Improvement Antenna Performance by using Artificial Magnetic Conductor at 28 GHz

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***Abstract*—The configurations of single patch antenna integrated with three different designs of patch artificial magnetic conductor (AMC) are presented in this paper in order to investigate the gain, radiation pattern, directivity and bandwidth of the antenna at a frequency of 28 GHz. Three cases of design configuration between patch antenna and three different designs of AMC are analyzed. First, configuration of patch antenna integrated with three designs of patch AMC. Second configuration of patch antenna integrated with non periodic patch AMC and third multilayer patch antenna with patch AMC. The details theory of the design configuration is explained. The simulated reflection coefficient and radiation pattern is presented. The simulated results showed that the gain, directivity and impedance bandwidth of all the design techniques are increased compared to patch antenna without AMC. For the first case, design of patch antenna integrated with design 1 AMC offer 13.96 % bandwidth and 12 % of the gain compared to patch antenna without AMC. In the second case, the overall size is reduced by 9.2 % and 14.14 % , respectively, compared with design in the first case. The third case of design structures provides more gain and bandwidth more than 3.57 %. In addition, the size is reduced compared to the previous two cases. Therefore, the result indicates the capability of this antenna integrated with AMC to be used for future 5G application.**

***Index Terms:* Artificial Magnetic Conductor; Bandwidth; Directivity; Gain.**

I. Introduction

Wireless communication technology has grown rapidly in recent years with the aim to meet the demand of high traffic capacity needed in communication applications. The 5G [1-3] technology is the technology that enhanced from the 4G technology and operates on a higher frequency band or millimeter wave frequency, which providing a large data capacity in order to support multi-Gbps data rates [4-5]. Moreover, the use of this technology at higher frequency bands is to collect more data which needed in the new mobile technology [4-5].

Communication systems that operating in the millimeter wave bands have a narrow beam at the transmitter and receiver, which are intended to avoid interference from neighboring beams [6]. However, a narrow beam on the receiver and transmitter has limited the multipath element of a millimeter wave range [6]. However, this limitation can be solved by adjusting the weight of the beam-forming to the direction of the base station effectively [6]. The rapid growth of customer demands for the use of wireless communications has created a need for antenna designs as a fundamental part of any wireless system.

In order to meet consumer demands in wireless communication services, the antenna produced must be cost effective, small size, compact, easy to manufacture, low profile and easy to integrate with wireless communication systems [7]. Besides that, the other requirements of the antenna are light weight, high gain and simple structure in order to maintain its dependability, mobility and efficiency [8].

Therefore, the microstrip patch antenna is chosen because of low profile antenna, easy to fabricate, easy to use as an array element or combined with other microstrip circuit components [9]. In addition, the patch antenna is very suitable and highly recommended used in the applications such circular polarization, dual band frequency, wide bandwidth, feed line technique and beam scanning [10].

In paper [4], three different configurations of patch array antennas are presented at a frequency of 28 GHz. The purpose is to investigate how the orientation of the patch array antenna can affect the beam forming and which orientation will produce a good response on the beam forming and beam steering. The computed results display that the antenna 1 and 2 offer beam shifting covers the angles up to 66°, while for Antenna 3 is 94°.

N.Ashikin Jaafar , M. H. Jamaluddin (2015) proposed the design of the H-shaped Dielectric Resonator Antenna (DRA) using high permittivity ($\varepsilon r = 30$) applied for future 5G application at a frequency above 6 GHz. The results show that this design antenna offers high impedance bandwidth of 58 %, high efficiency and has stable a radiation pattern. This antenna also has a compact size and low cost and able used for future 5G application [11].

Paper [12] designed a broadband elliptical-shaped slot antenna for the future fifth generation (5G) wireless applications. This antenna has a small size and an elliptically shaped slot is etched in the ground plane in order to improve the bandwidth. A stub also is added to the antenna line feed in order to attain the matching impedance bandwidth of the antenna. The simulated results show that the designed antenna has a wide impedance bandwidth which larger than 67 % and cover at a frequency band of 28 GHz./ 38 GHz.

