
Design of 5g Mobile Millimeter Wave Antenna

By

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ABSTRACT

This paper present the design and simulation of a single band microstrip patch antenna for 5G wireless application operating at 60GHz. The design is carried on Roger RT5880 with 2.2 dielectric, 0.0009 loss tangent and 0.003 mm thickness using inset feeding. The overall dimension of the patch antenna is $2.9 \times 3.5 \text{ mm}^2$, two rectangular U-slot in conjunction with H-slot were loaded into the radiator to enhance the antenna bandwidth. The antenna is design and simulated and the analysis were carried out on CST studio. The antenna achieve a maximum reflection coefficient of about -41.648731 dB at 60 GHz with a very wide bandwidth of about 30 GHz and 8.82 dB realized gain.

Keywords: millimeter-wave, 5G, U and H slot, Microstrip.

INTRODUCTION

Today and in the recent future, to fulfill the presumptions and challenges of the human needs, the wireless based network advances in various ways. The auspicious 5G technology uses higher frequency range from 28-72 GHz proposed by FCC in October, 2015 as FCC 15138 rule, to deliver a multi-Gigabit high data and can support as much as 1000x data rates by 2030 (Adane, Gallée, Propagation, & 2010, n.d.; Yang, Kishk, & Kai-Fong Lee, 2008) (Robertson & Sánchez-Hernández, 1994) (Coulibaly, Nedil, Talbi, of, & 2012, n.d.) (Saini, Computer, and, & 2017, n.d.). In general Table. 1 provides a summary of millimeter wave (mmWave) spectrum bands between 30 GHz to 300 GHz (Pasternack, 2017). The rapid increase of acute weather condition and rain attenuation with the target distance is what causes the disinclination to implement mmWave spectrum, and researches have shown a tremendous improvement on benefit of frequency reuse in conjunction with reduced coverage area (Qingling & Li, 2006) (Pi & Khan, 2011) (Rappaport et al., 2013) (Jilani, Abbas, Esselle, & Alomainy, 2015).

Heavy reliance on Ultra High Frequency (UHF) band by the telecommunication industries that covers only 1 % of the regulated spectrum incur an endless competition to the telecoms operators. Which requires urgent attention as the spectrum is exhausted. The abundance amount of bandwidth in mmWave spectrum can provide solutions to the problem (ITU-R, 2017). Millimeter wave communication tend to have higher path loss at various mm-wave frequencies, and to meet up with the 5G requirement and standard, ITU-R draft a report on 5G specification through IMT-2020 technical report with highest data rates of 20 Gbps in the downlink and 10 Gbps uplink per mobile base station, and improved spectral efficiency closed to LTE-Advance at 30 bps/Hz downlink

and 15 bps/Hz uplink, lower End 2 End (E2E) latency, massive connectivity of devices at lesser cost with better quality of experience (QOE)(ITU-R, 2017)(Gupta & Jha, 2015).

With application diversity in the next generation wireless broadband, a robust system that can fit in industries, schools, home, cars, personal communication is necessary. Patch antenna having satisfy all the relevant requirement such as light weight, low cost, easy to fabricate, and simple geometry is been considered. Low profile apart from ease of circuit assimilation with wireless mobile devices in array form or single entity is what makes micro-strip patch antenna, a vital element in modern wireless broadband communication than its conventional microwave antennas counterpart. Good resonant mode, bandwidth and polarization can be achieved through proper mode and patch selection(Muhammad, Yaro, & Alhassan, 2018; Yu & Kamarudin, 2016)(Yahya, Olaimat, & Abdel-Razeq, 2012)(Sun, Feng, Liu, & Zheng, 2012).

With the competence of 5G, a lot of industries in the area Artificial intelligence as seen in Augmented and Virtual Reality (AR/VR) system, and autonomous driving will be enhanced. Internet of Things (IoT) on the other hand that is fueling a need for massive connectivity of devices, and also a need for ultra-reliable, ultra-low-latency connectivity over Internet Protocol (IP)[2], [3](Fitri, Communication, Wireless, & 2017, n.d.)(Nasimuddin & Chen, 2009)(Liu, Akkermans, Propagation, 2009, & 2009, n.d.).

A patch array antenna at three different configuration operating at 28 GHz in order to analyze their radiation pattern and excitation phase feed through inset feeding technique is presented in (Yu & Kamarudin, 2016). Also a relatively high gain, dual band, and circularly polarized slotted patch antenna fed through single fed strip-line is analyzed in (Aliakbari, Abdipour, Mirzavand, Costanzo, & Mousavi, 2016), The operating frequency of the antenna is 28 GHz and 38 GHz designed without any 90° phase shift, for mmWave 5G application. To achieved circular polarization in the antenna an L-shaped strip is loaded into the rectangular radiator. The size of the radiator is recorded to be 3.1 mm × 3.1 mm suitable for mmWave 5G application, and the realized gain attained by the antenna at two band of interest is about 4 dBi at 28 GHz and 4.5 dBi at 38 GHz in that order. In all the papers presented 60 GHz frequency band is not covered, this work present a designed of an enhanced 60 GHz mmWave antenna with ultra wide bandwidth of about 30 GHz for 5G mobile application.

