Wideband 8×8 patch antenna array for 5G wireless communications

MD SAMSUZZAMAN[*,a,b], NORBAHIAH MISRAN[a], MD TARIKUL ISLAM[a], MOHAMMAD TARIQUL ISLAM[a]
*a*Faculty of Engineering and Built Environment,Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia
*b*Faculty of Computer Science and Engineering, Patuakhali Science and Technology University, Patuakhali, Bangladesh

This paper presents a broadband cross-shaped patch antenna with an elliptical slotted ground plan as single unit for coming 5G wireless communication networks. The proposed single antenna has resonating wideband frequencies from 22 to 45 GHz, which cover 28 GHz and 38 GHz operating frequency. The radiation efficiency of the single unit antenna is 92% at 28 GHz and 90% at 38 GHz. The measured return loss of at 28 GHz is -17.66 dB with maximum gain of 3.81dBi while return loss of 38 GHz is -13.24 dB with maximum gain of 4.86dB. The antenna is designed on low loss Rogers's 5880 substrates with dielectric constant 2.2 and dielectric loss of 0.009. The antenna has compact dimension of 0.392λ0 × 0.392λ0 × 0.019λ0 at 28 GHz. The proposed single unit antenna also fabricates in lab and validate with reflection coefficient simulation results. An 8×8-array configuration is also investigated to achieve maximum gain of 18.3dBi at 28 GHz and 20.7 dBi gain at 38 GHz, respectively. 3D electromagnetic simulator CST microwave studio and HFSS are applied for the layout design and characterizations of the antenna performance.

1. Introduction

Over the last decades, the wireless communication industry has established from the 3G technology towards 4G; then now it is going towards the 5G technology for the highest data rate. Several countries have already deployed the 4 G (Long Term Evaluation -LTE) technology for the high data rate. However, there is still a facing some problem like data rate, high-energy consumption and congested spectrum that are not solved by LTE technology. Nevertheless, for the next generation wireless communication technology, the increasing demand for higher data rate with lower energy consumption has put great interest in developing the 5G advanced technology [1]. 5G technology will be more advanced than the 4G in terms of its various characteristics like extremely high bandwidth and data rate.

5G technology was introduced in a new era of digital mobile communications systems, which introduces the Internet of Things (IoT) into the network of devices (D2Ds)[2] with wider bandwidth [3], lower battery consumption, higher data rates and better coverage [4], and will solve various challenges such as latency, security, reliability, availability and equipment costs [5]. Spectrum allocation is one of the main concerns of 5G communications. The fifth generation of mobile communications is being studied in the millimeter-wave band [2, 6-8]. Some of the expected bands which are recommended by FCC for 5G mobile communications are 27.5–29.5 GHz, 33.4–36 GHz, 37–40.5 GHz, 42–45 GHz, 47–50.2 GHz, 50.4–52.6 GHz and 59.3–71 GHz [9]. However, for cellular communications, the 28 GHz and 38 GHz bands are advantageous [9, 10], but operating at

higher frequency bands will bring complexity in the antenna design of mobile communication system [11-13]. To increase the data transfer rate, high gain antenna will be required for this type of frequency band. Microstrip antenna has several advantages compared to conventional microwave antennas some of them are lightweight, low volume and thin profile configurations, which can be made conformal, low fabrication cost, and can be easily integrated with microwave integrated circuits [14-16]. An analysis is done on a compact square shaped split ring resonator with rectangular stub connected in the outward direction to achieve triple band characteristics for LTE/ WLAN/ WiMAX applications where the lower band is narrow [17]. A metamaterial inspired antenna is described for Wi-Fi, WLAN and WiMAX applications where a straight feed line with inverse L slotted resonators are used to get dual band properties. In this work, the bandwidth at the lower band is also not enhanced [18]. A T-shaped patch antenna with a set of split ring resonators is proposed to achieve miniaturization but resulting in a very poor bandwidth [19]. Broad bandwidth, directional radiation pattern and comparatively high gain which are potential for 5G communication applications are provided by higher thickness based substrate with lower dielectric constant and low tangent loss. Several research works of 5G microstrip patch antennas have already done by many researchers. However, low patch antenna gain (gain <5 dB) is the vital disadvantageous of patch antenna design for 5G applications. Now the researcher is trying to increase the gain of patch antenna by introducing various technique like array antenna, stack type array antenna or metamaterial loaded antenna [2, 3, 6, 11, 13, 20-27]. Array antenna can be constructed through identical elements

with same orientation with a systematic way where the antenna array elements can receive and transmit the electromagnetic wave in the identical pattern. By adding each antenna, array elements the high power antenna beam is made to increases the total gain of the array antenna gain [28].

