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RESEARCH PAPER

A multilayer dual wideband circularly polarized microstrip antenna with DGS for WLAN/Bluetooth/ZigBee/Wi-Max/ IMT band applications

AMANPREET KAUR[1], RAJESH KHANNA[1] AND MACHAVARAM KARTIKEYAN[2]

In this paper, a three layered stacked circularly polarized rectangular dual band microstrip antenna with a defected ground structure (DGS) and a feed network with stub (showing dual wideband characteristic) is designed, fabricated, and tested for WLAN, Zig bee, Wi-Max, and IMT band applications. The proposed antenna is fabricated on an FR4 substrate with dielectric constant (ε_r) of 4.4; tanδ of 0.0024 and a height of 1.57 mm.The antenna has a surface area of 4.8 × 4.1 cm² and a total height of 5.1 mm. The designed antenna covers two wireless bands from 2.39 to 2.64GHz and 3.39–3.76 GHZ with impedance bandwidths (VSWR $<$ 2) of 250 MHz (9% bandwidth centered at 2.515 GHz) and 370 MHz (10% bandwidth centered at 3.57 GHz), respectively. This antenna is capable of covering IEEE 802.11b/g/n standards of WLAN from 2.4 to 2.485 GHz, bluetooth applications from 2.4 to 2.483 GHz, ZigBee applications from 2.4 to 2.485 GHz, IEEE 802.16/ Wi-MaX applications from 3.4 to 3.69 GHz and international mobile telecommunications (IMT) band from 3.4 to 3.6 GHz. As the antenna is circularly polarized, the misalignment of the receiver with transmitter does not affect the performance of the system. The antenna designing was done using CST MWS V'10 and the prototype of the designed antenna was tested for the validation of S_{11} (dB) and gain results against the simulated ones experimentally. The proposed antenna shows a gain of 4.08 dBi at 2.5 GHz and a gain of 5.024 dBi at 3.51 GHz.

Keywords: Stacked Aperture coupled MSA, DGS, WLAN, Bluetooth, ZigBee, WiMaX, IMT, Return loss, Circular polarization, Impedance bandwidth, Radiation pattern

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I. INTRODUCTION

Antennas are one of the most important components of any wireless communication system as they act as transducers and convert the information embedded on a high frequency carrier signal from electrical to electromagnetic waves and project those into free air for transmission and vice versa for reception. Since microstrip antennas have advantage over the other types of antennas of being smaller in size, ease of fabrication, conformability to planar and non-planar surfaces, and ease of integration with radio frequency (RF) front end circuits, these are a preferred choice for most of the wireless applications [1].

As there is a great demand for Multiband Microstrip antennas in the current wireless systems, to incorporate two or more applications in the same RF device, a lot of work is available in literature that concentrates on the design of multiband microstrip antennas [2–5]. But apart from possessing multiband characteristics, the antenna's design complexity is also a major issue. It should also be simple to fabricate and should be easily integratable with the RF circuits. Furthermore a high gain and a wide bandwidth antenna are highly desirable to support a good data rate and long range for all the proposed wireless applications.

For multi-frequency applications various designs like planar inverted F antenna (PIFA), a ring shaped antenna, and a fractal antenna with Pythagoras tree structure have been presented in [2, 4, 5]. Since complexity is a major issue while implementing multiband antenna, and a need to cover all the proposed wireless applications in the same antenna, gives an initiative to design a simple dual wide band stacked microstrip antenna.

Work is available in literature on the use of circularly polarized stacked microstrip patch antennas for S- and C-band applications. The proposed antenna structure had truncated corners in the radiating square patch for circular polarization [6]. Some researchers have also illustrated the use of stacked fractal antennas for wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) applications [7]. Since both the above mentioned antennas in [6, 7] are not capable of covering the desired

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wireless applications mentioned in the paper, a simpler approach in this context to achieve the desired results is to use rectangular stacked patches with a defected ground structure (DGS).

The proposed stacked microstrip antenna (MSA) has three layers of the dielectric substrates out of which two substrate layers have metal patches i.e. two unequal rectangular MSAs printed over them. These are stacked one over the other to improve the bandwidth and gain of the antenna as they excite two resonant frequencies close to each other thereby showing wideband behavior. This method leads to an increase in the overall height of the antenna but the surface area remains the same as that of the single layer patch antenna [8, 9]. In order to increase the bandwidth and gain of the stacked MSA further, aperture coupled feeding is used. This feeding method of MSAs avoids the problem related to the self-reactance of probe feeding, simplifies the fabrication process, and makes it free from soldering points that might lead to unwanted parasitic radiations and a greater radiation pattern symmetry due to feed line at the center with respect to the patch location is achieved [10].

