

# Textile Artificial Magnetic Conductor Waveguide Sheet with Wire Dipoles for Body Centric Communication

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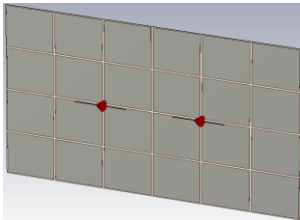
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## Article history

Received :12July 2012  
Received in revised form :  
4 April2013  
Accepted :15 April 2013

## Graphical abstract



## Abstract

A textile Artificial Magnetic Conductor (AMC) sheet-like waveguide with wire dipoles were designed to investigate the possibility of improving transmission between antennas. The textile AMC sheet is made of fleece fabric with conductive patches and ground plane made of SHIELDIT fabric. The AMC surface is designed to have in-phase reflection at 2.45GHz with the objective to enhance the transmission between antennas. The S-parameters performance of the two antennas with textile AMC sheet was investigated thoroughly. The effect of different antennas' placement and distance was also considered. Measurements were conducted rigorously to validate the simulated findings. Results show that the S<sub>21</sub> transmission between antennas improved significantly when having the AMC waveguide sheet beneath them. Directive radiation pattern with high gain was also achieved with the proposed AMC sheet-like waveguide.

*Keywords:* Artificial magnetic conductor; textile AMC; sheet-like waveguide; dipole; antenna

## Abstrak

Sejenis kepingan panduan-gelombang Konduktor Bermagnet Muatan (AMC) tekstil dengan antenna dwi-jalur telah direka untuk menyiasat kemungkinan bagi meningkatkan penghantaran gelombang di antara antenna-antenna. Kepingan tekstil AMC tersebut diperbuat daripada fabrik fleece dengan penambal konduktif dan satah bumi yang diperbuat daripada fabrik SHIELDIT. Permukaan AMC telah direka untuk mempunyai pantulan-pada-fasa di frekuensi 2.45 GHz bertujuan untuk meningkatkan penghantaran gelombang di antara antenna-antenna. Prestasi S-parameter untuk dua antenna dengan kepingan AMC tekstil telah dikaji dengan teliti. Kesan kepelbagaian penempatan dan jarak antenna telah juga dipertimbangkan. Seterusnya, pengukuran telah dijalankan dengan teliti untuk mengesahkan penemuan simulasi yang telah dijalankan terlebih awal. Keputusan kajian mendapati bahawa penghantaran gelombang S<sub>21</sub> di antara antenna-antenna tersebut telah meningkat dengan ketara apabila kepingan panduan-gelombang AMC diletakkan di bawah antenna-antenna tersebut. Corak radiasi berarah dengan gandaan tinggi telah turut dicapai dengan kepingan panduan-gelombang AMC yang dicadangkan.

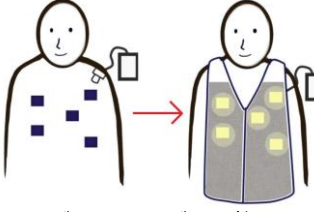
*Kata kunci:* Konduktor bermagnet muatan (AMC); AMC tekstil; kepingan panduan-gelombang; antenna dwi-jalur; antenna

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## 1.0 INTRODUCTION

Due to the need of a reliable short-range communication in human body, research in body centric communication has been getting attention from researchers all over the world [1]. Body centric communication is a human-to-human networking which combines a number of networks, one of them is the Wireless Body Area Networks (WBANs). WBAN operates such that it associates with wearable devices, such as wearable antennas, to provide a communication network within human body, which allows new conveniences and services which are useful to mankind.

Wearable antennas have been the focus in body centric communication in recent years [2-4]. The demand of such antennas in today's society is evident based on its wide range of applications including healthcare, personal entertainment, military, smart home and space exploration [5-10]. Wearable antennas are light, cheap, and flexible, and therefore suitable to be equipped on human body in the form of clothing, such as vests [11]. However, wearable antennas suffer performance degradation due to the distinct properties of the human body [12]. Human body causes unwanted high transmission loss between on-body antennas, disrupting the efficiency of the wireless networking system.