Recently some researchers have put forward various patch antenna designs particularly for the 5G mobile communications. Dual-band (28/38) GHz slotted patch antenna was designed through integration four antenna elements by introducing Wilkinson power divider for 5G wireless communication networks [26]. By using four elements antenna with 35mm×25mm×1.575mm, the proposed antenna gain was achieved 7.47 dBi and 12.1 dBi. A compact patch antenna for 5G mobile communications was presented with resonant frequencies at 10.15 GHz and 28 GHz and maximum gains of 5.51 dB at 10.15 GHz and 8.03 dB at 28 GHz [25]. The antenna was designed using a Rogers-5880 substrate with thickness of 0.787 mm and total area of 21mm×21 mm. APIFA antenna for 5G application was presented with operating frequencies of 28 GHz and 38 GHz consisting of shorted patch with a U-shape slot etched in the radiating patch [22]. The maximum gain obtained at 28 GHz is 3.75 dB and 5.06 dB at 38 GHz. An FR-406 substrate is used to isolate ground and the patch. A small antenna was proposed which was excited with coplanar waveguide (CPW) feed, attaining a maximum gain of 6.6 dB at 28 GHz, while a Roger RT5880 substrate is used with the size of 5×5 mm and height of 0.254 mm [24]. The authors have introduced an antenna array for 5G cellular networks and MIMO applications [29]. This array network helped in achieving a maximum gain of 6.6 dB at 28 GHz. A 5G capable slotted microstrip patch antenna having a resonance frequency at 11 GHz with a compact size of 22 mm ×19 mm has been presented [20]. The antenna has a directivity of 6.348 dBi and maximum gain of 6.3 dBi. The authors introduced a compact antenna using a microwave dielectric ceramics substrate for 5G applications with small size dimensioning as 14 mm×14 mm. The maximum gain for the design is 5.4 dBi with 93% radiation efficiency [27]. A T and L-shaped slotted microstrip patch antenna for future 5G mobile and wireless communication was presented, using FR4 epoxy material as the substrate with dimensions of 10 mm ×10 mm×1.6 mm [21]. The operating frequency of the antenna here is 28 GHz with the highest gain of 5.57 dB for the said resonant frequency.

The design complications such as complexity and larger size, along with low radiation efficiency, low gain are some of the main concerns associated with the cited research in the literature review section. The aim of this research is, therefore, to overcome the low performance and design complexity of the microstrip patch antenna for 5G mobile communication networks. An easy to fabricate microstrip patch antenna is proposed here, having an elliptical slotted circular radiating patch over a Roger RT-5880 substrate, due to its low dielectric constant and low loss dispersion, which is considered as a suitable material for Gigahertz frequency range. The required high gain and

radiation pattern for mobile communication is achieved by using an 8×8 array structure.

2. Design Layout of the Single antenna Structure

The geometric layout of the proposed antenna is shown in Fig. 1. For efficient 5G antenna, a compact wideband antenna with high gain is desirable that will be efficient in transmitting and receiving signal with minimal frequency dispersion. For this purpose, a compact, low profile, wider bandwidth, and the high efficient antenna is suitable. The prototype presented in this work has modified shaped radiating element with a dimension of 4.2 mm × 4.2 mm × 0.2 mm. For this dimension, the resonance frequency, in general, can be calculated using the equation [30, 31].

$$f_r = \frac{c}{\left[x\sqrt{2(\varepsilon_r + 1)} \right]} \qquad (1)$$

where fr is the center frequency, the speed of light is c, ε_r denotes relative permittivity, and overall length of the main resonator is **x**. The dimension is optimized such a way that it can radiate efficiently with large bandwidth spectrum. A modified slotted antenna is generated from a rectangular microstrip patch antenna. For analyzing the microstrip patch antennas, the most popular models are full-wave model, line model and cavity model that comprise primarily integral equations also called moment method. The simplest model is the transmission line model that delivers a good physical perception. So this method is mostly accepted for designing the proposed antenna. The antenna coves two radiating elements connected with the transmission line W_1. The nonhomogenous line is consists of two dielectrics, one is substrate, and another one is surrounding air. The radiator dimension is considered by the simplified formulation of the transmission line model [30, 31]. The antenna width is calculated by:

$$W = \frac{c}{2f_r} \left(\frac{\varepsilon_r + 1}{2} \right)^{-\frac{1}{2}} \qquad (2)$$

Here, c is the speed of light in free space, and f_r is the resonant frequency. To find the effective permittivity of the substrate the equation can be derived as:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \frac{12h}{W} \right)^{-\frac{1}{2}} \qquad (3)$$

Here, h is the substrate thickness. The path length (L) can be calculated as:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{re}}} - 2\Delta L \qquad (4)$$

