Artificial Magnetic Conductor to Enhance Microstrip Patch Textile Antenna Performance for WiMAX Application

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Abstract. A rectangular microstrip patch textile antenna with Artificial Magnetic Conductor (AMC) operated at the center frequency of 5.80 gigahertz (GHz) for Worldwide Interoperability for Microwave Access (WiMAX) application was designed and simulated using the CST Microwave Studio 2016 and fabricated in this study. The use of AMC could solve the inflexibility of FR4 substrate that limits human body movement and reduce the radiation scattered on the human body whilst increasing the antenna gain and directivity. The antenna consists of 5×5 square shape gap of AMC unit cells ground layer using ShieldIt Super, five substrate layers using cotton (viscose) fabric as well as patch layer and another ground layer using the same ShieldIt Super. AMC is a metamaterial that imitates the conduct of zero reflection phase of Perfect Magnetic Conductor (PMC) on the resonant frequency not evidently existed in nature. Overall, the antenna with AMC has the significant return loss, $S_{11}$ below than -30 decibel (dB), gain improved to more than 8 dB, and directivity elevated to more than 9 dBi at resonant frequency near to 5.80 GHz, respectively.

1. Introduction

Antenna is a component that works as a transmitter and receiver of electromagnetic signals [1]. Therefore, the efficiency of the system will be based on the performance and ability of the antenna. In addition, the well-designed antenna also contribute to reduce the complexity while at the same time enhance performance of the receiver [2]. There are several characteristics in designing the wearable textile antenna that need to be considered to ensure that the antenna able to perform well in all weather conditions in Malaysia, such as rainy, moisty, dusty and dry. Generally, fabric can be considered as a good textile as it has a low dielectric constant, thus it helps to get wide bandwidth from the antenna. Besides, the loss tangent, tan δ also need to be considered as it is known as dissipation factor that characterizes the amount of power turned into heat in the material. The higher the tan δ values, the higher the losses of dielectric substrate, thus reduced radiation efficiency [3]. A broadband system plays an important role for wireless service requirements for example, Worldwide Interoperability for Microwave Access (WiMAX). It is an alternative to cable and Digital Subscriber Line (DSL) where it provides portable mobile broadband connectivity. The application of WiMAX has three allocated frequency bands, which are the low band at 2.50-2.69 GHz, the middle band at 3.20-3.80 GHz and the upper band at 5.20-5.80 GHz [4].

Antenna with Artificial Magnetic Conductor (AMC) ground plane has been introduced to overcome the drawbacks of wearable antennas, by enabling the isolation of human body from the antenna electromagnetic radiation, apart from enhancing the gain [5]. It also eliminates the antenna impedance mismatch caused by the human tissues [5]. Besides, the introduction of AMC can solve the antenna array limitation, which are bigger occupied space configuration dimensions [6]. The textile AMC plane is a type of two-dimensional metasurface suitably used for wireless local area network
As an effective homogeneous metamaterial structure, the AMC acts as a magnetic conductor in a limited variety of frequencies. As the magnetic conductor provides a reflection phase of incident electric powered field, it will adorn the performance of antenna. There are various studies proposed for AMC for improving antenna radiating efficiency, reduction of main-to-side lobe ratio, and suppression of surface wave in revealed antenna. Besides, it can also empower the use of a more compact antenna configuration in cellular phones. Practically, AMC consists of a repeating pattern of resonant mobile systems (unit cells). To use AMC as an antenna reflector or ground planes, AMC needs to behave as a homogeneous plane for the antenna on the antenna operating frequency. This lets in the in-phase reflected image reaction and avoids any unwanted interactions with single resonator cells inside the AMC structure [8]. In this case, AMC planar surfaces, which are free from vias, should be designed in a very compact form to provide large in-phase bandwidth [9].

Since the wearable antenna is placed on the human body, the design of the antenna should be small, light, and thin. These features can be fulfilled by using appropriate textiles as substrate material for antenna design. The use of FR4 as a substrate is unsuitable due to inflexible, which limits body movement. Hence, the antenna needs to be designed with wearable materials or fabrics to overcome the limitations. Besides, it is also important to reduce the radiation that is scattered on the human body. This can be accomplished by placing the antenna on an AMC to protect the body and increase the gain of the antenna. The minimum spacing of antenna to a ground plane affects the efficiency of the antenna if placed too close, the antenna will suffer reduced gain and high return loss, $S_{11}$.

