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Small Size Broadband Printed Antenna for 5G Applications Covering 28 GHz / 38 GHz and 60 GHz Bands

Vijay SHARMA[1,*], Nipun K. MISHRA[2], Atul K. AGARWAL[3], N. L. GUPTA[4]

[1]Department of H & S (Physics), Govt. Mahila Engineering College, Ajmer, 305001, Rajasthan, India
[2]Department of Electronics and Communication Engineering, Guru Ghasidas Vishwavidyalaya, Bilaspur, 495009, Chhattisgarh, India
[3]Department of Physics, Govt. College, Nasirabad, Ajmer, 305601, Rajasthan, India
[4]Department of Physics, Govt. College, Kishangarh, Ajmer, 305801, Rajasthan, India

Highlights

- Article discusses designing a compact antenna for 5G application in three bands simultaneously.
- Hybrid approach includes the insertion of a slot in the ground and the modification of the patch.
- The offered antenna can be used in gadget-to-gadget applications for advanced 5G wireless systems.
- In future, the MIMO of this offered antenna can be designed and studied for other applications.

Article Info

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Keywords

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Abstract

This work offers the radiation insight of a compact modified monopole rectangular printed antenna suitable for 5G applications. A Double copper cladded RT Duroid 5880 material sheet with dimensions 4.4×5.0×0.5mm^3 is chosen as the base substrate in the offered design with a loss tangent of 0.004 and a dielectric constant of 2.2. In the provided strategy lower-left corner of a rectangular printed antenna is made in the form of a smooth circular curve. After extensive simulation, a circular slot with an elliptical patch is incorporated into this monopole antenna. The designed antenna parameters are adjusted to cover the impedance bandwidth from 21.7 GHz to more than 70.0 GHz. Three resonances at 28.0 GHz, 38.1 GHz and 60.2 GHz were observed in three bands allocated for 5G communication applications. The efficiency and gain values found sustained in the entire bandwidth range. Stable and desired radiation patterns at all three resonant frequencies 28/38/60 GHz prove the suitability of this antenna for recent 5G applications.

1. INTRODUCTION

An enormous development is seen in the wireless industry over the last decade. It has advanced from the long-term evaluation system (4G LTE) to the high data rates system (5G). Developing a trend-setting innovation for the upcoming age of wireless communication systems has put an extraordinary enthusiasm for investigators in the current scenario. The target is to attain increasing interest in cutting-edge data rates [1]. Particularly with the elaboration of the idea of the internet of things (IoT), that predicts the creation of more than twenty billion associated gadgets to the web in the skyline of 2020, all of which will claim availability with a huge capacity and ubiquitous coverage [2]. The fifth-generation (5G) technology guarantees more points of interest and advantages to society. It will make a fundamental contrast over 4G. However, 4G wireless communication systems have been used by various countries, but, some issues like high energy consumption and data rates were not rectified by 4G and thus came the fifth era of communication (5G). With this 5G technology, the earlier issues with mobile communication such as higher data rate transmission (speed), low latency rate (no drop in the connection) and ultra-wide bandwidth etc can be settled with less effort [3]. And these features can be given independently to all users irrespective of what number of clients is associated simultaneously. This is the future innovation that will go imperceptible like the power, with consistent and contiguous coverage [4]. 5G requires a spectrum range that potentially includes two spectra, explicitly sub 6 GHz band and millimeter wave bands for instance 28 GHz, 38 GHz, 60 GHz and 70 GHz to pass on unlimited consideration and support all use cases [5]. As the sub 6 GHz

*Corresponding author, e-mail: phyvijay@gmail.com

band (first spectra) is already being involved as of now, mm-wave 5G (second spectra) groups are esteemed and alluring as far as accessible bandwidth is concerned.

Due to the promising features of 5G such as meeting ultra-high broadband speeds a few explore the description of the realistic prospective capability of millimeter-wave frequencies for 5G applications [6-7]. Among a definitive appropriate candidate to guarantee the ever-expanding end-user performance requirements, Microstrip antennas are generally utilized because of their minimal cost, thin-profile flexibility, low weight and simplicity of mass production. But, the primary drawback of a Microstrip antenna is its narrow bandwidth [8]. Various researchers all around the globe are working on the design of Microstrip antennas for different 5G bands with enhanced gain and each design has its own merits and flaws. Common design issues include complex structures and large dimensions or high volumes [9].