Zihao Chen, Yue Ping Zhang (2013) proposed the design of a fixed-beam microstrip grid array on an FR4 substrate in a standard PCB technology for 5G mobile devices. The computed results present that the 10 -dB impedance bandwidth of an antenna is 7.16 GHz. The 3-dB gain bandwidth of 4.79 GHz offers a maximum realize gain of

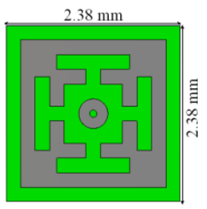
12.7 dBi at a frequency of 29.2 GHz. Other than that, the results indicate that the system PCB does not affect the antenna performance. [13]

A single patch microstrip grid array antenna at a frequency of 28 GHz is proposed in [14]. The antenna is designed with a diamond shape with a dimension of 34 mm x 54 mm. The proposed antenna achieved the antenna gain up to 11.32 dBi compared to the silicon diode antenna and stacked patch antenna arrays [14].

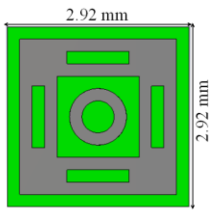
In this study, the configurations of single patch antenna integrated with three different designs of patch artificial magnetic conductor (AMC) are presented. The purpose is to investigate the antenna performance by using AMC for 5G application which operate in frequency of 28 GHz. Three cases of design configuration between patch antenna and three different designs of AMC are analyzed. First, configuration of patch antenna integrated with three designs of patch AMC. Second configuration of patch antenna integrated with non periodic patch AMC and third multilayer patch antenna with patch AMC. The simulated results are compared to the patch antenna without AMC and patch antenna with AMC.

II. PROPOSED AMC GEOMETRY

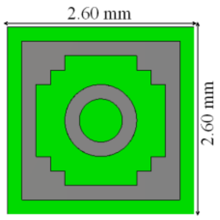
Three different geometries of AMC unit cells without grounded via are shown in Figure 1 which designed on a grounded RT 5880 substrate material with a thickness = 0.254 mm, dielectric constant, ε_r = 2.2 and tangent loss, $\tan\delta$ = 0.0009. The overall size of design 1 AMC is 2.38 mm x 2.38 mm., design 2 AMC is 2.92 mm x 2.92 mm and design 3 AMC is 2.60 mm x 2.60 mm.



(a) Design 1



(b) Design 2



(c) Design 3

Figure 1: The geometry of unit cell AMC

The comparison of reflection phase characteristic of the AMCs structure is simulated using CST Microwave Studio software. As presented in Figure 2, the plotted reflection phase varies continuously from +180° to -180° versus frequency. The operating bandwidth is obtained with a specified range of frequency when phase shift is between +90˚to -90˚.

The diagram shows that the operating bandwidth for the design 1 AMC falls within range of 27.090 GHz - 28.735 GHz, design 2 AMC of 26.659 GHz - 29.246 GHz and design 3 AMC of 26.952 GHz - 28.896 GHz. Therefore, the bandwidth for the design 1 is 5.88 %, design 2 is 9.24 % and design 3 is 6.94 %. This shows that increasing in AMC overall size will increase the operating bandwidth. The performance comparison of unit cell designs AMCs is given in Table 1.

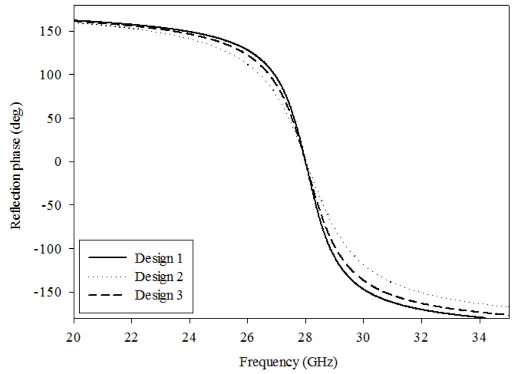


Figure 2: Reflection phase of unit cell design AMC

Table 1
Performance comparison of the unit cell design AMC

Pattern	Parameter Studied		
	Size (mm x mm)	Bandwidth (GHz)	Bandwidth (%)
Design 1	2.38 x 2.38	27.090 - 28.735	5.88 %
Design 2	2.92 x 2.92	26.659 - 29.246	9.24 %
Design 3	2.60 x 2.60	26.952 - 28.896	6.94 %

