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Tri-Band Defected Ground Plane Based Planar Monopole Antenna for Wi-Fi/WiMAX/WLAN Applications

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Abstract—Wireless technology plays a vital role in data transfer. There is an acute need of smart wireless devices which could respond effectively for specific applications. This paper presents a defected ground plane based planar antenna. The presented antenna has the potential to operate at 2.47 GHz, 3.55 GHz, and 5.55 GHz frequencies with gains of 3.88 dBi, 3.87 dBi, and 3.83 dBi having impedance bandwidths of 14.61%, 5.42%, and 5.40% respectively. Flame Retardant 4 (FR4) is employed as a substrate. The agreement between simulated and measured results points out the utilization of the presented structure for Wi-Fi/WiMAX/WLAN applications.

1. INTRODUCTION

The growing wireless technology demands geometrical change which could satisfy the present industry demand. It demands smart, compact, and application specific antennas which respond at targeted frequencies. Left Handed Material (LHM) is useful for the significant size reduction of an antenna. Also with LHM based antennas, desired frequency bands could be achieved by tailoring the dimensions of the LHM material. Metamaterials are special materials which have negative permeability and permittivity for certain frequency ranges [1–4]. In metamaterials, the fundamental blocks are split ring resonators. Synthetic metamaterials make them appropriate for improving electromagnetic properties for microwave devices such as filters, couplers, and antennas. With this, the filter performance could be boosted for overall size reduction of a structure and application specific frequency output [5, 6]. Multi-band microstrip antennas are useful for better performance at high frequencies [7]. Complementary Split Ring Resonator (CSRR) is also an effective mechanism for antenna performance enhancement [8]. The combination of SRR and slot plays a vital role in antenna miniaturization for dual-band performance [9]. SRR technique has also been analyzed to receive adequate output from reconfigurable antennas [10]. The miniaturization techniques and radiation characteristics are covered in [11]. Some of the literature exhibits wide spectrum of miniaturization with the absence of SRR/CSRR; however, in such cases, overall size reduction may not be feasible [12, 13]. At present the researchers focus on antenna model miniaturizations and antenna performance at targeted frequencies. For this, metamaterial antenna would be an appropriate solution [14–18]. Metamaterials are widely utilized in research domain to obtain precise electromagnetic stuffs not commonly found in nature [19–21]. The combination of patch and metamaterials may be helpful for receiving optimum power directivity and efficiency [22]. Some literature has presented structural variation and adopted one patch over another. The literature exhibits that dual bands with optimum values could be achieved by these changes [23]. It has been observed that antennas developed using a conventional patch suffer from the limitation of directivity. In such cases, metamaterial properties could be systematically adopted with common patch geometry to obtain focused radiation pattern [24]. A stacked metamaterial structure could be useful for improving return loss [25]. Negative permeability could be achieved from the scattering parameters [26]. Microatrip patch antenna

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has undesired transmission in vertical direction with reference to patch surface [27]. A monopole antenna could be utilized for improving the bandwidth from wideband to ultra-wideband. Also, the introduction of SRRs in ground plane may be useful for achieving additional narrow band [28]. The combination of SRR and monopole antenna could be adopted for tri-band applications of an antenna [29]. To achieve adequate response from the structure, different feeding mechanisms are adopted by the researchers such as inset feed, microstrip line feed, and quarter wave feed. In this paper, a defected ground plane based tri-band monopole antenna structure is demonstrated for Wi-Fi, WiMAX, and WLAN applications. In this paper, antenna design and fabrication are discussed in the initial phase where detailed structure of an antenna and related dimensions are given. The result and discussion are given in the subsequent section in which the software generated response and actual response are correlated. The entire technical discussion is followed by conclusion.

2. ANTENNA DESIGN

Figure 1 depicts the geometry of the claimed antenna. The commercially available FR4 epoxy material is chosen as a substrate which has the relative permittivity 4.4 and dielectric loss tangent 0.001. The height of the substrate is 1.56 mm. The compact monopole antenna is printed on a substrate for optimum radiation. The antenna is fed using quarter wave feeding technique to meet the 50 Ω impedance matching requirement. Five units of SRR are introduced on ground plane. The combination of monopole and SRR makes the antenna design suitable for triple band applications. The SRR units and their positions are visible on ground plane in Figure 1(a) which is back view of antenna. An SRR unit is an artificial resonator which gives radiation at particular frequency with a λ_0 which is greater than SRR length.

