Design of a Dual Band Microstrip Antenna with Broadband and Circular Polarization Characteristics Useful for Different Wireless Applications

T. D. Malakar[1], M. Mondal[2], S. Das[2], S. Bala[2], and B. Bag[3]

[1]Department of Electronics and Communication Engineering, RCCIIT, Kolkata, West Bengal, India
[2]Departmentof Electronics, Vidyasagar University, Midnapore, West Bengal, India
[3]Department of Electronics and Communication Engineering, Haldia Institute of Technology, Haldia, West Bengal, India

Corresponding author: S. Bala (susmitabala@mail.vidyasagar.ac.in).

ABSTRACT A multiband microstrip antenna has been proposed in this research article. The proposed antenna provides two bands. Two obtained bands are wideband in nature. Lower frequency band ranges from (1.3–1.6) GHz with 20.68% of bandwidth. Higher frequency band ranges from (2.7-5.7) GHz with 71.42% of bandwidth. Higher frequency band provides two 3 dB axial ratio bandwidth (ARBW). The % of 3 dB ARBW is 5.94% and 34%, respectively for the first and second circular polarized bandwidths, respectively for the higher frequency band. Measured peak gain of 4.7 dBi and 3.5 dBi have been obtained at the lower band and the upper band of the proposed antenna respectively. Also, good radiation patterns have been obtained from the desired frequency of radiation. Low cost and easily available FR4 material are used as a dielectric substrate for modeling the proposed structure. The proposed antenna is designed and simulated by using the ansoft High Frequency Structure Simulation (HFSS) software. The antenna is fabricated and results are compared with the simulated results. The reflection co-efficient, gain and radiation patterns of the proposed antenna are discussed here. There are good agreements between the simulated and measurement results. The antennas may be useful in part of L band, part of S band, part of C band, Wi-MAX and WLAN applications etc.

INDEX TERMS Broadband, circular polarization, microstrip antenna, multiband.

I. INTRODUCTION

THE key benefits of microstrip patch antennas (MPA) include their low profile, adaptability to both planar and non-planar surfaces, straightforwardness, and affordability to manufacture using current printed circuit technology [1–2]. Because of this, today's communication accessories frequently use microstrip patch antennas. By modifying radiating patch geometry and ground plane geometry, the MPA shows broadband, multiband, and circular polarization characteristics [3]. The broadband, multiband and circularly polarized antennas are extremely useful for fast data communication, multi-frequency operation, and avoiding misalignment polarization between electronic device transmission and receiver sections.

Many dual band microstrip antennas are reported in the previous literature so far. A small size dual broadband antenna was reported for C band and X band applications in [4]. It uses fractal geometry on rectangular patch to obtain two bands. A D shaped antenna uses split ring resonator for providing two bands in [5]. An antenna uses quasi-circular microstip patch with resonator on ground plane to obtain dual band in [6]. A circular ring type antenna was reported for dual frequency operation in [7]. A dual band monopole antenna with defected ground structure was proposed in [8] for Internet of thing (IOT) applications. Another IOT based dual band antenna was proposed in [9]. The antenna uses different shapes of radiating patch to obtain its desired characteristics. A dual band characteristic has been achieved by using V shaped radiating patch fed by V shaped stub in [10]. The antenna was useful for WLAN and Wi-MAX applications. In [11], a CPW-fed dual-band antenna is designed using crescent and T-shaped stubs for WI-FI and WIMAX applications. Shaojian Chen et al. present a dual-band compact antenna consisting of an L- shaped rectangular slot and defected ground structure for TD-LTE and WLAN applications in [12]. In order to achieve broadband application, fractal geometry was used on a patch as reported in [13] [14]. In [15], the modified star-like patch yields (1.6638-6.652) GHz bandwidth. For ground-penetrating radar, a wideband slot antenna was proposed in [16]. In [17], a smaller antenna with increased bandwidth by bounding box geometry was suggested. For the wireless system in [18], an antenna with a bandwidth of 1.15 GHz to 2.90 GHz and two triangle-shaped patches and four split ring resonators was proposed. In [19], a U-shaped antenna with slots was proposed for use in broadband applications. In order to achieve dual band with circular polarization, a smaller antenna was suggested in [20]. According to a report in [21], a microstrip antenna was proposed for Global System for Mobile communication (GSM) and Wi-MAX applications with two ARBW of 1.69 GHz to 1.94 GHz and 3.64 GHz to 3.88 GHz by using ring slots and U-shaped slots. In [22], a microstrip antenna with circular polarization and dual band was presented. A microstrip antenna [23] can reach a 3 dB axial ratio bandwidth of (3.25-3.43) GHz by using slots. A circular ultra-wideband antenna with band notch capability using fractal geometry was reported in [24]. Using fractal geometry dual band notched ultrawideband antenna was proposed in [25].

