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A CPW-Fed Triband Antenna for 2.4/3.5/5.5 GHz Applications

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Abstract—A novel and compact CPW-fed triband antenna suitable to support WLAN and WiMAX communications in 2.4/3.5/5.5 GHz bands is reported. The 5.5 GHz band extends from 4.9 to 5.94 GHz. So the proposed antenna can support the use of 4.94–4.99 GHz band allotted for fixed and mobile service (except aeronautical mobile service) for use in support of public safety and 5.85–5.925 GHz band for Dedicated Short-Range Communications (DSRC) services in the Intelligent Transportation System (ITS) radio service. Metallic radiating stub extending from the feed is used to excite the resonance at 2.4 GHz. An open slot in the stub and a pair of open slots in ground plane are used to excite the other resonances. An arc shaped parasitic element is also included in the design for improved radiation performance. The proposed antenna geometry is developed on FR4 glass epoxy substrate with relative permittivity 3.8 and loss tangent 0.02. The geometry is developed and optimized using High Frequency Structure Simulator and experimentally validated the results. Performance comparison of the proposed antenna with similar antennas in literature is presented. Measured radiation patterns and gain are also included in this paper.

1. INTRODUCTION

Wireless connectivity is evolved as an essential feature of modern electronic gadgets. Wireless Local Area Network (WLAN) in 2.4/5.25/5.77 GHz bands and Worldwide Interoperability for Microwave Access (WiMAX) in 2.7/3.5/5.79 GHz bands are the popular communication protocols used for this purpose. Hence a multiband antenna supporting all these bands is essential in these gadgets. This heavy demand for low cost, low profile and high performing antennas supporting all these services motivates RF engineers to explore more and more in this area.

Federal Communications Commission (FCC) allotted the frequency spectrum 4.940 to 4.990 GHz for fixed and mobile service (except aeronautical mobile service) for use in support of public safety in 2002 [1], and 5.850 to 5.925 GHz band for Dedicated Short-Range Communications (DSRC) services in the Intelligent Transportation System (ITS) radio service in 1998 [2]. Hence the antennas which can support these two bands along with WLAN and WiMAX will be highly useful. Printed antennas are good candidates for including in the RF section of present day compact gadgets. However, uniplanar antennas attract more interest due to their advantages like easy fabrication and wide band performance [3], over its counterpart — the microstrip antennas.

A simple rectangular or circular patch can be used for exciting resonance at desired frequency. Many other techniques like metallic strips/meander line/ring [4–8], slot loaded stubs [9–11], slot loaded or defective ground structures(DGS) [10–13], metamaterial structures [9, 14], fractal structures [3, 15], etc. are reported as suitable techniques for generating single or multiple resonances, in literature. These techniques are highly useful in miniaturization also.

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Li et al. [4] proposed a fork-shaped strip enclosed in rectangular ring as radiator for realizing a triple band monopole antenna. A rectangular slot in ground plane below strip line feed improved the impedance matching. Zhi et al. [5] reported a microstrip fed multiband antenna with two arc-shaped metallic strips on top side of the substrate as the radiating element. They achieved required impedance bandwidth in the midband by using two inverted "L" shaped parasitic elements etched on the bottom plane, above the ground structure. Patel et al. reported the use of meander line with multiple elements [8] to excite multiple resonances. In this work, proper impedance matching is ensured using truncated ground plane and offset feed.

Slots etched in radiating stub is another technique for exciting multiple resonances. By inserting two rectangular slots symmetrically on the trapezoidal monopole, dual band operation is realized by Rajeshkumar and Raghavan [9]. A third band is excited by converting upper rectangular portion of the monopole into a modified rectangular split ring resonator (SRR). In a modified rectangular patch antenna [14] designed for 5 GHz, two lower bands at 1.8 GHz and 2.4 GHz were excited using complementary folded triangle split ring resonators. Use of metamaterial property helped to realize the lower bands without increasing size of the antenna designed for 5 GHz.

Ali et al. [10] published a modified triangular microstrip patch antenna with a trapezoidal slot in patch and 12 rectangular slots in ground. The trapezoidal slot excites 5.7 GHz band, whereas three rectangular slots in ground plane produce 1.8, 2.8 and 9.8 GHz bands.

