Enhancement of Bandwidth and Gain using Proximity Coupled DGS Structure Patch Antenna for WiMAX / 5G Band Applications

Ambavaram Pratap Reddy[1], Pachiyaannan Muthusamy[2]

Abstract – **This research reports a design of a dual band, proximity coupled feed micro strip patch antenna for 2.4 GHz (WiMax 2.4-2.5 GHz) and 4.7 GHz (5G Band 4.5-4.9 GHz) frequencies. The suggested antenna is designed using slot-cutting approach on the toplayer and DGS (Defected Ground Structure) on ground layer for bandwidth and gain improvement. The dual layer is constructed by low cost FR-4 substrate material. Due to slot cutting and DGS approach the gain has attained 4.95 dB. Bandwidth at lower frequency is 120 MHz and at higher frequency 160 MHz. The operating bandwidths of the designed antennas are 2.35-2.47 GHz and 4.69-4.85 GHz. CST MWS is used for the numerical analysis and simulation. The proposed antenna has outstanding performance and good agreement with the simulated results. The proposed antenna shows good performance for WiMAX, 5G application also mobile network applications.**

Keywords – **5G, DGS, Dual band, Proximity coupled, WiMAX.**

I. Introduction

Compact antennas are required in modern communication systems. Also, further standards are required with regard to multiband functioning. In order to meet different communication applications, various research projects have focused on compact multiband antennas that have more than one band. However, because of the limited bandwidths and low strengths, it is not possible to get higher performance using conventional microstrip patch antenna. In [1] by Kumar Darimireddy *et al.,* a triple layer double U-slot antenna was designed for multiple wireless applications. With triple layer structure bandwidth is enhanced. In [2] by Faisal, a multi-layer triple band antenna was designedwith different dielectric constant materials. In [3] by Saini and Agarwal, a multiple L-slot microstrip patch antenna was designed to satisfy WLAN and WiMAX application. In [4] by Gautam *et al.*, a multi slot microstrip patch antenna for WiMAX and WLAN applications is reported. In [5] by Sugumaran and Balasubramanian, acompact DMJC FSS (Frequency Selective Surface unit cell) was presented for 2. ISM (Industrial Scientific Medical) band shielding applications. In [6] by Khan et al., a double layer rectangular microstrip patch antenna array with higher gain and directivity was designed for ISM band applications. In [7] by Faisal *et al.*, a single feed dual layer rectangular quad band microstrip antenna was designed for GSM (900 MHz), GSM (1800 MHz), IMT 2000 (885-2200), WiMAX and Wi-Fi (2400-2500), WLAN applications. In [8] by Duhan *et al.*, a multiband monopole patch antenna was designed for GSM, WiMAX and other wireless applications. The four frequency bands are centered at 0.9, 2.4, 3.7, 4.7 GHz. The antenna has a very compact size of 30×40×1.57 mm^3. In [9] by Yang *et a*l., a dual band antenna with 2.4 GHz and 5 GHz frequency bands was designed for ISM band in order to be used in the WLAN environment. In [10] by Mishra *et al.*, a broadband radiation pattern H-shaped microstrip antenna was designed for wireless applications. Based on the literature review, to improve the gain the dielectric constant should be deacreased or the height of the substrate should be increased and satisfy the fringing length i.e., $h < 0.05\lambda_0$, where λ_0 is free space wavelength. Improved results obtained by this chosen dual layer techniques are reported in Table 4. The single and dual layer structures both dual band and multiband antenna are reported in [11-15]. It is observed that compared to single layer, the dual layer antenna exhibited more gain. Based on the above literature, author has been motivated to design dual layer patch antenna for gain enhancement, very much required for modern day WiMax and 5G band application. The proposed and existing antennas are also compared here. The forth coming sections discuss about single layer, dual layer proximity coupled antenna design configuration, results and discussion.

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II. Single Layer and Dual Layer Antenna Configurations

In this section, single and dual layer antennas using proximity coupled feed are designed. The suggested antennas are made of the same FR-4 substrate material. Figs. 1(*a*) and (*b*) illustrate the proposed single layer and dual layer antennas, whereas Fig. 1(*c*) and (*d*) show the corresponding *S*-parameters and gain results. Table 1 illustrates the dimensions of the proposed antenna. The study founds that when compared to a single layer antenna, the dual layer antenna has a low return loss and a high gain. The length, width and impedance calculation are necessary to estimate the resonant frequency, the derived calculation is shown below. The feeding slot can be evaluated from Eq. (1) at 50 Ω impedance

$$I_0 = \frac{2\cdot 60\pi}{\sqrt{\varepsilon_r}\cdot\left[\frac{h_1}{w_d}+1.3+0.6\cdot\ln\left(\frac{h_1}{w_d}+1.4\right)\right]}, \tag{1}$$

where $I_0 = Z_0$ (Impedance).