The first important step in designing an antenna was the selection of the material substrate. The impedance matching and bandwidth of an antenna are highly influenced by the parameters of the substrate like height, dielectric constant and tangent loss (tan δ). High copper losses may occur due to using a very thin substrate while a thicker substrate can degrade the performance of antenna due to surface waves. In the proposed antenna design, a Roger RT-5880 substrate is used whose dimension,and electrical properties are given Table 1. The rogers substarte is used because of low loss and compatible for high frequency applications.
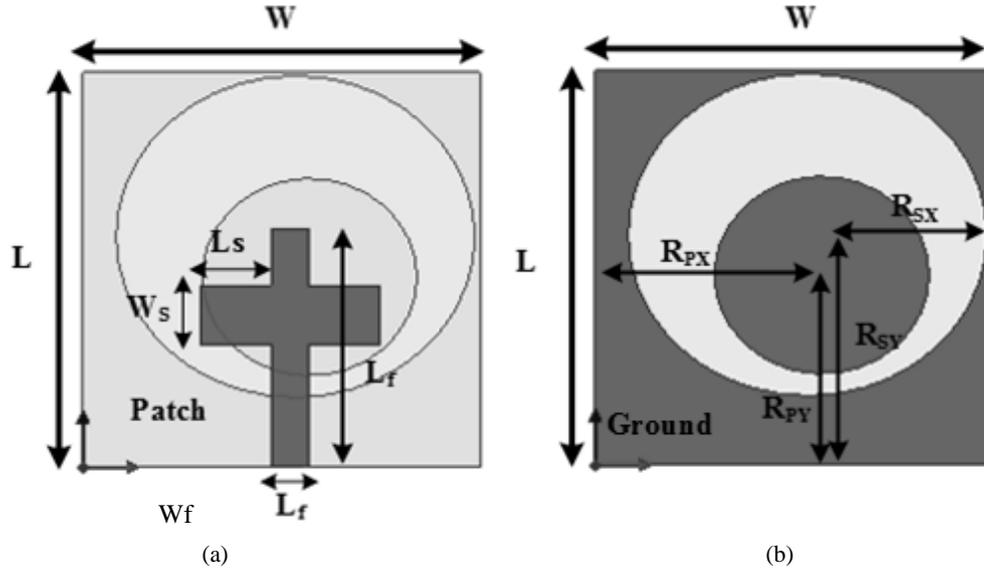
Fig. 1. Geometric design layout of the single unit (a) top view, and (b) the bottom view

The designed antenna dimensions s 4.2 mm × 4.2 mm with thickness 0.2 mm. The designed antenna consists of a cross shaped patch in the one side of the substrate and elliptical slot with elliptical parasitic element on the other side of the substrate. The level of resistance of the feed type of microstrip is 50Ω, which is definitely for the excitation of the substrate. An individual stub has been connected with shunt into the transmission feed line to improve impedance coordination. The overall performance of the proposed antenna preliminary design offers been analyzed in HFSS and CST simulation software program. The very first stage of the proposed antenna style we have tested in different shape to achieve a broad bandwidth, which is depicted in Fig. 2. It can be stated that by improving the coupling between elliptical slot and feed line and changing slot size and form great impedance coordinating can be obtained. We have selected to feed the cross-shaped form patch with 50-ohm impedance line. Right here, the cross-shaped patch element used as the microstrip line termination offers even more wideband behavior compared to the other ones. Fig. 3 defines the simulated consequence of reflection coefficient (S_{11}) of different designs shape of the antenna in HFSS, which may help us to select the right form of patch for broadband application. The maximum bandwidth is obtained by using the Table 2 optimized parameter through proposed design.

Table 1. Electricand dimension properties of the substrate

Parameter	Values
Substrate Dimension	4.2mm×4.2 mm
Dielectric Constant	2.2
Tangent Loss	0.009
Substrate Height	0.20 mm

Table 2. Design dimension of the proposed single antenna

Parameters	Values(mm)	Description
Ls	0.75	Cross patch length
Ws	0.63	Cross patch width
Rpx	2.4	Parasitic elliptical center from edge length X
Rpy	2.02	Parasitic elliptical center from edge length X
Rsx	2.25	Elliptical slot center from edge length X
Rsy	2.45	Elliptical slot center from edge length X
Lf	2.53	Feed length
Wf	0.75	Feed width
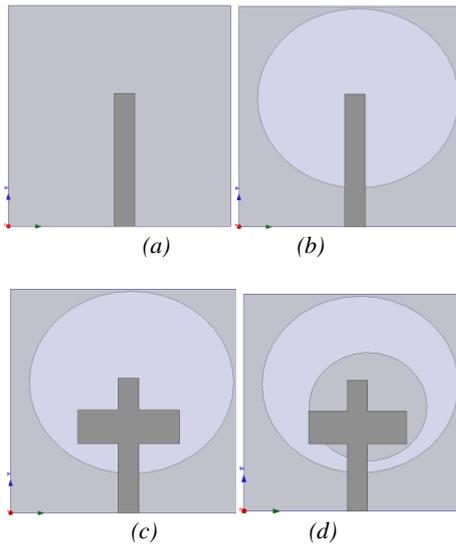
*Fig. 2. Different shape of the antenna a) design 1
b) design 2, c) design 3 and d) proposed design*
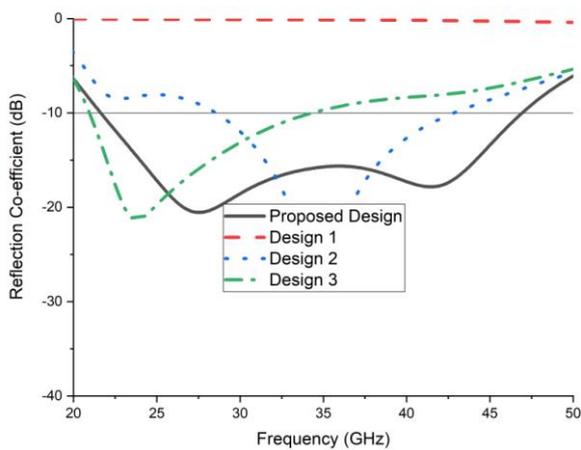
*Fig. 3. Parametric reflection coefficient (S_{11}) for
different shapes (color online)*

