# Triple-Band Tilted Square Ring shaped Aperture Antenna for Wireless Applications

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*Abstract* - **In this article, design and investigation of tilted square ring shaped aperture antenna is presented. The proposed aperture is fed with a simple microstrip line. Asymmetrical feed position along with square ring shaped aperture helps to achieve multiband characteristics. Fire redundant epoxy substrate (FR-4) is utilized to fabricate the proposed radiator. The complete analysis of proposed radiator has been done on HFSS EM simulator. For verifying the simulated outcomes, a prototype of proposed radiator is fabricated and tested. Experimental outcomes confirm that the proposed antenna supports three different wireless frequency bands i.e. 3.44-3.95 GHz, 5.24-5.45 GHz and 6.59-7.01 GHz with the resonant frequencies of 3.77 GHz, 5.33 GHz and 6.80 GHz, respectively. Stable far-field characteristics confirm that the proposed radiator is quite suitable for WiMAX (3.5 GHz), WLAN (5.3 GHz) and earth exploration satellite service (6.7 GHz) applications.**

*Keywords* – **Aperture antenna, Triple band, WiMAX, WLAN.**

## I. INTRODUCTION

From the last few years, printed antennas are widely used in the fields of commercial, satellite as well as military communication systems because of their several favorable features such as light weight, low cost, conformal to planar and non-planar surfaces [1]. Except all these features, these radiators have also supported multiband characteristics which make the single antenna suitable for multiple frequency bands simultaneously [2]. In literature, mainly three types of printed radiators are described: (i) microstrip antennas; (ii) monopole antennas and (iii) slot/aperture antennas. Conventional microstrip antenna is widely used, but it has narrow impedance bandwidth and it does not support omnidirectional pattern in both planes. For overcoming these drawbacks, monopole antenna comes into the existence. The use of partial ground plane reduces its gain feature. Slot antenna provides omnidirectional pattern in one of its principle plane without affecting the gain characteristics [3]. In open literature, different researchers have developed multiband features in slot based aperture antennas. Multiband radiators provide better signal to interference ratio in the operating frequency bands, which is advantageous over the wideband radiators.

The bandwidth and size are major issues for the designing of microstrip antennas. To get multi band characteristics, different shapes of slots have been utilized such as X- shaped slot [4], a simple circle shaped slot [5], a square shaped slot [6], and a circular aperture with an offset [7]. In dual-frequency antenna design using a rectangular microstrip antenna, the two operating frequencies are the resonant frequencies of the $TM_{01}$ and $TM_{10}$ modes of the rectangular microstrip patch. In the year 1998, W. S. Chen [6] presented a modified structure for a dual-frequency design. In this design, a square slot is cut in the centre of the rectangular patch. It causes to lengthen the excited surface current paths of the $TM_{01}$ and $TM_{10}$ modes which in other words lower both the resonant frequencies of the rectangular microstrip antenna. With the lowering of the two operating frequencies, the required antenna size for fixed dual-frequency operation can be reduced. Thus the design of dual-frequency microstrip antenna with reduced-size can be achieved.

In the year 2011, circular microstrip slot antenna for dual-frequency RFID application was proposed. By employing an offset microstrip-fed line and a strip close to the radiating edges, dual band properties were obtained but it has large antenna size [8]. Helix shaped aperture antenna was proposed in the past. It supports dual-band wireless applications but suffers from large antenna size [9]. A dual band aperture antenna has also been presented. Authors have used spurline for achieving the dual band, which makes its design more complex [10]. Kandasamy with his research group proposed a circularly polarized simple aperture antenna for multiband applications. This antenna overcomes all the above mentioned drawbacks but it suffers from large antenna size [11]. Dual rectangular aperture with an offset between them has also been presented for multiband wireless applications [12]. Various other antennas are also reported in literature to get triple band characteristics in one structure [13-21].

This article explains the design and analysis of a tilted square ring shaped aperture antenna for triple band wireless applications. Asymmetrical feed position helps to achieve the same characteristics. From review of literature it is observed that etching slot on patch causes an antenna to radiate significantly at different range of frequencies even with a single feed point. This concept is utilized in the design of proposed antenna. The proposed radiator supports three frequency bands i.e. 3.44-3.95 GHz, 5.24-5.45 GHz and 6.59-7.01 GHz with the resonant frequencies of 3.77 GHz, 5.33 GHz and 6.80 GHz, respectively. Present article is divided into five different sections: (i) introduction; (ii) antenna geometry; (iii) antenna analysis; (iv) results and discussion; and (v) conclusion.

