Jurnal Teknologi

Full Paper

IMPROVEMENT OF DIPOLE ANTENNA GAIN USING 8 CBU AMC-EBG AND 8 CBU FSS

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Article history
Received
16 March 2016
Received in revised form
13 February 2017
Accepted
15 March 2017

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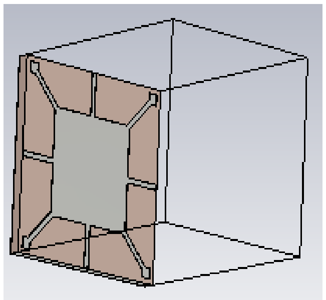
Graphical abstract



Abstract

This paper investigates the performances of dipole antenna incorporated with and without 8 CBU AMC-EBG and 8 CBU FSS at 5.8 GHz. The designs are simulated on Rogers RO 3010. Due to the flexibility of the material used as a substrate, the effect of a different angle is investigated. Both 8 CBU AMC-EBG and 8 CBU FSS act as reasonably good ground plane for the dipole antenna and help improving the realised gain and improve the radiation patterns by push the front lobe at the same time reduce the side lobes. The maximum improvements led by dipole antenna with 8 CBU AMC-EBG thus 8.543 dB of realised gain achieved and the front lobe is pushed higher and the side lobe is significantly lowered than with 8 CBU FSS. The designs of dipole antenna with 8 CBU AMC-EBG and 8 CBU FSS can be applied as high gain atenna for Intelligent Transport System (ITS).

Keywords: Artificial Magnetic Conductor (AMC), Electromagnetic Band Gap (EBG), Frequency Selective Surface (FSS), dipole antenna and 8 Connected Branches Uniplanar (8 CBU)

Abstrak

Prestasi antena dwikutub tunggal dan diintegrasi dengan 8 Cabang Bersambung Uniplanar Konduktor Bermagnet Buatan–Jurang Jalur Elektromagnet (8 CBU AMC-EBG) dan 8 Cabang Bersambung Uniplanar Kekerapan Permukaan Terpilh (8CBU FSS) disiasat pada 5.8 GHz. Kedua-dua rekaan ini disimulasi diatas Rogers RO 3010. Oleh kerana bahan lapisan yang digunakan adalah bahan yang boleh dilentur, kesan dilentur dari pelbagai sudut juga dianalisis. Kedua-dua 8 CBU AMC-EBG dan 8 CBU FSS bertindak sebagai lapisan bumi yang wajar untuk antena dwikutub dan membantu untuk meningkatkan penerimaan kuasa dan corak radiasi dengan menolak corak hadapan dan mengurangkan corak tepi. Peningkatan maksimum dicapai oleh antenna dwikutub yang didintegrasi dengan 8 CBU AMC-EBG iaitu penerimaan kuasa sebanyak 8.543 dB dan corak hadapan ditolak lebih ke hadapan dan corak tepi dikurangkan lebih dari 8 CBU FSS. Rekaan antena dwikutub dengan 8 CBU AMC-EBG and 8 CBU FSS boleh digunakan untuk aplikasi antena dengan penerimaan kuasa yang tinggi untuk Sistem Kenderaan Pintar (ITS).

Kata kunci: Pengalir Magnetik Buatan (AMC), Jurang Jalur Elektromagnet (EBG), Kekerapan Permukaan Terpilh (FSS), antena dwikutub dan 8 Cabang Tersambung Uniplanar (8 CBU)

1.0 INTRODUCTION

Recently, there has been growing research interest to develop flexible system technology. Flexible antennas are the main method implemented in body centric communications [1-2]. The usage of flexible antennas on human causes performance distortions due to distinct properties of human body itself [3]. Following that, research in flexible antennas has received remarkable interest [4-5].

The research activities in the field of antennas have focused on design of light-weight, conformable and small antennas [6-8] that could at the same time retain good radiation efficiency and support large enough bandwidth to accompany the requirements of high data rates in modern communication systems. The printed antennas on flexible substrate are being extensively researched; while it was demonstrated that the presence of human body can significantly affect the antenna radiation properties, it also gives rise to surface wave communication.