The antenna also has a DGS with an E shaped slot in the ground that helps it to show resonant behavior at the second frequency band. The DGS can be compared with a parallel *LC* resonant circuit whose resonant frequency is inversely proportional to the square root of product of *L* and *C* which are determined according to equation (1)

$$L = \frac{1}{4\pi^2 fo^2 C} \quad \text{and} \quad C = \frac{fc}{2Zo} \cdot \frac{1}{2\pi(fo^2 - fc^2)}, \tag{1}$$

where f_o, f_c, and Z_o denote the resonant frequency, cut off frequency and characteristic impedance of microstrip line above the DGS, respectively, and the resonant frequency of operation is defined by the structure of DGS and is given by equation (2).

$$f_r = \frac{1}{2\pi\sqrt{LC}}. \tag{2}$$

Moreover a DGS helps in antenna size reduction, cross polarization reduction, and harmonic suppression [11]. The present paper presents the design procedure, validation of simulated results against the measured results experimentally, and the applications of the proposed antenna in the current wireless scenario.

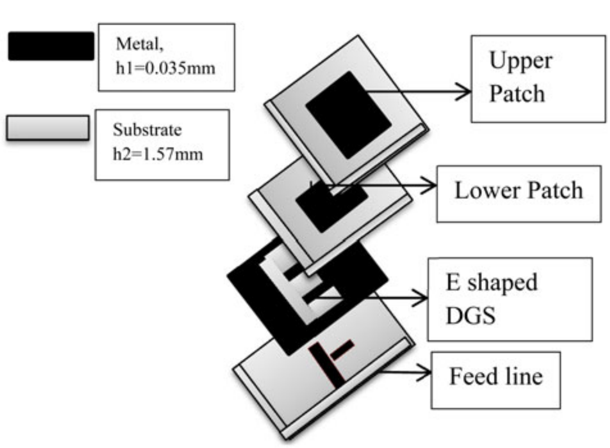

Fig. 1. Perspective view of the proposed antenna.

II. ANTENNA GEOMETRY AND DESIGN

The proposed antenna structure is capable of exciting two resonant frequencies with wideband behavior. The lower frequency band is obtained by stacking two unequal rectangular patch antennas one over the other. The size of upper patch is 9% larger than the lower patch and the

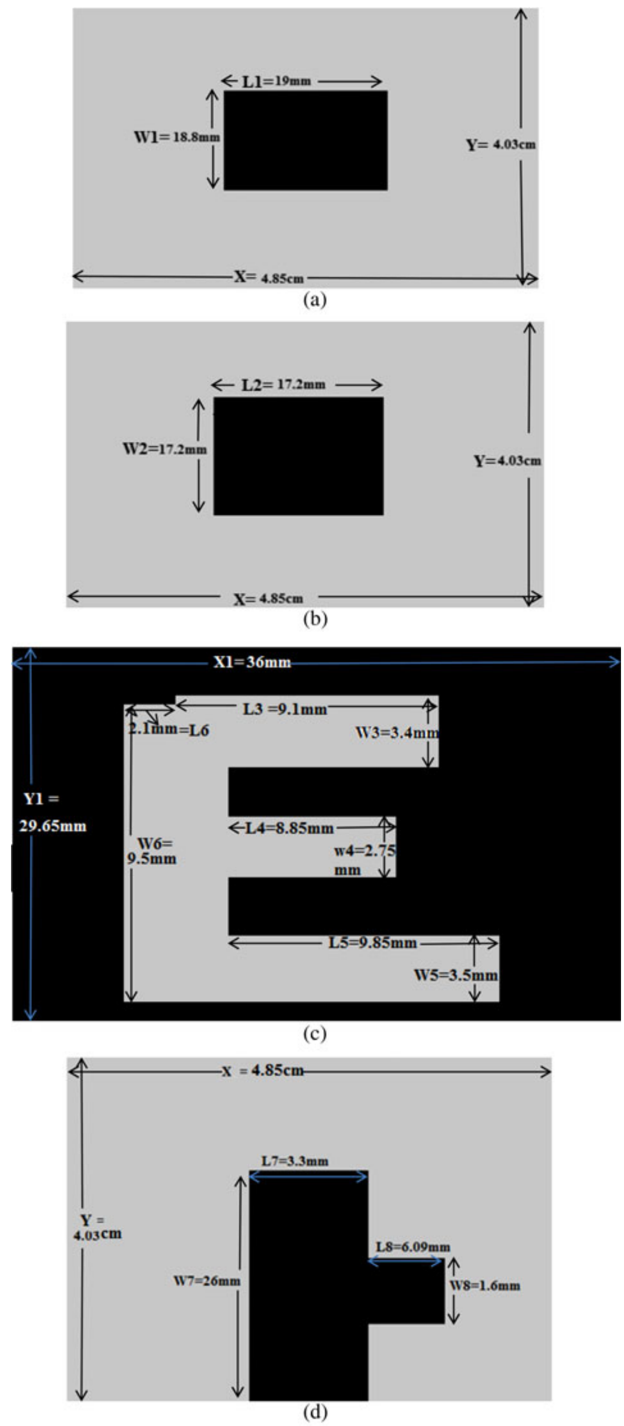

Fig. 2. (a) Upper patch antenna (topmost layer). (b) Lower patch antenna (middle layer). (c) Ground plane with E shaped defect (top of bottom Layer). (d) Feed line with a stub on the back side of lower substrate (back side of bottom layer).