## II. ANTENNA GEOMETRY

Fig. 1 displays the geometrical layout of the proposed antenna structure. The given antenna structure is fabricated on FR-4 substrate having thickness h = 1.6 mm, relative

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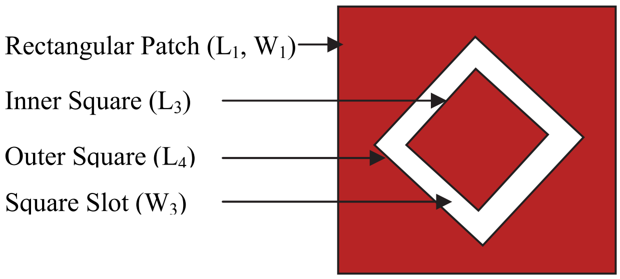
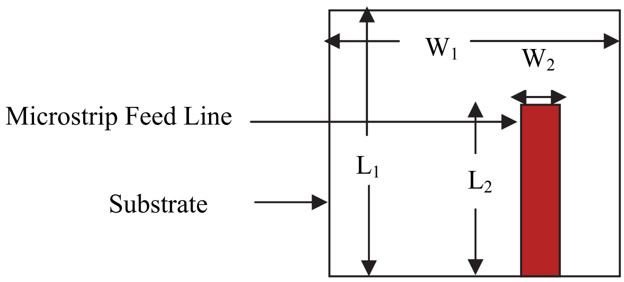
permittivity $\varepsilon_r = 4.4$ and loss tangent tan $\delta$ = 0.0148. On one side of the substrate, first a patch of dimension $L_1 \times W_1$ is printed and then a tilted square ring shaped slot is etched. One side arm of outer square is $L_4$ while that of Inner Square is $L_3$. Width of square ring slot is $W_3$. On the other side of the substrate a microstrip line of dimension $L_2 \times W_2$ is printed to feed the antenna. Fig. 2 shows the top and bottom view of the fabricated antenna structure.

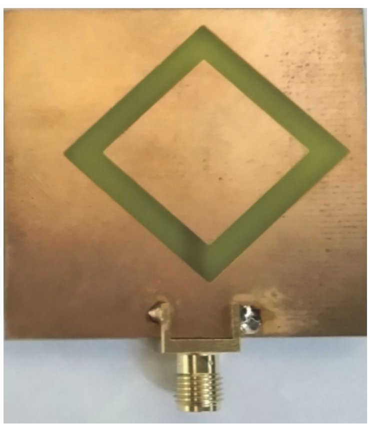



(a)

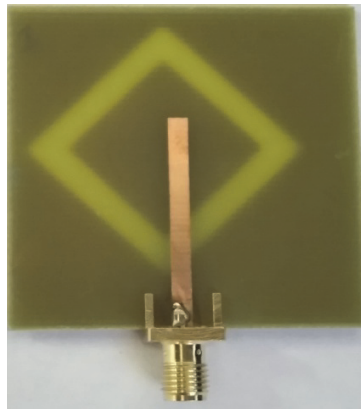



(b)

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



(a)



(b)

Fig. 2. Fabricated antenna: (a) Top view (b) Bottom view.

## III. Antenna Analysis

The parametric study is performed in order to get optimize location and dimension of feed element as well as that of tilted square ring slot. At a time only one parameter is varied and effect of that variation on return loss is observed. Valuable inferences are drawn from parametric study which is very useful in the designing of proposed antenna. Table I shows the optimized parameters of the proposed antenna. The step by step designing of the proposed antenna is shown in Fig. 3. The return loss analysis of different design stages (given in Fig. 3) is shown in Fig. 4. The observations obtained from Fig. 4 are described as follow: when a tilted square slot of dimension 25.2 mm × 25.2 mm is etched (design 1), the antenna behaves as a wide band antenna. This is due to the fact that a combination of slot of wider width (having multiple modes nearby) and appropriate feeding method create wideband characteristics in the structure. This antenna has a resonant frequency of 7.82 GHz with return loss of 22.8 dB. When a tilted square ring slot is etched in patch (design 2), the antenna behaves as a triple band antenna. This proposed antenna has three resonant frequencies $f_1$ = 3.77 GHz, $f_2$ = 5.33 GHz and $f_3$ = 6.80 GHz with return loss of 23.3 dB, 23.5 dB and 32.1 dB respectively. This is possible by splitting the fundamental resonant mode of an unslotted microstrip antenna into three separate resonant modes, and the structure exhibits characteristics of a triple band antenna.