In [10], Mpele et. al presented a small elliptical antenna with the defective ground for 5G application using two different substrates (Rogers RO4350B and Rogers RO3010) of different dimensions ($5.0\times5.0\times0.75mm^3$ and $2.265\times2.0\times0.75mm^3$). The designed antenna reasonably resonates at 28 GHz and 38 GHz respectively, however, due to the dual substrate layer the overall volume increases. In [11], Hasan et al presented a compact 2 × 2 MIMO (multiple-input and multiple-output) of mm-wave monopole antenna for 5G applications that work at 28/38 GHz. The radiating element is retrieved from a rectangular monopole by tapering it laterally in a hemispherical style to attain the dual band at the desired frequency. The fractional bandwidths of the designed antenna are 9.1% and 5.52% at 28 GHz and 38 GHz respectively. In [12], Kaeib et al using the fundamental design equation of rectangular patch antenna offered an antenna of size 8.06 mm × 6.96 mm × 0.8 mm for operating frequency 28 GHz on FR4 lossy substrate. To achieve better matching among the patch and fed a quarter-wave transformer is applied along with modification in the patch. Sharma et al discuss the design and testing of a miniature offset elliptical ring printed antenna for a 5G application covering a 2.31–40.0 GHz band [13]. Teresa and Umamaheswari [14] presented a miniature size (7.0 mm × 7.0 mm × 0.8 mm) compact rectangular patch antenna that resonates at 28 GHz frequency for 5G applications. Following this, a modified rectangular patch antenna is presented in this article that resonates at three frequencies and covers all three frequencies 28 GHz, 38 GHz and 60 GHz for 5G with a small size in comparison to [14]. The offered antenna is planned and investigated utilizing a 3-D full-wave electromagnetic tool which is a specialist tool for antenna and filter design and gives accurate and fast results at high frequencies.

2. DESIGN AND EVOLUTION OF ANTENNA

Keeping in mind the fact that there are an infinite number of resonant modes that exist for a rectangular patch radiator and each of which is characterized by a resonant frequency. Initially, a rectangular monopole antenna acting as a partly leaky cavity is designed to resonate at the two modes (TM_{10}& TM_{01}) of the greatest interest. The dimensions of the patch lying in the XY plane are characterized by its dimensions L and W. For a given resonant mode, the electric field E_z and resonant frequency f_{mn} can be written as

$$E_z = E_0 \cos\left(\frac{m\pi}{L}\right) x \cos\left(\frac{n\pi}{W}\right) y \quad , \tag{1}$$