Printed antennas are frequently used due to their advantages such as light weight, ease of fabrication and compact size [8]. The antennas have relatively narrow bandwidth characteristics. An ultra-wideband (UWB) antenna type is also developed and consists of printed planar dipole antenna. It is suitable since it provides a large bandwidth and also gives better polarisation in comparison with other structures in addition to their low cost [9]. There are many kinds of UWB antenna types such as bow-tie [10], TEM horn [11] and spiral [12].

For this research, the printed dipole antenna is the best candidate for the flexible system since it is simple, easy to fabricate and easy [13] to integrate with AMC, FSS and EBG. It also comes with wide variety of shapes. However, it is categorised as a low gain antenna where it is fundamentally limited by the size, radiation patterns and the frequency operation. However, flexible antennas themselves experience performance degradation such as frequency detuning, bandwidth reduction and radiation distortions when placed on human body. Moreover, the radiation that penetrates into the human cells is a major health concern [3]. One way to improve the overall antenna performance is to enhance the gain of a system at receiver end that can be achieved using AMC, FSS and EBG. All three metamaterials above have been used extensively in the past for enhancing the performance of antennas by improving the gain and reducing the radiation exposure to the human body [15-17].

Additionally, in [18], the realised gain is improved up to 2.1 dBi by using rigid substrate. While in [19], placing the EBG behind the antenna (using felt material substrate) reduces back radiation by at least 13 dB while improving gain by up to 3 dB in a direction away from the body. Furtheremore, in [20], the maximum gain enhancement is around 7.5 dB and the average gain enhancement is more than 4 to 5 dB for the complete operational band thus also using a rigid substrate with 10 mm gap distance between the antenna and the FSS structure.

Thus, this research involves the design and development of flexible antenna incorporated with AMC, FSS and EBG. All of the structures considered flexible materials as a substrate which are bendable and suitable for wearable communication. The characteristics of each AMC, FSS and EBG are evaluated and differentiated. Then the performances of dipole antenna incorporated with and without AMC, FSS and EBG are investigated.

In this paper, the performances of dipole antenna backed with 8 CBU AMC-EBG and 8 CBU FSS are evaluated at 5.8 GHz. The improved performances of dipole antenna while incorporatedwith 8 CBU AMC-EBG and 8 CBU FSS are investigated on flexible materials and their performance in terms of angles of incidence are studied. All design simulations are done using Computer Simulation Technology (CST) Microwave Studio software. Both AMC and FSS act as reasonably good ground plane for the dipole antenna and helps improve the realised gain and push the front lobe of the radiation patterns of the dipole antenna.

2.0 METHODOLOGY

8 CBU AMC-EBG Design

This section describes the designs of 8 CBU AMC-EBG that will be incorporated with the dipole antenna. As initial design, the properties of the square patch AMC are investigated followed by the 8 CBU AMC-EBG operating at 5.8 GHz.

The design of 5.8 GHz square patch AMC that is capacitive square patch frequency selective surface (FSS) backed by a ground plane with 0.035 mm thickness. This AMC is designed using the Rogers RO3010 substrate parameters; permittivity ε_r = 10.2, thickness h = 1.28 mm and tangent loss δ = 0.0023. The characteristics of the AMC such as reflection phase, reflection magnitude and surface impedance of the AMC are simulated using frequency solver in CST Microwave Studio.

As in [21], the inductance (L), capacitance (C), frequency response (f_r) and bandwidth (BW) of the equivalent circuit for mushroom EBG structure are given by [21]:

$$L = \mu_O h \quad (1)$$

$$C = \frac{W\varepsilon_O(1+\varepsilon_R)}{\pi} cosh^{-1}\left(\frac{2W+g}{g}\right) \quad (2)$$

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

$$BW = \frac{1}{\eta_O}\sqrt{\frac{L}{C}} \quad (4)$$

where η_o, ε_o and μ_o are the impedance, permittivity and permeability of free space, ω is the patch width and g is the gap between adjacent patches. At resonance, the surface impedance Z_s is determined by:

$$Z_S = \frac{j\omega L}{1-\omega^2 LC} \quad (5)$$

One of the most important considerations in designing the 8 CBU AMC-EBG is to make sure the structure and evaluate both AMC and EBG characteristics. The reflection phase of the design should vary from 180° to -180° and the resonance frequency is at the 0° reflection phase. Furthermore, the structure should also have a band gap at the resonance frequency.

