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Novel Artificial Magnetic Conductor for 5G Application

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Abstract
A design of novel bendable Artificial Magnetic Conductor (AMC) structures has been presented in this paper in two selected of frequencies at 5G application. These designs started with a square patch shape and continued with the combination of circular and Jerusalem shape which resonate at a frequency of 18 GHz and 28 GHz. Details of the theory and the structures of AMCs are explained. The reflection phase, bandwidth, angular stability and dispersion diagram were studied. The simulated results plotted that the novel AMC has good bandwidth and size is reduced by 53 % and 55 % for both frequencies. Other than that, it is also proved that the novel AMC has a stable reflection phase and no band gap performs at the specific frequency. The good performances of this novel AMC make it useful in order to improve antenna's performance.

Keywords*: Artificial Magnetic Conductor, Reflection Phase, Bandwidth, Angular Stability, Dispersion Diagram*

1. Introduction

Metamaterial is a structure that contains of a various kind of material that's designed to imitate the characteristics of specific materials that do not exist naturally such as perfect magnetic conductors (PMCs) [1]. The usage of metamaterials has received wide attention in recent years by reason of this unique electromagnetic manner [1] and the capability in improving gain, reducing back lobe radiation, wide bandwidth and also reducing the antenna size [1-5]. AMC or artificial magnetic conductor is one of the metamaterial that displays the manners of the zero-degree reflection phase [1] of PMC at a point of resonant frequency [1].

Several AMC design structures with applications such as Radio Frequency Identification (RFID) tags over metallic object and Wi-Fi applications are studied and compared. In [6] has presented four types of single-band high impedance surface structures using same dielectric substrate at a frequency of 2.45 GHz. The four types AMC structures are mushroom-like EBG structure, Uni-planar compact EBG structure, Peano curve of order 1, and Hilbert curve of order 2. The bandwidth is investigated and compared between four types of AMC structures. The simulated results showed that the mushroom-like EBG has the broadest bandwidth which around 12.08 %, followed by the Peano curve of order 1 (6.3 %), Uni-planar compact EBG (4.88 %) and the Hilbert curve of order 2 (4.69 %). However, the measured results are dropped for all types of the presented AMC which is from the mushroom-like EBG dropped to 3.46 %, Uni-planar compact EBG dropped to 2.95 %, Peano curves of order 1 dropped to half of its simulated result and Hilbert curve of order 2 dropped to 1.93 %.

In [7] has presented two different kinds of single-band AMC structures, namely the square patch and square loop FSS. In this paper, the sensitivity of the reflection phase with the incident angle is compared with the mushroom-like EBG, Uni-planar compact EBG, square patch and square loop FSS. The simulated results show that the square-loop FSS with a smaller period has the least sensitivity to the incident angle compared to the others. Other than that, the reflecting performance of AMC surfaces changes obviously with a large incident angle.

There is also a study that focuses on AMC miniaturization methods and bandwidth enhancement method due to the limitations of the new technology. M. Abu, et al., [8] has presented a method in miniaturizing the AMC structure by introducing variation of slot size to the AMC design at 0.92 GHz. The simulated results found that when the size of the slot is

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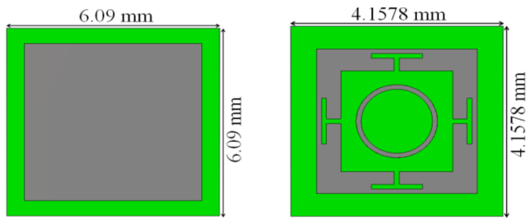
increased, both frequency and bandwidth is decreased by 0.91% and 6.50% respectively. Through the shape adjustment, the bandwidth had reduced from 2.25% to 1.86%.

Other than that, the bandwidth also can be improved by modifying the thickness of the AMC. In this paper, two types of thickness modification will be analyzed. The single layer of AMC structure with the overall thickness of 1.98 mm achieved the percentage bandwidth around 1.86 %. Then the thickness of the substrate is doubled with the increment of bandwidth to 2.04 % and stacked AMC structure with the overall thickness of 2.665 mm. The percentage bandwidth is improved up to 3.86 %.

In this study, a design of novel AMC resonated at frequencies of 18 GHz and 28 GHz is presented which applied for 5G application. The b novel AMC is designed to start with a square patch and continued with the combination of circular and Jerusalem shape which resonate at a frequency of 18 GHz and 28 GHz. The presented novel AMC has good bandwidth and smaller in size. Besides that, that the novel AMC has a stable reflection phase and no band gap performs at the specific frequency.