Gautam et al. [13] reported a monopole antenna for wide band from 2.4 to 6 GHz, with an annular strip encircled by a rhombus shaped strip. A cambered ground plane with rectangular slot below the strip line is used to control the impedance matching throughout the band.

Ali et al. [11] demonstrated the use of a simple kite shaped slot in the patch for miniaturization. With this novel technique, the size of the patch is reduced by 50%. Two "C" shaped and "G" shaped slots are etched in ground plane for ensuring multiband performance.

Fractal structure is also used [3, 15] effectively for antenna design. Singh and Singh [15] used Fibonacci word fractal geometry to design a dual band antenna which is supporting the bands allotted for fixed and mobile service of public safety wireless local area network (4.94–4.99 GHz) and vehicular communication in 5.85 to 5.925 GHz.

Optically Transparent Antennas (OTAs) are another category of antennas which can mount anywhere like mirrors, wind shield of automobiles, solar panels of satellites etc. [16, 17]. These antennas are developed using transparent conductive materials like micro metal mesh, tin oxide (indium), zinc oxides (fluorine, aluminum), and silver coated polyester (AgHT) on transparent substrates like borosilicate glass, plexiglass, etc.

A low cost CPW-fed triband antenna on an FR4 glass epoxy substrate with relative permittivity 3.8 and loss tangent 0.02 is proposed in this paper. An arc-shaped parasitic element is included in the design for improved radiation performance. It can support all WLAN and WiMAX communications in 2.4/3.5/5.5 GHz bands. It can also support the 4.94–4.99 GHz band, allotted for fixed and mobile service (except aeronautical mobile service) for use in support of public safety and 5.85–5.925 GHz band for Dedicated Short-Range Communications (DSRC) services in the Intelligent Transportation System (ITS) radio service.

The rest of this article is organized as follows. Section 2 presents the evolution of final antenna geometry. Section 3 presents the effect of parasitic arc used in the final geometry. Section 4 discusses the simulation and experimental results, and Section 5 concludes the article with a performance comparison of the proposed antenna with similar antennas reported in literature.

2. EVOLUTION OF THE GEOMETRY

The CPW-fed triband antenna geometry reported here is developed from the single band microstrip antenna reported by the authors [18]. In order to utilize the advantages like easy fabrication and broad band performance [3] of uni-planar antennas, the microstrip antenna is redesigned as CPW-fed single band antenna on a substrate with thickness 1.6 mm, relative permittivity, $\varepsilon_r = 3.8$ and loss tangent, $\tan\delta = 0.02$ as shown in Figure 1(a). The structure is converted into a dual band antenna with resonances at 2.4 GHz and 3.5 GHz by introducing two "L" shaped slots in ground plane [10–13] as shown in Figure 1(b). Another slot is introduced in the resonating stub (Figure 1(c)) to produce

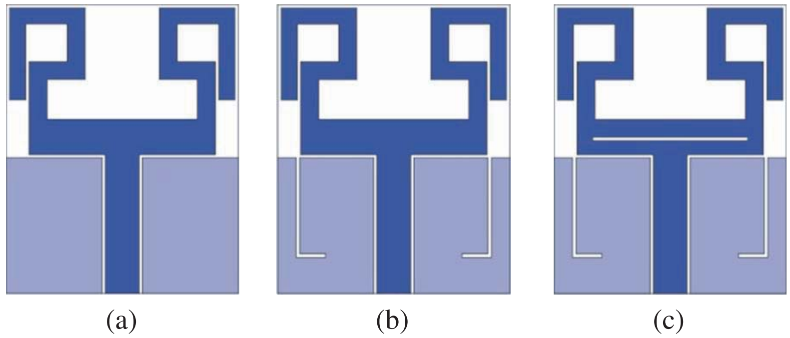


Figure 1. Development of proposed CPW fed triband antenna geometry; (a) single band (b) dual band and (c) triband antenna geometries.