The remaining section of the paper is organized as follows. Section II gives methodology of the designed antenna, results of the simulations is discussed in section III and the paper is concluded in section IV.

Table. 1 Specific frequencies of sub-millimeter and millimeter waves(Pasternack, 2017).

Standard	Band Name	Frequency (GHz)
ITU	EHF	30-300
IEEE	Ka	27-40
	V	40-75
	W	75-100
	mm	110-300
Waveguide Bands	Q	33-50
	U	40-60
	V	50-75
	E	60-90
	W	75-110
	F	90-170
	D	110-170
	G	140-220
	Y	170-500

METHODOLOGY

In this section, the methodology for the design of the proposed antenna is presented. The rectangular microstrip patch antennas is a commonly adopted shape in the design of wideband antenna capable of operating in the microwave and millimeter wave frequency bands which is considered in this paper. Figure 1 shows the structure of the proposed antenna on the rectangular microstrip patch operating at 60GHz for 5G mobile application. The front view of the antenna contains a rectangular radiator of about $2.9 \times 3.5 \text{ mm}^2$ in dimension which is fed through a 50Ω feed line probe of about $2.15 \times 0.41 \text{ mm}^2$ in dimension. On the back view, there is a ground plane of about $7.5 \times 8 \text{ mm}^2$ in dimension with a substrate between it (ground plane) and the radiator. Rogers RT5880 which has a dielectric constant of 2.2, loss tangent 0.0009, and thickness h of the copper 0.003 mm is used due to it light weight and high efficiency.

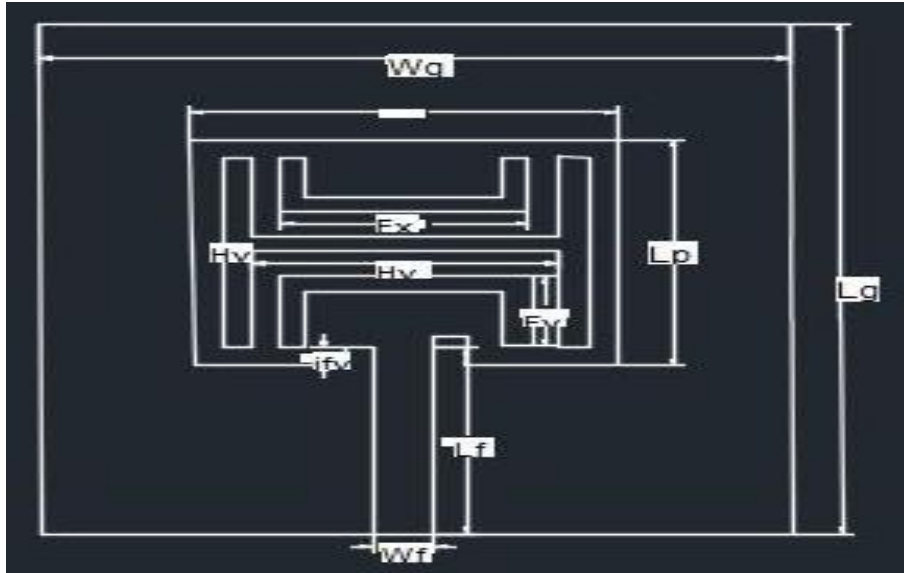


Figure 1. Geometry of the proposed Antenna.

The patch radiator is designed using closed-form equations for the fundamental mode in the following steps:

- i. The width (W_p) of the patch is calculated using (1).

$$W = \frac{c}{2f_0 \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

Where: $\epsilon_r = 2.2$ is the relative permittivity of the dielectric substrate, c = speed of light in vacuum, and $f_0 = 60$ GHz is the resonant frequency of the antenna.

- ii. The length (L_p) of the patch is determined using (2).

$$L = L_e - 2\Delta L \quad (2)$$

Where: L_e and ΔL are the effective length of the patch and the path length extension which are determined using (3) and (4) respectively.

$$L_e = \frac{c}{2f_0 \sqrt{\epsilon_e}} \quad (3)$$

$$\Delta L = 0.412h \frac{(\epsilon_e + 0.3) \left(\frac{W}{h} + 0.2 \right)}{(\epsilon_e - 0.2) \left(\frac{W}{h} + 0.8 \right)} \quad (4)$$

Where: ϵ_e is the effective relative permittivity of the dielectric substrate and is determined using (5).

