Design of Triple-band Dipole-type Antenna with Dual-band Artificial Magnetic Conductor Structure

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***Abstract*— A design of dual-band high-impedance surface called Artificial Magnetic Conductor (AMC) is presented. The AMC is designed to resonate at 0.92GHz and 2.45GHz. In this paper also, the design parameters that influence the AMC frequencies are discussed. The designed AMC then is incorporated with the designed triple-band printed dipole antenna (operating at 0.92GHz, 2.45GHz and 5.8GHz). Here, the performance of the dipole antenna with 2 and 4 unit cells of 0.92GHz and 2.45GHz AMC ground plane are presented. The reported results show that, by applying the AMC structure as a ground plane for the printed dipole antenna, the gain of the dipole antenna can be increased due to the attracting feature of the AMC surface that provide in-phase reflected waves with the incident waves.**

I. Introduction

Perfect Magnetic Conductor (PMC) does not exist in nature, thus it is known as an Artificial Magnetic Conductor (AMC) and exhibits as a PMC at a certain frequency band [1]. For design and analysis purposes, the AMC is characterized by its reflection magnitude and phase. At AMC resonant frequency, its magnitude and phase is +1 and 0° respectively. In addition, at its operating band, the surface impedance of an AMC is very high, so it also called a high-impedance surface (HIS) structure. Several AMC designs can be found in [2] and the brief explanation about the simulation set-up for the HIS can be obtained in [3]. Reference [4] proposed the wideband millimeter wave AMC by using a grounded Frequency Selective Surface (FSS) array of various slot dimensions. The AMC is useful for passive radio frequency identification (RFID) when it is acts as a ground plane to the dipole tag antenna to enable the dipole tag is mountable on the metallic objects. Thus, designing AMC for frequency below 1GHz is quite challenging when intended to be used for UHF RFID due to their size and thickness constraints [5]. A dipole tag antenna mountable on metallic objects using AMC for wireless identification was invented in [6]. In this paper, the proposed AMC as a ground plane for the printed dipole antenna are planar, simple, ease to fabricate (no vias) and no multilayer substrates are required. This is the extension research from [7], which is a triple-band printed dipole antenna was proposed and the single-band AMC was used as a ground plane for the designed dipole antenna.

II. A Unit Cell of Dual-band AMC

A unit cell of the periodic structures is shown in Fig. 1 and its reflection phase graph is plotted in Fig. 2. This structure has a rectangular slot in the patch. The slot in the patch can be used to meander the currents and create the multiple resonances. The inductance is produced from the length of the slot while the capacitance is originated from the width of the slot. Referring to Fig. 2, two operating bands of AMC are obtained. The lower AMC band is at 0.88GHz-0.98GHz and the upper AMC band is 2.40GHz-2.48GHz. These operating bands are obtained when the reflection phase is ±90° . The strong evidences are found when the plotted surface impedance of the AMC-HIS structure is high at both resonant frequencies shown in Fig. 3.

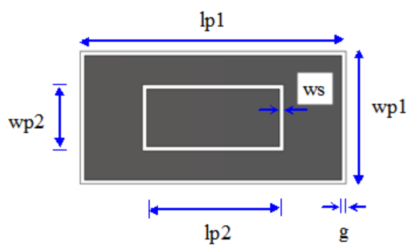


Fig. 1 A unit cell of 0.92GHz and 2.45GHz AMC (unit cell size = 64mm x 32mm, the main rectangular-patch size = 62mm x 29.5mm, the second rectangular-patch size = 31.5mm x14.5mm, slot width = 1mm)

