Compact microstrip monopole antenna with Enhanced Gain using Artificial Magnetic Conductor (AMC)

M. Abu*, S. A. Md. Ali, and H. Asha’ri
Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Kejuruteraan Elektronik & Kejuruteraan Komputer (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya 76100, Melaka, Malaysia
maisarah@utem.edu.my

Abstract. This paper presents the performance of a microstrip monopole antenna with and without an Artificial Magnetic Conductor (AMC). The antenna and AMC structures are designed at 2.45 GHz using Rogers RO3003 and RT5880 respectively. The thickness of the substrate of the antenna is 1.52 mm and the permittivity are 3. For the AMC, the thickness and the permittivity of the substrate are 3.18 mm and 2.2. The designed antenna has a hexagonal shape, and it is grounded by 3x3 AMC array. From the simulated results, it is found that integrating the AMC structure to the printed monopole antenna was significantly improved the gain and directivity of the antenna. With the AMC, the achieved gain is 6.54 dB, which exhibited 3.68 dB of increment. This antenna has high gain, as it has both high radiation efficiency and directivity. Its directivity increased from 3.01 dBi to 7.14 dBi. The measured results are in align with the simulated results. The antenna still operate at the desired frequency. The recorded measured gain is 5.33 dB, with 20.3 dB return loss at 2.4 GHz. Thus, the design of the monopole antenna with the AMC is suitable as a RFID tag, because it can improve the RFID reading distance.

1. Introduction
Radio frequency identification (RFID) is rapidly developing technology which uses RF signals for automatic identification of objects. RFID system consists of a reader, a tag (transponder) and a data processing system. Based on various applications, different spectrum bands were allocated for RFID system such as LF (125 - 134.2 kHz and 140 - 148.5 kHz) used for vehicle identification, HF (13.56 MHz) for electronic ticketing and access control, UHF (858 - 930 MHz) for work in progress tracking and SHF (2.446 - 2.454 GHz) for long range tracking. In RFID system, the role for reader and tag (antenna) were very important. The gain enhancement and size reduction of RFID antenna were the main issues in the system developer [1-5]. The reader antenna must have high gain and directivity to operate.

The antenna is developed due to the popularity in a wireless communication system and devices. Microstrip antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. The patch antenna radiated normal to the plane of the patch and the radiation travelling in the direction of the substrate was reduced by the ground plane. The key features of a microstrip antenna was easy to fabricate, light weight, low cost and so on. Unfortunatel, it was suffered from their drawbacks such as narrow bandwidth and lower gain [6-12].

Metamaterial is an artificial resonant structure that was designed to obtain specific characteristics which were not naturally occurring in nature. It was designed to improve the performance of antenna [13-16].
Artificial Magnetic Conductor (AMC) was a type of metamaterial which introduced an in phase reflection phase within the band gap of a desired frequency. By applying AMC, Frequency Selective Surface (FSS) and Electromagnetic bandgap (EBG), the radiation efficiency, directivity and gain of antenna can be improved [13-20].

This paper presents a microstrip monopole antenna incorporated with artificial magnetic conductor (AMC) at 2.45 GHz by using Rogers RO3003 with the thickness of 1.52 mm and permittivity of 3. The aim of this project is to enhance the antenna performances in terms of gain and directivity to produce a directive antenna, thus can be applied for RFID application.

2. Methodology

Fundamentally, the performance of the antenna depends on the resonance frequency, return loss, bandwidth, gain, directivity, radiation efficiency and dimension. The design of microstrip patch antenna required the precision physical dimensions and power feeding method for the antenna.

The microstrip monopole antenna was designed based on three parameters. The substrate used was Rogers RO3003 with a dielectric constant of $\varepsilon_r = 3$ and height, $h = 1.52$ mm. The frequency of interest was $f_0 = 2.45$ GHz. Each side of the substrate had a copper cladding with thickness, $t$ of 0.035 mm. The define specifications of the antenna were as shown in Table 1.

| Parameter         | Specification |
|-------------------|---------------|
| Operating frequency | 2.45 GHz      |
| Gain              | > 2 dB        |
| Return loss       | < -10 dB      |

Figure 1 shows the design of the circular monopole antenna. Circular patch was fed by a 50 $\Omega$ microstrip feed line. The radius of the circle is calculated using equation (1),

$$ r = \frac{87.94}{f_0\sqrt{\varepsilon_r}} $$

The parameters for antenna was obtained by transmission line method. The width of the rectangular antenna was calculated by:-

$$ W = \frac{c}{2f_r\sqrt{\varepsilon_r+1}} $$

The effective constant can be obtained by:
\[ \varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2} \sqrt{1 + 12 \frac{h}{W}} \]  