The patch length, width and permittivity (ε_r) of the proposed design are calculated from Eqs. (2)-(5).The width of patch is

$$\omega = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} . \quad (2)$$

Effective dielectric constant of the patch is

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \left[1 + 12 \frac{h}{\omega}\right]^{-\frac{1}{2}} . \quad (3)$$

The extended incremental length of the patch is

$$\Delta L = 0.412 \cdot h \cdot \frac{\left(\varepsilon_{eff} + 0.3\right) \cdot \left(\frac{\omega}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right) \cdot \left(\frac{\omega}{h} + 0.8\right)} . \quad (4)$$

Finally effective length is

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} . \quad (5)$$

Length of patch is

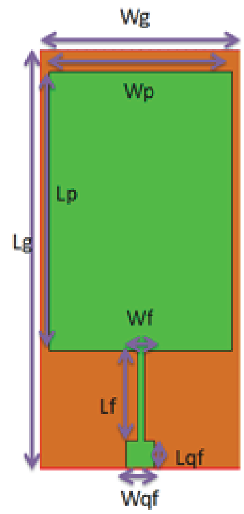
$$L = L_{eff} - 2\Delta L . \quad (6)$$

With reference to above equations, it is required to calculate the proposed antenna design and feeding slot dimensions to attain the desirable frequency.

This proposed structure initially started with single layer and calculation of patch length and width applied conventional method i.e., based on λ value. Structure for the value of patch 20×30 mm^2 resonating at 2.4 GHz is shown in Fig. 1(*a*). Initially the conventional rectangular patch designed for the frequency of 2.4 GHz using quarter wave transmission to match the Z_L load impedance of 240 Ω and input impedance of 50 Ω is with characteristic impedance 100Ω. Based on the free space wavelength and guided wavelength the frequency is calculated. The detailed patch diagram is shown in Fig. 1(*a*) and a dual layer structure with improved gain is shown in Fig. 1(*b*) and (*c*).

It is very essential to improve the bandwidth and gain for access more users for 5G transmission and greater directivity. In this way, the dual layer structure is proposed. There are many ways to improve the gain like using array pattern but the larger the size of the antenna, the greater its complexity. Instead of increasing number of elements, the number of layers along height side has been increased.

In this proposed design, proximity coupled feeding structure is applied. There are three layers: one is ground layer with DGS pattern, second layer is microstrip feed line layer and top layer is an active patch. The top layer and the feed line are coupled through FR4 substrate layer. This may help to improve the gain, and DGS help to improve the bandwidth. The details of design diagram are shown in Fig. 1(*b*). From S_{11} plots of both the single layer and the dual layer antennas, the return loss characteristics have been improved from −16 dB to −20 dB as shown in Fig. 1(*c*) and (*d*). The corresponding single layer and dual layer gains showing Omni directional pattern at an angle of phi 0 degree provides 1.18, 2.35 dB.



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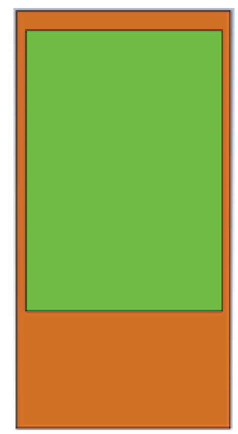
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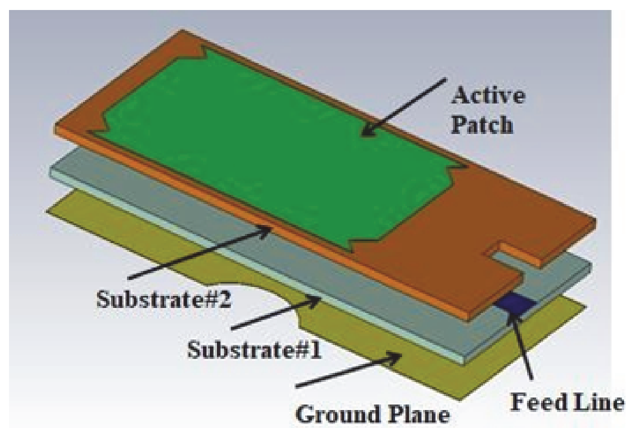