III. CONFIGURATION OF INSERT FEED LINE ANTENNA

The configuration of single patch antenna with insert feed line is shown in Figure 3. The radiating edge of the patch is cut out in order to locate a 50 Ω driving point impedance. Table 2 presents the optimized parameters for a an antenna.

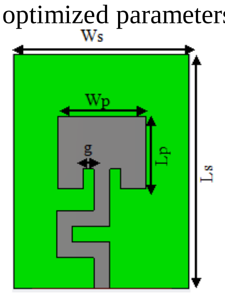


Figure 3: Configuration of insert feed line antenna

Table 2
The optimized parameters for antenna

Parameter	Value (mm)
Ws	8.47
Ls	11.2585
Wp	4.235
Lp	3.4715
g	0.525

IV. Configuration of Antena and AMC

A. Three different configurations of patch antenna integrated with patch AMC.

The insert feed line microstrip antenna is chosen to integrate with the AMCs structure for improving its gain, bandwidth and efficiency. Figure 4 - Figure 6 represents a single patch antenna are integrated with three different configurations of patch AMC structure. The patch of AMCs structure is placed at the same height with patch antenna. The width and length of the feed line antenna is adjusted until it achieved 50 Ω impedance matching at operating frequency.

The overall size of antenna with design 1 AMC, design 2 AMC and design 3 AMC is 11.2635 mm x 10 mm, 11.2585 mm x 12.6 mm and 11.6685 mm x 11 mm, respectively. The gap between the patch antenna and design 1 patch AMC is 1 mm, patch antenna with design 2 patch AMC is 0.48 mm and patch antenna with design 3 patch AMC is 0.8 mm.

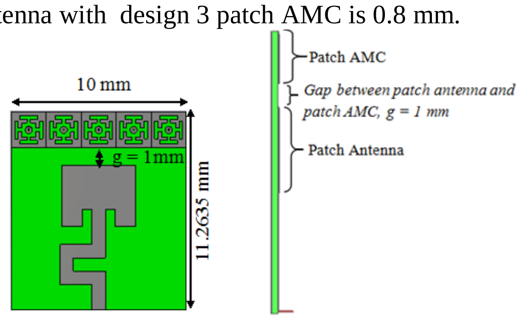


Figure 4: The patch antenna integrated with design 1 patch AMC

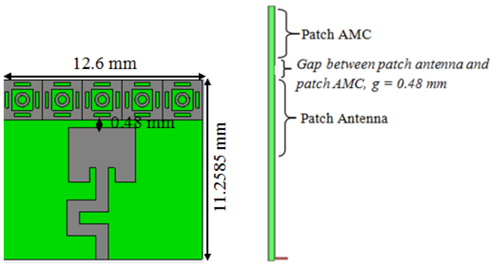


Figure 5: The patch antenna integrated with design 2 patch AMC

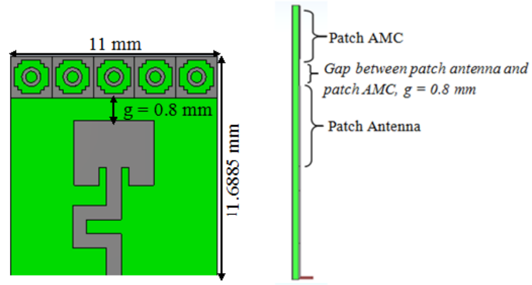


Figure 6: The patch antenna integrated with design 3 patch AMC

Comparison of predicted negative return loss or reflection coefficient of the antenna without and integrated with patch AMCs is presented in Figure 7. The acceptable reflection coefficient is considered at $|s11|$ below than - 10 dB. There are four conditions were analyzed: patch antenna without patch AMC, patch antenna integrated with design 1 patch AMC, patch antenna integrated with design 2 patch AMC and patch antenna integrated with design 3 patch AMC.

