A Modified Ring Shaped Slot Radiator for Triple-Band Wireless Applications

Som Pal Gangwar[1], Kapil Gangwar[2], Arun Kumar[3]

Abstract – **This article explains the design of a modified ring shaped slot printed antenna applicable for three different wireless frequency bands simultaneously. The modified ring shaped slot is simply a combination of a circular slot and an elliptical ring slot. Modification in ring shaped slot along with symmetrical feed structure makes the proposed radiator capable of supporting triple frequency bands. For practical verification, prototype of proposed antenna has been fabricated and tested in electromagnetic interference (EMI) free environment. Practically obtained outcomes confirm that the proposed radiator is providing optimum performance in three different frequency bands i.e. 2.48-3.2 GHz, 4.58-5.12 GHz and 6.68-7.34 GHz with the fractional bandwidth of 24.5%, 11.2% and 9.3% respectively. Far-field patterns of proposed radiating structure are stable in all three operating frequency bands. The proposed antenna design can find applications in S (2-4 GHz) and C (4-8 GHz) frequency bands.**

Keywords – **Slot antenna, Triple band, S-Band, C-Band.**

I. Introduction

In this age of cellular communication, the most widely used radiator is microstrip antenna because of its various advantageous features such as linear and circular polarizations, ease and cheap fabrication, ease in integration with monolithic microwave integrated circuits (MMIC) and so-on [1]. All these features make it highly attractive in today's wireless communication market. But, it is lacking at two important points i.e. inability to create omnidirectional pattern in both planes and narrow impedance bandwidth. In order to overcome these drawbacks along with maintaining its advantages, a modification is created in conventional microstrip antenna by cutting slots of different shapes and sizes. This modified radiator is known as slot radiator [2]. In current age of wireless communication, researchers are widely concentrating on multiband radiators. Multiband radiators can support different wireless frequency bands simultaneously, which is helpful in obtaining compactness in wireless communication devices. Another important advantage of multiband radiator is its capability to improve signal to noise ratio (SNR) values by rejecting the unusable frequency bands [3].

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Initially, in later 90's, different shape of slots was used to obtain dual band characteristics such as cross shaped slot [4], circular shaped slot [5], square shaped slot [6] and circular shaped slot shifted from centre [7]. A helix based slot radiator was developed for global positioning satellite applications. It supports dual frequency bands, but at the same time, it suffers from large physical size [8]. In the year 2016, a slot radiator was proposed which can support two different frequency bands. Authors used spurline as well as cavity backing concept for getting dual frequency bands with higher value of gain. But, all these components make the design more complex [9]. In the same year, another slot antenna with simple trimmed square structure was proposed which can support two different frequency bands. Authors used split ring resonator for getting circular polarization feature, but it also suffers from large physical size [10]. A circularly polarised square slot antenna is also proposed for multiband applications. This antenna design consists of dual rectangular slots along with an offset between them. It is suitable for wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) applications [11]. But, its size is larger as compare to proposed antenna structure. In the year 2018, a dual-band modified circular slot antenna for WLAN and WiMAX applications was reported in literature [12]. Recently, a triple-band tilted square ring shaped aperture antenna was proposed for WiMAX, WLAN and earth exploration satellite service applications [13]. The size of this antenna is same but it has narrow bandwidth as compared to proposed antenna.

This article concentrates on the design and analysis of modified ring shaped slot printed antenna, which is suitable for multiband applications. Multi-frequency application is achieved by combining a circular slot and an elliptical ring slot. The proposed radiator operates over three different frequency ranges i.e. 2.48-3.2 GHz, 4.58-5.12 GHz and 6.68-7.34 GHz. Monopole type of radiation characteristics makes the proposed radiator helpful to operate for WLAN and WiMAX applications. Apart from introduction, the given article is segmented into four sections comprising of geometrical layout of antenna, analysis of proposed antenna, experimental outcomes and finally conclusion.

II. Antenna Geometry

Geometrical layout of the proposed radiator is shown in Fig. 1 with two different views, i.e. top as well as bottom view. The structure is designed and fabricated on low cost and easily available glass epoxy FR-4 substrate having thickness h = 1.6 mm, relative permittivity ε_r = 4.4 and loss tangent tan δ = 0.0148. The length and width of substrate are L_1 and

W_1, respectively. The proposed antenna is printed on both sides of the single substrate. On one side of the substrate, modified ring slot i.e. combination of a circular slot and an elliptical ring slot has been etched, while on the other side, a microstrip line of dimension $L_2 \times W_2$ has been printed. The major axis and eccentricity of outer ellipse are a_2 and e_2 respectively while those of inner ellipse are a_1 and e_1 respectively. The radius of slotted circle is R. The optimized dimensions of proposed structure are shown in Table I. Fabricated prototype of proposed antenna structure is shown in Fig. 2 with two different views, i.e. top and bottom.