Figure 1(b) shows magnified view of SRR for details. Figure 1(c) gives the top view of an antenna focusing monopole geometry. The positions of SRRs and monopole antenna with reference to each other are predicted from Figure 1(d).

Table 1 shows detailed dimensions of the antenna structure.

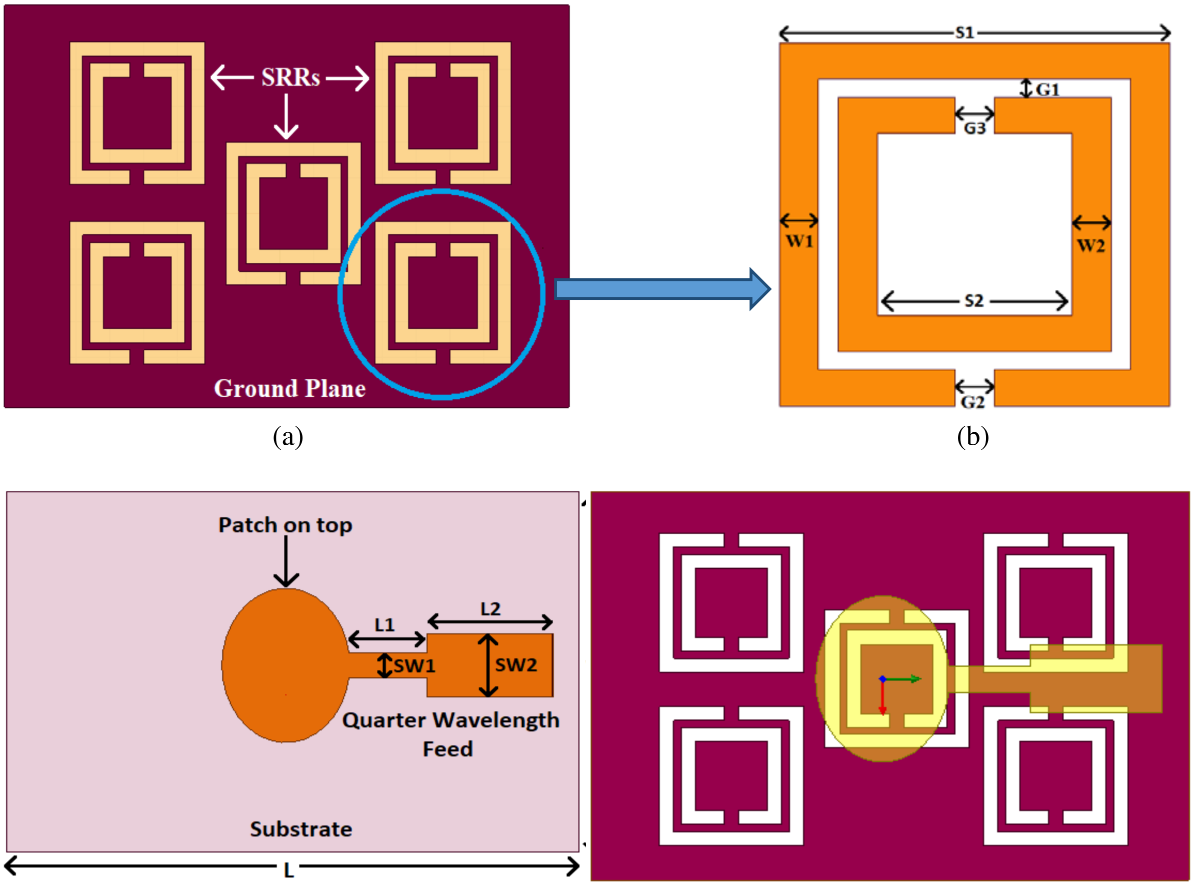
Table 1. Details of antenna dimensions.