3. Results and discussion

The antenna is fabricated using low loss Rogers's 5880 dielectric substrates with the height of 0.20 mm. Fig. 4 depicts the fabricated sample prototype of the proposed antenna and measurement setup. The Agilent N5227A (10 MHz-67 GHz). PNA is used for measurement of reflection coefficient (S_{11}) parameter in microwave lab, UKM. There is a reasonable agreement between measured and simulated results as depicted in Fig. 4. Both the simulated (HFSS and CST) and measured reflection coefficient results of the proposed antenna graph justify the required band of operation for 5G applications. From the graph, it is clear that the simulated S11 is less than -10dB in the ranges of 22- 45 GHz (HFSS) and 20 -42 GHz (CST), while in measured S11 is less -10 dB in the ranges of 22-44 GHz. The proposed antenna's peak gain, which is depicted in Fig. 7, obtains from HFSS and CST simulation software

and gain varies from 3.1dBi to 5.2dBi. The simulated radiation efficiency of the proposed antenna is displayed in Fig. 8. It can be seen that the proposed antenna was realized more than 85% radiation efficiency across the desired operating band.
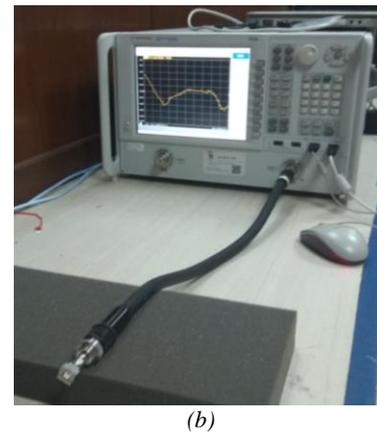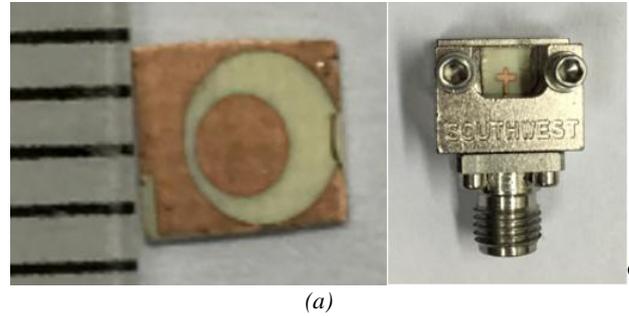
*Fig. 4. (a) Fabrication layout and (b) Measurement
setup of the proposed antenna*
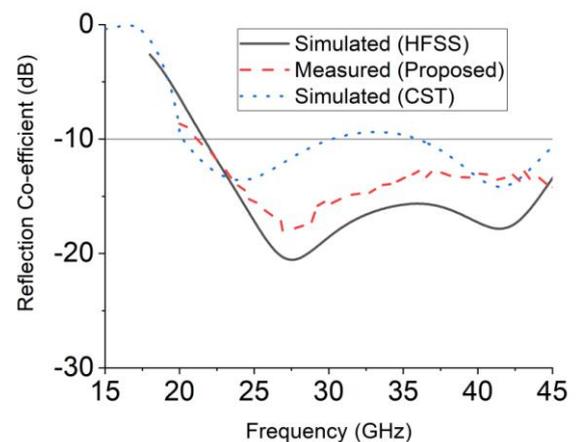
*Fig. 5. Simulated and measured reflection coefficient
(S_{11}) results (color online)*
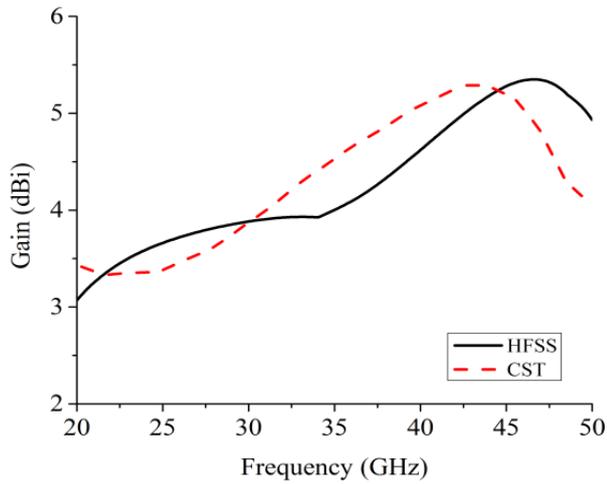
Fig. 6. The simulated (CST and HFSS) peak gain results of the proposed antenna (color on line)
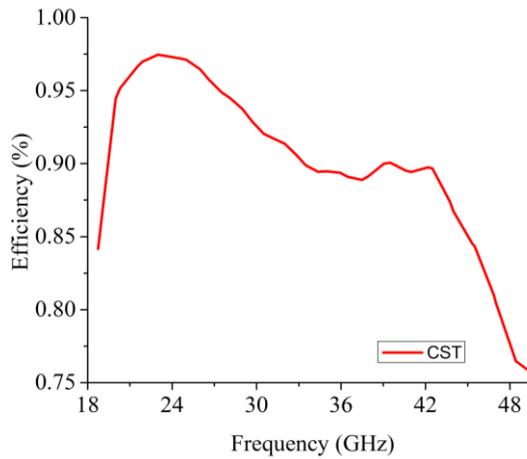
Fig. 7. The radiation efficiency of the proposed antenna

