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# Technique to Enhance the Bandwidth of a Very Thin Artificial Magnetic Condutor (AMC)

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**ABSTRACT**

*This paper introduces a technique to enhance the bandwidth of the Artificial Magnetic Conductor (AMC). A multilayer patch type of Frequency Selective Surface (FSS) is stacked on the AMC structure, to increase the thickness of the overall structure contributing to the lower inductivity consequently the higher the bandwidth. Both AMC and FSS structures were designed by using Rogers RT5880 with the thickness of 0.254 mm and permittivity of 2.2. The bandwidth of the AMC structure is successfully enhanced from 1.97% to 3.79%. The AMC was designed at 12 GHz which can be applied for 5G applications.*

**Keywords:** Artificial Magnetic Conductor (AMC), Frequency Selective Surface (FSS), Multilayer, Thin, Bandwidth.

## 1. INTRODUCTION

Metamaterial is a structure that is designed to imitate the characteristics of specific materials that do not exist in nature such as perfect magnetic conductors (PMCs) [1]. The use of metamaterials has received wide attention in recent years because of its unique electromagnetic manner and the capability in improving gain and bandwidth, reducing back lobe radiation, wide bandwidth and reducing the antenna size [2-8].

Several AMC design structures with applications such as Radio Frequency Identification (RFID) tags over metallic object and Wi-Fi applications were studied and compared [9-13]. Significant research had started to build around the 5G (fifth generation) wireless communication technologies. It was expected that the 5G mobile communication systems will become commercially available sometime around 2020 [14-17]. The objectives for developing 5G cellular networks include higher capacity, higher data rate, lower end-to-end latency, massive device connectivity, reduced cost, and consistent quality of experience.

In [18], the authors presented a novel AMC for 5G application. They started with a square patch shape and continued with the combination of the circular and Jerusalem shape which resonate at a frequency of 18 GHz and 28 GHz respectively. Therefore, 6.98% and 2.39% of the bandwidth was achieved for the square patch and novel AMC respectively. However, the bandwidth decreased by approximately 66% with the decrease of the overall size by around 53%.

G.K. Pandey *et al.,* [19] presented a triple band AMC (3.6 GHz, 7.5 GHz, and 12.2 GHz) with coplanar waveguide fed UWB antenna (2.9 GHz to more than 13 GHz). The bandwidth of the AMC structure was observed in the range of 3.3 GHz−3.9 GHz (1st Band), 7.2 GHz−7.7 GHz (2nd

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Band), and 12.1 GHz−12.5 GHz (3rd Band), thus contributed to 16.67%, 6.67% and 3.27% of the useful bandwidth respectively.

In [20], the authors introduced techniques to enhance the useful bandwidth of the AMC structure which is designed on a very thin substrate (0.13 mm). Different shapes of PEC metallization were discussed and other approaches for increasing the bandwidth was by applying the ring patch around the substrate as well as by implementing the DGS ground plane. From the simulation of octagonal AMC with four rectangular slots and DGS ground plane shows that the DGS with opposite metallization exhibit more bandwidth as compared to the DGS using similar metallization shape.

This paper presents an alternative technique to enhance the bandwidth of the AMC structure. The design starts with an AMC structure followed by the stacking with the Frequency Selective Surface (FSS) in order to enhance the bandwidth. The AMC and FSS were designed to operate at 12 GHz for 5G applications by using a very thin substrate which is Rogers RT5880 with the thickness of 0.254 mm and a permittivity of 2.2. that should follow.

## 2. METHODOLOGY

The basic geometric configuration of AMC is based on a square structure as shown in Figure 1, thus assigned impedance equal to that of parallel LC circuit and has high surface impedance at resonant frequency. The inductance arises from the current flowing between the patches through the metallic vias while the capacitance arises from the proximity of adjacent patches.

