© Universiti Tun Hussein Onn Malaysia Publisher's Office

JEVA

Journal homepage: http://publisher.uthm.edu.my/ojs/index.php/jeva
e-ISSN : 2716-6074

Journal of Electronic Voltage and Application

Microstrip Patch Antenna Design with Artificial Magnetic Conductor (AMC) at 26 GHz

Zakyra Imana Othman[1], Shipun Anuar Hamzah[1]*, Khairun Nidzam Ramli[1], Shaharil Mohd Shah[1], Suhaimi Saiman[1]

[1]Fakulti Kejuruteraan Elektrik dan Elektronik (FKEE), Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jeva.2022.03.01.009
Received 30 July 2021; Accepted 21 December 2021; Available online 30 June 2022

Abstract: Advancements in 5G wireless communication systems are expected to enhance the communication capability significantly to achieve the higher data rate by accommodating broad bandwidth. In this paper, three compact sizes of rectangular microstrip patch antennas that were made of RT5880, FR-4 and RO3003 substrates with 0.5 mm thickness and resonating at 26 GHz were proposed for the 5G applications. However, the antenna having narrow bandwidth and low gain which contributes to drawback of this microstrip patch antenna design and hence an Artificial Magnetic Conductor (AMC) was proposed to overcome this drawback. The 3.5 mm × 3.5 mm rectangular loop-slot AMC was designed at 26 GHz using FR-4 and it is found that integrating the AMC structure to the printed patch antenna significantly improved the gain and directivity of the antenna. With the help of AMC design, for RT5880 patch antenna, the gain increased for approximately 5% from 6.04 dBi to 6.34 dBi. Besides that, RO3003 patch antenna gain improved for 78.62% from 4.77 dBi to 8.52 dBi and for FR-4 patch antenna, the gain escalated from 2.24 dBi to 7.86 dBi (roughly 251% increment). As a conclusion, the directivity of RT5880 substrate solely decreased for approximately 13.75%. Meanwhile for RO3003 and FR-4 patch antennas, with the assist from AMC design, the directivity of antenna escalated for more than 120 % compared to without AMC and this proved that this design has potential to be used for 5G wireless networks and applications.

Keywords: 5G, microstrip patch antenna, artificial magnetic conductor, gain, bandwidth

1. Introduction

Currently, with the rapid evolution in communication systems, people tend to opt for fast and reliable communication services [1]. Hence, the fifth generation's future wireless communication networks (5G) need antennas that can accommodate broad bandwidth due to the higher data rate [2]. Microstrip planner technology is essentially limited to directional antennas in wireless communication systems [1] in order to achieve high network efficiency and higher spectrum efficiency that enable many users to communicate at a very high speed simultaneously [3]. However, narrow bandwidth and low gain are significant drawback of the typical microstrip patch antenna [1].

The most popular models for the design analysis of microstrip patch antennas is the transmission line model and therefore, this technique is chosen for this project as it is the simplest of all and gives good physical insight, but it is less accurate [4]. It is also used to predict rectangular microstrip antennas input characteristics due to its accuracy and numerical efficiency [5]. Substrates play an important part in the design of microstrip antennas. The patch antenna configuration of the microstrip depends on the thickness of the substrate. Therefore, the selection of substrates is an essential matter that need to be taken into account at the beginning to achieve the desired characteristics for a given application [6].

*Corresponding author: shipun@uthm.edu.my
2022 UTHM Publisher. All rights reserved.

In the past, many studies shown that metamaterial structures have demonstrated that they can be used to improve the performance of antennas and microwave circuits in a multitude of ways with the help of a Perfect Electric Conductor (PEC) in order to improve the gain. To obtain gain amplification with a low profile design, several AMC planes with many unit cells were being used as reflection grounds [7]. In [7], a rectangular microstrip patch antenna was placed above the 3×3 unit cells of hexagonal annular gap AMC ground plane to increase the gain of the original antenna.