TABLE I
OPTIMIZED PARAMETERS OF PROPOSED ANTENNA

| **Parameters** | **Unit** |
|---|---|
| Length of substrate / patch ($L_1$) | 40 mm |
| Width of substrate / patch ($W_1$) | 40 mm |
| Length of microstrip line ($L_2$) | 29 mm |
| Width of microstrip line ($W_2$) | 2.5 mm |
| One side arm of outer square ($L_4$) | 25.2 mm |
| One side arm of inner square ($L_3$) | 18.2 mm |
| Width of square slot ($W_3$) | 3.5 mm |

The detailed discussion of results for the proposed antenna design is described in the next section (results and discussion). The effect of change in position of feed, length of feed and position of Inner Square on the performance of proposed structure are discussed in the following paragraphs.

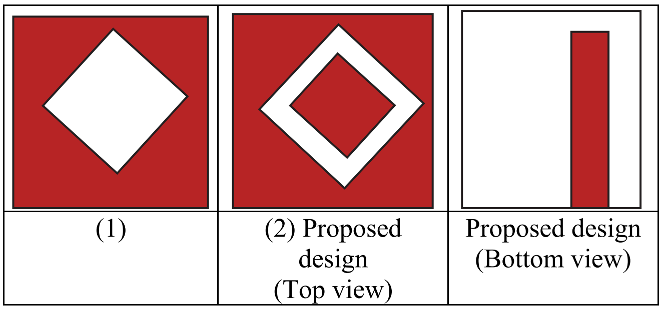



Fig. 3. Step wise step design of proposed antenna.

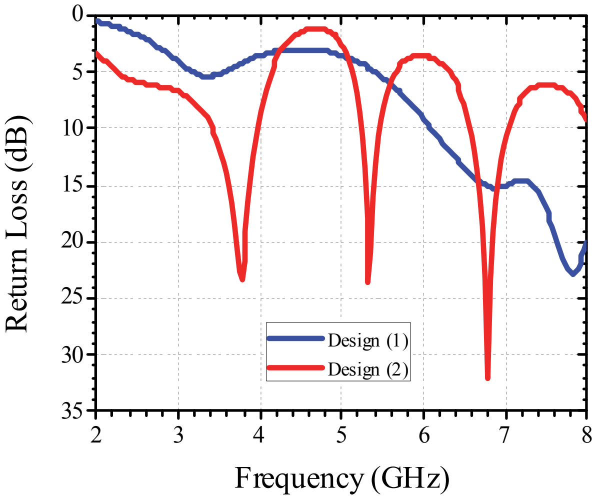



Fig. 4. Return loss versus frequency curve for different designs.

The variation of return loss for movement of position of feed from center towards right is shown in Fig. 5. Feed position is the position of microstrip line feed from center. Thus, feed position 1, 2 and 3 means position of feed is 2 mm right from center, 4 mm right from center and 6 mm right from center, respectively. With movement of feed position from 1 to 3; $f_1$ and $f_3$ shifts towards higher side slightly, second frequency band (5.24-5.45 GHz) disappears, and structure exhibits characteristics of a dual band antenna. It is clearly observed from Figure 5 that only feed position 1 provides triple band characteristics.

Fig. 6 shows variation of return loss for different values of length of feed ($L_2$). As $L_2$ decreases from 31 mm to 27 mm, $f_1$, $f_2$ and $f_3$ shifts towards higher side slightly. For $L_2$ = 27 mm, second frequency band (5.24-5.45 GHz) disappears, and structure exhibits characteristics of a dual band antenna. For $L_2$ = 31 mm, first frequency band (3.44-3.95 GHz) almost disappears practically, and structure exhibits characteristics of a dual band antenna. Therefore, better results are obtained for $L_2$ = 29 mm.

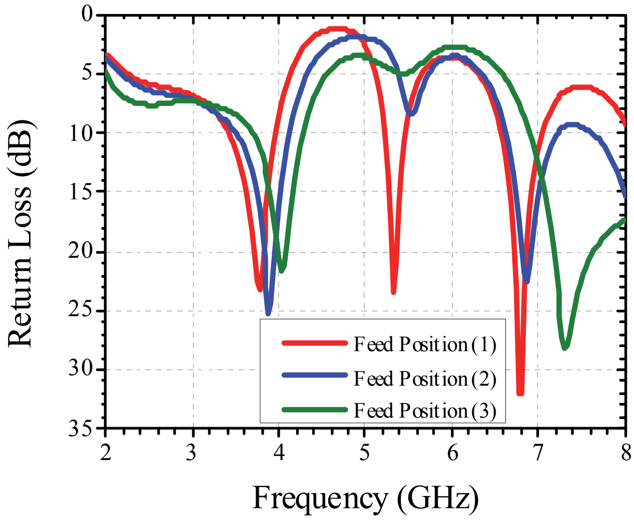



Fig. 5. Return loss with variation in position of feed.