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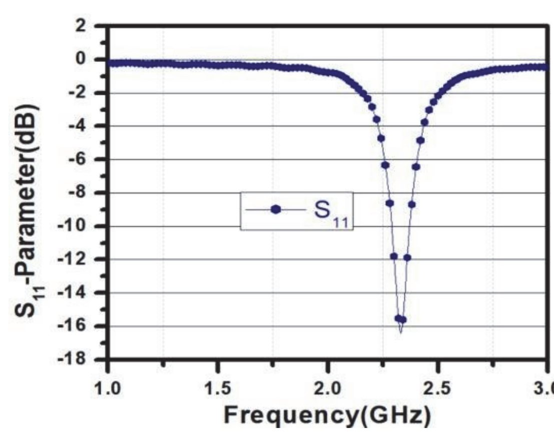

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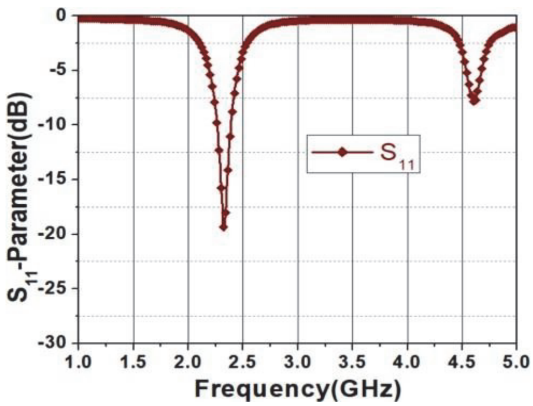

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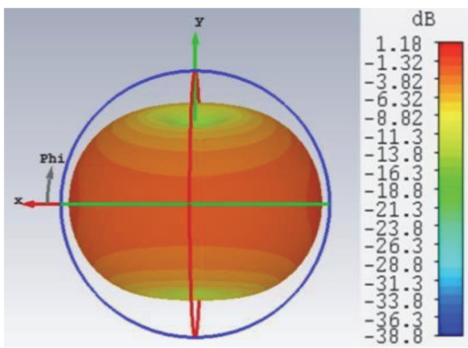

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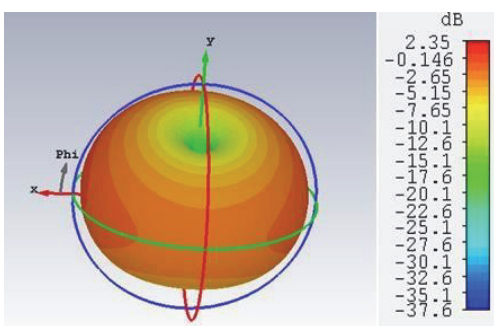

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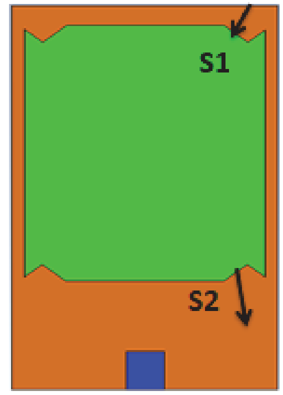
Fig. 1. (a) Proposed single layer antenna, (b) proposed dual layer antenna, (c) stacked proposed design, (d) S_{11} result single layer antenna, (e) S_{11} result dual layer antenna, (f) gain of the single layer antenna, and (g) gain of the dual layer antenna

TABLE 1
ANTENNA DIMENSIONS

Parameters	Dimensions [mm]
Wg , Lg	22, 45
Wp , Lp	20, 30
Wf , Lf	0.7, 9.1
Wqf , Lqf	3.1, 3



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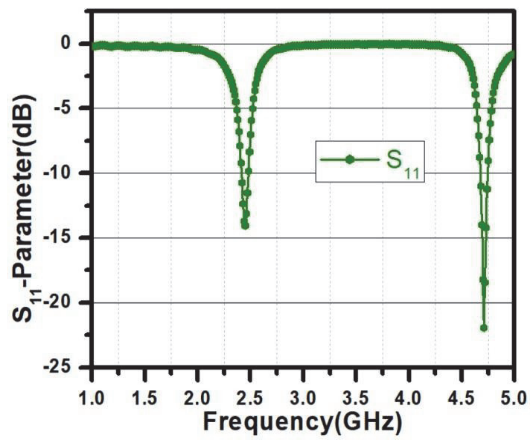