(3)

Length L of the antenna patch was given as:

\[ L = \frac{\lambda_0}{2} - \Delta L \]  

(4)

\[ \Delta L = \left[ 0.412 h \frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}=0.258} \left( \frac{W/h+0.264}{W/h+0.8} \right) \right] \]  

(5)

From equation (2) to equation (5), the ground plane or substrate dimensions can be determined by:

\[ L_g = 6h + L \]  

(6)

\[ W_g = 6h + W \]  

(7)

The width of 50 Ohm feed line (w) can be approximately calculated using equation (8).

\[ 50 = \frac{377}{\sqrt{\varepsilon_r}} \left( \frac{1}{w/h+2} \right) \]  

(8)

The calculated and optimized values of microstrip monopole antenna were shown in Table 2. Initially, the radius of the circle was calculated by using the equation 1. Then, the hexagon shape for the patch of antenna was designed and optimized. Followed by the calculation of the feed line width by using the equation 8 to accomplish the characteristic impedance of the transmission line, 50 Ω.

Figure 2 shows the structure of the monopole antenna. A hexagon patch was printed on the top of the rogers RO3003 substrate. The patch was feed by 50 Ω microstrip feed line. This antenna had a partial ground plane at the back of the substrate. For the purpose of simulation, the feed line was connected to the waveguide port.
Figure 2. Hexagonal-shaped monopole antenna: (a) simulation design and (b) prototype

Table 2. The optimized dimension of microstrip monopole antenna.

| Parameter (mm)                           |
|------------------------------------------|
| Width of substrate, $W_l$                | 55.0 |
| Length of substrate, $L_l$               | 55.0 |
| Radius of hexagon patch, $r$             | 11.0 |
| Width of feed line, $m$                  | 3.7  |

Next, the design of Artificial Magnetic Conductor (AMC) operated at 2.45 GHz, printed at Rogers RT5880 substrate. The 55 mm x 55 mm square of AMC involved 3x3 periodic structures was shown in Figure 3. The optimized width and length of a unit cell patch AMC was 17.4 mm. Each the unit cell contained an octagon slot at the center of the patch. It was then stimulated using CST Microwave studio software to obtain the reflection phase diagram. Figure 3 shows the structure of 3x3 AMC and Table 3 tabulates it’s optimized dimension.
Then, the antenna was incorporated with 3x3 arrays of AMC. The AMC structure acted as an antenna ground plane. No gap between the antenna and AMC structure. AMC was introduced to enhance the performances of antenna in term of gain and directivity. The use of AMC can increased the current distribution of omnidirectional monopole antenna.

3. Results and discussion
Table 4 performance comparison of the antenna alone and as with AMC. The operating frequency was at 2.4 GHz. Even though there was a slightly frequency shifted, the antenna still operate well at 2.45 GHz. Noted that there was a degradation on the return loss as the antenna work with AMC. Thus because of the mutual coupling occurred as the antenna and the AMC were attached with no gaps. The main objective of this integration was successfully achieved as the gain of the antenna was increased to 6.54 dB in simulation and 5.33 dB in measurement as compared to the alone antenna gain which was 2.87 dB.

Figure 4 (a) and Figure 4 (b) show the directivity for microstrip monopole antenna and microstrip monopole antenna with AMC ground plane, respectively. Noted that the integration of AMC successfully enhanced the antenna directivity from 3.01 dBi to 7.14 dBi. The integration between the antenna with the AMC contributed to a directive antenna.
Table 4. The performance comparison of the antenna alone and as with AMC

| Parameters        | Simulation       | Measurement       |
|-------------------|------------------|-------------------|
|                   | Antenna          | Antenna with AMC  | Antenna with AMC |
| Frequency (GHz)   | 2.45             | 2.45              | 2.40             |
| Return Loss (dB)  | -24.07           | -16.96            | -20.30           |
| Gain (dB)         | 2.87             | 6.54              | 5.33             |

Figure 4. The simulated directivity: (a) antenna alone and (b) with AMC

4. Conclusion
The printed monopole antenna with hexagonal shape and AMC were designed at 2.45 GHz. Then the performance comparison of the antenna and the antenna with AMC were analyzed. It was found that integrating the AMC structure to the printed monopole antenna significantly improved the gain and directivity of the antenna. With the AMC, the achieved gain was 6.54 dB, which exhibited 3.68 dB of increment. Its directivity increased from 3.01 dBi to 7.14 dBi. Both of the antenna and AMC structures were simple and much less complex, easy to fabricate and low fabrication cost. The fabricated antenna continued to operate at the desired frequency. The recorded measured gain was 5.33 dB, with 20.3 dB return loss at 2.4 GHz. Thus, the design of the monopole antenna with the AMC was suitable as a RFID tag, as it was able to improve the RFID reading distance.

