

## Ring Slotted Circularly Polarized U-Shaped Printed Monopole Antenna for Various Wireless Applications

K.G. Jangid<sup>1</sup>, P.K.Jain<sup>2</sup>, B. R. Sharma<sup>3</sup>, V.K.Saxena<sup>2</sup>, V.S.Kulhar<sup>1</sup>, D. Bhatnagar<sup>2</sup>

<sup>1</sup>Department of Physics, Manipal University, Jaipur, India-303007

<sup>2</sup>Microwave Lab, Department of Physics, Jaipur, India-302004

<sup>3</sup>Department of Physics, SKITM&G, Jaipur, India-302017

\*corresponding author, E-mail: kgkris1980@rediffmail.com

### Abstract

In this communication, the design and performance of micro strip line feed U-shaped printed monopole antenna for Bluetooth/WI-MAX/WLAN communications systems is reported. The proposed monopole antenna has an eight shaped slot on the patch and an eight shaped ring structure in the ground with a metallic reflector beneath the ground plane. The CST Microwave Studio 2014 used for the simulation analysis of antennas while measurements performed by applying Vector Network Analyzer (R&S-ZVA 40). This radiating structure provides triple broad impedance bandwidths, i.e. 265MHz (in 2.280 GHz to 2.545 GHz frequency range), 116 MHz (in 2.660 GHz to 2.776 GHz frequency range) & 2.12 GHz (in 3.83 GHz to 5.956 GHz frequency range), wider 3dB axial ratio bandwidth 1.33 GHz (in 4.69GHz to 6.02GHz range), nearly flat gain (with maximum gain close to 5.56 dBi) and good radiation patterns in the desired frequency range. This antenna may be a useful structure for 2.45GHz Bluetooth communication band as well as in WLAN & WI-MAX communications bands.

### 1. Introduction

The rapid advancements in the wireless communication systems, especially in the field of high data transfer, have awakened more interest of the scientific community towards the performance enrichment of the wireless antennas. These antennas must perform well for application in communication systems, including WLAN applications specifically 802.11b and 802.11g for 2.4 GHz communication systems, 802.11a standard for the 5 GHz communication system, high-speed 802.11n for operation in both 2.4 GHz and 5.0 GHz bands as well as in WI-MAX applications [1-2]. Circularly polarized planar monopole patch antennas are found suitable for these bands due to their flexibility in orientation, easy feeding, low profile structure and low fabrication cost of mass production [3]. Looking these advantages, extensive efforts have been made by researchers to improve the inherent limitations of planar antennas [4-17]. These include design of fork like monopole with a wide slot ground [4], wideband E-shaped micro strip patch antenna for 5-6 GHz wireless

communications systems [5], miniaturized U-slot patch antenna with enhanced bandwidth [6], Wideband omni directional monopole antenna [7], flared monopole antenna with a V-shaped sleeve [8], L-shaped printed monopole antenna with wide impedance bandwidth [9] etc. A trapezoid conductor backed plane applied to get a dual band antenna incubating WLAN and WI-MAX in [10]. A triple-band monopole patch covering the WLAN & WI-MAX communication systems obtained by using electric-LC (ELC) and EBG structures [11]. A new design of coaxial probe feed dual layer circular patch antenna presented in [12]. With the substantial bonding between two patches, a wide bandwidth approx. 25% obtained. Most of these references have larger patch size, but the compactness of structure is the main requirement in modern wireless communication systems. A very compact asymmetric coplanar strip fed monopole structure for dual frequency bands presented in [13]. Another compact design presented in [14] which has L-shaped radiating element, a modified inverted-F-shaped stub and a C-shaped parasitic radiating element for WLAN and WI-MAX application. Triple bands obtained by applying a pair of inverted-L slots etched on the ground plane and a split-ring resonator (SRR) in [15]. A tapered printed structure attached to U-slot reported in [16] to achieve WLAN dual frequency bands. In [17], a directional dual band performance obtained by tuning the lengths of the inner symmetrical trapezoidal slots and the outer trapezoidal arms.