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Table 1. Design parameters of the antenna.

Parameter	Size in mm
L1	19
W1	18.8
L2	17.2
W2	17.2
L3	9.1
W3	3.4
L4	8.85
W4	2.75
L5	9.85
W5	3.5
L6	2.1
W6	9.5
L7	3.3
W7	26
L8	6.09
W8	1.6
X	48.5
Y	40.3
X1	36
Y1	29.65

antenna is excited using aperture coupled feeding. A horizontal stub is also attached to the aperture coupled feed line in quadrature to it, that helps in achieving circular polarization of the antenna. An E shaped defected structure is etched in the ground plane to excite the second resonant frequency, with appreciable bandwidth. Figure 1 shows the perspective view of the proposed antenna. Each layer of antenna is designed on FR4 glass epoxy substrate having a dielectric constant $\varepsilon_r = 4.4$, height $h = 1.57$ mm, and a loss tangent of 0.0024. Transmission line model equations are used for rectangular patch antenna design [1, 7].

The design steps of the antenna are:

(i). Calculation of the dimensions of the rectangular patch antennas according to the transmission line model depending upon the height and effective dielectric constant of the substrate(FR4) [1, 7].
(ii). The optimization of feed line parameters for an aperture coupled feeding method using the CST MWS V'10 software.
(iii). Calculation of dimensions of the E shaped slot using equations (i) and (ii) of L and C in [11] according to the second resonant frequency of operation.
(iv). Optimization of the E shaped slot using the software to cover the desired wireless application bands.

The optimized antenna has a larger rectangular patch of dimensions 19 × 18.8 mm² printed on the topmost substrate (Fig. 2(a)), A smaller rectangular patch of dimensions 17.2 × 17.2 mm² with a E shaped defect on its ground plane is printed on the middle substrate (Fig. 2(b)). The height of E shaped DGS slot is 9.5 mm and the length of the largest E sub arm is 9.85 mm (Fig. 2(c)). The feed line of dimensions 3.3 × 14.407 mm² is etched on the ground plane of lower substrate with a horizontal stub of dimensions 6.09 × 1.6 mm² attached in quadrature to it (Fig. 2(d)). When the antenna is energized, the vertical feed line provides the vertical component of the E field and the horizontal stub provides the horizontal component of the E field there by making the antenna circularly polarized. The detailed dimensions of all the antenna part are also mentioned in Table 1.

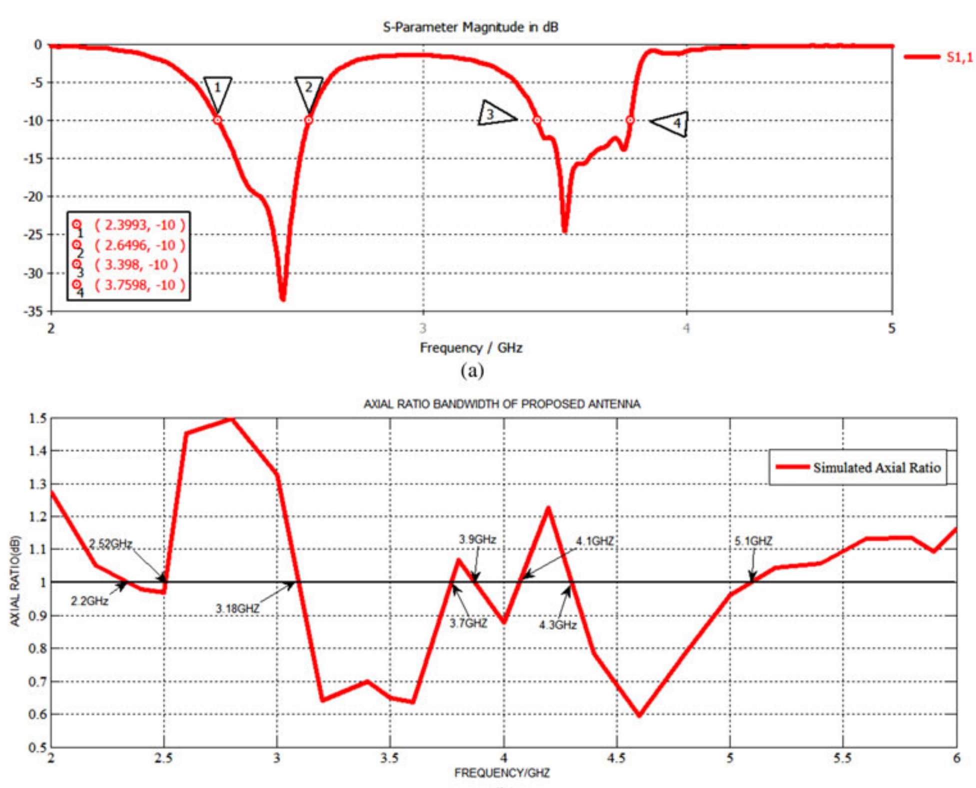

Fig. 3. (a) Simulated S_{11} (in dB) plot of the proposed antenna. (b) Shows the AR bandwidth of the proposed antenna.

