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Compact Microstrip Antenna Design at 60 GHz for Next Generation Communication Systems

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***Abstract*— A 60 GHz unlicensed spectrum promises high-bandwidth for the commercial wireless communication applications. In this work, a rectangular microstrip patch antenna at 60 GHz using inset feeding is designed for the next generation communication system. The suggested antenna will transfer audio and video data up to few gigabits per second. The return loss is found to be 24.77 dB at the operating frequency. The gain and directivity achieved at resonant frequency is 7.654 dB and 7.580 dBi respectively. In addition, slots are introduced to increase the bandwidth of this antenna. Furthermore, the results obtained by C shaped slot and circular ring are optimized. The bandwidth achieved by using C shaped slot is 0.9631 GHz and the bandwidth achieved by using circular ring is 1.005 GHz. The proposed design is designed on low budget RT/duroid 5880 substrate with overall extent as (3.43×3.83×0.04) mm^3**

***Index Terms* - Microstrip antenna, Bandwidth, Millimeter Wave and Slot**

I. INTRODUCTION

Microstrip antennas are becoming popular due to low cost, low profile and are easily fabricated. Microstrip antenna is manufactured using printed circuit. A microstrip antenna consists of three layers that is patch, substrate and ground plane. Some of disadvantages of microstrip are poor polarization, low power, very narrow bandwidth but can be improved by many techniques. Stacking one of the methods used to increase the bandwidth [1]. Defected ground structure [2] is used in rectangular microstrip antenna to enhance the bandwidth.

To meet these requirements, microstrip antennas can be used. These antennas are conformable to planar and non-planar surfaces, simple and inexpensive. Manufacturers for mobile communication base stations often fabricate these antennas directly in sheet metal and mount them on dielectric posts or foam in a variety of ways to eliminate the cost of substrates and etching [3]. This also eliminates the problem radiation from surface waves excited in a thick dielectric substrate used to increase bandwidth. Basic antenna radiates due to current distribution but in case of microstrip antennas it is the advantageous voltage distribution due to fringing fields which results in the patch radiation. Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. The patch is generally made of conducting material such as copper or gold and a patch can take any possible shape. There are different feeding techniques that play an important role in impedance matching which will lead to maximum power transmission [4].

This proposed antenna is designed using inset microstrip line feeding technique. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. The frequency band is from 57- 64 GHz and 60 GHz is our operating frequency. As 60 GHz frequency is unlicensed and provides high data rates. It lies in the V-Band of the millimeter band, it is made unlicensed everywhere and therefore it is free from any congestion or traffic [5]. The rectangular patch antenna is approximately a one-half wavelength long section of rectangular microstrip transmission line. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increases the electrical length of the antenna slightly. The microstrip antennas are inherently linearly polarized. The rectangular microstrip antenna is used because it has highest impedance bandwidth and comparatively easy analysis and fabrication as compared to the others.

According to the Shannon's theorem because of its huge bandwidth, it further provides large channel capacity and high data rates (25Gbps). A millimeter-wave (57-64 GHz) band for unlicensed use, worldwide available and provides 7 GHz spectrum [6].These characteristics make 60 GHz communication most suitable for close-range applications of gigabit wireless data transfer. In addition to providing massive bandwidth for future WPANs and WLANs, adoption of wireless connectivity will soon be necessary, which is evident from the consideration of skin and proximity effects, substrate losses, and dispersion of wired interconnects at carrier frequencies of 60 GHz to hundreds of GHz. Various important features of 60 GHz are discussed. 60-GHz millimeter-wave (57-64 GHz) band for unlicensed use and worldwide available, path loss and used for short range applications. It gives high data rates of around 25Gbps, dense frequency reuse pattern. At higher frequency like 60GHz leads to smaller size of components, so it is used to achieve compact size antenna [7]. MMW band has large spectral capacity, compact antenna structure and allows large data transfers than any other antenna and also provides 20 times more bandwidth than any other. One of the advantages of the resonant frequency is that signals are attenuated due to oxygen absorption this feature gives it interference immunity and high security and can be used for indoor and underground communications [8]. MMW travel solely by line of sight and are blocked by the obstacles and suffers weak penetration [8]. Designing an antenna at high frequency is a challenging task and further difficult to fabricate because of its small dimensions.