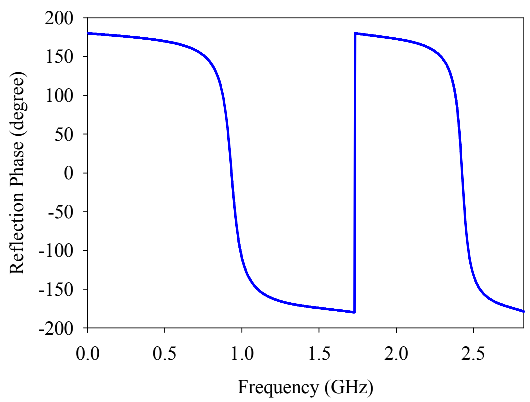
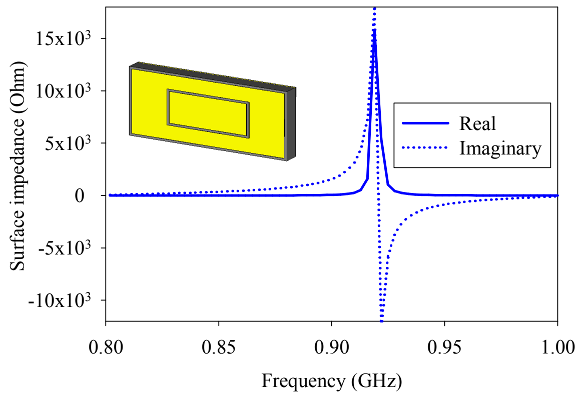
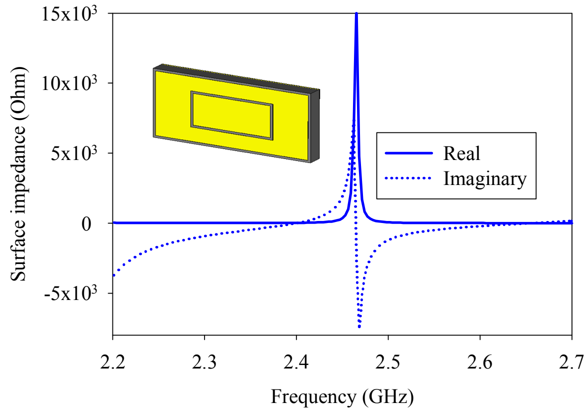


Fig. 2 Reflection phase graph of the periodic structures studied in Fig. 1



(a)



(b)

Fig. 3 Surface impedance of the rectangular-patch with rectangular slot AMC–HIS at the (a) lower and (b) upper band

III. RECTANGULAR-PATCH WITH RECTANGULAR SLOT AMC-HIS PARAMETRIC STUDY

Based on simulating a unit cell structure with periodic boundary condition for x and y-axis, several parameters that affect the AMC frequencies are simulated at a given specific substrate parameters (permittivity, ε_r = 3.2 and thickness, h = 6.35mm). They are main rectangular-patch length (lp1) second rectangular-patch length and width (lp2), the gap between the elements (g) along x-axis and slot width (ws).

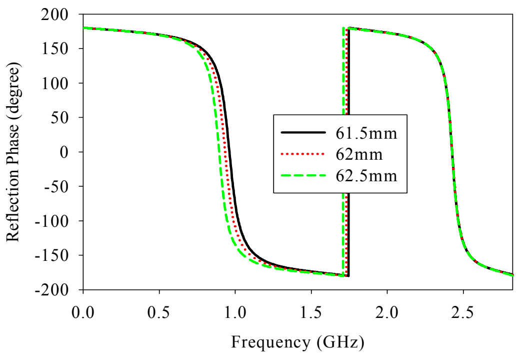


Fig. 4 Graph of reflection phase with different values of main rectangular-patch length

The graph of reflection phase with different values of main rectangular-patch length (here g is also varied along the x-axis) can be seen in Fig. 4. From this figure, it can be concluded that the lower resonant frequency can be shifted to higher frequencies by decreasing the lp1.

As expected, by maintaining the other values the upper AMC frequency can be shifted to the higher frequencies by decreasing the second or inner rectangular patch length. However, the computed AMC bandwidth at the upper band is remained same, 2.9% for three simulated points.

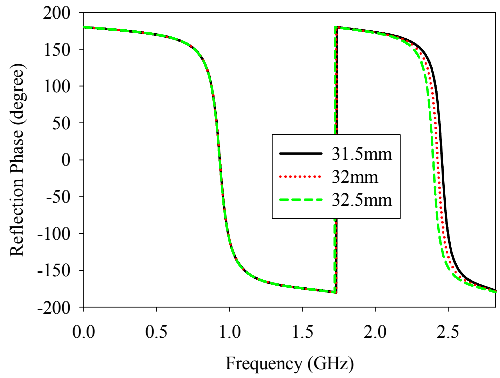


Fig. 5 Graph of reflection phase with different values of second rectangular-patch length

From Fig. 6, it shows that the upper AMC frequency also can be varied by varying the width of the rectangular slot. However, no major effect is observed at the lower resonant frequency. From the plotted graph, it is found that the simulated upper AMC frequency is 2.41GHz when ws is 0.75mm and 2.47GHz when ws is 1.25mm. Fig. 7 plots the reflection phase graph for three different points of gap between the unit cells along the x-axis, g_x. In spite of varying the main patch length, the lower operating band also can be varied by varying the gap between the elements along the x-axis.