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III. RESULTS AND DISCUSSIONS

The antenna was designed and simulated using computer simulation technology software version 2010. This is a three-dimensional (3D) electromagnetic (EM) simulator based on the finite integration technique and is used for full wave analysis of antennas. The analysis in this case is done considering perfect boundary conditions and a finite ground plane. The simulation results in terms of impedance bandwidth (S_{11} (dB)), axial ratio (AR) bandwidth, gain and current distribution are presented in the following sections A–D.

A) Impedance bandwidth and AR bandwidth

The return loss i.e. S_{11} (in dB) of the proposed antenna structure is shown in Fig. 3(a). The S_{11} (dB) on *Y*-axis of the antenna is plotted against frequency on the *X*-axis. It can be seen from Fig. 3(a) that the antenna shows dual wideband behavior from (2.39 to 2.64 GHz) with an impedance bandwidth of 250 MHz (centered at 2.51 GHz) and impedance bandwidth of 370 MHz from (3.39 to 3.76 GHz) (centered at 3.57 GHz).

Figure 3(b) shows the 1 dB AR bandwidth (<1 dB) of the antenna; this is a plot of AR (in dB) on *Y*-axis with respect to frequency on *X*-axis. The antenna shows an AR bandwidth of 320 MHz from (2.2 to 2.52 GHz), AR bandwidth of 520 MHz from (3.18 to 3.7 GHz), an AR bandwidth of 200 MHz from (3.9 to 4.1 GHZ), AR bandwidth of 800 MHz from (4.3 to 5.1 GHz) thereby showing circular polarization at the mentioned bands of antennas operation.

B) Current distribution on the antenna

The proposed aperture coupled MSA is energized to see the energy concentration on its structure at the two center resonant frequencies of the two mentioned wireless bands and also justify the antennas resonant behavior at the two bands because of the respective structural parts of the antenna.

Figure 4(a) shows that the E shaped DGS slot in the antenna is mainly responsible for showing a resonant band from 2.39 to 2.64 GHz as the maximum current distribution of 108.4 A/m is observed in the E shaped slot as compared with the upper patch antenna with a current distribution of 14.2 A/m at the center frequency of 2.51 GHz. Figure 4(b) shows that the major part of energy is concentrated on the two rectangular patches at 3.51 GHz. These two patch antennas are responsible for showing a resonant band from 3.39 to 3.76 GHz. The current distribution on the upper- and lower-patch antennas is