Replacing a continuous ground plane with an AMC allows the antenna to be placed arbitrarily close to the surface without damaging the radiation characteristics [10].

### 2. System Description

The microstrip patch antenna is among the most popular microwave antenna. Figure 1 shows the microstrip antenna structure.

![Microstrip Patch Antenna](image)

**Figure 1.** Microstrip Patch Antenna

The length, $l$ and width, $w$ of the microstrip patch antenna can be calculated using the formulas below:

$$w = \frac{c}{2f \left( \frac{\varepsilon_r + 1}{2} \right)}$$

(1)

$$L = \frac{c}{2f \left( \sqrt{\varepsilon_{reff}} \right)} - 0.824h \left( \varepsilon_{reff} + 0.3 \right) \left( \frac{w}{l} + 0.264 \right)$$

$$\left( \varepsilon_{reff} - 0.258 \right) \left( \frac{w}{l} + 0.8 \right)$$

(2)
Where,

$$\varepsilon_{ref} = \left( \frac{\varepsilon_r + 1}{2} \right) + \left( \frac{\varepsilon_r - 1}{2} \right) + \left( 1 + \left( \frac{12h}{w} \right) \right)^{-\frac{1}{2}}, \text{ and } c = 3 \times 10^8 \text{ m/s.}$$

(3)

The fabric becomes as the important element contained for designing and fabrication of the proposed antenna. In this project, the cotton (viscose) is used for substrate layer whereas the ShieldIt Super is used for patch and ground layers, respectively. Table 1 and Table 2 enlist the specifications of both cotton (viscose) and ShieldIt Super materials.

Table 1. The Specification of Cotton (Viscose) Fabric

| Parameter                  | Value  |
|----------------------------|--------|
| Substrate thickness, $h$   | 0.32 mm|
| Relative permittivity, $\varepsilon_r$ | 1.309168 |
| Loss tangent, $\delta$     | 0.006578 |

Table 2. The Specification of ShieldIt Super

| Parameter                  | Value |
|----------------------------|-------|
| Substrate thickness, $h$   | 0.17 mm |
| Conductivity, $\varepsilon_r$ | $1.18 \times 10^5$ S/m |

Figure 2. Cotton (Viscose) Fabric

Figure 3. ShieldIt Super Fabric
Figures 2 and 3 show both the cotton (viscose) and ShieldIt Super fabrics used to fabricate the microstrip patch textile antenna in this study. The CST Microwave Studio 2016 software was used to design and simulate the antenna performance. Figures 4 - 6 show the geometry of the patch textile antenna and AMC with specific dimensions.

Figure 4. Rectangular Patch Antenna (Front View)

Figure 5. Rectangular Patch Antenna (Back View)

Figure 6. Geometry of (a) Textile Antenna, (b) AMC Plane, and (c) Perspective
Figure 7 shows the exact thickness of the proposed textile rectangular patch antenna with AMC ground plane. In this design, there are five layers of cotton (viscose) as substrate was used. Overall, the thickness of the textile antenna with AMC was 3.71 mm. Figure 8 shows the fabrication of the textile patch antenna with the soldered SMA connector and AMC prototypes using the cotton (viscose) and ShieldIt Super fabrics.

Figure 8. Fabrication of Textile Rectangular Patch Antenna and AMC (Front View)

3. Result and Discussion

The simulation results were acquired by designing the textile antenna using the CST Microwave Studio 2016 software and measured results performed by using a network analyzer. Both simulation and measurement operated at 5.80 GHz operating frequency. The simulation process became the main part in designing the textile antenna with Artificial Magnetic Conductor (AMC). This simulation part was very important to determine the performance of antenna whether it could enhance or not the performance of textile antenna with AMC for WiMAX application. Thus, all the parameters that affected the result of the simulation were analyzed. The simulation process measured the results of the return loss, gain, and directivity. Figures 9 and 10 show the radiation pattern of directivity for both antennas with/without AMC. In this case, the proposed antenna with AMC had the higher directivity of 9.363 dBi. This means that the radiation pattern of antenna with AMC ground plane was more focus. Figures 11 and 12 show that the radiation pattern of gain for both with/without AMC. Again, the proposed antenna with AMC had the higher gain of 8.222 dB, respectively. The higher gain shows that the proposed antenna enabled to reflect the wave without any phase reversal propagating through the AMC ground plane.
Figure 9. Radiation Pattern of Directivity without AMC (Directivity = 7.835 dBi)