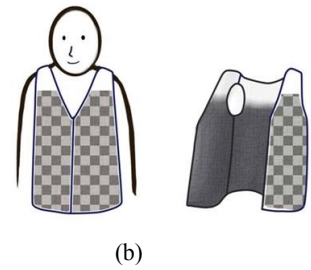
is of wearable antennas, a new communication is introduced. This structure onto sheets to be worn. Waveguide structures are capable of providing an independent waveguide without interference. To improve the transmission between antennas, a Perfect Magnetic Conductor (AMC) waveguide sheet. AMC is made up of a grounded dielectric substrate printed with metallic arrays and it is chosen to be implemented in this study because of its in-phase reflection characteristic [14-15]. Its ability to mimic Perfect Magnetic Conductor (PMC) allows the improvement of transmission between antennas.

**2.0 TEXTILE WAVEGUIDE IN BODY CENTRIC COMMUNICATION**

Waveguide is a structure that provides a path for electromagnetic wave propagation. This designated path significantly reduces the wave signal loss since the wave propagates in a confined structure. Thus, the application of waveguide is appropriate for short range on-body communication. Waveguide structures come in many forms; one of them is the sheet-like waveguide, which is the structure most suitable to be used for body centric wireless communication. It has also been implemented in the infrastructure of sensor networks [16].

For on-body application, the sheet-like waveguide is called the free access mat by authors in [17], and it is easy to be coupled with external antennas. A free access mat is able to efficiently transfer power at a center frequency of approximately 2.45 GHz [18]. In some cases, it could also support two frequency bands [19]. As for the design of a free access mat, a tightly coupled double layered microstrip resonator array is used as the materials [20]. These materials provide conductivity to the structure. It is then embedded inside textile to provide flexibility to be worn on human’s body. The combination of conductivity and flexibility contributes to the conformity of the wearable sheet-like waveguide [21].

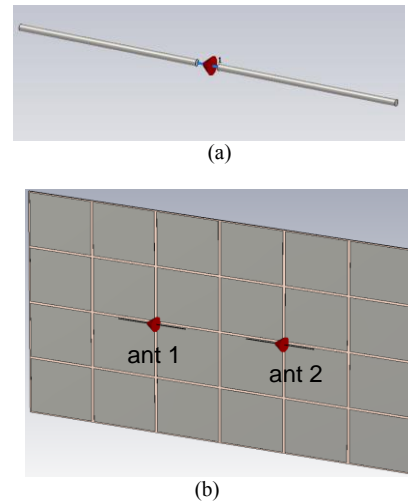
In this research, an application of textile conformal waveguide for wireless body centric communication in electrocardiography (ECG) is proposed. A sheet-like waveguide is equipped into a jacket (Figure 1a) and it is coupled to the wireless sensors so that patient’s data could be collected and instructions could be sent over to ECG control unit wirelessly [12]. The waveguide structure is equipped with antennas. In addition, AMC periodic structures are applied to the sheet design (Figure 1b). The reason being is that in recent years, AMC is one of the metamaterials that has been actively used in microwave and antenna engineering [22-24] and applications with AMC give better signal transmission [25-27]. This study investigates the applications of the design in off-body environments. Several different placements of antennas were also considered to investigate the possibilities in practical application.



**Figure 1** The concept of sheet-like waveguide jacket (a) Waveguide jacket on ECG sensors. (b) Proposed waveguide jacket with AMC structure

**3.0 DESIGN CONSIDERATION**

A wire dipole (Figure 2a) has been designed to investigate the transmission performance between antennas over textile AMC sheet-like waveguide. The dipole has an optimized diameter of 0.85 mm and a total length of 55 mm including 3 mm gap to resonate at 2.45 GHz. In addition, textile AMC structures were also designed to operate at 2.45 GHz. After optimization, the size of the patch is 51 mm with 2 mm gap between the patches. The textile used is a fleece fabric with permittivity 1.3, tangent loss 0.025 and thickness 1 mm. The structure comprises 6x4 arrays of conductive square patches made of SHIELDIT fabric (Figure 2b). The same conductive fabric is used as the ground plane.