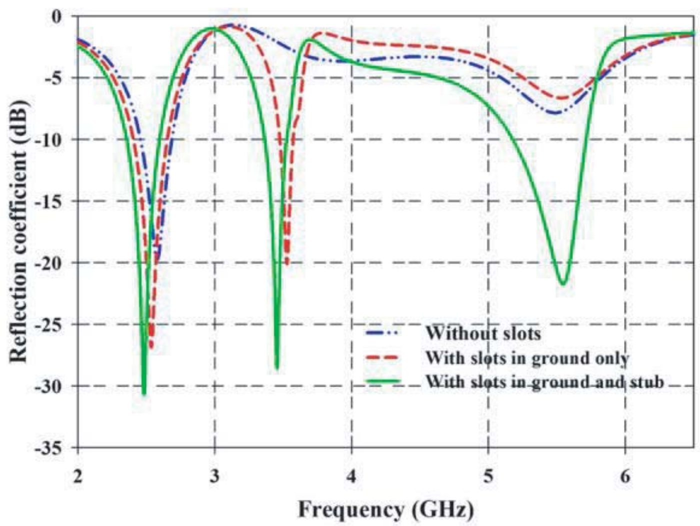


Figure 2. Reflection characteristics of single band, dual band and triband antenna geometries shown in Figures 1(a) to (c).

the third resonance around 5.5 GHz [9–11]. Reflection characteristics of the single, dual and triband antennas are shown in Figure 2. To improve the radiation performance further, the structure is slightly modified by introducing an arc shaped parasitic element through a 1.8 mm wide opening at the center of the slot as given in Figure 3. The metallic arc has uniform width of 0.75 mm and a radius of 10.92 mm (at the center of arc shaped strip) with an arc angle of 50.38 degrees. Separation of the arc from the ground conductor is 4.75 mm. All the parameters are optimized carefully and final dimensions are given in Table 1.

Table 1. Dimensions of the final antenna geometry. All dimensions are in millimeters.

L_{sub}	W_{sub}	L_g	L_1	L_2	L_3	L_4	L_5	L_6
31.2	25	14.65	8.2	4.5	7.71	4.1	4.3	9.1
L_7	L_8	L_9	L_{10}	L_{11}	W_1	W_2	W_3	W_4
20	2.5	15	10.75	2.75	1.7	1.71	1.9	1.9
W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}	W_{12}	W_P
1.9	1.9	3.8	2	3.6	4.3	0.41	1.8	1

3. PARASITIC ARC IN ANTENNA PERFORMANCE

Reflection characteristics of the geometry described in Figure 1(c) and the final geometry (Figure 3) are given in Figure 4(a). Fractional bandwidth of 5.5 GHz band is increased from 9.82% to 14.92% in the final geometry with parasitic arc, without affecting the other two bandwidths considerably. In addition to the improved impedance bandwidth, this modification contributes to a significant improvement in the radiation performance of the antenna in 3.5 GHz and 5.5 GHz bands as shown in Figure 4(b). In both the bands, reduction in gain towards the upper limit improved by 7.4 dBi and 9.8 dBi, respectively.

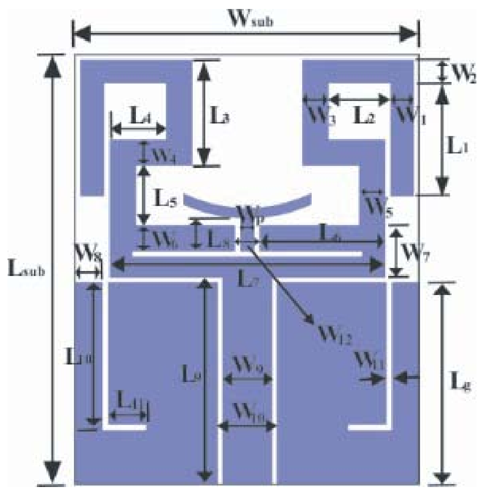
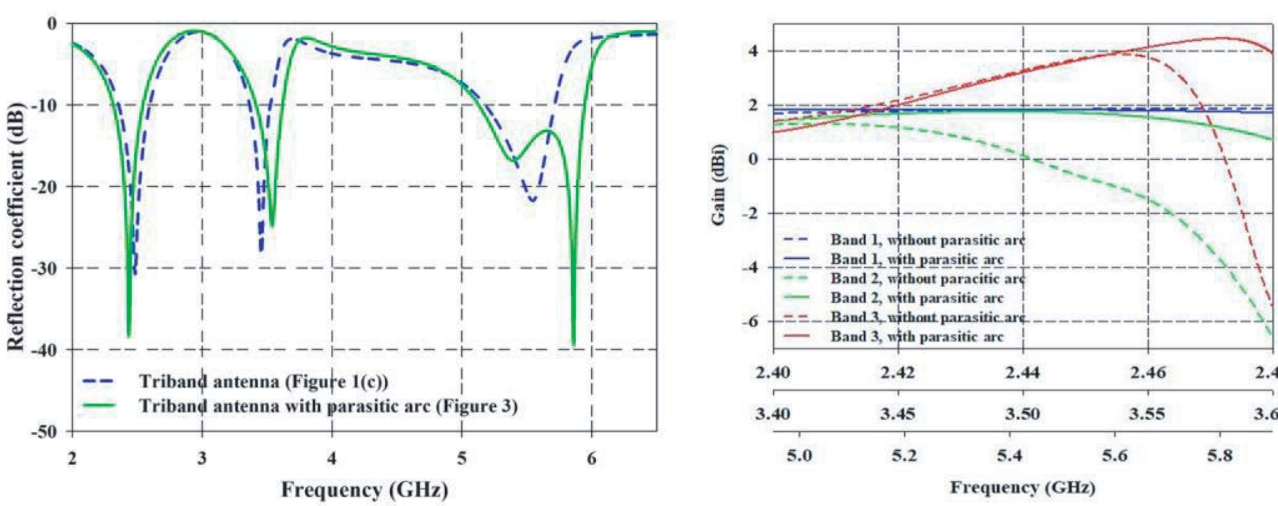


