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RESEARCH PAPER

Omnidirectional multi-band stacked microstrip patch antenna with wide impedance bandwidth and suppressed cross-polarization

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In this paper, triple-band stacked microstrip patch antennas (MPAs) are presented with wide impedance bandwidth and suppressed cross-polarization level. Triangular and circular shaped slots are embedded in the patch of antenna. Slot-loaded microstrip patches are fed with meandered microstrip line supported by a semi-ground plane structure. Triangular shaped slot-loaded MPA shows triple resonance at frequencies 2.2, 4.45, and 5.3 GHz having bandwidth of 45.9, 19.23, and 15.67%, respectively. Circular shaped slot-loaded MPA also shows triple resonance at frequencies 2.2, 4.42, and 5.38 GHz having bandwidth of 50.24, 33.21, and 13.43%, respectively. Using circular slot in place of triangular; bandwidth of the first and the second band is improved by 4.34 and 13.98%, respectively. Both the proposed antennas show an omnidirectional radiation pattern at all three resonance frequencies in the xz-plane with almost 0 dBi gain. Both the proposed antennas are fabricated on a FR-4 epoxy substrate and show a minimum level of cross-polarization radiations.

Keywords: Antenna, Cross-polarization suppression, Multi-band, Omnidirectional antenna, Stacked antenna, Triple band, Wide band

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I. INTRODUCTION

Nowadays multi-band microstrip patch antenna (MPA) have attracted considerable attention with the rapid development of mobile communication system due to their numerous advantages like light weight, low profile, ease of fabrication, low cost, superior performance, and multi-band operation. The need for multi-band antenna has gained much attention since it is more practical for a single-antenna system to support multiple communication standard simultaneously. In recent years, the microwave research community is actively working on wide multi-band antennas in order to avoid using multiple antennas for different operating frequencies. Multi-band microstrip antenna exhibits simultaneous operation for different applications such as universal mobile telecommunications system (UMTS), long term evolution (LTE), Bluetooth, worldwide interoperability for microwave access (WiMAX), and wireless local area network (WLAN) bands [1].

Generally, multi-band performance is realized by different resonating structure or resonator in the antenna. However, most of them are relatively large and/or do not provide desired bandwidths. One method of improving the bandwidth and reducing the size is to use a planar monopole antenna with slots on the patch and ground plane. However, design of a wide multi-band antenna that simultaneously operates in above bands is a tedious and challenging task. Thus, the multi-band behavior can be achieved either due to slotted patch, defected ground structure (DGS), and meandered microstrip feed since it creates additional effective inductance and capacitance thereby increasing the current path on the surface of the antenna patch [2].

Currently various types of designs have been proposed to obtain multi-band antennas. In [3], multi-band monopole antenna has been designed using split ring resonators for WLAN and WiMAX applications. Multi-band performance has been achieved by modifying the radiating elements by introducing slots that create multi-resonant paths and hence multiple frequency bands in [4–7]. In above [4–7], a parametric study of slots of the proposed antenna is provided to obtain the required operational frequency bands for WLAN and WiMAX application. However, most of these antennas are design for either single or dual-band operation.

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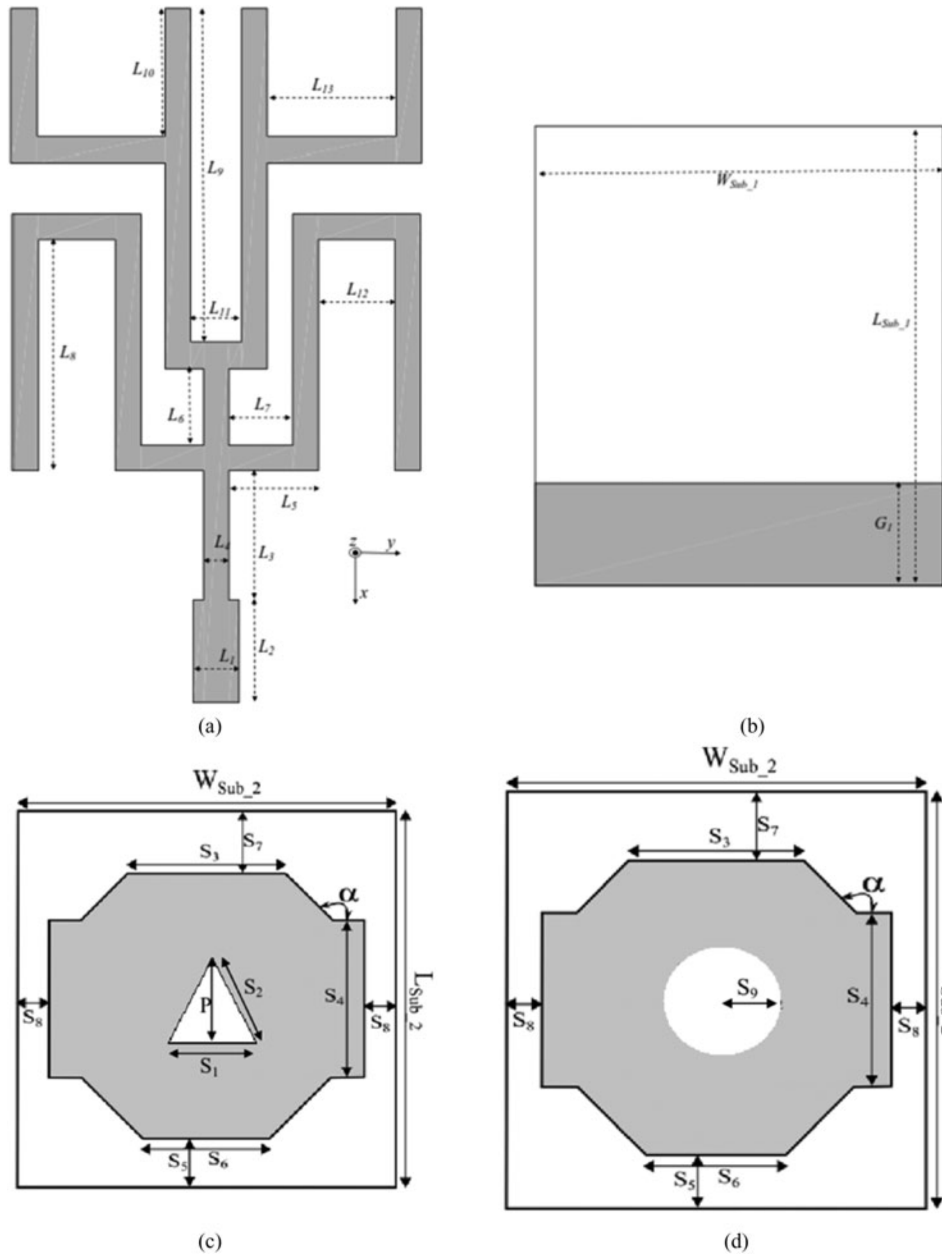