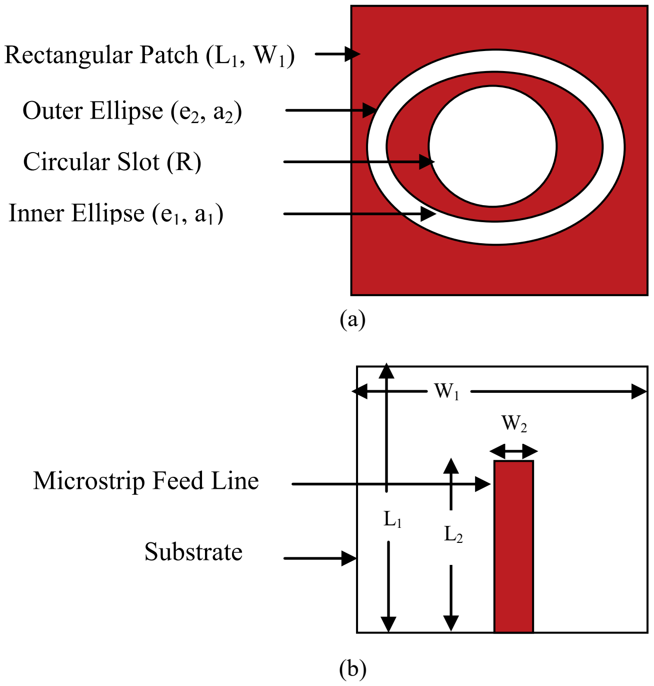

Fig. 1. Geometry of proposed antenna: (a) top view, (b) bottom view

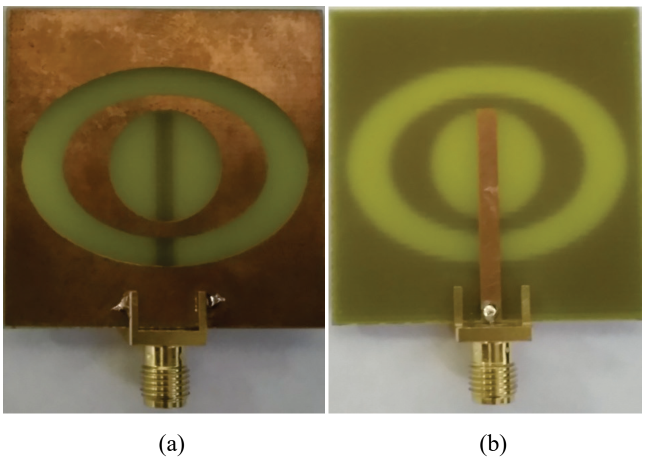

Fig. 2. Fabricated antenna: (a) top view, (b) bottom view

TABLE I
OPTIMIZED PARAMETERS OF THE PROPOSED ANTENNA

Parameters	**Unit**
Length of substrate / patch (L_1)	40 mm
Width of substrate / patch (W_1)	40 mm
Length of microstrip line (L_2)	27 mm
Width of microstrip line (W_2)	2.5 mm
Inner ellipse major axis (a_1)	13 mm
Outer ellipse major axis (a_2)	18 mm
Radius of circle (R)	7.071 mm
Inner ellipse eccentricity (e_1)	0.7
Outer ellipse eccentricity (e_2)	0.7
Feed position	center

III. ANTENNA ANALYSIS

In order to study the effects of different parameters on the performance of proposed antenna, parametric analysis is performed. When the effect of one parameter is studied, the other parameters are kept constant. The parametric observations provide valuable suggestions for the designing of practical antennas. The parametric analysis of the proposed antenna is performed to get optimized dimension of antenna and feed element. Fig. 3 displays the step by step designing process of the proposed radiator. Similarly, Fig. 4 shows return loss variation for each antenna design (1, 2 and 3). The observations from Figs. 3 and 4 are as follows: when only elliptical ring shaped slot is cut in the patch, design (1), the structure acts as a single band antenna having a resonance at 7.4 GHz. When only a circular shaped slot is cut in the patch, design (2), the structure does not have any resonance. When one elliptical ring slot and one circular shaped slot are cut in the patch, design (3), the structure exhibits characteristics of a triple band antenna.