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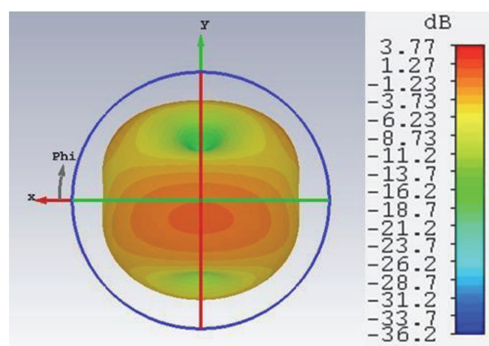

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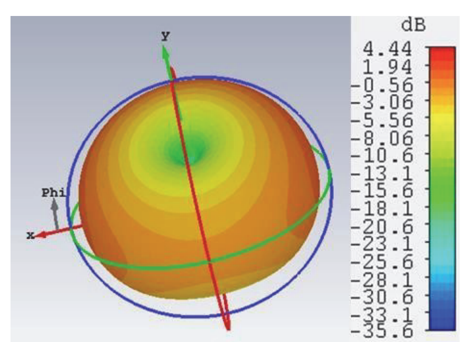


(*d*)

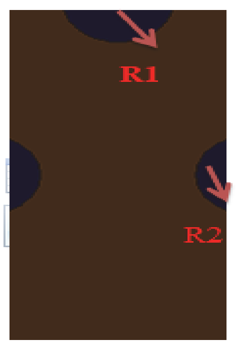
Fig. 2. (a) Slot cutting dual layer antenna, (b) S_{11} parameter, (c) gain at 2.4 GHz, and (d) gain at 4.7 GHz

III. Slotted Structure Proximity Coupled Dual Layer Analysis

A small slot of proximity coupled proposed antenna's corner sides is etched for greater enhancement. The slots have diameters of S1=2.2 mm and S2=1.7 mm. Fig. 2 shows the proposed slot cutting antenna, the corresponding *S*-parameter and gains at the desired frequencies. With slot cutting, a new band frequency of 4.7 GHz may be obtained with low return loss and high gain. The gain at2.4 GHz is 4.44 dB and at 4.7 GHz is 3.77 dB.

IV. DGS Structure Dual Layer Antenna Analysis

DGS techniques help to improve the bandwidth, gain and attenuate surface wave. The characteristic of the return loss has been improved to −34 dB, and maximum gain of 5.8 dB is achieved. A dual layer microstrip antenna with DGS has been discussed in this section. For further improvement, ground portions with radius r1(2.2r) and r2(1.7r) are etched. The proposed results are shown in Fig. 3(*a*)-(*d*). With partial grounding effects, low return loss and improved gains are attained. The current distribution of the stacked at the resonant frequencies is shown in Fig. 3(*e*) and (*f*). The operating bandwidths are 2.35-2.47 GHz and 4.69- 4.85 GHz.



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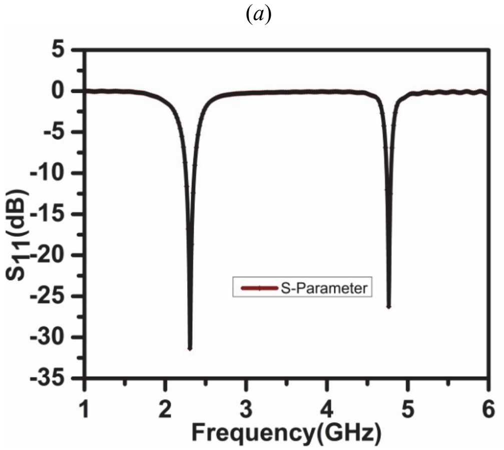

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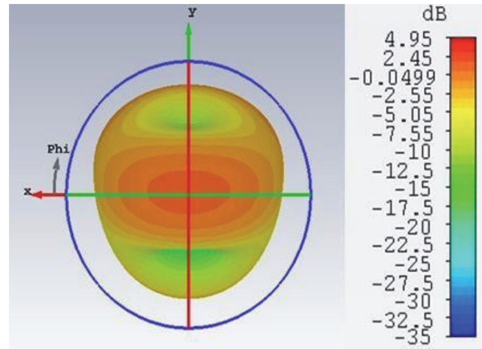