Fig. 1. Schematic of the proposed antenna: (a) feed lines, (b) ground plane, (c) patch with triangular slot, and (d) patch with circular slot.

Narrow size planar inverted-F antenna has been designed for multi-band operation in [8, 9]. However, it has a high level of cross-polarization. Proximity coupling is used to provide large bandwidth, low spurious radiation and flexibility in choosing the feedline geometry [10]. But the antenna proposed in [10] operates only in two bands.

A compact and multi-band multiple input multiple output technology (MIMO) antenna system covering global system for mobile communications (GSM) 850/900, digital communication system (DCS), personal communication system (PCS), UMTS, WLAN, and WiMAX bands has been studied in [11]. The above antenna studied in [11] was realized using two printed monopoles including the effect of decoupling structure on the isolation between antenna elements. A small-size printed antenna with multi-band wireless wide area network (WWAN)/LTE operation has been proposed by introducing a parasitic shorted strip and a C-shaped ground plane [12]. However, the width of printed circuit board in [11, 12] can further be reduced by changing the orientation of the antenna elements and decoupling structure. Proximity-coupled multi-band MPA has been proposed for different band applications in [13, 14], in which the effect of slots and microstrip feed on different parts of the antenna has been studied.

Table 1. Optimized parametric values of proposed antenna.

All dimension in mm

L_{Sub_1}	W_{Sub_1}	L_{Sub_2}	W_{Sub_2}	L_1	L_2	L_3	L_4	L_5	L_6
27	24	24	24	1.8	4	5	0.9	3.26	3
L_7	L_8	L_9	L_{10}	α	S_1	S_2	S_3	S_4	S_5
2.45	9	13	5	135	8	8.95	10	10	3
S_6	S_7	S_8	S_9	L_{11}	L_{12}	L_{13}			
8	4	2	3	2	3	5			

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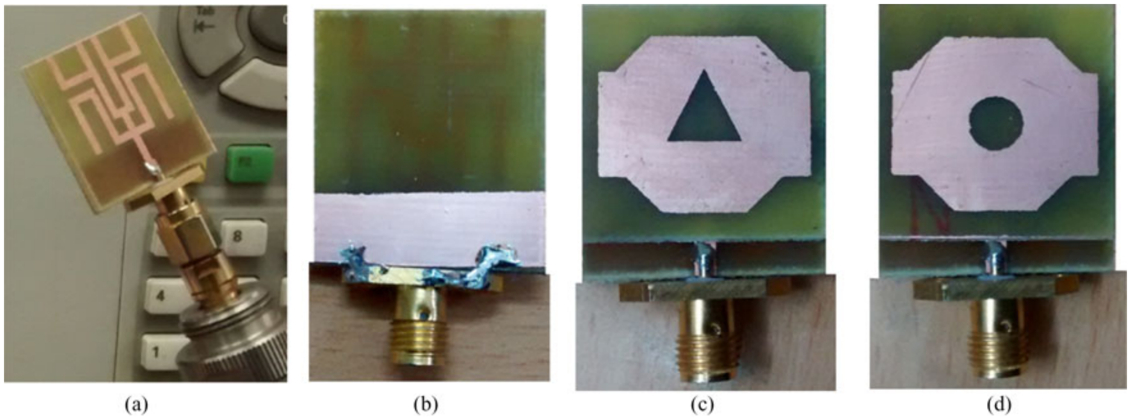

Fig. 2. Prototypes of fabricated antennas: (a) feed lines, (b) ground plane, (c) patch with triangular slot, and (d) patch with circular slot.

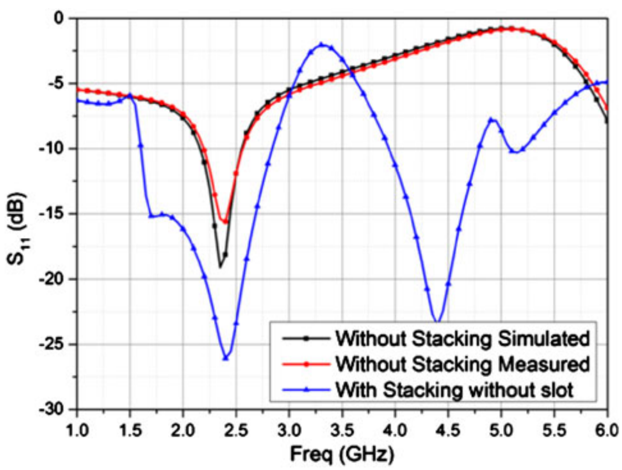

Fig. 3. S_{11} characteristics with frequency of meandered fed with semi-ground plane and without stacking and with stacking without slot.