The proposed patch antenna printed in a 1.6 mm thickness substrate with dielectric constant of 4.4 is placed with 6 mm distance ($\lambda/10$) of the operating frequency at 4.69 GHz, between the rectangular patch antenna and the AMC ground plane to achieve wide bandwidth. To increase the gain of microstrip patch antennas that were made of RT5880, RO3003 and FR-4 lossy type of substrates and enable to resonate at 26 GHz, a rectangular loop-slot AMC with FR-4 lossy substrate structure was designed as the ground plane of the rectangular patch antennas to fulfil the requirement for 5G communication system.

2. Proposed Design

The project design is separated into two parts: The first is the process of creating microstrip patch antennas, and the second is the creation of an AMC that will assist in improving the performance of the microstrip patch antennas created previously to fulfil the requirements of the 5G communication system.

2.1 Microstrip Patch Antenna Design

Three types of substrates used to design microstrip patch antennas which were RT 5880, FR-4 and RO 3003 with the thickness of 0.5 mm. The dielectric constant for RT5880, FR-4 and RO3003 are 2.2, 4.4 and 3 respectively. The tangent loss for RT5880, FR-4 and RO3003 are 0.0009, 0.025 and 0.0010 respectively. The process of calculating the optimised dimension of the proposed patch antenna as shown in Fig. 1 were based on equations in reference [8]. Firstly, the antenna is design from a ground plane made of copper, then followed by the chosen substrate that have the same size as the ground plane and patch made of copper at the top which is typically smaller than the size of the substrate and ground plane resonated at 26 GHz. The optimized dimensions of those three antennas were tabulated in table 1.

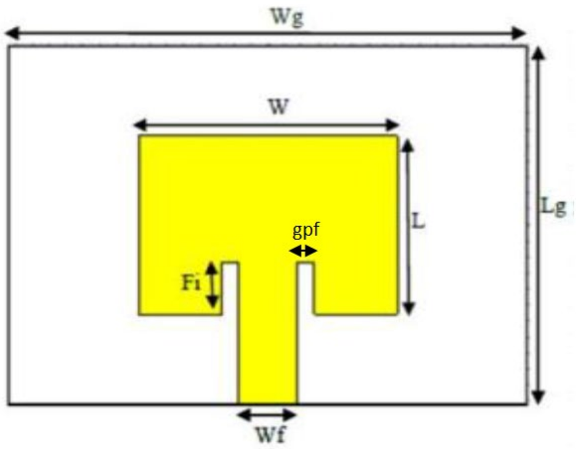

Fig. 1 - The proposed rectangular shaped microstrip patch antenna [8]

Table 1 - Optimised dimension of the proposed antennas

Parameters	Dimensions (mm) based on type of substrates		
	RT5880	FR-4	RO3003
Ground Plane Length, Lg	6.57	5.55	6.07
Ground Plane Width, Wg	7.56	6.51	7.08
Length of Patch, L	3.57	2.55	3.07
Width of Patch, W	4.56	3.51	4.08
Height of Substrate, h	0.5	0.5	0.5
Width of Feedline, Wf	1.21	0.89	1.07
Feedline Insertion, Fi	0.86	0.78	0.82
Ground Thickness, t	0.035	0.035	0.035

Gap between Patch and Insertion Fed, gpf	0.5	0.5	0.5
Antenna size (mm^2)	16.28	8.95	12.53

2.2 Artificial Magnetic Conductor (AMC)

Once the antennas designs were completed, the 3.5 mm × 3.5 mm AMC resonated at a frequency of 26 GHz, printed at RT5880, FR-4 and RO3003 lossy substrates with the thickness of 0.3 mm were designed as shown in Fig. 2. The design is based on the works in reference [9]. There is a rectangular loop slot located at the center of the patch in AMC unit cell. The AMCs were then simulated using CST Studio Suite software to obtain the reflection phase diagram. Table 2 tabulates its optimized dimension.

