Design of Stacked Wafers AMC at 920 MHz for Metallic Object Detection in RFID Application

M. Abu, E.E. Hussin, A.R. Othman, N.M. Yatim, F.M. Johar, R.F. Munawar.
Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100
Durian Tunggal, Melaka.
Email: maisarah@utem.edu.my, eryana88@hotmail.co.uk, rani@utem.edu.my, norhidayahm@utem.edu.my,
fauzi@utem.edu.my, rosefarahiyan@utem.edu.my

Abstract – **Artificial Magnetic Conductor, AMC is introduced into RFID application to overcome the problem of metal object detection. The AMC act as the Perfect Magnetic Conductor, PMC exhibits a reflectivity of +1 (in-phase reflection). In this paper, the stacked wafers AMC structure is designed to operate at 920 MHz frequency. The proposed stacked wafers AMC is an evolution from the basic square patch AMC. By introducing different size of slots into the square patch will help to reduce the frequency hence increase the bandwidth of the reflection phase. Another method to increase the bandwidth is by increasing the thickness of the structure. For the single cell of stacked wafers AMC proposed in this paper, the simulated bandwidth is 3.5% with reduced size of 45.56% than the square AMC. An optimized structure of 3x2 stacked wafers AMC give better return loss = -21.8 dB and gain = 3.04 dB with total efficiency of 82.3%.**

Keywords-stacked wafers, bandwidth, frequency respond, artificial magnetic conductor,reflection phase, high impedance surface, dipole antenna

I. INTRODUCTION

Radio Frequency Identification (RFID) is one of emerging technology nowadays. It consist of three major part; a tag which will be mounted on the object, an antenna that will communicate to the tag, and a reader that connects to the antenna to proses the data send to or received by the tag [1]. The unique feature of the RFID tag that contactlessly respond to the antenna with no line of sight makes it useful for many kind of application such as for baggage handling in airport, books tracking in library and anti-theft system in hypermarket depends on its operating frequency. The RFID frequency lies between Low Frequency (125 KHz) until Microwave Frequency (24 GHz). UHF (Ultra High Frequency) RFID system is used for wide range application such as supply chain and security management. In any cases when RFID tag is placed near the metal or perfect electronic conductor (PEC) object the electromagnetic wave transmitted by the dipole tag will be reflected by the metallic object [2]. The value of gain will be decreased and the efficiency of the tag's antenna will be very small (≈ 0%) which means that the tag cannot respond to the reader. There are two ways to overcome this problem; either to add spacer or to introduce a dielectric material between the tags and metal object. However by providing space or gap between them may lead to larger structure.

Recently, the study of metamaterial structure such as EBG, FSS and AMC has been conducted to overcome the metallic detection on antenna design [3-5]. In RFID system, AMC has become famous because it gives a smaller structure. The challenge in designing AMC at lower frequency is that when the value of inductance, L and capacitance, C will be increased. Hence, the dimension of AMC structure will become bigger due to the increased value of width, w. This can be proved by the equation (1) and (2) [6]. By applying slots around the AMC structure can help to reduce the frequency while maintaining the outer dimension of the HIS [7-8].

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

$$C = \frac{w\varepsilon_\circ(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{2w+g}{g}\right) \tag{2}$$

$$L = \mu h \tag{3}$$

Artificial Magnetic Conductor suppress the surface wave propagation between two different medium by removing the unwanted radiation for smoother radiation pattern. The AMC is also known as High Impedance Surface because at the resonant frequency the surface impedance will be very high (approach to infinity) with zero reflection phase.

II. BACKGROUND STUDY

A. Effect of metal on tag performance

When dipole antenna placed on the PEC, the image current that formed on the metal surface are in opposite direction with the electromagnetic current. Therefore, the input impedance, radiation pattern and percentage of efficiency of the antenna will be changed [9-11]. The AMC patch will be exploited into a structure that makes the image current to be in-phase to the electromagnetic current [12].

B. Triple-band printed dipole antenna

In this paper, dipole antenna will be used in the simulation using CST Microwave Studio representing the RFID tag. The design process of dipole will not be explained in details. Table 1 shows the parameters of dipole antenna used in this paper.