A printed multi-band coplanar waveguide (CPW)-fed inverted-F antenna is presented for universal serial bus (USB) application in [15]. A CPW-fed multi-band bow-tie monopole antenna is proposed for triple-band operation in [16]. Three parallel rectangular open slots etched on the ground plate of the printed antennas, are presented for multi-band applications in [17]. In the above antenna, multi-band behavior has been achieved by using CPW fed structure as well as different shaped slots on to the patch of antenna. DGS has been used for achieving circularly polarized triple-band operation for various wireless applications in [18]. Dual-band stacked circularly polarized microstrip antenna has been achieved for various wireless applications in [19, 20].

In this paper, a novel design of wide multi-band antenna has been achieved using different shaped slots in the patch antenna and providing meandered microstrip fed in the ground plane. In this work, multi-band operation has been achieved firstly by using different shaped slots on the top of the patch such as circular and triangular slots. Secondly by using defected microstrip fed structure in the ground plane so as to provide desired impedance resonating structure needed for wide multi-band operation. Each operating frequency of the proposed antenna can be evaluated easily and

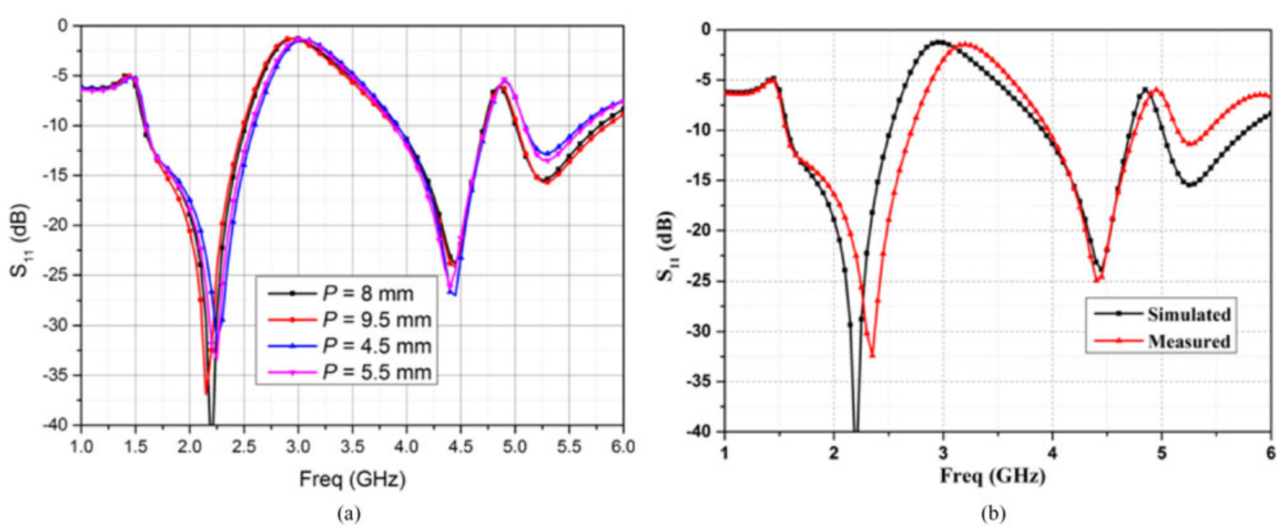

Fig. 4. S_{11} characteristics with frequency of meandered fed with semi-ground plane and stacked with triangular slot; (a) For different values of P, (b) For $P =$ 8 mm.

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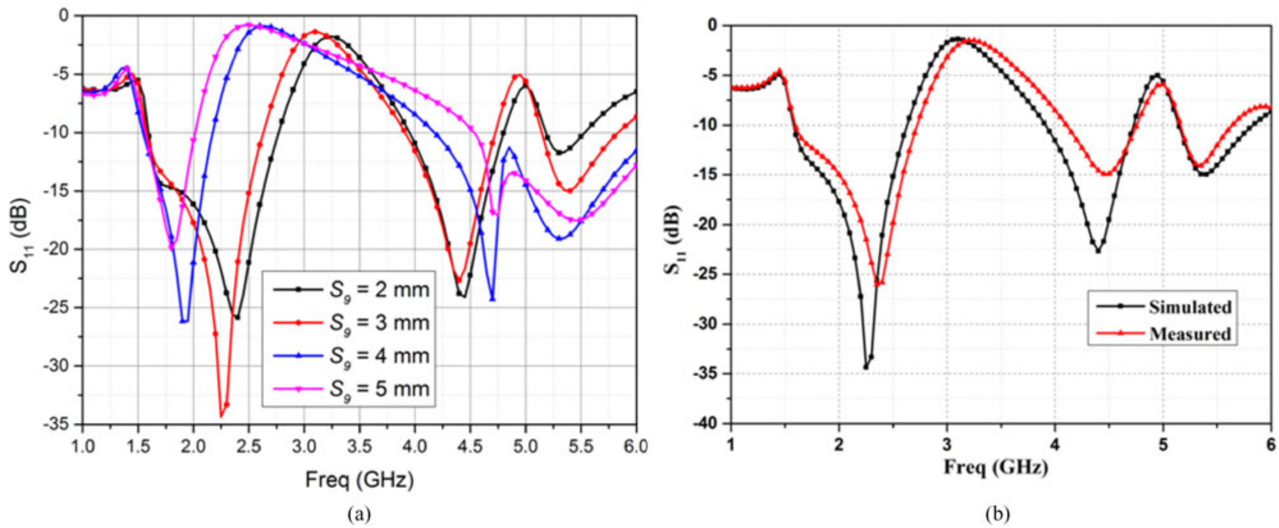

Fig. 5. S_{11} characteristics with frequency of meandered fed with semi-ground plane and stacked with circular slot; (a) For different radius of circular slot, (b) For $S_9 = 3$ mm.

almost independently. Proximity coupling is a technique that provides flexible feedline design in order to excite the preferred resonating modes and for the impedance matching. Till now very few wide multi-band antennas has been designed which are being fed by a proximity coupling technique.

