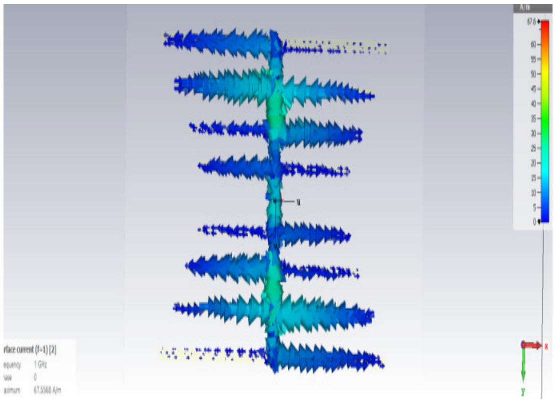

Fig. 14. The current distribution of modified design using CST simulator

The results obtained from HFSS DLPDA design are shown below.

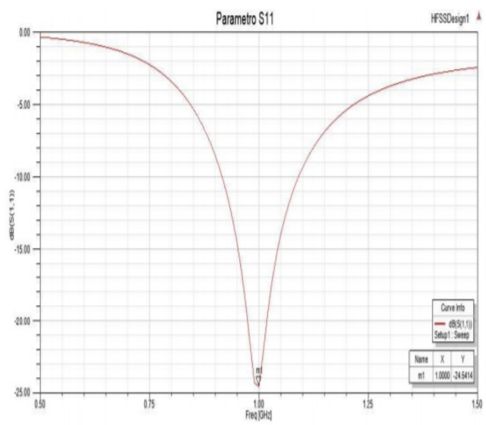

Fig. 15. S_{11} of LPDA with modifications using HFSS tool.

From the simulation results shown in Fig.15, it is observed that the -24dB reflection coefficient is obtained at 1GHz frequency.The impedance of the modified design antenna in HFSS is observed to be turning positive near 1GHz frequency as presented in Fig.16.

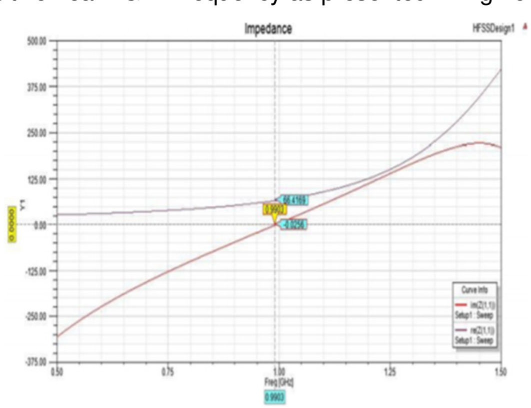

Fig. 16. Impedance characteristics of modified design using HFSS tool.

At a theta value of -90° and 270°, the directivity shown in Fig. 17, of the proposed antenna is obtained as 1.8047, which is a satisfactorily directive antenna result using HFSS tool.

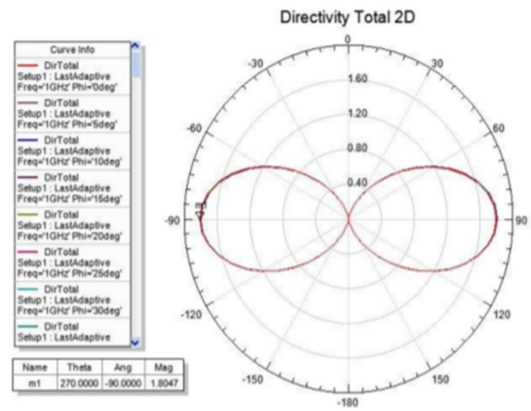

Fig. 17. Directivity characteristics of modified design using HFSS tool.

IV. CONCLUSION

From the proposed modification to the DLPD antenna design, the following important points are observed. The bandwidth has improved from 14.55% to 15.88%. The impedance of the antenna has improved from 60 Ω to 630 Ω. The power radiated is improved to 24 dBm from 21 dBm. The center frequency of the modified antenna exhibits a center frequency shift from 915MHz to 906 MHz which does not deviate the antenna performance from expected.

HFSS mesh adaption algorithm analysis Ansoft HFSS, which is a frequency domain solver is observed to be convergingslower than the CST time domain solver for the same design. The mesh size can be manually adjusted in CST solver for achieving more accuracy. The LPDA antenna designed using CST exhibits a reflection coefficient of -35dB at 906MHz and the HFSS tool results reflection coefficient of about -24dB at 1GHz. The impedance characteristics are also observed going positive near 1 GHz in both cases. Both tools exhibit highly directive properties of the proposed modified antenna design.

V. FUTURE SCOPE

The LPDA can be implemented with switching devices using electronic switching devices like PIN diodes, Varactor diodes, etc or by using mechanical switches such as MEMS for the reconfigurable abilities. Therefore based on the switching criteria, the current distribution and the effective length of the antenna,different ranges of operating frequencies and their applications can be observed.

Conflict of Interest. It is to disclose that all the conflicts of interest of the authors and other potentially conflicting interests,involvingany financial interests and relationships and affiliations relatedto the International Journal on Emerging Technologies. The authors agree that they would disqualify themselves from the activities like reviewing, editing, or participating in editorial decisions about any IJET journal submission in which either the authors or any member of their immediate family hasany financial interest. This alsoapplies to the past 5 years and the foreseeable future.

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