In this paper, a dual band microstrip antenna has been proposed. To design the proposed antenna, at first, a reference antenna is considered as step1. Then, using monopole geometry and modified the radiating patch, the microstrip antenna (reference antenna) converts into a proposed antenna which shows dual band, broadband and circularly polarized characteristics. The antenna may be useful in various wireless applications.

II. ANTENNA GEOMETRY

The proposed antenna is shown in Figure 1. The proposed antenna is designed and simulated by HFSS simulation software. FR4 dielectric substrate with a height (h) of 1.6 mm, a dielectric constant (ε_r) of 4.4 and a loss tangent of 0.023 is used to design the proposed antenna. The total substrate volume to design the proposed antennas is 60×60×1.6 mm^3. All dimensions are shown in the layout of Figure 1. The evolution process of the proposed structure is shown in Figure 2. The evolution process consists of three steps. First step is shown in Figure 2(a).This step consists of microstrip antenna with an inset feed transmission line. Figure 2(b) shows the step2 which is the broadband antenna. It uses truncated ground plane and microstrip line feed technique to excite the antenna. Third step is shown in Figure 2(c). It uses some additional slits to obtain circular polarization characteristics. The microstrip transmission line (22.74×3.06 mm^2) feed technique is used to excite the proposed antenna. The simulated reflection co-efficient verses frequency curve for the proposed antenna is shown in Figure 3(a), the simulated axial ratio versus frequency curve of the proposed structure is shown in Figure 3(b) and the simulated gain versus frequency curve is shown in Figure 3(c). After comparing different steps, the third step has been considered as the proposed antenna. Snapshots of the proposed antenna including its different steps is shown in Figure 4(a, b and c).

The calculation of the length $L^/$ and width W of the metal patch of the step1 is given below. The calculations are done by using the equations (i-v) [1]. Here taken resonant frequency is 4.5 GHz.

Here width of the metal patch of the basic antenna (step1) is,

$$W = \frac{30}{2(4.5)}\sqrt{\frac{2}{4.4+1}}$$

= 2 cm (i)

The effective dielectric constant (ε_{eff}) of the metal patch is

$$\varepsilon_{eff} = \frac{4.4+1}{2} + \frac{4.4-1}{2}^{-1/2}\sqrt{1+12(\frac{0.16}{2})}$$

= 3.9 cm. (ii)

The increased length of the metal patch of the basic antenna (step1) is, $\Delta L^/$

$$\Delta L^/ = (0.16 \times 0.412)\frac{(3.9+3)(\frac{2}{0.16}0.264)}{(3.9-0.258)(\frac{2}{0.16}+0.8)}$$

= 0.0309 cm (iii)

The true length of the metal patch of the basic antenna (step1) is

$$L^/ = \frac{\lambda}{2} - 2\,\Delta L^/$$

= 1.62 cm (iv)

So, the effective length of the metal patch of the basic antenna (step1) is

$L_{eff}= L^/+2\Delta L^/$ = 1.68 cm (v)

After calculation, the taken optimized length and width of the metal patch of the basic antenna (step1) are 14.53 mm and 19.22 mm, respectively. The optimized length and width of the inset feed line is taken as L_0 = 5 mm and W_0 = 0.6 mm respectively. All the dimensions of the proposed antenna are tabulated in the TABLE I.