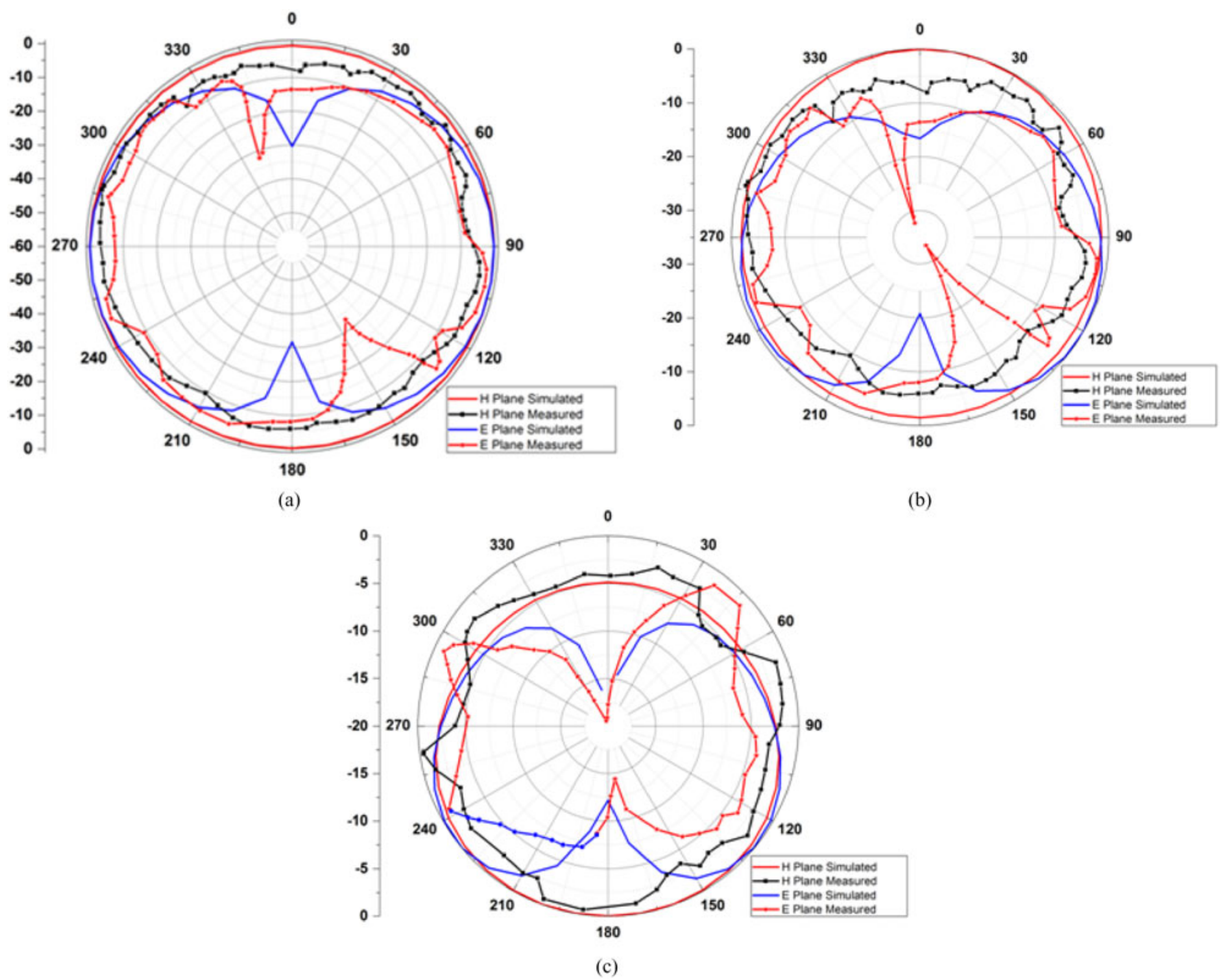

Fig. 6. Gain characteristics of *Ant2* (with triangular slot) at: (a) 2.2 GHz, (b) 4.45 GHz, and (c) 5.3 GHz.

II. ANTENNA STRUCTURE

The configuration of proposed multi-band antenna is shown in Fig. 1. The geometry of meander line microstrip fed structure and slotted ground plane is shown in Figs 1(a) and 1(b), respectively. While the geometry of the proposed multi-band antenna with triangular and circular slot dimensions are shown in Figs 1(c) and 1(d), respectively. The proposed antennas are fabricated using two stacked layers each having a thickness of 0.8 mm FR-4 epoxy substrate. The relative permittivity of the substrate is 4.4 and loss tangent is 0.001. In this design, corner-truncated rectangular patch with a triangular and circular slot at its center is printed on top of the upper layer. The meandered microstrip feedline is provided on top of the lower substrate layer to obtain proximity coupling. On the other side a semi ground plane is used. Meandered line is working as a monopole antenna and shows resonance at 2.35 GHz. Further, fed line is stacked with shaped patch antenna and proposed structure shows dual-band characteristics. To achieve triple-band characteristics triangular and circular shaped slots are embedded on the patch. Length of the upper substrate layer is slightly smaller than the lower layer in order to keep a provision for connection of inner conductor of an sub-miniature A connector (SMA) connector to the microstrip fed. Commercial software Ansoft HFSS 14 is used to perform the simulations.

