

5G Fixed Beam Switching on Microstrip Patch Antenna

Low Ching Yu, Muhammad Ramlee Kamarudin

Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM),
Malaysia

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ABSTRACT

5G technology is using millimeter-wave band to improve the wireless communication system. However, narrow transmitter and receiver beams have caused the beam coverage area to be limited. Due to propagation limitations of mm wave band, beam forming technology with multi-beam based communication system, has been focused to overcome the problem. In this letter, a fixed beam switching method is introduced. By changing the switches, four different configurations of patch array antennas are designed to investigate their performances in terms of radiation patterns, beam forming angle, gain, half-power bandwidth and impedance bandwidth at 28 GHz operating frequency for 5G application. Microstrip antenna is preferred due to its low profile, easy in feeding and array configurations. Three different beam directions had been formed at -15° , 0° , and 15° with half-power bandwidth of range 45° to 50° .

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Corresponding Author:

Low Ching Yu,
Wireless Communication Centre (WCC),
Faculty of Electrical Engineering,
Universiti Teknologi Malaysia (UTM),
81310 Skudai, Johor, Malaysia.
Email: lowchingyu@outlook.my

1. INTRODUCTION

Wireless communication has undergone a tremendous evolution to meet the demand of high traffic capacity due to the drastic increasing usage of smartphones and mobile electronic devices. Begin from 0G technology since 1970s, followed by 1G, 2G, and 3G, until today 4G technology, they show a great development on mobile technology from Radio Common Carrier (0G-RCC) to Long Term Evolution Advance (4G-LTEA). In order to meet the fast growing wireless data capacity demands due to increasing users of smartphones, high growth in web and streaming, 5G technology now are highly given attention and undergo a huge research. The 5G technology has huge data capabilities to support multi-Gbps data rates and has ability to gather unrestricted call volumes as well as infinite data broadcast within latest mobile technology [1]. Therefore millimeter-wave communication systems are required.

Millimeter-wave communication systems using narrow beams at the transmitter and receiver, which suppress the interference of neighboring beams. The narrow beam also strongly reduces the angular spread of the incoming waves and the multipath components of millimeter waves to be limited. Therefore, by having the beam forming, beam-forming weights can be adjusted to a desired area or location [2]. There are two types of beam forming technology. The first one is fixed beam forming and another is adaptive beam forming [3]. Adaptive beam forming forms effective beams by adapting beam width and beam direction depending on the surrounding state of radio channels. It requires high hardware complexity and needs extra feedback mechanism for beam forming. While in fixed beam forming, beams with a fixed direction and width are generated. Therefore, switched beam forming is introduced as it is simpler and lesser operation system than adaptive beam forming. The concepts of beam steering or beam shifting are developed for scanning array antennas. Scanning array antennas were developed initially for aircraft, maritime and

aeronautical applications. In terms of practical implementation, various technologies such as GPS, radio-frequency identification (RFID), tracking, traffic control and collision avoidance radars and wireless local area network (W-LAN), have been employed in developing the indoor localization and scanning systems [4].

Modern wireless communication systems require a low profile, lightweight, high gain and simple structure antennas to ensure reliability, mobility, and high efficiency [5]. Therefore, microstrip antenna is highly preferred due to its low profile, easy to fabricate and feed, and easy to use in the array or incorporate with other microstrip circuit elements [6].

Patch antennas are used as simple and highly preferred in many applications. Circular polarizations, dual characteristics, dual frequency operation, frequency agility, broad bandwidth, feed line flexibility and beam scanning can be easily obtained from these patch antennas [7]. The patch can take any shape with rectangular and circular configurations are the most famous. The radiation pattern of a patch array antenna is fixed. However, by controlling the progressive phase difference between the elements, the maximum radiation can be shifted in any desired direction to form a scanning array [8]. This type of antenna is called a phase array antenna.

In this letter, by controlling the switches, four different configurations of patch array antennas which operate at 28 GHz are designed and presented. The antennas are designed with beam shifted at $+15^\circ$ and -15° by consider the overall performances of the antenna in terms of gain, bandwidth, return loss, VSWR and side lobe level as well as beam shifted angle.