**Figure 2** Dipoles above Textile AMC sheet

Dielectric probe method was used to characterize the properties of the fleece textile, whilst a special cutter machine was used to fabricate the patches for better accuracy. Figure 3a shows the fabricated textile AMC waveguide sheet with two wire dipoles. The two wire dipoles are placed 5mm above the textile AMC surface to investigate the transmission performance between antennas. Vector Network analyzer was used to measure the S-parameters readings to verify the simulation (Figure 3b). In this study, only off-body environment were considered. The AMC surface was investigated in laid flat settings.

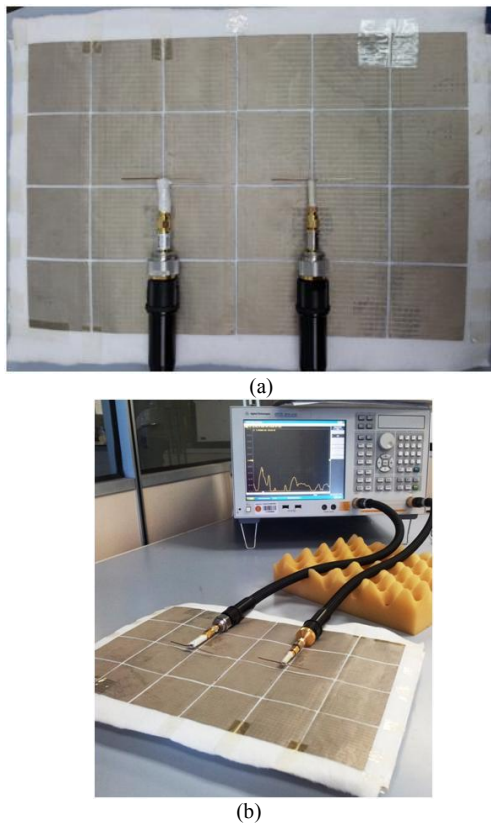
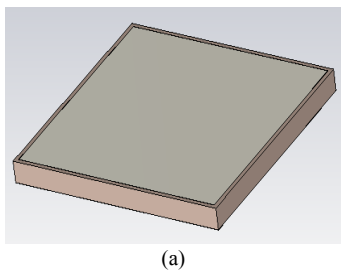


Figure 3 Fabricated Textile AMC sheet with wire dipoles

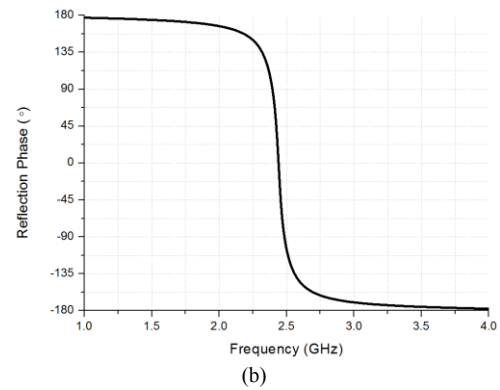
## 4.0 RESULTS AND DISCUSSIONS

### 4.1 Textile Artificial Magnetic Conductor

In this study, the performance of transmission between wire dipoles when placed above a textile AMC surface was investigated. Series of simulations using CST Microwave Studio were performed to investigate the possibility of transmission enhancement between two antennas with the proposed textile AMC waveguide. Initially, the reflection phase characteristic of a square AMC was studied using unit cell simulation (Figure 4a). The optimized reflection phase diagram was obtained after conducting rigorous parametric studies. The reflection phase diagram of a fleece square patch with 50 mm width resonating at 2.45 GHz is as shown in Figure 4b.



(a)



(b)

Figure 4 Reflection Phase diagram of a textile square patch AMC (a) Unit cell (b) reflection phase

From the unit cell result, simulation of two wire dipoles with AMC arrays was then conducted to obtain the most optimized configuration. The  $S_{11}$  and  $S_{21}$  results of wire dipoles above AMC surface with varying patch's width is shown in Figure 5. From the graph it can be observed that the resonance frequency can be tuned by adjusting the size of patch accordingly. Figure 5 shows that the  $S_{11}$  and  $S_{21}$  resonate at 2.45 GHz when the patch width is 51 mm. As the patch's size increases, the resonance frequency decreases.