Parameter	Value
Dimension	130 mm x 20 mm
Substrate	Rogers RO3010
	Dielectric constant, εr = 10.2
	Thickness, h = 1.28 mm

III.   A SINGLE CELL OF WAFER AMC

Firstly, the basic square patch AMC is designed using the equation (1) to (3) using Rogers RO03010 dielectric substrate with εr = 10.2 and thickness = 1.28mm. It has copper cladding on both sides with 32µm thickness. The overall size of the square patch AMC is 90 mm x 90 mm with gap,g = 1 mm. Next, square patch AMC is proposed by introducing various sizes of slots into the structure. Figure 1 shows the single cell of stacked wafers AMC with reduced size of 51.5 mm x 51.5 mm with gap, g = 1.25 mm. The size of each slots are as follows, a = 1 mm x 2 mm, b = j = i = 2 mm x 4 mm, c = 2 mm x 8 mm, e = g = m = 8 mm x 2 mm, h = 2 mm x 16 mm, k = 16 mm x 2 mm, d = 2 mm x 1 mm, f = 4 mm x 2 mm.
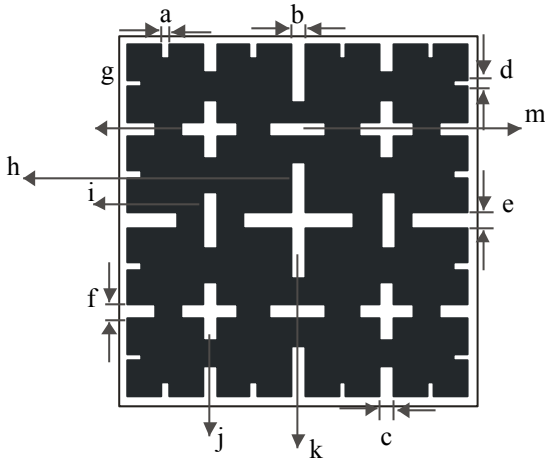
Figure 1: Single cell structure of wafer AMC

The simulated wafer AMC structure exhibit 90° and -90° at 910 MHz and 925 MHz of reflection phase respectively. Wafer AMC had overcome the problem of larger AMC size but its bandwidth is slightly smaller than the square patch AMC. 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, another layer of wafer AMC is stacked at the back of substrate to increase the thickness of the AMC. Figure 2 shows the 3D view of stacked wafers AMC which consist of one ground plane and 2 two pairs of substrate and wafer structure. Using equation (4) the stacked wafers AMC increase the bandwidth of 1.7% to 3.5%. Figure 3 shows the reflection phase of these three different structures; square patch, wafer AMC and stacked wafer AMC.

$$Bandwidth = \frac{fu\ (90°) - fl\ (-90°)}{fr\ (0°)} \qquad (4)$$

Where

f_u = upper frequency , f_l = lower frequency, f_r = resonant frequency

Figure 4 shows the stacked wafers AMC has relatively high surface impedance at the operation frequency of 920 MHz which explain the behavior of the AMC.
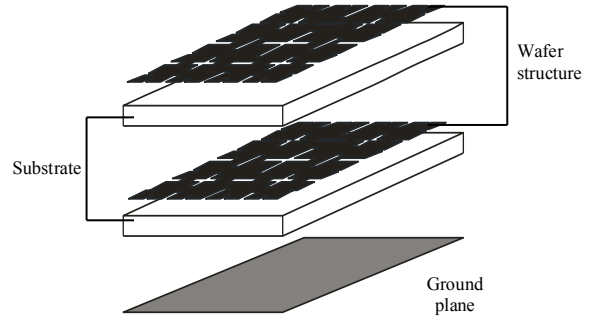
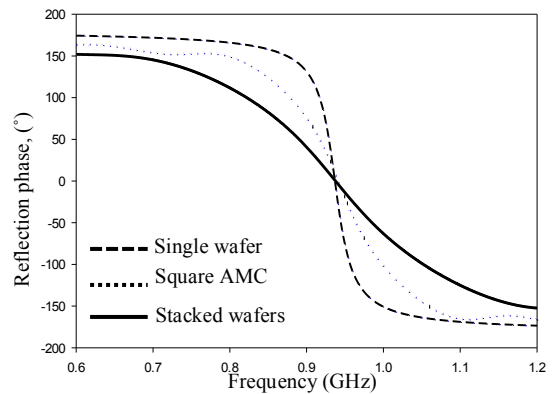Figure 2: 3D design for stacked wafers AMC