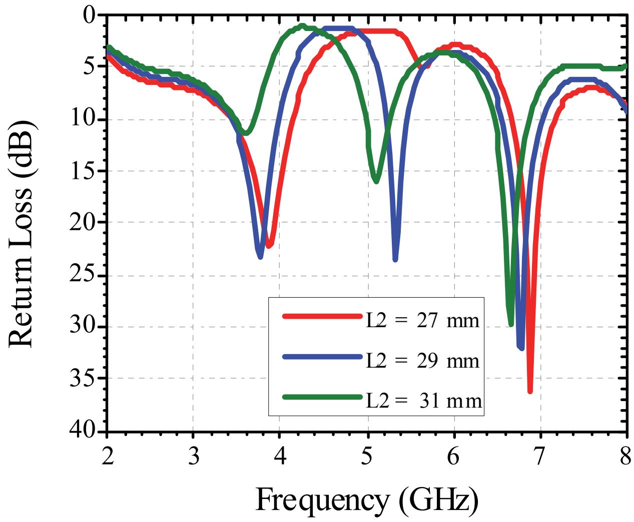



Fig. 6. Return loss with variation in length of feed ($L_2$).

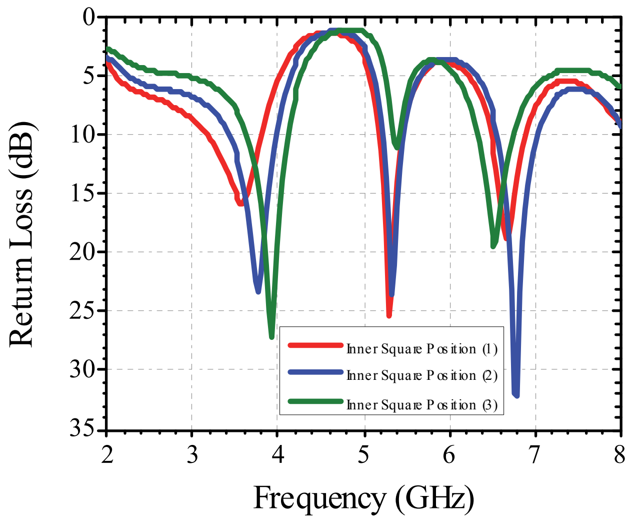



Fig. 7. Return loss with variation in the position of inner-square.

Fig. 7 shows variation of return loss with movement of the position of Inner Square which is inclined at 45 degree. Inner square position is the position of Inner Square from center. Thus inner square position 1, 2 and 3 means position of inner square is at center- 2 mm left, center and center + 2 mm right, respectively. From changing position 1 to 3; $f_1$ shifts towards higher side slightly, $f_2$ has negligible effect, $f_3$ first shifts towards higher side slightly (1 to 2) and then shifts towards lower side slightly (2 to 3). For inner square position 3, second frequency band (5.24-5.45 GHz) almost disappears practically, and structure is a dual band antenna. Therefore, in terms of return loss, better results are obtained for inner square position 2.

## IV. Results and Discussion

In this section, simulation based outcomes are verified with the assistance of experimental results. Various parameters are measured by using Vector Network Analyzer (Agilent Technologies, Model No. E5071C). The return loss versus frequency curve of the proposed antenna is shown in Fig. 8. Simulated and measured values of return loss are in close agreement for entire frequency range 2-8 GHz. The proposed antenna has three resonant frequencies $f_1$ = 3.77 GHz, $f_2$ = 5.33 GHz and $f_3$ = 6.80 GHz with return loss of 23.3 dB, 23.5 dB and 32.1 dB respectively. The impedance bandwidths of antenna in the frequency bands 3.44-3.95 GHz, 5.24-5.45 GHz and 6.59-7.01 GHz are 13.5 %, 3.9% and 6.2% corresponding to central frequency $f_1$, $f_2$ & $f_3$ respectively. The return loss is greater than 23 dB at all three resonant frequencies. The impedance bandwidth is calculated using the following equation [1]:

$$BW(\%) = \frac{f_H - f_L}{f_c} \times 100, \quad (1)$$

where BW (%) is impedance bandwidth in percentage, $f_H$ and $f_L$ are the upper and lower cut-off frequencies, and $f_c$ is the central frequency of the corresponding band. At $f_H$ and $f_L$, value of return loss is 10 dB; and at $f_c$ its value is maximum in that particular frequency band.