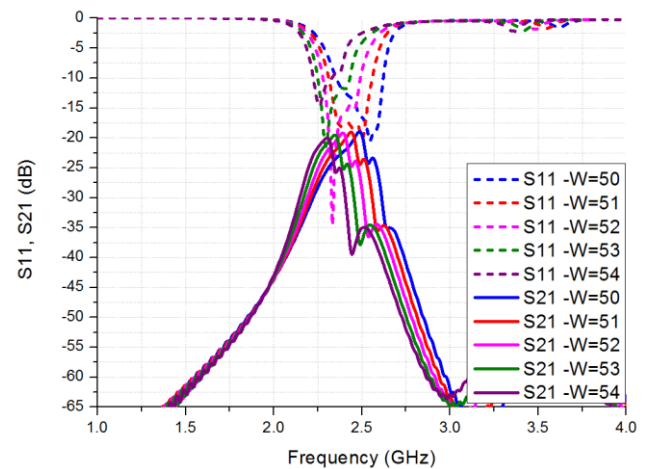


Figure 5 Simulated results for  $S_{11}$  and  $S_{21}$  of dipoles above Textile AMC waveguide sheet with different patch width

### 4.2 Transmission between Wire Dipoles

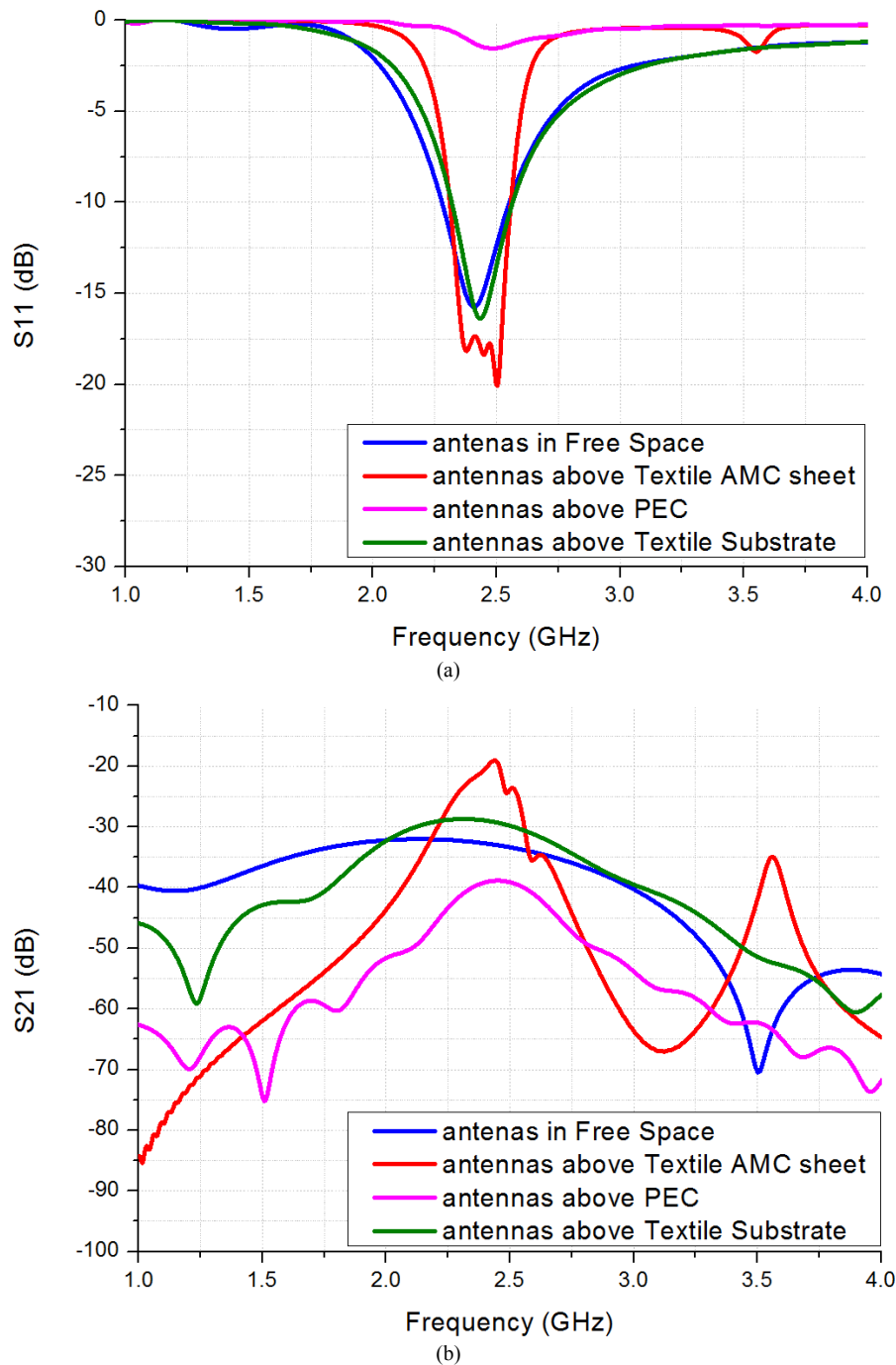
Following that, study was conducted to investigate the performance of two wire dipoles in four different environments. The settings include wire dipoles in free space, above metal surface, above textile substrate and above AMC waveguide sheet. The dipoles were placed 5 mm above the mentioned surfaces.