The main objectives of this communication to obtain a single structure which has compactness, high gain, multiple operation bands and circular polarization. Rectangular and circular configurations are the most common configuration. In this communication, a new U-shaped design has offered which has a compact size compared to other configurations and provides circular polarization that desires in several wireless communications. Broadband performance and circular polarization have achieved through U-shaped monopole structure with an eight shape ring slot in the patch geometry and an eight shape ring in the ground plane. The gain of the antenna has improved through application of a metallic reflector placed beneath the radiating structure. The CST Microwave Studio 2014 has used for the simulation analysis of antennas while measurement has performed by

using Vector Network Analyzer (R&S-ZVA 40) & RF signal generator.

## 2. Antenna Design and Analysis

The geometrical model of a U-shaped patch antenna having dimension  $L \times W$  is depicted in Fig. 1 (a). This antenna is designed on a glass epoxy FR-4 substrate having relative permittivity ( $\epsilon_r$ ) of 4.4, thickness of the patch ( $t$ ) 0.0035 mm, substrate height ( $h$ ) 1.59 mm and loss tangent 0.025. A microstrip line feeding structure with length  $L_f$  and width  $W_f$  is employed to feed this geometry. The optimized dimensions of the proposed antenna are provided in Table 1.

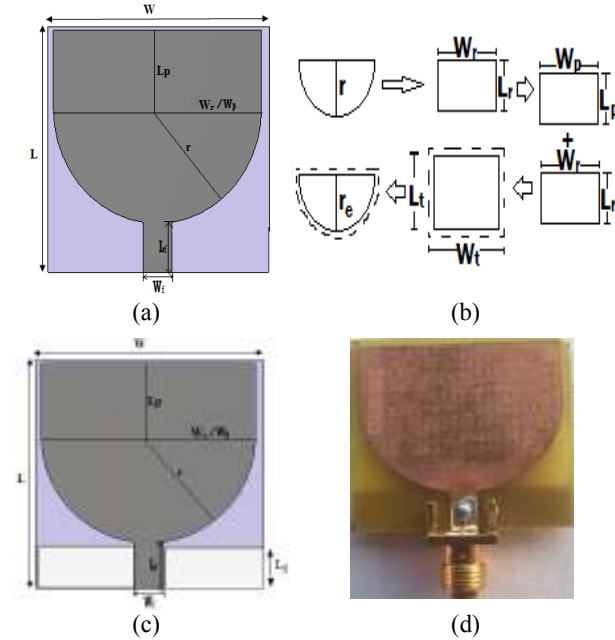


Figure 1: (a) Geometry of U-shaped planar antenna having finite ground, (b) Modeling details of patch geometry, (c) Geometry of U-shaped monopole patch antenna, (d) Prototype of U-shaped monopole patch antenna

Table 1: Optimized dimensions of proposed antenna.

Dimension of proposed antenna	Value[in mm]
Size of substrate/ground ( $L \times W$ )	30 X 30
Dimensions of feed line ( $L_f \times W_f$ )	6 X 3.8
Radius of semi-circular part of the patch ( $r$ )	14
Dimensions of rectangle part of the patch ( $L_p \times W_p$ )	9.5 X 28

The resonance frequency of this antenna is then estimated through mathematical modeling of patch geometry. The radiating patch is considered a combination of a semicircle of radius ' $r$ ' & diameter  $W_r = 2r$  and a rectangular part having dimensions  $L_p \times W_p$  where  $W_p \approx W_r$ . Following [18], the semicircular part of the considered microstrip patch (SCMSP) is then modeled by assuming it equivalent to a rectangular microstrip patch (RMSP) as shown in Fig. 1(b). The length  $L_r$  of the RMSP is equal to  $\Pi r / 4$  and width  $W_r$  of the RMSP is equal to the diameter ( $2r$ )

of the SCMSP. After converting this SCMSP into RMSP, we have added the rectangle part ( $L_p \times W_p$ ) in it. The culminating part of the radiating structure is then considered equivalent to a rectangle having dimensions  $L_t \times W_t$  where  $L_t = L_r + L_p$  and  $W_t = W_p = W_r$ . Due to fringing effect, the effective dielectric constant and the edge extensions for all four sides of the RMSP has calculated by using equation (1) & (2) [19].

$$\epsilon_{eff} = \epsilon_r - [(\epsilon_r - \epsilon_{eff}(0))/(1 + P)] \quad (1)$$