Symbolizations	**Sizes (mm)**	**Symbolizations**	**Sizes (mm)**
$G1$	1	$L1$	11.3
$G2$	2	$L2$	18.1
$G3$	2	L	83.0
$S1$	20	W	56.0
$S2$	10	$SW1$	39.0
$W1$	2	$SW2$	90.0
$W2$	2	-	-

Figure 2 illustrates the fabricated model using a PCB fabrication machine.

3. RESULT AND DISCUSSION

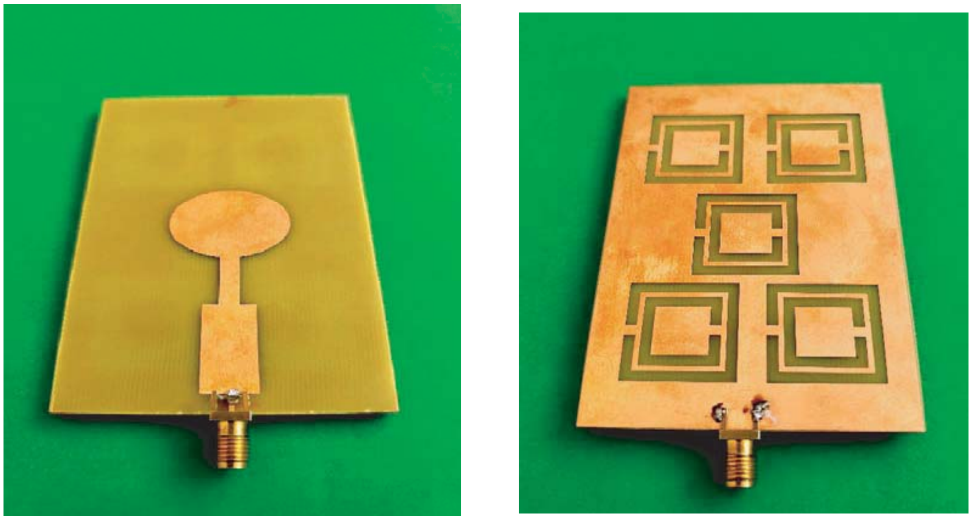
The presented structure is verified using High Frequency Structure Simulator (HFSS). The S_{11} parameter of the model is measured using Keysight Vector Network Analyzer N9912A. Figure 3 depicts the correlation between simulated and measure responses of return loss. The solid line and dashed line present simulated and measured outputs, respectively. The overlapping lines indicate the potential of developed antenna for resonating at targeted frequencies. As shown in Figure 3, the Voltage Standing Wave Ratio (VSWR) meets the typical antenna demand of 2 : 1. The measured VSWR is 1.20 at 2.47 GHz, 1.43 at 3.55 GHz, and 1.32 at 5.55 GHz frequency. The dimensions of the split ring resonators are varied during multiple iterations to improve the return loss. The difference between the simulated and measured return losses is because non-ideal conditions are after fabrication



(a) (b)

(c) (d)

Figure 1. Proposed antenna design. (a) Rear view, (b) SRR block, (c) view from top, (d) monople antenna and ground plane.



(a) (b)

Figure 2. Fabricated model of presented antenna. (a) Bird eye view. (b) Back view.

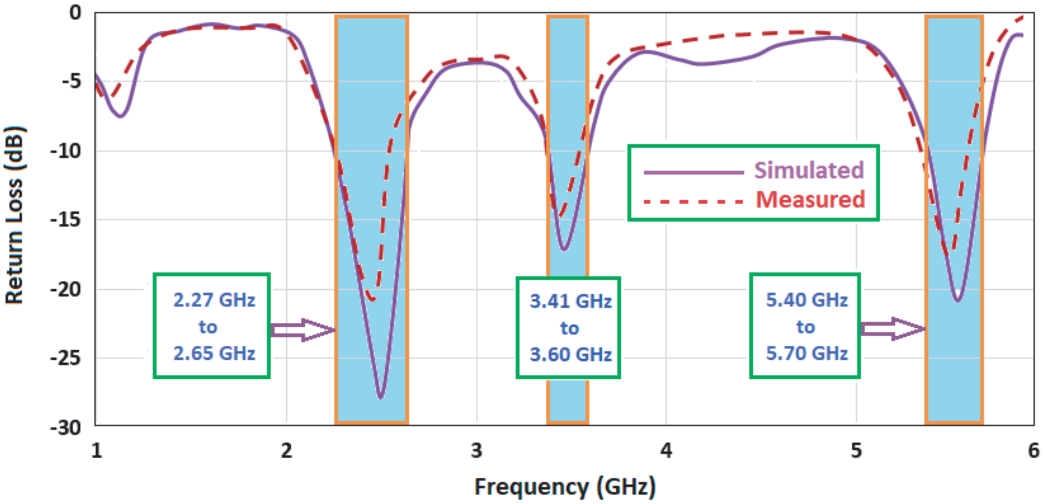


Figure 3. Return loss (simulated against measured).

