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Compact Monopole Antenna Loaded with Hybrid Dipole Elements for 5G Sub – 6GHz Applications

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Abstract: The design and realization of a flexible broadband tapered transmission line fed log periodic dipole array antenna (LPDA) characterized by a compact size 22.5mm x 11mm x 1.6mm and loaded with hybrid dipoles are presented in this paper. The proposed antenna is dedicated for Industrial Scientific and Medical (ISM) as well as 5G sub-6-GHz band, particularly at the frequency of 3.6 GHz. The proposed antenna is evolved from a traditional LPDA, where hybrid dipoles and tapered fed are used to improve antenna's bandwidth and other parameters. The antenna shows good results compared to related works in the same domain. The good results of proposed work with state of the art work in terms of bandwidth, impedance matching, radiation patterns and radiation efficiency demonstrates the potential of the proposed antenna for ISM and 5G applications.

Index Terms **- Log Periodic Dipole Array (LPDA), Hybrid dipoles, Sub – 6GHz, 5G, Radiation efficiency, Impedance bandwidth.**

I. INTRODUCTION

Fifth-generation (5G) is a new mobile broadband technology that is in its early stages and is planned to be widely used after 2020. Mobile communication systems, which became widespread after the 2000s, are evolved quite rapidly with different technologies over the last three decades from the analog transmission-based first generation (1G) to Internet Protocol (IP) based fourth-generation (4G) technologies. LTE-A (Long Term Evolution - Advanced) is an insufficient technology against the increasing demand for data, owing to smart devices is also defined as mobile users on the Internet of Things (IoT). Increasing demands for high data rates, low connection latency, low cost, low energy usage, and support for more users paved the way for the emergence of the fifth-generation (5G) technology. After the 5G, which is called next-generation technology, it is planned to overcome shortcomings of 4.5G and replace it in the near future. [1].

5G technology aims to meet the requirements of high data rates, faster connections and much more versatility than existing wireless networks. The most important expectation for the commercialization of 5G technology is the determination of all required standards, especially frequency spectrum sharing. Today, cellular communication is widely used in the sub-6 GHz band, especially at frequencies below the 3 GHz spectrum. The frequency spectrum of 5G systems is defined in two ranges as sub-6 GHz and above-6 GHz in terms of physical properties [2]. The International Telecommunication Union (ITU) adopted the IMT-2020 (International Mobile Telecommunication-2020) standards at the meeting held in Geneva in 2015. These standards contain the requirements for 5G networks, devices and services and are published as a report. According to this report; the frequency bands of 3.4 GHz to 3.6 GHz, 5 GHz to 6 GHz, 24.25 GHz to 27.5 GHz, 37 GHz to 40.5 GHz and 66-76 GHz are allocated for 5G communications [3]. After this development, the frequency band between 3.4 GHz to 3.6 GHz is shared with mobile services in almost all countries and the availability of this spectrum for IMT is increasing worldwide. 3.4-3.8 GHz frequencies, which is the combination of LTE 42 and LTE 43 bands, is a band that is common to almost all countries, and this frequency band has significant potential for 5G researchers. International regulatory associations defined the different parts of 3.3- 4.2 GHz spectrum for 5G sub-6 GHz as given in Figure 1 [4].

As in all wireless communication systems, one of the most important elements of 5G mobile technologies is the antenna design appropriate to the system. Lots of antenna researchers focus on this topic and several sub-6 GHz 5G antennas are also proposed [5-7]. A hybrid MIMO antenna system with multiple antennas is presented by Ban et al. [5]. The proposed hybrid MIMO antenna system consists of two separate antenna modules for LTE and 5G. The LTE module has a two-element MIMO antenna system that can cover GSM, UMTS and LTE operations. n the 5G module, there is an eight element MIMO array working with 3.5 GHz band that can cover 3400-3600 MHz frequencies. The proposed hybrid MIMO antenna has a 140 mm × 70 mm overall size and prototyped on an FR4 substrate with 0.8 mm thickness while each MIMO element has a 16 mm × 3 mm dimensions. Parchin et al. [6] also proposed a MIMO antenna consisting of four elements for 5G mobile terminals. Each antenna element consists of a double-fed square ring slot resonator and its dimensions are 30 mm × 30 mm × 1.6 mm. The proposed MIMO antenna system has an overall dimension of 75 × 150 mm2 and is etched on an FR4 substrate. The proposed 5G MIMO antenna system has a dual-polarized 3.4-3.8 GHz frequency bandwidth. Chattha [7] reported a two-element Planar Inverted-F Antenna (PIFA) antenna system that each element is fed by dual-port. Both PIFA elements are the same and each identical element consists of a radiating plate with

16 mm × 33 mm; while the PIFA antenna has a ground plane with 50 mm × 100 mm overall size. Also, an FR4 substrate with 4.4 relative permittivity and the thickness of 1.5 mm was used in the prototype of the proposed PIFA antenna. Patch antennas, also called planar or microstrip antennas, are the most common types of antennas used in mobile systems because of their small size and ease of manufacture. Today's mobile communication systems, low profile broadband antennas are needed for high mobility and high-speed data transmission. However, a narrow bandwidth is one of the main shortcomings of traditional patch antennas. In the literature, different methods such as slots [8], defective ground structures (DGS) [9] and log periodic arrays [10-12] have been tried to solve the narrow bandwidth problem of patch antennas.