The proposed design i.e. design (3), generates triple band performance which can be theoretically explained as follows: by cutting suitable size of circular slot in the patch, the fundamental resonant mode TM_{11} for an unslotted microstrip antenna can be split into two separate resonant modes and the antenna exhibits characteristics of a dual band antenna [4], [5]. When one circular shaped slot and one elliptical ring slot are cut in the patch, the antenna exhibits characteristics of a triple band antenna. The coupling of circular and elliptical ring slot is accountable for the third frequency band. The proposed antenna design has three resonant frequencies; f_1 = 2.93 GHz, f_2 = 4.88 GHz and f_3 = 7.04 GHz with return loss of 20.1 dB, 42.1 dB and 14.4 dB respectively.

In Fig. 5, variation in return loss values with respect to three different position of feed are displayed. In this graph, feed position 1, 2 and 3 means position of feed is at center, 2 mm right from center and 4 mm right from center, respectively. Small variations in resonant frequencies and return loss values are seen at first resonance with change in feed positions. At second resonance, very small change in resonant frequencies but large change in return loss values are observed. Almost no change in resonant frequencies and return loss values are noticed at third resonance.

Fig. 6 shows variation of return loss values for three different values of length of feed. For feed length $L_2 = 29$ mm, the first resonance nearly disappears and antenna structure is practically only a dual band antenna. The values of return loss at second resonance for feed length $L_2 = 25$ mm is quite lower than for feed length $L_2 = 27$ mm. Therefore, for better results, feed length $L_2 = 27$ mm is selected.

Figs. 5 and 6 are very helpful in deducing that the resonant frequencies f_1, f_2 and f_3 can be adjusted to other intended frequencies by varying position of feed and length of feed. Although, movement of position of feed from center has negligible effect on f_3 but f_1 and f_2 can be varied significantly. Also, the change in length of feed has significant effect on f_1; f_2 and f_3 can also be changed marginally.