Where  $\epsilon_{eff}(0)$  is the static effective dielectric constant, and is given as

$$\epsilon_{eff}(0) = 1/2[(\epsilon_r + 1) + (\epsilon_r - 1)G]$$

$$G = \left(1 + \frac{10h}{L_t}\right)^{-AB} - \left[\frac{\ln 4}{\pi}\right](t \cdot (L_t h)^{-1/2})$$

$$A = 1 + \frac{1}{49} \ln \left\{ \frac{(L_t/h)^4 + \frac{L_t^2}{(52h)^2}}{(L_t/h)^4 + 0.432} \right\}$$

$$+ \frac{1}{18.7} \ln \{1 + (L_t/18.1h)^3\}$$

$$B = 0.564 \exp \left\{ \frac{-0.2}{\epsilon_r + 0.3} \right\}$$

$$P = P_A P_B [(0.1844 + P_c P_d) f_n]^{1.5763}$$

$$P_A = 0.27488 + \left[ 0.6315 + \left\{ \frac{0.525}{(1 + 0.0157 f_n^{20})} \right\} U \right. \\ \left. - 0.065683 \exp(-8.7513U) \right]$$

$$P_B = 0.33622 [1 - \exp(-0.03442 \epsilon_r)]$$

$$P_c = 0.0363 \exp(-4.6U) \left[ 1 - \exp \left\{ - \left( \frac{f_n}{38.7} \right)^{4.97} \right\} \right]$$

$$P_D = 1 + 2.751 \left[ 1 - \exp \left\{ - \left( \frac{\epsilon_r}{15.916} \right)^8 \right\} \right]$$

$$f_n = 47.713kh, \text{ where } k = \frac{2\pi}{\lambda}$$

$$U = \frac{2[L_t + (dL_t - L_t)/\epsilon_r]}{h}$$

$$dL_t = L_t + \frac{t}{\pi} \left[ 1 + \ln \left\{ \frac{4}{\sqrt{\frac{t}{h}} + \left( \frac{L_t}{t} + 1 \right)^2} \right\} \right]$$

The edge extension for the length of this combined radiating structure has dictated through equation (2)

$$\Delta L_t = h \frac{\xi_1 \xi_2 \xi_3 \xi_5}{\xi_4} \quad (2)$$

$$\text{Where } \xi_1 = 0.434907 \frac{\epsilon_{eff}(f)^{0.81+0.26} (L_t/h)^{0.80.85441+0.236}}{\epsilon_{eff}(f)^{0.81-0.189} (L_t/h)^{0.80.85441+0.87}}$$

$$\xi_2 = 1 + \frac{(L_t/h)^{0.371}}{2.358\epsilon_r + 1}$$

$$\xi_3 = 1 + \frac{0.5274 \arctan \{0.067(L_t/h)^{1.9413/\xi_2}\}}{\epsilon_{eff}(f)^{0.81}}$$

$$\xi_4 = 1 + 0.03770 \arctan \left\{ 0.067 \left( \frac{L_t}{h} \right)^{1.456} \right. \\ \left. \times [6 - 5 \exp\{0.036(1 - \epsilon_r)\}] \right\} \\ \xi_5 = 1 - 0.218 \exp \left( -7.5 \frac{L_t}{h} \right)$$

Similarly we also get the edge extension ( $\Delta W_t$ ) for the width of this radiating structure.

By using equation (1) and (2)

$$L_{\text{teff}} = L_t + \Delta L_t \quad \text{and} \quad W_{\text{teff}} = W_t + \Delta W_t$$

To find out the resonant frequency of different modes we applied a method that is used in [20]. According to effective rectangular geometry is again considered equivalent to a semi circle having effective radius  $r_e$  where

$$r_e = \sqrt{\frac{L_{\text{teff}} W_{\text{teff}}}{\pi}}, \quad (3)$$

Following [20-21], the resonance frequency of proposed geometry may be obtained as:

$$f_r = \frac{k_{nm} c}{2\pi r_e \sqrt{\epsilon_{\text{eff}}}} \quad (4)$$

Here  $k_{nm}$  is the  $m$ th zero root derivative of Bessel function of order  $n$ ;  $\epsilon_{\text{eff}}$  is the effective dielectric constant of the substrate material and  $c$  is the velocity of light.

