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Improvements of trapezoid antenna gain using artificial magnetic conductor and frequency selective surface

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ABSTRACT

This paper presents the performance enhancement of the trapezoid antenna with Artificial Magnetic Conductor (AMC) and Frequency Selective Surface (FSS). The antenna, AMC and FSS structures are printed on 0.254 mm of RT/Duroid 5880 high frequency laminate. The performances of the antenna with and without AMC and FSS were evaluated. Three cases are analyzed; antenna alone, antenna with AMC and antenna with AMC-FSS. The 2x3 arrays of AMC and AMC-FSS were positioned at the back of the antenna with 6 mm air gap. The antenna alone works at 12 GHz, and shifted to 12.35 GHz and 12.33 GHz for case 2 and case 3, respectively. Despite the shift in the resonance, the antenna is still operating well at 12 GHz with a return loss –16.70 dB for case 2 and–16.84 dB for case 3. Case 3 effectively enhanced the antenna gain from 4.43 dB to 6.74 dB and contributed to a directive antenna. Moreover, case 3 also successfully reduced the radiation of the antenna that penetrates into human body as the antenna is applied for on-body applications.

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1. INTRODUCTION

Research in wideband and flexible antennas have received remarkable interest. Design of small, light-weight and conformable antennas are part of considerations in the design process [1-4]. Thus retain a good radiation efficiency and at the same time support large enough bandwidth to accompany the requirements of high data rates in modern communication systems are certainly more desirable and have become increasingly studied [5-8]. Antennas experienced performance degradation, i.e. frequency detuning, bandwidth reduction and radiation distortions as placed on human body [9-12]. Moreover, the radiation that penetrates into the human cells is a major health concern [13-15]. Metamaterials such as Artificial Magnetic Conductor (AMC) and Frequency Selective Surface (FSS) were first used due to its ability to increase gain and improve the radiation performances of the antenna [16-19].

Both AMC and FSS exhibit the properties of the zero-degree reflection phase of perfect magnetic conductor (PMC) at resonant [20-22]. A perfect electric conductor (PEC) is typically used as a reflector to enable antenna radiation to focus in one direction. However, the use of PEC produces an image current that flows in the opposite direction relative to the original current. The image current will interfere with the original current, thereby attenuating or even cancelling the latter and consequently degrading the radiation efficiency.

Interestingly, the image current problem can be solved by utilizing a PMC, which produces an image current in the same direction to the original current as illustrated in Figure 1. This implies that the reflection phase is 0^{o} and the magnitude of reflection coefficient, Γ, equals +1. However, a PMC does not exist in nature, so an AMC can be designed only within a limited frequency band. AMC behaves like a PMC in the designed band, while it exhibits PEC characteristics in other bands [23-25].

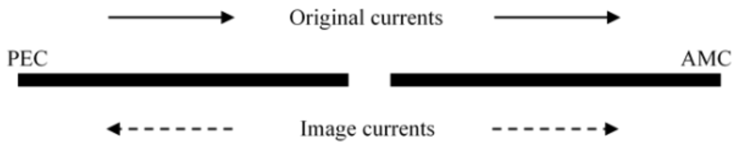


Figure 1. Trapezoid antenna design operating at 12 GHz.

This paper presents the performance enhancement of the antenna when incorporate with AMC, FSS and AMC-FSS. All of the structures were printed on 0.254 mm RT/Duroid 5880. The antenna is initially resonated at 12GHz. The frequency shifted to 12.35 GHz and 12.33 GHz as the antenna incorporates with AMC and AMC-FSS respectively. The realized gain of the antenna alone is 4.43 dB. It is enhanced to 9.73 dB when the antenna incorporates with AMC-FSS structure.

2. RESEARCH METHOD

This paper starts with the design of trapezoid antenna, AMC and FSS. The three structures are printed on an RT/Duroid 5880 substrate laminated with 0.035 mm Perfect Electric Conductor (PEC). The thickness and permittivity of the substrate are 0.254 mm and 2.2 respectively.