and mechanical inaccuracies. As apparent from the return loss, the antenna provides wide impedance bandwidth in the order of 14.61%, 5.42%, and 5.40% for 2.47 GHz, 3.55 GHz, and 5.55 GHz, respectively.

Figure 4 illustrates the gain against frequency graph. The values of gain are 3.88 dBi, 3.87 dBi, and 3.83 dBi at 2.47 GHz, 3.55 GHz, and 5.55 GHz frequencies correspondingly. Receiving the adequate gain along with size miniaturization is a difficult task. A lot of research has been done to achieve the adequate gain for a compact structure [30–37].

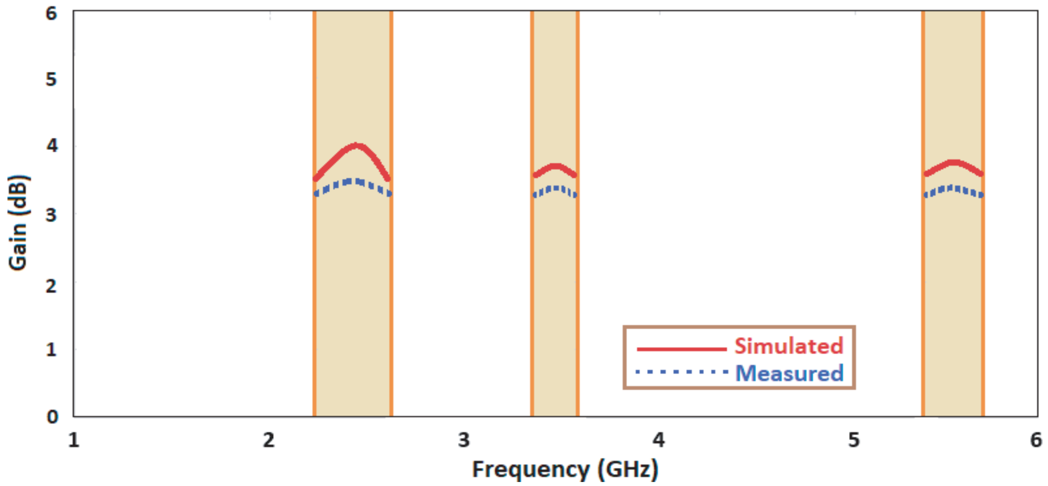
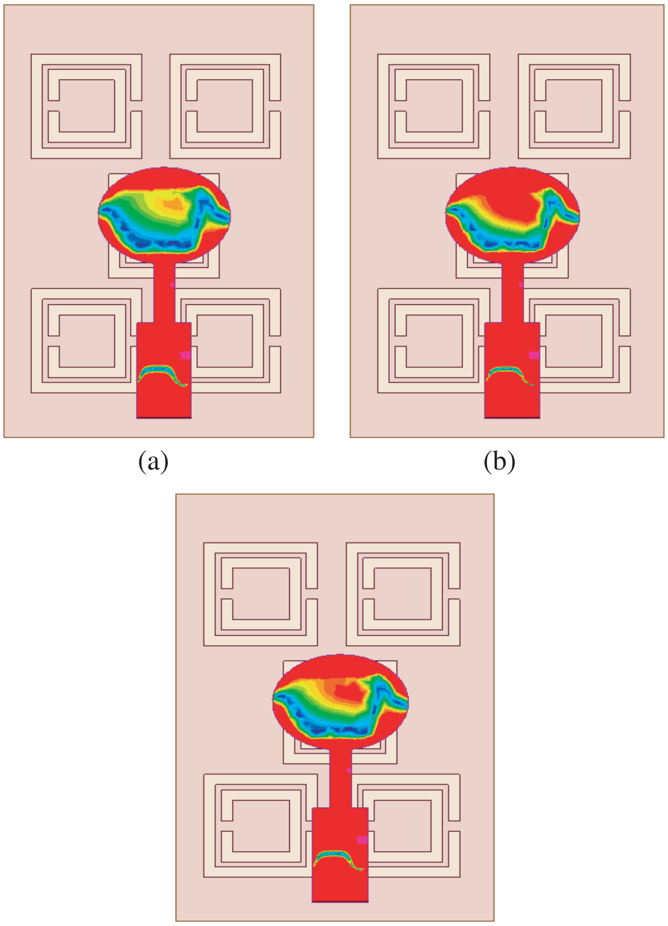