2. RESEARCH METHOD

Figure 1(a), (b), (c) and (d) show the proposed antennas with four different configurations to compare on their performances. Each antenna basically makes up of three layers. The lower layer is a fully ground plane with copper that covers the rectangular shaped substrate. The middle substrate is Rogers 5880 with dielectric constant, $\epsilon_r=2.2$ and dielectric loss tangent, $\tan \delta =0.0009$, and a height of substrate, $h=0.254$ mm. The thickness of the copper used is 0.017mm. The upper layer is the patch antenna. The rectangular patch has a size of 4.52×3.52 mm (width \times length). Distance between two patches is almost equivalent to $\lambda/2$ (calculate from center-to-center of the patches). Quarter wave transformer with power division method is used for matching patch by a microstrip line with 50Ω input impedance. The operating frequency of all designed antennas is about 28 GHz, which is suitable for 5G applications.

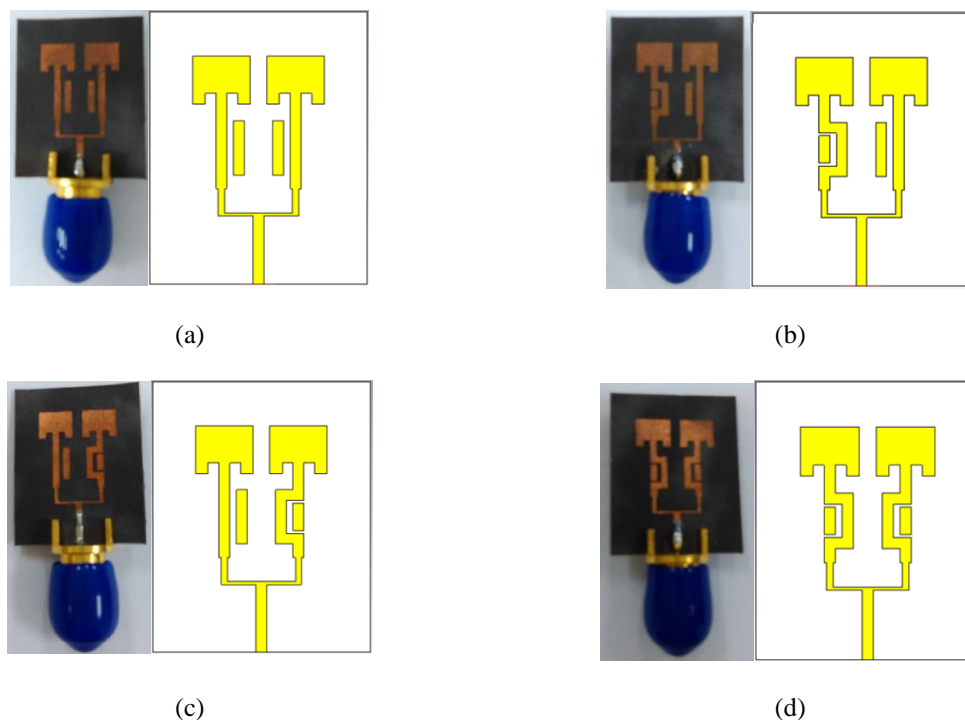


Figure 1. Four different configurations of patch array antennas designed. (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, (d) Antenna 4

Initially the patch antenna with a single radiating element was designed as shown in Figure 2. The calculations [8] on the dimensions of a single element of the rectangular patch antenna are shown below by Equations (1)-(7). Calculation of the patch width, W :

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

Substitute $c=3 \times 10^8$, $f=28\text{GHz}$ and $\epsilon_r=2.2$; $W=4.24$ mm. Calculation of Effective dielectric constant, ϵ_{eff} :

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \quad (2)$$

Substitute, $W=4.24$ mm and $h=0.254$; $\epsilon_{eff}=2.06$. Calculation of the Effective length, L_{eff} :

$$L_{eff} = \frac{c}{2fr\sqrt{\epsilon_{eff}}} \quad (3)$$

Substitute $\epsilon_{eff}=2.06$; $L_{eff}=3.73$ mm. Calculation of the length extension, ΔL :