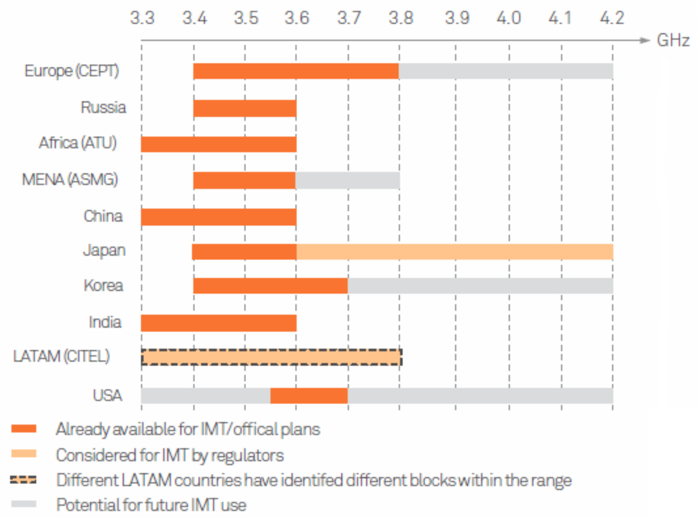


Figure 1. Worldwide availability and planning of the 3.3-4.2 GHz frequency ranges [4]

In this paper, log periodic dipole array antenna has been designed and simulated on FR – 4 epoxy material having dielectric constant of 4.4 and its thickness is 1.6mm using High Frequency Structure Simulator (HFSS) electromagnetic computational tool. This planar dipole achieved impedance bandwidth of 470MHz over 3.46 - 3.93GHz with reflection coefficient of -17.82dB at 3.68GHz resonant frequency. After doing dipole modifications, the proposed tapered log periodic I – shaped dipole array antenna has been proposed for 5G application frequencies 3.3 – 3.8GHz with good impedance matching condition. Following sections discussed about the proposed design geometric configuration and its discussion on obtained parameters. Finally concluded with conclusion.

II. Antenna Design Configuration, Parameters & Results Discussion

2.1Log Periodic Planar Dipole Array Antenna (LPPDA)

A systematic step-by-step design procedure of the LPPDA follows. This procedure may be used for designing any LPPDA for any desired bandwidth.

1). Decide on an operating bandwidth 'B' between lowest frequency,f1 & highest frequency, f2.

$$B=f2 / f1 \tag{1}$$

2).LPPDA needs to first define the required directivity, Do. choose τ and σ from the figure 2

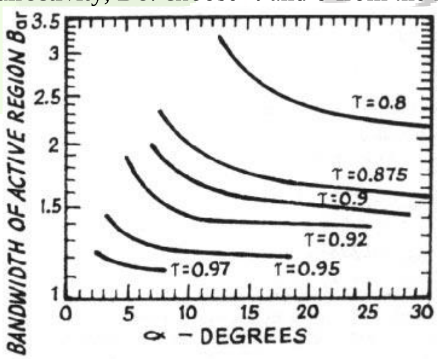


Figure 2. B_{ar} varies with τ and α

3). Determine the apex-half angle, α

$$\propto = tan^{-1}(\frac{1-\tau}{4\sigma}) \tag{2}$$

4).Determine the bandwidth of the active region, Bar from figure.2

$$\propto = tan^{-1}(\frac{1-\tau}{4\sigma}) \tag{3}$$

5).Determine the structure (array) bandwidth of the antenna, Bs

$$Bs=B*Bar \tag{4}$$

6).Determine the total boom length of the antenna, L

$$\propto = tan^{-1}(\frac{1-\tau}{4\sigma}) \tag{5}$$

Where λ_{max}=longest free space wavelength= $\frac{c}{f_{min}*\sqrt{\varepsilon_{eff}}}$ (6)

l_{max}=length of the longest dipole element

7). Determine the number of elements, N

$$N = 1 + \frac{ln(B_s)}{ln(\frac{1}{\tau})} \tag{7}$$

8). The width of the largest dipole element 'Wn'

$$Z_n = \frac{\eta_0}{\Pi}[l_n(\frac{L_n}{a_n}) - 2.25] \tag{8}$$

Where an=radius of the largest dipole in order to give 50Ω average characteristic impedance