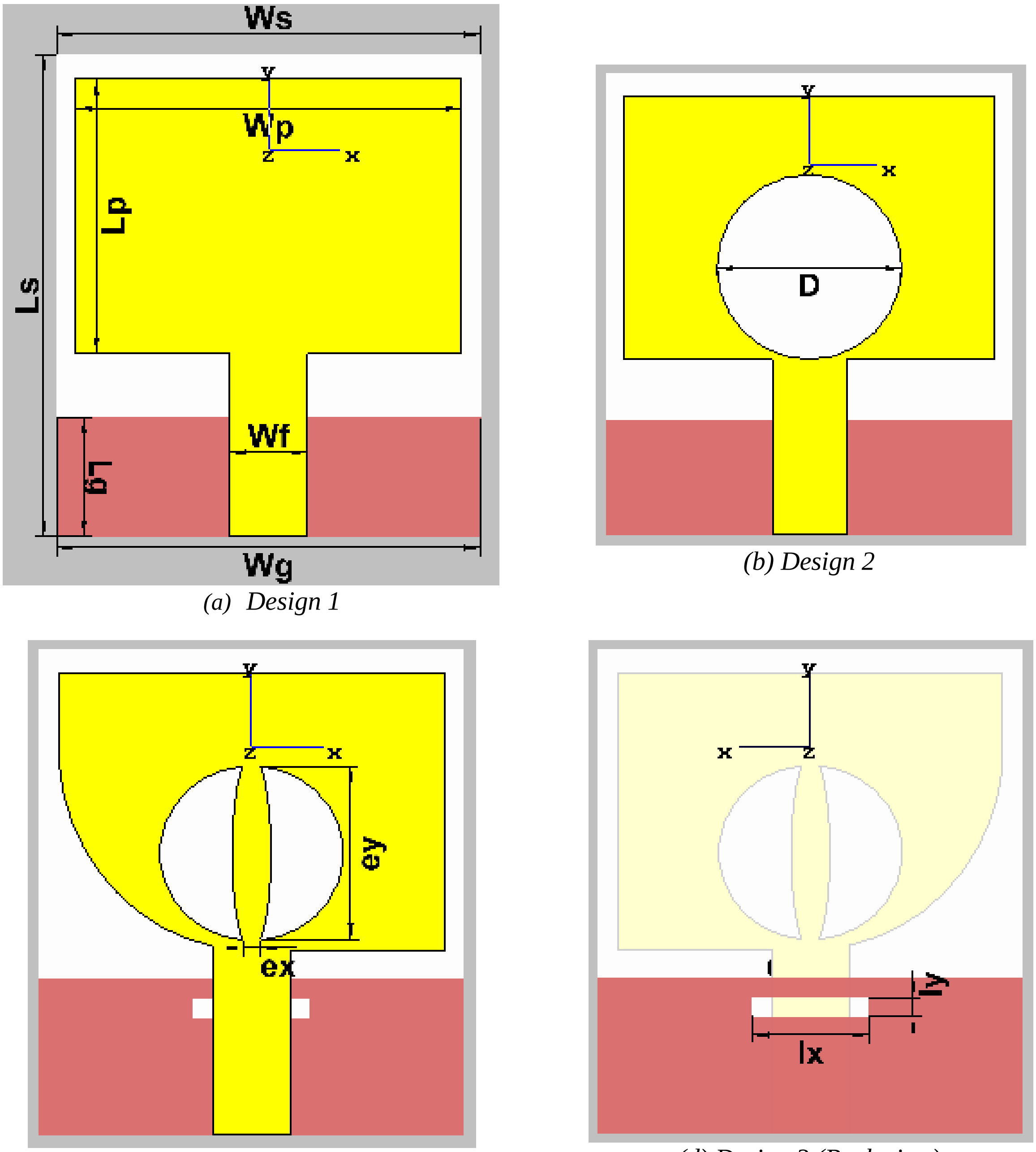
$$f_{mn} = \frac{k_{mn} c}{2\pi\sqrt{\varepsilon_r}} \tag{2}$$

$$k_{mn} = \sqrt{\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{W}\right)^2} \tag{3}$$

Here, m and n are integers $(m, n = 0,1,2 \ldots \ldots)$ c is the speed of electromagnetic waves and ε_r is the permittivity of substrate material taken.

In the present study the double copper cladded RT duroid 5880 material is chosen as the base substrate having a loss tangent of 0.004, a substrate permittivity value of 2.2 and height h =0.5 mm. Following Equations (1) and (2), in the first step, a rectangular monopole antenna is planned as appeared in design 1 Figure 1 (a). It consists of a microstrip line feeding port of width Wf and a rectangular ground plane of dimension (Lg*Wg). The dimension of the substrate material is (Ls*Ws) whereas the dimension of the patch is (Lp*Wp). The values of all these parameters are given in Table 1.

The dimensions are chosen such that the offered antenna resonates at 28.0 GHz (in 27.5–28.35 GHz band) and 38.0 GHz band (37–38.6 GHz) for different modes. Also due to the fringing fields on the boundaries of the patch, the patch will act as if there are marginally higher dimensions. As a rule, semi-empirical factors are introduced to get this effective dimension that can be found in the referenced text [15]. The obtained effective dimensions of the patch correspond to considering the edge effect is nearly 2.85 mm and 4.0 mm.



(a) Design 1

(b) Design 2

(c) Design 3 (Front view)

(d) Design 3 (Back view)

Figure 1. *Schematic design steps (a) Design 1 (b) Design 2 (c) Design 3 (Front view) and (d) Design 3 (Back view)*

Table 1. *Parameters of the proposed antenna 'Design 1', 'Design 2' and 'Design 3'*

Parameter	Value (in mm)	Parameter	Value (in mm)
Length of ground 'Lg'	1.24	Dimension of minor axis of elliptical patch 'ex'	0.2
Width of ground 'Wg'	4.4	Dimension of major axis of elliptical patch 'ey'	1.0
Length of patch 'Lp'	2.85	Dimension of slot in ground along X- axis 'lx'	1.2
Width of patch 'Wp'	4.0	Dimension of slot in ground along Y- axis 'ly'	0.2
Length of substrate 'Ls'	5.0	Width of feed 'Wf'	0.8
Width of substrate 'Ws'	4.4	Diameter of circular slot 'D'	0.95