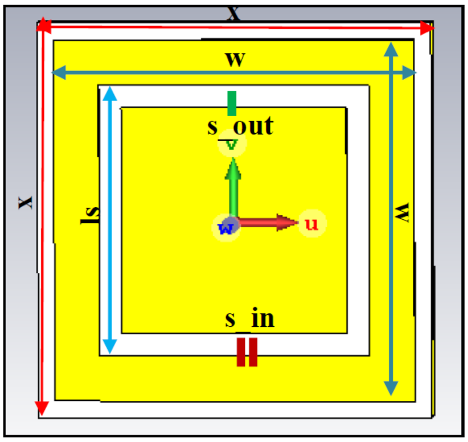

Fig. 2 - The proposed rectangular loop slot AMC design

Table 2 - Optimised dimension of the proposed AMC

Parameter	Dimension (mm)
Length and width of substrate and ground, x	3.5
Height of substrate, h	0.3
Length and width of patch, w	3.2
Height of patch and ground, t	0.035
Inner slot, s_in	1
Outer slot, s_out	1.2
Length of rectangular slot, ls	2.4

The values of the proposed AMC dimensions stated in table 2 were fixed throughout the whole process of creating AMC by using three different types of substrates. After the designed AMC were simulated, the antenna parameters obtained were observed based on zero-phase delay point, reflection magnitude, ±90° bandwidth and the percentage of the operating bandwidth. From the simulation results, AMC with FR-4 substrate was chosen as the fixed AMC variable to be integrated with the proposed rectangular microstrip patch antenna design in order to improve the gain of the patch antennas created. For this integration, the distance between the microstrip patch antenna and the AMC plane was about one-ten of the wavelength ($\lambda/10$) at 26 GHz.

3. Results and Discussion

In this work, the antenna performances were observed in two conditions; (a) simulation of the patch antenna without AMC and (b) simulation of the patch antenna with AMC. Fig. 3 shows the reflection coefficients obtained for RT5880 microstrip patch antenna. Without AMC, the reflection coefficients bandwidth started from 25.73 GHz to 26.39 GHz with the centre frequency of 26.06 GHz. The return loss was -11.62 dB with the operating bandwidth of 0.653 GHZ. As for the simulated results of RT5880 patch antenna with AMC, the patch antenna resonated at 26.06 GHz with a bandwidth ranges from 25.71 GHz to 26.61 GHz. The bandwidth had an increment for 39.36% from 0.653 GHz to 0.91 GHz with a return loss of -18.42 dB.

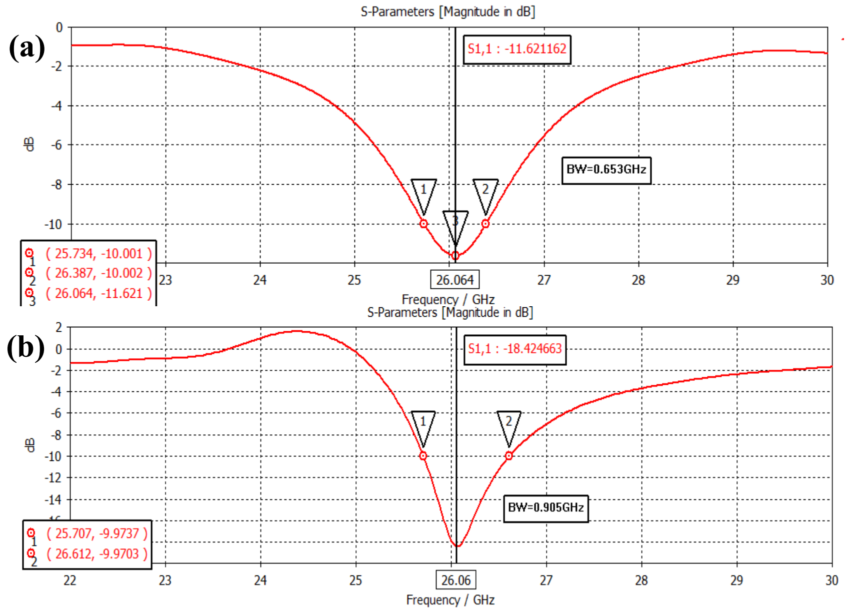

Fig. 3 - (a) RT 5880 patch antenna without AMC; (b) RT 5880 patch antenna with AMC

Fig. 4 demonstrates the 2-D polar of the farfield realized gain for the RT5880 antenna. The gain has increased for approximately 5% from 6.04 dBi to 6.34 dBi. Both conditions proved that the antennas radiated in wider angular span (i.e., more than 60°).