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + \frac{1}{W}}} \right] \quad (5)$$

h = height of the dielectric substrate.

The H and U slot cut on the patch help to enhance the impedance bandwidth, the length and width of U slot pair are cut at 1.5 mm and 1.35 mm respectively. Table. 2 provides detail dimension of the antenna and slots used to achieve 60 GHz frequency with ultra-wide bandwidth.

Table 2. Dimension of the Proposed Antenna

Parameter	wg	lg	Wp	Lp	Wf	Lf	lfx
Dimension (mm)	8	7.5	3.5	2.9	0.41	2.15	0.2
Parameter	lfy	Hx	Hy	Ex	Ey	D	h
Dimension (mm)	0.2	2.4	2.5	1.5	1.35	0.3	0.003

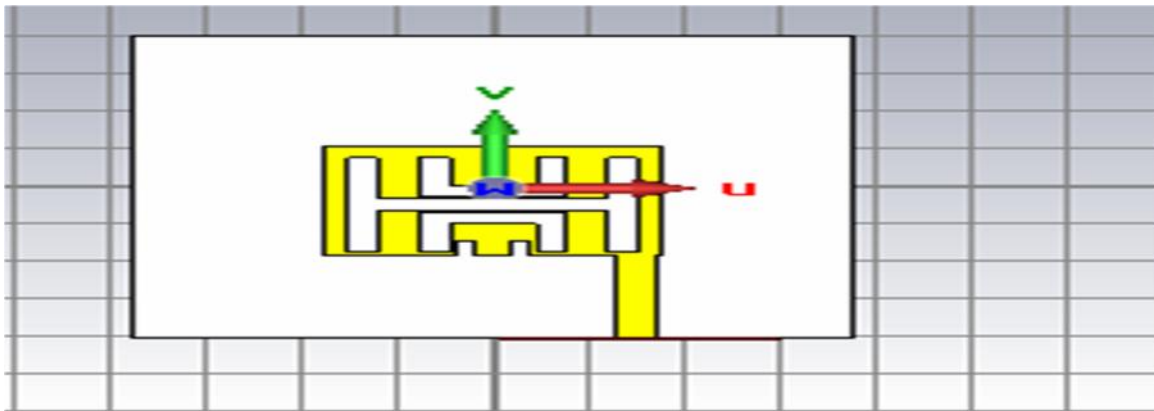


Figure 2. The Simulated Microstrip Patch Antenna.

Simulation Result and Discussion

The antenna was modeled and simulated using Computer Simulation Technology (CST) Microwave commercial software programs and each layer of the proposed design was assigned with its respective physical and electrical properties. The result of the return loss, VSWR (Voltage Standing Wave Ratio), gain and the radiation pattern of the single patch element obtained is shown in Figure 3 through Figure 7. The $|S_{11}|$ parameters at 60 GHz is about -41.65 dB taken as the base value which is favorable for mobile communication as shown in Figure 3. The acceptable level of VSWR for wireless application should be in the ratio of 2:1 and Figure 4 provide a good VSWR at in the ratio of 1.8:1. The antenna achieved a high gain of 8.82dB at 60 GHz which is considered excellent in terms of a compact microstrip patch antenna as shown in Figure 4. The radiation pattern at $\phi=0^\circ$ and $\theta = 90$ is presented in Figure 5, and a nearly omnidirectional pattern of the proposed antenna is achieved with a small back lobe. Table 3. Summarizes the results finding of the design.

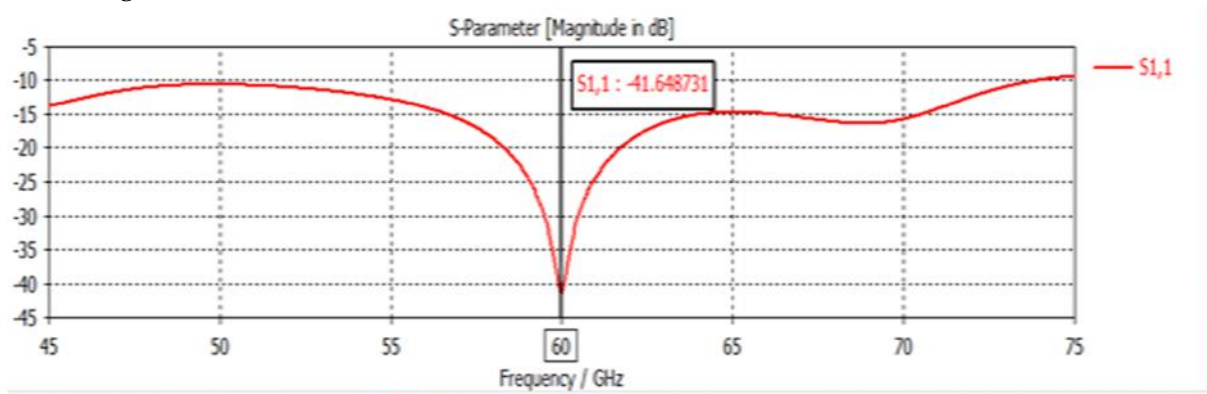


Figure. 3 Reflection coefficient magnitude against frequency for the design antenna.