Basically, the 8 CBU AMC-EBG structure involves square shape of substrate with a main square patch on the centre of the substrate. While the main square patch is connected with eight branches and each four of them has a corner square connected at the end of branch. All the branches are designed alternately between the basic branches with the connected corner square branches. Furthermore, each branch is designed at the centre of each length of the main square.

Notice that capacitance is introduced by the gaps between neighbouring patches and inductance is provided by the narrow branches. The series inductors combined with the shunt capacitors constitute an array of parallel LC circuits thus has a high surface impedance at the resonant frequency. The 8 CBU AMC-EBG structure is shown in Figure 1 and Table 1 defines the technical description and dimensions of the structure.

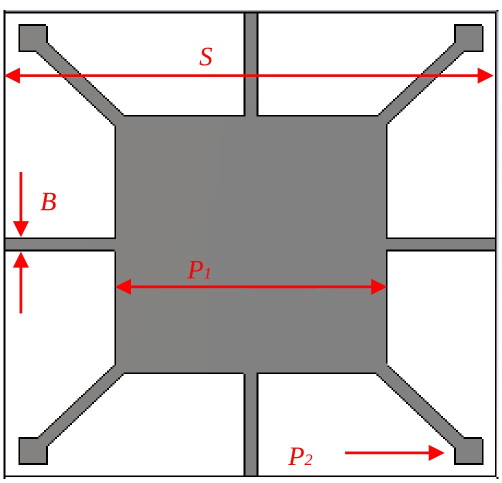


Figure 1 8 CBU AMC-EBG design at 5.8 GHz

Table 1 Technical descriptions and dimension of 8 CBU AMC-EBG at 5.8 GHz

Description	Design Parameter	Dimension (mm)
Branch width	*B*	0.26
Main-square length	P_1	5.20
Sub-square length	P_2	0.52
Substrate length	*S*	9.36

8 CBU FSS Design

This section describes the designs of 8 CBU FSS that will be incorporated with the dipole antenna. The properties of the 8 CBU FSS are investigated at 5.8 GHz.

FSS structure involves only patch and substrate layers differ to AMC which involves patch, substrate and ground layers. Basically, the shapes of patch for both 8 CBU FSS and 8 CBU AMC-EBG are exactly the same but with a different overall size. The structure of 8 CBU FSS is bigger than 8 CBU AMC-EBG and Table 2 shows the technical descriptions and dimensions of the unit cell of 8 CBU FSS at 5.8 GHz.

Table 2 Technical descriptions and dimension a unit cell of 8 CBU FSS at 5.8 GHz

Description	Design Parameter	Dimension (mm)
Branch width	*B*	0.42
Main-square length	P_1	0.84
Sub-square length	P_2	8.36
Substrate length	*S*	15.05

Dipole Antenna Design

In this section, the basic design of dipole antenna is designed at 5.8 GHz. The radiating elements which is made of Perfect Electromagnetic Conductor (PEC) with 0.035 mm thickness are printed on flexible material. The flexible material used is Fast Film with thickness of 0.13 mm, dielectric constant of 2.7 and tangent loss of 0.0012. Both radiating elements are connected to the 50 Ω Sub Miniature Version A (SMA) connector as shown in Figure 2. While Table 3 is the technical description and dimensions of the structure.