2. Research Method

RT 5880 has been used as a substrate material with the thickness of 0.254 mm. The dielectric constant, ε_r and tangent loss, $\tan\delta$ of the substrate is 2.2 and 0.0009, respectively. An AMC basic structure consists of ground plane located at the bottom, patch at the top and substrate located between the ground plane and patch. A designing of AMC firstly starting with a square patch shape which resonated at 18 GHz with an overall size of 6.09 mm x 6.09 mm as shown in Figure 1(a). Then, this continued with the combination of circular and Jerusalem shape which resonated at a frequency of 18 GHz as shown in Figure 1(b). The overall size of novel AMC is 4.1578 mm x 4.1578 mm. The size is reduced around 53 %.



(a) Square patch AMC (b) Novel AMC

Figure 1. A unit cell AMC at 18 GHz

The computer simulation of reflection phase diagram comparison between square shape AMC and novel AMC is shown in Figure 2. The results displays that the useful AMC bandwidth of the square shape AMC is small compared to the novel AMC design. An AMC structures frequency bandwidth is described as a specified range of frequency when phase shift is between +90˚ to -90˚.

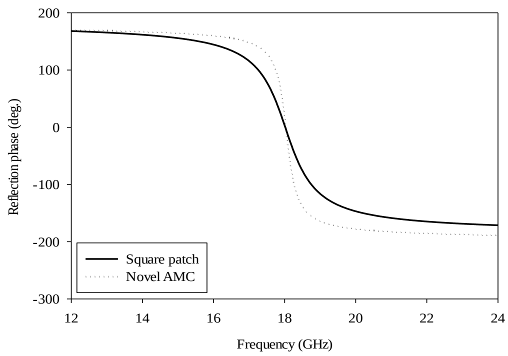


Figure 2. Reflection phase of square patch AMC and novel AMC design

The reflection phase of square patch AMC falls within a range of 17.387GHz to 18.644 GHz while novel AMC falls within a range of 17.80 GHz to 18.231 GHz. Therefore, these given 6.98 % useful bandwidths for the square patch design AMC and 2.39 % bandwidth of novel AMC. The bandwidth is decreased around 66 % with the decrement of overall size around 53 %. The bandwidth has decreased for novel AMC probably due to the multiple of shape with various dimensions that composed together in order to form a novel AMC structure.

The simulated reflection magnitude of the square patch AMC and novel AMC at 18 GHz are shown in Figure 3. Reflection magnitude is obtained from the reflection phase of AMC structure. As shown in Figure 3, both AMC structure has a reflection magnitude of 0.977 and 0.94, respectively. However, both designs can be considered as a good reflector because the reflection magnitude is almost to 1.00.

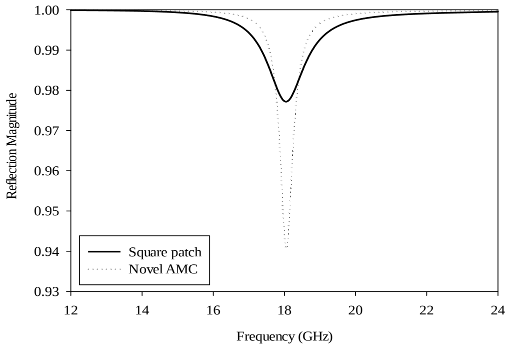
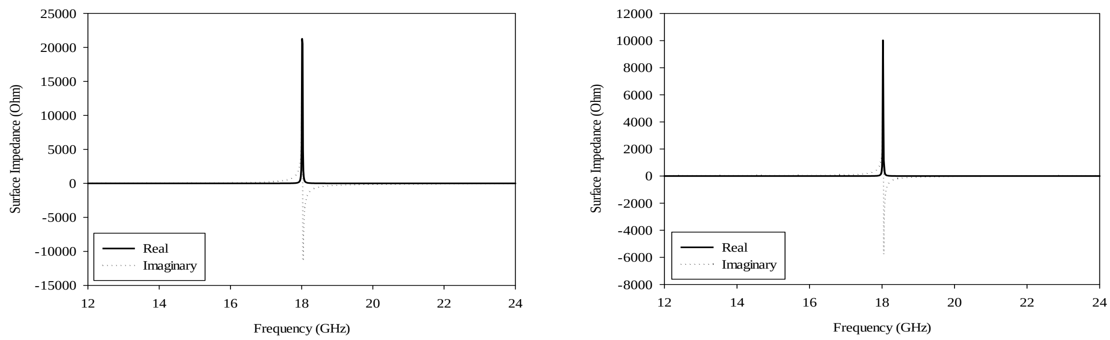