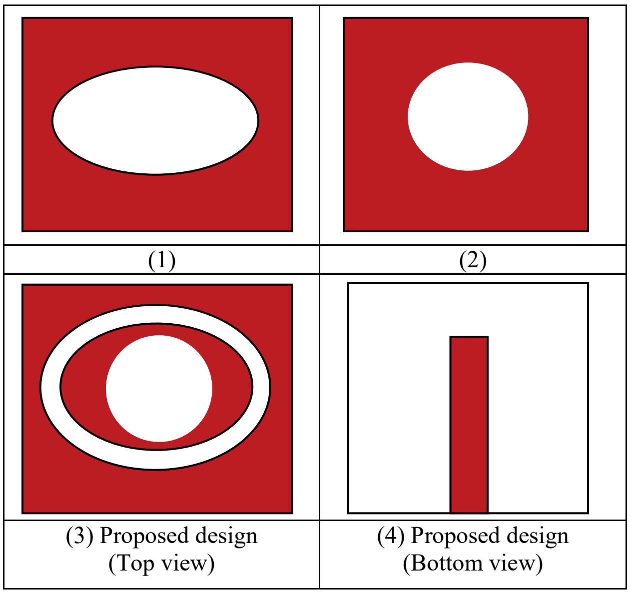

Fig. 3. Step wise step designing of proposed antenna

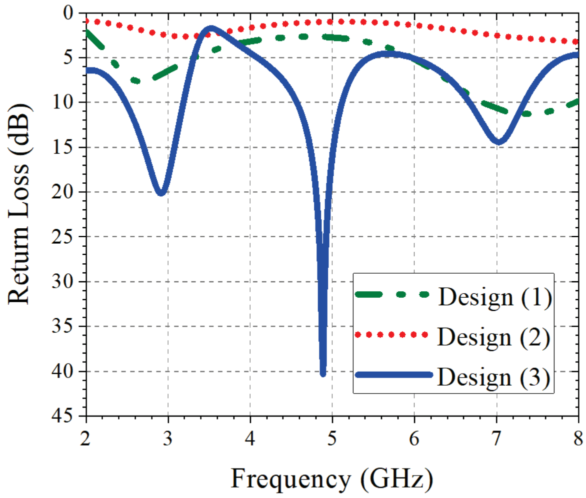

Fig. 4. Return loss versus frequency curve for different designs

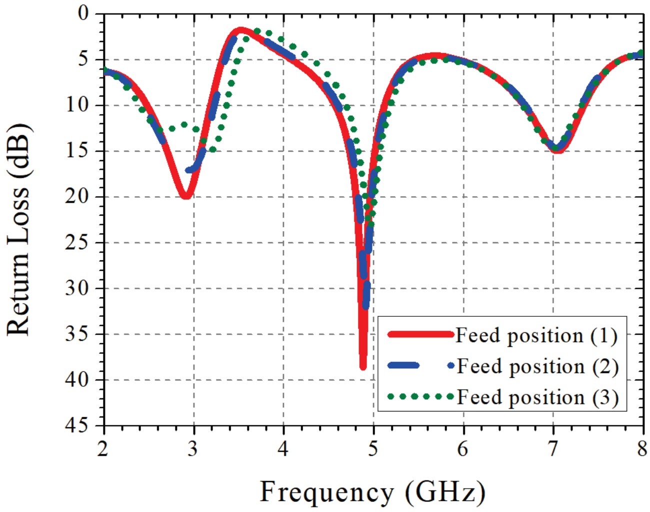

Fig. 5. Return loss with variation in position of feed

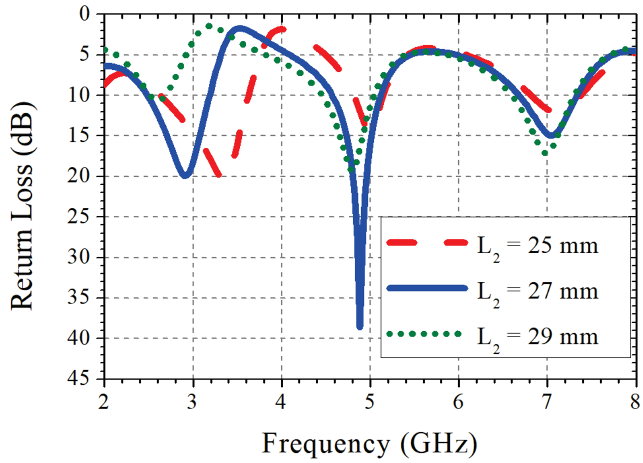

Fig. 6. Return loss with variation in length of feed (L_2)

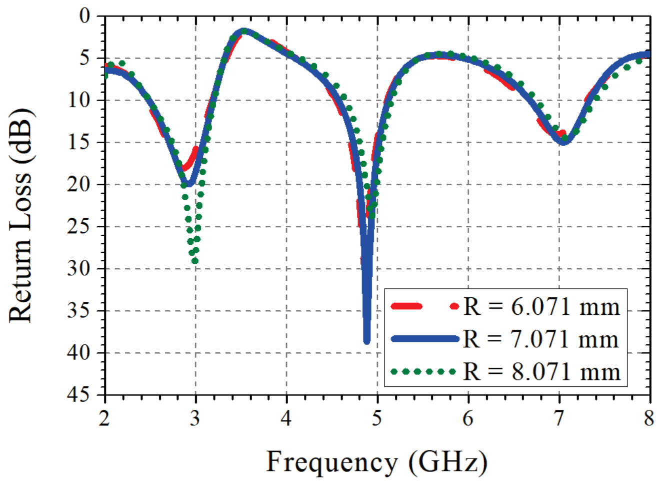

Fig. 7. Return loss with variation in radius of circle (R)

Fig. 7 shows variation of return loss for change in circle radius (R). As R increases from 7.071 mm to 8.071 mm, f_1, f_2 and f_3 shifts towards higher values marginally, the return loss increases significantly at f_1; decreases significantly at f_2 and decreases marginally at f_3. As R decreases from 7.071 mm to 6.071 mm, f_1, f_2 and f_3 shifts towards lower values marginally, the return loss decreases marginally at f_1 and f_3; but decreases significantly at f_2. Better results are obtained for R = 7.071 mm.

The idea of this work is taken from author's own previous work [12] and [13]. The basic design equations and how other antenna parameters are chosen, is briefly described in [12] and [13]. To avoid repetition they are not described in this manuscript.

IV. Results and Discussion

The simulation of proposed structure has been done using high frequency structure simulator (HFSS) software (Ansys HFSS, version 14.0) and measurements have been taken by using vector network analyzer (Agilent Technologies, Model No. E5071C). Fig. 8 displays the measured and simulated return loss variation of proposed radiator. There is good agreement between measured and simulated outcomes.