TABLE I. Dimensions of the proposed antenna (mm)

Parameter	Dimension	Parameter	Dimension
A	60	H	10
B	60	I	4.61
C	2.26	J	5
D	14.52	K	12.8
E	4.61	L	2.74
F	30.06	M	22.74
G	15	N	5

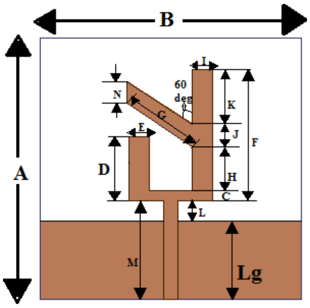


FIGURE 1. Geometry of the proposed antenna

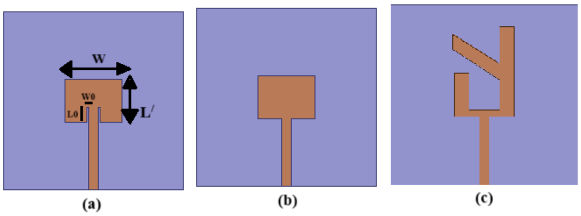
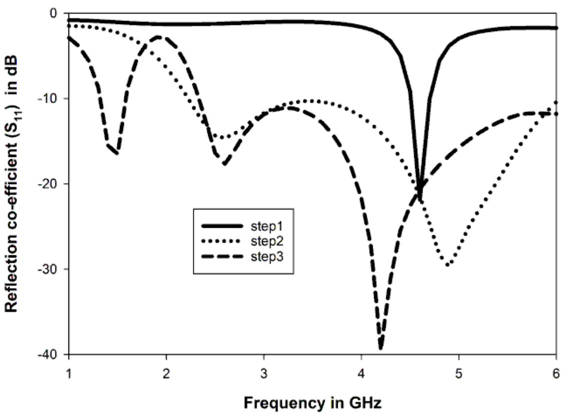
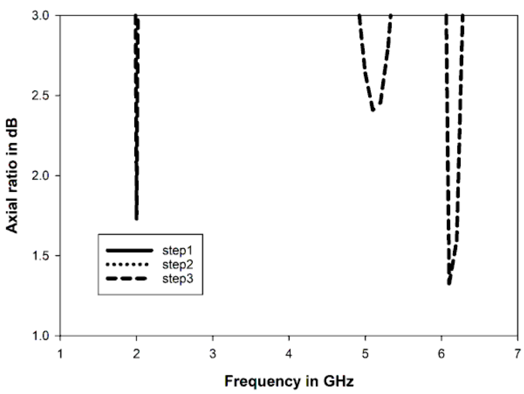


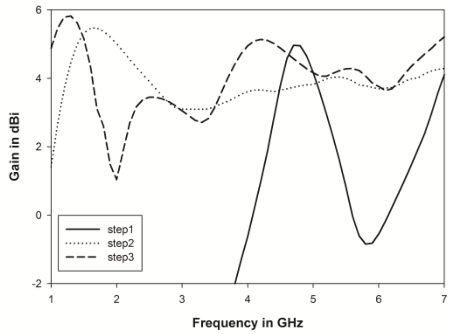
FIGURE 2. Evolution of the proposed antenna (a) step1 (b) step2 (c) step3 (proposed antenna)



(a)

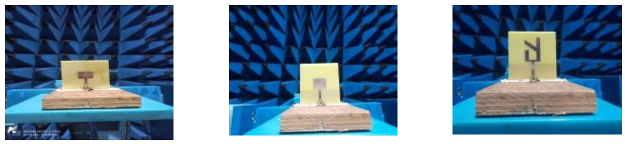


(b)



(c)

FIGURE 3. Evolution steps of the proposed antenna (a) reflection co-efficient versus frequency plot (b) axial ratio versus frequency plot (c) gain versus frequency plot

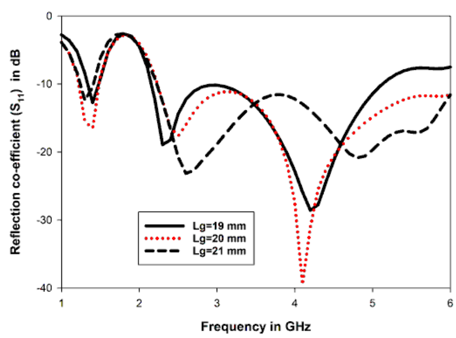


(a) (b) (c)

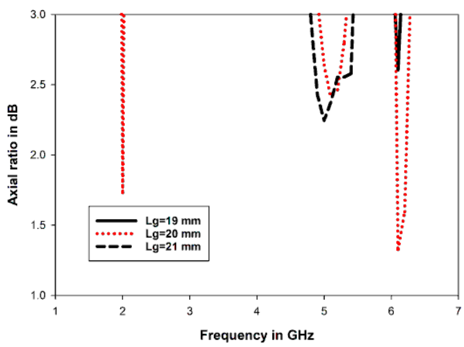
FIGURE 4. Snapshot of the different steps of the proposed antenna (a) step1 (b) Step2 (c) step3 (proposed antenna)