3. DISCUSSION AND ANALYSIS OF ANTENNA CHRACTERSTICIS

Initially, Design 1 (rectangular monopole antenna) is energized with a properly fed arrangement of 50 ohms. The observed reflection coefficient variation of design 1 with frequency is illustrated in Figure 2. Figure 2 reflects that the antenna is resonating at 30.9 GHz and covering the 28 GHz band with an impedance bandwidth (IBW) value of 19.6 GHz (63.4%) corresponds to a -10dB reflection coefficient. Perhaps the IBW is sufficiently high for various applications, however, to transform this structure from single frequency (band) to dual/ triple frequency (band) further modifications are sought.

Considering this design 1 is modified by applying a circular slot at the center (Figure 1b), it serves the purpose of generating a new resonance mode. As, it is well known that a slot act as a radiator itself, if one of its modes, resonates close to the resonance frequency of the patch in which the slot is introduced, these two modes may overlap to give rise to the extended bandwidth. The reflection coefficient variation of design 2 with frequency, in which two resonance dips exist at 27.8 GHz and 34.1 GHz respectively are observed in Figure 2. A reasonable shift in resonance frequency along with an additional resonance is observed due to the introduction of the circular slot. The first frequency lies in the 28 GHz band whereas the second resonance frequency is not falling in the 38 GHz band and is slight lowers for 5G applications. This can be optimized to fall in the desired band (38 GHz) by optimizing the parameters of the circular slot like its radius and location in the patch.

As the prime focus is to achieve a prototype design that works for all tri bands viz 28 GHz, 38 GHz and 60 GHz simultaneously, further alteration is needed in design 2 (Figure 1b). Keeping this in mind, an elliptical shape patch is introduced in this circular slot as shown in Figure 1c and named 'design 3'. The reflection coefficient variation of design 3 with frequency is shown in Figure 2, which reflects that it gives three resonances in three different bands allocated for 5G applications with enormous bandwidth. Design 3 is resonating at three frequencies viz 28.0 GHz, 38.1 GHz and 60.2 GHz with -10dB impedance bandwidth 21.6 GHz to more than 70 GHz.

