A Study on the EBG and AMC on Radial Line Slot Array Structure at 28 GHz

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***Abstract*— This paper is a study on the electromagnetic band gap (EBG) and artificial magnetic conductor (AMC) on the radial line slot array (RLSA) antenna structure at a frequency of 28 GHz. The RLSA antenna is known based on its characteristic which has high gain, durable, simple structures, high efficiency and low cost of fabricating. This project is focusing on the study of the RLSA antenna with the Electromagnetic Band Gap (EBG) and Artificial Magnetic Conductor (AMC) with analyzes the effect of number EBG and AMC structures applied to the antenna. It enhances the performances of the RLSA antenna before the EBG structure is added. This may be due to eliminating the several numbers of slots on the radiating plate is the reason for the present number of EBG structures applied to it. The lowest value of S11 for eight (8) units EBG is -41.4686 dB at a frequency of 29.86 GHz, the directivity value is 25.60 dBi and realizes a gain of 25.26 dB at a frequency of 28 GHz. While the AMC structure can reduce the side lobes from -2.7 dB for non-element of AMC to -1.7 dB for eight (8) and nine (9) elements. This RLSA antenna with AMC and EBG produces high directivity which is 26.10 dBi compared to conventional RLSA antenna which is 21.70 dBi. This antenna can also be used as widely applications such as RADAR and satellite communication.**

***Index Terms*— Radial Line Slot Array antenna, Millimeter wave, 28 GHz, EBG, AMC, Air Gap Cavity Structure.**

I. INTRODUCTION

The antenna can classify into three types such as Omni-Directional antenna is propagated in all directions means 360 degrees, Semi-Directional antenna that defined by the specific angle and Hi-Directional antenna that has a narrow beam likely as pencil shaped that allow highly directional and high directivity. This RLSA antenna is in the category as a Hi - directional antenna. In Malaysia, the research about RLSA antenna is more focus on the latest application possible on RLSA antenna and for simplifying the design and fabrication process and reducing the antenna size but maintaining the directivity is one of the characteristics of this antenna. According to Jamlos [1] to have a high gain antenna an RLSA antenna design is more beneficial and this antenna can achieve much more like 50% higher gain than the conventional microstrip antenna.

Radial Line Slot Array (RLSA) antenna has been widely used for high gain, high efficiency in operating frequency range, simple structure and unchallenging while doing fabrication parts. Usually the development of RLSA antenna has been multilayer using FR4 with a dielectric constant of 4.7 [1] and 5.4 as in [2-7], hence already applied the multilayer to RT/Duroid 5880 with a dielectric constant of 2.2 [8,9] and Rogers Duroid 6006 which have a dielectric constant of 6.15 [10].

Metamaterials or also called as artificial electromagnetic materials are material does not exist in the natural appearing yet it is typically engineered novel or artificial structures with has unique electromagnetic properties [11,12]. The Electromagnetic band gap (EBG) structure is one of the families of metamaterials [13]. Many researchers have proven that the EBG structures can rise up the performance and can compatible with a wide range of wireless communication system. There are several periodic arrangements EBG structures of the dielectric or metallic element in one, two or three dimensional [14]. For example, such as mushroom type and uniplanar are the family of EBG structure as shown below in Figure 1.

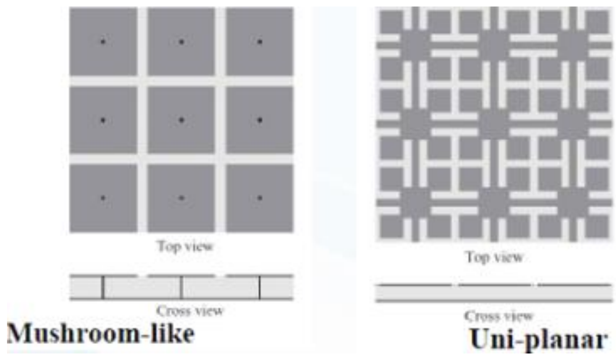

Figure 1: The Mushroom and Uni-planar of EBG structure [15,16]

The EBG structure is applied to avoid some undesired operating modes and control the harmonics Hence, to reduce the specific absorption rate or SAR (back radiation) [17]. As two dimensional (2D) EBG structure, they have a low profile, light weight, easier to design and low in fabricating cost. While for uniplanar structure, there are no vias comparable to the mushroom design of EBG structure. However, the type of EBG structures depends on the type of antenna will be used [14].

The effect of AMC on sidewall structure in parallel plate slot antenna was introduced by Fernandez and Castener, with having aimed to analyze on the effect of EBG sidewalls that functions as the Artificial Magnetic Conductor (AMC) sidewalls. In the parallel plate waveguide and acts as the practical application in the parallel plate plot antennas were placed. In addition, that position can improve the uniform field distributions, thus allowed the directivity to be at the best level and improve the efficiency of the antenna. The standard waveguide with PEC sidewalls does not have a good uniform field distribution instead of the AMC sidewalls waveguide already proven in [18].