Figure 3. Geometry of the proposed CPW fed triband antenna with parasitic arc.



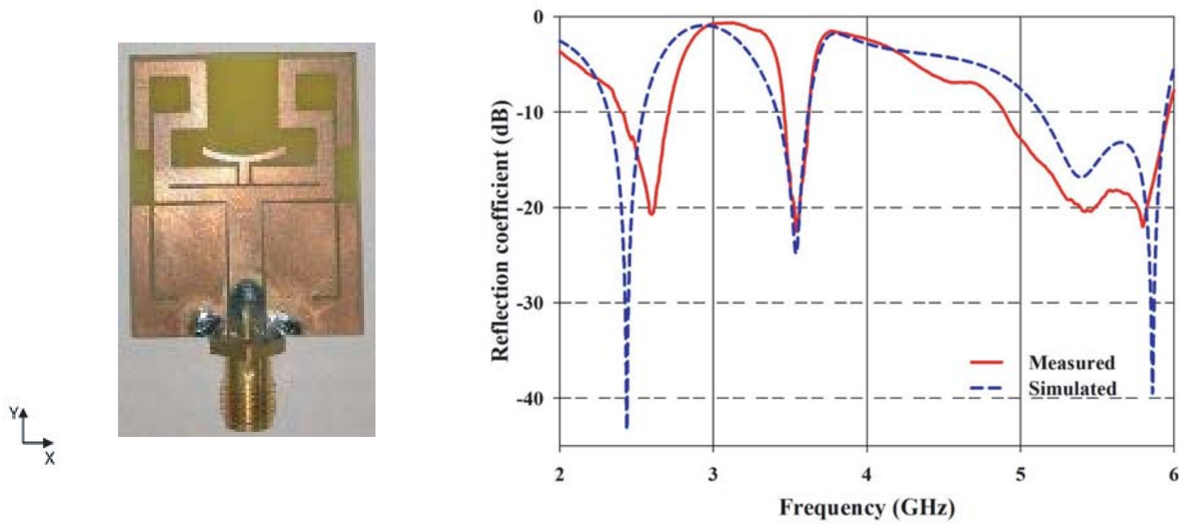
(a) (b)

Figure 4. Reflection characteristics and realized gain of the CPW fed triband antenna (Figure 1(c)) and CPW-fed triband antenna with parasitic arc (Figure 3); (a) reflection characteristics (b) realized gain.