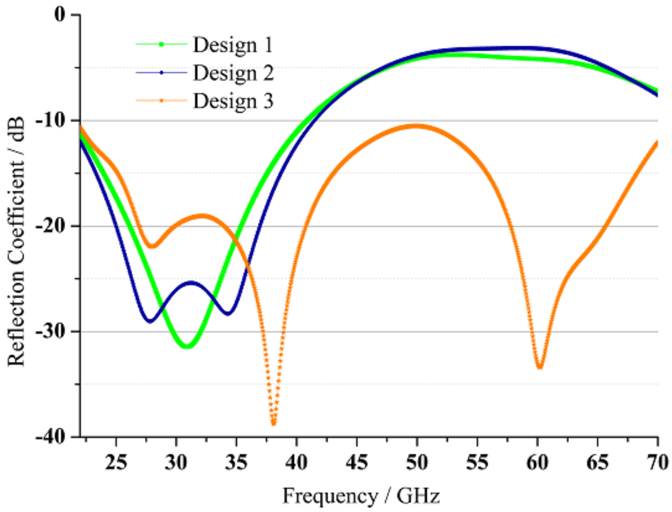
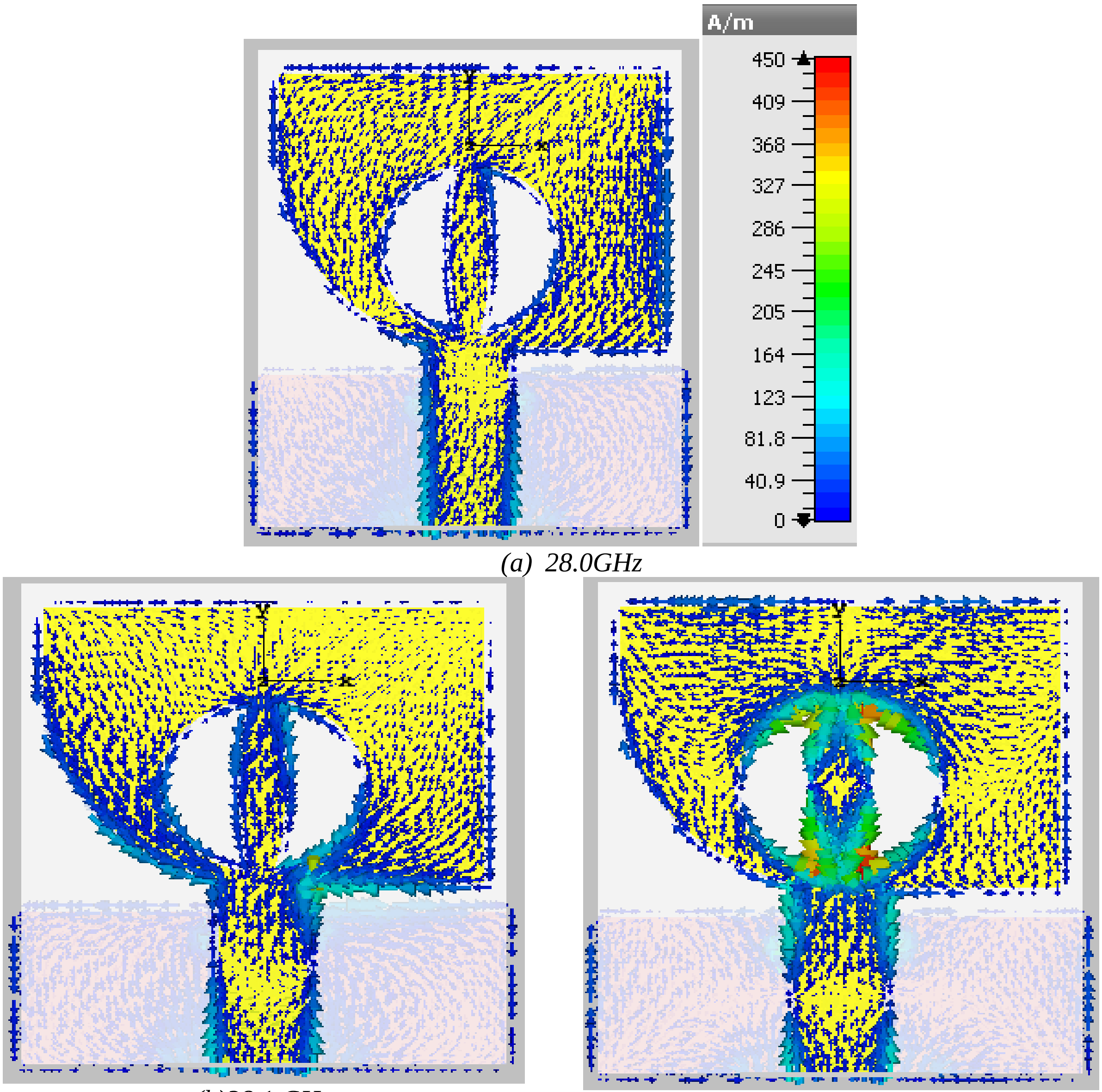


***Figure 2**. The reflection coefficient variation with frequency for (i) Design 1 (ii) Design 2 (iii) Design 3*



(a) 28.0GHz

(b)38.1 GHz

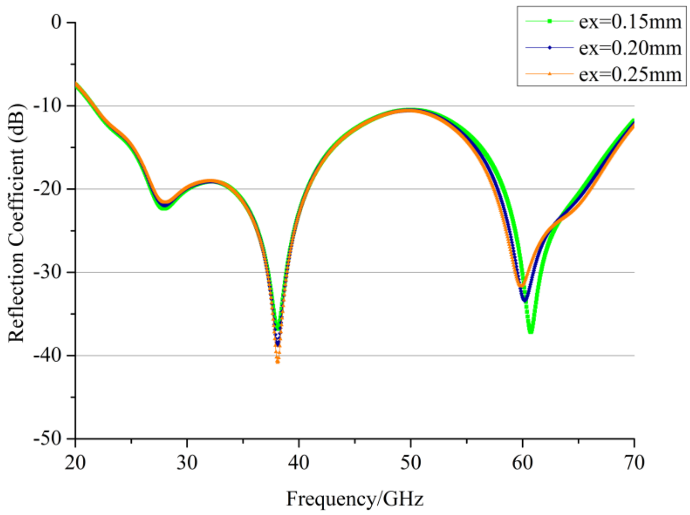
(c) 60.2 GHz

***Figure 3.** The distribution of surface current at three resonance frequencies (a) 28.0 GHz (b) 38.1 GHz and (c) 60.2 GHz*