The graph shows that the negative return loss of the antenna without patch AMC is - 26.302 dB with the impedance bandwidth of 2.65 % (27.629 GHz - 28.371 GHz). When integrated with design 1 patch AMC, the negative return loss and impedance bandwidth is improved by -30.758 dB and 2.78 % (27.594 GHz - 28.371 GHz) . The impedance bandwidth is expanded to 3.02 % (27.577 GHz - 28.423 GHz) when the patch antenna integrated with design 2 patch AMC compared to design 1 patch AMC. The impedance bandwidth of patch antenna with design 3 patch AMC is similar with design 1 AMC by 2.78 % (27.629 GHz - 28.406 GHz).

The reflection coefficient for patch antenna integrated with design 2 and design 3 patch AMC is still well matched and below than -10 dB. The comparison result is tabulated in Table 3.

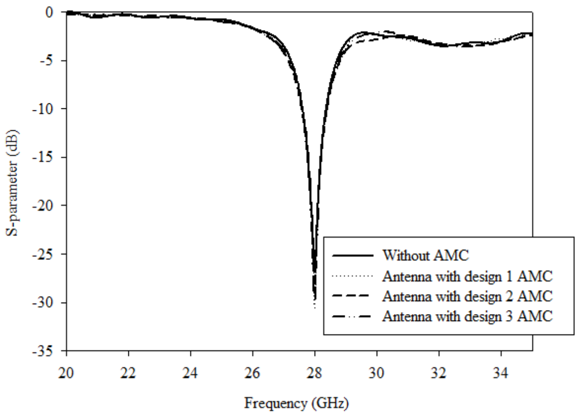


Figure 7: Reflection coefficient of antenna without and with designs patch AMC

Table 3
Comparison result of patch antenna without and with designs AMC

Pattern	Parameter Studied		
	Reflection coefficient (dB)	Bandwidth (%)	% Increment of bandwidth
Antenna without AMC	-26.302	2.65	-
Antenna with design 1 AMC	-30.758	2.78	4.91 %
Antenna with design 2 AMC	-29.046	3.02	13.96 %
Antenna with design 3 AMC	-29.845	2.78	4.91 %

Comparison of simulated radiation pattern for patch antenna without and with patch AMC when Phi - 0 ° at frequency 28 GHz are illustrated in Figure 8. The main properties that need to analyze is the gain. The gain is used to measure how much the power is radiated into a given direction. Antenna with wide beamwidth provide low gain while the antenna with narrow beamwidth offer higher gain.

The comparison results are presented in Table 4. From the Table 4, this show that the integrated patch antenna with three different of the patch AMC design structure offer a higher gain, directivity and efficiency compared to the patch antenna without patch AMC.

The percentage increments of gain for antennas without patch AMC compared to antenna with patch design 1 AMC, patch design 2 AMC and patch design 3 AMC is 7.61 %, 12 % and 5.45 %, respectively. This show that the patch antenna integrated with design 2 patch AMC radiate more power and offer narrow beamwidth compared to the others.

The maximum peak directivity of the antenna without patch AMC is 7.19 dBi. When integrated with patch AMC, this value is expanded to 7.8 dBi for patch antenna with design 1 patch AMC, 8.19 dBi or patch antenna with design 2 patch AMC, 8.19 dBi and 7.85 dBi for patch antenna with design 1 patch AMC.

