Design Synthesis of 5.8 GHz Octagonal AMC on a Very Thin Substrate

M. Abu, E. E. Hussin, R. F. Munawar and H. Rahmalan

Abstract—**This paper proposed a development of 5.8 GHz Artificial Magnetic Conductor, AMC using very thin substrate with thickness of 0.13 mm. Different shapes of PEC metallization are discussed in order to achieve the highest bandwidth of unit cell AMC. Another approaches for increasing the bandwidth is by applying the ring patch around the substrate as well as implementing the DGS ground plane. The proposed design produces 1.96 % bandwdith of unit cell. Applying the 2 x 4 unit cell arrangement gives the best result for directivity equal to 6.75 dBi, gain of 6.83 dB, efficiency = 98.41 % and return loss = -45.63 dB.**

Index Terms—**Artificial Magnetic Conductor, gain and Radio Frequency Identification.**

I. INTRODUCTION

Metamaterial structure defined by Rodger M. Walser as cited in [1] as macroscopic composites having synthetic; three dimensional and periodic architecture designed to produce as optimized combination, not available in nature. The use of metamaterial structure such as electronic band gap, EBG or Frequency Selective Surface, FSS gives advantages in communication electronic component such as antenna, filter and microwave couplers. Considering the equation (1) and (2), as the thickness, *h* of the substrate decreased, the inductance, *L* will increased. Whilst, the value of resonant frequency will be decreased (the capacitance, *C* is kept maintained)

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

$$inductance \ L = \mu_o h \tag{2}$$

Another characteristic of AMC need to be measured is the bandwidth. Referring to (3), the bandwidth of the AMC can be increased by increasing the inductance or reducing the capacitance. In [2] stated that the capacitive element can be decreased by using a substrate with low permittivity or by increasing the gap between the metallization edge and unit

cell-edge. Hence, in this paper the development of 5.8 GHz AMC on 0.13 mm substrate with different metallization modification of the copper patch will be proposed.

$$bandwidth \ BW = \frac{1}{\eta_o}\sqrt{\frac{L}{C}} \tag{3}$$

The use of AMC as ground plane can increase the performance of the antenna compared to the conventional ground plane. In [3] stacked ring-patch artificial substrate is designed with a combination of square patch (upper layer) and square ring patch (bottom layer) shows that the structure can act as high impedance surface at certain frequency with good surface wave suppressing of 0° phase angle. In RFID application, the use of AMC give advantage by improving the performance of the RFID tag by increasing the gain, directivity as well as the reading distance to the reader [4-8]. In addition, the use of AMC can solve the problem of metallic object detection in RFID tag application. The unique feature of AMC is it can reduce the effect of surface wave by removing the unwanted signal formed by the metal or copper substance. Thus, smoother radiation pattern with low backlobe power will be formed [9-11].

Paper [12] presented the dual-band hexagonal AMC for wearable antenna application designed on felt fabric of 4mm thickness produce the output bandwidth of 11.76 % and 18.18 % at 2.4 GHz and 5.8 GHz respectively. Later in [13], the novel design of broadband AMC (>20%) unit cell is presented with six-dipoles shape arrangement at each 60° into the hexagonal patch served to modified the resonant frequency of operation. The presented hexagonal AMC shows polarization-angle independency, low cross-polarization angle and ±10° angular margin stability when applied to different incidence of angle from 0° to 60°.

II. DESIGN PROCEDURES AND RESULTS DISCUSSION

This section will discuss the optimization steps and the simulated results of 5.8 GHz Artificial Magnetic Conductor including its parametric study, incidence of angle and the integration between dipole antenna and AMC.

A. AMC with Different Copper Metallization Shape

Table I shows five different shape of polygons unit cell designed in the same substrate of *fast*Film TM-27. The simulation results show different bandwidth percentage for each polygon unit cell shape. The octagon unit cell AMC (with 8-edges) shows the highest bandwidth percentage compared to others. It increase 57.14 % of bandwidth
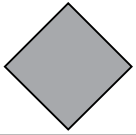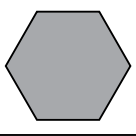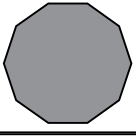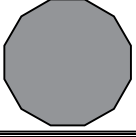
compared to the tetragon (4-edges) shape.

Taking the consideration in Table I, the octagon shape will be used for further modification. The full patch octagon AMC is modified by introducing slots into the shape as in Fig. 1. Four slots with dimension of 0.7 mm x 4.5 mm are inserted into the design had reduced the bandwidth until 1.01 %. However, when applying the square-outer-ring into the design is in Fig. 2 had increase the bandwidth to 1.40 %.