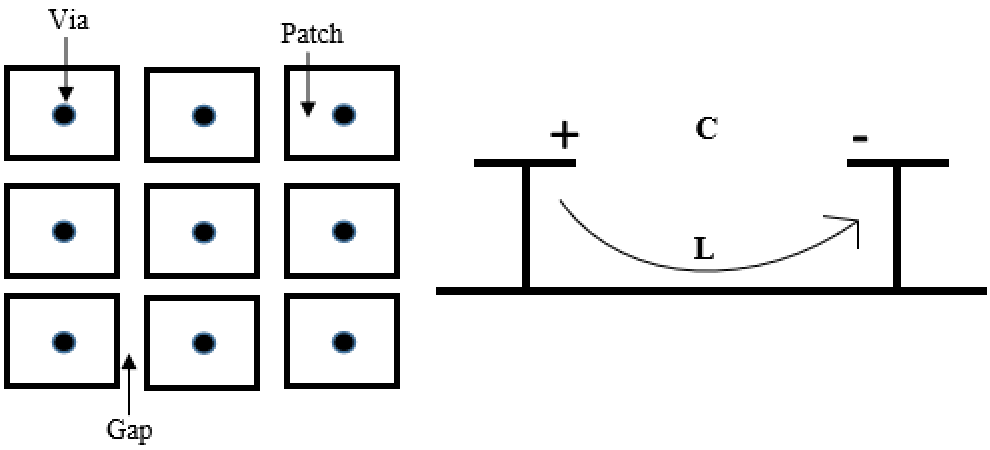



**Figure 1.** Basic AMC structure.

As in [18-20], the inductance (L), capacitance (C), frequency response (fr) and bandwidth (BW) of the equivalent circuit for mushroom EBG structure are:

$$L = \mu_0 h \tag{1}$$

$$C = \frac{W\varepsilon_0(1+\varepsilon_R)}{\pi} cosh^{-1}\left(\frac{2W+g}{g}\right) \tag{2}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{3}$$

$$BW = \frac{1}{\eta_0}\sqrt{\frac{L}{C}} \tag{4}$$

where $\eta_o$= impedance, $\varepsilon_o$ = permittivity, $\mu_o$ = permeability of free space, $w$ = patch width and $g$ = the gap between adjacent patches.

The AMC consists of patch, substrate and ground layer. Meanwhile, the FSS differs to AMC in terms of layers configuration. The FSS structure only consists of patch and substrate layers. FSS is also known as AMC without ground plane while AMC is also known as FSS with ground plane. The patch and ground layers used are the Perfect Electromagnetic Conductor (PEC) with the thickness of 0.035 mm. Meanwhile, the substrate used are 0.254 mm thick Rogers RT5880.

The square shape of the substrate was introduced for both AMC and FSS structure. T T-shaped with a circle at the center for the AMC patch is shown in Figure 2. While all the parameters for the square shape AMC are shown in Table 1.

The basic structure was introduced for FSS as shown in Figure 3. The 8.5 mm square shape substrate with the square ring for the patch. Table 2 shows the parameter for the square shape of FSS at 12 GHz.

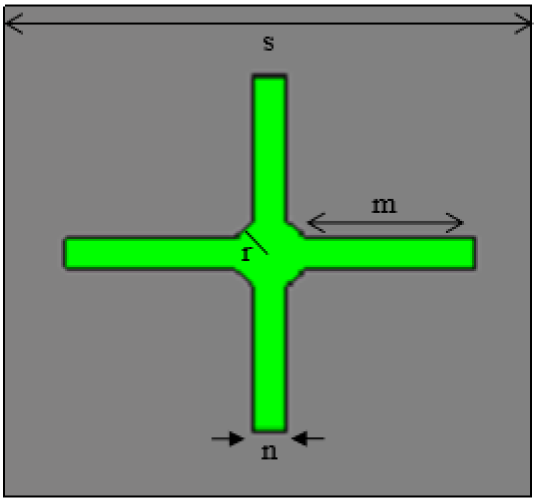



**Figure 2.** Dimension of AMC structure designed at 12 GHz.

**Table 1** Parameters of square AMC

| Variable | Parameter (mm) |
|---|---|
| Square substrate, s | 6.13 |
| Length of T-shaped, m | 1.43 |
| Width of T-shaped, n | 0.33 |
| Radius of center circle, r | 0.41 |