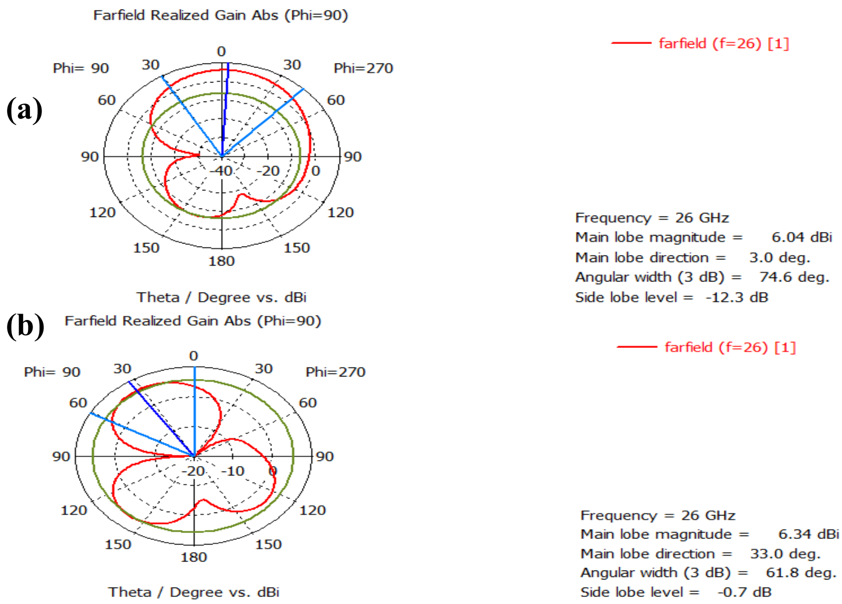

Fig. 4 - (a) RT 5880 patch antenna without AMC; (b) RT 5880 patch antenna with AMC

Fig. 5 shows the 2-D polar of the farfield directivity plot for the RT5880 antenna. The directivity has slightly decreased for approximately 13.75% from 7.78 dBi to 6.71 dBi.

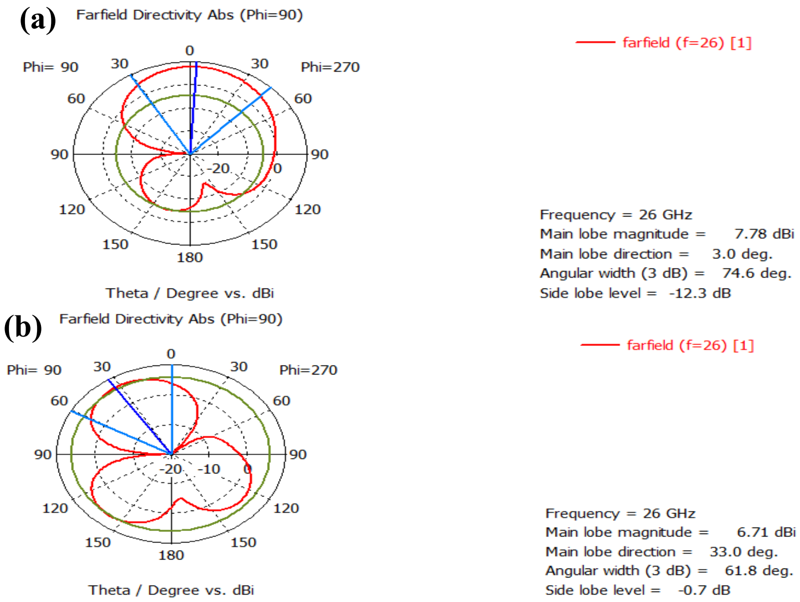

Fig. 5 - (a) RT 5880 patch antenna without AMC; (b) RT 5880 patch antenna with AMC

Fig. 6 illustrates the reflection coefficients obtained for RO3003 microstrip patch antenna. Without AMC, the reflection coefficients bandwidth obtained was from 26.49 GHz to 26.95 GHz with the operating frequency of 26.496 GHz. As for the simulated results of RO3003 patch antenna with FR-4 AMC, the patch antenna resonated at 26.439 GHz with a bandwidth ranged from 26.28 GHz to 26.599 GHz. The bandwidth subsides more than 60% from initial results obtained (i.e. 64.84% decrement) from 0.91 GHz to 0.32 GHz with a -3.38 dB increment of return loss from -14.78 dB to -18.16 dB.