The simulations are carried out to investigate the effect of different dimensions of the slot-loaded antenna as well as different dimension of meander microstrip feedline to obtain desired multi-band operation. From the result it can be seen that good input impedance matching for all of the UMTS, LTE, Bluetooth, WiMAX, and WLAN bands can be obtained by tuning different dimensions of the corner-truncated triangular and circular slot-loaded patch as well as different dimension of meander microstrip line. The optimal antenna parameters as obtained are given in Table 1. Fabricated structure is connected with a 50 Ω SMA connector.

III. DESIGN CONSIDERATION AND RESULT ANALYSIS

All the proposed antennas are fabricated by standard photolithography process on the substrate FR-4 epoxy having permittivity and loss tangent of 4.4 and 0.001, respectively. All the substrates are used with height of 1.6 mm. Electrical characteristics of the fabricated antennas are measured by Agilent PNA-L series Network Analyzer (see Fig. 2). SMA connector is used for feeding the structure. Antenna without stacking is showing a resonance at 2.35GHz. The return loss level of the meandered fed with semi-ground plane (without

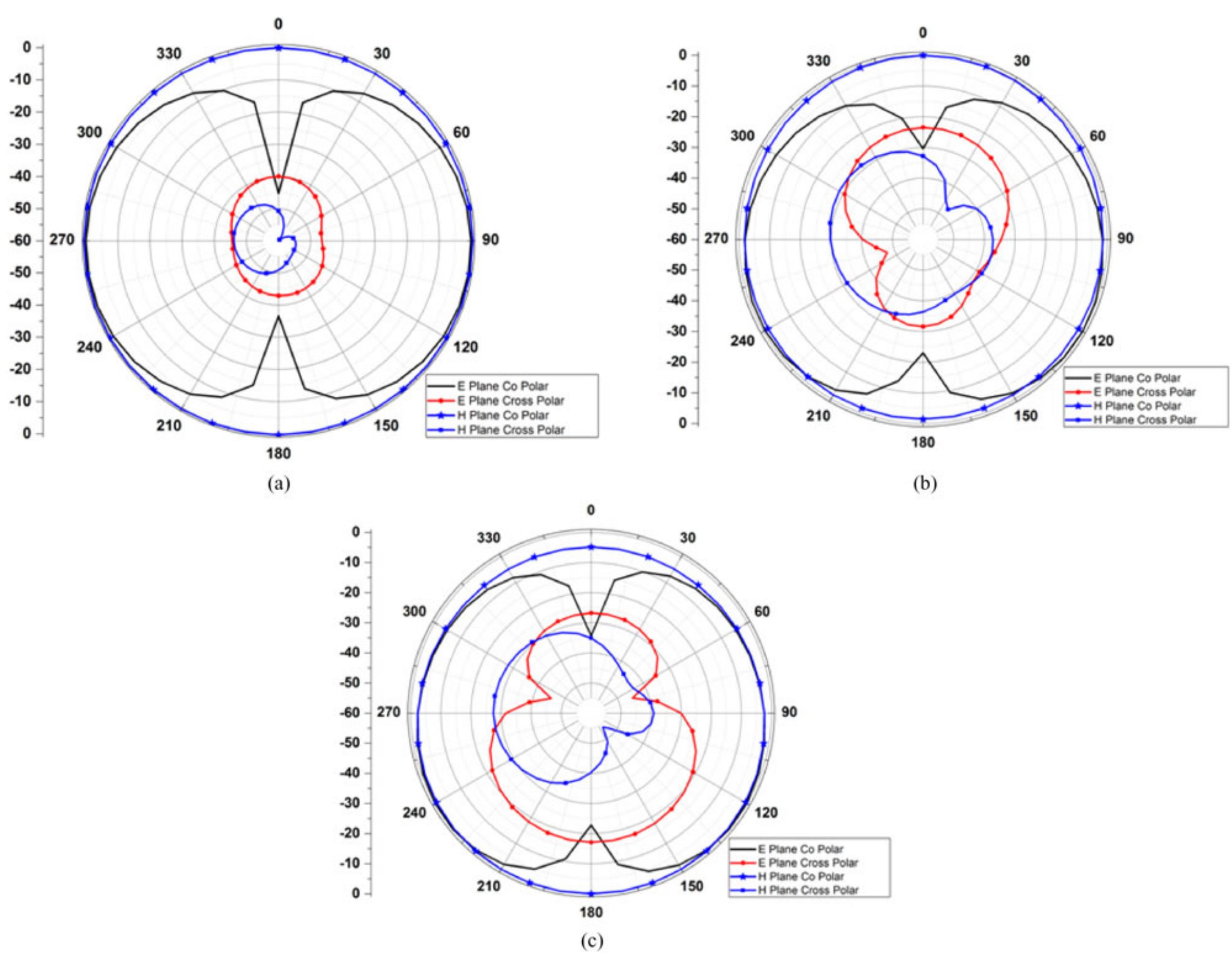

Fig. 7. Normalized radiation pattern of *Ant2* (with triangular slot) at: (a) 2.2 GHz, (b) 4.45 GHz, and (c) 5.3 GHz.