Figure 4. Gain Vs Frequency (simulated and measured).

Figure 5 depicts electric field (E-field) distribution through the surface of monopole antenna. This field radiation is shown for 2.47 GHz, 3.55 GHz, and 5.55 GHz frequencies, respectively. The field distribution is the highest over the feed-line being the closest point to the feed. It has been relatively distributed equally along the elliptical patch which is the lowest at the center of the patch. The surface current on the patch determines the overall fringing field of emanating by patch antenna. This fringing field further determines the uniformity of the radiation pattern of the antenna.

Similarly, Figure 6 shows magnetic field (H-field) distribution over the surface of monopole antenna. The dimensions of monopole antenna are carefully fixed to achieve maximum impedance matching. This distribution is for 2.47 GHz, 3.55 GHz, and 5.55 GHz frequencies, respectively.

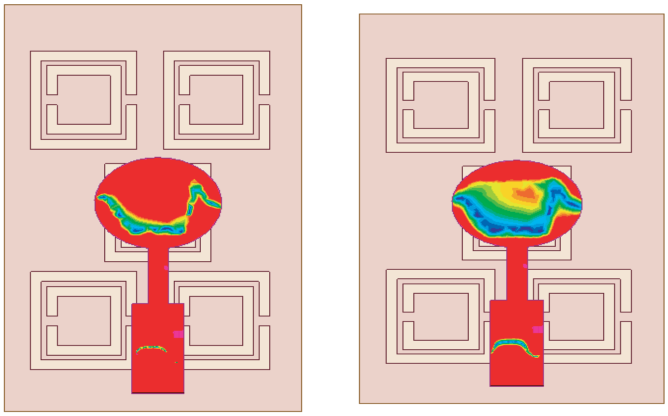


(a) (b)

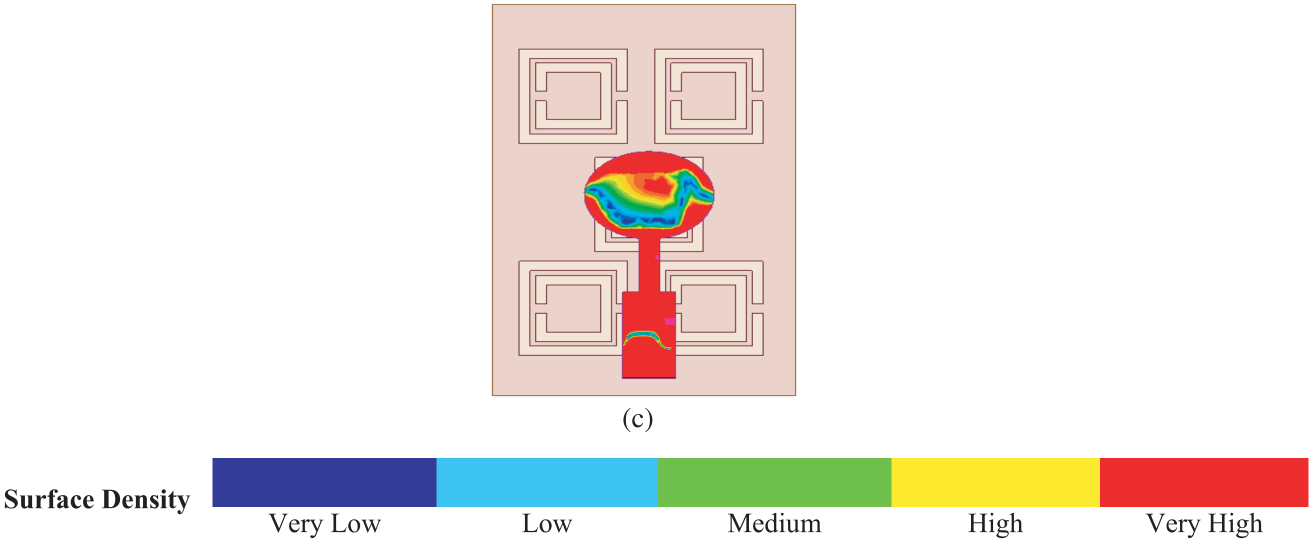
(c)