From Fig. 8, it can be observed that the proposed radiator operates over three frequency bands, i.e. 2.48-3.2 GHz, 4.58-5.12 GHz and 6.68-7.34 GHz. The impedance bandwidths of antenna in the frequency bands 2.48-3.2 GHz, 4.59-5.45 GHz and 6.88-7.34 GHz are 24.5%, 11.2% and 9.3% corresponding to central frequency f_1, f_2 and f_3 respectively.

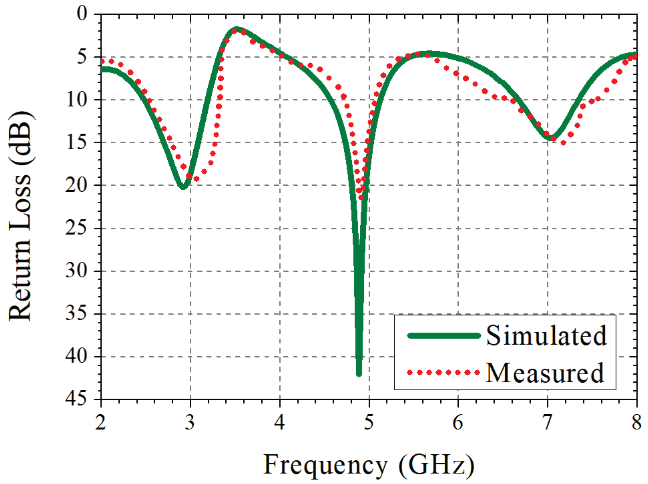

Fig. 8. Measured and simulated return loss versus frequency curve

The simulated and measured voltage standing wave ratio (VSWR) versus frequency curve of proposed antenna is shown in Fig. 9. The VSWR is in between 1 and 2 for all three frequency bands and its values are 1.22, 1.02 and 1.47 at frequencies f_1, f_2 and f_3 respectively. This indicates very good matching between the antenna and feed network.

The variation of measured input impedance (real and imaginary part) with frequency is shown in Fig. 10. The input impedance is close to 50 ohm. Its value is 49.36 – j 9.58 at 2.93 GHz, 49.24 - j 0.52 at 4.88 GHz and 52.93 + j 18.34 at 7.04 GHz.

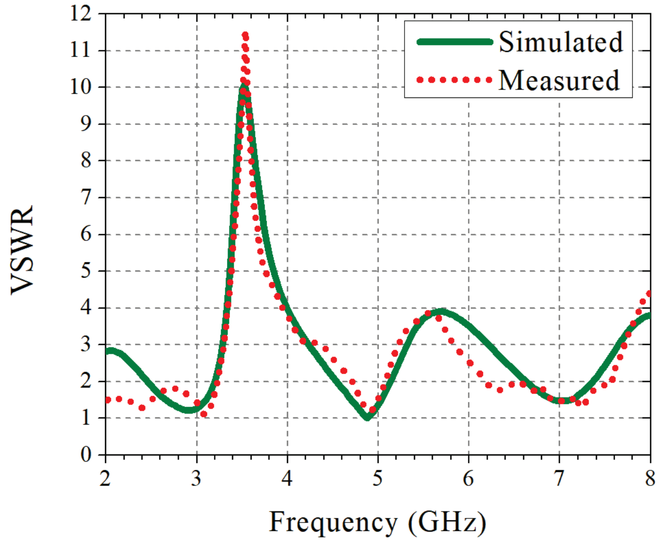

Fig. 9. Measured and simulated VSWR versus frequency curve

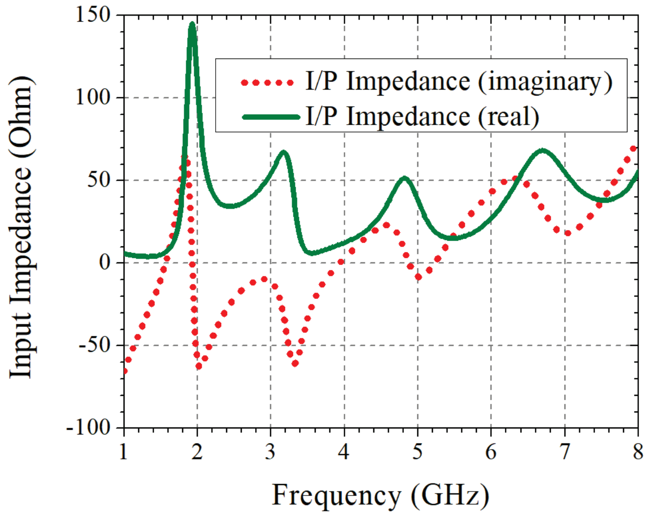

Fig. 10. Input impedance (measured) versus frequency curve

Fig. 11 displays the gain (simulated and measured) variation of proposed radiator. From Fig. 11, it can be observed that the simulated gain of proposed radiator is 1.64 dB, 3.06 dB and 0.42 dB at resonant frequencies f_1, f_2 and f_3, respectively. The gain is positive at all three resonant frequencies. Moreover, simulated and measured values of gain are almost same.