III. PARAMETRIC STUDY

Parametric studies have been done for different parameters of the proposed antenna mentioned in this section. At first, parametric study for the ground plane of the proposed antenna has been done. The other parameters remain constant. The proposed antenna provides broadband characteristics due to the modification of the ground plane. Here parametric study for the ground plane of different dimensions (Lg = 19 mm, 20 mm and 21 mm) is done. The reflection co-efficient versus frequency curve and axial ratio versus frequency curve is shown in Figure 5(a and b). Comparing with different dimensions, Lg = 20 mm has been selected for the proposed Antenna.

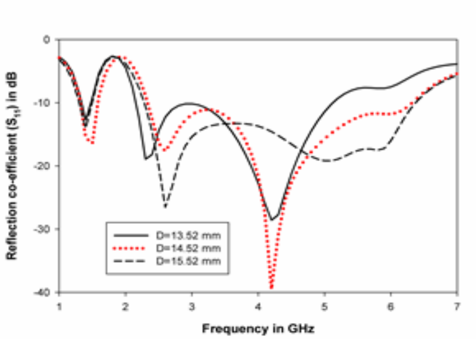


(a)

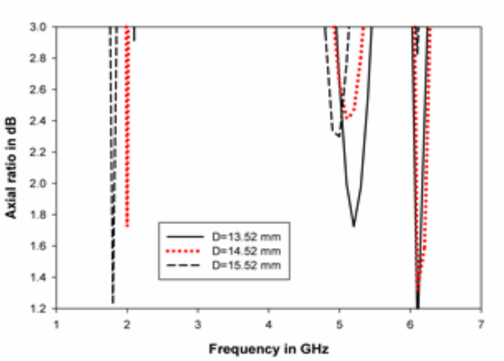


(b)

FIGURE 5. Parametric studies for Lg parameter (a) the reflection co- efficient versus frequency curve (b) axial ratio versus frequency curve



(a)

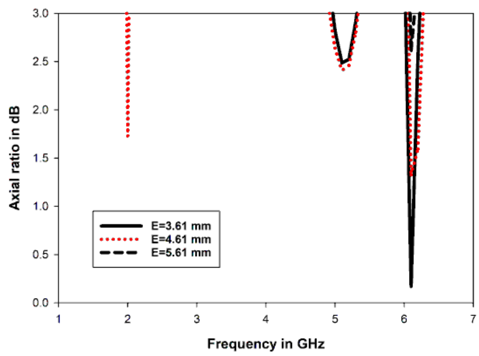


(b)

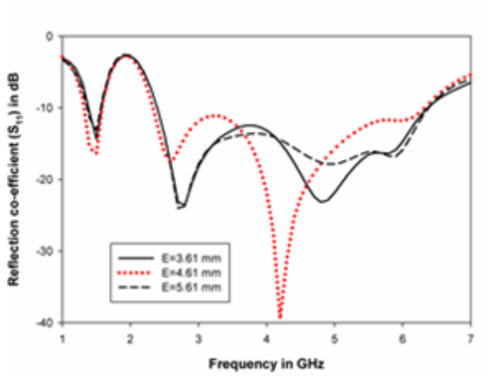
FIGURE 6. Parametric studies for D parameter (a) the reflection co-efficient versus frequency curve (b) axial ratio versus frequency curve

Parametric study for the parameter D has been done for the proposed antenna. Here parametric study for the different dimensions of D has been studied. Parametric analysis for D=13.52 mm, 14.52 mm and 15.52 mm has been done. The reflection co-efficient versus frequency curve and axial ratio versus frequency curve are shown in Figure 6(a and b). Comparing with different dimensions, D=14.52 mm has been selected for the proposed antenna. At the time of analysis other parameters are remained kept fixed.

