International Journal of Electrical and Computer Engineering (IJECE)
Vol. 10, No. 3, June 2020, pp. 3086~3094
ISSN: 2088-8708, DOI: 10.11591/ijece.v10i3.pp3086-3094

Developed high gain microstrip antenna like microphone structure for 5G application

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Article Info

Article history:

Received Sep 20, 2019
Revised Nov 27, 2019
Accepted Dec 10, 2019

Keywords:

5G
CST
Microstrip patch antenna
Parasitic
VSWR

ABSTRACT

We present a new development of microstrip antenna structure combining a simple circular structure with a ring antenna structure as the parasitic element to improve the antenna gain and bandwidth for 5G mobile application. The proposed antenna was fed by a 50Ω microstrip feeding line due to its advantages in performance. The antenna was designed and simulated using a single substrate with double layered copper (top and bottom) with the radiating patch on the top layer and full ground on the bottom layer of the same substrate. Three antennas have been designed namely; design1, design2 and design3 to complete the research works. The antennas ware simulated and optimized at 18 GHz using Computer Simulation Technology (CST) with permittivity, $\varepsilon_{r=}$2.2 and thickness, *h*=1.57mm on low-loss material Roger RT-Duroid 5880 substrate. The antennas ware reasonably well matched at their corresponding frequency of operations. The simulation and measurement results have shown that the antenna works well. The simulation results have shown that the three antennas works well at the selected frequency. The final simulated antenna for design1, design2 and design3 has been fabricated to measure the performance and also to validate the simulation result with the measurement result. The measurement data for antenna design1, design2 and design3 shows frequency shift of 3% from the simulation result. The final protype of design3 gives 6.6dB gain,-14.51dB return loss, 180MHz bandwidth, and antenna efficiency of 53.9%. All three antennas ware measured using Vector network analyzer (VNA) and Anechoic chamber.

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1. INTRODUCTION

Many researchers have used microstrip antenna in their antenna design due to its advantages of light weight, low volume and thin profile configuration[1-3]. Most of the antenna development have chosen this microstrip antenna structure to focus on reducing the antenna size [4-5]. In the incoming 5G network technology, small size antennas are highly in demand to cater for high frequency allpication and thus, microstrip antennas are found to be among the most suitable antennas to be adopted for the next generation antenna devices. Easier to design, low profile configuration and wide range of applications [6] are some of reasons of why most of the researchers opted for microstrip antenna. Although the microstrip antenna possess a lot of advantages, the microstrip has some limitations. Among them are losses from the leakage at the open boundary, small radiated power and bandwidth, low power handling capabilities [7] and limited gain [8].

In advance, many antennas have been developed by many researchers such as in [5] to improve microstrip antenna performance and these scenarios have increase the antenna demand in many systems such as Wi-Fi [9], WiMAX [10], WLAN [11] and other applications [12]. Recently, the mobile application and design have experienced significant growth, especially due to the future 5G mobile network [13]. Many researchers have developed and designed their antennas based on these new requirements. Some researchers have designed their antennas to cover high frequency band due to this rapid development of 5G wireless network [14]. Typically, a patch antenna has a gain value of between 5 to 6dBi [2]. With this limitation, researcher has developed future antenna proposedly to improve the antenna gain. Some researcher have used metamaterial [15], array structure [16], slotted structure [17] and dielectric loaded Vivaldi structure [18] to improve the microstrip antenna gain.

In this research works, the designed antenna structure is simulated using an user friendly software, Computer Simulation Technology (CST). Three antennas have been designed to complete the research works for gain improvement. The first antenna with basic circular shaped has been designed due to its advantages as mentioned in [19] to resonant at 18GHz. Then, the second antenna has been designed using a ring–shaped structure that can resonant at the same frequency band as design 1, which is 18GHz. Antenna design 3 with the combination of design1 and design 2 has been designed as the final prototype and is optimized to improve the antenna gain. The ring antenna that is rounded outside the circular radiating patch works as the parasitic element [20] to improve the antenna gain. The effect of the parasitic element that is placed around the main radiating patch has been observed using CST software. The final optimization for antenna design1, antenna design2 and antenna design3 have been fabricated and measured for validation purpose. The simulation and fabrication results such as gain, bandwidth and efficiency are in good agreement.