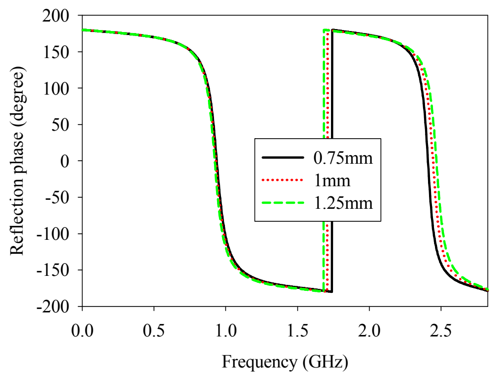


Fig. 6 Graph of reflection phase with different values of slot width

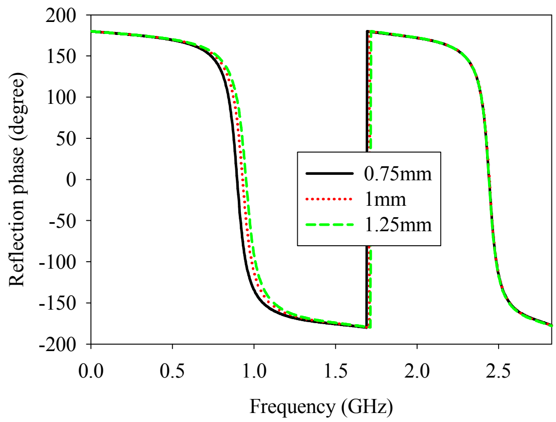


Fig. 7 Graph of reflection phase with different values of gap size

IV. Triple-band Meandered Dipole Antenna

The simulated and measured return loss of fabricated triple-band meandered dipole antenna (see Fig. 8) is plotted in Fig. 9. The second dipole radiating element is meandered to reduce the antenna size as well as the prime radiating dipole element. The antenna is designed to radiate at ultra-high frequency (UHF; 0.92GHz,) and microwave frequencies (MWF; 2.45GHz and 5.8GHz). The computed bandwidth of the antenna is 0.12GHz, 0.07GHz and 0.4GHz at each band. The antenna is fabricated on the Taconic substrate which has a permittivity and thickness of 3.54 and 0.508mm respectively.

Fig. 8 Fabricated triple-band dipole-type antenna

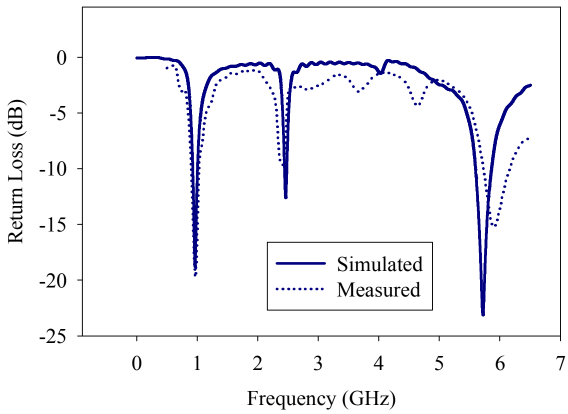
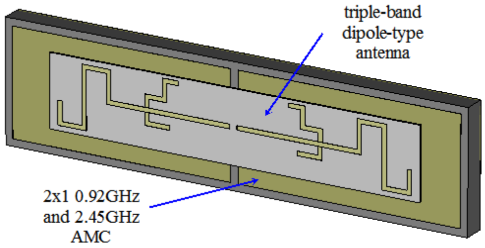


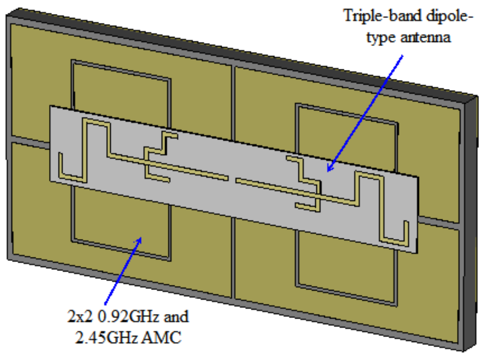
Fig. 9 Simulated and measured return loss of the dipole antenna

V. Triple-band Dipole Antenna with Dual-band AMC

In this part, the performance of the dipole antenna is studied at 0.92GHz and 2.45GHz with absent of AMC layer placed at the bottom of the dipole substrate and followed by the dipole antenna with 2 and 4 unit cells of dual-band AMC as shown in Fig. 10(a) and Fig. 10(b). The dimension of dual-band 2x1 and 2x2 rectangular-patch with rectangular slot AMC is 132mm x 34mm and 132mm x 66mm respectively.