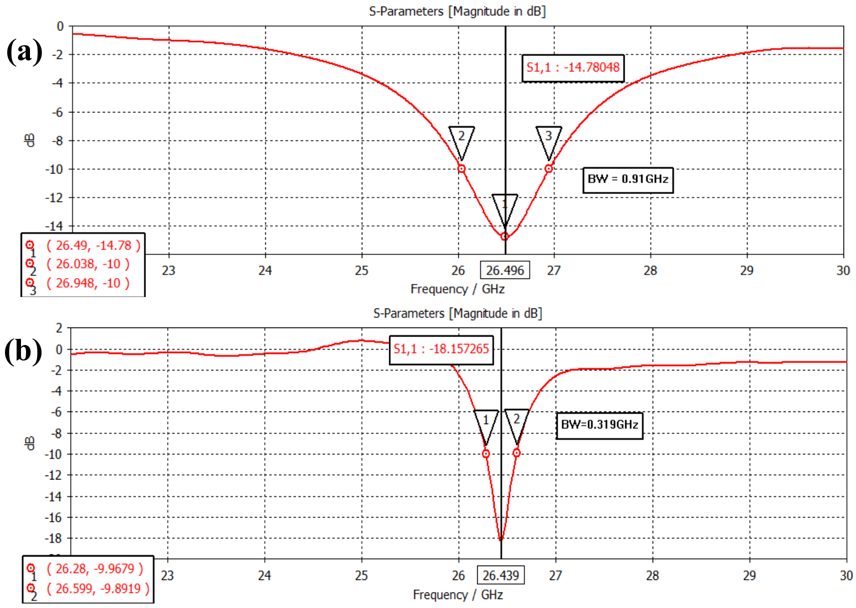

Fig. 6 - (a) RO3003 patch antenna without AMC; (b) RO3003 patch antenna with AMC

Fig. 7 illustrates the 2-D polar of the farfield realized gain for the RO3003 antenna. The gain improved for 78.62% from 4.77 dBi to 8.52 dBi. Both conditions proved that the antennas radiated in wider angular span (i.e. more than 60°).

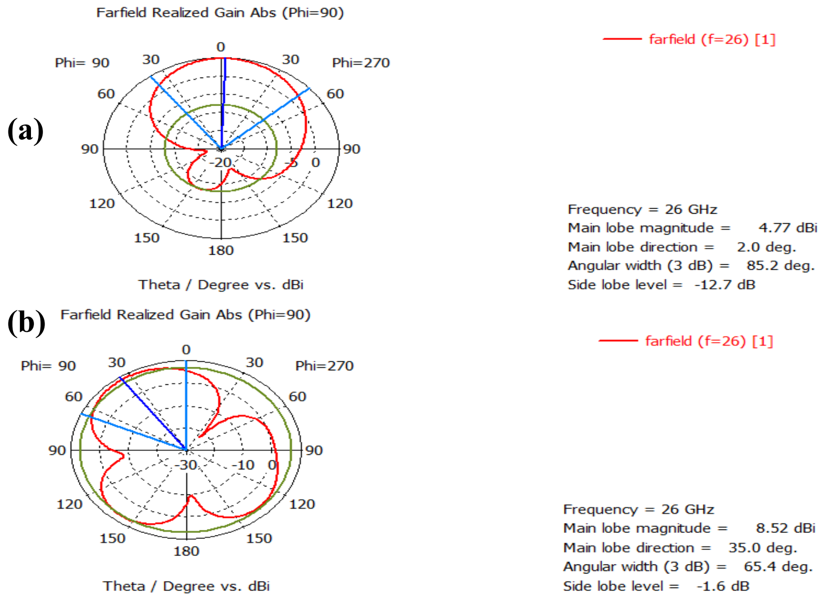

Fig. 7 - (a) RO3003 patch antenna without AMC; (b) RO3003 patch antenna with AMC

Fig. 8 depicts the 2-D polar of the farfield directivity plot for the RO3003 antenna. The directivity has escalated for 121.57% from 6.86 dBi to 15.2 dBi.