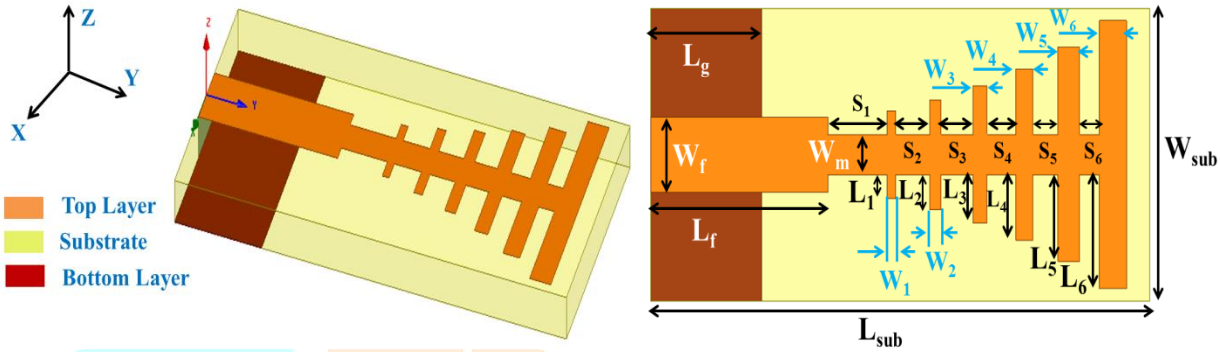
Wn=Π* an (9)

9). Relation between geometrical arrangement of LPPDA and dipoles are given by:

$$\frac{1}{\tau} = \frac{l_2}{l_1} = \frac{l_{n+1}}{l_n} = \frac{R_2}{R_1} = \frac{R_{n+1}}{R_n} = \frac{d_2}{d_1} = \frac{d_{n+1}}{d_n} = \frac{s_2}{s_1} = \frac{s_{n+1}}{s_n} \tag{10}$$

where ln=length of the nth element, Rn=distance between the two elements, dn=diameter of the nth element, sn=center to center spacing betwen the two elements

Figure 3 shows the designed LPPDA on FR – 4 epoxy material with partial ground. It is a 3 layered structure, patch as top of the substrate and ground as bottom of the substrate. Table 1 shows the parameters represented on the designed structure.



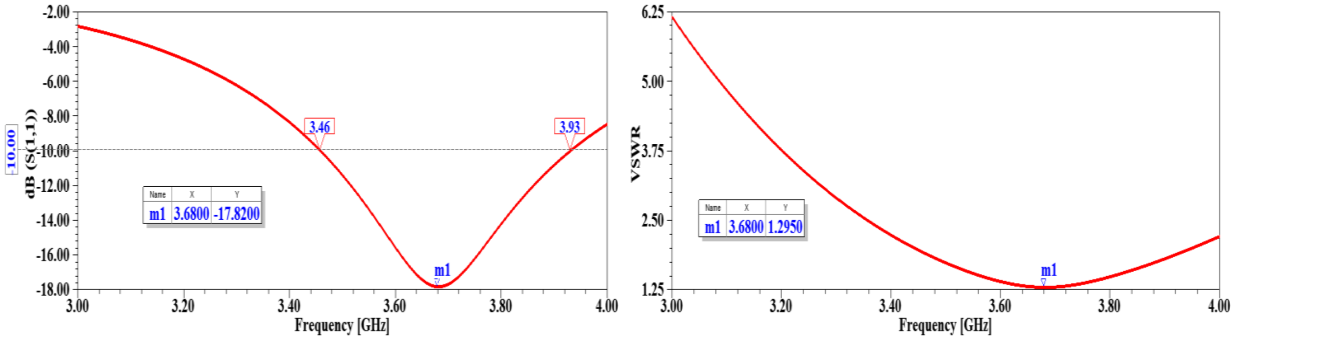
(a) 3D view (b) Top view

Figure 3. Geometrical configuration of log periodic planar dipole array antenna (LPPDA) with partial ground

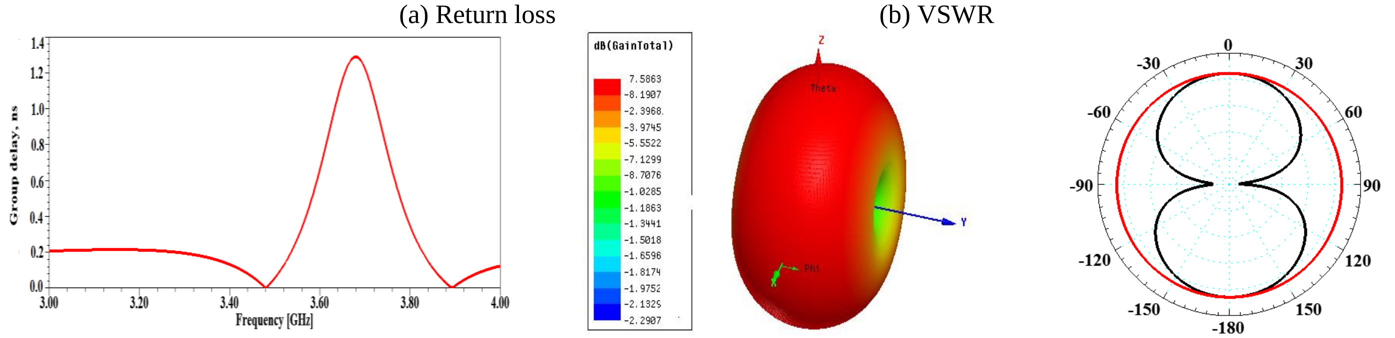
Table 1: Parameters represented on figure 3 (All dimensions are in mm)