TABLE I: THE EFFECT OF DIFFERENT SHAPE UNIT CELL METALLIZATION TO THE BANDWIDTH

AMC Unit cell	Shape	Bandwidth
Tetragon		0.77 %
Hexagon		1.04 %
Octagon		1.21 %
Decagon		0.98 %
Dodecagon		0.97

B. Octagonal Shape Modification

Another method of increasing the bandiwdth is by applying the defected ground plane (DGS) at the back of the structure by replacing the conventional full PEC ground plane [14]. There are two types of DGS to be implemented; DGS 1 (with same metallization shape) and DGS 2 (with opposite metallization shape). The disparity are shown in Fig.3(a) and 3(b).
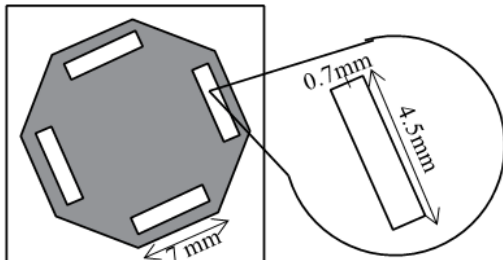

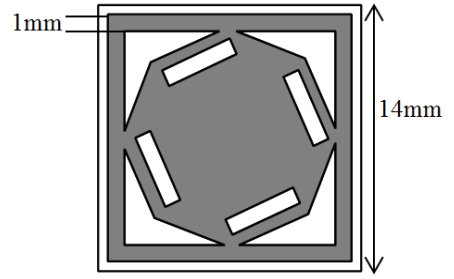Fig. 1: Octagonal AMC with four rectangular slots.

Fig. 2: Octgonal AMC with four rectangular slots and square-outer-ring.
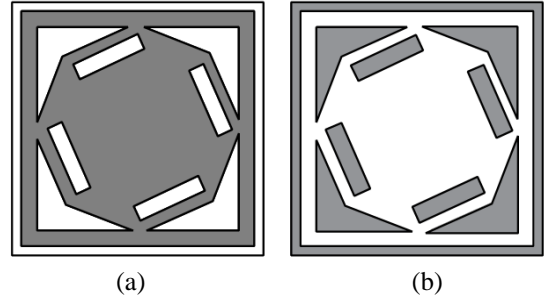

(a)   (b)

Fig. 3:(a) DGS with same metallization shape and (b) DGS with opposite metallization. (shaded areas are the metallization of PEC patch)

From the simulation results of octagonal AMC with four rectangular slots and DGS ground plane shows that the DGS with opposite metallization increase more bandwidth compared to the DGS with same metallization shape. Table II shows the comparison of bandwidth values for octagonal AMC with different metallization made to the original octagonal shape AMC. The final structure of Octagonal AMC with four rectangular slots, full ground plane, outer square ring and DGS 2 shows the simulated bandwidth of 1.96 %.

TABLE II: THE COMPARISON OF BANDWIDTH VALUES FOR OCTAGONAL AMC WITH DIFFERENT METALLIZATION MADE TO THE ORIGINAL OCTAGONAL SHAPE AMC

AMC	Bandwidth
Full plane octagonal AMC with full ground plane	1.04 %
Octagonal AMC with four rectangular slots and full ground plane	1.01 %
Octagonal AMC with four rectangular slots and full ground plane and outer square ring	1.40 %
Octagonal AMC with four rectangular slots, outer square ring and DGS 1	1.44 %
Octagonal AMC with four rectangular slots, outer square ring and DGS 2	1.96 %

C. Incidence of Angle

By using the FSS Unit Cell Boundaries Template in CST Microwave Studio Software, the structure is now being simulated at different angle from 0 ° to 60 °. Fig. 4 shows the simulated magnitude and phase of Octagonal AMC with four rectangular slots, outer square ring and DGS 2.