4. RESULTS AND DISCUSSION

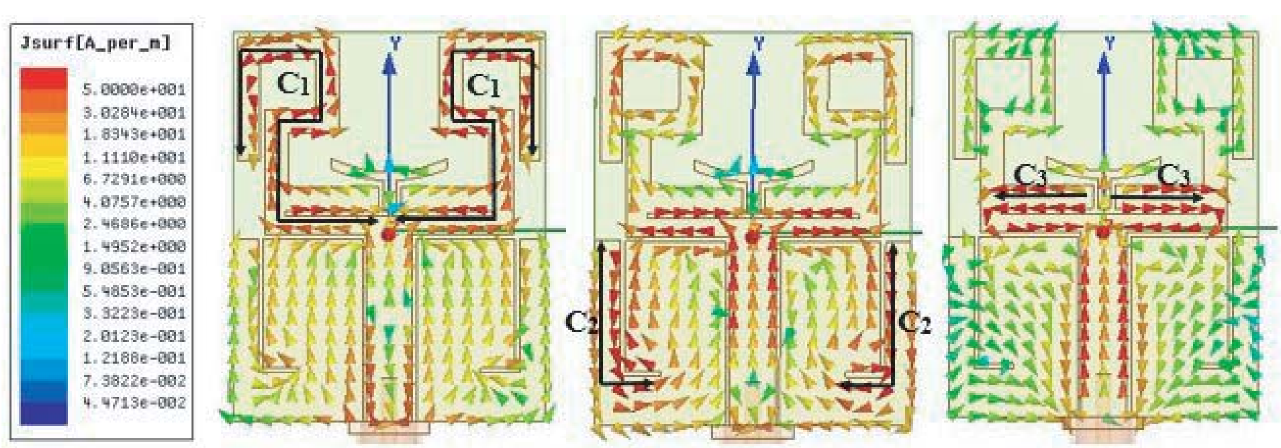
The antenna is fabricated using conventional photolithographic technique and characterized using Agilent Vector Network Analyzer E8362B. Simulated and measured reflection characteristics of the antenna are shown in Figure 5(b). A photograph of the prototype is given in Figure 5(a). The measured and simulated reflection characteristics are well matched in the mid and upper bands. In the lower band the measured resonance is shifted to 2.39–2.7 GHz with respect to the simulation result (2.3–2.53 GHz). But still it is entirely covering the application band from 2.4 to 2.48 GHz. The second band is covering the frequencies from 3.41 to 3.61 GHz. The upper band is extending from 4.9 GHz to 5.94 GHz. So the proposed antenna can support all the applications (WLAN and WiMAX) in 2.4, 3.5 and 5.5 GHz bands. In addition to this, it can also support the bands allotted for fixed and mobile service (except aeronautical mobile service) for use in support of public safety in 4.94–4.99 GHz band and Dedicated Short-Range Communications (DSRC) services in the Intelligent Transportation System (ITS) radio service in 5.85 to 5.925 GHz band.

Surface current distributions of the antenna plotted at different resonant frequencies (2.45, 3.5, 5.5 GHz) are shown in Figures 6(a) to (c). At 2.45 GHz, the current is mainly concentrated along the



(a) (b)

Figure 5. Proposed CPW-fed triband antenna with its reflection characteristics (a) prototype and (b) simulated and measured reflection characteristics.



(a) (b) (c)

Figure 6. Surface current distributions of the proposed triband antenna at (a) 2.45, (b) 3.5 and (c) 5.5 GHz.

horizontal stub and its flared elements. Total length of this element along the path C_1 (40.01 mm) is nearly equal to half wavelength in substrate. Resonance at 3.5 GHz is influenced by the "L" shaped slots in ground plane as seen in Figure 6(b), length (13.5 mm) of which is approximately equal to a quarter wavelength in substrate at 3.5 GHz. Role of the slot in horizontal stub is evidenced with the surface current distribution along its edges (Figure 6(c)). Since this slot is opened through the sides of parasitically coupled arc, these two sections are behaving as parallel slots with path length (8.35 mm) nearly equal to the quarter wavelength of the guided wave at 5.5 GHz.

4.1. Radiation Patterns

Co-polar and cross-polar patterns of the proposed antenna in E plane (YZ plane) and H plane (XZ plane) at 2.45, 3.5, and 5.5 GHz are measured and plotted in Figures 7(a) to (f) along with the respective simulated patterns. The differences between the simulated and measured patterns are caused due to the fabrication errors, the angle error when placing the antenna on the fixture at the anechoic chamber [19], and the imperfection in soldering. Patterns are almost omnidirectional in nature for lower bands while the pattern at 5.5 GHz has slightly deviated from the omnidirectional nature.