The 77 GHz of frequency also lies in the millimeter wave band [9]. It is the part of the W band which ranges from (75-110) GHz. 77 GHz is also an unlicensed band which is presently used for the radar and automobile applications[10].It also provides high data rates like the 60 GHz band. Greater capability for distinguishing between objects is the main advantage of the 77 GHz frequency in the radar application, therefore providing high resolution. The 77-GHz band consists of two sub-bands, 76-77 GHz for narrow-band long-range radars and 77-81GHz for short-range wideband radar[11]. In this to enhance the bandwidth we have introduced the two slots namely C shaped and Circular ring slots, which gave us dual band operation at 60 and 77 GHz frequency with 50 ohm inset feed. These slots gave us two frequency bands one at 60 and other at 77 GHz and now our antenna operates at the two bands namely V and W bands. Slots are used to achieve good impedance matching to increase the bandwidth. Slots force the current to flow through the longer path, increasing the effective dimensions of the patch [12]. Slots can be of various shapes like toothbrush, double bend, cross, U, E, L and circular.

The rest of the paper is organized as follows: Section 2 presents the antenna design methodology. Simulation results of the proposed antenna are discussed in the section 3. Section 4 discussed the conclusion.

II. ANTENNA DESIGN

A. Design of 60 GHz microstrip antenna

For a good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides larger bandwidth and better radiation [13]. But on increasing the thickness of the substrate the size of antenna increases. So there is always a tradeoff between the antenna dimensions and the parameters. It cannot say particular parameters to be ideal; a designer has to achieve his specified and desired performance characteristics at a specified operating frequency [14]. Already known parameters are dielectric constant, thickness of substrate, resonant frequency and loss tangent. To design a particular microstrip antenna follow the following steps:

B. Substrate Selection

To select a substrate with appropriate thickness and loss tangent. The RT/duroid 5880 having dielectric constant 2.2, loss tangent 0.0005 and thermal conductivity 0.22 is chosen as the substrate material and a matlab code is used for its length and width calculations. Calculated dimensions of the proposed antenna 1, proposed antenna 2 and proposed antenna 3 are shown in table 1, table 2 and table 3 respectively.

C. Element Width and Length

These two calculations are very important. As length of antenna is called as the resonant dimension and width of the antenna should be equal to 1.5 of the length dimension. Many other parameters like resonant frequency, radiation pattern, input impedance and bandwidth depends on these two parameters.

$$L = L_{eff} - 2\Delta L \qquad (1)$$

$$L_{eff} = \frac{c}{f\sqrt{\epsilon_{eff}}} \qquad (2)$$

The effective dielectric constant

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2} \qquad (3)$$

$$\Delta L = 0.412h \frac{\left(\epsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \qquad (4)$$

$$W = \frac{c}{2f\sqrt{\epsilon_r + 1}} \qquad (5)$$

where, W and L are the width and length of the patch respectively.

III. SIMULATION RESULTS

CST (computer simulation technology) Microwave Studio for designing inset feed rectangular microstrip antenna at 60 GHz operating frequency and 5mm operating wavelength for next generation communication system.

