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Antenna Performance Enhancement using AMC Structure for 5G Frequency Range

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ABSTRACT

This paper presents a microstrip patch antenna operated at the fifth generation (5G) frequency range, which is at 3.5 GHz. To enhance the performance of the proposed antenna, an Artificial Magnetic Conductor (AMC) structure is implemented into the design. The 1x3 AMC is sandwiched between two FR-4 substrates and the performance of the proposed antenna is compared with the antenna without AMC structure. The simulated results prove that the proposed antenna offers better reflection coefficient with -50.45 dB compared to only -15.55 dB for the conventional antenna. Wider bandwidth is also achieved with 427 MHz of frequency bandwidth as opposed to only 135 MHz for the antenna without AMC. Besides that, the integration of AMC enhances the gain of the antenna when 3.7 dBi is achieved in contrast to only 3.21 dBi for the conventional antenna. Moreover, the efficiency of the antenna with AMC is also improved up to 68.54%. Furthermore, the ability to shrink 52.23% of the size of the antenna without AMC making it very favorable to be applied in 5G bands.

1. Introduction

The development of mobile technology happens every day, hence the number of mobile subscribers tremendously increase day by day. According to [1], fifth generation (5G) connections will surpass 1 billion in 2022 and 2 billion by 2025. 5G accounted for more than 5.5% of mobile connections compared to only 2.2% for 3G and 4G within 18 months after its launching.

Applications that use 5G offer a lot of advantages such as higher data rates and hyperconnectivity, but the actual performance of a 5G device is determined by its antenna. As a microstrip patch antenna offers benefits such as small, low profile and low cost fabrication, it is very suitable to be used for 5G antennas [2-5]. However, the microstrip patch antenna provides low gain, narrow bandwidth, and limited efficiency. Therefore, various techniques have been conducted to overcome the drawbacks. One of the methods is by adding the parasitic elements into the antenna design to

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achieve wider bandwidth [6, 7]. The parasitic patch can also be used to shrink the size of the antenna [8]. Moreover, the bandwidth improvement can also be done by creating the slotted patch antenna [9-11]. Besides that, the method of using superstrate into the design had also been proposed to boost the gain of the antenna [12-15].

On the other hand, the used of metamaterial had also been one of the best approaches to improve the performance of the antenna. Artificial Magnetic Conductor (AMC) is one kind of the metamaterial that widely used due to their special electromagnetic characteristics that do not exist in nature.

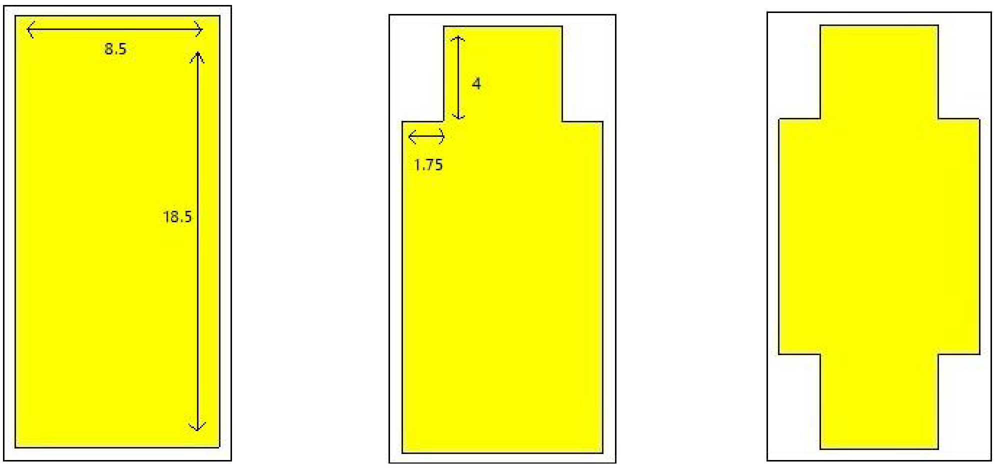
AMC has been used in a Multiple-Input-Multiple-Output (MIMO) array antenna to reduce the size, improve gain and efficiency of the antenna [16]. Additionally, the gain enhancement can also be obtained using a dual band AMC surface for wireless body area network applications [17] and ultra-thin AMC in antenna-on-chip [18, 19].

In this paper, a microstrip patch antenna with AMC structure has been designed to test the performance enhancement of the antenna for 5G frequency range, which is in sub-6GHz. Several techniques to boost the performance of the antenna are reviewed, followed by the antenna design and geometry, results, and discussion, and finally a brief conclusion is given.