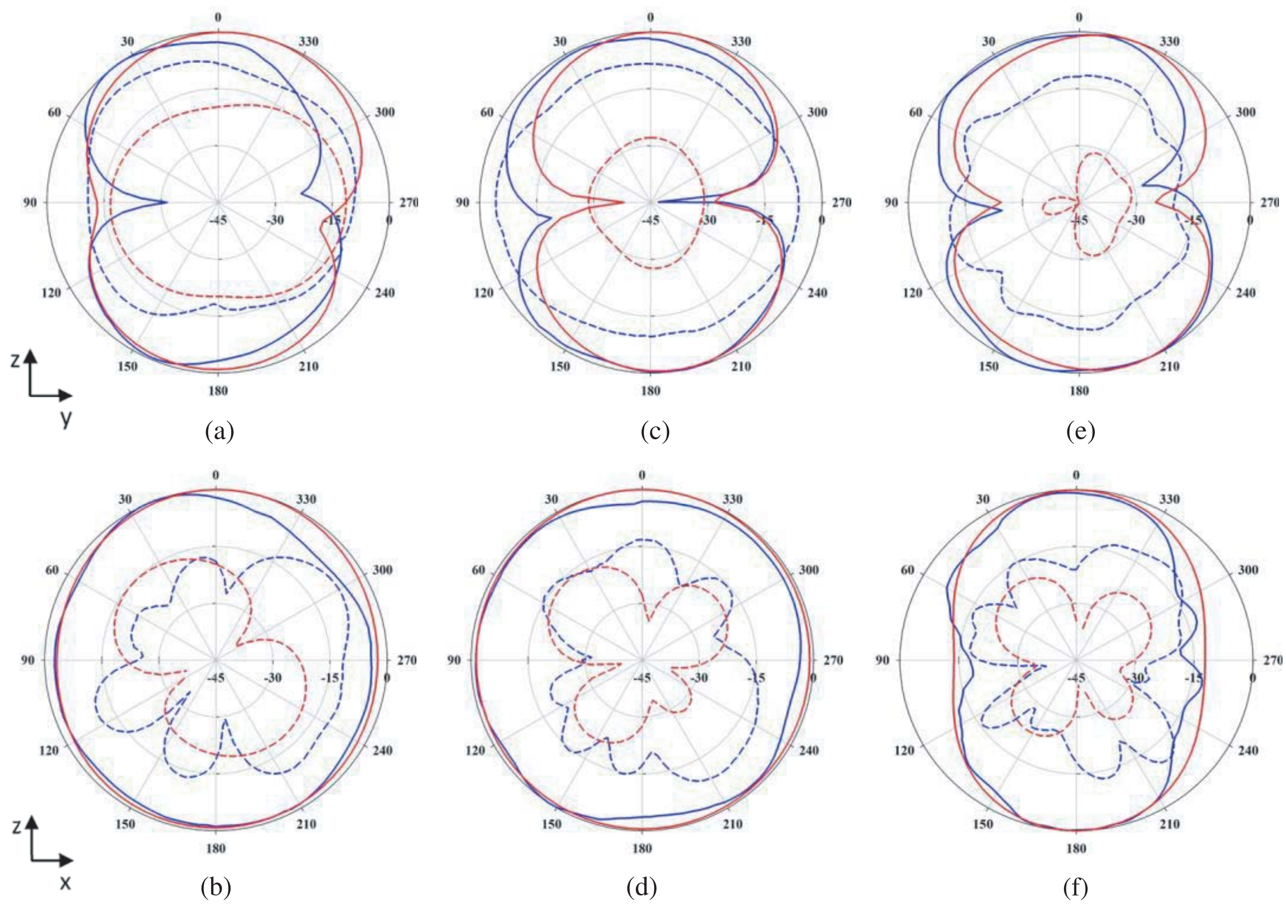


Figure 7. Simulated and measured radiation patterns of the proposed triband antenna in YZ and XZ plane at (a) and (b) 2.45 GHz, (c) and (d) 3.5 GHz, (e) and (f) 5.5 GHz. (Blue: measured and Red: simulated. Solid and doted lines indicate Co and Cross polarization patterns).