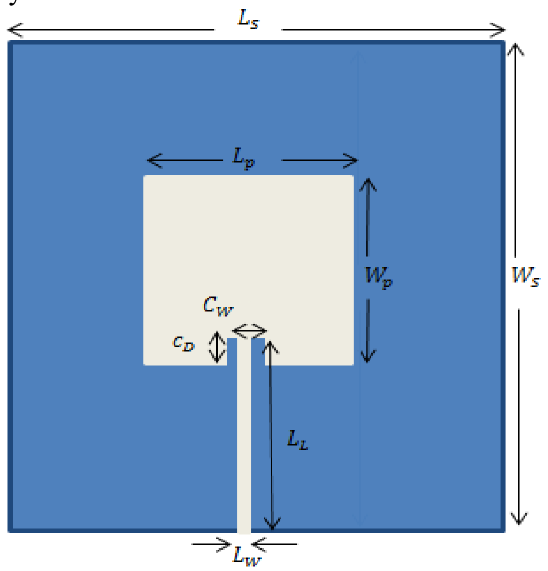

Fig. 1: Design of proposed antenna using inset feeding

TABLE 1: Dimensions of Proposed Antenna 1

S. No	Parameters	Values(mm)
1.	Width of patch(W_P)	1.9174
2.	Length of patch(L_P)	1.5978
3.	Width of substrate(W_S)	3.8348
4.	Length of substrate(L_S)	3.42818
5.	Feeding point(y_0)	0.31957
6.	Cut Width (C_W)	0.3197
7.	Cut Depth(C_D)	0.3197
8.	Width of Microstrip line(W_L)	0.02
9.	Length of Microstrip line (L_L)	1.5835

The parameters used in this are optimized according to the requirements of the designer

A. Return Loss

The return loss of the microstrip antenna at 60GHz is -24.77 dB. If the dip is below -10dB, it means 1/10th of the RF energy is being reflected [5], Usually this is taken as the threshold when most devices are considered to be tuned and have a reasonably good impedance matching and it is equivalent to the VSWR 1.9. Below -20dB is 1/100th of the RF energy is reflected and its equivalent to 1.2 VSWR.

B. Bandwidth

The bandwidth of the antenna is the range of frequencies over which the return loss is greater than -10 dB [15]. Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 1.0716% GHz.

$$\text{Bandwidth} = \frac{(f_h - f_l)}{f_c} * 100 \qquad (6)$$

C. Directivity

The Directivity plot represents amount of radiation intensity i.e. is equal to 7.580 dBi. The simulated antenna radiates more in a particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 7.580dBi.

D. Antenna Gain

The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source [16]. The gain plot gives the gain 7.654dB.

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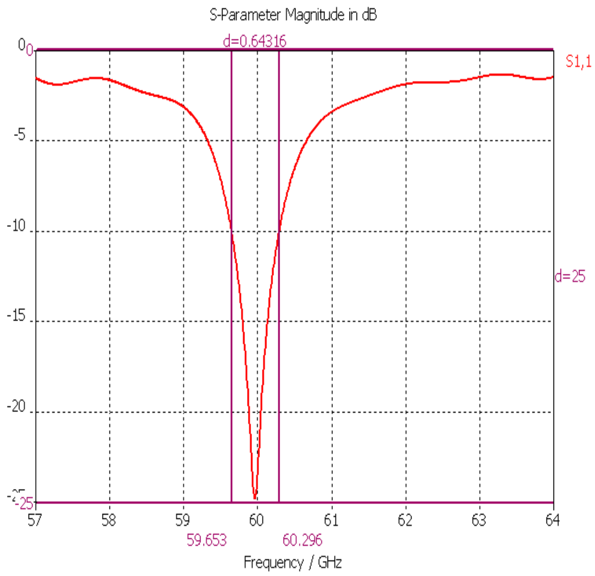