The 2D radiation patterns at 28 GHz and 38 GHz frequencies are depicted in Fig. 8 in the XZ and YZ of the major planes. The solid line represented the co plane and dashed line represents the cross-plane radiation pattern. From the 2D radiation pattern of Fig. 8, it can be stated that the antenna exhibits an almost omnidirectional pattern in both planes. 3D gain plots for the single antenna configuration are shown in Fig. 9 at the specific frequencies of 28 GHz and 38 GHz respectively. It can be clearly observed from Fig. 9 that the single antenna exhibits dipole like radiation pattern at both frequencies. Surface current distributions of microstrip antenna at target frequencies of 28 GHz and 38 GHz are given in Fig. 10. The electric field is manufactured by current flow through the feed line. From the top current distribution, it could be noticed that current source through the feed collection has been distributed over the patch and at higher current source through the patch formed so the proposed antenna fulfills the mandatory characteristics.

XZ   YZ

(a)

(b)
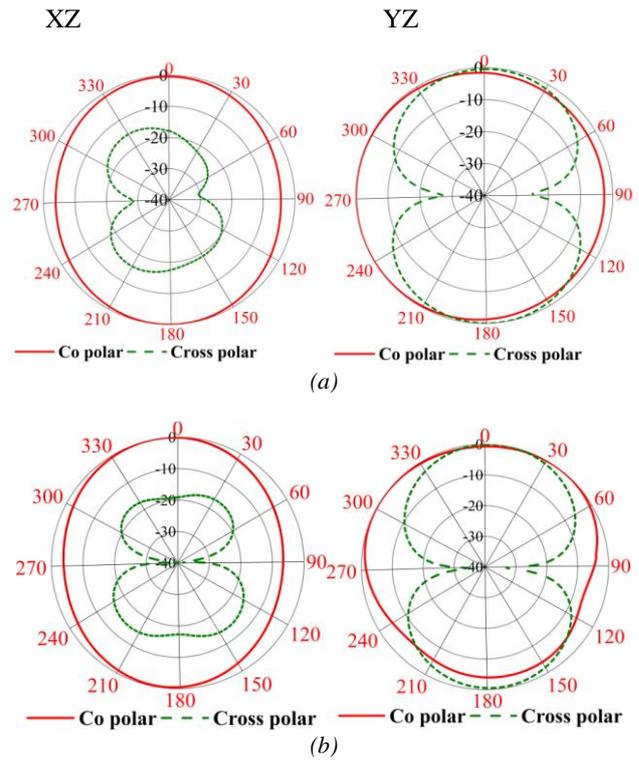
Fig. 8. Polar plots of XZ and YZ plane at (a) 28 GHz and (b) 38 GHz (color online)

(a)