L_{sub}	W_{sub}	L_f	W_f	L_g	W_m	L_1	L_2	L_3
22.5	11	8	2.8	5	1.5	0.9	1.31	1.82
L_4	L_5	L_6	W_1	W_2	W_3	W_4	W_5	W_6
2.47	3.28	4.29	0.4	0.5	0.625	0.78	0.98	1.22
S_1	S_2	S_3	S_4	S_5	S_6	W_{f1}		
2.64	1.55	1.43	1.3	1.12	0.9	1.6		

Figure 4(a) shows the return loss characteristics, figure 4(b) shows the VSWR, figure 4(c) shows the group delay, figure 4(d) shows the 3D polar plot and figure 4(e) shows the radiation pattern characteristics of log periodic planar dipole array antenna. Obtained parameters of designed antenna are illustrated in table 2.



(a) Return loss (b) VSWR



(c) Group delay (d) 3D gain polar plot (e) Radiation pattern (Red – elevation plane, black – Azimuthal plane)

Figure 4. Simulated characteristics of designed LPPDA with partial ground

2.2 Log Periodic C - Shaped Dipole Array Antenna (LPCDA)

Figure 5 shows the modified dipole as C – shape structure obtained by etching rectangular slot. This modified structure called as Log periodic C – shaped dipole array antenna (LPCDA). Where Ln represents the length of the n^{th} dipole and Wn represents the width of n^{th} dipole.

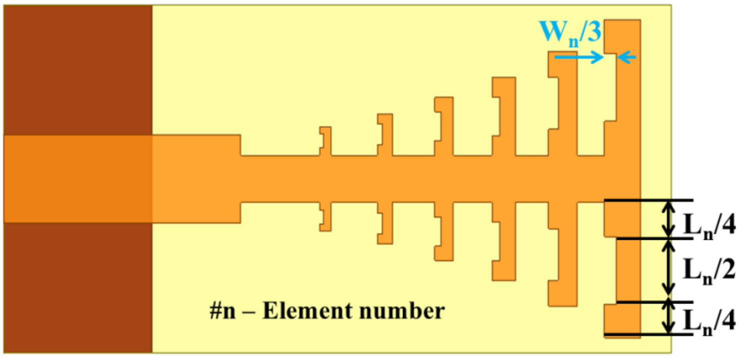
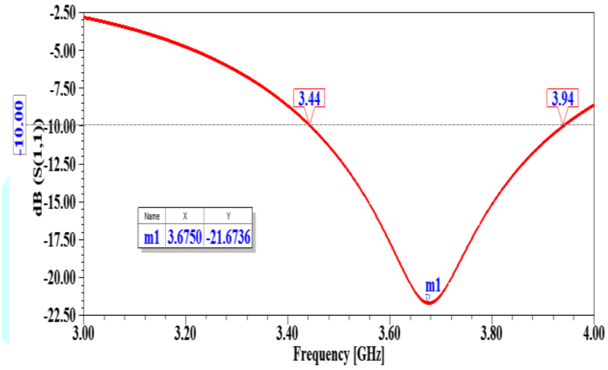
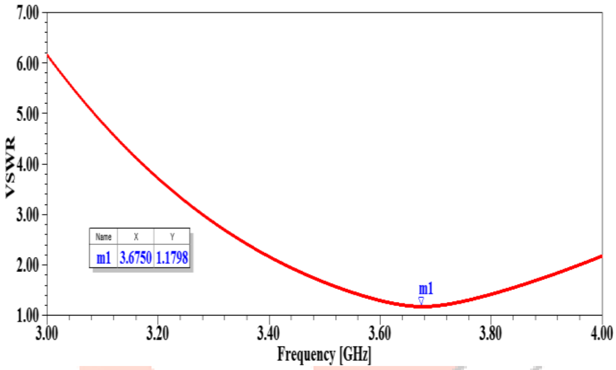


Figure 5. Geometrical configuration of log periodic C - shaped dipole array antenna (LPCDA) with partial ground

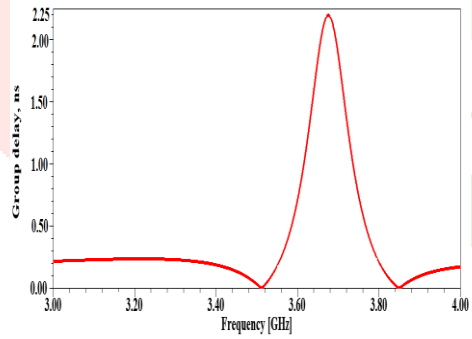
Figure 6(a) shows the return loss characteristics, figure 6(b) shows the VSWR, figure 6(c) shows the group delay, figure 6(d) shows the 3D polar plot and figure 6(e) shows the radiation pattern characteristics of log periodic C - shaped dipole array antenna. Obtained parameters of designed antenna are illustrated in table 2.