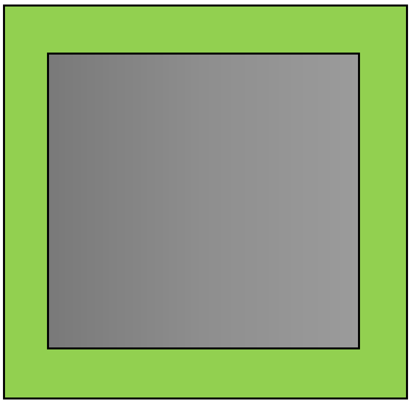
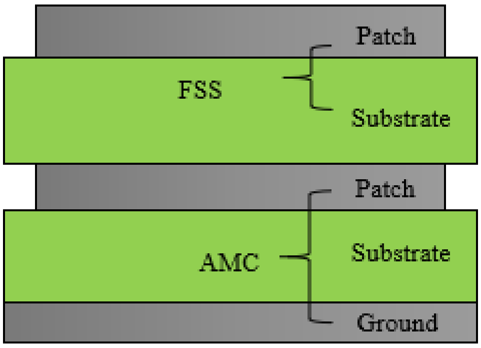


**Figure 3.** Dimension of AMC structure designed at 12 GHz.

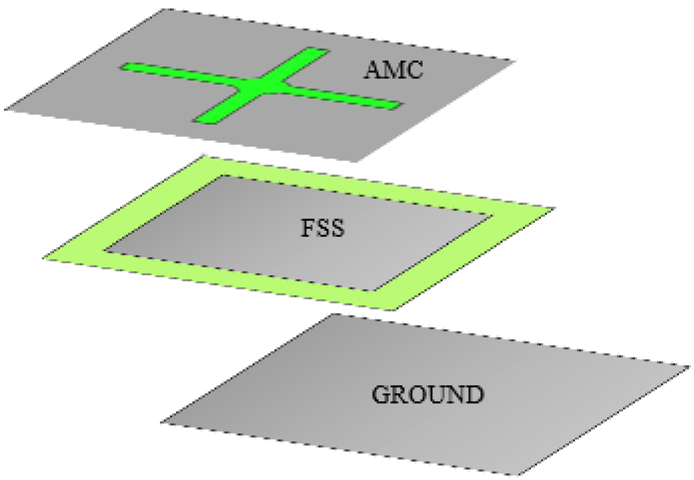
**Table 2** Parameters of square FSS

| Variable | Parameter (mm) |
|---|---|
| Square substrate, s | 8.50 |
| Square patch, m | 7.50 |

The AMC with multilayer patch type FSS was introduced in order to enhance the AMC bandwidth. The FSS structure was stacked on the top of the AMC structure as shown in Figure 4 as in the side and 3D views. The structure consists of FSS and AMC backed by a ground plane. The total thickness of the integrated structure is around 0.61 mm.




(a)




(b)

**Figure 4.** Dimension of AMC with the multilayer patch type FSS; (a) side view and (b) 3D view.

## 3. RESULTS AND DISCUSSION

The reflection magnitude and phase of the AMC structure are shown in Figure 5. It shows that the reflection magnitude of the AMC is -0.69 dB which is almost zero reflection, contributes to the best reflector and the structure can be applied as a good and reasonable ground plane for the low profile antenna.

The AMC surface varied continuously from $180^o$ to $-180^o$ relative to the frequency and was equal to zero degrees nearly at 12 GHz, meaning that all the AMC were successfully realized. By using equation 5, the bandwidth of the AMC was calculated based on the reflection phase at $\pm 90^o$. The AMC structure exhibited $90^o$ and $-90^o$ at 11.89 GHz and 12.13GHz of reflection phase respectively, thus contributing to 1.97% bandwidth.