Fig. 12 shows the radiation efficiency variation. Radiation efficiency is 99%, 93% and 99 % at resonant frequencies f_1, f_2 and f_3 respectively, which indicates that antenna radiates effectively.

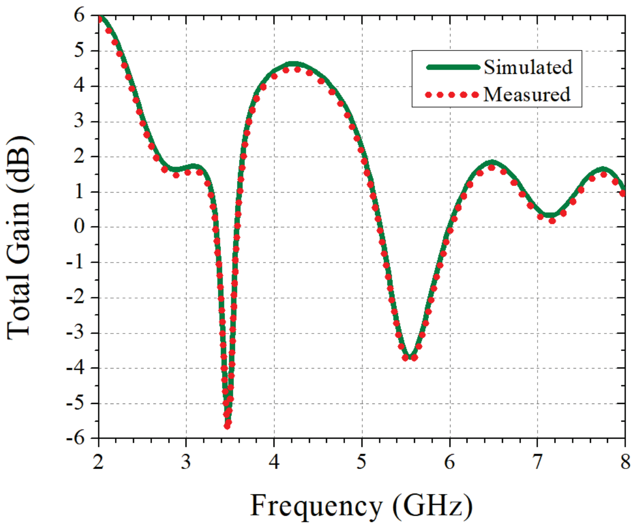

Fig. 11. Total Gain (simulated) versus frequency curve

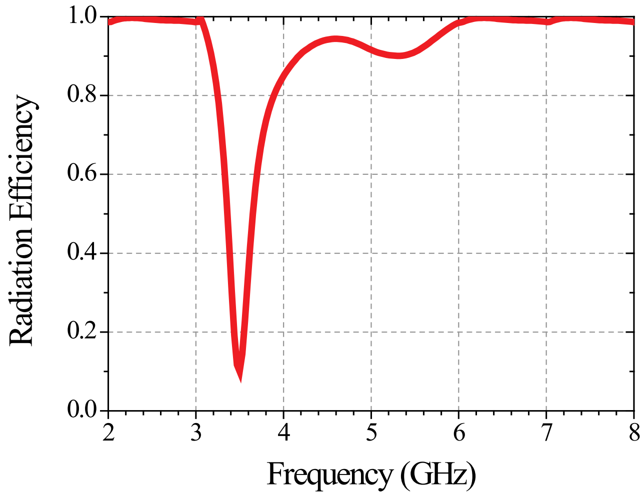

Fig. 12. Radiation efficiency (simulated) versus frequency curve

The simulated and measured co-polar and cross-polar two dimensional radiation pattern in E-plane (x-z plane) and H-plane (y-z plane) are shown in Fig. 13 at three different resonant frequencies 2.93 GHz, 4.88 GHz and 7.04 GHz. The radiation pattern is almost omnidirectional in E-plane and bidirectional (8-shaped) in H-plane, which confirms that the proposed antenna acts as a monopole antenna. These patterns also suggest that the simulated and measured patterns are almost identical in shape. In E-plane and H- plane the co-polar patterns are at least 10 dB higher than cross polar patterns.

The possible causes of the discrepancy between simulated and measured results are imperfect antenna materials, defective fabrication, contact losses, cable losses, and measurement errors.

A comparison of the performance (in terms of antenna size, operating frequency bands, bandwidth and possible applications) of the proposed antenna and other triple band antennas already published in literature are listed in Table II [13-21]. The proposed antenna is a good union of wider impedance bandwidth (in triple band) and smaller size among all other antennas.