Table 2: Different calculated parameters of U-shaped antenna

Calculated Parameter	Value
$L_{\text{teff}}$	21.34 mm
$W_{\text{teff}}$	28.82 mm
$r_e$	13.99 mm
$\epsilon_{\text{eff}}$	4.07
$k_{nm}$ (TM <sub>110</sub> & TM <sub>210</sub> )	1.84118 & 3.05424
Resonant Frequency for TM <sub>110</sub> & TM <sub>210</sub>	3.115 GHz & 5.167 GHz

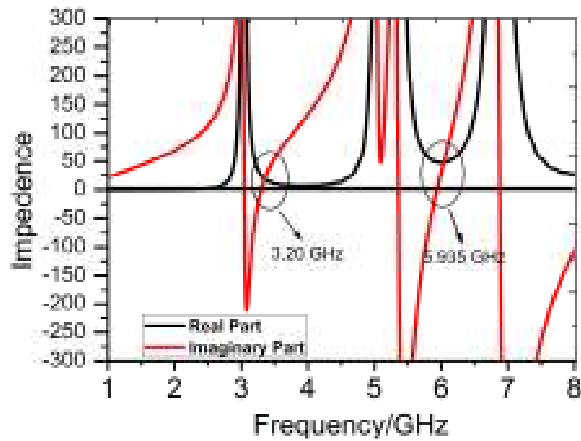


Figure 2: Variation of Impedance with frequency.

The simulation analysis carried out through CST Microwave Studio simulator 2014, reveals that the resonant frequencies of these modes (where imaginary part of input impedance is zero) are 3.20GHz and 5.935GHz respectively. The modeled and simulated resonance frequencies of antenna are in good agreement in TM<sub>110</sub> mode. A nice matching of the antenna with feed line has

realized at frequency 5.93GHz as shown in Fig. 3. The simulated impedance bandwidth of considered U-shaped antenna with the finite ground plane is nearly 2% with respect to central frequency 5.942 GHz and average gain with obtaining bandwidth is close to 1dBi. This impedance bandwidth and gain value is significantly low; hence antenna has modified in steps.

## 2.1. Wideband circularly polarized antenna

In the next step of modification, the size of considered finite ground having dimensions  $L \times W$  is reduced to ( $L_g \times W$ ) after several optimizations. The design of this antenna has shown in Fig. 1 (c) while the developed prototype has shown in Fig. 1 (d). The simulation analysis of this monopole antenna reveals that it is effectively operating at frequencies 3.53GHz and 5.25 GHz as shown in Fig. 2. The simulated impedance bandwidth of the antenna is close to 3.05GHz or 67% with respect to central frequency 4.53GHz. The presence of higher order modes in planar monopole antenna contributes to the enhancement of impedance bandwidth that is also realized in the considered geometry. The measured results of proposed geometry are in excellent agreement with simulation results as shown in Fig. 3. The measured resonance frequencies of antenna are 3.48GHz and 5.34GHz while the measured impedance bandwidth is 2.97GHz or ~66% with respect to central frequency 4.487 GHz. More alterations in the patch and ground plane are carried out to further improve the performance of the antenna. The geometry of this circularly polarized wideband antenna is next modified in two steps. In the first step, a horizontal eight shaped ring slot in patch geometry having outer & inner radius  $R_1$  and  $R_2$  respectively with slot thickness  $W_1$  is introduced. Thereafter, retaining this ring slot on patch geometry, a horizontal eight shaped ring having outer & inner radius  $R_3$  and  $R_4$  respectively with slot thickness  $W_2$  also introduced in ground plane. The front and back views of modified geometrical models of the proposed monopole patch antenna are presented in Figs. 4 (a) and 4 (b) while these views of developed prototype are shown in Figs. 4 (c) & 4 (d) respectively. The design details are given in Table 3.

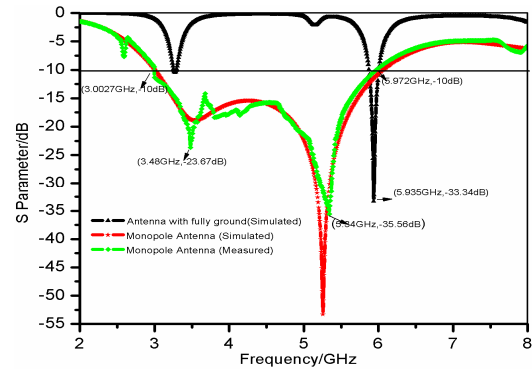


Figure 3: Measured/Simulated reflection coefficient of antenna with frequency in different cases.