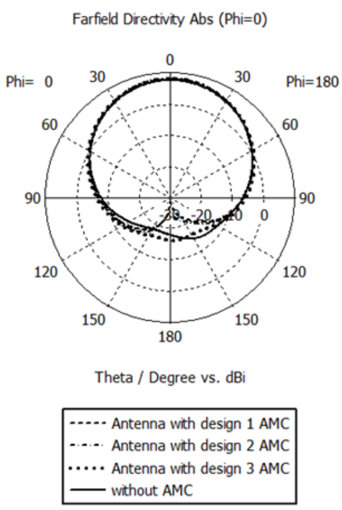


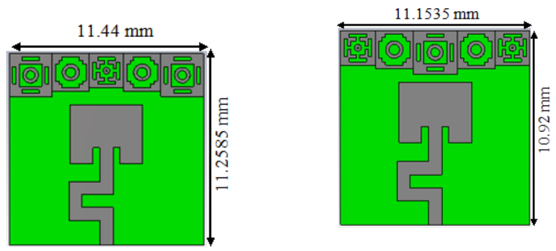
Figure 8: Radiation pattern antenna without and with designs patch AMC

Table 4
Comparison result of radiation pattern between patch antenna without and with designs AMC

Pattern	Parameter Studied		
	Gain (dB)	Radiation efficiency (%)	3 dB beamwidth
Antenna without AMC	7.190	91.3	71.3
Antenna with design 1 AMC	7.737	96.2	70.3
Antenna with design 2 AMC	8.053	95.6	67.8
Antenna with design 3 AMC	7.582	93.3	72.2

B. Two different configurations of patch antenna integrated with non periodic patch design AMC.

Figure 9 (a)-(b) represent the two designs of patch antenna integrated with three different patterns which is design 1, design 2 and design 3 of patch AMC. The AMC structure is not arranged periodically as each structure has a predetermined size on a frequency of 28 GHz.



(a) (b)

Figure 9: Patch antenna integrated with non periodic patch AMC

Figure 10 displays the comparison of the reflection coefficient of patch antenna without AMC, patch antenna with patch AMC as in Figure 9(a) and patch antenna with patch AMC as in Figure 9(b). All designs have achieved the specification that necessary for a good antenna with a reflection coefficient below than -10 dB. When integrated with patch AMC as in Figure 9(a), the impedance bandwidth increased by 2.84 % (27.611 GHz - 28.406 GHz) compared to patch antenna without AMC. However, the increase in impedance bandwidth has occurred significantly by 2.98 % (27.592 GHz - 28.425 GHz) to the design shown in Figure 9(b). The comparison results are illustrated in Table 5.

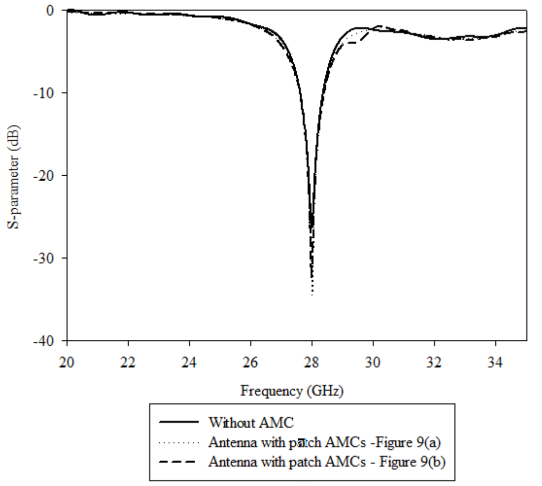


Figure 10: Reflection coefficient of antenna without and with non periodic patch designs AMC

Table 5
Comparison result of patch antenna without and with designs AMC

Pattern	Parameter Studied		
	Reflection coefficient (dB)	Bandwidth (%)	% Increment of bandwidth
Antenna without AMC	-26.302	2.65	-
Antenna with design AMCs (Figure 9(a))	-34.230	2.84	7.17 %
Antenna with design AMCs (Figure 9(b))	-32.295	2.98	12.45 %

The comparison of radiation pattern is presented in Figure 11. Note that the gain of patch antenna with patch AMC as in Figure 9(a) and Figure 9(b) is 7.729 dB and 7.862 dB, respectively compared to patch antenna without AMC. Therefore, the percentage increments of gain for both designs compared to patch antenna without patch AMC are 7.5 % and 9.3 %. The maximum peak directivity of design in Figure 9(a) and Figure 9(b) is slightly increased by 4.08 % (7.9 dBi) and 5.66 % (8.02 dBi) compared to patch antenna without AMC. The comparison result is recorded in Table 6.