TABLE II
COMPARISON OF TRIPLE BAND ANTENNAS

Ref. No.	L× W × h (mm×mm×mm)	Frequency Bands (GHz)	BW (%)	Applications
[13]	40 × 40 × 1.6	3.44-3.95 5.24-5.45 6.59-7.01	13.5 3.9 6.2	WLAN WiMAX Earth exploration satellite service
[14]	35×30×1.6	2.4-3.0 3.25-3.68 4.9-6.2	22.2 12.3 23.2	WLAN WiMAX
[15]	53×54×1.6	1.39-1.48 1.75-4.2 5.04-6.0	6.2 9.8 17.5	IOT
[16]	100×65×10	0.92-0.96 1.9-2.2 3.4-3.8	4.2 4.3 11.1	LTE Comm.
[17]	30×41×1.6	1.7-1.88 3.4-3.69 5.25-5.85	11 28 13	DCS1800 WiMAX
[18]	28×33×1.6	2.29-2.67 3.16-4.68 5.16-6.19	15.3 38.8 18.1	WLAN WiMAX
[19]	45×28×1.6	2.16-2.75 3.51-3.8 5.0-6.5	26.9 8.3 9.2	WLAN WiMAX
[20]	29.5×30.6×1.6	2.3-2.7 3.28-3.88 5.03-6.09	16 17.1 6	WLAN WiMAX
[21]	39×39×1	2.35-2.52 2.91-3.72 5.12-5.34	7.1 23.1 4.2	WLAN WiMAX
Pro. Ant.	40 × 40 × 1.6	2.48-3.2 4.58-5.12 6.68-7.34	25 11 9	S Band C Band

V. CONCLUSION

In this article, design and analysis of a modified ring shaped slot printed antenna has been described. This antenna structure supports three different frequency bands, with the assistance of a circular slot and an elliptical ring slot. This simple antenna structure operates over three frequency ranges, i.e. 2.48-3.2 GHz, 4.58-5.12 GHz and 6.68-7.34 GHz. The remarkable feature of the antenna is that it utilizes only a simple rectangular metal strip to achieve impedance matching for the slots loaded patch without any external matching circuitry. Far-field pattern of proposed radiator confirms that it acts like a monopole radiator. Radiation efficiency is greater than 90% at all three resonant frequencies. All these features make it suitable for various applications in S (2-4 GHz) and C (4-8 GHz) frequency bands.