(b)
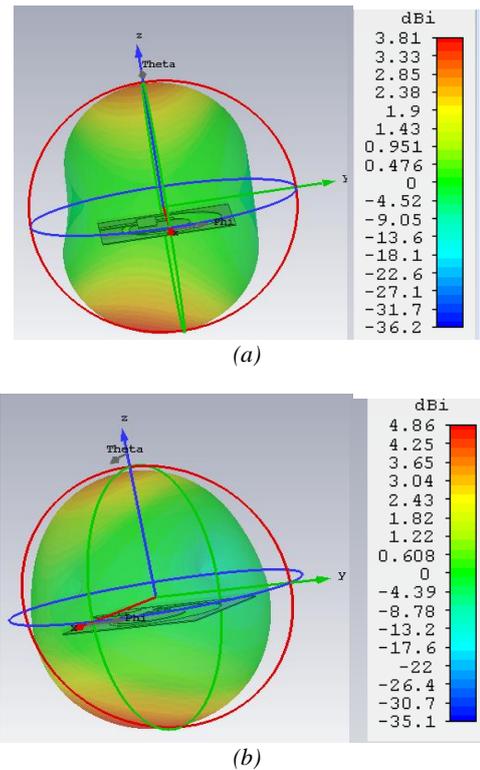
Fig. 9. 3D gain plots of the single antenna configurations at (a) 28 GHz and (b) 38 GHz (color online)
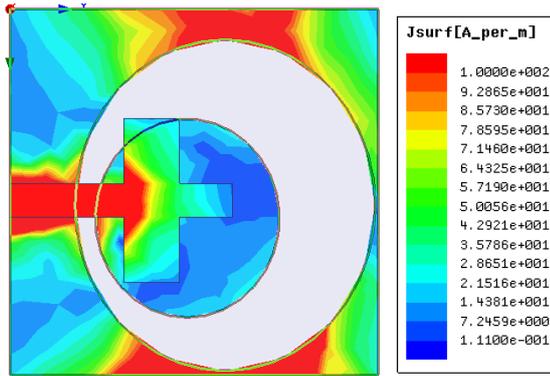
(a)
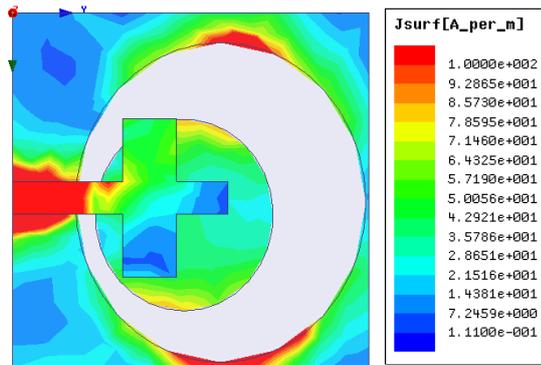
(b)

Fig. 10. Surface current distributionsof the single antenna
at spot frequencies of (a) 28GHz and (b) 38GHz (color online)

Fig. 11. 8×8 array layout of the proposed array
antenna configuration
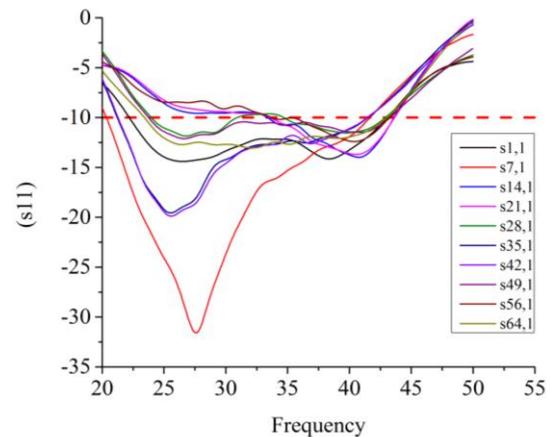
Fig. 12. S-parameters of the proposed array configuration
(color online)
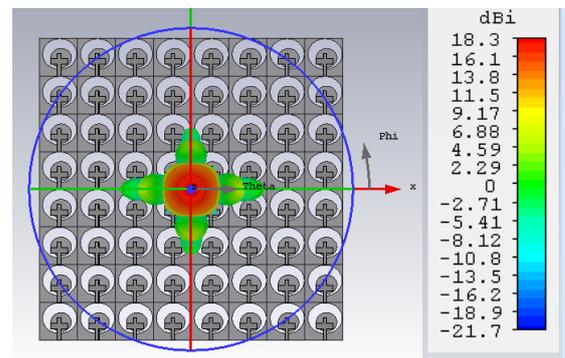
(a)
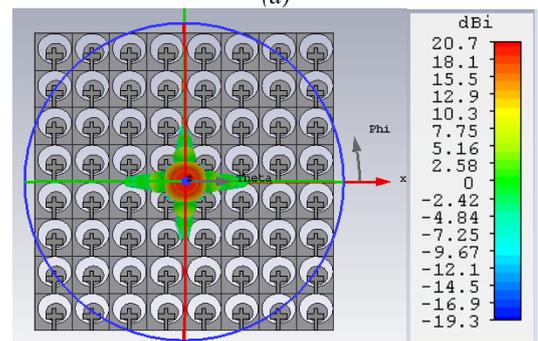
(b)

Fig. 13. 3D radiation pattern of 8x8 array at (a) 28 GHz
and (b) 38 GHz (color online)

The proposed antenna is applied to a 5G communication system that holds an array of the antenna. Nevertheless, it is essential to examine the value of the mutual coupling between those antennas. There are 64 antennas used to form antenna array for 5G communication system with 8 columns, and 8 rows are shown in Fig. 11 which is design in CST simulation software. The overall dimension of the proposed array antenna is about 36.60 mm ×36.60 mm×0.2 mm. In order to access the performance of the 64 antennas array system we examine S11, S21, S31, S41, S51, S61, S71….S64,1 correlation in Fig. 12. The antenna array works within 22 GHz to 42 GHz with more gain. 3D gain plots for the array configurations are displayed in Fig. 13 at the spot frequencies of 28 GHz and 38 GHz, respectively. It is observed from the figure that with increase in gain the beam width becomes narrower. Fig. 14 shows the 2D Cartesian far-field radiation of the 8×8 antenna in Phi =0 and Phi = 90. Main lobe magnitude is -3.57dBi with side lobe level -5.3dB and angular width is 14.2 degree for phi 0, and main lobe has been increased for 38 GHz. The increased lobe is 4.25dBi. Simultaneously main lobe magnitude is 18.3dBi at 28 GHz, and 20.7dBi for phi 90 at 38GHz and angular width is 11.8 degree. The polar plot of the proposed array antenna also discussed in the Fig. 16 and Fig. 17 at 28 GHz and 38 GHz respectively.