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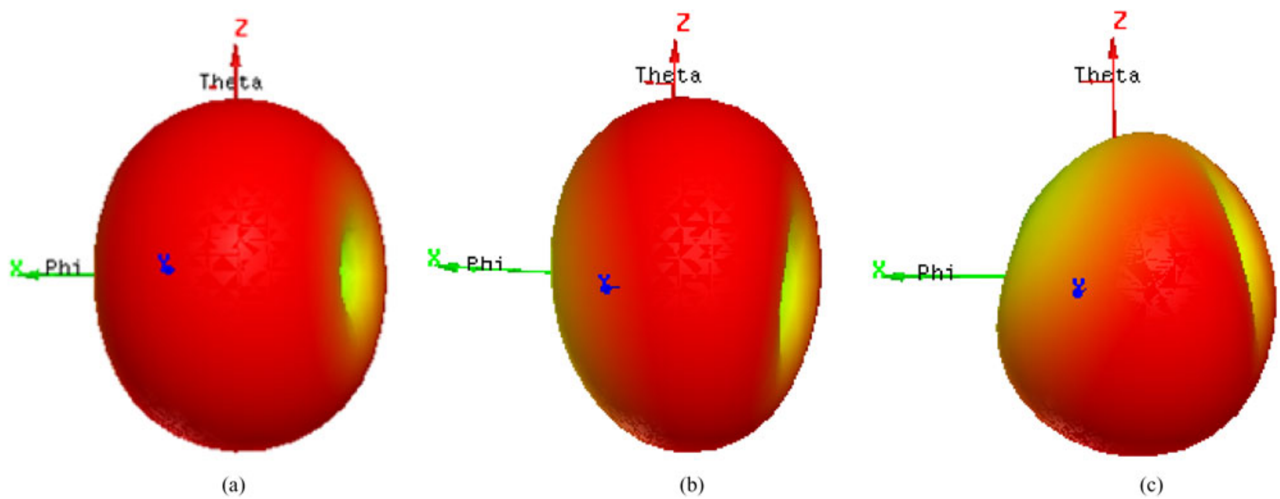

Fig. 8. 3D radiation pattern of *Ant2* (with triangular slot) at: (a) 2.2 GHz, (b) 4.45 GHz, and (c) 5.3 GHz.

stacking) is about 19.1 dB at 2.35 GHz as shown in Fig. 3. The proposed feed is stacked with shaped patch and stacked structure starts to show dual-band characteristics. Further, the proposed patch structure with triangular shaped slot is stacked to feed and it shows triple-band characteristics. The proposed antenna with triangular shaped slot shows three resonances with minimum return loss level of 44.44, 23.91, and 15.85 dB at 2.2, 4.45, and 5.3 GHz, respectively. The S_{11} characteristics of *Ant2* are shown in Fig. 4. *Ant2* has impedance bandwidth of 45.9, 19.23, and 15.67%, respectively. Figure 4(a) shows the return loss characteristics of *Ant2* for different values of *P* of triangular slot. For $P = 8$ mm better