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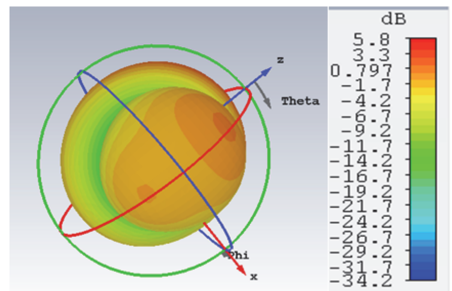

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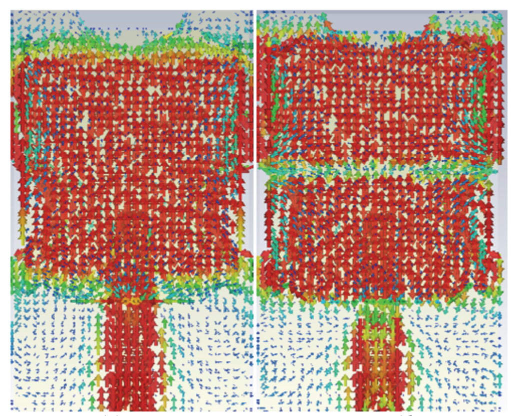
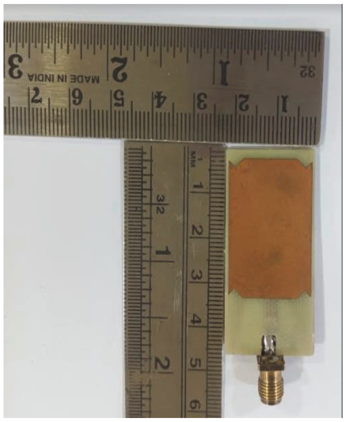


(*e*) (*f*)

Fig. 3. (a) Back view of the proposed antenna, (b) S_{11} parameter, (c) gain at 2.4 GHz, (d) gain at 4.7 GHz, (e) current distribution at 2.4 GHz, and (f) current distribution at4.7 GHz

V. Results and Discussion

Table 2 compares the gains of all of the antennas that have been proposed. As can be seen, gain increases with each proposed design. The minimal return loss of the desired dual layer proposed antenna is shown in Fig. 3(*b*). Fig. 4 shows the fabricated prototype desired antenna, as well as the measurement and simulation results at the two frequencies. Fig. 4(*e*) depicts the gain vs frequency at the both target frequencies. Fig. 4(*f*) and (*g*) depicts E-plane and H-plane radiation patterns at the target frequencies. Table 3 compares the measured and simulated results and Table 4 displays comparison of the proposed work with the existing works.



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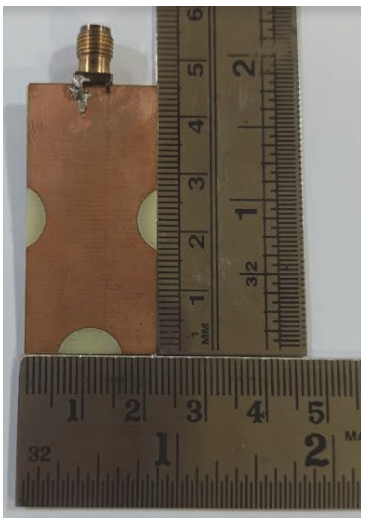
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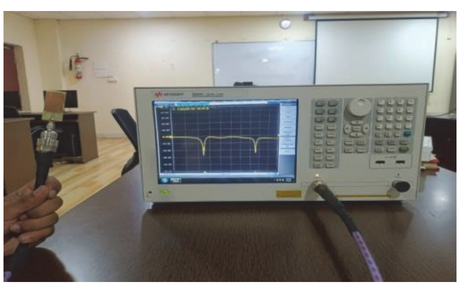
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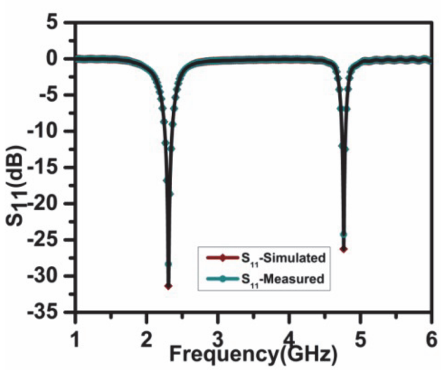