The  $S_{11}$  and  $S_{21}$  of the four different wire dipoles' conditions are as illustrated in Figure 6a,b.  $S_{11}$  results as illustrated in Figure 6a for the four conditions read -14.9 dB for free space, -1.5 dB for PEC plate, -16.2 dB for textile substrate and -18.4 dB for AMC surface. Low return loss is observed with PEC settings while high return loss is achieved with the AMC surface.

On the other hand, the  $S_{21}$  transmission results as shown in Figure 6b give -33 dB for free space, -38.9 dB for PEC plate, -29.3 dB for fleece substrate and -19.3 dB for AMC sheet. From

the results, it can be noticed that the  $S_{21}$  peaks up to -19.3 dB, an increment of 13.7 dB from free space transmission. From the results, it can be observed that high  $S_{21}$  transmission can be achieved when the AMC sheet-like waveguide is beneath the two wire dipoles. The transmission between two dipoles is

significantly improved at the resonance frequency with the introduction of the textile AMC surface. By having the AMC waveguide sheet, the two wire dipoles achieved transmission enhancement that is desired.



**Figure 6** Simulation results for wire dipoles in four different conditions (a)  $S_{11}$  (b)  $S_{21}$

Results show that the  $S_{11}$  and  $S_{21}$  of the wire dipoles when placed above metal plate suffer a very high mismatched and transmission loss. This is due to the dipoles being shorted as they were not placed for more than  $\lambda/4$  above the Perfect Electric Conductor (PEC) plate. To place antennas above a metal plate, a distance of  $\lambda/4$  is crucial to attain a good result. However,

such distance restriction is not needed for the AMC surface. This gives a low profile configuration advantage for the AMC surface as opposed to metal plate configuration.

The AMC sheet performs as a high impedance surface that improves the transmission between two antennas apart from the low profile configuration benefit. The high transmission capability

achieved by the textile AMC sheet is predicted due to the in-phase reflection characteristic of the AMC structure.

4.3 Different Antenna's Placement

Further investigation was carried to explore the placement of the wire dipoles above the AMC sheet-like waveguide. Four different positions were investigated as laid in Figure 7. In this study, the wire dipoles are in horizontal orientation but with different placement and distances between each other. Position A and B represents a parallel arrangement with different distance with A having shorter distance. Position H and G depict diagonal arrangement with different distances respectively, with G being further than H, as shown in the diagram (Figure 7).