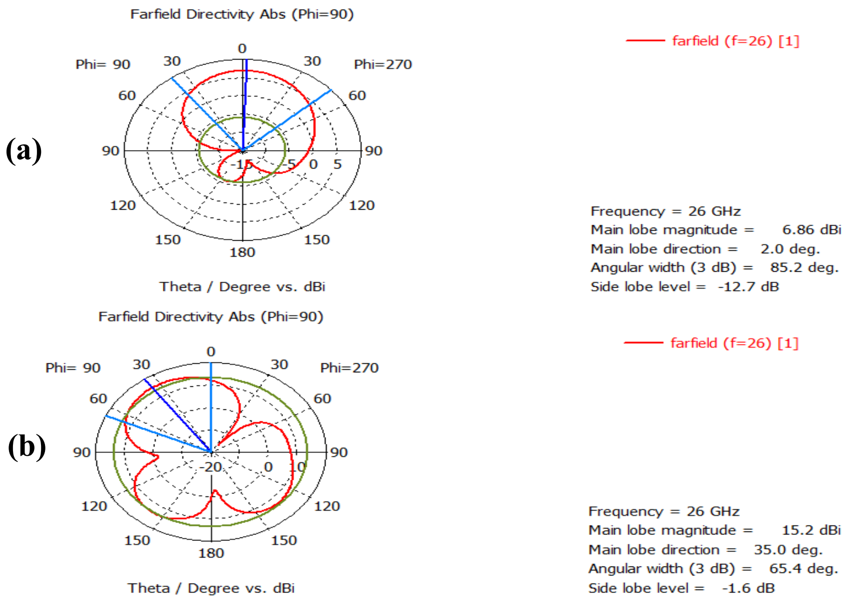

Fig. 8 - (a) RO3003 patch antenna without AMC; (b) RO3003 patch antenna with AMC

Fig. 9 shows the reflection coefficients obtained for FR-4 microstrip patch antenna. Without AMC, the reflection coefficients bandwidth obtained was from 25.48 GHz to 26.47 GHz with operating frequency of 25.976 GHz. As for the simulated results of FR-4 patch antenna with FR-4 AMC, the patch antenna resonated at 26.004 GHz with a bandwidth ranged from 25.932 GHz to 26.072 GHz. The operating bandwidth subside for 85.80% (i.e. from 0.986 GHz to 0.14 GHz) and the return loss showed 2.43 dB decrement as it goes from -14.63 dB to -12.20 dB.

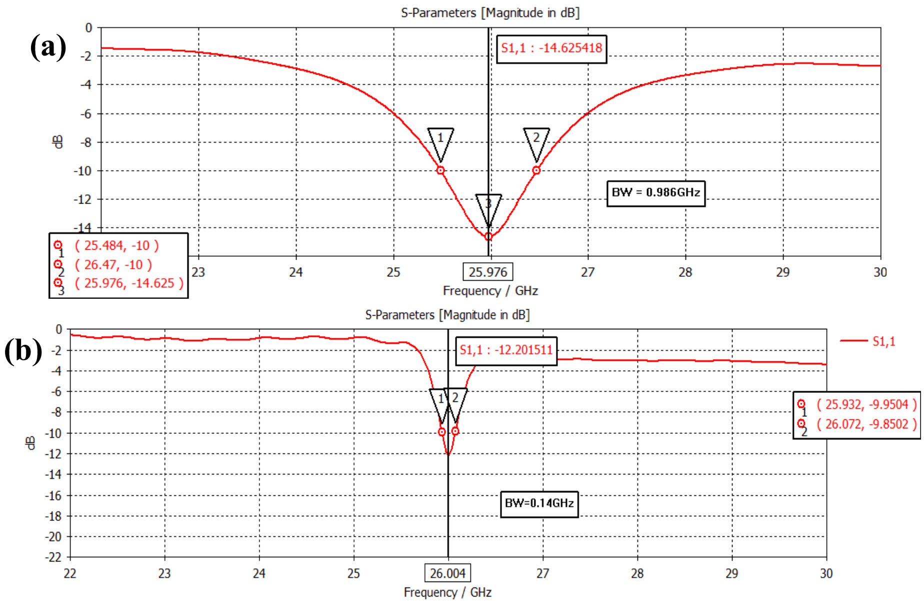

Fig. 9 - (a) FR-4 patch antenna without AMC; (b) FR-4 patch antenna with AMC

Fig. 10 illustrates the 2-D polar of the farfield realized gain for the FR-4 antenna. The gain enhanced for roughly 251% from 2.24 dBi to 7.86 dBi.