Fig. 2: Bandwidth of proposed antenna 1

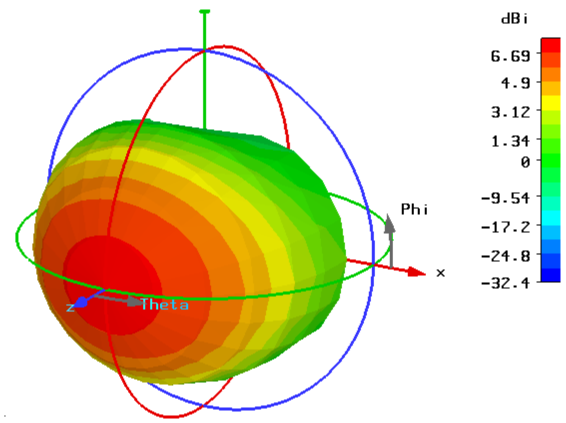

Fig. 3: Directivity of proposed antenna 1

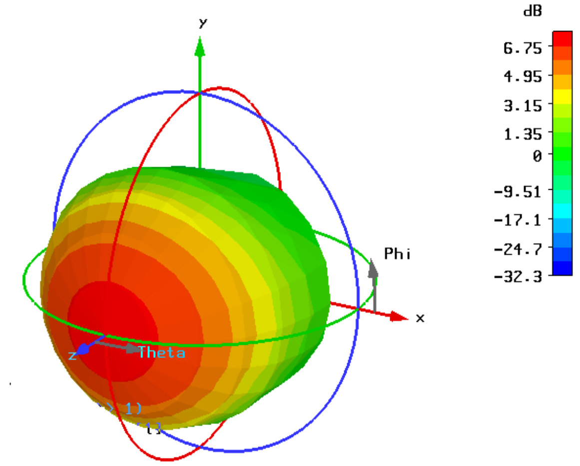

Fig. 4: Gain of proposed antenna 1

To enhance the bandwidth, slot namely C introduce which results dual band operation at 60 and 77 GHz frequency with 50 ohm inset feed. The proposed antenna 2 is shown in the fig.5 and simulated result of dual band antenna is further discussed.

The designing is same as the previous one only the slot dimensions are introduced for the dual band operation. The width of the slot can be calculated using

$$W = \frac{c}{2\,Lower\sqrt{\varepsilon_{eff}}} - 2(L + 2\Delta L - E) \qquad (7)$$

Where, E is the thickness of the slot, L is the length of the slot and W is the width of the slot. The given bandwidth of the antenna has increased from 1.071% to 1.461 % GHz at 60 GHz operating frequency and 0.81% at 77 GHz operating frequency. The main reason behind the use of the slot is only the enhancement of the given antennas bandwidth.

TABLE 2: Parameters of slot of proposed antenna 2

S No.	Parameter	Value(mm)
1.	Width of slot(L_{s1})	0.7994
2.	Length of slot(W_{s1})	0.3734
3.	Thickness of slot (W_0)	0.0012

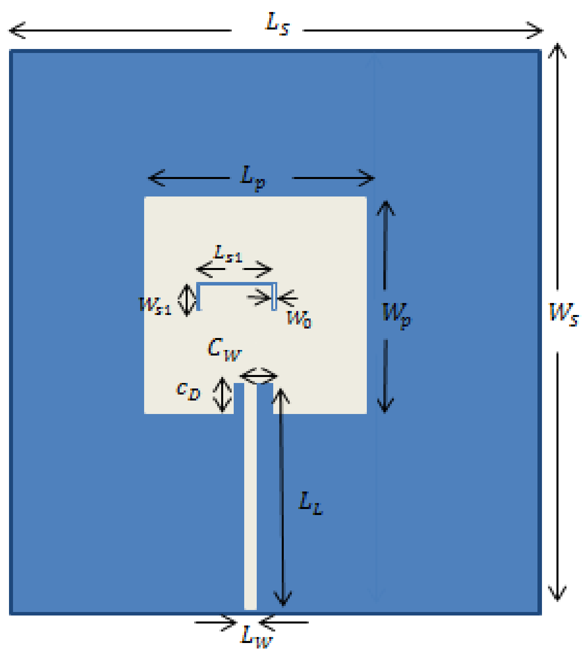

Fig. 5: Design of proposed antenna 2

The directivity of the antenna is increased from 7.5 to 7.77 dBi. To further enhance the bandwidth, Circular ring shaped slot is introducing on the patch surface.