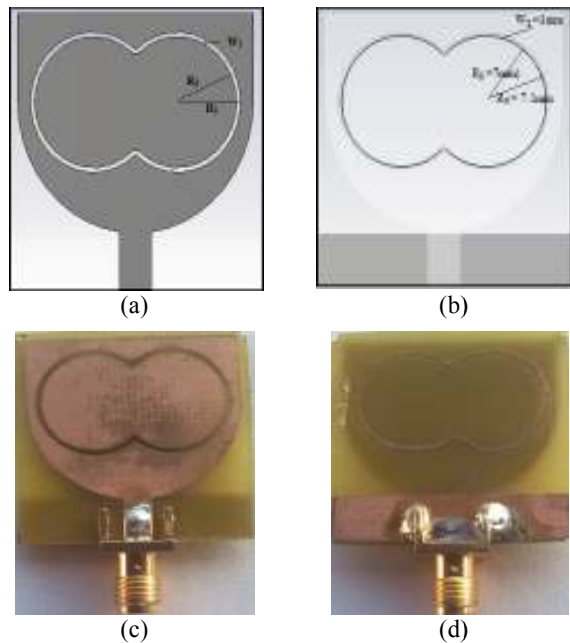


Figure 4: Geometrical model and prototype of modified monopole patch antenna of U shaped planar antenna.

Table 3: Optimized dimensions of proposed antenna.

Geometrical parameters	Value(in mm)
Inner radius of slot ( $R_2$ )	7 mm
outer radius of slot ( $R_1$ )	7.5 mm
Thickness of introduced slot $W_1$	0.5 mm
Inner radius of ring( $R_3$ )	7.0 mm
outer radius of ring ( $R_4$ )	7.1 mm
Thickness of introduced ring $W_2$	0.1 mm

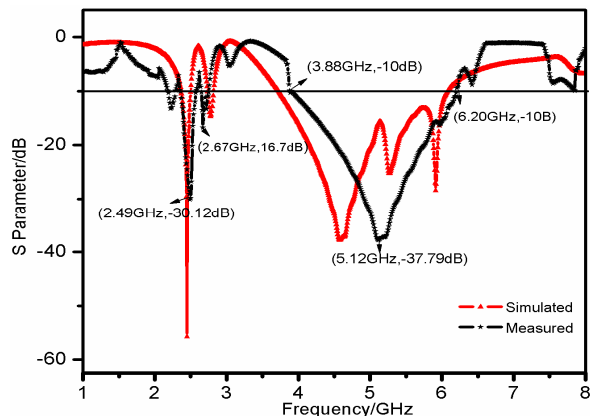


Figure 5: Measured/Simulated variation of reflection coefficient of antenna with frequency

A comparison between simulated and measured reflection coefficient variations for this antenna having a slot in the patch and ring in the ground plane has shown in Fig. 5. A nice agreement for simulated and measured result at frequencies 2.49GHz, 2.67 GHz & 5.12GHz has realized. The frequencies 4.57GHz and 5.91GHz for which nice matching is realized through simulation cannot be achieved through measurements. The involved design complications limit is perhaps responsible for the

disagreement. The simulated and measured impedance bandwidths of antenna are 2.35GHz and 2.32GHz respectively which are in good agreement. Fig. 6 illustrates the simulated surface current distribution of the antenna at 2.45 GHz, 2.77 GHz and 5.27 GHz. In each case, the maximum current density concentrates mainly on the eight shaped slot on the patch, hence it is responsible for the improved performance of the antenna.