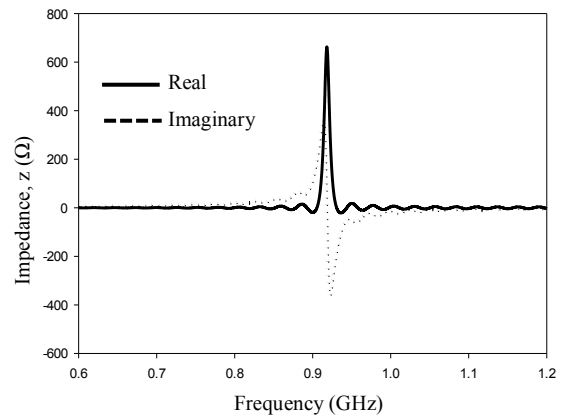Figure 3: Reflection phase of square patch, wafer and stacked wafers AMC

Figure 4: Surface Impedance of stacked wafers AMC

IV.   TRIPLE-BAND PRINTED DIPOLE ANTENNA WITH OPTIMIZED STACKED WAFERS AMC

The 920 MHz single cell of stacked wafers AMC is optimized periodically with the dipole antenna. Discrete port is used to replace the chip at 920 MHz frequency. Figure 5 shows the optimized 3x2 periodic cell of stacked wafers AMC attached to the dipole antenna with size of 126 mm x 84 mm and thickness = 3.11 mm.
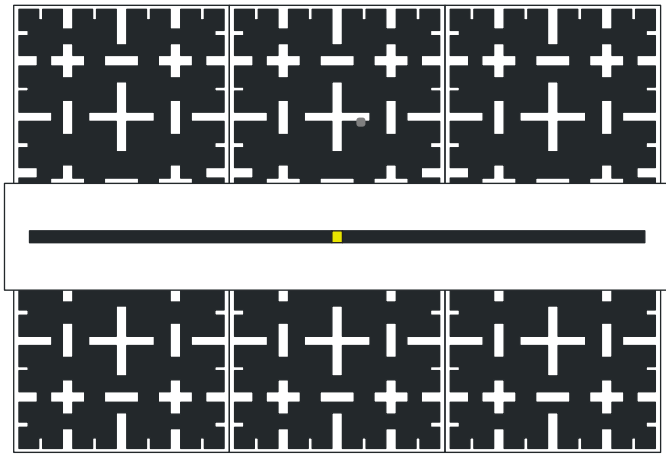
Figure 5: 3x2 stacked wafers AMC attach to triple-band meandered dipole antenna.

The simulation result of three different cases; dipole antenna, dipole antenna with PEC and dipole antenna with stacked wafers AMC is shown in Figure 6. From the simulation result of dipole antenna with PEC, the return loss value form in one straight line which is approximately at 0 dB. This means that the dipole tag failed to function. Then, by applying the 3x2 stacked wafers AMC at the back of the dipole antenna, the value of return loss is decreased to -21.8 dB with increased value of gain. The problem of introducing metamaterial element into antenna design is the reduction of bandwidth. Because, frequency band of the antenna will become narrow. Figure 6(b) shows the radiation pattern of those cases discussed in Figure 6(a). It shows that, the existence of 3x2 stacked wafers AMC helps to reduce the back lobe of the antenna. Hence, it will increase the directivity of the antenna by increasing the major lobe. Table 2 shows the summarization of simulation result for those three cases.

(a)

Dipole antenna
Dipole antenna with PEC
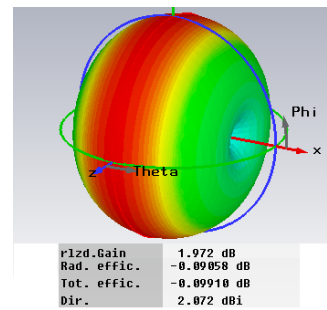Dipole antenna with 3x2 Stacked Wafer AMC
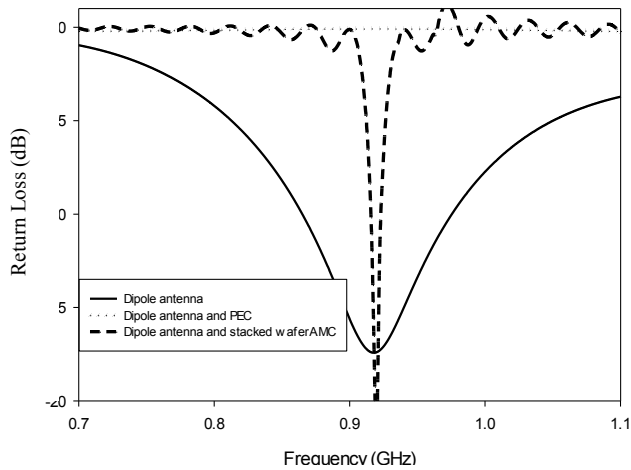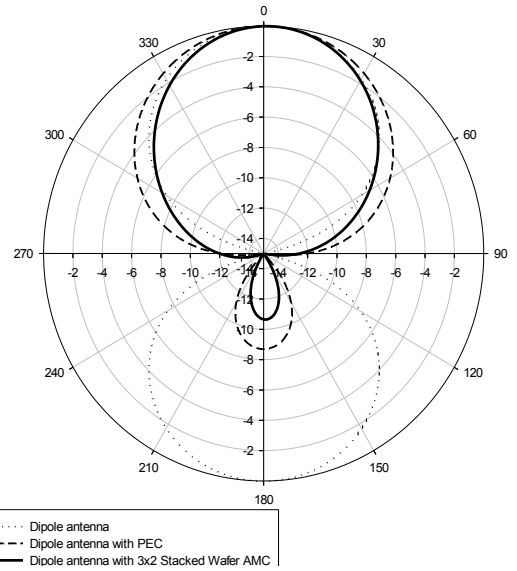
(b)