Simulation was carried to explore the S-parameters results of two dipoles above AMC sheet with different placement and distances. Figure 8 shows the simulated results of  $S_{11}$  and  $S_{21}$  for different antenna's positions.

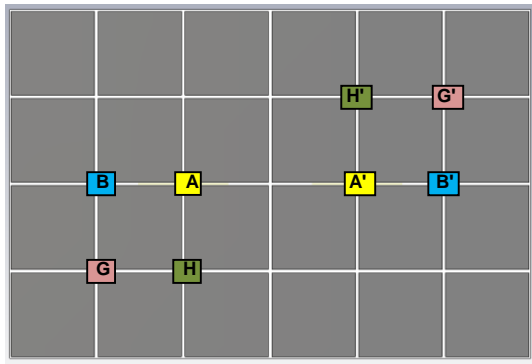


Figure 7 Antenna's positioning above AMC waveguide sheet

From the S-parameters results (Figure 8), the  $S_{21}$  transmission decreases as the distance increases, as predicted. The arrangement of the antennas also influenced the  $S_{21}$  results with diagonal arrangement gave higher transmission loss compared to parallel arrangement. The  $S_{11}$  results remained to resonate at 2.45 GHz for all four positions.

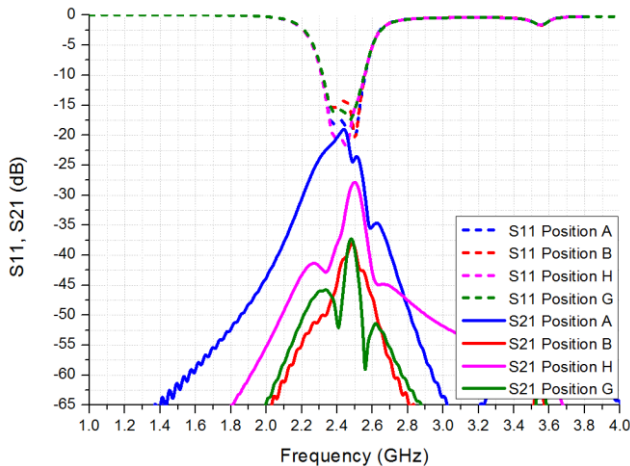


Figure 8 Simulated results for the  $S_{11}$  and  $S_{21}$  of dipoles for different placements

Measurement was then carried to validate the simulation results (Figure 9). The trend between simulated and measured results shows reasonable agreement. Measured results verify that the transmission between the two dipoles is improved with the presence of Textile AMC waveguide sheet. Highest  $S_{21}$  peak is observed at -10.7 dB at 2.3 GHz. Slight fabrication error is predicted to cause the frequency shift. Despite the  $S_{21}$  peak resonance shift, transmission improvement is still obtained at 2.45 GHz.  $S_{21}$  improvement of 12.3 dB is achieved at 2.45 GHz and 17 dB at 2.3 GHz compared to free space condition for Position A.

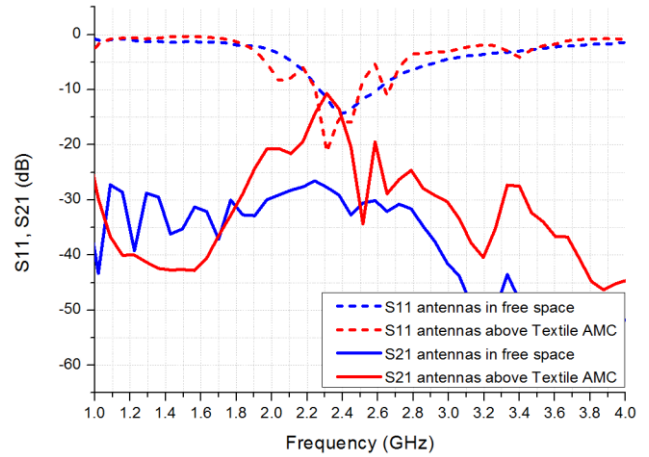


Figure 9 Measured results for the  $S_{11}$  and  $S_{21}$  of dipoles with and without AMC waveguide