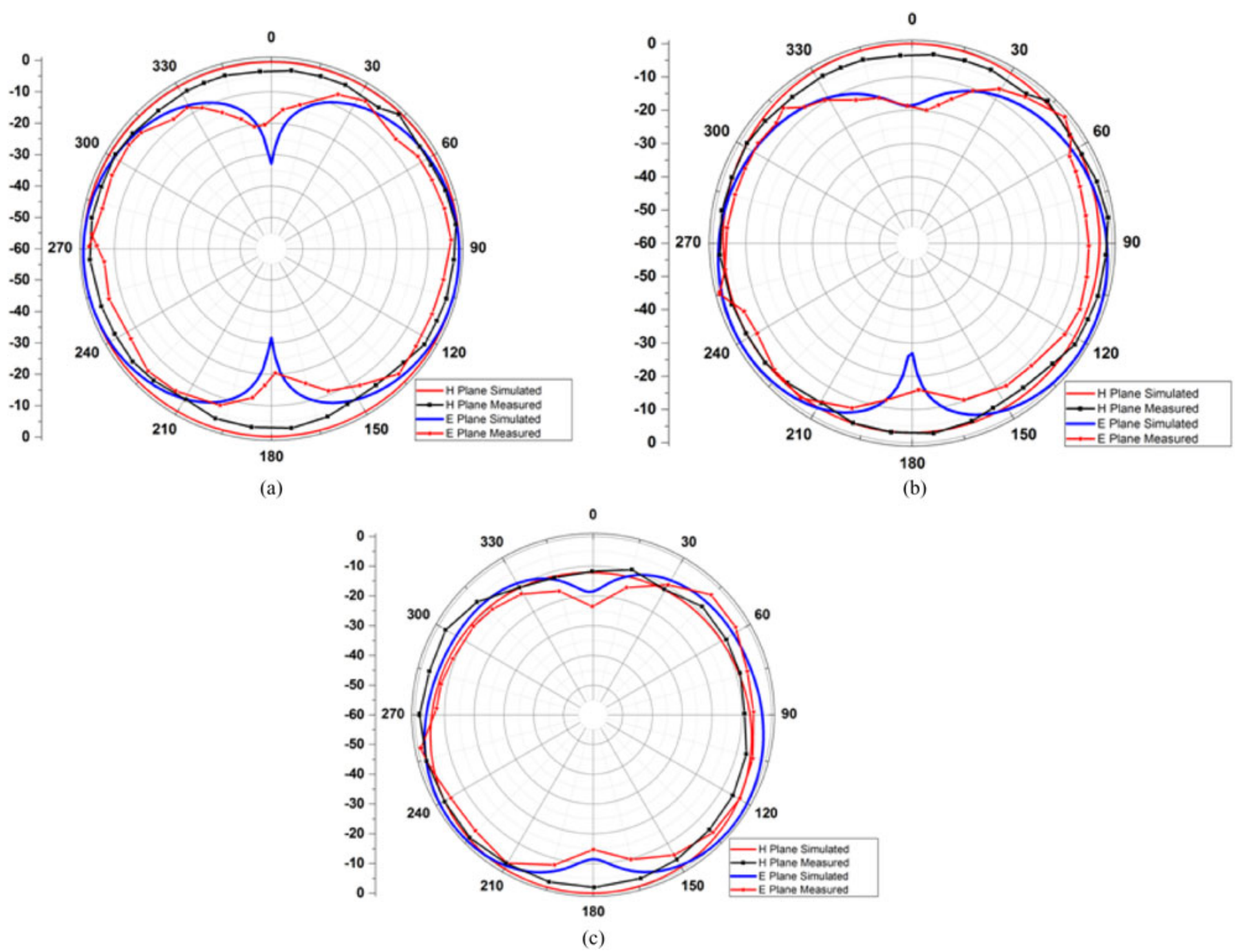

Fig. 9. Gain characteristics of *Ant3* (with circular slot) at: (a) 2.25 GHz, (b) 4.4 GHz, and (c) 5.4 GHz.

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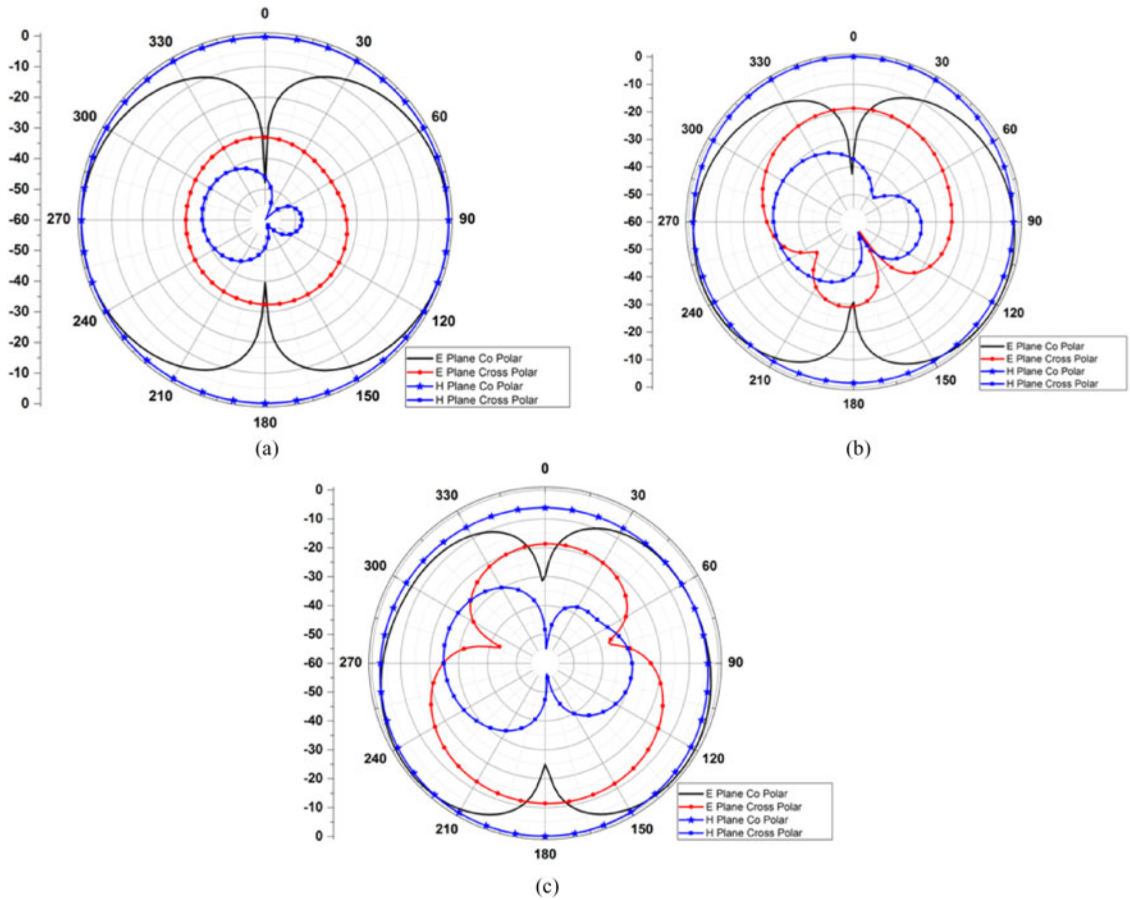

Fig. 10. Normalized radiation pattern of *Ant3* (with circular slot) at: (a) 2.25 GHz, (b) 4.4 GHz, and (c) 5.4 GHz.

results are obtained and *Ant2* is fabricated for the same value. For $P = 9.5$ mm almost same results are observed but comparably higher loss is achieved for the first band; thus we take 8 mm value for fabrication purpose. With the lower value of P the third band shows higher losses. Further, triangular slot is replaced by circular slot (*Ant3*) and impedance bandwidth at the first and second bands is enhanced. *Ant3* resonates with the return loss level 36.13, 22.47, and 14.95 dB at 2.2, 4.42, and 5.38 GHz, respectively. *Ant3* shows impedance bandwidth of 50.24, 33.21, and 13.43% respectively. Bandwidth at the first and second resonances is enhanced by 4.34 and 13.98%, respectively. The S_{11} characteristics of *Ant3* are depicted in Fig. 5. Return loss characteristics of *Ant3* for different values of radius S_9 of circular slot are shown in Fig. 5(a) and it is observed that the proposed antenna shows the best triple-band characteristics for $S_9 = 3$ mm. With the increase of S_9 higher