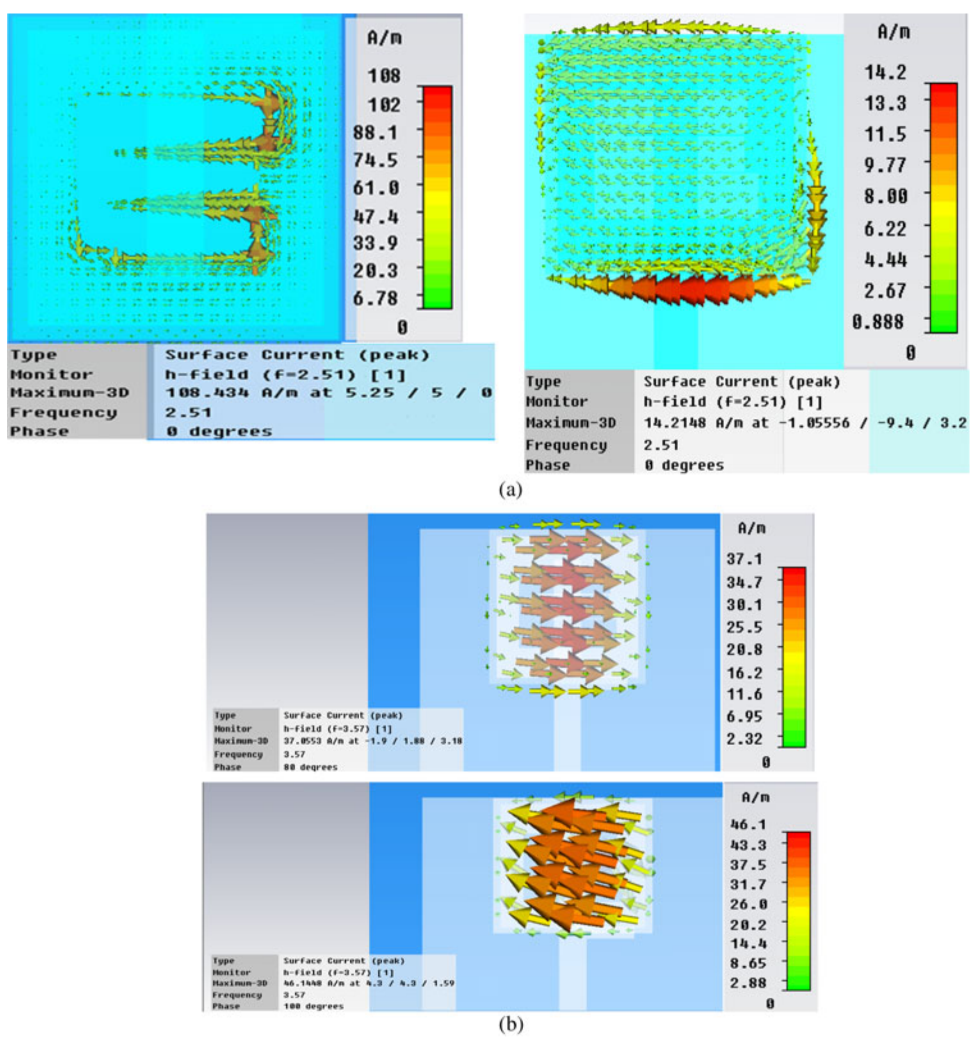

Fig. 4. (a) Surface current distribution on the ground of antenna in comparison with the upper patch antenna at 2.51 GHz. (b) The surface current distribution on the upper lower and lower patch antennas at 3.57 GHz.

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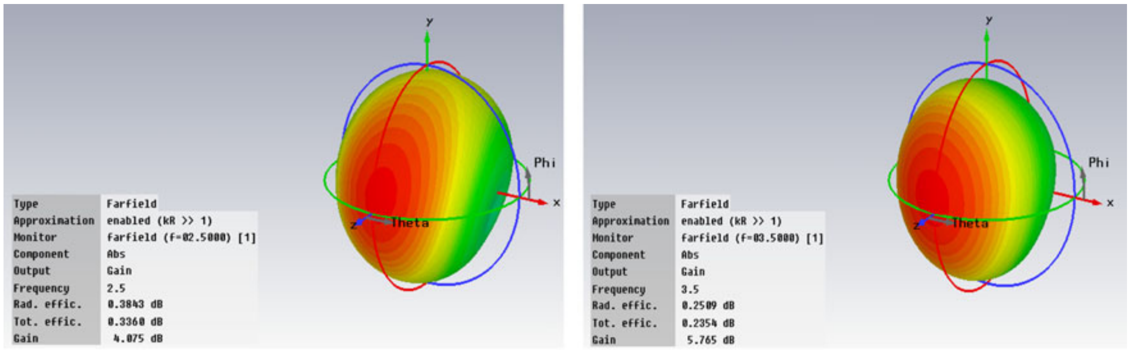
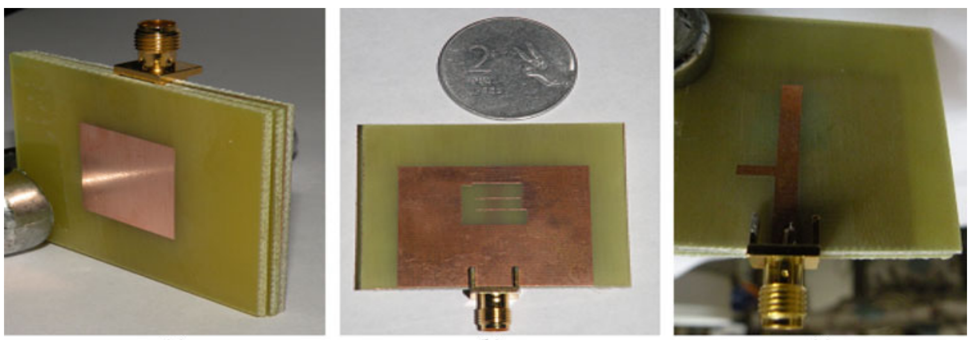


(a) (b)

Fig. 5. (a) Gain plot of antenna at 2.5 GHz. (b) Gain plot of antenna at 3.5 GHz.



(a) (b) (c)

Fig. 6. (a) Assembled antenna. (b) View of the DGS. (c). Bottom view of the antenna.

circularly polarized since both the horizontal and vertical components of electric field are supplied by the feed line.

C) Gain

Figures 5(a) and 5(b) show the gain of antenna at 2.51 and 3.5 GHz, respectively, the antenna shows a gain of 4.07 dBi at 2.5 GHz and a gain of 5.765 dBi at 3.51 GHz.

IV. MEASUREMENT RESULTS

The proposed antenna was fabricated using photolithography process (wet etching). The fabricated antenna has metal (copper) layer of thickness 0.035 mm deposited on the FR4 substrate. Figure 6(a) shows the assembled view of the fabricated prototype of the proposed antenna; Fig. 6(b) shows the view of ground plane with an E shaped defect and Fig. 6(c) shows the bottom view of the antenna. The prototype was tested for S_{11} parameter measurements on Agilent's vector network analyser (VNA) model no.E5071C for validation of impedance bandwidth results.