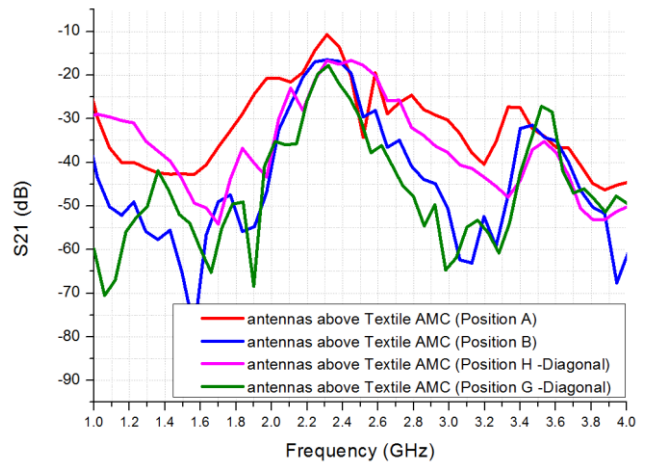


Figure 10 Measured results for the  $S_{21}$  of dipoles above textile AMC with different distance and position

Following that, measurements were also carried for different antennas' placements. Figure 10 illustrates the  $S_{21}$  results for the four different antennas' positioning. The  $S_{21}$  peaks are also observed at 2.3 GHz for all cases. Transmission enhancements were also realized at the positions B, H and G at both 2.4 GHz and 2.3 GHz as opposed to the free space transmission.

At position B, the  $S_{21}$  transmission is enhanced by 15.4 dB and 21.6 dB from the free space environment at 2.4 GHz and 2.3 GHz respectively. As for the diagonal arrangement, the transmission improved by 20.5 dB at 2.45 GHz and 20.6 dB at 2.3 GHz for position H. While position G obtained enhancement of 24.6 dB and 19.8 dB for 2.45 GHz and 2.3 GHz respectively.



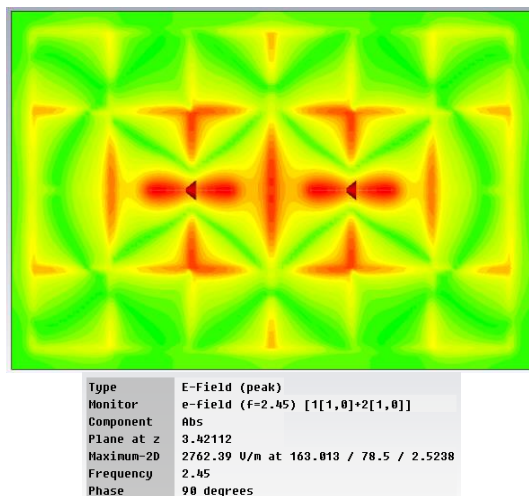
**Table 1** Measured  $S_{21}$  for antennas with and without AMC waveguide sheet

Freq (GHz)	$S_{21}$ (dB)							
	Antennas only				With Textile AMC			
	Position A	Position B	Position H	Position G	Position A	Position B	Position H	Position G
2.45	-32.7	-35	-37.2	-49.9	-20.4	-19.6	-16.7	-25.3
2.3	-27.7	-38.1	-37.3	-37.6	-10.7	-16.5	-16.7	-17.8

Table 1 shows the summary of measured  $S_{21}$  transmission between wire dipoles with and without AMC waveguide sheet. As mentioned earlier, all the  $S_{21}$  results showed transmission improvement compared to when the dipoles were radiating in free space, at both 2.45 GHz and peak 2.3 GHz. The measured results verify that the  $S_{21}$  transmissions are significantly enhanced when textile AMC sheet is at presence with the maximum peak of -10.7 dB. From both simulated and measured results, it can be concluded that  $S_{21}$  performance decreases as the distance increases. Parallel arrangement shows better transmission compared to diagonal placement. However, for all positions, significant improvement and high  $S_{21}$  peak are still achieved when having AMC sheet compared to free space transmission. Electromagnetic waves are being concentrated into the AMC surface. Therefore low transmission loss between two antennas is observed.