2. ANTENNA DESIGN

The first antenna was developed using a circular structure as shown in Figure 1. A 50 Ohm feeding line was used to connect the radiating patch with the electrical source [21]. Thedimension of the circular antenna was calculated using equations in [22-23]. To design the circular structure, some calculated dimenions shall be determined in order to develop the antenna structure especially for the patch radius. The actual radius (a) of the circular patch is given by [22].

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \tag{1}$$

Where F is a constant given by (2):

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \tag{2}$$

The effective radius of the patch (a_e) is determined by (3):

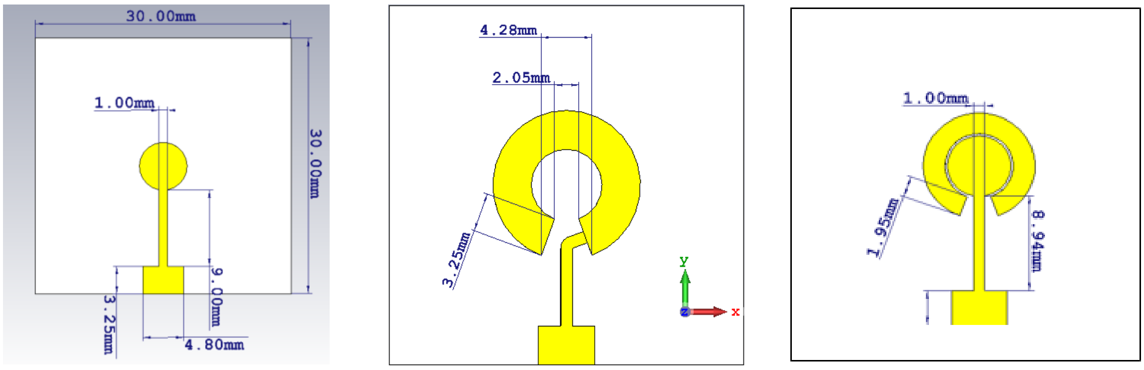
$$a_e = a\left\{1 + \frac{2h}{\pi \varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \tag{3}$$

Hence, the resonant frequency is shown by (4):

$$(f_r)_{110} = \frac{1.8412 v_0}{2\pi a_e \sqrt{\varepsilon_r}} \tag{4}$$

where V_0 is the free space speed of light.

After the completion of antenna design1, we developed second antenna (antenna design2) using a ring shape as shown in Figure 1 (b). The antenna has been designed to resonant at the same frequency as the antenna design1. Once completed, the antenna design3, which is acombination of design1 and design2 (that works as a parasitic element) has been designed as shown in Figure 1 (c). The objective of this combination is to to solve the previous design issue which was to improve the antenna gain for 5G application.



(a) (b) (c)

Figure 1. Antenna (a) design1 (b) design2 (c) design3

The proposed antenna was designed on a full ground copper in order to improve the electromagnetic reflection[24]. The total size of the antenna was 30 mm x 30 mm, and the antenna has achieved resonant at 18GHz for 5G mobile application [25].The dimension of the proposed final design3 antenna structure are given in Table 1.

Table 1. Antenna design3 parameter

Parameters	Value [mm]
Diameter of patch	5.6
Length of feed	8.94
Length of substrate	30
Material's thickness	1.57
Width of parasitic element	1.95
Width of feed	4.9
Width of substrate	30