Figure 7(a) shows the snap shot of antenna testing using a VNA. The comparison of simulated and measured results is shown in Fig. 7(b) and it depicts a close approximation between the simulated and measured results. A little deviation in the impedance bandwidth at the two bands is also observed. The main reason behind this deviation could be the errors introduced while fabricating the antenna and also due to the misalignment problems of the three layers while soldering the connector to the antenna. The testing results show an impedance bandwidth of 200 MHz from (2.43 to 2.64 GHz) and 530 MHz from (3.4 to 3.93 GHz) thereby allowing the antenna to be suitable for the proposed wireless applications.

The antenna was also tested for gain measurements in an anechoic chamber operating in the frequency range between 8.5 KHz and 20 MHz using a Standard Horn antenna with a calibrated gain of 12 dBi. Figures 8(a) and 8(b) and Figs 9(a) and 9(b) show the simulated and measured radiation patterns of the antenna for *E*- and *H*-planes at 2.51 and 3.51 GHz, respectively.

It can be observed from the Figs 8 and 9 that the measured radiation patterns of the antenna at the center frequency of the two resonant bands are in close approximation with the simulated results. There is a little mismatch between the simulated and measured radiation pattern results (*H*-plane view) at both the bands the possible reason for this could be attributed to the alignment errors while placing the antenna in an anechoic chamber and also due to the inaccuracy in measuring a small valued signals in the presence of low noise signals.

V. PARAMETRIC ANALYSIS OF THE ANTENNA

A) Parametric study of the length of lower patch antenna

The size of patch antennas and the dimensions of E shaped slot were optimized using the CSTMWS V'10 software for getting the desired dual wideband operation at the two bands of antennas operation. Figure 10(a) shows the