Parametric study for the parameter of E has been done. The values of E = 3.61 mm, 4.61 mm and 5.61 mm are done for



(a)

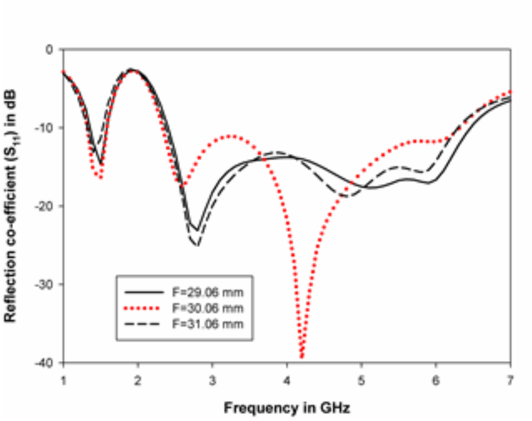


(b)

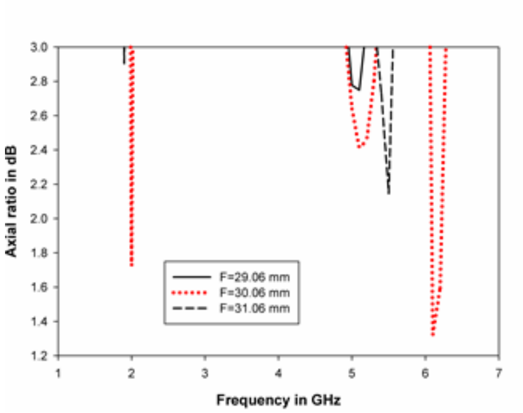
FIGURE 7. Parametric studies for E parameter (a) the reflection co-efficient versus frequency curve (b) axial ratio versus frequency curve

Parametric analysis purpose. The reflection co-efficient frequency curve and axial ratio versus frequency curve are shown in Figure 7(a and b). Comparing with different dimensions after parametric analysis, E = 4.61 mm has been selected for the proposed antenna.
Parametric study for the different dimension of the F for the proposed antenna has been done keeping other parameters fixed. Here parametric study for the different dimensions of F = 29.06 mm, 30.06 mm and 31.06 mm has been done. The reflection co-efficient versus frequency curve and axial ratio versus frequency curve are shown in Figure 8(a and b). Comparing with different dimensions, F = 30.06 mm has been selected for the proposed antenna.
Parametric study for the different dimensions of the I for the proposed antenna has been done. Other parameters are fixed. Here parametric study for the different dimensions of I = 3.61 mm, 4.61 mm and 5.61 mm has been done. The reflection co-efficient versus frequency curve and axial ratio versus frequency curve are shown in Figure 9(a and b). Comparing with different dimensions, I = 4.61 mm has been selected for the proposed antenna.

Parametric study for the different dimensions of the G for the proposed antenna has been done. Here parametric study for the different dimensions of G = 14 mm, 15 mm and 16 mm has been done keeping other parameters fixed. The reflection co-efficient versus frequency curve and axial ratio versus frequency curve are shown in Figure 10(a and b). Comparing with different dimensions, G = 15 mm has been selected for the proposed antenna.

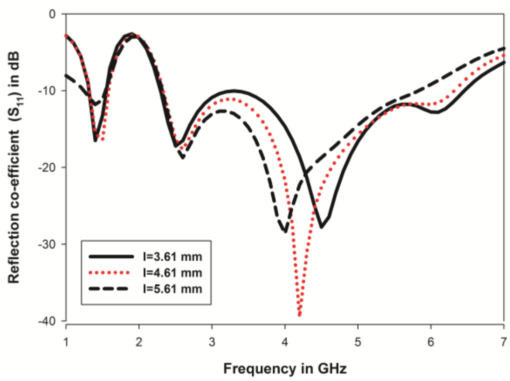


(a)

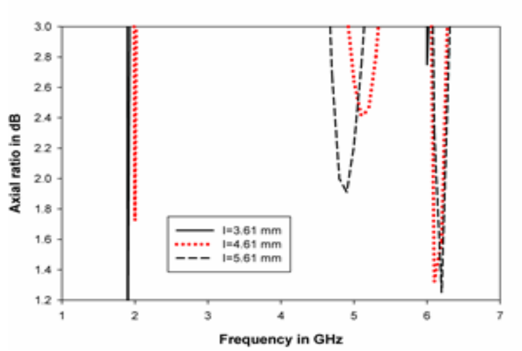


(b)

FIGURE 8. Parametric studies for F parameter (a) the reflection co-efficient versus frequency curve (b) axial ratio versus frequency curve