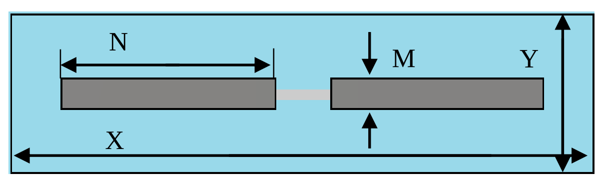


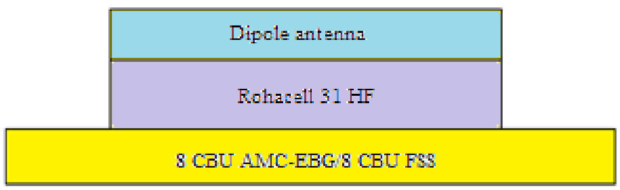
Figure 2 Dipole antenna ta 5.8 GHz

Table 3 Technical descriptions and dimension of dipole antenna at 5.8 GHz

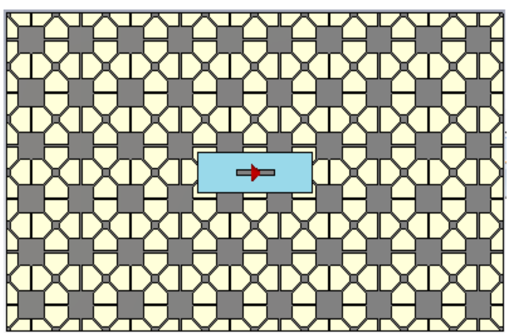
Description	Design Parameter	Dimension (mm)
Patch width	*M*	2.50
Patch length	*N*	19.98
Substrate width	*Y*	10
Substrate length	*X*	28

Dipole Antenna with and without 8 CBU AMC-EBG and 8 CBU FSS

The performances of the dipole antenna with 8 CBU AMC-EBG and 8 CBU FSS are investigated in this section. The configurations of the dipole antenna with 8 CBU AMC-EBG / 8 CBU FSS are given in Figure 3. The 8 CBU AMC-EBG and 8 CBU FSS are placed below the antenna with a certain gap distance. Both of them act as a reasonably good ground plane for the antenna when impedance is very low. Thus, all the capacitive components more or less cancelled all of the inductive components and achieved a very low transmission coefficient and in phase reflection over entire bandwidth. The gap is maintained by using a special material, Rohacell 31HF with dielectric constant of 1.05. This material is used as the spacer between the antenna and the 8 CBU AMC-EBG and 8 CBU FSS surface.



(a)



(b)

Figure 3 Configurations of the dipole antenna with 8 CBU AMC-EBG / 8 CBU FSS: (a) side view, and (b) front view

3.0 RESULTS AND DISCUSSION

8 CBU AMC-EBG Design

The unit cell and the reflection phase of 5.8 GHz square patch AMC are shown in Figure 4. The designed AMC has a patch width of 56.4 mm and 1 mm gap between the elements. Based on the equation (1) to (3), the calculated AMC resonant frequency is 5.8 GHz where *C* is 0.61 pF and *L* is 0.63 nH.

As shown in Figure 1, the reflection phase varies from 180^0 to -180^0. At 5.8 GHz, the reflection phase is 0^0 and at ±90^0 reflection phase, the frequency is laid between 5.77 GHz to 5.83 GHz.

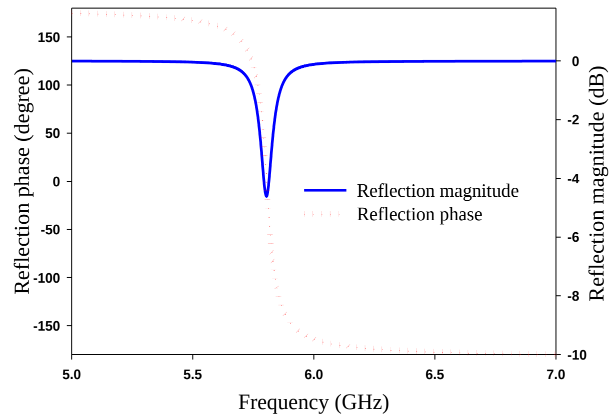


Figure 4 The reflection phase and magnitude of unit cell square patch AMC at 5.8 GHz

Then, the simulated reflection phase and magnitude and surface impedance for 8 CBU AMC-EBG are plotted in Figure 4(a) and (b) respectively. The reflection phase varies from 180^0 to -180^0. At 5.8 GHz, the reflection phase is 0^0 and at ±90^0 reflection phase, the frequency is laid between 5.77 GHz to 5.82 GHz. While the reflection magnitude is -0.87 dB corresponding to 0.90 and has a very high impedance at the resonant frequency.

Bandwidth of the structure evaluates from the reflection phase diagram of the 8 CBU AMC-EBG and square patch AMC at 5.8 GHz. Based on ±90^0, the computed bandwidth of the 8 CBU AMC-EBG is 0.86% while the bandwidth of square patch AMC is 0.17% higher than 8 CBU AMC-EBG. However, the 8 CBU AMC-EBG configuration produces a 41% of size reduction than the square patch AMC.