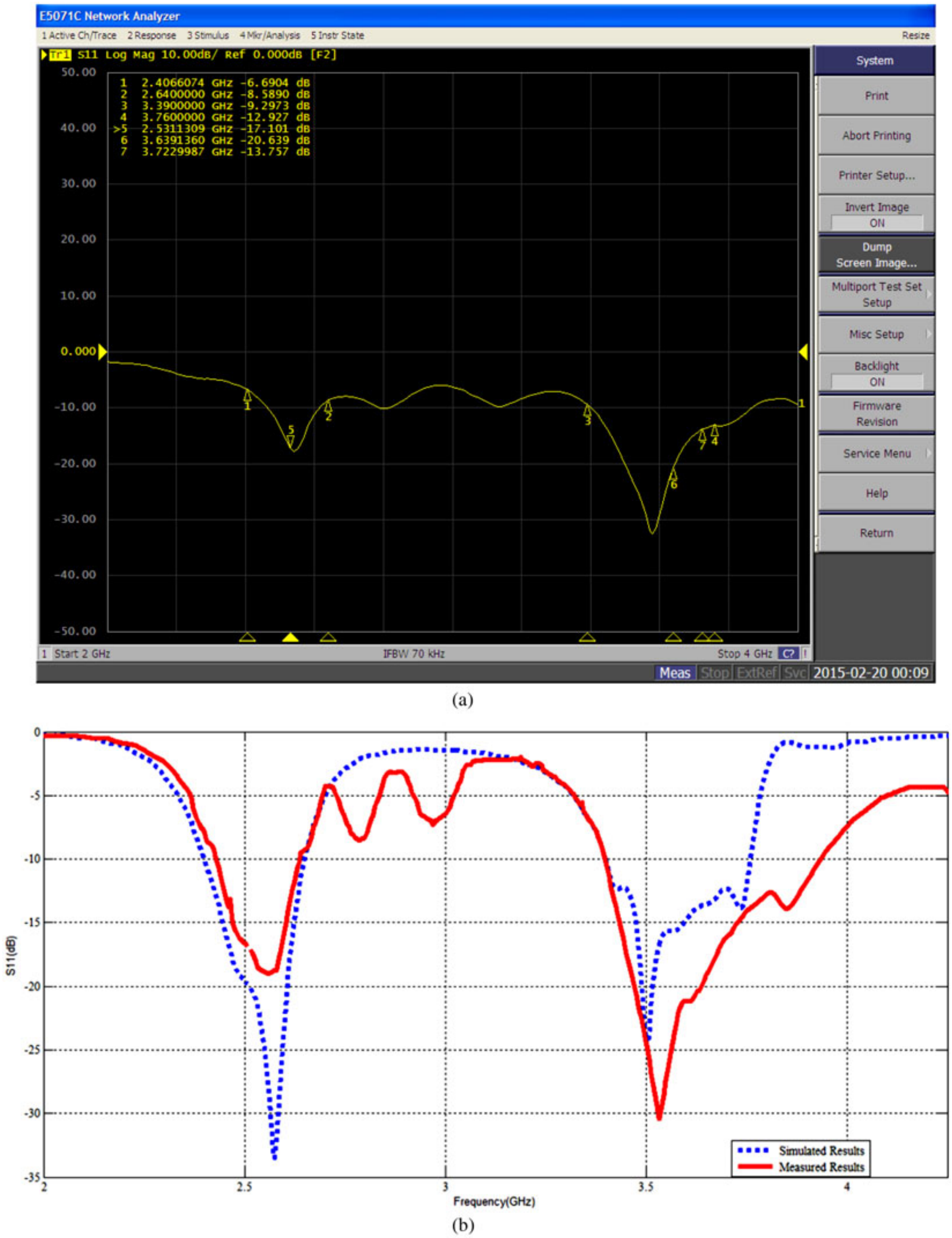


Fig. 7. (a) Snapshot of VNA while testing the antenna. (b) Comparison of simulated and measured S_{11} (dB) plot of the antenna.

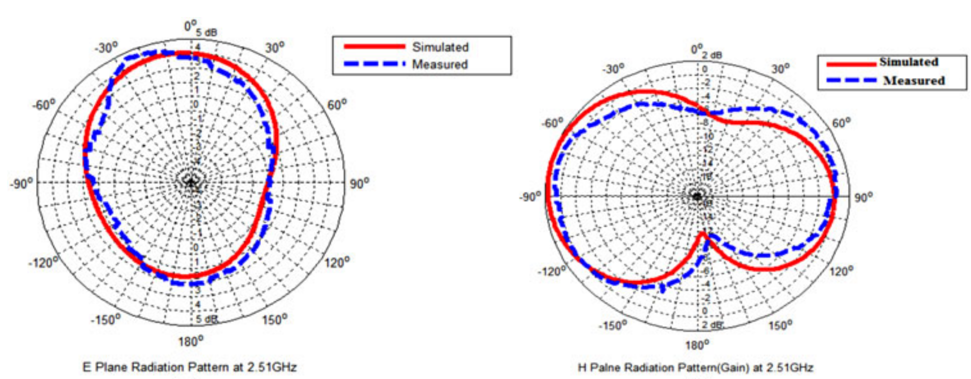


Fig. 8. Simulated and measured (a) elevation-plane radiation pattern (b) Azimuthal-plane radiation pattern at 2.51 GHz.

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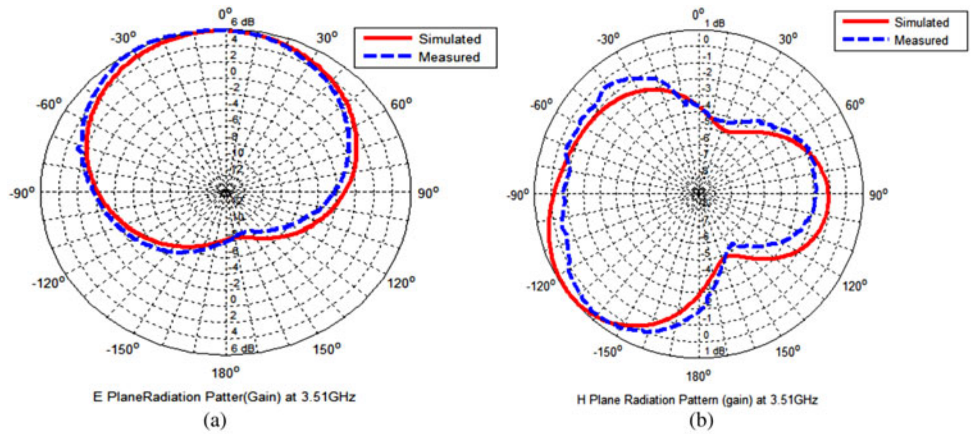

Fig. 9. Simulated and measured (a) elevation-plane radiation pattern (b) Azimuthal-plane radiation pattern at 3.51 GHz.