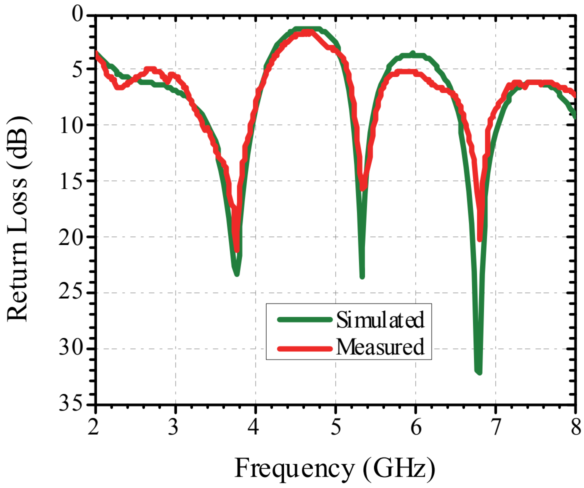



Fig. 8. Return loss versus frequency curve.

Fig. 9 shows gain (simulated and measured) versus frequency curve of proposed antenna in its operating band. The simulated gain is 3.13 dB, 0.26 dB and 4.65 dB at $f_1$, $f_2$ and $f_3$ respectively while the measured gain is 2.88 dB, 0.23 dB and 4.41 dB at $f_1$, $f_2$ and $f_3$ respectively. The gain is positive at all three resonant frequencies; also simulated and measured values of gain are very close to each other at frequencies $f_1$, $f_2$ and $f_{3,}$ respectively. The gain is experimentally measured by two antenna method using the following equation [1]:

$$(G)dB = 10\, log_{10}\left[\frac{P_r}{P_t}\right] - (G_t)dB - 20\, log_{10}\left[\frac{\lambda_0}{4\,\pi\, R}\right], \quad (2)$$

where $P_t$ is the power transmitted by reference antenna (pyramidal horn antenna); $P_r$ is the power received by proposed antenna (antenna under test); $G_t$ is the gain of the reference antenna; R is the distance between transmitting and receiving antennas; and $\lambda_o$ is corresponding wavelength.

Fig. 10 shows simulated and measured VSWR variation over the operating frequency bands. The VSWR is in between 1 and 2 for all three operating frequency bands 3.44-3.95 GHz, 5.24-5.45 GHz and 6.59-7.01 GHz and its value is 1.15, 1.14 and 1.05 at frequencies $f_1$, $f_2$ and $f_3$ respectively. This indicates very good matching between the antenna and feed network.

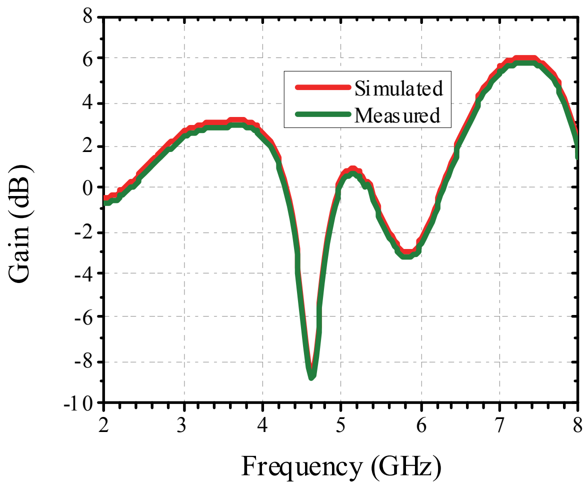



Fig. 9. Gain versus frequency curve.

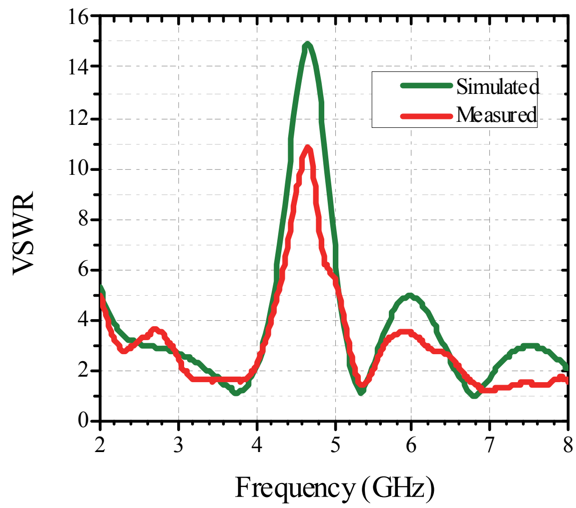



Fig. 10. VSWR versus frequency curve.