Due to the flexibility of the substrate material, the effect of different angles is investigated. Thus the different bending angles of the structure significantly affect the performances of the 8 CBU AMC-EBG. Otherwise, the structure has a high angular stability due to the resonance frequency that was not really affected by the changes of incident angle. Figure 5 shows the reflection phase of the 8 CBU AMC-EBG with different incidence angles. From the observation, the frequency response of the structure was not affected by the changes of incidence angle thus the 8 CBU AMC-EBG has the high angular stability.

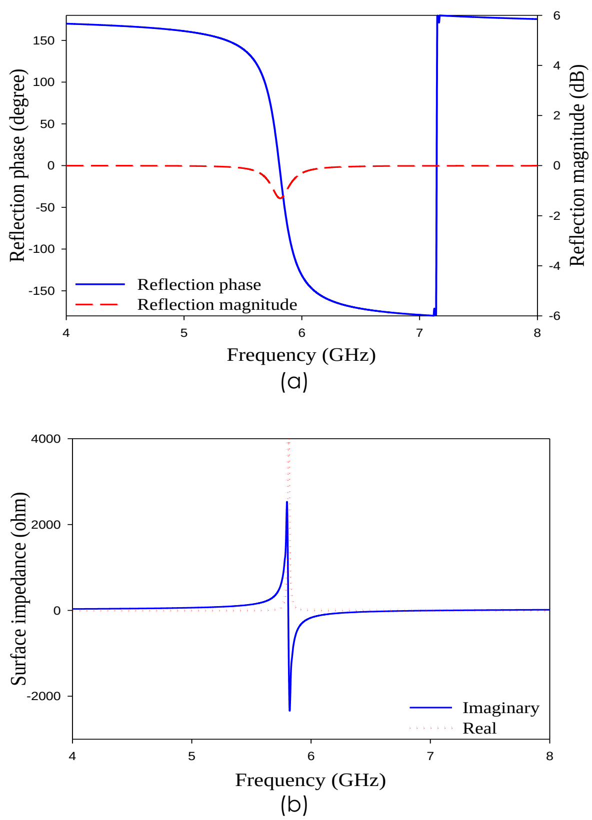


Figure 4 8 CBU AMC-EBG design at 5.8 GHz: (a) reflection phase and magnitude, and (b) surface impedance

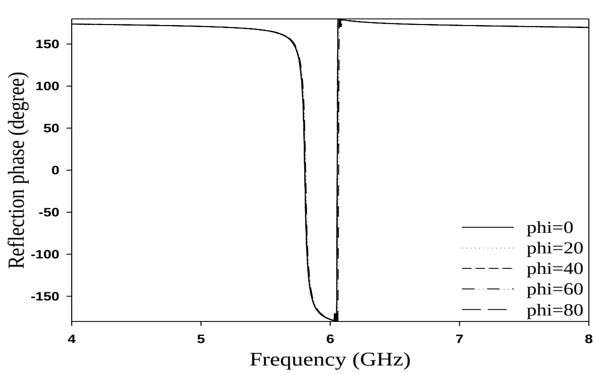


Figure 5 Reflection phase of the 8 CBU AMC-EBG at 5.8 GHz with different incidence angle

Besides, this paper also investigates the band gap occur for 8 CBU AMC-EBG design. In order to characterise the band gap, the 10 x 6 arrays of 8 CBU AMC-EBG is built. The method of suspended 50 Ω micro-strip line [22] is applied through time domain solver of CST. The supporting material and suspended line layers are added to the basic layers of 8 CBU AMC-EBG that consists of patch, substrate and ground. Two 50 Ω SMA connectors are located at the both ends of transmission line to transmit and receive Electromagnetic (EM) waves.

Figure 6 illustrated the transmission and reflection for 10 x 6 arrays of 8 CBU AMC-EBG. The results show that the structure successfully achieves a band gap at 5.8 GHz. Based on -20 dB transmission value, the band covers from 4.64 GHz to 7.46 GHz. As long as the resonance frequency falls into this band gap frequency range, the surface wave can be suppressed while antenna incorporates with this structure.