$$bandwidth = \frac{f_{u(90^o)} - f_{L(90^o)}}{f_{r(90^o)}} \quad (5)$$

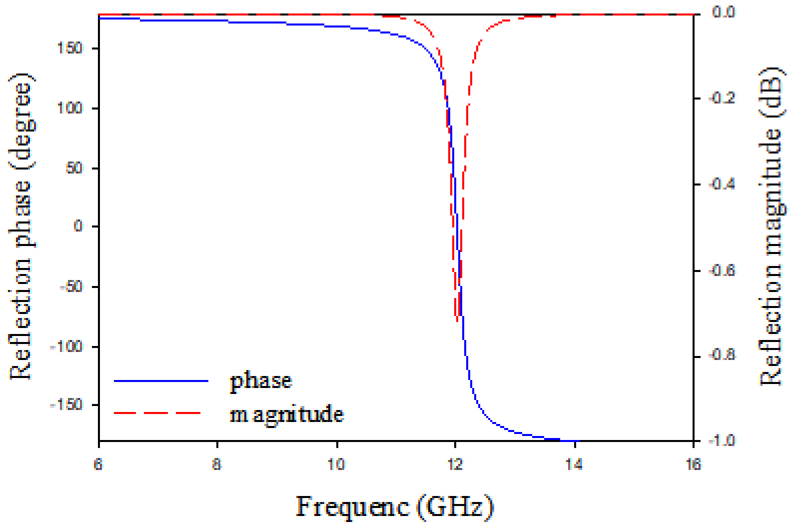



**Figure 5.** Reflection magnitude and phase of AMC at 12 GHz.

Figure 6 shows the transmission and reflection coefficient of the FSS structure at 12 GHz. The reflection of the structure is almost zero which is around -0.03 dB, while the transmission is -47.03 dB. Based on -10 dB transmission, the frequency lies between 5.52 GHz to 16.43 GHz, thus contributing to around 10.91 GHz of bandwidth.

In order to increase the bandwidth, the inductivity of the cell must be decreased. From equation (3) the inductance, L can be decreased by increasing the thickness, h of the substrate. So, the FSS structure is stacked at the back of AMC to increase the thickness of the overall structure. As shown in figure 4, the 3D view of stacked AMC and FSS consist of one ground plane and 2 two pairs of substrate and patch structure. The FSS structure was stacked on the top surface of the AMC and the total thickness is 0.61 mm. Initially, the bandwidth of the AMC was 1.97%.

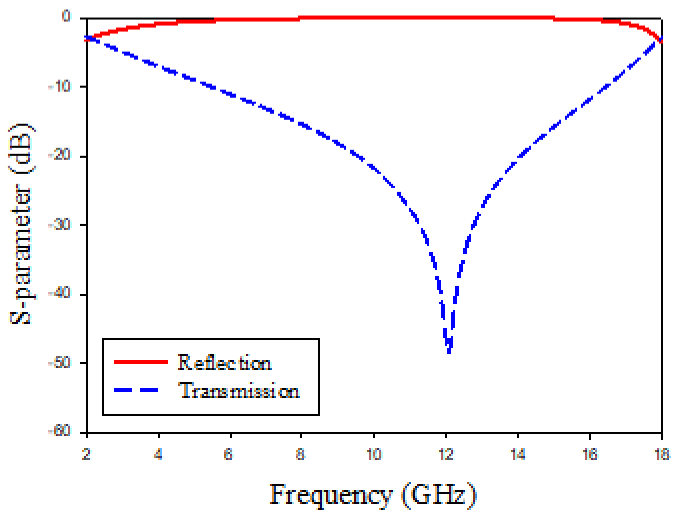



**Figure 6.** Transmission and reflection of FSS at 12 GHz.

Figure 7 shows the reflection phase of the AMC with the multilayer patch type FSS structure. At 12 GHz, the reflection phase is 0°. Therefore, the reflection magnitude of the AMC is -0.69 dB which is almost zero reflection. Meanwhile, at ±90° reflection phase, the frequency lies between 12.23 GHz to 11.77 GHz, thus contributing to 3.79% bandwidth. The integrated structure ~~is~~ has successfully increased the AMC bandwidth by approximately ~~to~~ 1.82%.