3. RESULTS AND DISCUSSIONS

In this section, the simulated results for the antenna design1, design2 and design3 are compared in term of their performance, respectively. Figure 2 shows the antenna reflection coefficient, S_{11} for antenna (a) design1, (b) design2 and (c) design3. From the results obtained in Figure 2, the reflection coefficient shows that the antenna design1 have achieved S_{11} of -33.59dB at 18GHz. From the simulation, it shows that the antenna has covered 7.6% of operating bandwidth at the desired frequency range from 17.43GHz to 18.75GHz.Meanwhile in antenna design, a good reflection coefficient has been achieved after optimization process. However, the antenna design2 have obtained smaller bandwidth than design1, which is only 6.6% from 17.35GHz to 18.49GHz. In the third antenna design, the integration of antenna design2 into antenna design1 was performed to optimize the side effect of the return loss. From the Figure 2, it shows that the reflection coefficient of the proposed antenna for antenna design3 has been improved to -37.73dB with bandwidth coverage of17.14GHz to 18.58GHz, an improvement of 8.4% of operational bandwidth. From the figure, it is clear that the optimized structure is obtained from the combined structure (design3), which has achieved good impedance matching and broader bandwidth as compared to design1 and design2.

Figure 3 shows the VSWR for antenna design1, design2 and design3, respectively. The values for the proposed antenna is less than 2dB at the desired band of frequency (17.5 GHz-18.5GHz). From the simulation results, it shows that the proposed antenna can be designed for 5G Mobile communication system application (base on the ITU standard) [26]. The simulation works were continued to evaluate the antenna current distribution as shown in Figure 4. Figure 4 shows that the current distribution is concentrated at the edge of the radiating patch structure and it is shows that the proposed antenna have been well match to the 50Ω input impedance of the system design. Then, further investigation has been made by evaluating the antenna radiation pattern. Radiation pattern is very important aspect in designing an antenna. The radiation pattern is used to observe the dependency of the radiation strength of the antenna with respect to its angular direction from a source. Figure 5 shows the antennas radiation pattern in 2-D view for design1, design2 and design3, respectively. Meanwhile Figure 6 shows the antenna radiation pattern in 3-D view for three antenna, respectively.

The summary of the simulated result of the designed antenna are given in Table 2. As shown in the table, the antenna design3 has better performance as compared to design1 and design2. At 18GHz, the gain of the antenna design3 is 9.18dBi. Meanwhile the reflection coefficient is -37.73dB and the bandwidth is 1307MHz. Therefore, design3 is demonstrated to give better gain, bandwidth and efficiency as compared to design1 and design2, correspondingly.

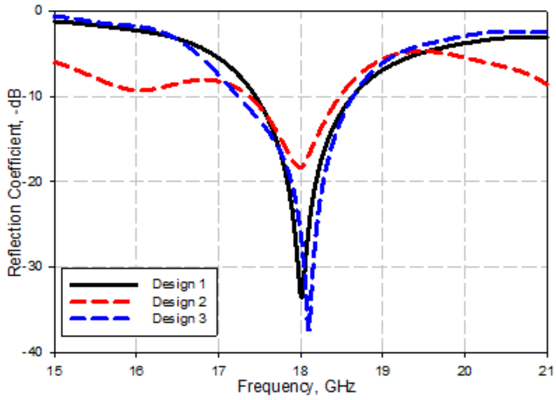


Figure 2. Reflection coefficient antenna design1, design2 and design3

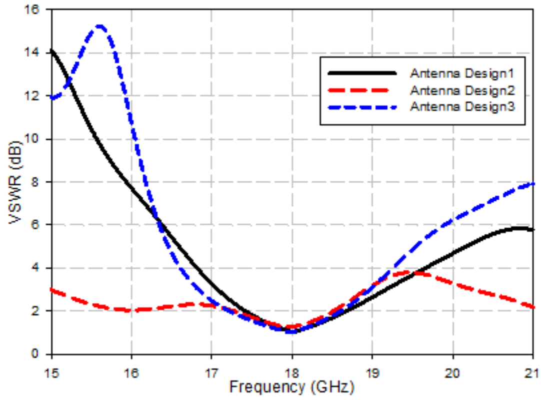
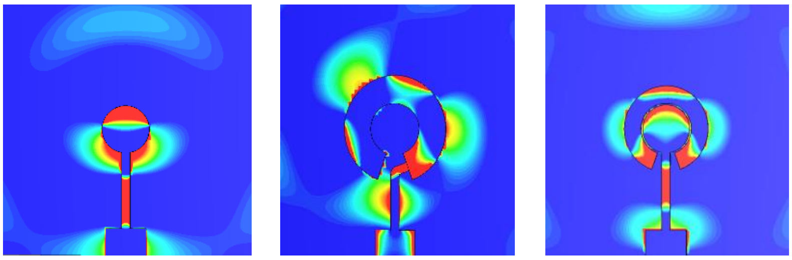