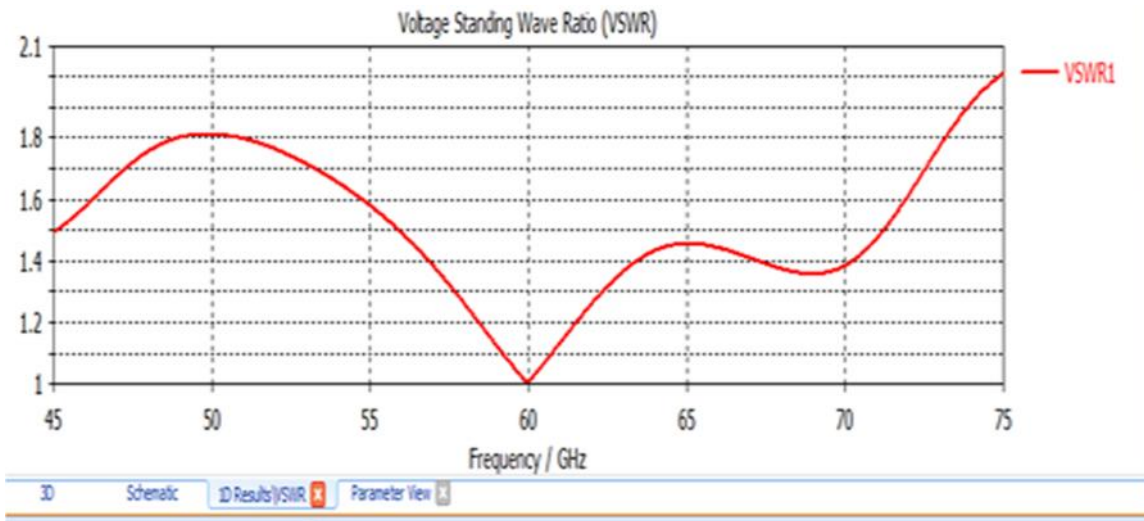
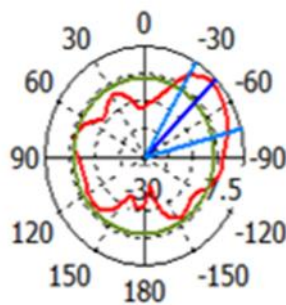


Figure 4. VSWR curve of proposed antenna

Farfield Directivity Theta (Phi=0)

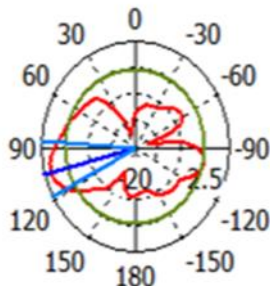


Theta / Degree vs. dBi

— farfield (f=60) [1]

Frequency = 60
 Main lobe magnitude = -1.4 dBi
 Main lobe direction = -45.0 deg.
 Angular width (3 dB) = 44.4 deg.
 Side lobe level = -7.3 dB

Farfield Directivity Theta (Theta=90)



Phi / Degree vs. dBi

— farfield (f=60) [1]

Frequency = 60
 Main lobe magnitude = 7.59 dBi
 Main lobe direction = 105.0 deg.
 Angular width (3 dB) = 32.0 deg.
 Side lobe level = -5.5 dB

Figure 5. Simulated 2D radiation pattern (a) Theta = 0° (b) Theta = 90°

Table 3. Summary of the simulated results.

Antenna parameter	$ S_{11} $ at 60 GHz	VSWR	Realized Gain (dB)	Bandwidth (GHz)
Specification Detail	41.65dB	1.8:1	8.82	30

CONCLUSION

In this paper, a rectangular microstrip patch antenna is proposed and designed for 5G mmWave wireless communication. The antenna resonates at 60 GHz with a return loss of about -41.65 dB, the bandwidth achieved at -10 dB reference point is about 23 GHz (50 - 73 GHz) for wideband application. The realized gain of the antenna is 8.84dB with omnidirectional radiation pattern. The integration of the antenna can be done in devices where space is a major concern and can be used in future 5G wireless devices.

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