2. Antenna Design and Geometry

2.1 Artificial Magnetic Conductor (AMC)

First, an 8.5 x 18.5 mm^2 Artificial Magnetic Conductor (AMC) unit cell is designed on a 9.5 x 19 mm^2 FR-4 substrate. Three alterations have been made until zero degree of reflection phase at 3.5 GHz is achieved, as shown in Figure 1 and Figure 2.



(a) (b) (c)

Fig. 1. The alterations of AMC unit cell (a) First alteration (b) Second alteration (c) Third alteration

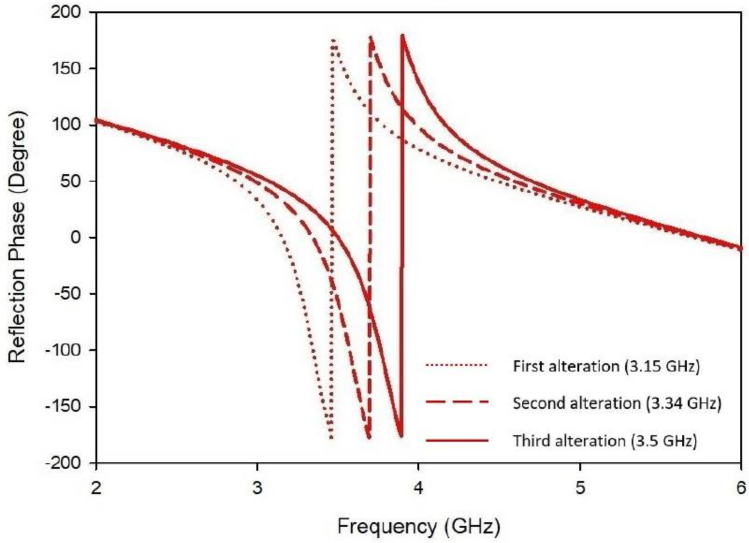


Fig. 2. The reflection phase for each alteration

From the graph of reflection phase, the bandwidth of AMC unit cell can be defined as illustrated in Figure 3. The bandwidth of the reflected phase crosses zero degree at 3.5 GHz is determined between +90° to -90°. As a result, the bandwidth of the proposed AMC unit cell is 40.57%, ranging from 2.33 GHz to 3.75 GHz.

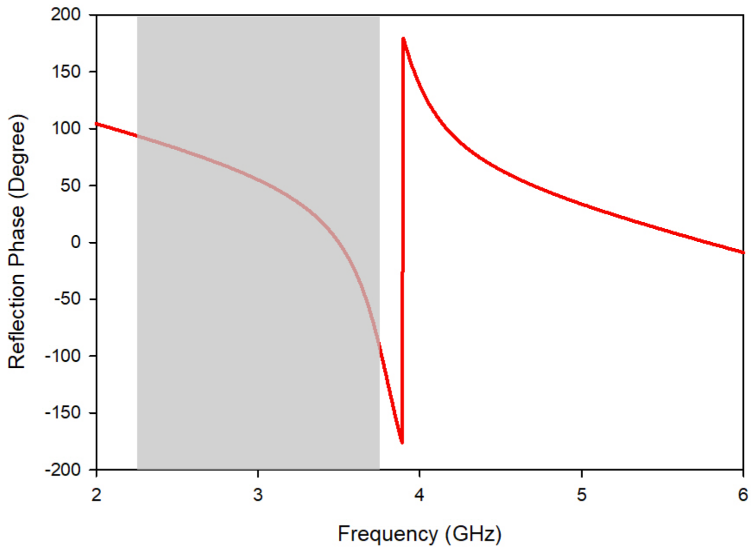
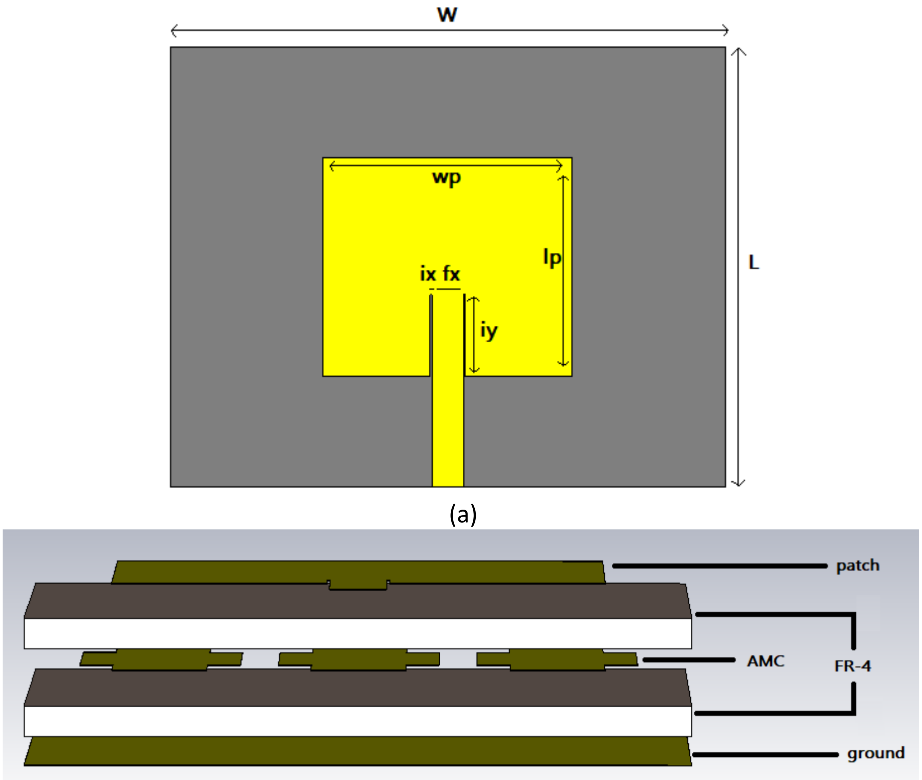