Figure 3. VSWR simulation result



(a) (b) (c)

Figure 4. Antenna (a) design1 (b) design2 (c) design3

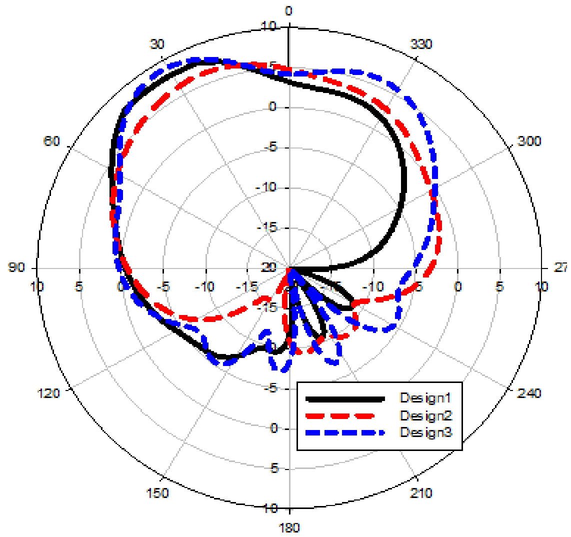
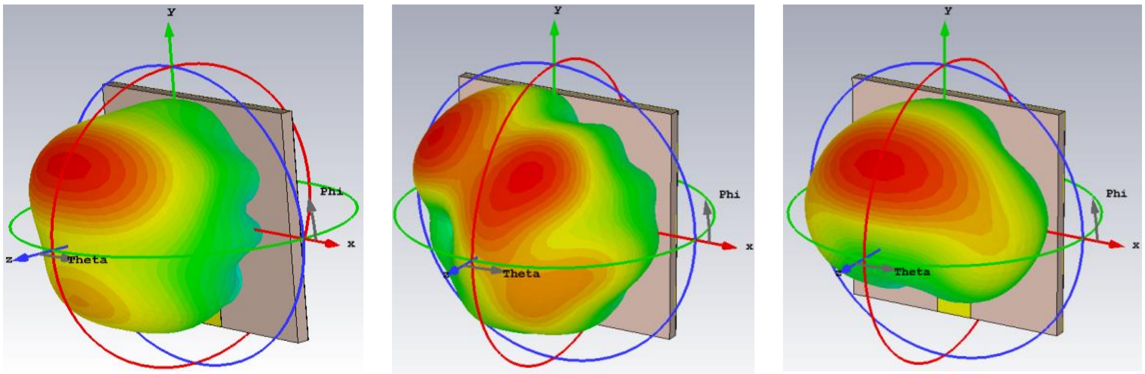


Figure 5. 2-D radiation pattern of antenna design1, design2 and design3



(a) (b) (c)

Figure 6. 3-D view of far-field radiation pattern for (a) design1, (b) design2 and (c) design3

Table 2. Simulation result

Parameters	Design1	Design2	Design3
Frequency (GHz)	18	18	18
S11 (dB)	-33.59	-18.31	-37.73
Gain (dBi)	7.87	6.33	9.18
Bandwidth (MHz)	1192	1140	1307
VSWR (dB)	1.042	1.276	1.001
Efficiency (%)	82.8	85.5	91.9

4. MEASUREMENT RESULT

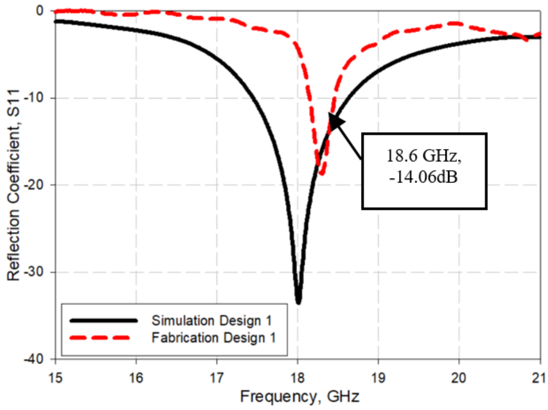
As shown in Figure 7, three antennas have been fabricated to measure their performance and to verify their simulation and measurement result. The antenna performance has been measured using Keysight Vector Network Analyzer for the reflection coefficient and using anechoic chamber for the far-field radiation pattern. The antenna reflection coefficient is compared between simulation and fabrication result as shown in Figure 8.