Figure 5. E-field distribution in primary patch at (a) 2.47 GHz (b) 3.55 GHz and (c) 5.55 GHz frequencies.

The radiation patterns for E-field and H-field for the presented antenna were measured in an anechoic chamber which is visible in Figure 7. The anechoic chamber is of 3 m × 3m × 3 m size. The monopole antenna is compact, so the given dimension of the anechoic chamber suits the measurement. Figures 8 and 9 represent the E-field and H-field radiation patterns for 2.47 GHz, 3.55 GHz, and 5.55 GHz frequencies, respectively.

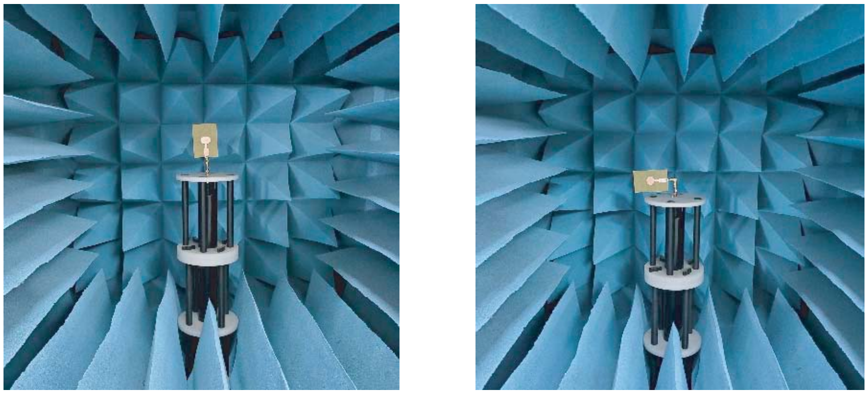


(a) (b)



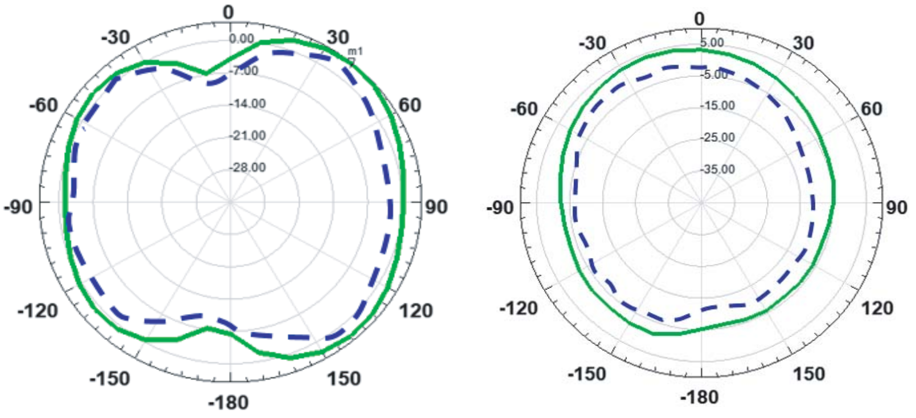
(c)

Figure 6. H-field distribution in primary patch at (a) 2.47 GHz (b) 3.55 GHz and (c) 5.55 GHz frequencies.