Fig. 3. The bandwidth of the proposed AMC unit cell

2.2 Antenna Design Geometry

The AMC unit cell is then implemented into a microstrip patch antenna design. The proposed antenna consists of five layers as shown in Figure 4. The top layer is where the microstrip patch is located. The second and third layers are the AMC substrate and AMC structure, respectively. The fourth layer consists of the antenna substrate while the fully ground planed is placed at the bottommost layer. FR-4 is used for both AMC substrate and antenna substrate with dielectric constant, ε_r = 4.3, thickness, h = 1.6 mm and loss tangent, δ=0.019. To have better performance, three different arrangements of AMC structure have been simulated which are 1x1, 1x2 and 1x3.



(b)

Fig. 4. Geometry of the proposed microstrip patch antenna (a) patch structure (b) 3D view

Besides that, a 52.6 x 40.4 mm^2 conventional antenna has also been designed with the same substrate and patch, however no AMC structure is added into the design. After optimization, the antenna with AMC managed to shrink to only 35 x 29 mm^2 of size. This means that 52.23% of the size antenna without AMC can be reduced. Therefore, this miniaturization can fulfil the requirement of 5G as small antenna is needed to be applied in this kind of technology.

The following relationships are used to calculate the dimension of the proposed microstrip patch antenna. The width of the patch, *wp* is calculated by Eq. (1):

$$wp = \frac{1}{2f_r\sqrt{\varepsilon_r}}\frac{2}{\varepsilon_r+1} \quad (1)$$

The effective length is given by:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (2)$$

where c is the free space velocity, f_r is the resonant frequency with the effective dielectric constant, ε_{eff} given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{wp}}}\right) \quad (3)$$

where h is the thickness of the substrate. Next, the length extension, ΔL is the fringing field effect created at the radiating edge can be calculated as in Eq. (3).

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

The length of the patch, lp is given by:

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

Finally, the actual width, W and length, L of the proposed antenna design is determined by Eq. (6) and Eq. (7).

$$W = 6h + wp \quad (6)$$

$$L = 6h + lp \quad (7)$$

A parametric study has been done to optimize the dimension of the quarter wave transmission line, feedline and other parameters in order to have better reflection coefficient, wide bandwidth and sufficient gain at the resonant frequency. The overall parameters are tabulated in Table 1.

Table 1
Dimension of the proposed microstrip patch antenna

Parameter	*W*	*L*	*wp*	*Lp*	*fx*	*ix*	*iy*
Value	35	29	26	19.05	3	0.15	2.5

3. Results and Discussion

The proposed antenna is simulated in sub-6GHz 5G frequency band, which is at 3.5 GHz using the CST Microwave Studio software. Figure 5 shows the reflection coefficient (S_{11}) of the proposed antenna and the antenna without AMC structure. The result clearly illustrates that better S_{11} can be achieved with the implementation of AMC. The antenna with AMC structure offers better S_{11} with -34.19 dB for 1x1 arrangement and -50.45 dB for 1x3 arrangement, compared to only -15.55 dB for the antenna without AMC. Based on Figure 5, the S_{11} of the antenna is improved when more unit cells are added into the AMC structure. The 1x3 of AMC arrangement is sufficient in order to obtain better S_{11} while maintaining the compact size of the antenna.