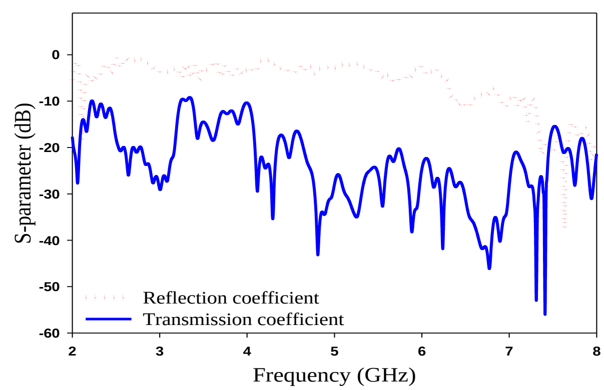


Figure 6 Transmission and reflection curves of 10 X 6 arrays 8 CBU AMC-EBG

8 CBU FSS Design

The simulated transmission and reflection curves are plotted in Figure 7. From the plotted graph, the 8 CBU FSS evaluates -31.28 dB of transmission and reflection for about -0.11 dB at 5.8 GHZ. Based on -10 dB, the frequency is laid from 5.62 GHz to 5.96 GHz thus computed bandwidth of the 8 CBU FSS is 5.86%.

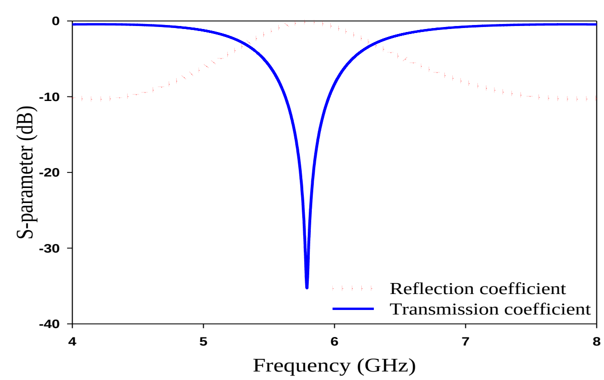


Figure 7 Transmission and reflection curves of unit cell 8 CBU FSS at 5.8 GHz

Same as 8 CBU AMC-EBG, the effect of different angles is investigated. The reflection phase of the 8 CBU FSS with different incidence angles is plotted in Figure 8. From the observation, the frequency response of the structure was not affected by the changes of incidence angle thus the 8 CBU FSS has the high angular stability.

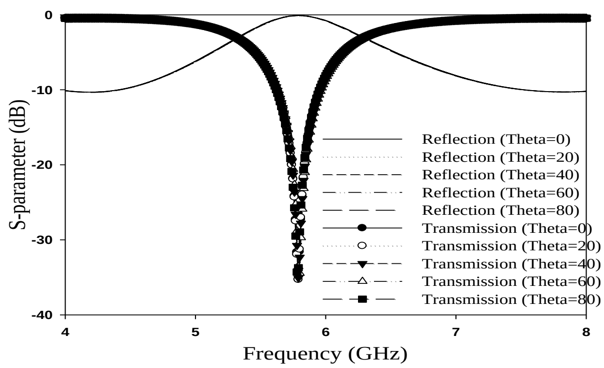


Figure 8 Transmission and reflection curves of the 8 CBU FSS at 5.8 GHz with different incidence angle

Dipole Antenna Design

Figure 9 shows the return loss of the dipole antenna at 5.8 GHz. The return loss is around -39.12 dB at 5.8 GHz. While based on -10 dB return loss, the frequency is laid between 5.36 GHz to 6.34 GHz which contributes around 16.7% bandwidth. The realised gain of the antenna is 2.10 dB.