The measurement data for antenna design1, design2 and design3 show the frequency shift of 3% from the simulation due to the imprecision in handling the measurement process and fabrication inaccuracies [2]. However, the measured frequency is within the range of 5G network [25, 26]. Figure 9 shows the antenna radiation pattern in 2-D view that has been measured using anechoic chamber and Figure 10 shows the 3-D view of the patterns.

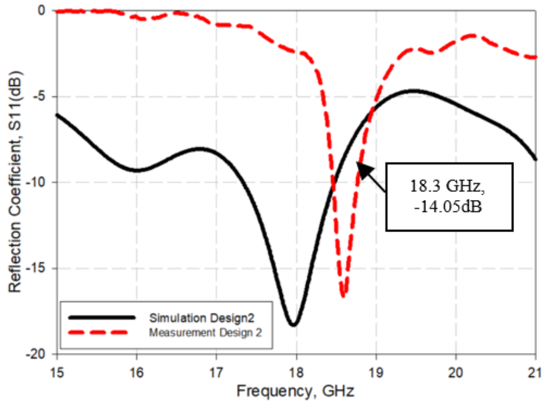
Although the antenna reflection coefficient hasslightly shifted from the simulated result, the measurement of the final antenna shows a very close agreement to the simulated result. As shown in Figure 9, the antenna 2-D radiation pattern shows good measurement result. However, the gain is lower as compared to the simulated result. The result shows that the gain of the antenna design1 has decreased from 7.87dBi to 6.2dBi, and for design 2, the gain is reduced from 6.33dBi to 5.98dBi as well as from 9.16dBi to 6.6dBi for design3. These reductions of gain values are believed due to the improper handling when the antenna is placed on the antenna holder in the chamber. The measurement result is summarized in Table 3.

(a) (b) (c)

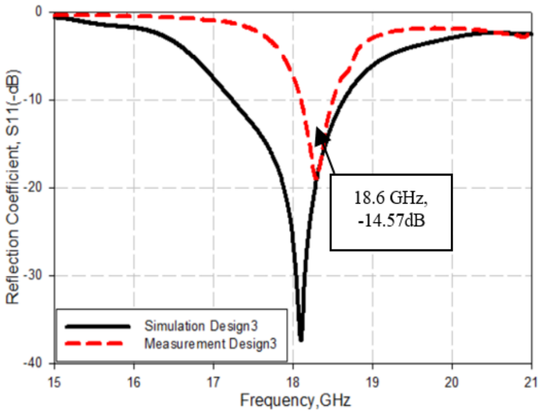
Figure 7. Fabricated antenna (a) design1, (b) design2 and (c) design3



(a)

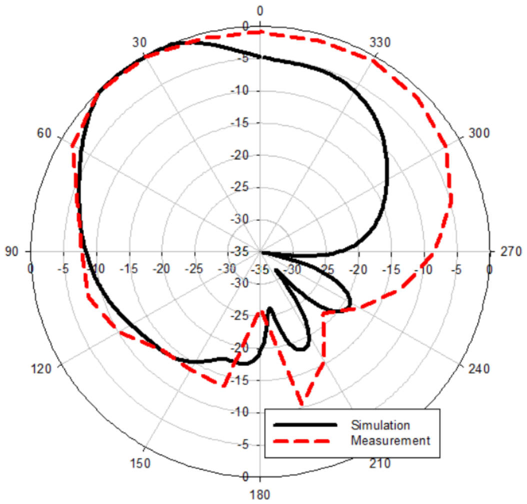


(b)