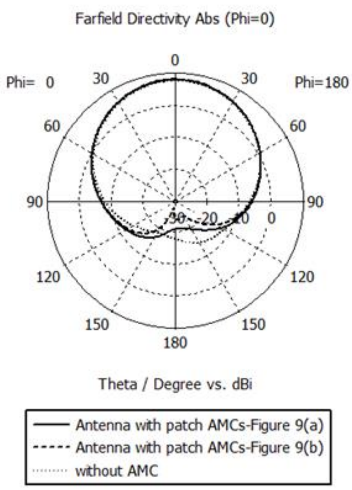


Figure 11: Radiation pattern antenna without and with patch designs AMC

Table 6
Comparison result of radiation pattern between patch antenna without and with designs AMC

Pattern	Parameter Studied			
	Gain (dB)	Radiation efficiency (%)	3 dB beamwidth	Maximum peak directivity (dBi)
Antenna without AMC	7.190	91.3	71.3	7.59
Antenna with design AMCs (Figure 9(a))	7.729	96.2	70.9	7.90
Antenna with design AMCs (Figure 9(b))	7.862	95.6	69.8	8.02

The performance of these two designs is slightly lower compared to the design configuration as in Figure 5. But, the advantage of these two designs is smaller in size. Therefore, it is seen that the size of design configuration as in Figure 9(a) and Figure 9(b) is reduced by 9.2 % and 14.14 % , respectively compared with design in Figure 5.

C. Three different configurations of multilayer patch antenna and AMC

The other important characteristic of 5G application is the bandwidth ≥ 1 GHz (3.57 %) [15] at a frequency of 28 GHz. Since the design, configuration which discussed before are not attaining the required, another technique to enhance the bandwidth of antenna by using AMC is proposed. Figure 11 - Figure 13 present a recommended antenna and AMC with three different configurations. Each antenna consists of seven layers which the lower layer is a fully ground plane with PEC.

There are three layers of RT 5880 substrate which at the top of each substrate layer consists of patch antenna, 1 unit cell AMC and three unit cell AMC. The overall size of design configuration 1, design configuration 2 and design configuration 3 is 11.1185 mm x 8.47 mm, 11.3785 mm x 8.47 mm and 11.2985 mm x 8.47 mm, respectively. The overall thickness for the configurations in 6.902 mm.

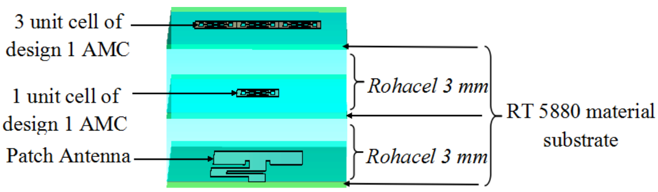


Figure 11: Configuration of multilayer patch antenna with design 1 AMC

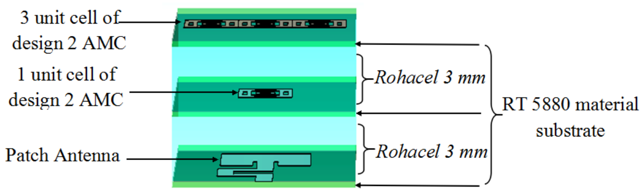


Figure 12: Configuration of multilayer patch antenna with design 2 AMC

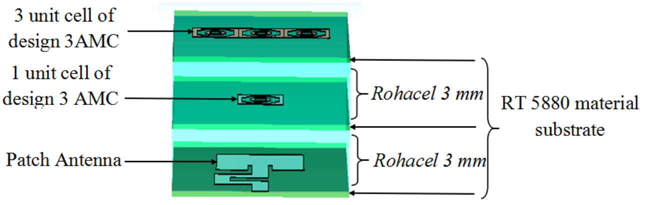


Figure 13: Configuration of multilayer patch antenna with design 3 AMC

The calculated reflection coefficient of multilayer antenna with AMC against the frequency for the designed in Figure 11 - Figured 13 is plotted in Figure 14. Compared to the previous design technique of antenna with AMC, the multilayer antenna with design 1, design 2 and design 3 AMC exhibits wider bandwidth and higher gain. Multilayer antenna with design 1 and design 3 AMC structure contribute the impedance bandwidth more than than 1 GHz (3.57 %). Therefore, these structures achieve the requirement of 5G technology at a frequency of 28 GHz.