(a)



(b)

Fig. 10 Triple-band meandered dipole antenna incorporated with: (a) 2x1 and (b) 2x2 rectangular-patch with rectangular slot AMC

Table I and Table II compare the antenna's performance in terms of return loss and realized gain for dipole antenna, dipole antenna with 2x1 and 2x2 dual-band AMC ground planes. As can be seen, the dipole antenna is still operated well at the desired frequencies and the gain is increased at 0.92GHz and 2.45GHz. The increment of gain is recorded for dipole antenna with 2 unit cells of the AMC structure and the gain is getting higher with the increment of unit cells.

TABLE I. The Performance of Dipole Antenna at 0.92GHz

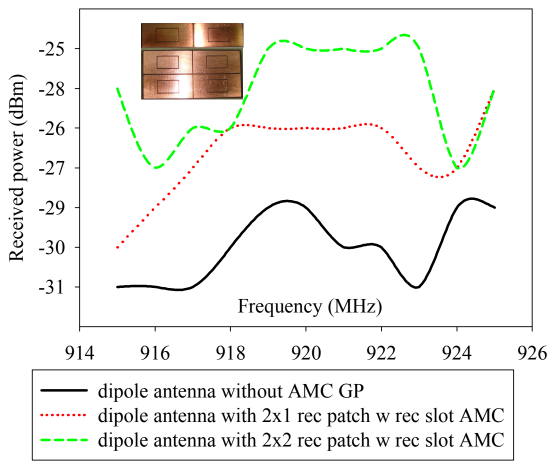
	Return loss (dB)	Realized gain (dB)	Calculated reading distance (m)	Measured reading distance (m)
Triple-band meandered dipole antenna	-11.15	1.49	5.90	4.00
Antenna with 2x1 rectangular patch with rectangular slot AMC GP	-19.79	4.41	8.55	5.75
Antenna with 2x2 rectangular patch with rectangular slot AMC GP	-17.05	5.19	9.30	7.00

TABLE II. THE PERFORMANCE OF DIPOLE ANTENNA AT 2.45GHz

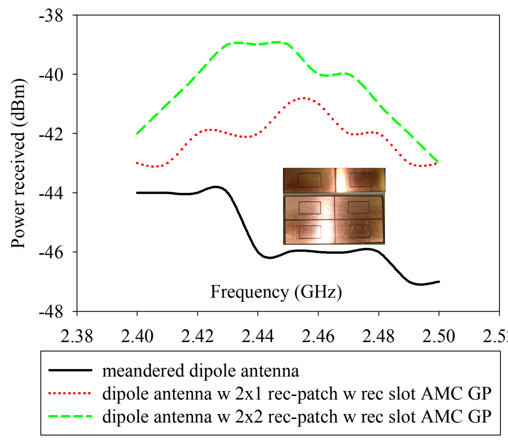
	Return loss (dB)	Realized gain (dB)	Calculated reading distance (m)	Measured reading distance (m)
Triple-band meandered dipole antenna	-12.44	1.44	1.32	0.80
Antenna with 2x1 rectangular patch with rectangular slot AMC GP	-10.51	3.87	1.72	0.90
Antenna with 2x2 rectangular patch with rectangular slot AMC GP	-9.81	5.61	2.09	0.95

The reading distance of the dipole tag (when the antenna is feeding with the microchip at the centre of the antenna) is calculated using the Frii's formula. In order to validate the calculated one, the reading distance of the tag is measured using UHF RFID Gen2 reader module and microwave 2.45 GHz RFID readers. The measurement of the reading distance is performed in free space environment. The difference between the calculated and measured reading distance is due to the mismatch between the antenna and microchip, conductor and cable losses and environment factor.

From Fig. 11(a) and Fig. 11(b), the measured power received at the first and second band dipole antenna can be compared. There are clearly shows that the power received of the dipole antenna with AMC ground plane provides higher value compared to the dipole antenna with no high impedance structure.



(a)



(b)

Fig. 11 Measured power received of the triple-band meandered dipole antenna with and without AMC ground planes at the (a) first and (b) second band of dipole antenna

VI. CONCLUSION

The AMC is useful as a ground plane for the printed dipole antenna. The gain of the antenna is increased due to the attracting feature of the AMC that provides in-phase reflected waves with the incident waves. Furthermore, the recorded data show that, higher antenna gain can be obtained with more AMC structures. In total, the longer reading distance of the dipole tag antenna is achieved with AMC GP.

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