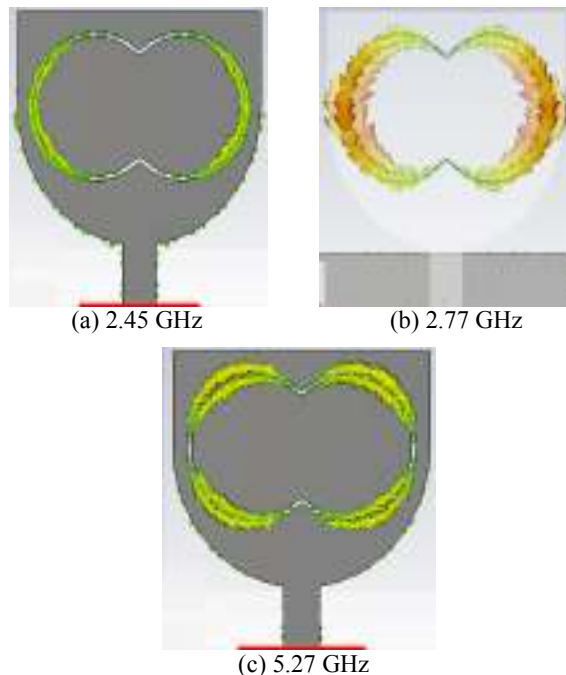


Figure 6: Simulated surface current distribution of the proposed antenna at various frequencies.

The simulated gain of antenna at frequencies 2.45GHz and 2.77GHz are 1.24dBi and 0.60dBi respectively, while in the frequency range of interest (3.70GHz to 6.07GHz). The gain values of present structure are low and almost constant. A comparison between simulated variations of axial ratio in two cases has shown in Fig. 7. The testing for circular polarization has performed at several ( $\theta$ ,  $\phi$ ) values and finally with  $\theta = 75^\circ$  and  $\phi = 85^\circ$ , the best performance (maximum axial ratio bandwidth) of the antenna has obtained. In the first case when patch has a ring shaped slot only, the axial ratio bandwidth has achieved from 5.09GHz to 5.93GHz, while in the second case, when patch has a ring shaped slot and ground has a ring, the axial ratio bandwidth has obtained from 4.69GHz to 6.02 GHz. In this way, the simulated axial ratio bandwidth which has 840 MHz or 15% with respect to central frequency 5.51GHz in the first case has increased to 1.33GHz or 24.84% with respect to central frequency 5.35GHz on the introduction of a ring in the ground plane. The two dimensional simulated and measured E & H-planes radiations patterns of proposed structure have obtained at two frequencies 2.45GHz and 5.12GHz. The simulated and measured E & H Plane radiation patterns are in excellent agreement as depicted in Fig. 8. The E-plane patterns of both frequencies are almost omnidirectional and

resembles with those of a monopole antenna. The direction of maximum radiation is normal to patch antenna, but more power has directed in backward direction. The H-plane patterns have a dumbbell shape formation with almost equal radiations in forward and backward directions. The obtained 3dB beam widths are close to 78° & 62° degree respectively at these frequencies.

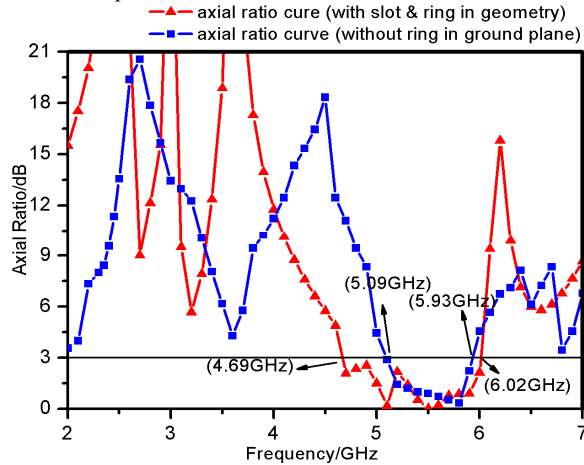


Figure 7: Simulated axial ratio variation with frequency

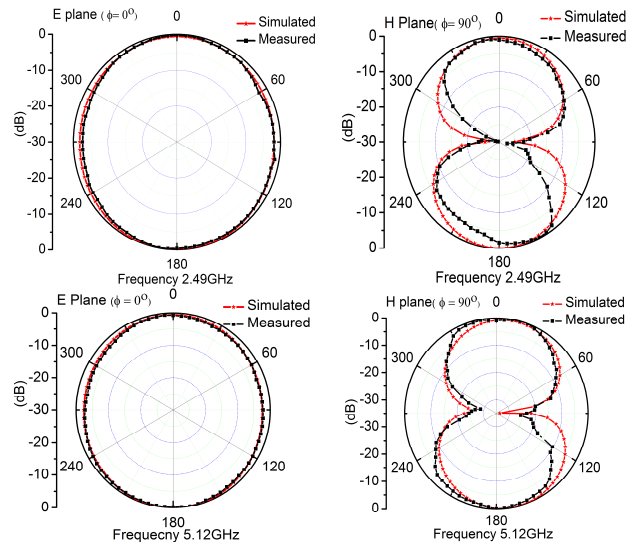


Figure 8: E & H plane radiation pattern of the proposed antenna at different frequencies.