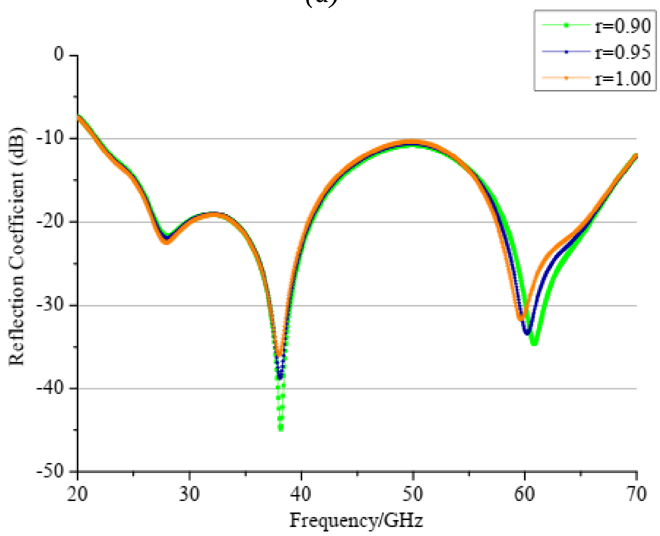
The third resonance is excited due to the presence of this elliptical shape patch and can be verified by analyzing the surface current distribution using an electromagnetic simulation tool [16]. The distribution of surface current at all three resonance frequencies 28.0 GHz, 38.1 GHz and 60.2 GHz is given in Figure 3 (a-c). It is observed that at 28.0 GHz most of the energy is flowing in the feed portion of design 3. The second resonance at 38.1 GHz appears among the gap between the ground and curvature part and the lower straight periphery of the patch due to coupling. At 60.2 GHz most of the current density is potent on the elliptical shape patch and the inner periphery of the circular slot.

3.1. Optimization of Various Parameters

Figure 4a shows the effect of the minor axis value of an elliptical patch put in a circular slot. Since lowering the patch size increases the frequency, the frequency moves to the higher side when the minor axis value decreases. The minor axis value is chosen so that the resonance dip appears at 60.2 GHz. In addition, the variation of the radius of the circular slot along the horizontal axis (x-axis) is investigated and shown in Figure 4b; the effect is significant in the 60.2 GHz range, whereas it is minimal in the 28 GHz and 38 GHz bands. Figure 4c depicts the effect of a short rectangular strip in the ground beneath the feed line functioning as a matching slot. With the installation of a slot, a favourable matching is found in the 38 GHz and 60 GHz bands, with a reflection coefficient value of nearly 35 dB. Various optimizations have been accomplished to finalize the values of the dimension and position of the slot. The final value of the parameters is mentioned in Table 1.



(a)



(b)

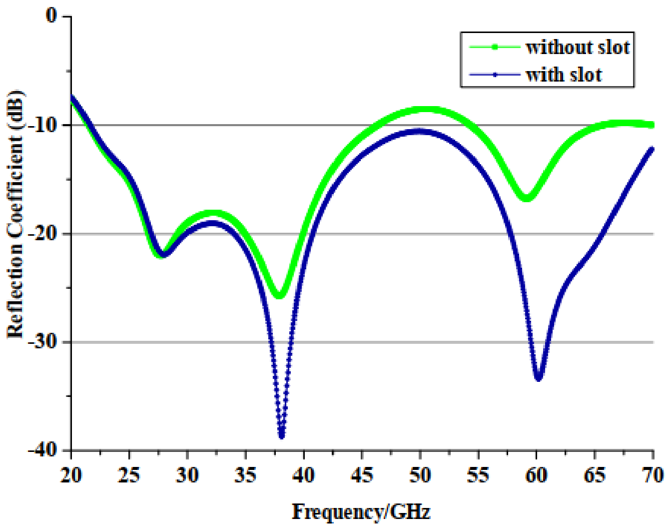
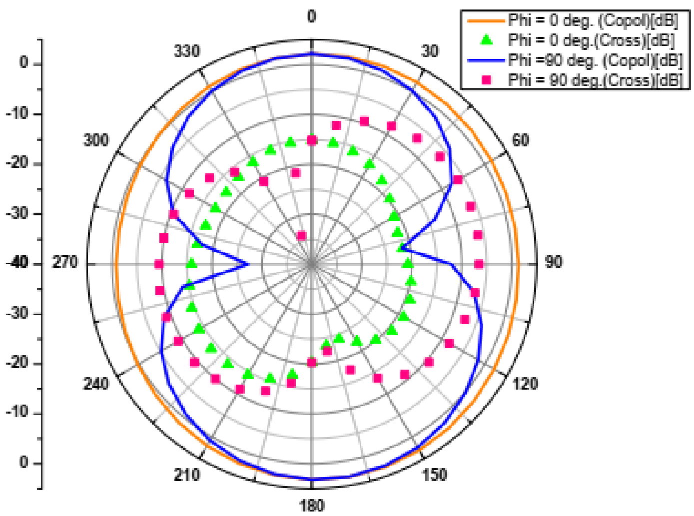