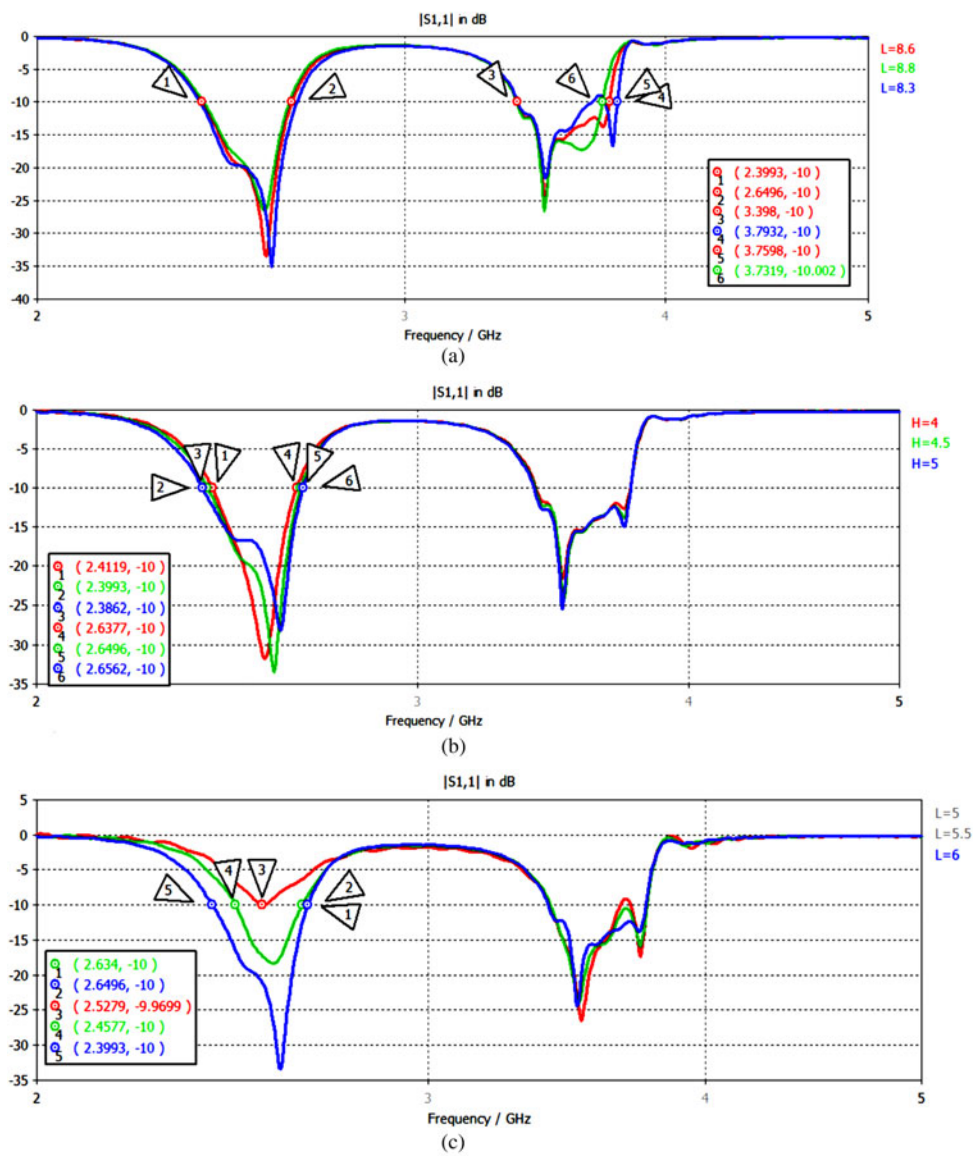

Fig. 10. (a) Effect of variation in the height of the lower patch antenna. (b) Effect of variation of the height of E slot in the ground of the antenna. (c) Effect of variation of the length of longer arm in E slot in the DGS of the antenna.

resonance frequency at 3.5 GHz shifts to left as the height of the lower patch is increased and the bandwidth of the band at a center frequency of 3.5 GHz reduces as the height of the lower patch antenna is reduced which is justified according to the current distribution results also. An optimized value of the height (Y-axis) of the lower patch is chosen to be 8.6 mm in order to cover the desired wireless applications.

B) Parametric study of height of E arm in the defected ground structure

It can be observed from Fig. 10(b) that as the height of the E arm is increased, it leads to a reduction in the value of S_{11}(dB) at the lower band of antennas operation (at 2.39 GHZ), thereby showing less impedance matching at this band. Thus the height of E arm is optimized at 4.5 mm.

C) Parametric study of the length of longer arm of the E slot in ground plane

Figure 10(c) shows that when the longer E arm of the E shaped slot in the ground plane is varied, the resonant frequency at 2.51 GHz shifts towards right and the impedance bandwidth also reduces, which justifies the theoretical concepts explained in the above sections that the slot in ground is responsible for showing resonance at 2.5 GHz.

VI. CONCLUSIONS

In this paper, a multilayer circularly polarized stacked rectangular patch antenna with a DGS has been proposed and tested to suit the wireless applications of WLAN/Bluetooth/ZigBee/Wi-Max/IMT Bands. The proposed antenna has a gain of 4.08 dBi at 2.5 GHz and a gain of 5.765 dBi at 3.51 GHz which makes it suitable for long range indoor RF applications. The antenna has a drive point impedance of 50 Ω to match the impedance of an subminiature (SMA) connector, this helps in achieving a voltage standing wave ratio (VSWR) of 1.23 at 2.51 GHz and a VSWR of 1.38 at 3.51 GHz. The two unequal rectangular patch antennas stacked one above the other give a wideband behavior from 3.39 to 3.76 GHz and an optimized E shaped DGS in ground, gives a wideband from 2.39 to 2.64 GHz which is justified by the current distribution results. The Aperture coupled feeding method that is followed gives an added advantage as it leads to a much wider bandwidth as compared with the other methods of feeding MSA. The testing of the prototype was done using a VNA and an anechoic chamber; the measured results are found to be closely agreeing with the simulated ones which allow the antenna to be practically suitable for the proposed wireless applications.

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