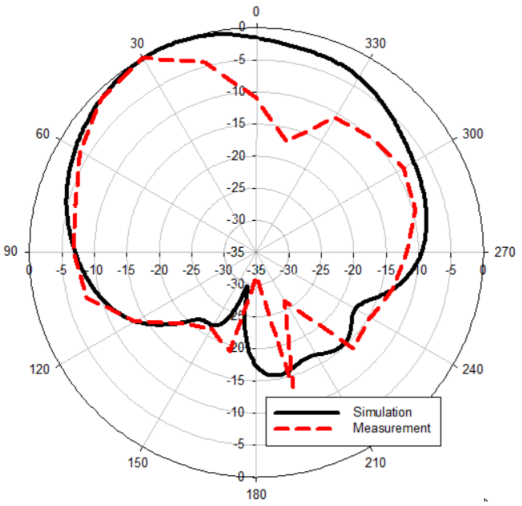


(c)

Figure 8. Comparison of simulated and measured reflection coefficient for antenna, (a) design1 (b) design2 and (c) design3

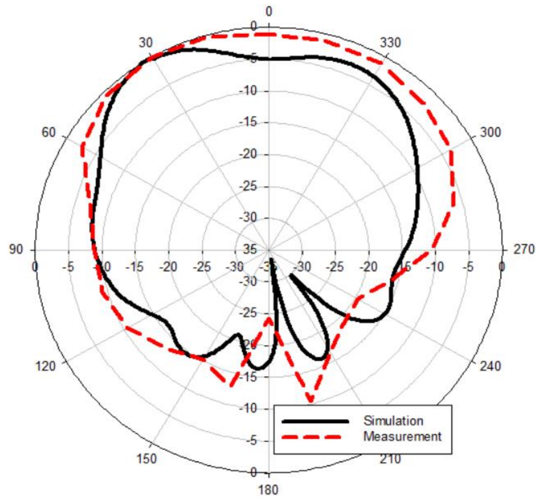


(a)



(b)

Figure 9. Comparison of far-field radiation pattern between simulation and measurement result, (a) design1, (b) design2



(c)

Figure 9. Comparison of far-field radiation pattern between simulation and measurement result, (c) design3 (*continue*)

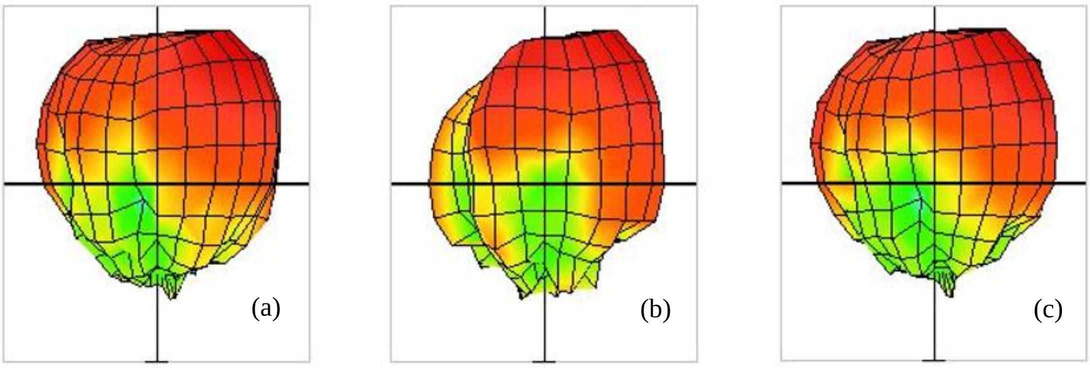


Figure 10. Measured 3-D far-field pattern for (a) design1, (b) design2 and (c) design3

Table 3. Antenna measurement result

Parameters	Design1		Design2		Design3	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
Frequency (GHz)	18	18.6	18	18.3	18	18.6
S11 (dB)	-33.59	-14.06	-18.31	-14.05	-66.48	-14.51
Gain (dBi)	7.87	6.2	6.33	5.98	9.18	6.6
Bandwidth (MHz)	1197	160	1170	160	1307	180
Efficiency (%)	82.8	52.8	85.5	51.5	91.9	53.9