Fig. 11 displays simulated radiation efficiency over the entire operating frequency range. Radiation efficiency is 94% and 76% and 93 % at resonant frequencies $f_1$, $f_2$ and $f_3$ respectively. The large values (>75%) of radiation efficiency indicate that antenna is able to radiate effectively. The variation of measured input impedance (real and imaginary part) with frequency is shown in Fig. 12. The desirable value of input impedance is 50 ohm at resonant frequencies $f_1$, $f_2$ and $f_3$. The input impedance of proposed antenna is close to 50 ohm. Its value is 43.96 – j 2.14 ohm, 50.73 + j 6.00 ohm and 47.73 + j 3.20 ohm at 3.77 GHz, 5.33 GHz and 6.8 GHz, at $f_1$, $f_2$ and $f_3$, respectively.

The simulated and measured, co-polar & cross-polar radiation pattern in E-plane (x-z plane) & H-plane (y-z plane) are shown in Fig. 13(a)-(b), 13(c)-(d), 13(e)-(f) at resonant frequencies $f_1$, $f_2$ and $f_3$ respectively. At frequency $f_1$, in E-plane, the co-polar radiation pattern is omnidirectional while the crosspolar radiation pattern is nearly omnidirectional with two nulls at ± $90^0$; in H-plane, crosspolar radiation pattern is omnidirectional while the co-polar radiation pattern is nearly omnidirectional with two nulls at ± $90^0$. At frequency $f_2$; in E-plane, the copolar and crosspolar radiation pattern are nearly omnidirectional; in H-plane crosspolar radiation pattern is omnidirectional while the co-polar radiation pattern is nearly omnidirectional with two nulls at ± $90^0$. At frequency $f_3$, in E-plane, the co-polar radiation pattern is nearly omnidirectional and cross-polar radiation pattern is omnidirectional with three nulls at $10^0$, $90^0$ and $170^0$ respectively while in H plane copolar and cross-polar radiation pattern is nearly omnidirectional. These patterns suggest that the simulated and measured patterns are almost identical in shape; and are nearly omnidirectional (except nulls in some cases).

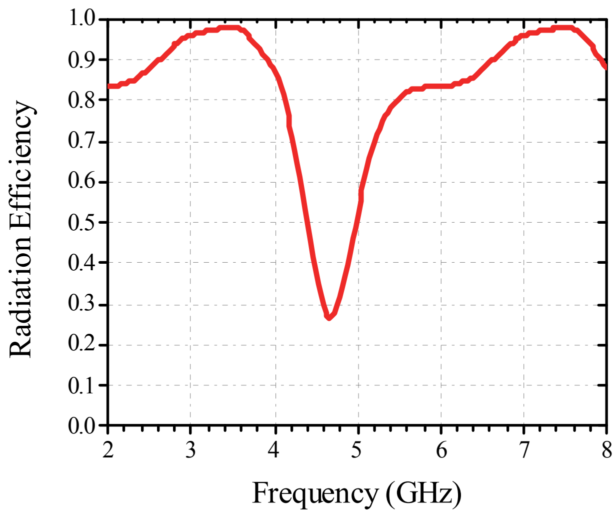



Fig. 11. Radiation efficiency versus frequency curve.

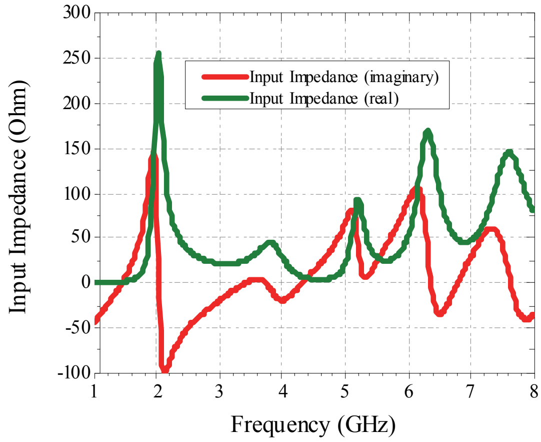



Fig. 12. Input impedance versus frequency curve.