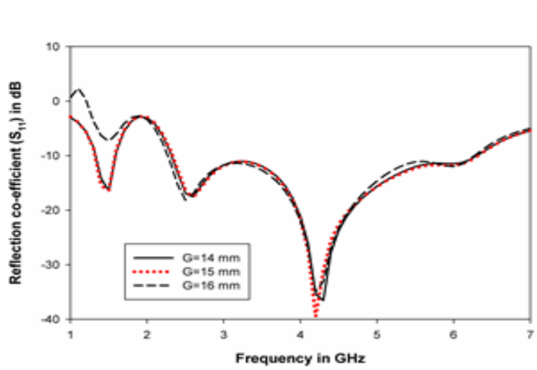


(a)

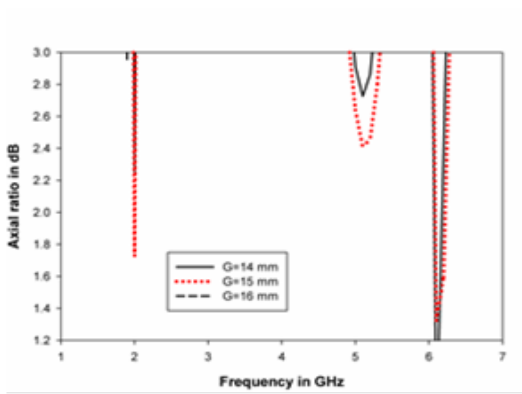


(b)

FIGURE 9. Parametric studies for l parameter (a) the reflection co-efficient versus frequency curve (b) axial ratio versus frequency curve



(a)



(b)

FIGURE 10. Parametric studies for G parameter (a) the reflection co-efficient versus frequency curve (b) axial ratio versus frequency curve

III. RESULT AND DISCUSSION

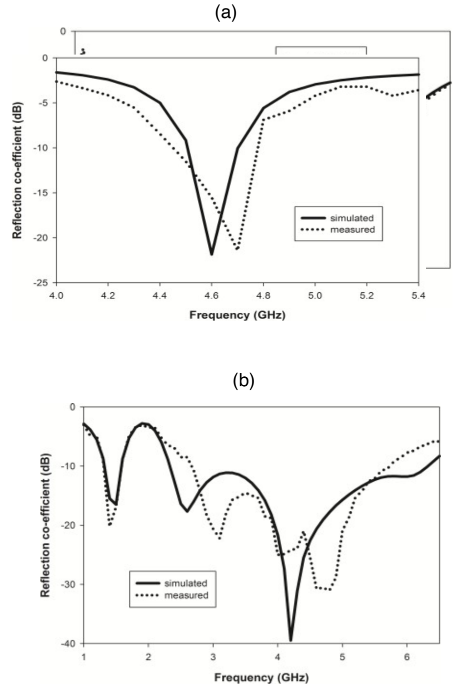
In this section, simulated and measured results of the proposed antenna have been discussed. The simulation of the antennas has been done using HFSS software. Here, the results of the reflection coefficient (S_{11}), gain and radiation patterns of the proposed antenna is discussed. Figure 11(a) depicts the simulated and measured reflection coefficient plot of step1 of the proposed antenna. Step1 provides a single band of frequency. The range of simulated frequencies is