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

Substitute, $W=4.24$, $h=0.254$ and $\epsilon_{eff}=2.06$; $\Delta L=0.13$ mm. Calculation of the actual length of antenna, L :

$$L = L_{eff} - 2\Delta L \quad (5)$$

Substitute $L_{eff}=3.73$ mm, $\Delta L=0.13$ mm; $L= 3.47$ mm. Calculation of the inset feed length, y_0 :

$$y_0 = \frac{L}{\pi} \left\{ \cos^{-1} \sqrt{\frac{Z_0}{Z_1}} \right\} \quad (6)$$

$$Z_1 = \sqrt{Z_0 Z_{in}} \quad (7)$$

where y_0 is width of inset, Z_0 is 50Ω transmission lines, Z_1 is characteristic impedance and Z_{in} is input impedance at the edge of the patch antenna. The parameters of the antenna had been optimized so that the antenna can perform optimally as shown in Table 1.

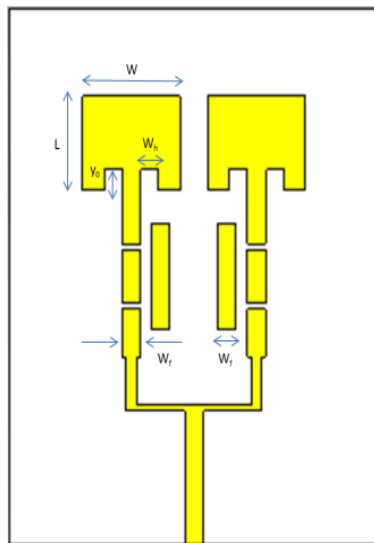


Figure 2. Dimension of designed antenna

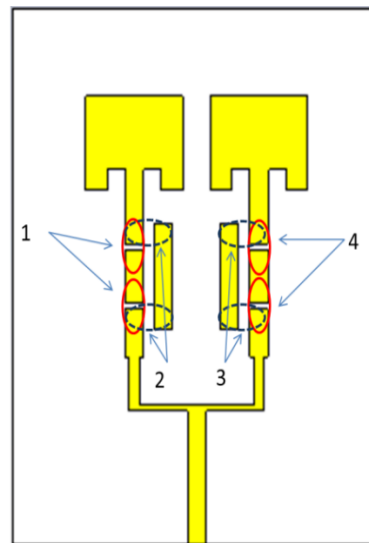


Figure 3. Switches on the designed antenna

Table 1. Optimized parameters of designed antenna

Parameter	Value (mm)
W	4.52
L	3.52
y_0	0.79
W_h	0.79
W_f	0.79

From the Figure 3, it can be seen that there are four locations of switches. By manipulating the switches, four different configurations of patch array antennas were designed as shown in Figure 1. In this letter, two radiating elements of patch array antennas are presented. The different configurations of designed antennas are comparing their performance in terms of gain, bandwidth and beam shift angle.

3. RESULTS AND DISCUSSION

The patch array antennas operate at 28 GHz is designed and optimized using software CST Microwave Studio. Simulated results of S-parameter designed antennas are compared with measured results given by the performance network analyzer. Simulated far-field radiation patterns for each different configuration of designing antennas are shown as well.

Figure 4 presents the measured and simulated reflection coefficient results $|S_{11}|$ of the fabricated antennas. Two different configurations of antennas designed (b) and (c) have an almost similar curve of $|S_{11}|$ due to both designed antennas are only opposite in the shape of the patch. The difference in the measured and simulated results is mainly caused by the shift in the resonant frequencies [9]. This frequency shift is due to fabrication tolerance on the insertion loss of Cu microstrip during etching and gravure processes. The reflection coefficients for all designed antennas are about -20 dB with some frequency shifting except for Antenna 4 which has the value of -12 dB. This is due to the structure of Antenna 4 causes significant mutual coupling between two radiating patches, influencing the return loss of the radiating elements [10].