According to Munir [19] the bandwidth for Artificial Magnetic Conductor (AMC) structure that is based on the square patch array is able to improve by the use of multiple slot techniques. The square patch has a specific nature due to produce a narrow-band bandwidth response. There are two (2) slot techniques was proposed such as the uniform slot and gradual slot length [19].

Therefore, this study focuses on the study of the integration of EBG with RLSA antenna and AMC with RLSA antenna. As a result, when added the numbers of EBG or AMC enhanced the directivity result rather than conventional RLSA antenna has been developed at 28 GHz.

II. Methodology

Separately in two parts which means the RLSA antenna integrated with electromagnetic band gap and the RLSA antenna integrated with an artificial magnetic conductor with the material design shown in Figure 2 and Figure 5.

A. *Electromagnetic Band Gap (EBG)*

The EBG structure is added to the top of a radiating plate of RLSA antenna and the structure is designed as shown in Figure 2 below.

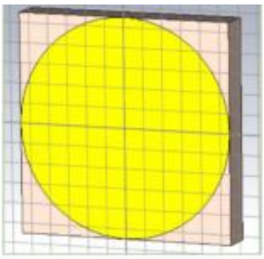

Figure 2: The 1 unit cell EBG structure

Table 1 below shows the specification that is used for designing the EBG structure as in the table below.

Table 1
The EBG structure specification

The patch	Copper
Radius	5.0 mm
Thickness of patch	0.035 mm

The surface wave is one of the features of EBG structures that demonstrate the reflection phase behavior. Reflection property of an object can describe with the parameter of the reflection coefficient. Commonly, it has a complex value with the corresponding magnitude and phase. When all the energy is reflected back no matters, it is forever one for magnitude value, wherever a ground plane exists in an analyzed lossless structure.

The PEC and the total tangential *E* field must be zero in order to fulfill the boundary condition when the plane wave is normal interferes. Both must have opposite signs in order to get results in reflection coefficient of -1 between reflected *E* field and incident *E* field. The PEC case should have 180° reflection phase and the total tangential *H* field must be zero for the PMC. Furthermore, the reflected *E* field and the incident *E* field have the same region while the reflected *H* field and the incident *H* field must have the opposite signs. Hence, the reflection coefficient is equal to one and the corresponding reflection phase is 0° for PMC case. Even though, the PMC does not exist in nature.

Figure 3 shows an FDTD of the EBG structure for reflection phase characterization.

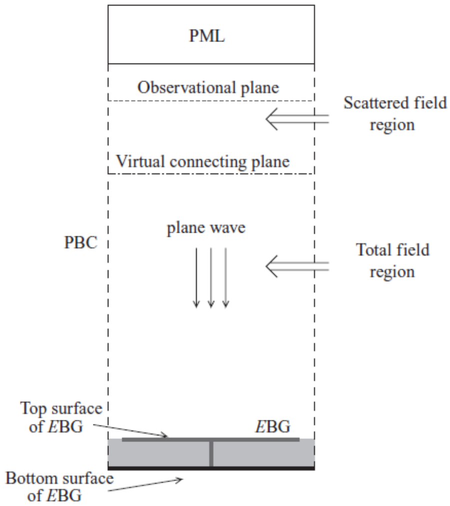

Figure 3: An FDTD of the EBG structure for reflection phase characterization [15]

The equation (1) shows the reflected phase of the EBG structure is normalized to the reflected pulse from the PEC surface:

$$\emptyset = \emptyset^{EBG} - \emptyset^{PEC} + \pi \quad (1)$$

The illustration shows in Figure 4 below the engineering figured that was designed the structure using the CST software. On top the radiating plate is allocated the EBG structure which is circular in shape. Where in (a) the circular EBG structure is two where allocate one opposite side, (b) four circular EBG structure where three units on the left and one unit on the right and (c) eight circular EBG structure where six units on the left and two on the right side.

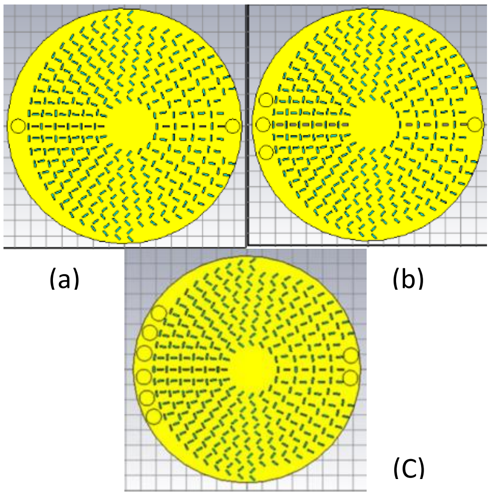

Figure 4: The RLSA antenna with EBG structure (a) 2 units EBG, (b) 4 units EBG and (c) 8 units EBG.

B. *Artificial Magnetic Conductor (AMC)*

The EBG structure is added to the top of a radiating plate of RLSA antenna and the structure is designed as shown in Figure 5 below.