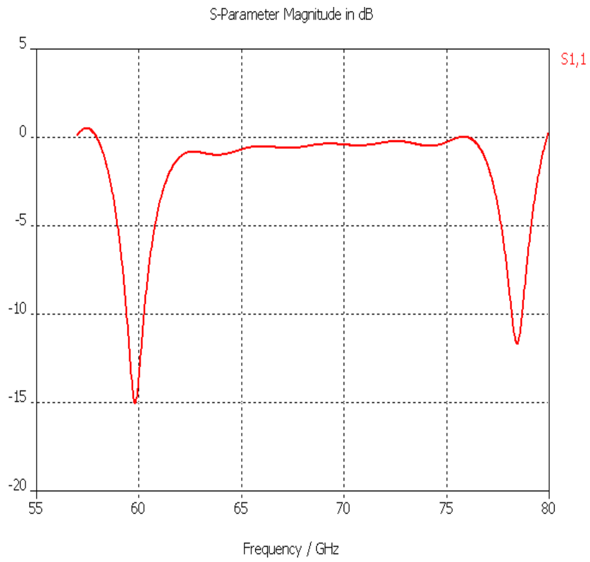

Fig. 6: Bandwidth of proposed antenna 2

The proposed antenna 3 is shown in the Fig.8 and simulated result of dual band antenna is further discussed.

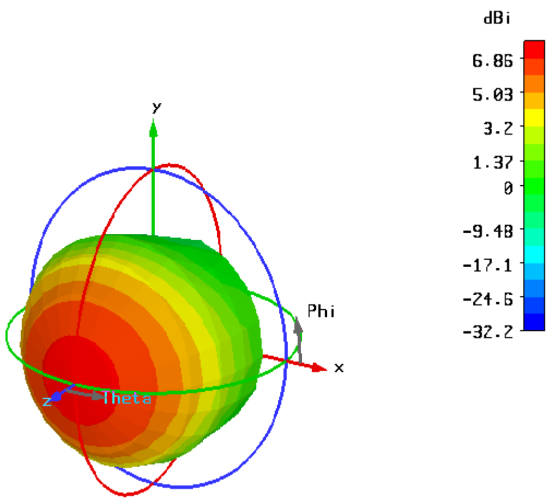

Fig. 7: Directivity of proposed antenna 2

TABLE 3: Parameters of circular ring slot

S No.	Parameters	Value(mm)
1.	Radius of outer circle(r_2)	0.05 mm
2.	Radius of outer circle(r_1)	0.044 mm

The bandwidth of the proposed antenna 3 has been increased to the 1.7185% GHz and the 77 GHz operating frequency is giving 0.97% bandwidth. The directivity has also increased to 7.842 dBi.