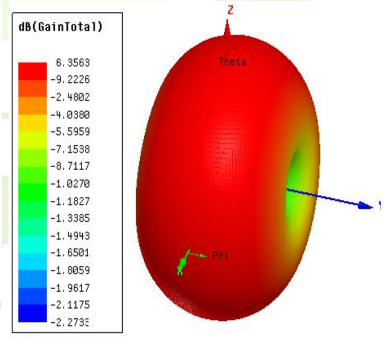
(a) Return loss



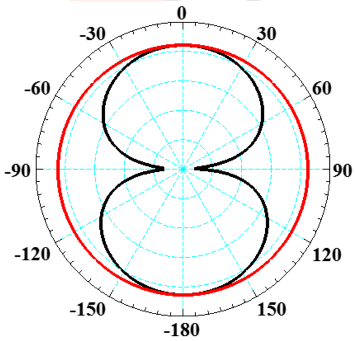
(b) VSWR



(c) Group delay



(d) 3D gain polar plot



(e) Radiation pattern (Red – elevation plane, black – Azimuthal plane)

Figure 6. Simulated characteristics of designed LPCDA with partial ground

2.3 Log Periodic I - Shaped Dipole Array Antenna (LPIDA)

Figure 7 shows the modified dipole as I – shape structure obtained by etching rectangular slots on middle of both sides to dipole element. This modified structure called as Log periodic I – shaped dipole array antenna (LPIDA). Where Wn represents the width of n^{th} dipole.

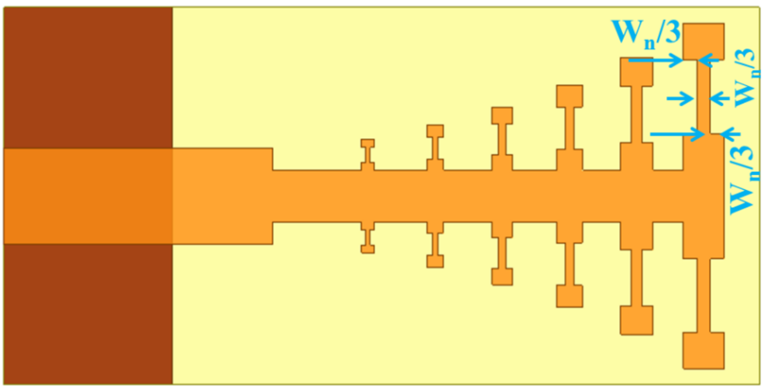
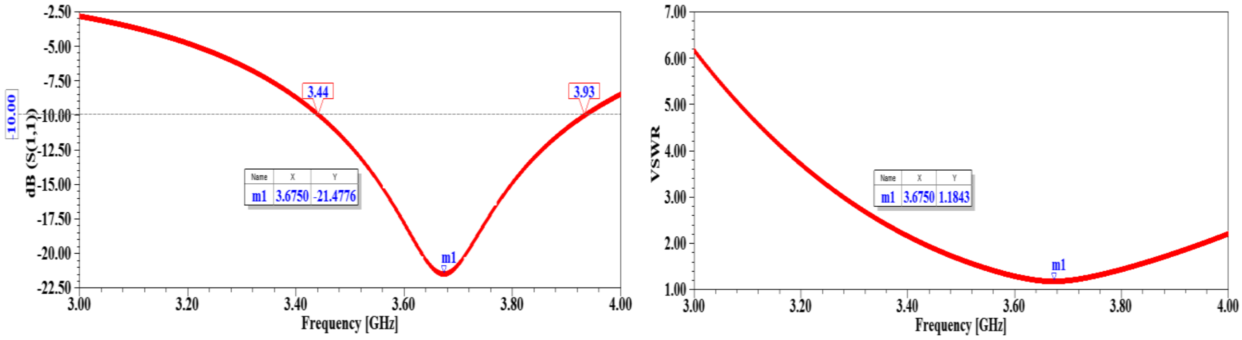
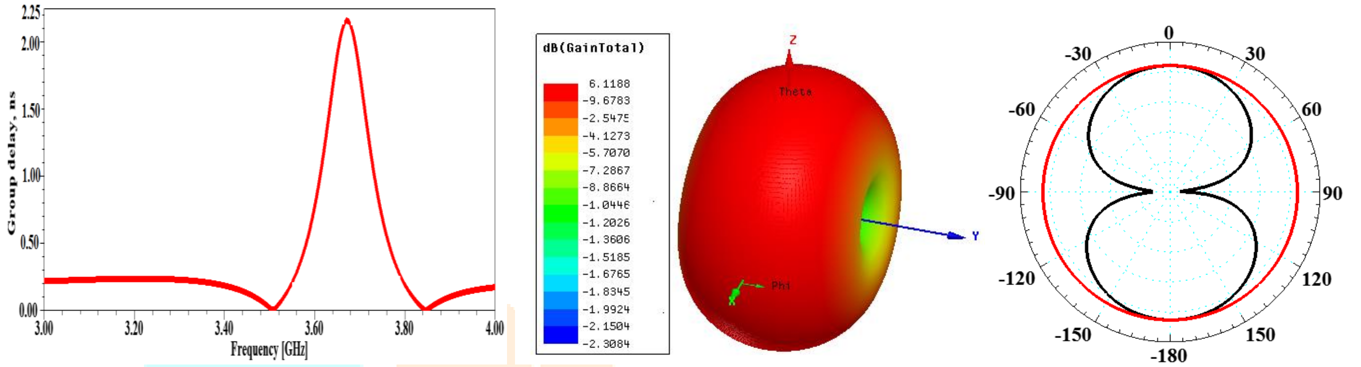