Figure 3. Reflection magnitude of square patch AMC and novel AMC design

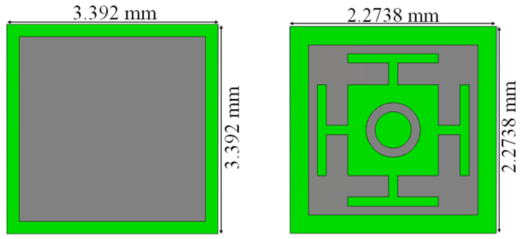
The simulated surface impedance of the square patch AMC and novel AMC at frequency 18 GHz are plotted in Figure 4(a) and Figure 4(b). The results show that, square patch AMC surfaces have a very high surface impedance within a specific frequency range compared to novel AMC. This is because that the reflection magnitude of the square patch AMC is almost to 1.00 as shown in Figure 3. It can be concluded that the reflection coefficient magnitude and surface impedance for both designs ideally can attain +1 and infinity [10].



(a) Square patch AMC (b) Novel AMC

Figure 4. Surface Impedance of unit cell AMC at 18 GHz

The design structure of a square patch AMC and novel AMC at 28 GHz are presented in Figure 5. The overall size of the square patch AMC is 3.392 mm x 3.392 mm and the overall size of novel AMC is 2.2738 mm x 2.2738 mm. The size is reduced about 55 %.



(a) Square patch AMC (b) Novel AMC

Figure 5. A unit cell AMC at 28 GHz

The reflection phase of unit cell square patch AMC and novel AMC are presented in Figure 6. The 12.7 % square patch AMC useful bandwidth found from the reflection diagram occurs at 26.237 GHz to 29.795 GHz, while the 4.88 % novel AMC bandwidth falls at 27.24 GHz to 28.607 GHz. Mentioning to Figure 7, the simulated reflection magnitude 0.988and 0.97 are achieved at the preferred resonating frequency of square patch AMC and novel AMC structure.

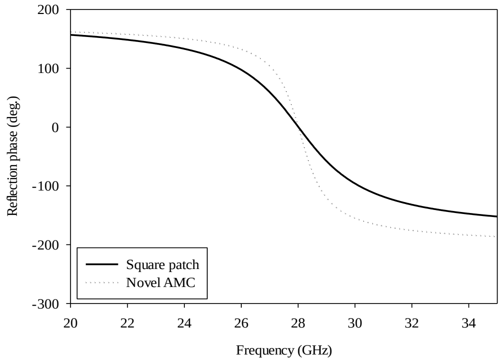


Figure 6. Reflection phase of square patch AMC and novel AMC design

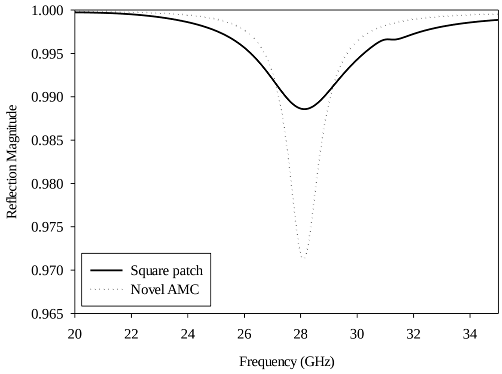
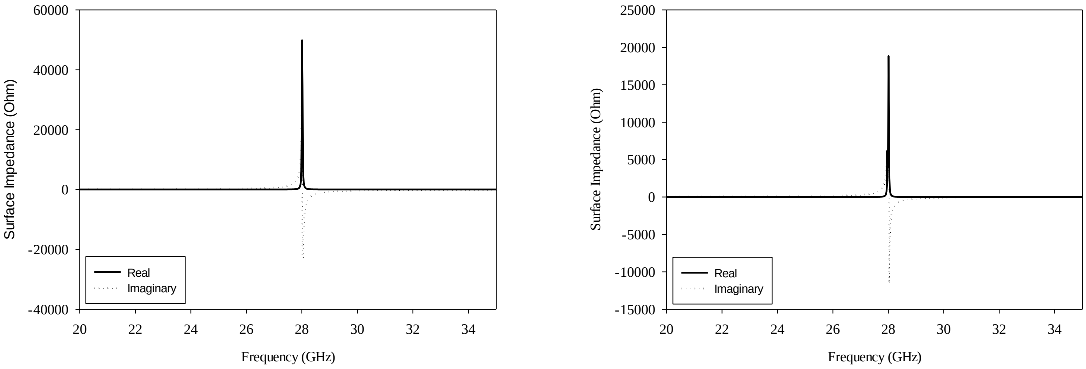


Figure 7. Reflection magnitude of square patch AMC and novel AMC design

The surface impedance of the square patch AMC and novel AMC at 28 GHz are presented in Figure 8(a) and Figure 8(b). As shown in Figure 8(a) and Figure 8(b), the AMC structures has very high impedance which occurs at operating frequency.