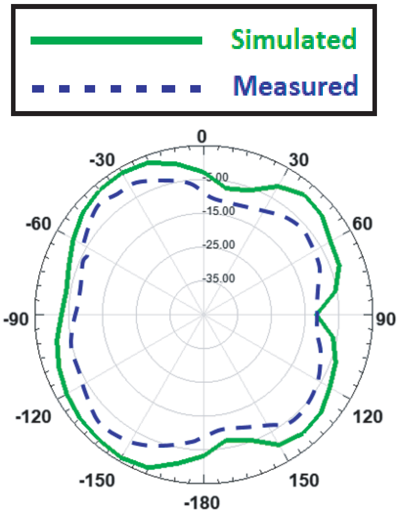


(a) (b)

Figure 7. Antenna under test in anechoic chamber. (a) *E*-plane, (b) *H*-plane.

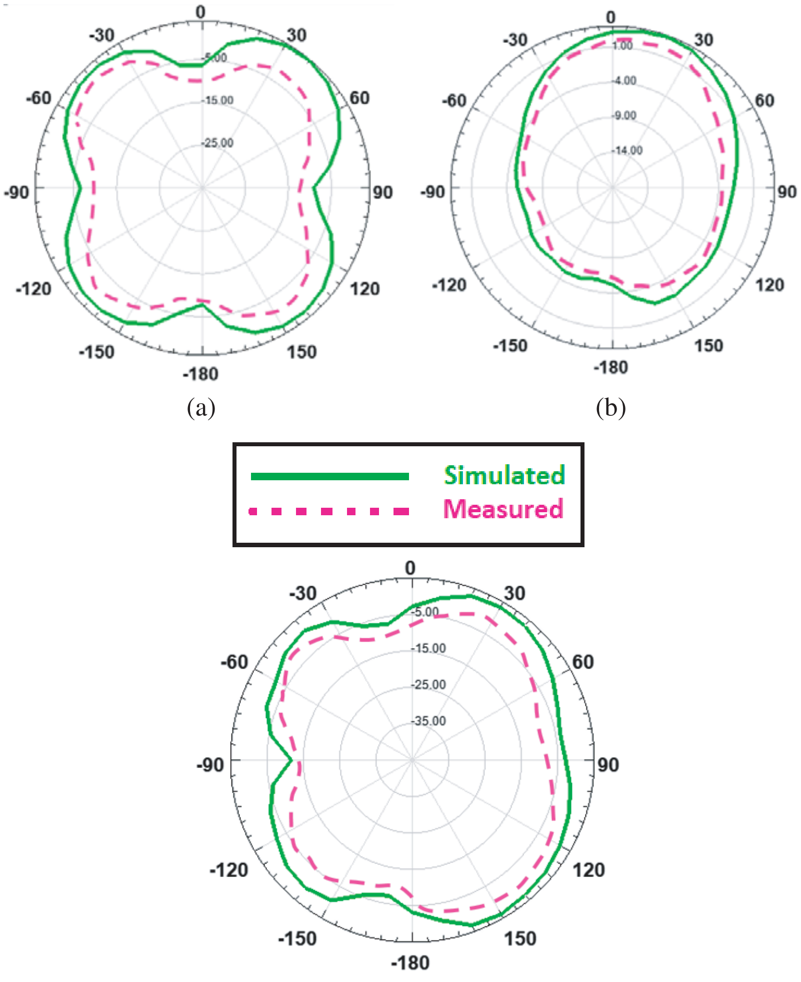


(a) (b)



(c)

Figure 8. E-field radiation pattern for 2.47 GHz, 3.55 GHz and 5.55 GHz frequencies.



(a) (b)

(c)

Figure 9. H-field radiation pattern for 2.47 GHz, 3.55 GHz and 5.55 GHz frequencies.

4. CONCLUSION

A defected ground plane based monopole antenna is successfully designed and demonstrated. The presented antenna is an appropriate candidate for resonating at 2.47 GHz, 3.55 GHz, and 5.55 GHz frequencies which are Wi-Fi/WiMAX/WLAN applications. At targeted frequencies, peak gains of 3.88 dBi, 3.87 dBi, and 3.83 dBi were obtained with impedance bandwidths of 14.61%, 5.42 %, and 5.40%, respectively. The means of triple band operations at desired frequencies are confirmed with software generated and measured results. The optimum performance is also observed for other similar structure parameters such as radiation patterns and return loss. The combination of defective ground plane and metamaterial plays a key role in performance enhancement.

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