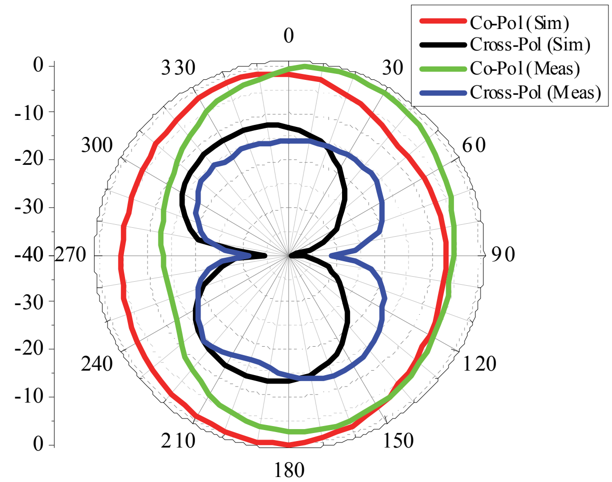



Fig. 13. (a) E-plane radiation pattern at 3.77 GHz.

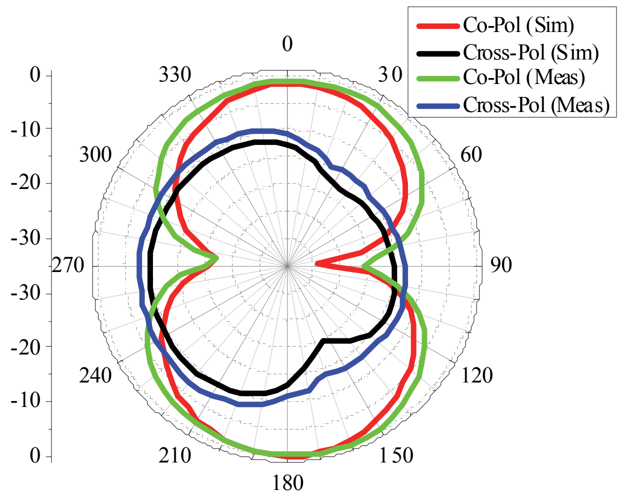



Fig. 13. (b) H-plane radiation pattern at 3.77 GHz.

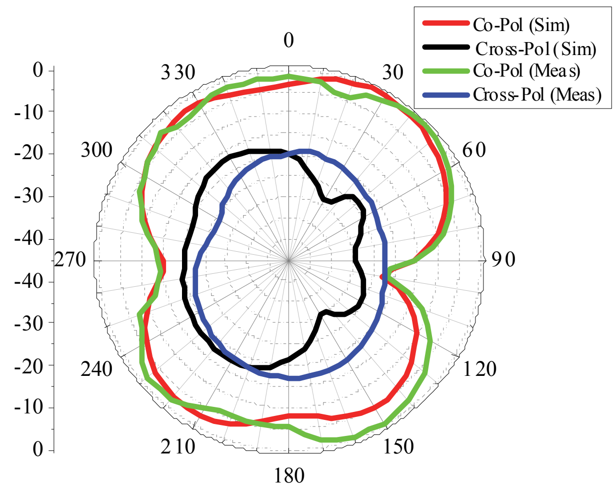



Fig. 13. (c) E-plane radiation pattern at 5.33 GHz.

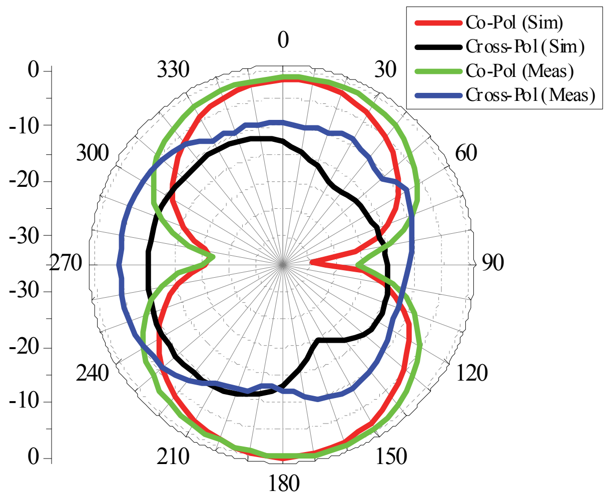



Fig. 13. (d) H-plane radiation pattern at 5.33 GHz.

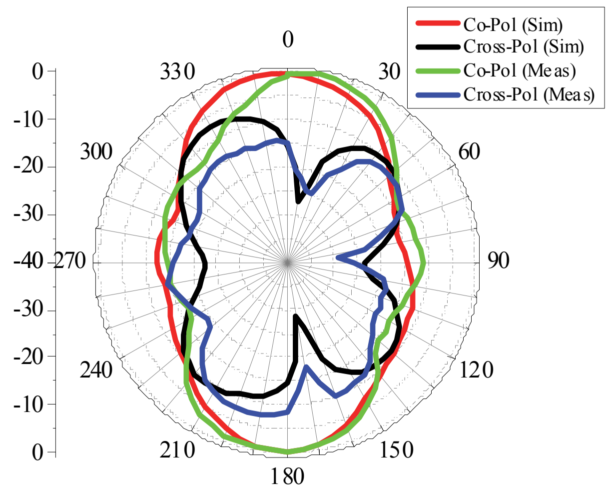



Fig. 13. (e) E-plane radiation pattern at 6.80 GHz.