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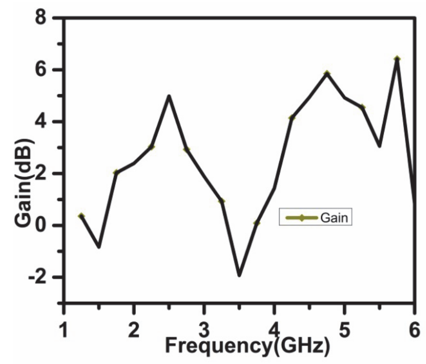

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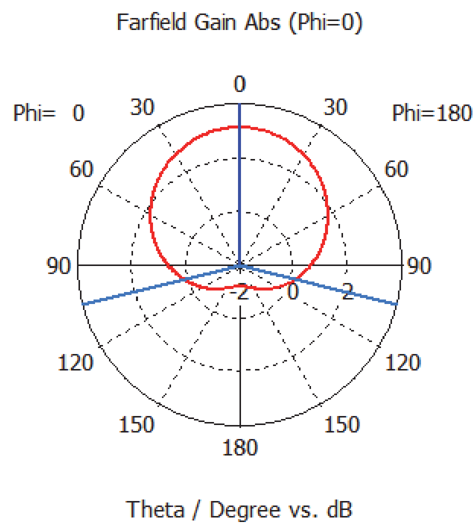

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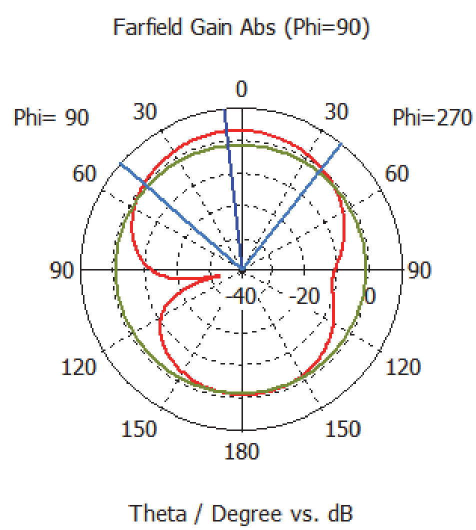

(*g*)

Fig. 4. Prototype model of the proposed antenna: (a) front view, (b) back view, (c) measurement set-up, (d) measured and simulated S_{11} parameters, (e) gain vs frequency, (f) E-plane radiation pattern, and (g) H-plane radiation pattern

TABLE 2
GAIN COMPARISON OF DIFFERENT ANTENNAS

Antenna	Frequency [GHz]	Gain [dB]
Antenna 1	2.4	1.18
Antenna 2	2.4	2.35
Antenna 3	2.4 & 4.7	3.77 & 4.44
Antenna 4	2.4 & 4.7	4.95 & 5.8

TABLE 3
SIMULATION AND MEASUREMENT COMPARISON

Parameter	Simulated	Measured
S_{11}	33.34 dB @ 2.4 GHz, 26.54 dB @ 4.7 GHz	29.22 dB @ 2.4 GHz, 24.56 dB @ 4.7 GHz

TABLE 4
COMPARISON OF THE PROPOSED ANTENNA WITH THE EXISTING WORKS

Ref. No	Frequency [GHz]	No of layers	Gain [dB]	Bandwidth [GHz]
[11]	2.4	single	11.6	2.24-2.5
[12]	0.9, 1.7 & 2.4	dual	-	21, 17 & 13.7 MHz
[13]	2.2, 4.45 & 5.3	dual	>14	-
[14]	3.3 & 4.5	single	7.17	3.29-3.63 & 4.39-5.2
[15]	2.4, 3.4 & 5.3	single	1, 4 & 3.7	3.3-3.6 & 5.1-5.3
Proposed work	2.4 & 4.7	dual	4.95 & 5.8	2.35-2.47 & 4.69-4.85

VI. CONCLUSION

This paper has presented a dual-layer proximity coupled feed dual-band antenna for WiMax and 5G band applications, constructed by low cost FR4 substrate material operating at frequencies of 2.4 GHz and 4.7 GHz. Due to slot cutting and partial grounding, bandwidth and gain were increased. The low frequency bandwidth is 120 MHz, whereas the higher frequency bandwidth is 160 MHz. The suggested antennas are designed using slot-cutting approach and DGS for gain improvement. The gain of slotted cutting approach is 4.4dB and of DGS approach is 4.95dB. The operating bandwidths of the designed antennas are 2.35-2.47 GHz and 4.69-4.85 GHz. CST MWS is used for the numerical analysis and simulation. These reported antennas are very much essential for WiMax and 5G applications.

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