Figure 10. Radiation Pattern of Directivity with AMC (Directivity = 9.363 dBi)

Figure 11. Radiation Pattern of Gain without AMC (Gain = 6.136 dB)
Figure 12. Radiation Pattern of Gain with AMC (Gain = 8.222 dB)

Return loss, $S_{11}$ determined the power loss of the antenna when the signal was being transmitted or reflected. Hence, every aspect, such as dimension of ground, substrate and patch layers had to be taken into account so that the $S_{11}$ is below -10 dB. For this textile antenna, the AMC addition affected the performance of the $S_{11}$. The simulations of return loss, $S_{11}$ for both textile antennas without and with AMC are shown in Figures 13 and 14, respectively. It was found that the simulated $S_{11}$ of the textile antenna without AMC was -37.30 dB. On the other hand, the simulated $S_{11}$ of the textile antenna with AMC was -30.04 dB at the resonant frequency of 5.81 GHz. In sum, the proposed textile antenna with AMC still had a significant performance for upper band WiMAX application since its return loss was below -10 dB, a standard threshold value for the antenna design specification in determining how many signal is reflected back to the antenna. The more signal is reflected, the less signal is delivered to the load.

Figure 13. Simulated Return Loss of Textile Antenna without AMC
The fabricated textile antenna was then measured using a network analyzer. Both the simulation and measurement results were being compared in terms of return loss, $S_{11}$ for the proposed textile patch antenna without/with AMC.

**Figure 14.** Simulated Return Loss of Textile Antenna with AMC

**Figure 15.** Simulated $S_{11}$ vs. Measured $S_{11}$ Response for Patch Antenna without AMC

**Figure 16.** Simulated $S_{11}$ vs. Measured $S_{11}$ Response for Patch Antenna with AMC
Figure 15 shows the comparison of simulated $S_{11}$ and measured $S_{11}$ parameters for the patch antenna without AMC whereas Figure 16 shows the comparison of the same parameters for the patch antenna with AMC, respectively. It can be seen in both cases, the simulated and measured $S_{11}$ responses occurred almost near to 5.80 GHz. Moreover, Figure 17 shows the comparison of simulated $S_{11}$ parameter between patch antenna and patch AMC. Figure 18 shows the comparison of measured $S_{11}$ parameter between patch antenna without AMC and patch antenna with AMC.

![Figure 17. Simulated S_{11} Patch Textile Antenna vs. Simulated S_{11} Patch AMC](image)

![Figure 18. Measured Patch Antenna without AMC vs. Measured Patch Antenna with AMC](image)

Table 3 enlists the comparison performance between the microstrip patch antenna with and without AMC in terms of simulated gain, simulated directivity, and measured return loss, $S_{11}$, respectively. It can be seen that the AMC can enhance the antenna gain and directivity simultaneously whilst having the return loss below than – 30 dB.

**Table 3. The Comparison Performance between Textile Patch Antenna with and without AMC**

|          | Simulated |          | Measured |
|----------|-----------|----------|----------|
|          | Frequency (GHz) | Gain (dB) | Directivity (dBi) | Frequency (GHz) | $S_{11}$ (dB) |
| With AMC | 5.8087 | 8.22 | 9.36 | 5.80 | -31.70 |
| Without AMC | 5.8034 | 6.14 | 7.83 | 5.75 | -37.80 |
4. Conclusion

In sum, the proposed AMC significantly improves the microstrip rectangular textile patch antenna radiation performance in terms of gain and directivity whilst ensuring $S_{11}$ significantly below -30 dB. Moreover, the designed patch textile antenna with AMC has the return loss resonant frequency near to 5.80 GHz, which makes it suitable for upper band WiMAX application. Finally, using both ShieldIt Super and cotton (viscose) fabrics, the small-sized microstrip patch antenna with AMC ground plane is successfully designed and fabricated suitable to be deployed on human body.

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