Figure 1 shows the geometry of the proposed antenna design where a trapezoidal patch is introduced the end of the two rectangular patches at both left and right sides which are connected with a 50 Ω SMA connector as shown in Figure 2. The antenna's performances are evaluated based on Return Loss (RL), Mismatch Loss (ML) and Voltage Standing Wave Ratio (VSWR).

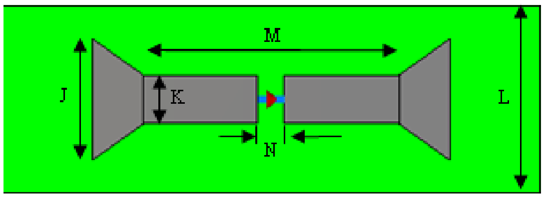


Figure 2. Trapezoid antenna design operating at 12 GHz. (J = 9.04 mm, K = 3.63 mm, L = 14 mm, M = 18.96 mm, N = 2 mm)

Figure 3 shows the unit cell of an AMC which was designed based on trapezoid slot shape. The structure is built with three layers configurations; patch, substrate and ground. The AMC is developed using 1 mm trapezoid shape which is slotted on a 7.79 mm square PEC. Then it is printed on 10 mm square of 0.254 mm thick RT 5880 substrate. FSS is constructed using two layers configurations; a patch and a substrate. A ring shape is printed on the top layer with no metal laminated on the 0.254 mm thick RT 5880 substrate as shown in Figure 4.

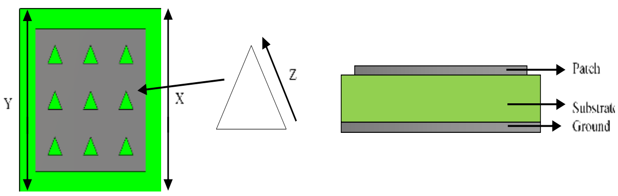


Figure 3. A unit cell of an AMC operating at 12 GHz. (X = 10 mm, Y = 7.79 mm, Z = 1 mm)

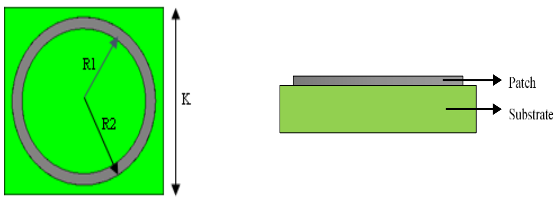


Figure 4. A unit cell of FSS operating at 12 GHz. (K = 10 mm, R_1 = 3.88 mm, R_2 = 4.50 mm)

3. RESULTS AND ANALYSIS

The trapezoid antenna, AMC and FSS are initially characterized. The antenna is characterized with return loss (Γ), mismatch loss (ML) and voltage standing wave ratio (VSWR). The unit cell of AMC is considered the reflection magnitude. Followed by the unit cell of FSS which is explained by the transmission coefficients. The realized gain of the trapezoidal shaped antenna is also takes to account as the antenna was incorporated with the AMC and FSS at the final stage. The antenna resonates at 12 GHz with -27.35 dB return loss as shown in Figure 5. The frequency lies between 11.33 GHz to 12.63 GHz, contributed to bandwidth 1.30 GHz approximately to 10.79% of. The calculated values of Γ, ML and VSWR are 0.043, 0.008 and 1.090, respectively.

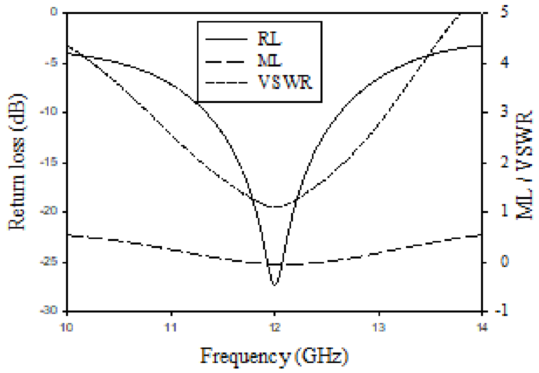


Figure 5. Performances of the trapezoid shaped antenna at 12 GHz.