## 2.2. Proposed antenna structure with reflector

The main limitation of this monopole structure is its low gain and poor directivity as almost equal radiations are realized both in forward and backward directions. To overcome this limitation, a thin rectangular metal sheet having dimensions 60 mm x 60 mm has placed as a reflector at proper place ( $H = 24$  mm) beneath the proposed antenna structure. The distance of reflector from the antenna has chosen to satisfy the condition of constructive interference of radiations. The proposed monopole antenna with reflector has shown in Fig. 9 (a) while developed prototype has shown in Fig. 9 (b).

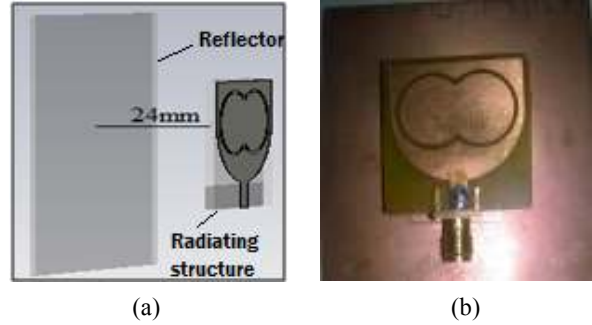


Figure 9: Geometrical & fabricated prototype proposed patch antenna with reflector.

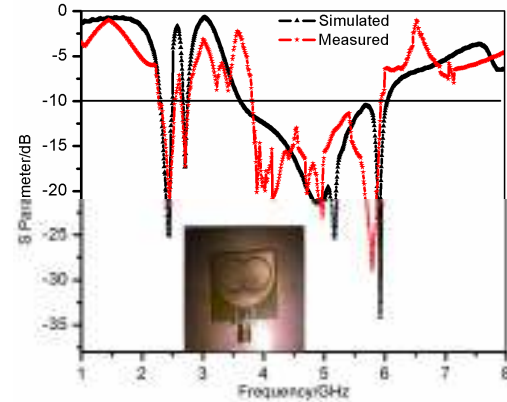


Figure 10: Variation of reflection coefficient with frequency of proposed antenna with reflector.

The simulated and measured variations of reflection coefficient with frequency are demonstrated in Fig. 10. The measured results present triple band behavior of the antenna as it shows impedance bandwidth of 265MHz in the frequency range 2.280 GHz to 2.545 GHz, 116 MHz in the frequency range 2.660 GHz to 2.776 GHz & 2.12 GHz in the frequency range 3.83 GHz to 5.956 GHz. These frequency bands are useful for Bluetooth and WLAN/WIMAX communication systems. The marginal difference between simulated and measured results has observed due to the complications involved in design & fabrication of antenna and measurement surroundings. When the backward directed wave radiated from the antenna falls on the reflector, it gets reflected. If the distance between the antenna and reflector is selected in such a way that the reflected waves from the reflector and radiated waves from the antenna are in phase, then the directivity and hence the gain of the antenna improves. The measured and simulated far field radiation patterns of antenna in E ( $\phi = 0^\circ$ ) and H ( $\phi = 90^\circ$ ) planes at frequencies 2.45GHz, 5.17GHz and 5.79GHz are shown in Fig. 11, which indicates that radiation patterns are now more directed in the front direction. The measured radiation pattern is fully unidirectional in lower and middle frequency range. A comparison of gain performance of antenna with and without metallic reflector is also shown in Fig. 12. With introduction of metallic reflector, the gain of the antenna at frequency 2.45GHz is 4.90dBi, at frequency 2.71GHz is 4.94dBi, and in the frequency range extended from 3.83 GHz to 5.956 GHz, it is variable from 4.4dBi to 4.9dBi.



These gain values are almost four times higher than those realized in the previous sections. The maximum gain of the antenna in the present case is close to 5.56 dBi at 2.42 GHz. The obtained results suggest that on the introduction of a reflector, gain and directivity of the antenna are improved considerably without any compromise with bandwidth and circular polarization results.