5. CONCLUSION

A new antenna design in the form of a microphone structure was designed and evaluated. Through the antenna simulation software, a parametric study was performed to analyze and to optimize the final antenna design3 configuration. The antenna was designed to achieve good matching at the resonant frequency of 18GHz with high gain. The final antenna with a circular ring located around the main radiating patch works as a parasitic element, which has improved the overall antenna performance in termsof gain, bandwidth and efficiency. Although the simulation result shows clear improvement on the result, the performance of the fabricated antenna has shown some degradations due to improper handling during measurement process. Further investigation shall be done to improve the antenna performance especially to minimise the shifting error. The radiation pattern, which was shown to be shifted from 0° direction in E-plane also shall be investigated in future to improve the antenna performance in real 5G application and environment.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Teknologi MARA for sponsoring the work. Authors would also like to express gratitude to the members of the Antenna Research Center (ARC), Faculty of Electrical Engineering, Universiti Teknologi MARA for supporting the research work.

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N. H. Abd Rahman (M'15**)** obtained her M. Eng. in Electronic from University of Surrey, Guildford, United Kingdom in 2008 and a Ph.D in Electric, Electronic and Systems Engineering from Universiti Kebangsaan Malaysia (UKM), Bangi, Malaysia in 2014. Her Ph.D work was on designing and analyzing satellite-mount parabolic reflector antenna for Malaysia beam coverage by adopting ray-tracing method. This project was a collaboration between UKM and the National Defense Academy, Yokosuka, Japan. In 2014, she was appointed as a senior lecturer in Universiti Teknologi MARA Malaysia (UiTM). She has work experience in the field of satellite and communication engineering. In 2008, she joined Astronautic Technology (M) Sdn. Bhd. (known as ATSB®) as a spacecraft engineer. At ATSB®, she was involved in various small-class satellite development projects such as CubeSAT and InnoSAT, and an R&D project related to satellite X-band transmission system. She was also involved in mission definition study for national communication satellite project. She has experiences in modelling, designing and developing RF and communication modules, specifically antennas and RF transmitters. Currently, she is a post-doctorate fellow at Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia (MJIIT-UTM) Kuala Lumpur. She has received several research grants in wearable antennas, lens and reflector antennas, and other communication-related areas, obtained from government and the university. Currently, she is supervising several postgraduate and undergraduate students. She has published more than 50 scientific papers in indexed journals and conference proceedings. In addition, she is also active in reviewing research articles for several journals related to antennas and propagation. Her current research interests include antennas for space and terrestrial applications, array antennas, reflector and lens antennas, wearable and flexible antennas, RF and microwave design and electromagnetic analysis.

Mohd Aziz Aris was born in Semporna Sabah in 1975. He received the Diploma in electrical engineering from Universiti Teknologi MARA Shah Alam in 1999. In 2003, he received the B. Eng degree (Hons) in electrical engineering (Communication) and the master degree in 2006 from Universiti Teknologi MARA Shah Alam. Now he completed his PhD in electrical engineering (Communication) with Antenna Research Center (ARC) faculty of electrical engineering Universiti Teknologi MARA. In 2006, he join Universiti Teknologi MARA at Terengganu Campus after completed his master. Active in research activities, he received three fundamental research grant scheme (FRGS) under Ministry of Higher Education to lead the research on antenna design and nondestructive material measurement for RF applications. As academician, Mohd Aziz also member of Institute of Electrical Electronic Engineering Society (IEEE) that actively presenting and publishing research activities at national and internationals level. During pursuing his PhD, he also received the award title as an innovative and dedicated technological researcher based on his contribution in research and ideas.

Hadi Jumaat received the B. Eng. in engineering electronics and M.Sc. degree in electrical engineering from the Universiti Teknologi MARA (UiTM), Selangor, Malaysia in 2012 and 2015. He is currently working towards the Ph. D. degree in electrical engineering at Antenna Research Center (ARC) in Universiti Teknologi MARA. Since 2015, he joined UiTM as a lecturer. His research interests are in communication antenna design, biomedical antenna and electromagnetic wave propagation**.**