Figure 6 and Figure 7 show the reflection phase of a unit cell of an AMC and the transmission coefficient of a unit cell of FSS respectively. The unit cell of AMC resonates at 12 GHz with the reflection phase is varies from -180° to 180°. The useful bandwidth is 3.75%, evaluated based on ±90° of reflection phase. Meanwhile, the transmission of the FSS unit cell is -48.46 dB operating at 12 GHz. Thus contributed to 8.06 GHz bandwidth, which is 67.16%.

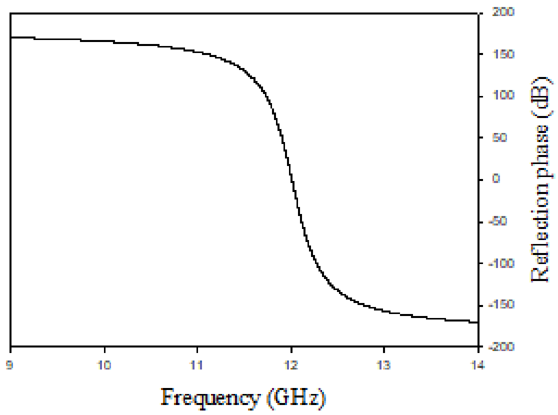


Figure 6. Reflection phase of a unit cell of AMC operating at 12 GHz

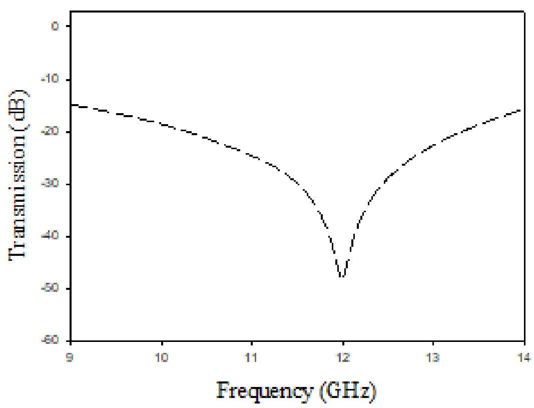
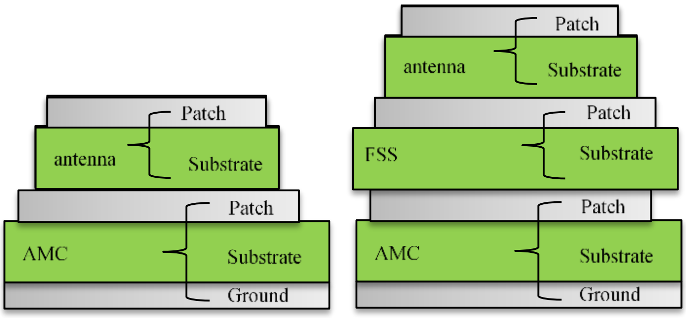


Figure 7. Transmission coefficient of a unit cell of FSS at 12 GHz

The return loss and gain of the designed trapezoid shaped antenna with the AMC and FSS are investigated. The performances of the antenna alone is Case 1, antenna with AMC as Case 2 and Case 3 is when the antenna integrated with AMC-FSS. In all cases, both AMC and AMC-FSS structures are arranged by 2 x 3 arrays and are positioned at the back of the antenna with $\lambda/2.8 \approx 9$ mm air gap. Figure 8 shows the arrangement of the antenna with AMC and AMC-FSS as they worked together.



(a) (b)

Figure 8. The layers configuration for (a) case 2 and (b) case 3

The return loss for 3 cases are plotted in Figure 9. Noted that the resonant frequency shifted to 12.35 GHz and 12.33 GHz for Case 2 and case 3, respectively. Despite the shift in resonance, the antenna is still performed well at 12 GHz with the return loss of –16.70 case 2 and the –16.84 dB for case 3. The bandwidth produced by case 1 is 1.29 GHz ≈ 10.79%, meanwhile the bandwidth for case 2 is 13.95% ≈ 1.72 GHz. On the other hand, the bandwidth for case 3 ranges from 11.51 GHz to 13.24 GHz giving a bandwidth of 14% approximately to 1.73 GHz. The enhancements of the trapezoid antenna radiation characteristics for three cases are summarized in Table 1.