In case of multilayer antenna with design 2 AMC, the impedance bandwidth is 3.32 %. This is because the size of unit cell design 2 AMC is large compared to a unit cell design 1 and design 3 AMC. Therefore, the gap between the substrate and AMC patch is small compared to the others. The comparison result is presented in Table 7.

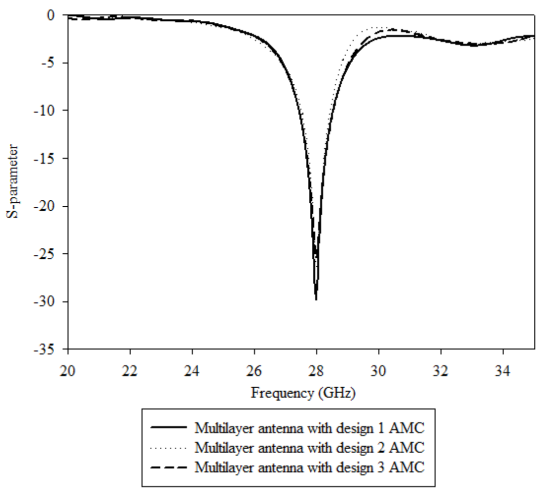


Figure 14: Reflection coefficient of multilayer antenna with three designs of AMC

Table 7
Comparison result of multilayer antenna with three deigns of AMC

Pattern	Parameter Studied	
	Reflection coefficient (dB)	Bandwidth (%)
Multilayer antenna with design 1 AMC	-29.718	3.89
Multilayer antenna with design 2 AMC	-26.358	3.32
Multilayer antenna with design 3 AMC)	-25.401	3.95

Figure 15 introduces a radiation pattern for the design of multilayer antenna with design 1 AMC, multilayer antenna with design 2 AMC and multilayer antenna with design 3 AMC. From the Table 8, it is seen that the gain of these designs is increased compared to the previous design structure.

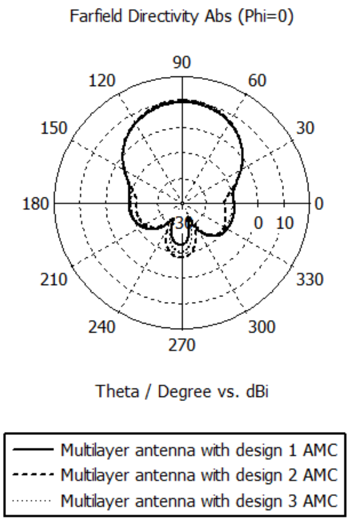


Figure 15: Radiation pattern of multilayer antenna with three designs of AMC

Table 8
Comparison result of radiation pattern of multilayer antenna with three designs of AMC

Pattern	Parameter Studied		
	Gain (dB)	Radiation efficiency (%)	3 dB beamwidth
Multilayer antenna with design 1 AMC	9.622	93.2	57.9 °
Multilayer antenna with design 2 AMC	10.54	93.9	55.3 °
Multilayer antenna with design 3 AMC	10.09	93.1	56.4 °

V. Conclusion

The configuration of patch antenna with three different designs of the AMC is designed using for 5G application and operate at a frequency of 28 GHz. Three cases of design configurations of patch antenna and AMC are analyzed. The simulated result shows that all the designs configuration offer higher gain, directivity and bandwidth compared to patch antenna without AMC. Therefore, all these characteristics make it a suitable for future 5G application.

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