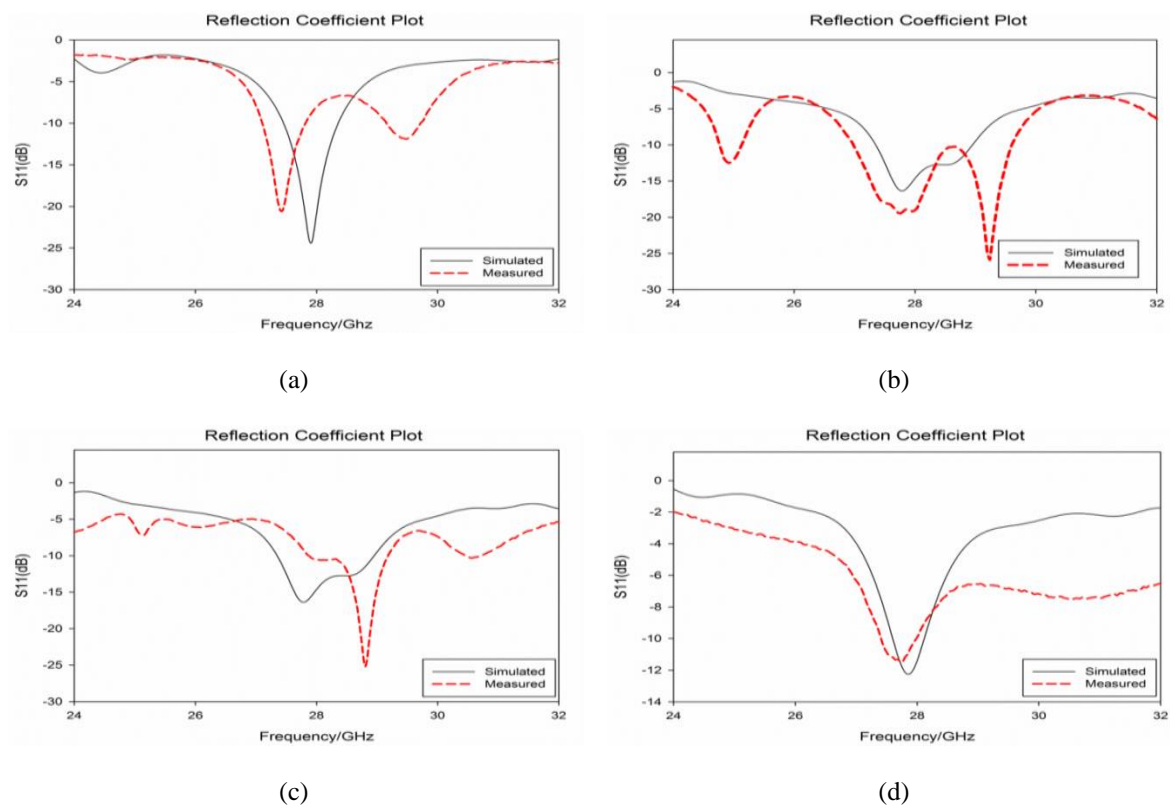


Figure 4. Measured and simulated return loss $|S_{11}|$ on four different configurations of patch array antennas designed, (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, (d) Antenna 4

Figure 5 shows simulated far-field for four different designed antennas. It can be seen that there is no beam shifting in Antenna (a) and Antenna (d) as there is no phase shift difference between two radiating patches. However, the main beam of the Antenna (b) and Antenna (c) have shifted by 15° . This is because the two radiating patch elements radiate at different rate due to the existence of phase shift difference. As a summary, manipulating the electrical length of the feeders can provide a phase difference between two patches of antennas.