(a)

(b)

Fig. 14. 8x8 array antenna of 2D far-field of Phi=0 at
(a) 28GHz and (b) 38GHz (color online)
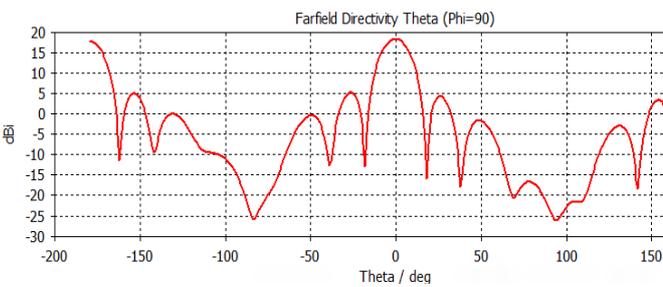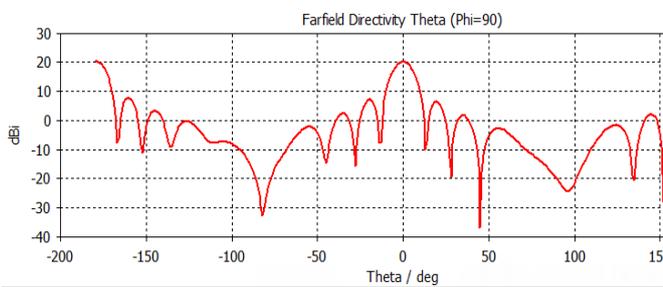
(a)

(b)

Fig. 15. 8×8 array antenna Far-field of Phi=90 at
(a) 28GHz (b) 38GHz (color online)
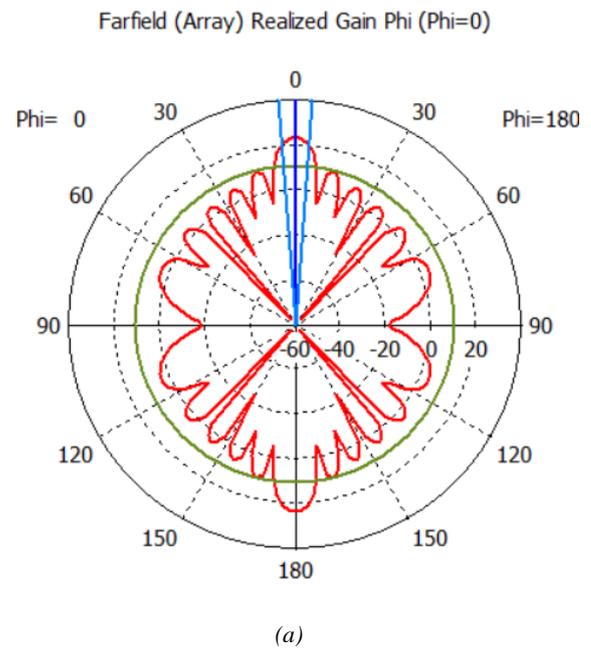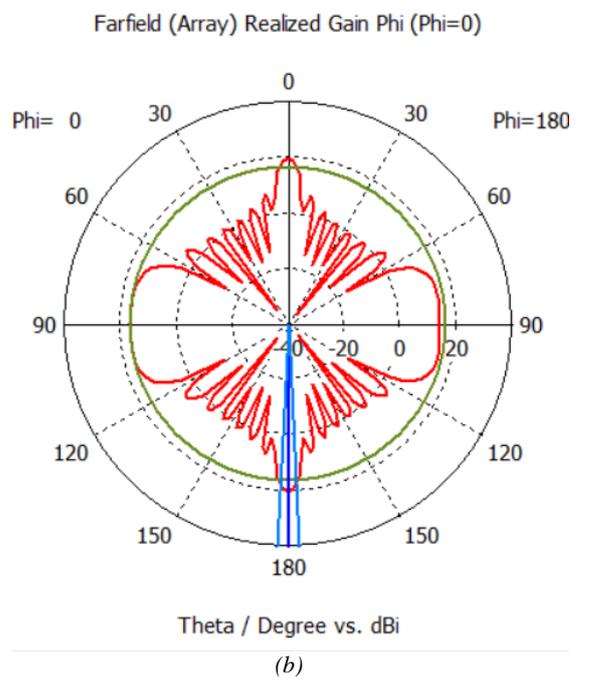
(a)