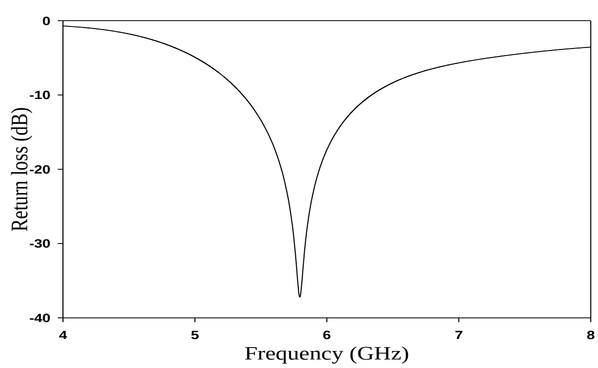


Figure 9 Return loss of dipole antenna at 5.8 GHz

Dipole Antenna with and without 8 CBU AMC-EBG

The 10 x 6 arrays of 8 CBU AMC-EBG is developed in order to incorporate with dipole antenna. The gap between the antenna and 8 CBU AMC-EBG surface is maintained at 10 mm. Figure 10 illustrated the return loss of dipole antenna with and without 8 CBU AMC-EBG observed and all of the results agree each other.

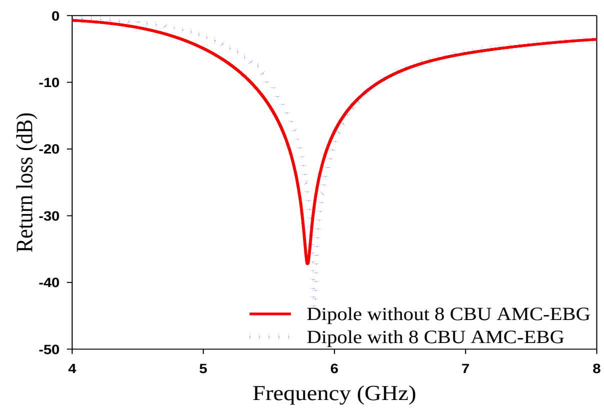


Figure 10 Return loss of dipole antenna with and without 8 CBU AMC-EBG

The Cartesian plot of the dipole antenna with and without 10 x 6 arrays of 8 CBU AMC-EBG is plotted in Figure 11. The interesting finding is the significant increase of directivity. The radiation pattern of the antenna is improved by increasing the front radiation and reducing the side radiation.

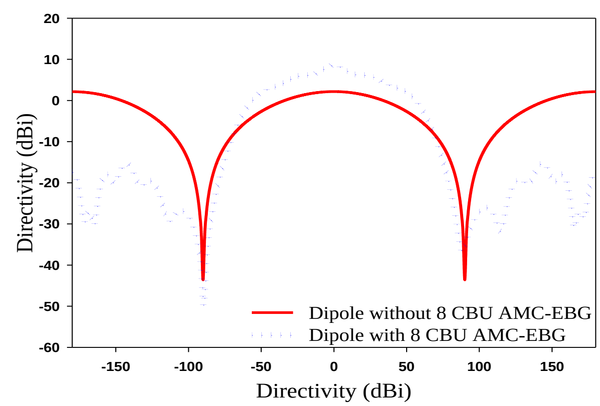


Figure 11 The Cartesian plot of the dipole antenna with and without 8 CBU AMC-EBG

Dipole Antenna with and without 8 CBU FSS

The 5 x 3 arrays of 8 CBU FSS is built to incorporate with dipole antenna. The gap is also maintained at 10 mm. The plotted return loss of dipole antenna with and without 8 CBU FSS shown in Figure 12.

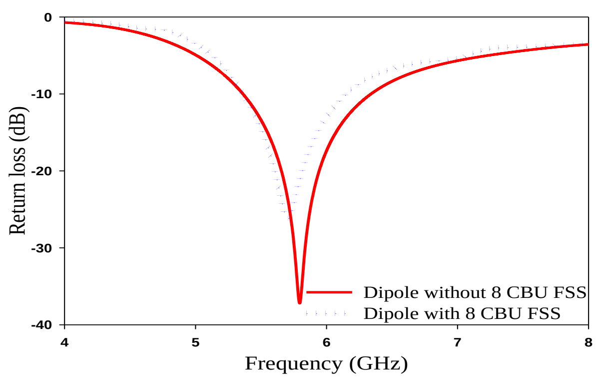


Figure 12 The simulated and measure return loss of dipole antenna with and without 8 CBU FSS

While Figure 13 shows the Cartesian plot of the dipole antenna with and without 8 CBU AMC-EBG and 8 CBU FSS. The front radiation of the antenna is directed while incorporated with both structures and reduced the side radiation at the same time. However, with 8 CBU AMC-EBG, the front lobe is pushed to higher and the side lobe is significantly lower than with 8 CBU FSS.