5. Acknowledgments
The authors wish to thank the Center for Research and Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka (UTeM) for the support of this work under the grant number JURNAL/2018/FKEKK/Q00011.
6. References

[1] Abu M, Rahim M K A, Suaidi M K, Ibrahim I M, Nor N M 2009 A meandered triple-band printed dipole antenna for RFID, *Asia Pacific Microwave Conference* 1958-1961.

[2] Aye E T, and New C M 2016 High gain fabry-perot cavity antenna for RFID applications, *17th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)*.

[3] Necibi O, Hamzaoui D, Vuong T P and Gharsallah A 2015 A novel RFID-HIS-PRS reader antenna for the millimeter wave band 30 GHz *Microwave and Optical Technology Letters* 57 62–64.

[4] Dahlman E, Mildh G, Parkvall S, Peisa J, Sachs J and Selén Y 2014 5G Radio Access. *Ericsson Rev.* 91 42–48.

[5] Prakash P, Abegaonkar M P, Basu A and Koul S K 2019 A W-Band EBG-Backed Double Rhomboid Bowtie-Slot On-Chip Antenna *IEEE Antennas and Wireless Propagation Letters*.

[6] Deepanshu K & Shannuganatham T 2016 Danger microstrip patch antenna for fixed satellite applications *International Conference on Emerging Technological Trends (ICETT)*.

[7] Nikhil K and Lohiya G B 2016 A Compact Microstrip Patch Antenna using Metamaterial *International Journal of Engineering and Innovative Technology (IJEIT)* 42 365-369

[8] Rashmi A, Pandhare P, Zade L and Mahesh P A 2016 Miniaturized microstrip antenna array using defected ground structure with enhanced performance *Engineering Science and Technology, an International Journal* 19 1360-1367

[9] Alok K, Nancy G and Gautam P C 2016 Gain and Bandwidth Enhancement Techniques in Microstrip Patch Antennas - A Review *International Journal of Computer Applications* 9-14.

[10] Bharatendra Singh Niboriya, Chetan Choudhary and Gyan Prabhakar 2013 S-shape Wideband Microstrip Patch Antenna with Enhanced Gain and Bandwidth for Wireless Communication *International Journal of Computer Applications* 73 17-20.

[11] Ranjan, M 2016 An Overview of Microstrip Antenna *International Journal of Technology Innovations and Research (IJTIR)* 21 663-666

[12] Ribhu A P, Upasana P, Nibedita B and Kiran T 2017 Microstrip Patch Antenna Design at 5.2GHz *International Journal of Engineering Science and Computing* 7 6638-6642

[13] Abu M, Rahim M K A 2012 Single-band Zigzag Dipole Artificial Magnetic Conductor *Jurnal Teknologi* 58 19-25.

[14] Abu M, Hassan H, Zin M S I M, Ali S A M 2016 Design of single-band geometric pattern artificial magnetic conductor *ARPN Journal of Engineering and Applied Sciences* 11 3184-3187.

[15] Ali S A M, Abu M, Mohammad N R, Muhamad M and Hassan H 2016 Flexible sipole antenna incorporated with flexible frequency selective surface *ARPN Journal of Engineering and Applied Sciences* 11 5054-5059.

[16] M Abu, EE Hussin, RF Munawar, H Rahmalan 2015 Design synthesis of 5.8 GHz octagonal AMC on a very thin substrate Int. J. Inf. Electron 5 376-380.

[17] Hamad E K I and Nady G. 2019 Bandwidth Extension of Ultra-wideband Microstrip Antenna Using Metamaterial Double-side Planar Periodic Geometry *Radio Engineering* 28 25-32.

[18] Surajit K, Ayan C, Sanjay K J and Susanta K P 2018 A Compact Umbrella-Shaped UWB Antenna with Gain Augmentation Using Frequency Selective Surface *Radio Engineering* 27 448-454.

[19] Kamardin K, Rahim, M K A, & Hall, P S 2015 Textile Diamond Dipole and Artificial Magnetic Conductor Performance under Bending, Wetness and Specific Absorption Rate Measurements *Radio Engineering* 729–738.

[20] Abu M and Ali S A M 2017 Improvement of Dipole Antenna Gain Using 8 CBU AMC- EBG and 8 CBU FSS *Jurnal Teknologi* 79 27-34.