4.2. Gain

Gain of the proposed antenna is determined using gain transfer method. Measured gain is shown in Figure 8. The measured gains in the lower and mid bands are in good agreement with the simulation

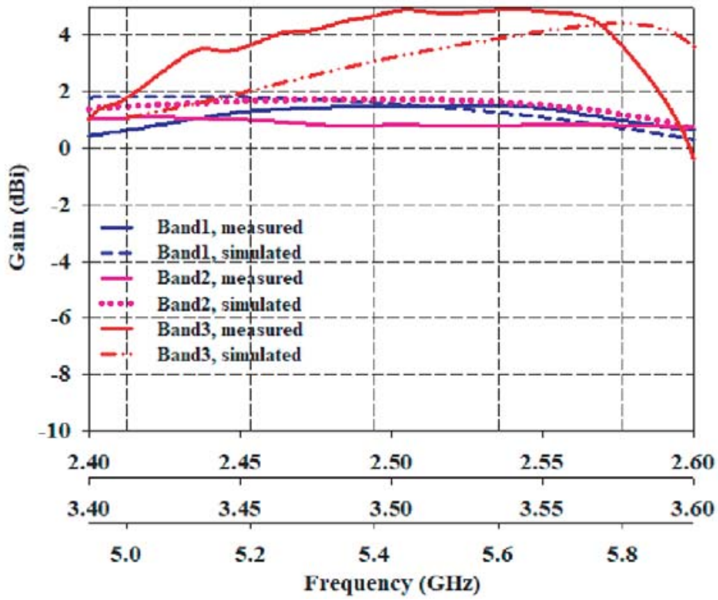


Figure 8. Simulated and measured gain of the proposed triband antenna.

Table 2. Performance comparison of the proposed triband antenna with similar antennas reported in literature.

Reference/ year	Substrate parameters	Antenna size in millimeters	Operating bands in GHz	Peak gain in dBi
[3], 2019	RT/duroid 5880 with $\varepsilon_r = 2.2$ and $\tan\delta = .0009$	55 x 60 x 3.175	2.6, 4.4 and 8.7	3.6, 5.5 and 7.3
[4], 2016	FR4 with $\varepsilon_r = 4.4$	34 x 18 x 1.6	2.5, 3.5 and 5.5	-0.1-0.28, 0.24-1.42 and 2.67-4.76
[7], 2017	FR4 with $\varepsilon_r = 4.4$ and $\tan\delta = 0.02$	45 x 65 x 1.6	1.57, 2.02 and 2.55	0.8, 1.5 and 1.7
[9], 2015	FR4 with $\varepsilon_r = 4.4$ and $\tan\delta = 0.018$	27 x 25 x 1.6	2.4, 5.2, and 5.8 or 5.2 and 5.8	1.97, 2.45 and 2.98
[11], 2018	FR4 with $\varepsilon_r = 4.4$ and $\tan\delta = 0.01$	32 x 32 x 1.6	3.5, 5.95, 6.75, 8.55 and 9.59	1.2, 1.6, 2.1, 2.5 and 2.7
[12], 2016	Rogers RO4350 with $\varepsilon_r = 3.48$ and $\tan\delta = .004$	18 x 20 x 0.76	2.4 and 5.2	-1.7 and 2.4
[15], 2018	FR4 with $\varepsilon_r = 4.4$ and $\tan\delta = 0.017$	50 x 44	4.9 and 5.9	2.3 and 4.7
Proposed work	FR4 with $\varepsilon_r = 3.8$ and $\tan\delta = 0.02$	25 x 31.2 x 1.6	2.4, 3.5 and 5.5	1.56, 1.16 and 4.9

result. In lower and mid frequencies of upper band, the measured values are significantly greater than simulation due to the improved impedance matching in these frequencies as seen in Figure 5(b). Peak gain at 2.45, 3.5 and 5.5 GHz bands are 1.56, 1.16 and 4.9 dBi respectively.

5. CONCLUSION

A compact CPW-fed antenna for 2.45, 3.5, and 5.5 GHz applications (WLAN, WiMAX) is presented. The simulated results are experimentally validated. The performance of the proposed antenna is compared with similar antennas reported in literature and tabulated in Table 2. The proposed antenna offers better or comparable gain with respect to [4, 9, 11, 12, 15]. The proposed antenna is compact with respect to other antennas reported in [7, 11, 15] and comparable to those in [4, 9]. With respect to the triple band antenna (which can reconfigure as a dual band antenna supporting first and third bands) in [9], the proposed antenna operates from 4.9 GHz to 5.94 GHz and hence supports the fixed and mobile service (except aeronautical mobile service) for public safety in 4.94–4.99 GHz band also. Radiation patterns in 2.45 and 3.5 GHz bands are omnidirectional in nature. The radiation pattern in 5.5 GHz band is slightly deviating from omnidirectional nature.

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