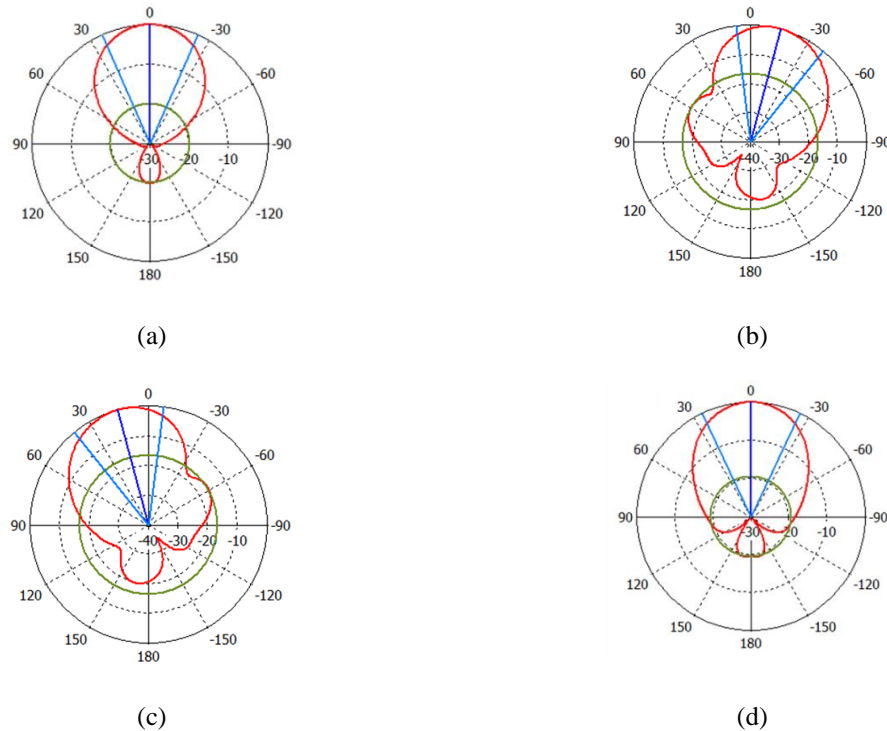


Figure 5. Simulated far-field cutting on the H-plane, (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, (d) Antenna 4

Table 2. Comparison of performances of four different configurations designed antennas

Antenna	Gain/ dB	Half Power BW Angle	Simulated BW/ GHz	Measured BW/ GHz	Beam's Shift Angle
1	10.9	47.5°	0.92	0.96	0°
2	10.4	45.9°	1.61	1.55	-15°
3	10.4	45.9°	1.60	1.30	15°
4	9.54	49.7°	0.51	0.60	0°

Table 2 shows the summary on the performances of the four units design antennas. Antenna 1 has the highest gain of 10.9 dB while Antenna 4 has the lowest gain of 9.54 dB. Antenna 2 and Antenna 3 have same gain of 10.4 dB as both structures are just opposite to each other. The simulated bandwidth (BW) and measured bandwidth show a good agreement as there is only slightly different in the taken reading. However, Antenna 4 has very low bandwidth with a simulated bandwidth of 0.51 dB and measured bandwidth of 0.60 dB. The low bandwidth is due to the strong mutual coupling between the elements that degrade the overall performance of the antenna array [11]. All the designed antennas have wide half power bandwidth of range 45° to 50° .

4. CONCLUSION

In this letter, the beam switching method with one input port to connect with two radiating elements phased arrays antenna were designed, fabricated, and analysed. The beam of the linear antenna array can be steered only in one plane. The simulated results showed that both Antenna 2 and 3 provide switched range from -15° to 15° in the H-plane, while Antenna 1 and 4 project the main beam at the broadside in the H-plane.

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BIOGRAPHIES OF AUTHORS



He received first degree in 2015 from Universiti Teknologi Malaysia in the field of Electrical & Electronics Engineering. Currently, he is doing his Master Research in Wireless Communication Centre (WCC), Universiti Teknologi Malaysia. His research interest is phased array antenna design for 5G applications.



Muhammad Ramlee Kamarudin obtained his first degree from Universiti Teknologi Malaysia (UTM), Malaysia, with Honours, majoring in Electrical and Telecommunication Engineering, graduating in 2003. He then joined UTM as a lecturer at the Wireless Communication Centre (WCC), Faculty of Electrical Engineering, UTM. He has been awarded a scholarship from the government of Malaysia to further study in the United Kingdom. He received the MSc in communication engineering in 2004 and the PhD in 2007 from University of Birmingham, UK. Dr. Ramlee is an author of a book chapter for book entitled "Antennas and Propagation for Body-Centric Wireless Communications", an IEEE magazine article, and a number of technical papers including journals and conferences on antennas performance and design for on-body communication channels and antenna diversity. His research interests include antenna design for wireless on-body communications, RF and microwave communication systems, and antenna diversity and reconfigurable. Currently, Dr. Ramlee is a member of IEEE, team member of Wireless Communication Centre (WCC) and supervising a number of PhD, Master and Undergraduate students.