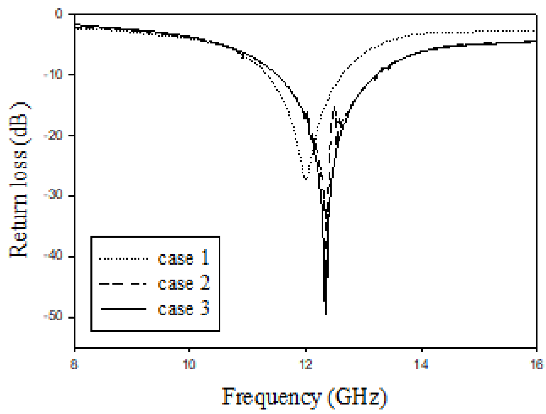


Figure 9. Return loss of the wideband antenna for 3 cases.

Case 3 produced the highest bandwidth and gain enhancement. Figure 10 shows the improvements of the radiation characteristics of the antenna for case 3 at 12 GHz. The radiation efficiency is 98.30%, higher than the total efficiency, which is 96.21%. Thus due to the mismatch loss which indicate how much of the signal is lost because of the line mismatch. The radiation pattern of the antenna for case 3 is directive patterns. Such forward directive pattern is appropriate for on body application since it minimizes the radiation that penetrates into the human.

However the return loss of the antenna alone is better compare to case 3. The return loss of the antenna alone is -27.35 dB meanwhile for case 3 is -16.84 dB due to the mismatched during incorporation. Case 3 gives much improvements on the realized gain of the antenna which from 4.43 dB up to 6.74 dB. Almost more than 50% gain enhancement since both of the AMC and FSS are acted as a good reflector for the antenna.

Table 1. Improvements of antenna radiation characteristics

	Return loss (dB)	Bandwidth (%)	Gain (dB)
Case 1	-23.74	10.79	4.43
Case 2	-16.70	13.95	6.73
Case 3	-16.84	14.00	6.74

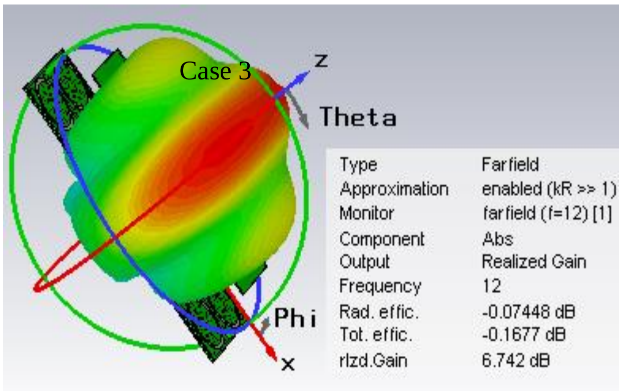


Figure 10. Radiation characteristics of the trapezoid antenna for case 3

4. CONCLUSION

The trapezoid antenna with Artificial Magnetic Conductor (AMC) and Frequency Selective Surface (FSS) are successfully designed on a 0.254 mm of RT/Duroid 5880 high frequency laminate. Three cases are analyzed; antenna alone, antenna with AMC and antenna with AMC-FSS. The 2x3 arrays of AMC and AMC-FSS were positioned at the back of the antenna with 6 mm air gap. The antenna works at 12 GHz, shifted shifted to 12.35 GHz and 12.33 GHz for case 2 and case 3, respectively. Despite the shift in resonance, the antenna is still performed well at 12 GHz with the return loss of –16.70 dB for Case 2 and return loss of –16.84 dB for case 3. Case 3 effectively enhanced the gain of the antenna from 4.43 dB to 6.74 dB and contributed to a directive antenna which successfully reduced the radiation of the antenna that penetrates into human body as the antenna being applied on on-body applications.

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