(b)

Fig. 16. 8×8 array antenna of 2D far-field of Phi=0 at
(a) 28GHz and (b) 38GHz (color online)

Farfield (Array) Realized Gain Theta (Phi=90)

(a)

Farfield (Array) Realized Gain Theta (Phi=90)

Theta / Degree vs. dBi
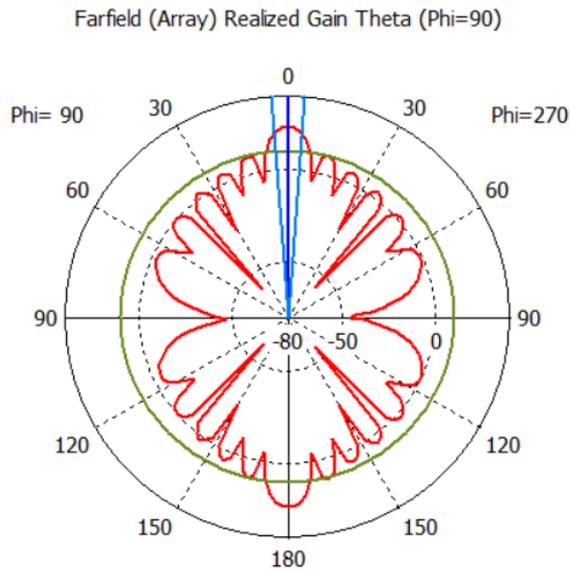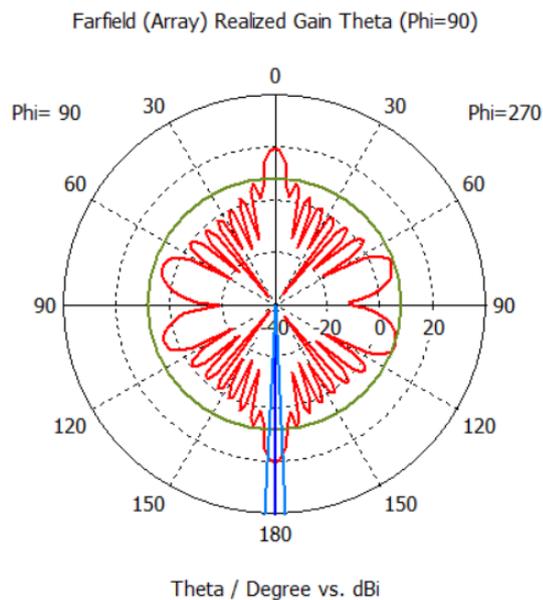
(b)

Fig. 17. 8×8 array antenna Far-field of Phi=90 at
(a) 28 GHz (b) 38 GHz (color online)

Table 3 summarizes the performance of the existing literature in the introduction section with the proposed antenna. The design complications such as complexity and larger size along with low radiation efficiency, low gain are some of the major concerns associated with the existing literature research. The aim of this research is, therefore, to overcome the low performance and the design complexity of the microstrip patch antenna for 5G mobile communication networks.

Table 3. Comparison of the proposed antenna with existing antennas

Ref.	Antenna dimension (mm^2)	Frequency (GHz)	Gain (dBi)	Efficiency (%)
[25]	21×21	10, 28	7.5	62
[22]	3×7	28, 38	3.7	69
[24]	5×5	28	6.6	73
[29]	120×40	28	6.6	77
[20]	22×19	11	6.3	-
[27]	14×14	28	5.4	93
[21]	10×10	28	5.57	-
[32]	6×6	28,45	7.6,7.21	85.6, 95.3
Proposed	4.2×4.2 – Single 36.60×36.20	28, 38	3.81,4.86 18.3,20.7	92, 90 -

4. Conclusion

A new broadband rectangular microstrip antenna with elliptical ground slot and elliptical parasitic element based antenna is presented in this article for 5G wireless applications. The proposed single antenna is further configuration to an array of 8×8 element antenna for broadband 5G applications. The antenna consists of the cross-shaped patch with elliptical slotted ground plane. The unit cell dimension is 4.2 mm×4.2 mm along with 0.2 mm of height, which is printed on high dielectric Rogers's substrate. Cross-shaped patch and rectangular ground with the elliptical slot is associated with a 50-Ω microstrip transmission feed line. The maximum gain of 3.81 dBi is achieved at 28 GHz for single antenna and gain of 4.86 dBi at 38 GHz, and the gain is further increased to 18.3dBi at 28 GHz in array configuration to make the antenna system suitable for 5G mobile applications, with a gain of 20.7dBi at 38 GHz. The directional properties of the radiation pattern are also simulated for the specific 5G specific frequencies 28 GHz and 38 GHz and were found to be in good competition with designs already available in the existing researches. Since the proposed antenna is less, expensive and simple to design with high data transfer capacity to utilize 5G wireless communication applications.

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[*]Corresponding author: samsuzzaman@ukm.edu.my