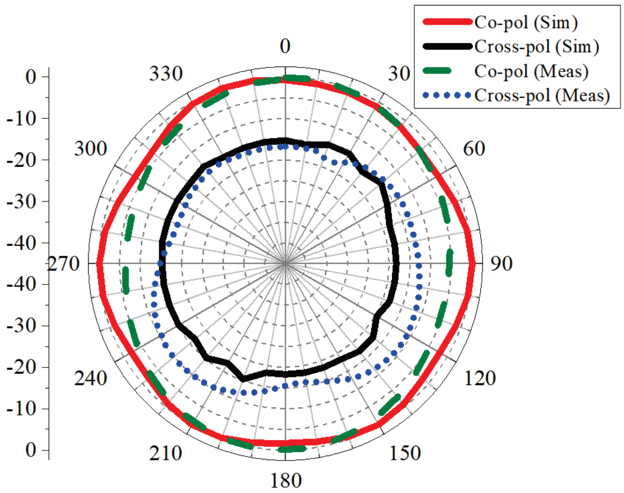

Fig. 13. (a) E-plane radiation pattern at 2.93 GHz

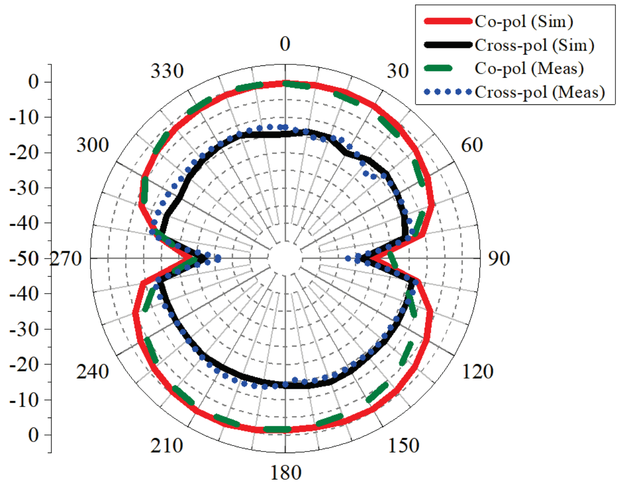

Fig. 13. (b) H-plane radiation pattern at 2.93 GHz

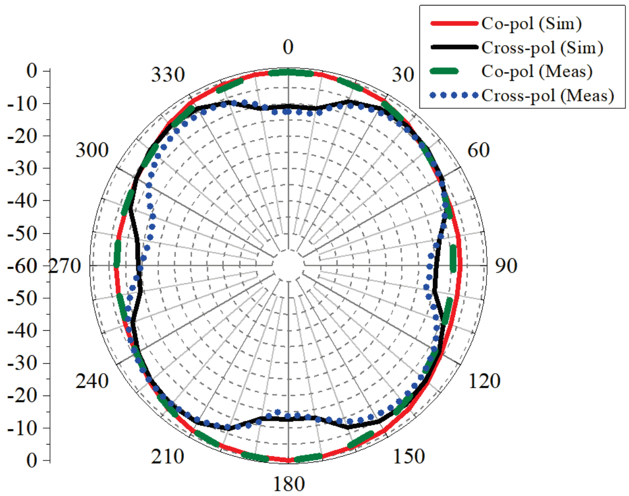

Fig. 13. (c) E-plane radiation pattern at 4.88 GHz

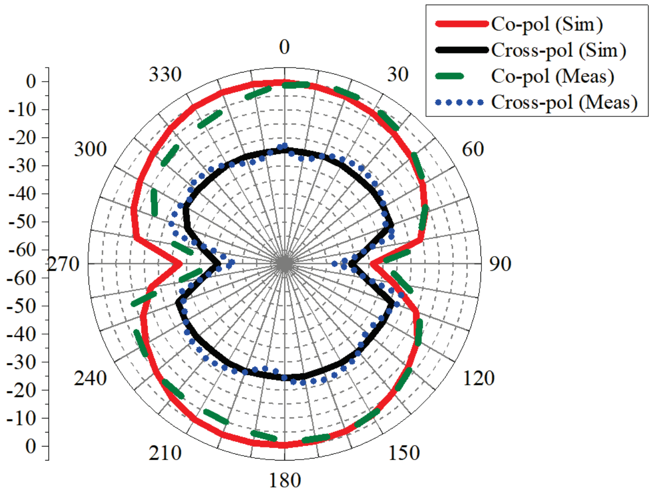

Fig. 13. (d) H-plane radiation pattern at 4.88 GHz

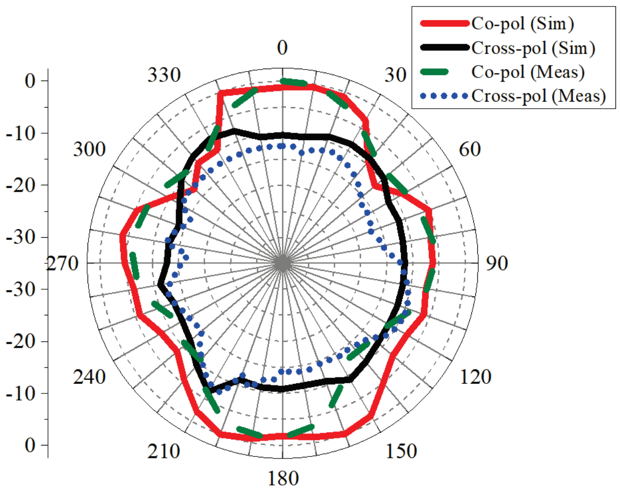

Fig. 13. (e) E-plane radiation pattern at 7.04 GHz

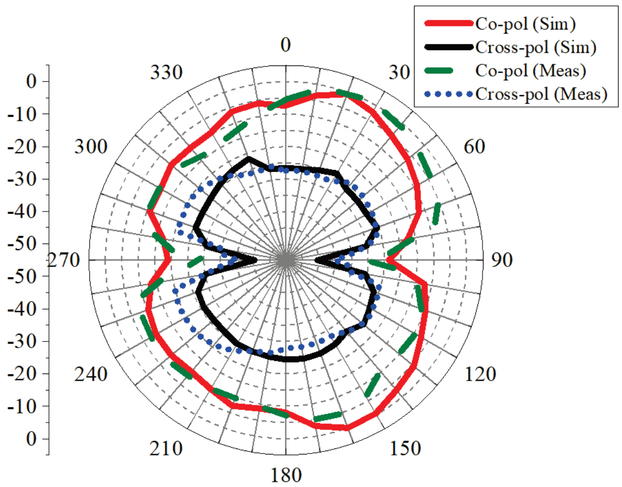

Fig. 13. (f) H-plane radiation pattern at 7.04 GHz

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