Figure 4. *The reflection coefficient variation with frequency for (a) variation of minor axis value of elliptical patch and (b) variation of radius of circular slot along horizontal axis*

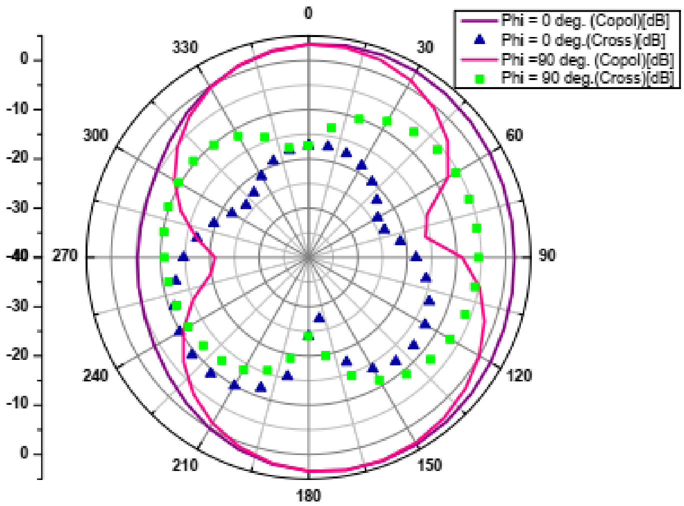
4. ANALYSIS OF RADIATION PROPERTIES

The computed radiation patterns of the proposed design 3 in three bands 28.0 GHz, 38.1 GHz and 60.2 GHz respectively are offered in Figure 5 (a-c). The outcomes incorporate co-polarization and cross-polarization (XP) in the E-plane (YZ plane) and the H-plane (XZ plane). The measured results are not supplied here as the pattern measurement facility is not available for these higher frequency bands. Although these computed results in all three bands are proven, the styles resemble a doughnut form with a nearly omnidirectional H-plane pattern and a nature of eight patterns in the E-plane that is noteworthy proof towards its applicability in practical application for 5G. Significant isolation of more than 15dB is observed between Co & Cross polar components for 28 GHz and 38.1 GHz; however, at 60.2 GHz it is a little less.

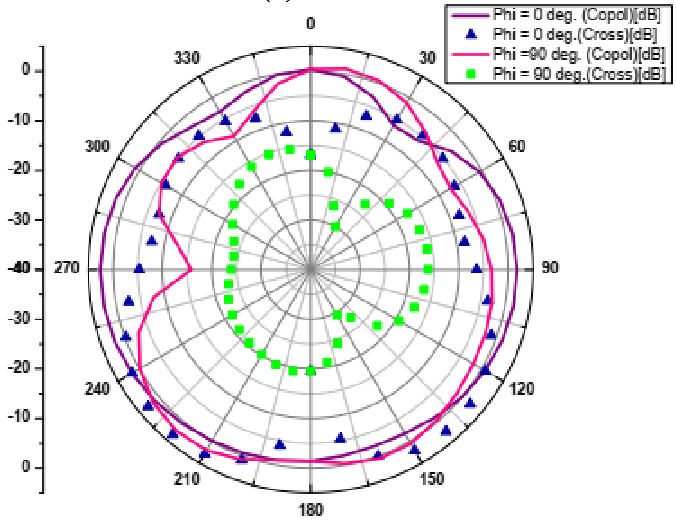
The efficiency and gain variation for proposed antenna design 3 with frequency are given in Figure 6 and Figure 7. It is realized from Figure 6 that radiation efficiency throughout the bandwidth range is above 90% whereas the total efficiency is nearly 90% and it is also sustained in the entire region of impedance bandwidth. Figure 7 offered, that antenna gain is also in the permissible range of gain variation (nearly 1dBi). It is also observed that in the high-frequency band 60GHz, due to more radiations, the gain is maximum.