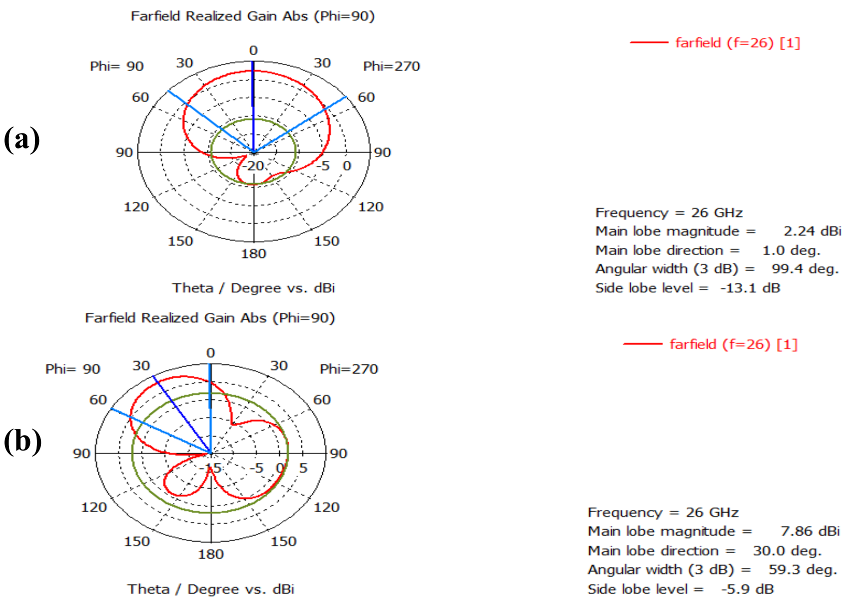

Fig. 10 - (a) FR-4 patch antenna without AMC; (b) FR-4 patch antenna with AMC

Fig. 11 depicts the 2-D polar of the farfield directivity plot for the FR-4 antenna. The directivity has escalated for 3019.73% from 5.93 dBi to 185 dBi.

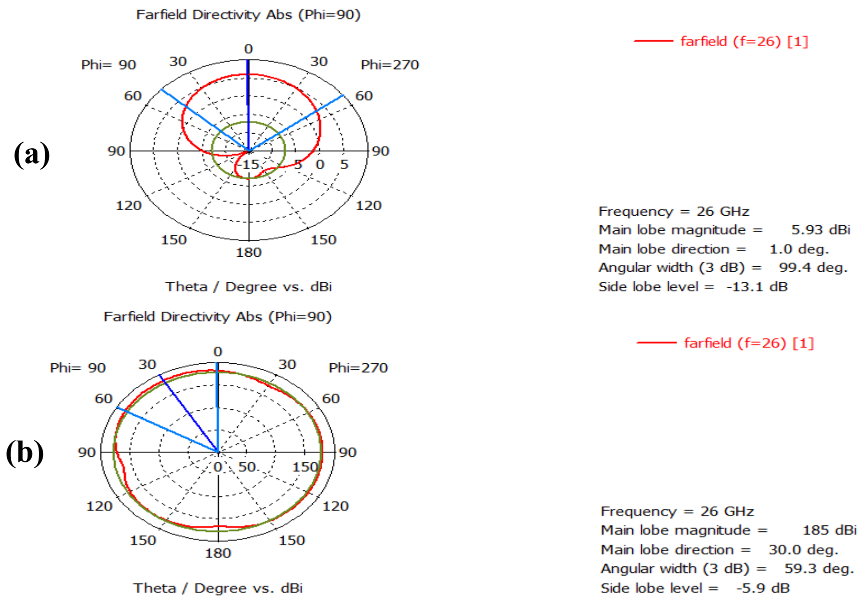

Fig. 11 - (a) FR-4 patch antenna without AMC; (b) FR-4 patch antenna with AMC

Finally, table 3 summarized the simulation results obtained for the microstrip patch antenna with and without AMC for the proposed antenna design. The comparisons were made based on seven parameters such as operating frequency, return loss, bandwidth, voltage standing wave ratio (VSWR), gain, directivity and antenna size.