Figure 6: Simulation result (a) return loss (b) radiation pattern of dipole antenna, dipole antenna with PEC and dipole antenna with stacked wafer AMC.

TABLE 2: COMPARISON BETWEEN DIPOLE ANTENNA, DIPOLE ANTENNA WITH PEC AND DIPOLE ANTENNA WITH STACKED WAFERS AMC

Parameter	Dipole antenna		
		With PEC	With stacked wafers AMC
Dimension	105 mm x 20 mm	135.8 mm x 47.5 mm	135.8 mm x 47.5 mm
Return Loss (dB)	-16.2	-0.02	-21.8
Gain (dB)	1.97	-13.60	3.04
Directivity (dBi)	2.07	5.38	5.149
Efficiency (%)	99.74	0.12	82.3

rlzd.Gain   1.972 dB
Rad. effic.   -0.09058 dB
Tot. effic.   -0.09910 dB
Dir.   2.072 dBi

(a)

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Rad. effic.    -0.4536 dB
Tot. effic.   -18.98 dB
rlzd.Gain     -13.60 dB
Dir.            5.380 dBi
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(b)


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Rad. effic.    -2.081 dB
Tot. effic.    -2.110 dB
rlzd.Gain       3.039 dB
Dir.            5.149 dBi
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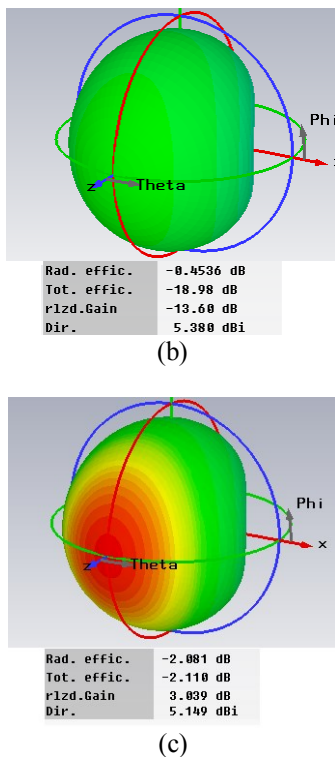
(c)

Figure 7: 3D result of gain and directivity of (a) dipole antenna, (b) dipole antenna and PEC (c) dipole antenna with stacked wafers AMC

Figure 7 shows the 3D result of gain and directivity of the meandered dipole antenna, meandered dipole antenna with PEC and meandered dipole antenna with stacked wafers AMC. From Figure 7(b), when meandered dipole antenna is placed on the PEC element, the directivity is increased (5.38 dBi) but the value of gain is slightly decrease which means that the meandered dipole antenna cannot operated when attached to metal based object. When stacked wafers AMC is placed between the antenna and PEC, the value of directivity and gain is increased.

V. CONCLUSION

In this paper, the characteristic of AMC is studied. From the Figure 5 the comparison between basic square patch AMC and stacked wafers AMC is shown. By using the same substrate and simulation setup, the stacked wafers shows higher bandwidth improvement and smaller size. This is because of the different size of slot introduced into the stacked wafers AMC which can help to reduce frequency without increasing the size of the metal patch of the AMC. The optimized 3x1 stacked wafers AMC is proven to improve the directivity, gain and efficiency of the RFID tag antenna when placed onto metal object. The directivity of the antenna with stacked wafers AMC is increased because of the characteristics of the AMC that can help to increase the gain of the main lobe of the radiation pattern. The reading distance of the RFID tag also will be increased when using AMC as a ground plane. Different size of metal object will give different reading range measurement [14] but this will not be discussed in this paper.

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