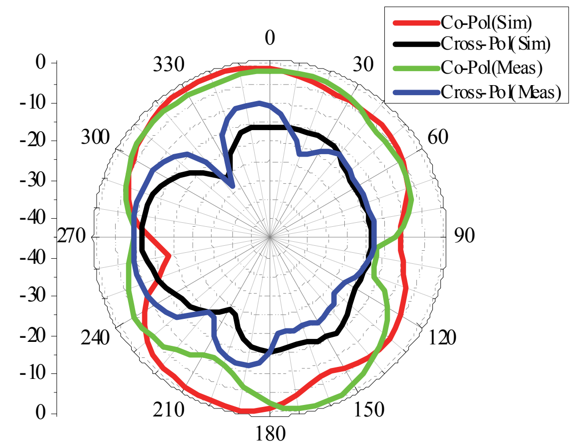



Fig. 13. (f) H-plane radiation pattern at 6.80 GHz.

TABLE II
COMPARISON BETWEEN THE PROPOSED ANTENNA AND SOME OTHER TRIPLE BAND ANTENNAS

| Ref. No. | L× W × h (mm) | $\varepsilon_r$ | Freq. Band (GHz) | BW (%) |
|---|---|---|---|---|
| [13] | 35×30×1.6 | 4.4 | 2.4-3.0, 3.25-3.68, 4.9-6.2 | 22.2, 12.3, 23.2 |
| [14] | 34×18×1.6 | 4.4 | 2.41-2.71, 3.31-3.79, 5.13-5.91 | 12, 13.7, 14.2 |
| [15] | 53×54×1.6 | 4.3 | 1.39-1.48, 1.75-4.2, 5.04-6.0 | 6.2, 9.8, 17.5 |
| [16] | 100×65×10 | 1.0006 | 0.92-0.96, 1.9-2.2, 3.4-3.8 | 4.2, 14.3, 11.1 |
| [17] | 30×41×1.6 | 4.4 | 1.7-1.88, 3.4-3.69, 5.25-5.85 | 11, 28, 13 |
| [18] | 28×33×1.6 | 4.6 | 2.29-2.67, 3.16-4.68, 5.16-6.19 | 15.3, 38.8, 18.1 |
| [19] | 45×28×1.6 | 4.6 | 2.16-2.75, 3.51-3.8, 5.0-6.5 | 26.9, 8.3, 39.2 |
| [20] | 29.5×30.6×1.6 | 4.4 | 2.3-2.7, 3.28-3.88, 5.03-6.09 | 16, 17.1, 6 |
| [21] | 39×39×1 | 1.9 | 2.35-2.52, 2.91-3.72, 5.12-5.34 | 7.1, 23.1, 4.2 |
| Prop. Ant. | 40 × 40 × 1.6 | 4.4 | 3.44-3.95, 5.24-5.45, 6.59-7.01 | 13.5, 3.9, 6.2 |

Table II shows a comparative study of the proposed antenna with some existing triple band antennas on the basis of antenna size (L×W×h), dielectric constant ($\varepsilon_r$), frequency bands and percentage impedance bandwidth in these frequency bands. The proposed antenna is a good combination of wider impedance bandwidth (in triple band) and smaller size among all other antennas.

The small difference in simulated and measured return loss and radiation pattern is mainly due to imperfect antenna material (dielectric and conducting), the fabrication imperfections, contact losses (soldering is done to connect SMA connector to microstrip feed), cable losses, and measurement errors.

## V. Conclusion

This article provides the detail analysis of triple band tilted square ring shaped aperture antenna. Triple frequency bands are obtained by utilizing the two important concepts: (i) asymmetrical feed position; (ii) conversion of square shaped slot into square ring shaped slot. The proposed radiator potentially works on three different frequency bands i.e. 3.44-3.95 GHz, 5.24-5.45 GHz and 6.59-7.01 GHz with the fractional bandwidth of 13.5%, 3.9% and 6.2% respectively. The proposed radiator provides monopole type radiation characteristics in all the operating frequency bands. All these features of proposed radiator make it suitable for WiMAX (3.5 GHz), WLAN (5.3 GHz) and earth exploration satellite service (6.7 GHz) applications.

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