From the results, the resonant frequency did not much affected by the changes of incidence angle. However, the magnitude of the structure is shows small increments (in negative side). Meanwhile, the bandwidths are increased when applied to incidence angle from 0 ° to 40 ° but started decreasing as the incidence angle change to 50 ° and 60 °.
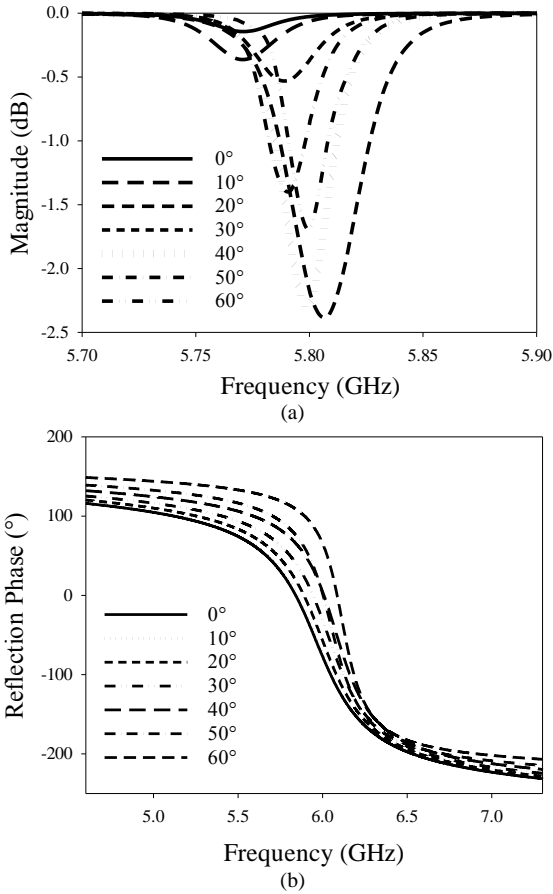
Fig. 4: (a) Magnitude and (b) phase of Square-Ring Octagonal AMC with DGS when applied to different incidence angle from 0° to 60°.

D. AMC-Dipole Integration

In this part, the Octagonal AMC with four rectangular slots, outer square ring and DGS 2 will applied to 5.8 GHz dipole antenna to measure the performance in term of gain, directivity and efficiency.
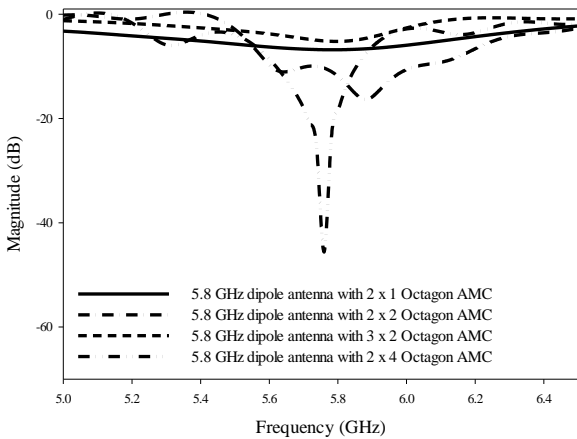

Fig. 5: Radiation pattern for Octagonal AMC with four rectangular slots, outer square ring and DGS 2 with various unit cell arrangements.

Fig. 5 shows the simulated S_{11} of Octagonal AMC with four rectangular slots, outer square ring and DGS 2 with different arrangement. The 2 x 4 unit cell arrangement shows the best value of magnitude at resonant. The smallest gain shows by the 2 x 1 unit cell arrangement which is the smallest size compared to other unit cell arrangement. For this structure, two types of unit cell arrangement can be suggested to be used

in RFID tag application; 2 x 2 and 2 x 4 unit cell arrangament. Fig. 6 shows the 2 x 4 Octagonal AMC with four rectangular slots, outer square ring and DGS 2 applied to the dipole antenna with dimension of 26.2 mm x 52.4 mm.
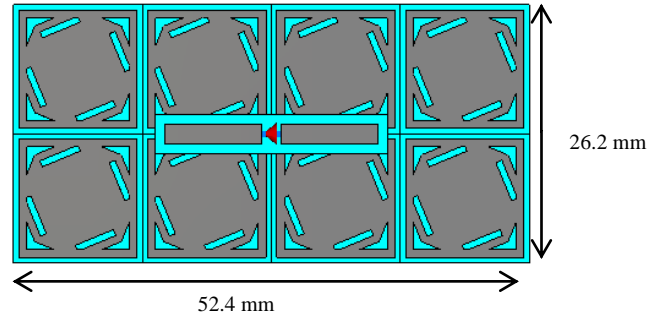

Fig. 6: Octagonal AMC with four rectangular slots, outer square ring and DGS 2

From the radiation pattern shows in Fig. 7, the radiation occur at both front and back direction. Which means, the use of Octagonal AMC with four rectangular slots, outer square ring and DGS 2 still maintaining the properties of dipole antenna without reducing the backlobe radiation. The radiation pattern shows that the antenna still having the back-lobe radiation but in the same time improve the major-lobe radiation. For 2 x 1 Octagonal AMC with four rectangular slots, outer square ring and DGS 2 unit cell, the power pattern forms like a circle shape. It means that the radiation of the antenna can be received around the 360°angle. While the other three unit cell arrangement shows eight-shape radiation but with different value of angular width.

Fig. 7: Radiation pattern for Octagonal AMC with four rectangular slots, outer square ring and DGS 2 with various unit cell arrangements.