(a) 28.0 GHz



(b) 38.1 GHz



(c) 60.2 GHz

Figure 5. *Co & Cross polar radiation performance of the proposed design 3 in E plane and H plane at (a) 28 GHz (b) 38.1 GHz and (c) 60.2 GHz*

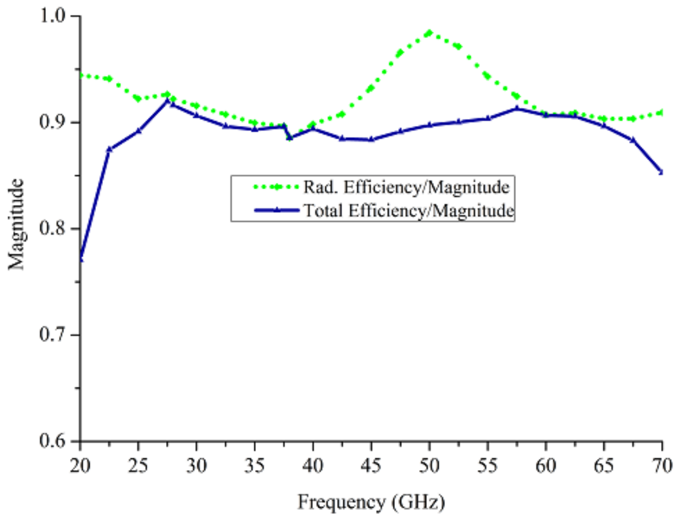


Figure 6. *Variation of the magnitude of the efficiencies (radiation and total) with frequency 'Design 3'*

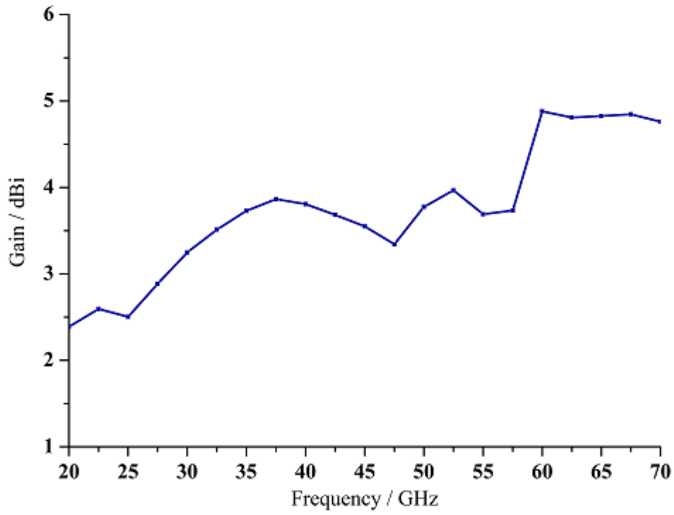


Figure 7. *Variation of the gain with frequency for offered 'Design 3'*

5. CONCLUSION

In this communication, the analysis of a printed monopole rectangular patch antenna modified with a circular slot and the elliptical patch is conferred. By transfiguring the conventional monopole rectangular antenna with one side (left) of the feed with a curved surface and on another side (right) of the feed conventional gap is undertaken that gives an extended impedance bandwidth. With the help of surface current distribution and by optimizing the parameters properly, resonance in three bands viz 28.0 GHz (in 27.5–28.35 GHz band), 38.0 GHz band (37–38.6 GHz) and 60.0 GHz band (57–64 GHz) are attained. The significant gain, efficiency and desirable radiation patterns are achieved in all three bands, however, due to the lack of a measurement facility the measured results are not presented. Taking into consideration all these features it may be flawlessly incorporated on compact gadgets working at 28/38/60 GHz bands planned for the gadget-to-gadget (G2G) applications for advanced 5G wireless systems.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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