Table 3 - Comparisons between patch antennas with and without AMC

Antenna Parameters	**Microstrip Patch Antenna (MPA)**					
	RT 5880	**MPA (RT5880) + AMC**	**RO3003**	**MPA (RO3003) + AMC**	**FR-4**	**MPA (FR-4) + AMC**
Operating Frequency (GHz)	26.064	26.06	26.496	26.439	25.976	26.004
S_{11} (dB)	-11.62	-18. 42	-14.78	-18.16	-14.63	-12.20
Bandwidth (GHz)	0.653	0.91	0.91	0.32	0.986	0.14
VSWR	1.71	1.27	1.45	1.28	1.46	1.65
Gain (dBi)	6.04	6.34	4.77	8.52	2.24	7.86
Directivity (dBi)	7.78	6.71	6.86	15.2	5.93	185
Antenna Size (mm^2)	16.28		12.53		8.95	

4. Conclusion

In conclusion, both microstrip patch antennas with and without AMC structure were constructed at 26 GHz. Integrating the AMC structure into the patch antenna enhanced the gain and directivity of the proposed antenna design significantly. By incorporating the patch antenna with AMC, the antenna still able to perform at the resonance frequency of 26 GHz. However, the greater the value of the gain and directivity, the value for operating bandwidth obtained is inversely proportional. The VSWR value achieved at the operating frequency was considered good due to less than two. The proposed antenna designs were small and compact in size which paves the way as the prospective contender to be employed in 5G wireless applications.

Acknowledgement

The author would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) for its support.

References

[1] U. Keskin, B. Döken, and M. Kartal, "Bandwidth improvement in microstrip patch antenna," *Proc. 8th Int. Conf. Recent Adv. Sp. Technol. RAST 2017*, pp. 215–219, 2017, doi: 10.1109/RAST.2017.8003005.

[2] S. Johari, M. A. Jalil, S. I. Ibrahim, M. N. Mohammad, and N. Hassan, "28 GHz Microstrip Patch Antennas for Future 5G," *J. Eng. Sci. Res.*, vol. 2, no. 4, pp. 1–6, 2018, doi: 10.26666/rmp.jesr.2018.4.1.

[3] C. Seker and M. T. Guneser, "Design and simulation of 26 GHz patch antenna for 5G mobile handset," in *ELECO 2019 - 11th International Conference on Electrical and Electronics Engineering*, 2019, pp. 676–678, doi: 10.23919/ELECO47770.2019.8990634.

[4] V. Bernard, J. Paul, and I. Iloh, "Microstrip Antenna Design Using Transmission Line Model," *Microstrip Antenna Des. Using Transm. Line Model*, vol. 3, no. 11, 2013.

[5] S. Subramanian, S. K. Selvaperumal, V. Jayapal, and R. M. T. Abdulla, "Multiband high gain microstrip patch antenna at ka band (26 ghz)," *J. Adv. Res. Dyn. Control Syst.*, vol. 11, no. 12 Special Issue, pp. 667–673, 2019, doi: 10.5373/JARDCS/V11SP12/20193263.

[6] M. Patch, A. Parameters, and E. Setup, "Chapter 2. Microstrip Patch Antenna Parameters and Experimental Setup (Simulation, Fabrication and Measurement)," pp. 56–80.

[7] L. Chen, "Millimeter-Wave Wide Band Antenna Array for 5G Mobile Applications," 2019, [Online]. Available: https://ruor.uottawa.ca/handle/10393/39446.

[8] O. Darboe, D. Bernard, O. Konditi, and F. Manene, "A 28 GHz Rectangular Microstrip Patch Antenna for 5G Applications," vol. 12, no. 6, pp. 854–857, 2019.

[9] X. Tang, Y. Kawkami, T. Hori, and M. Fujimoto, "Bandwidth Characteristics of Loop-slot AMC with Dielectric Layer," vol. 0, no. 2, p. 2009, 2009.