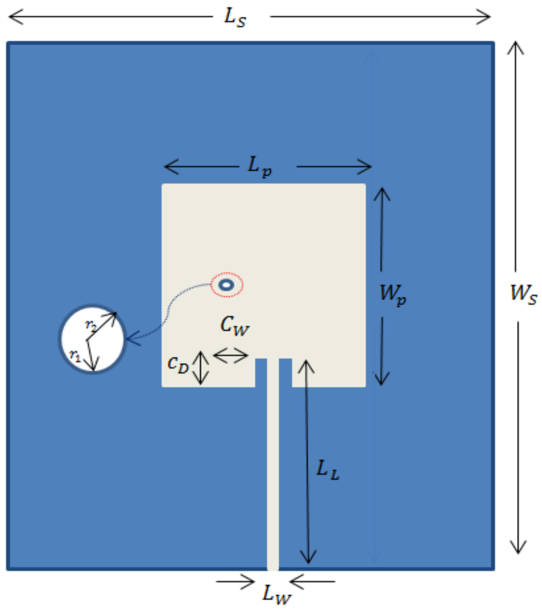

Figure 8: Design of proposed antenna 3

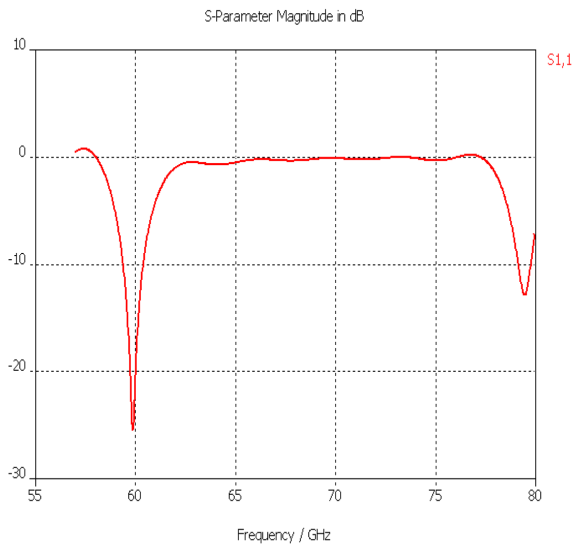

Fig. 9: Bandwidth of proposed antenna 3

In communication field the bandwidth is very important parameter which needs to be maximized therefore increased the overall importance of our antenna by increasing its bandwidth [17]. As we have increased the bandwidth it has further increased the directivity and gain of the antenna. As according to the Shannon's theorem with the increasing bandwidth the overall channel capacity also increases [18]. Comparison between the proposed antenna 1,2 and 3 are discussed in below Table.

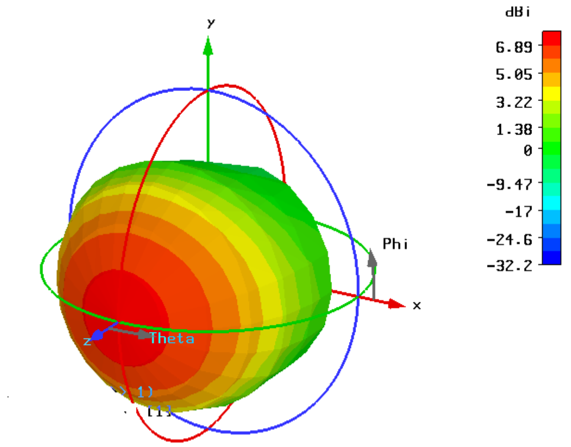

Fig. 7: Directivity of proposed antenna 3

Table 4: Comparison of proposed antenna 1, 2 and 3

Parameters	Frequency (GHz)	Directivity (dBi)	Return loss (dB)	Bandwidth (GHz)
Single band Antenna	60	7.580	-24.77	0.64316
Dual band Antenna with C slot	60	7.772	-14.8	0.9631
	77	5.150	-11.61	0.71189
Dual band Antenna with circular slot	`60	7.808	-25.46	1.005
	77	5.135	-12.79	0.79564

Table 5: Comparisons of bandwidth in conventional and proposed antenna 3

S No.	Ref	Bandwidth Enhancement Techniques	Bandwidth (%)
1.	[19]	Miniature hybrid microwave integrated circuits technology	1.7 %
2.	[20]	Switchable multi-sector antenna	1.756%
3.	[21]	Miniature hybrid microwave integrated circuits	1.78%
4.	[22]	Substrate integrated waveguide	1.8%
5.	Proposed Antenna 3	Circular ring slot	3%

IV. CONCLUSION

In this article, a compact microstrip antenna design at 60 GHz for Next Generation Communication System is discussed. The proposed antenna 3 achieved Bandwidth of 1.005 GHz at 60 GHz and 0.79564 GHz at 77 GHz respectively. To enhance the bandwidth slots are introduced to proposed antenna 1. The values of return loss, gain and, directivity are in acceptable limit that ensures good performance of proposed antennas.

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