#### 4.4 Current Distribution

To observe the current flows between antennas above an AMC surface, simulated current distribution was retrieved for a visible view. Figure 11 illustrates the current distribution of two wire dipoles placed on top of a textile AMC waveguide sheet.

**Figure 11** Current distributions of two dipoles above textile AMC

Strong current distribution is observed between two dipoles along neighbouring patches. The diagram shows electromagnetic waves concentrating into the AMC surface. High strength of current is seen flowing between the dipoles via the middle patches.

Therefore, it is evidenced that enhanced transmission between antennas is achieved when having AMC surface beneath them.

#### 4.5 Radiation Patterns

Finally, the radiation patterns of the two wire dipoles were investigated. Figure 12 depicts the radiation patterns for antenna 1 and antenna 2 for both E and H planes. The radiations in E plane show directional pattern with small back lobe. However, the back lobe for antenna 1 shows a shift to the left while antenna 2 has a back lobe shifted to the right. This is mainly due to the coupling effect between both antennas since they were placed and excited in parallel to each other.

As for the H plane radiation patterns, similar directional patterns were obtained for both antenna 1 and 2. Forward radiation with minimum back lobe is expected when having an AMC ground plane that acts as high impedance surface. Owing to the characteristic of AMC array, a high gain of 6.82 dB for both antennas is obtained.

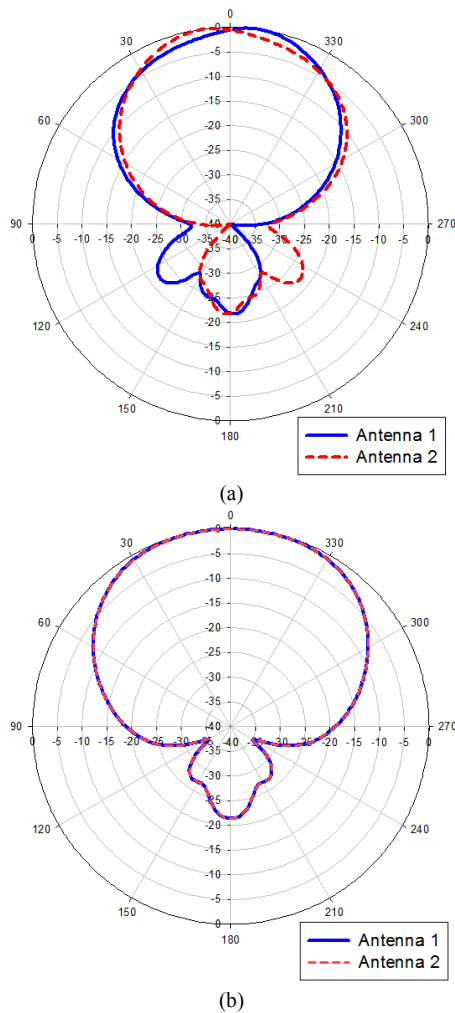


Figure 12 Radiation patterns for antenna 1 and 2 (a) E plane (b) H plane

## 5.0 CONCLUSION

In this study, a textile AMC waveguide sheet with wire dipoles have been designed and investigated. The substrate for the textile AMC was made of Fleece fabric while the conductive patches and ground plane were made of SHIELDIT fabric. The performance of  $S_{21}$  transmission between two wire dipoles was explored thoroughly for off-body and laid flat settings. Several antenna placements were investigated in this work. Simulated and measured results show significant transmission improvement when placing the AMC sheet beneath the antennas. The in-phase reflection characteristic is predicted to contribute to the transmission enhancement between the antennas. Forward directive radiation pattern with minimum back lobe was obtained with high gain, owing to the AMC behaviour as high impedance surface.

## Acknowledgement

The authors are grateful to the Malaysian Ministry of Science Technology and Innovation (MOSTI), Universiti Teknologi Malaysia (UTM) and the Malaysian Ministry of Higher Education (MOHE) which enables the publication of this article. The authors also wish to thank Professor P.S. Hall and Communications

Engineering group at the University of Birmingham for the help and guidance.

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