(4.5–4.7) GHz with a centre frequency of 4.6 GHz where as measured band of frequency ranges from 4.46 GHz to 4.76 GHz with a centre frequency of 4.7 GHz. The magnitude of the simulated reflection coefficient is -21.85 dB at a resonant frequency of 4.6 GHz. The magnitude of the measured reflection coefficient is -21.4 dB at a resonant frequency of 4.7 GHz. The simulated bandwidth of the step1 is (4.7–4.5) GHz = 0.20 GHz and the percentage bandwidth is 4.34%. The measured bandwidth of the microstrip antenna is (4.76–4.46) GHz = 0.30 GHz and the percentage bandwidth is 6.5%. The bandwidth is narrow. Now to increase the impedance bandwidth of the step1, step2 has been modified and step2 uses monopole concept to broaden the bandwidth. Figure 11(b) depicts a plot of the reflection coefficient versus frequency curve. The range of the simulated frequency is (2.2-6.1) GHz with a deep resonant frequency of 5 GHz and the measured frequency range is (2.32-6.12) GHz. The simulated bandwidth of the step2 is (6.1-2.2) GHz = 3.9 GHz and the percentage bandwidth are 93.97%. The measured bandwidth of the antenna is (2.32-6.12) GHz =3.8 GHz with the percentage bandwidth of 90.04%. The reflection co-efficient versus frequency plot of the step3 (proposed antenna) is shown in Figure 11(c). The proposed antenna supports dual bands. One band is very narrow and the other band is wide. The simulated first band is (1.3–1.6) GHz with a deep centre frequency of 1.5 GHz. The measured first band is (1.3–1.6) GHz with a deep resonant frequency of 1.4 GHz. The simulated and measured bandwidth of the first band is 0.30 GHz with a percentage bandwidth of 20.68%. The second band is wideband. The simulated bandwidth for the second band of the proposed antenna is (6.3-2.3) GHz=4 GHz and the percentage bandwidth are 93.02%. The measured bandwidth for the second band of the proposed antenna is (2.7-5.7) GHz =3 GHz and the percentage bandwidth are 71.42%. The peak gain for the different steps of the proposed antenna has been observed at some frequencies. The simulated peak gain is 4.6 dBi at the resonant frequency of 4.6 GHz has been obtained from the step1. The measured peak gain of 4 dBi has been obtained at 4.7 GHz from the step1. In case of step2, the simulated peak gain of 3.8 dBi is obtained at a resonant frequency of 4.9 GHz whereas the measured peak gain of 4.1 dBi has been obtained at the frequency of 4.9 GHz. The peak gain plot of the proposed antenna is shown in Figure 12. In lower band, 5.1 dBi simulated peak gain has been obtained at 1.5 GHz of the proposed antenna whereas 4.7 dBi measured peak gain has been obtained at 1.5 GHz from the proposed antenna structure. In upper band, the simulated and measured peak gain at 4.2 GHz frequency is 5.1 dBi and 3.5 dBi respectively.

The suitable normalized E-H plane radiation patterns have been obtained for the step1, step2 and the proposed antenna (step3) are shown in Figure 13(a-f). The LHCP and RHCP radiation patterns at the frequency of 5.2 GHz of the proposed antenna are shown in Figure 13(g-h).

The proposed antenna provides an additional characteristic of circular polarization in the second band. The circular polarization (CP) is defined by the 3 dB axial ratio bandwidth (ARBW). The 3 dB axial ratio versus frequency plot is shown in Figure 14. Two 3 dB axial ratio bandwidths have been obtained in the second wideband of (6.3-2.3) GHz. Two 3 dB ARBW bandwidth are (4.9-5.2) GHz and (6.06-6.27 GHz). The % of 3 dB ARBW is 5.94% and 34%, respectively for the first and second CP bandwidths, respectively.

(a)



(c)

FIGURE 11: Reflection co-efficient plot for (a) step1, (b) step2 and(c) step3 (proposed antenna)

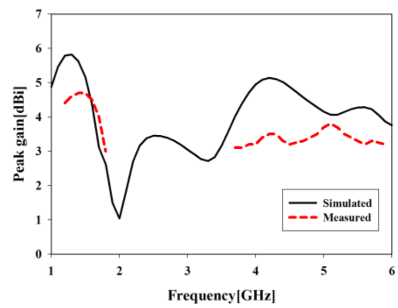
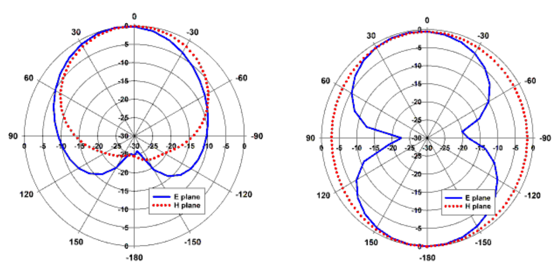