Figure 7. Geometrical configuration of log periodic I - shaped dipole array antenna (LPIDA) with partial ground

Figure 8(a) shows the return loss characteristics, figure 8(b) shows the VSWR, figure 8(c) shows the group delay, figure 8(d) shows the 3D polar plot and figure 8(e) shows the radiation pattern characteristics of log periodic I - shaped dipole array antenna. Obtained parameters of designed antenna are illustrated in table 2.



(a) Return loss (b) VSWR



(c) Group delay (d) 3D gain polar plot (e) Radiation pattern (Red – elevation plane, black – Azimuthal plane)

Figure 8. Simulated characteristics of designed LPIDA with partial ground

2.4 Tapered Feed Log Periodic I - Shaped Dipole Array Antenna (TLPIDA) with Partial Ground

A feed region connection, between the feed line and the monopole, was incorporated to improve the antenna performance and resonance shifting for 5G operation. A tapered connection between the feed line and the main patch is applied to smooth the current's path, thus providing wider impedance bandwidth and perfect impedance matching condition. Figure 9 shows the proposed tapered log periodic I – shaped dipole array antenna (TLPIDA) with partial ground.

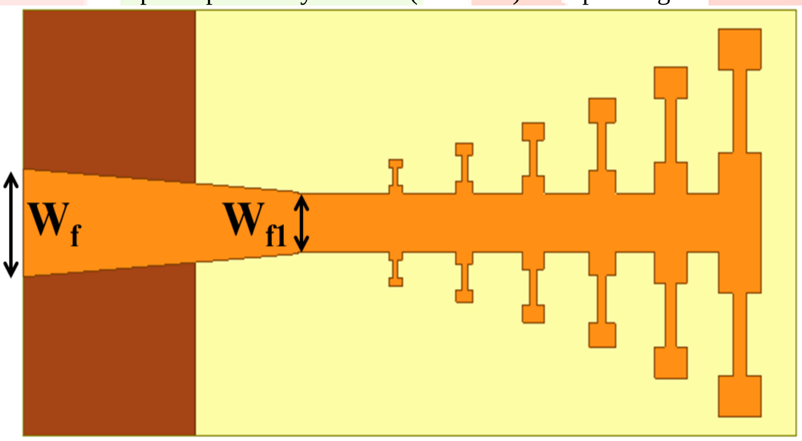
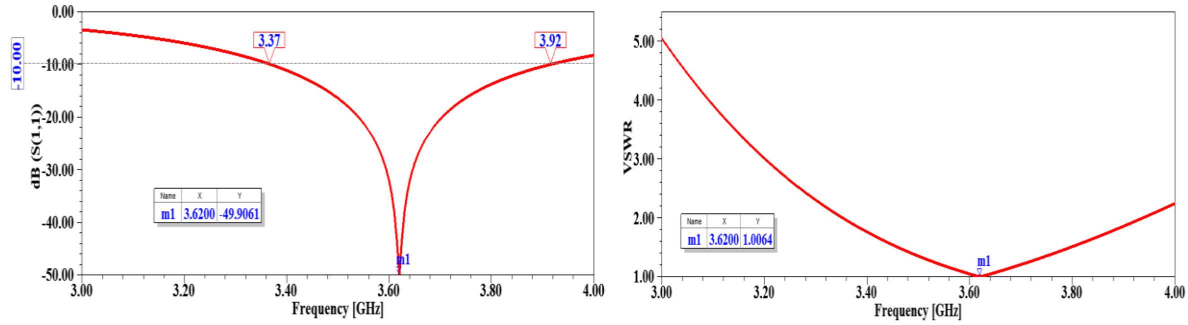
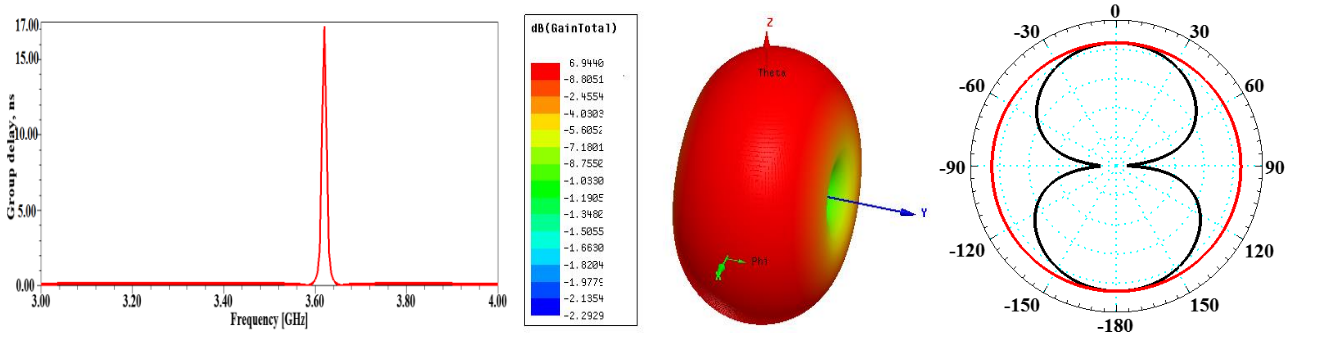