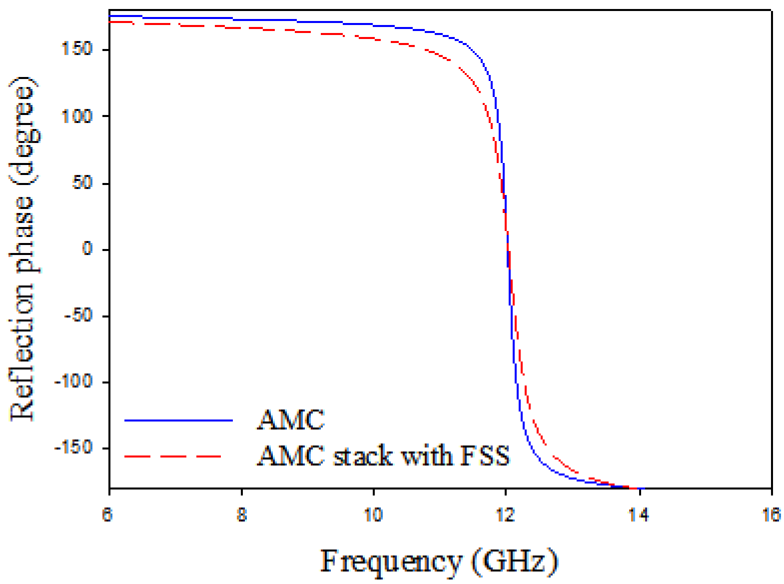



**Figure 7.** Reflection phase of AMC with multilayer patch type FSS.

The second FSS structure is stacked on the top of the AMC with the multilayer patch type FSS. The bandwidth increased to 6.92 % with the overall thickness of 0.90 mm. Table 3 shows that the bandwidth increased with the multilayer patch type FSS. Meanwhile Figure 8 shows the relationship between the bandwidth and the overall thickness of the structure. Note that the bandwidth increased in direct proportion to the overall thickness. Increasing the thickness of the overall structure contributes to the the lower the inductivity consequently the higher the bandwith. Fortunately, for this case, an AMC with double FSS layers leads the bandwidth enhancement and is still considered a thin structure (thickness < 1 mm), due to its ultra-thin substrate thickness.

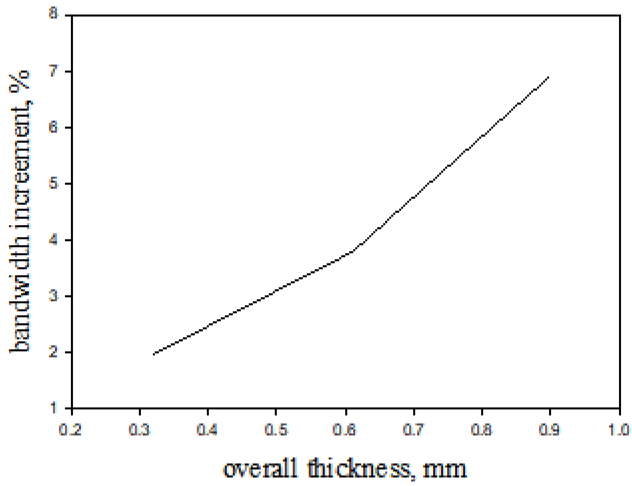



**Figure 8.** Relationship between bandwidth and total structure thickness.

**Table 3** Bandwidth increment with the multilayer type FSS

| | **Bandwidth (%)** | **Overall thickness (mm)** |
|---|---|---|
| **AMC** | 1.97 | 0.32 |
| **AMC with FSS** | 3.79 | 0.61 |
| **AMC with double FSS** | 6.92 | 0.90 |

## 4. CONCLUSION

The technique to enhance the useful bandwidth of the Artificial Magnetic Conductor (AMC) was successfully presented. A multilayer patch type of FSS is stacked on the AMC structure, increasing the thickness of the overall structure contributing to the lower the inductivity consequently the higher the bandwith. Both AMC and FSS structures were designed by using Rogers RT5880 with the thickness of 0.254 mm and permittivity of 2.2. The bandwidth of the AMC structure is successfully enhanced from 1.97% to 3.79%. The AMC was designed at 12 GHz which can be applied for 5G applications.

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