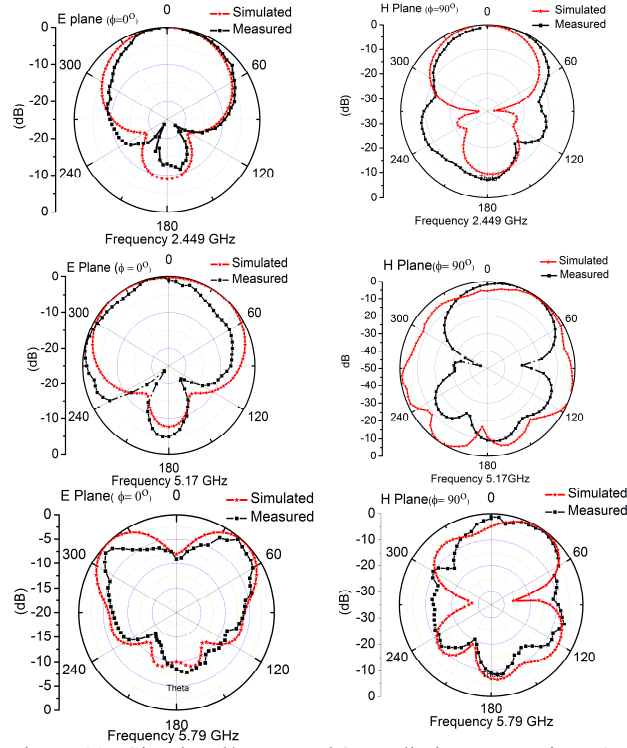


Figure 11: Simulated/Measured 2D radiation pattern in E & H planes at various resonance frequencies

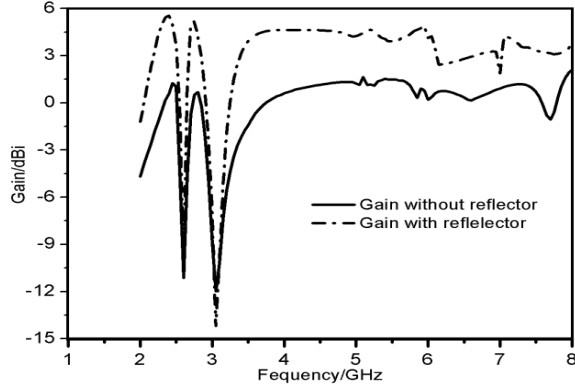


Figure 12: Simulated variation of gain with frequency of proposed antenna with reflector.

### 3. Discussion

The comparison of performance of different recent antenna designs with proposed antenna is given in Table 3 which demonstrates that the proposed antenna structure has a compact size and high gain characteristics.

Table 4: Comparisons of performance of the Proposed Antenna with other multi band designed antenna

Ref.	Size(mm <sup>2</sup> )	Operating Frequency Band (GHz)	Avg. Peak Gain(dBi)
Proposed Antenna	30×30	2.280 to 2.545, 2.660 to 2.77, 3.83 to 5.95.	5.56
22	35×30	2.4/5.2/5.8 GHz WLAN Bands 3.5/5.5GHz WiMAX Bands	4.1
23	38×20	2.4/5.8 GHz WLAN Bands 3.5 WiMAX Bands	3.1
24	35×25	2.4/5.2/5.8 GHz WLAN Bands 3.5/5.5GHz WiMAX Bands	2.4
25	16×70	2.1 GHz-6.0GHz	----
26	28×58.6	1.9GHz-5.2GHz	4.5
27	39×46	2.27 GHz-4.64 GHz	2.85
28	33×2	2.45 /5.8 GHz	3.27

### 4. Conclusions

Proposed U-shaped monopole planar antenna having eight shaped ring slot in patch and eight shaped ring in ground plane with metallic reflector beneath the ground plane provide triple band performance. The impedance bandwidths in these bands extend from 2.280 GHz to 2.545 GHz, 2.660 GHz to 2.776 GHz and 3.83 GHz to 5.956 GHz respectively. Desired flat gain (close to 5dBi), better directivity and good radiation patterns in the desired frequency range are also realized with proposed geometry. The maximum gain of the antenna is close to 5.56dBi at 2.4GHz. This antenna may be proved a useful structure for modern wireless communication systems, including in devices like Bluetooth, WLAN, WI-MAX and lower band of UWB communication systems.

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