Figure 9. Geometrical configuration of proposed tapered log periodic I - shaped dipole array antenna (TLPIDA) with partial ground

Figure 10(a) shows the return loss characteristics, figure 10(b) shows the VSWR, figure 10(c) shows the group delay, figure 10(d) shows the 3D polar plot and figure 10(e) shows the radiation pattern characteristics of tapered log periodic I - shaped dipole array antenna with partial ground. Obtained parameters of designed antenna are illustrated in table 2.



(a) Return loss (b) VSWR



(c) Group delay (d) 3D gain polar plot (e) Radiation pattern (Red – elevation plane, black – Azimuthal plane)

Figure 10. Simulated characteristics of designed LPIDA with partial ground

Figure 11 shows the radiation efficiency characteristics of proposed antenna with partial ground structure. From this plot we observe that this antenna achieves approximately 96 – 98% radiation efficiency, this shows good working condition of proposed antenna. Figure 12 shows the magnitude and vector surface current distribution of proposed antenna. This current flow indicates the behavior of resonance within the 5G band.

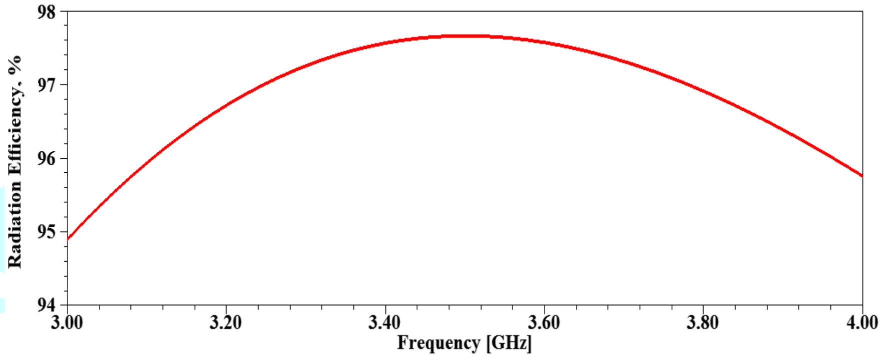
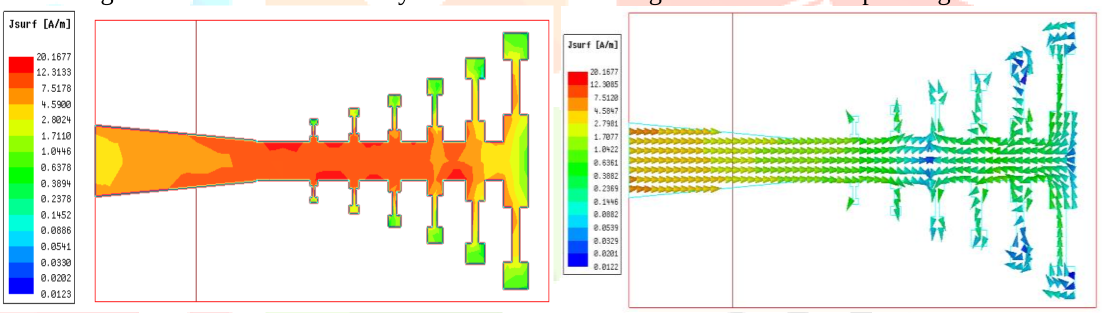