(a) Square patch AMC (b) Novel AMC

Figure 8. Surface Impedance of unit cell AMC at 28 GHz

Table 1 summarizes the analysis of square patch AMC and novel AMC at a frequency of 18 GHz and 28 GHz.

Table 1. The analysis of AMC structures bandwidth at frequency of 18 GHz and 28 GHz

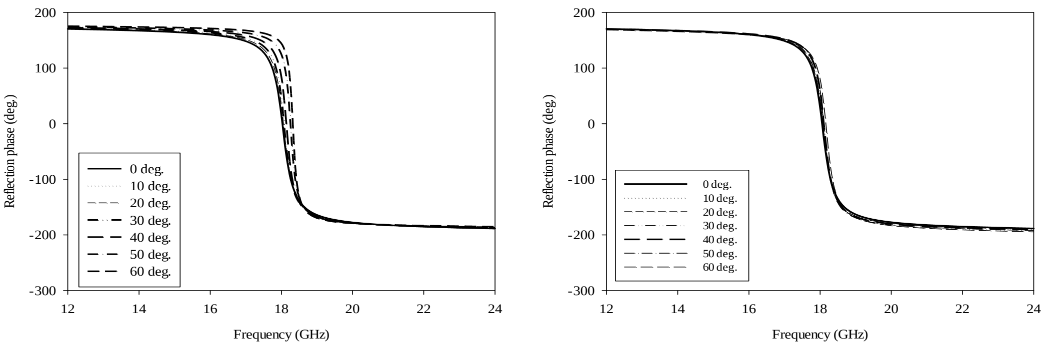
Pattern	Parameter Studied		
	Frequency (GHz)	Bandwidth (GHz)	Bandwidth (%)
Square	18 GHz	17.387 – 18.644	6.98 %
AMC	28 GHz	26.237 – 29.795	12.7 %
Novel	18 GHz	17.80 – 18.231	2.39 %
AMC	28 GHz	27.24 – 28.607	4.88 %

3. Results and Analysis
3.1. Reflection Phase for Different Angle of Incident

Angular stability of novel AMC at a frequency of 18 GHz and 28 GHz is being analyzed for both TE and TM polarizations. The analysis of an incidence angle varies from 0° to 60°. The bandwidth is described within the reflection phase of ±45° [11]. The reason is to prevent the occurrence of a decrease in | Γ | at large incidence angles, especially for TE modes [12]. Other than that, in order to produce a good performance, the maximum shift in operating frequency that occurs at various incident angles should be lower than half of the bandwidth [13].

The simulated results of the reflection phase at different incidence angles of novel AMC are shown in Figure 9 and 10. From the achieved results, it displays that there is a slight shift to the right and to the left of the operating frequency affected by the several of incident angles.

Therefore, there is some decreasing and increasing of bandwidth as the incidence angle changes. It can be concluded that the recommended novel AMC unit cell has a stable reflection phase. The stability of this AMC structure makes it more interesting to use as a reflector which able to improve the gain and decrease the back-lobe level of antennas [15]. Results for a novel AMC reflection phase of TE and TM modes at a frequency of 18 GHz and 28 GHz are summarized in Table 2 - Table 5.



(a) TE-mode (b) TM-mode

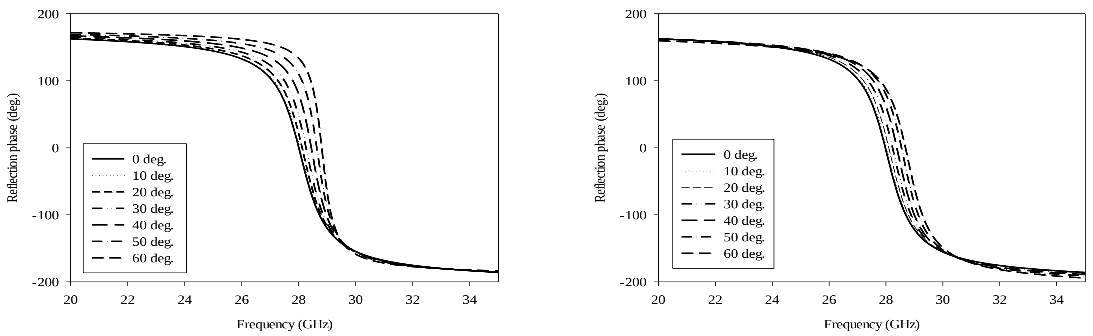
Figure 9. Novel AMC reflection phase with different angles of incidence at 18 GHz