FIGURE 12: Gain plot for proposed antenna



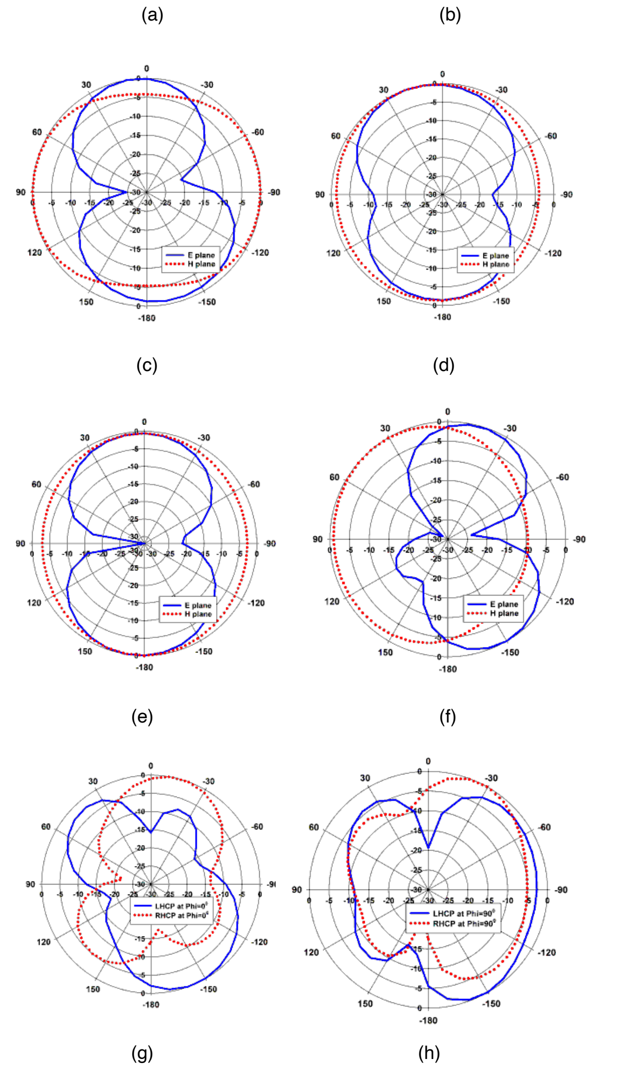


FIGURE 13. Radiation patterns of the different steps of the proposed antenna (a) step1 at 4.6 GHz (b) step2 at 2.6 GHz (c) step2 at 4.9 GHz (d) step3 at 1.5 GHz (e) step3 at 2.6 GHz (f) step3 at 4.2 GHz (g-h) step3 at 5.2 GHz

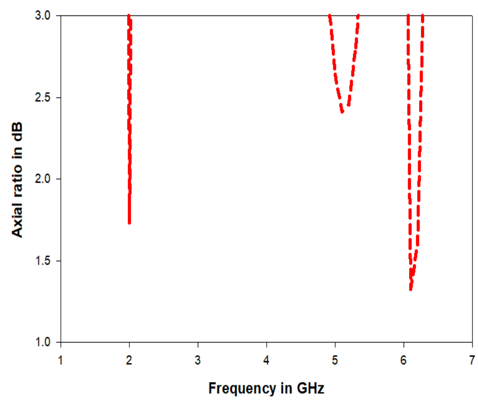


FIGURE 14: Axial ratio versus frequency curve of the proposed antenna

The proposed work in this article has been compared (TABLE II) with the other works which are reported so far. The proposed work has been compared in terms of substrate area, bandwidth, gain and applications with the other works which were mentioned in the introduction part. After comparing, it is concluded that our work provides the best work.

TABLE II. Comparison table

Ref No	Substrate Area (mm^2)	Bandwidth (MHz)	Gain (dB)	Applications
[4]	40×40	630 1350	5.2 7	C band and X band
[5]	18×20	500 250	3.35 1.8	Wi-MAX and C band
[6]	3846.5	63 318	-1.97 4.12	Wireless Networks
[7]	48×48	25 24	Not given	GSM Wi-MAX
[8]	14×14	200 400	1.76 3.32	5G Wi-Fi
[9]	13×12	200 170	1.58 1.7	Different Wireless Area
[10]	18×26	470 1020	1.51 2.34	WLAN
This work	60×60	300 3000	4.7 3.5	Wi-MAX, Part of L band, part of C band WiMAX, WLAN

V. CONCLUSION

In this article, a dual broadband circularly polarized microstip antenna has been proposed. The antenna provides a narrow band of 1.3 GHz to 1.6 GHz bandwidth and a wide bandwidth of 2.7 GHz to 5.7 GHz bandwidth. The measured peak gain of 4.7 dBi and 3.5 dBi have been observed at the lower band and upper band of the proposed antenna respectively. Also 3 dB axial ratio bandwidth has been observed at the upper band of the proposed antenna. Satisfied radiation patterns have been observed from the proposed antenna. The antenna may be applicable in various wireless fields.

ACKNOWLEDGMENT

We are thankful to Prof. Partha Pratim Sarkar and Dr. Sushanta Sarkar for their help to carry out the works. I am thankful to Department of Engineering and Technological Studies of University of Kalyani for their help and inspiration.

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