The final conclusion is the 2 x 4 arrangement gives the best results where the directivity = 6.75 dBi, gain = 6.83 dB, efficiency = 98.41 % and return loss = -45.63 dB. Fig. 8(a) shows the farfield view of dipole antenna (without attached to AMC). The maximum radiation can be seen to be at 360° around the structure. Then, the farfield view in Fig. 8(b) shows the maximum radiation for Octagonal AMC with four rectangular slots and full ground plane only occur on the front lobe. This is happens because the full PEC plane had reflect all the radiation from the backlobe. However, in Fig. 8(c) by

applying the DGS 2, the backlobe radiation is increased as well as the frontlobe. The oval shape of farfield shows that the use of Octagonal AMC with four rectangular slots, outer square ring and DGS 2 with 2 x 4 unit cell arrangements had increase the radiation of the 5.8GHz dipole antenna.

Circular radiation shape

(a)

Radiation at frontlobe (improved)

Radiation at backlobe (cancelled)

(b)

Oval radiation shape

(c)

Fig. 8: Farfield view of (a) dipole antenna, (b) dipole antenna on 4 x 4 Square-Ring Octagonal AMC with full GP and (c) dipole antenna on 2 x Octagonal AMC with four rectangular slots, outer square ring and DGS 2 with various unit cell arrangements.
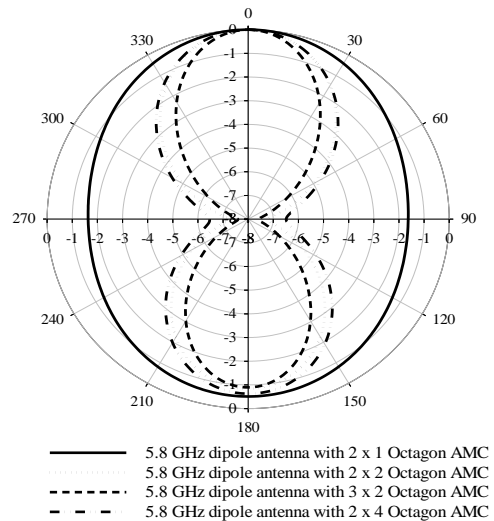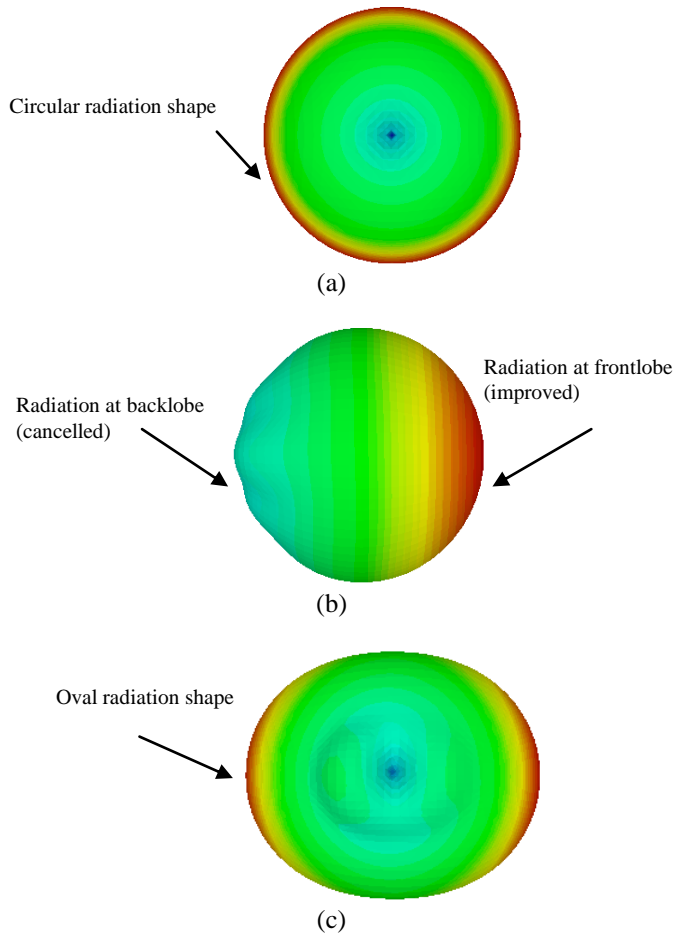
III. CONCLUSION

The bendable 5.8 GHz AMC are succesfully designed using a very thin substrate (with thickness of 0.13 mm) and thier performance in terms of angle of incidence are studied. The maximum bandwidth and gain achieved for the octagonal AMC with four rectangular slots, outer square ring and DGS 2 are 1.96 % and 6.83 dB respectively. The designed AMC can be applied to dipole antenna application such as Wifi and others communication devices. It also can be used to improve the object detection in RFID application for both metal and non-metal detection.

ACKNOLEDGMENT

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