Table 2. Novel AMC reflection phase of a TE-mode at 18 GHz

Incident Angles (°)	± 45° of bandwidth	
	Bandwidth (GHz)	Bandwidth (%)
0	17.930 – 18.124	1.078 %
10	17.930 – 18.116	1.033 %
20	17.969 – 18.147	0.990 %
30	18.000 – 18.155	0.860 %
40	18.070 – 18.209	0.772 %
50	18.202 – 18.318	0.644 %
60	18.287 – 18.372	0.472 %

Table 3. Novel AMC reflection phase of a TM-mode at 18 GHz

Incident Angles (°)	± 45° of bandwidth	
	Bandwidth (GHz)	Bandwidth (%)
0	17.961 – 18.147	1.033 %
10	17.969 – 18.147	0.989 %
20	18.000 – 18.171	0.950 %
30	17.992 – 18.155	0.906 %
40	18.031 – 18.186	0.861 %
50	18.039 – 18.186	0.817 %
60	18.093 – 18.240	0.817 %



(a) TE-mode (b) TM-mode

Figure 10. Novel AMC reflection phase with different angles of incidence at 28 GHz

Table 4. Novel AMC reflection phase of a TE-mode at 28 GHz

Incident Angles (°)	± 45° of bandwidth	
	Bandwidth (GHz)	Bandwidth (%)
0	27.699 – 28.272	2.046 %
10	27.752 – 28.314	2.007 %
20	27.849 – 28.382	1.904 %
30	28.014 – 28.488	1.693 %
40	28.227 – 28.653	1.521 %
50	28.469 – 28.798	1.175 %
60	28.682 – 28.944	0.936 %

Table 5. Novel AMC reflection phase of a TM-mode at 28 GHz

Incident Angles (°)	± 45° of bandwidth	
	Bandwidth (GHz)	Bandwidth (%)
0	27.680 – 28.253	2.046 %
10	27.733 – 28.285	1.971 %
20	27.820 – 28.372	1.971 %
30	27.965 –28.488	1.868 %
40	28.120 – 28.624	1.800 %
50	28.285 – 28.779	1.764 %
60	28.421 – 28.934	1.832 %

3.2. Bandgap Analysis on Novel Amc

The structure that has a forbidden frequency band or in other words, no propagation of electromagnetic wave can be described by its dispersion diagram [14]. The dispersion diagram is used to describe the wave vector graphics which depend on the frequency and provide information about the location of the pass-band and stop-band within the frequency spectrum [15].

The simulated results of the dispersion diagram which attained using the Eigenmode solver of CST MWS is represented in Figure 11 and Figure 12. It was found that there is no band gap performs at the specific frequency range because no vias are applied to this structure. Therefore, this structure is not working as EBG structure.

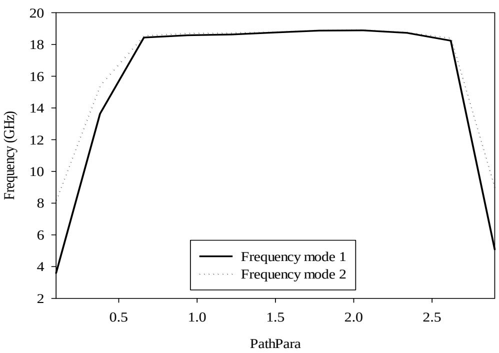


Figure 11. Dispersion diagram of Novel AMC at 18 GHz

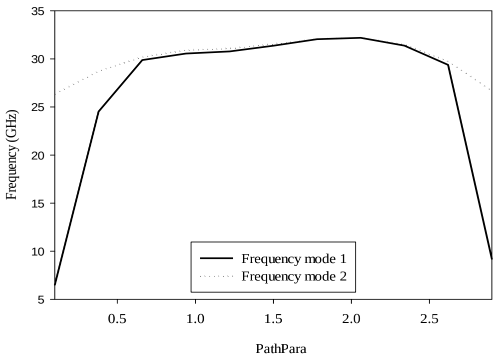


Figure 12. Dispersion diagram of Novel AMC at 28 GHz

4. Conclusion

A novel bendable AMC structure has been proposed for 5G applications. The structure is designed to start with a square patch and continued with the combination of circular and Jerusalem shape which resonate at a frequency of 18 GHz and 28 GHz. From the results plotted, it is exposed that the novel AMC has good bandwidth and size is reduced by 53 % and 58 % for both frequencies. Other than that, it is also proved that the novel AMC has a stable reflection phase and no band gap performs at the specific frequency. The good performances of this novel AMC make it useful in order to improve antenna's performance.

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