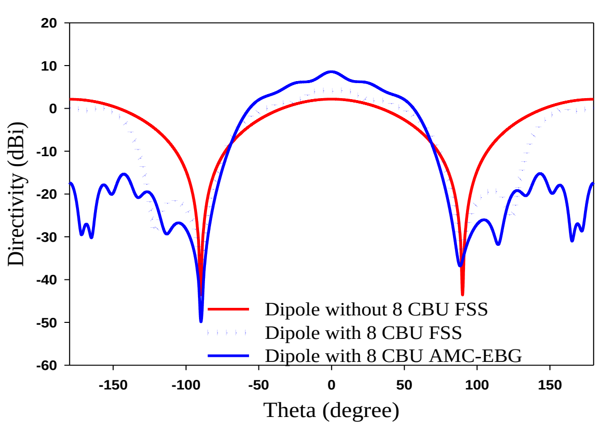


Figure 13 The Cartesian plot of the the dipole antenna with and without 8 CBU AMC-EBG and 8 CBU FSS

Performances Summary of Dipole Antenna with and without 8 CBU AMC-EBG and 8 CBU FSS

The vertical bar chart in Figure 14 shows the performances summary of dipole antenna with and without 8 CBU AMC-EBG and 8 CBU FSS. The plotted bar chart shows the interesting findings are the significant increase of realised gain and directivity. From the observation, dipole with 8 CBU AMC-EBG leads high increment for both realised gain and directivity. The presence of the ground plane for AMC-EBG contributes a more directive antenna as compared to the FSS with no ground plane. As in Figure 14, the front lobe is pushed higher and the side lobe is significantly lower than with 8 CBU FSS.

The aim of this research is achieved which the realised gain is improved from 2.04 dB to 8.54 dB with AMC-EBG with considering the thicker substrate which is flexible as compared to the previous research study. The realised gain is improved only up to 2.10 dBi, 3 dBi and 7.50 dB as in [18], [19] and [20]. Although 7.50 dB is achieved in [20], the substrate material used is rigid for both antenna and FSS structure.

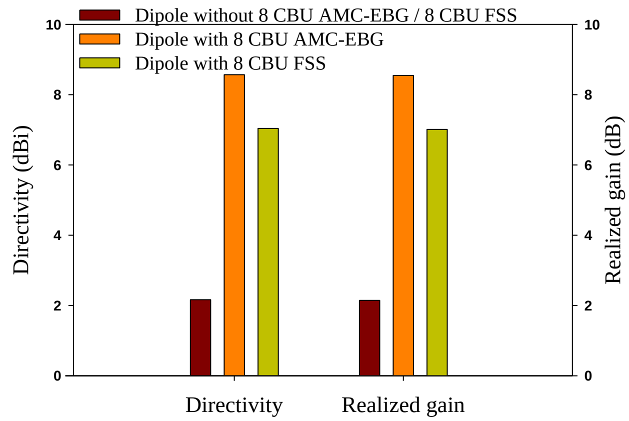


Figure 14 The comparison of performances dipole antenna with and without 8 CBU AMC-EBG and 8 CBU FSS

4.0 CONCLUSION

The performance improvement of dipole antenna while incorporating with 8 CBU AMC-EBG and 8 CBU FSS are successfully designed on the flexible materials and their performance in terms of angle of incidence are studied. Both 8 CBU AMC-EBG and 8 CBU FSS act as a reasonably good ground plane for the dipole antenna and help improving the realised gain and improve the radiation patterns by push the front lobe at the same time reduce the side lobes. The maximum improvements led by dipole antenna with 8 CBU AMC-EBG thus 8.54 dB of realized gain achieved and the front lobe is pushed higher and the side lobe is significantly lower than with 8 CBU FSS. The designs of dipole antenna with 8 CBU AMC-EBG and 8 CBU FSS at 5.8 GHz can be applied as high gain atenna for Intelligent Transport System (ITS).

Acknowledgement

The authors wish to thank the Ministry of Science, Technology and Innovation (MOSTI), Center for Research and Innovation Management (CRIM of Universiti Teknikal Malaysia Melaka (UTeM) for the support of this work under the grant number PJP/2015/FKEKK(2B)/S01406.

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