Figure 11. Radiation efficiency characteristics of designed TLPIDA with partial ground



(a) Magnitude (b) Vector

Figure 12. Surface current distribution characteristics of designed TLPIDA with partial ground

2.5 Design summary

Table 2 shows the design summary of designed antennas LPPDA, LPCDA, LPIDA and TLPIDA with partial ground interms of low frequency (fL, GHz), high frequency (fH, GHz), bandwidth (BW, MHz), resonant frequency (fr, GHz), fractional impedance bandwidth ratio (FBW), reflection coefficient (S11, dB), voltage standing wave ratio (VSWR), radiation efficiency (η, %), maximum peak gain (G, dB) and group delay (td, ns). Table 3 represents the computed antenna parameters of designed antennas LPPDA, LPCDA, LPIDA and TLPIDA with partial ground.

Table 2: Design specifications of proposed antenna in various configurations

S.No	Configuration	f_L	f_H	BW	fr	FBW	S_{11} dB	VSWR	% η	G	t_d
1	LPPDA	3.68	3.93	470	3.68	12.77	-17.82	1.295	96.80	7.58	1.32
2	LPCDA	3.44	3.94	500	3.675	13.60	-21.67	1.17	96.30	6.35	2.2
3	LPIDA	3.67	3.93	490	3.675	13.33	-21.47	1.18	98.25	6.11	2.2
4	TLPIDA	3.37	3.92	550	3.62	15.19	-49.90	1.00	96.56	6.944	16.8

Table 3: Computed parameters of designed log periodic array antenna in various configurations

S.No	Parameter	LPPDA	LPCDA	LPIDA	TLPIDA
1	Max U	995.4µW/Sr	1.01 mW/Sr	995.48 µW/Sr	989.48 µW/Sr
2	Peak directivity	1.3041	1.3271	1.3212	1.2892
3	Peak gain	1.2624	1.2781	1.298	1.245
4	Peak realized gain	1.2509	1.2697	1.251	1.2435
5	Radiated power	9.5921mW	9.5677mW	9.4689mW	9.6448mW
6	Accepted power	9.9086mW	9.9346mW	9.63075mW	9.9877mW
7	Incident power	10mW	10mW	10mW	10mW
8	Radiation efficiency	96.80%	.96.30%	98.25%	96.56%
9	Front to back ratio	1.0918	1.1042	1.1106	1.0895

III. Advantages of Proposed Antenna Compared with Existing Models

Table 4 represents the antenna performance compared with existing models owing with respect to used material and its thickness, bandwidth, compact size and radiation efficiency.

Table 4: Comparison of proposed work with earlier antennas

Ref	Material	Thickness	Bandwidth	Size, mm^2	Radiation efficiency
[13]	Rogers RO4003C	1.5mm	3.4 – 3.6GHz	100 x 50	55 – 60%
[14]	FR4 substrate	0.8mm	3.4 – 3.6GHz	136 x 68	-NA-
[15]	Rogers 5880	1.6mm	3.55 – 3.65GHz	75 x 150	52 – 76%
[16]	FR4 substrate	0.8mm	3.4 – 3.6GHz	150 x 75	35 – 50%
[17]	FR4 substrate	1.6mm	3.4 – 3.6GHz	145 x 70	30 - 50%
[18]	FR4 substrate	0.8mm	3.4 – 3.6GHz	136 x 68	40 – 60%
[19]	FR4 substrate	0.8mm	3.4 – 3.6GHz	150 x 80	60 – 75%
[20]	FR4 substrate	0.8mm	3.4 – 3.6GHz	150 x 73	50 – 70%
[21]	FR4 substrate	0.8mm	3.4 – 3.6GHz	150 x 75	50 – 80%
[22]	FR4 substrate	0.8mm	3.4 – 3.6GHz	150 x 75	60 – 70%
Proposed work	FR4 substrate	1.6mm	3.37 – 3.92GHz	22.5 x 11	95 – 97%

IV. Conclusion

In this paper, frequency independent antenna is designed for 5G applications. Initially log periodic planar dipole array antenna (LPPDA) is designed and simulated on FR – 4 material with partial ground. After that modified C – shaped dipole and I – shaped dipole is designed for better performance characteristics. Finally, tapered LPIDA with partial ground is proposed to cover 5G applications within frequency range of 3.37 – 3.92GHz with impedance bandwidth of 550MHz and it is resonating at 3.62GHz with corresponding magnitude reflection coefficient of -49.90dB. The VSWR value at resonating frequency is 1 and realized peak gain is 6.94dB. Radiation characteristics of proposed antenna show the omnidirectional in elevation and donut in azimuthal plane. Magnitude and vector surface current distribution of proposed antenna are discussed in above section. Maximum radiation efficiency obtained for proposed antenna is 96.56%. This novel wideband patch antenna with the log periodic array is presented for sub-6 GHz 5G mobile systems.

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