Besides that, the proposed antenna also obtains 427 MHz of frequency bandwidth, and only 135 MHz for the conventional antenna. Furthermore, the utilization of AMC structure also gives benefit to the gain of the antenna when 3.7 dBi is achieved, as opposed to only 3.21 dBi for the antenna without AMC. This result proved that the AMC structure not only wider the bandwidth but also enhance the gain of the proposed antenna.

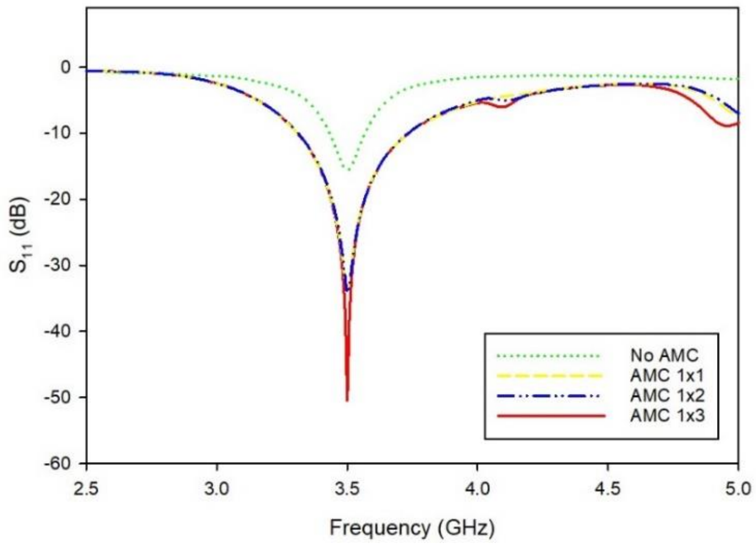


Fig. 5. The S_{11} for the antenna with AMC and without AMC

Figure 6 illustrates the radiation pattern of the antenna in xz and yz-plane. Based on the 2D polar plots, the radiation pattern in xz-plane shows a bi-directional shape with 153° of main lobe direction. In contrast, the quasi-omnidirectional pattern is observed in yz-plane with the main lobe directs at 11°. On the other hand, the enhancement of the antenna performance has also been obtained in term of the efficiency. By adding the AMC structure into the antenna design, the total efficiency is increased up to 68.54%. Table 2 tabulates the overall performance of the proposed antenna and the antenna without AMC.

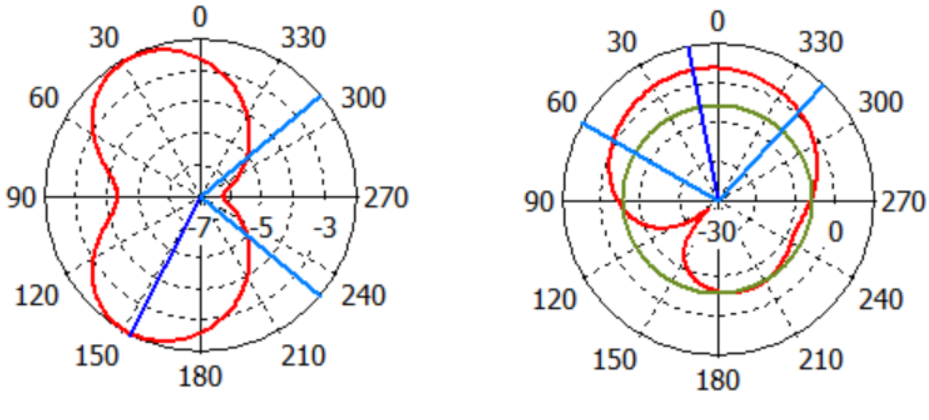


Fig. 6. Radiation pattern of the antenna: (a) xz-plane (b) yz-plane

Table 2
The overall performance of the antenna

Parameter	Antenna without AMC	Antenna with AMC
Size (mm^2)	52.6 x 40.4	35 x 29
S_{11} (dB)	-15.55	-50.45
Bandwidth (MHz)	135	427
Gain (dBi)	3.21	3.70
Efficiency (%)	46.50	68.54

4. Conclusion

A microstrip patch antenna with AMC structure has been proposed in this paper. The implementation of AMC structure into the antenna design shows that performance of the microstrip patch antenna can be enhanced. By obtaining -50.45 dB of reflection coefficient, the antenna achieves better S_{11} and offers wider bandwidth compared to the antenna without AMC. Besides that, better S_{11} can also be achieved when more unit cells are added in the AMC arrangement. Moreover, the utilization of AMC managed to reduce 52.23% of the antenna size, achieve higher gain and better efficiency. Therefore, the proposed antenna could be one of the methods to overcome the drawbacks of microstrip patch antenna, and indirectly very favorable to be applied in 5G frequency range.

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