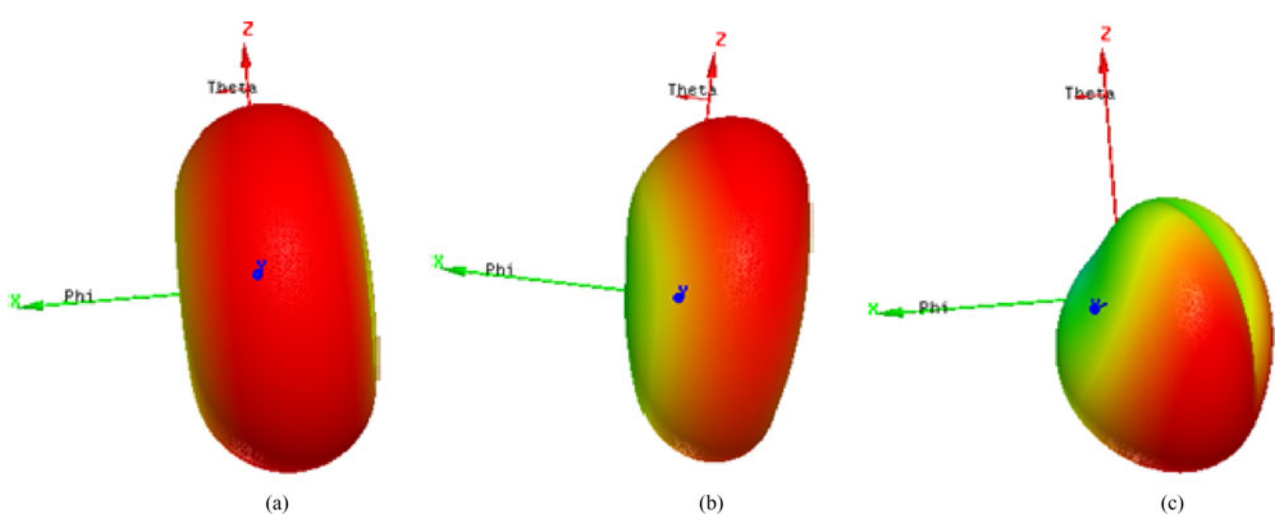

Fig. 11. 3D radiation pattern of *Ant3* (with circular slot) at: (a) 2.25 GHz, (b) 4.4 GHz, and (c) 5.4 GHz.

bands are merged and start to show wide band. On comparison of Figs 3–5; it is cleared that only feed (without stacking) shows single-band characteristics, by stacking with the proposed shaped patch without any slot antenna starts to show dual-band characteristics, further triple-band characteristics are achieved by embedding triangular and circular slots.

Figure 6 shows the gain characteristics of triangular slot-loaded stacked patch antenna. *Ant2* shows an omnidirectional pattern in the *H*-plane (*xz*-plane) at first two resonances. *Ant2* has almost unity gain in the *xz*-plane at first two resonances and negative gain in an orthogonal plane; which is a merit of proper omnidirectional pattern. *Ant2* shows about −2 dBi gain at 90° and 270° at second resonance 4.45 GHz. At 5.3 GHz; *Ant2* is not showing proper omnidirectional pattern and gain is below unity from 90° to 270°.

The normalized co-polar and cross-polar radiation characteristics of *Ant2* are shown in Fig. 7. The minimum values of the cross-polarization level of *Ant2* in the *E*-plane are −40, −25, and −20 dB at 2.2, 4.45, and 5.3 GHz, respectively. In the *H*-plane; the minimum values of cross-polarization of *Ant2* are −40, −30, and −28 dB. Figure 8 shows the three-dimensional (3D) radiation patterns of *Ant2* at all three working frequencies. From Fig. 8 it is very clear that *Ant2* has an omnidirection pattern in the *xz*-plane at the first two frequencies.

Figure 9 shows the gain characteristics of circular slot-loaded stacked patch antenna. *Ant3* shows omnidirectional pattern in *H*-plane (*xz*-plane) at first two resonances. *Ant3* shows good radiation characteristics as an omnidirectional antenna; it has almost unity gain in the *xz*-plane at the first two resonances and negative gain in the orthogonal plane. At 5.4 GHz; *Ant3* is not showing a proper omnidirectional pattern around 0°.

The normalized co-polar and cross-polar radiation characteristics of *Ant3* are shown in Fig. 10. The minimum values of the cross-polarization level of *Ant3* in the *E*-plane are −42, −29, and −10 dB at 2.25, 4.4, and 5.4 GHz, respectively. In the *H*-plane; the minimum values of cross-polarization of *Ant3* are −50, −40, and −35 dB. The cross-polarization level is more suppressed by using circular slot except at 5.4 GHz in the *E*-plane. Figure 11 shows the 3D radiation patterns of *Ant3* at all the three working frequencies. From Fig. 11 it is very clear that *Ant3* has an omnidirection pattern in the *xz*-plane at the first two frequencies.

IV. CONCLUSION

A novel design of wide multi-band antenna feed with proximity coupled meandered microstrip line is proposed for various wireless applications such as Bluetooth, WiMAX, and WLAN bands. In this design, a corner-truncated rectangular patch with triangular and circular slots is proposed for wide multi-standard operation due to the slotted ground plane so as to provide a desired impedance resonating structure. Both the antenna shows triple resonance at frequencies 2.2, 4.45, and 5.3 GHz having excellent bandwidth. By using the circular slot in place of triangular; bandwidth of the first and second bands is improved by 4.34 and 13.98%, respectively. Each operating frequency of the proposed antenna can be evaluated easily and almost independently. The antenna shows stable gain and omnidirectional radiation characteristics for entire triple-band operation. Also the antenna shows small cross-polarization characteristics. The circular slot provides a larger impedance bandwidth in comparison with triangular slot; however, it leads to a larger level of cross-polarization than the antenna with the triangular slot. The simulated and measured results are shown to have good agreements.

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