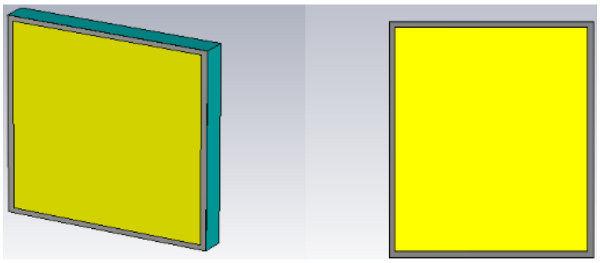

Figure 5: Overview of AMC structure

The Table 2 below has shown the table of a parameter of the AMC structure to be used.

Table 2
The AMC structure specification

Material	Dimension
Copper	10.5 mm x 10 mm
PEC	9.9 mm x 9.5 mm
Substrate	FR4

When an incident plane wave on the array is zero, there is the phase of the reflection coefficient with a high impedance surface of the array face is realized. The example shows the square loop elements as in Figure 6**.** The low impedance which has the reflection phase is 180° adverse the PEC surface, while the high impedance surface is an electric current source is a parallel does not short out it means it can radiate. The AMC may be specified by specific conditions. Furthermore, a certain angle and polarization of incidence, the zero reflection phase occur only at the resonant frequency. Hence, the conditions for high impedance behavior to require that the reflection phase range from -90° to +90°, a non-zero frequency bandwidth can be obtained by knowing that high impedance bandwidth and the resonant frequency are shown it is exclusive of periodic AMC structures.

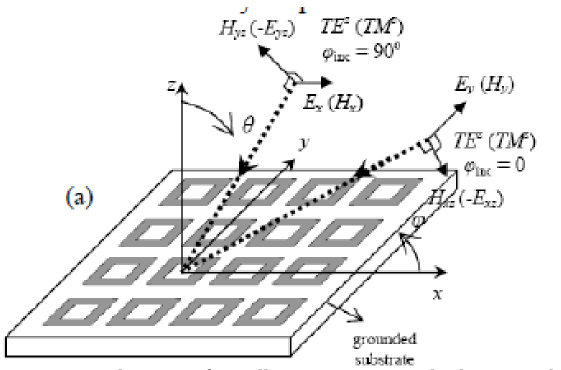

Figure 6**:** Periodic array of metallization on a ground substrate with AMC properties [20]

The multilayer RLSA antenna seems likely as a sandwich structure where is consisting of radiating plate which is copper, dielectric (the combination of substrate and air gap) and ground which also copper. Where space means by cavity thickness is forever fulfill by a dielectric material of permittivity ε_r>1.0.

Equation (2) shows that the equation λ_g is represented by the wavelength of the slow wave in the guide and λ_o is the free space wavelength.

$$\lambda_g < \lambda_o \quad (2)$$

Figure 7 represents the side and top view of a typical RLSA.

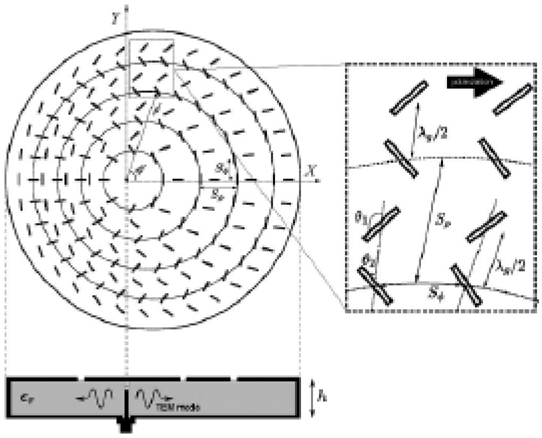

Figure 7: Side and top view of a typical RLSA [9]

III. Results And Discussion

The Electromagnetic Band Gap (EBG) structure is being designed at first to make sure that one (1) unit EBG resonate or falling down at 28 GHz which more than -10 dB is achieved. The Figure 8 shown that the s-parameter| of one (1) unit cell EBG falls at -52 dB which is a good result.

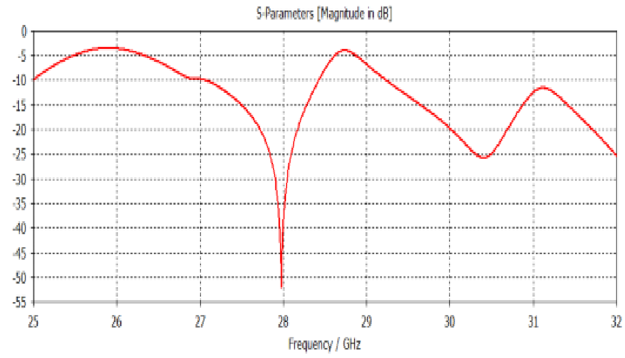

Figure 8: Simulated return loss of a unit EBG cell

The Artificial Magnetic Conductor (AMC) structure is designed to make sure a unit of AMC cell resonates at a frequency of 28 GHz obtained. Figure 9 shows the S11 graph of one (1) unit cell.

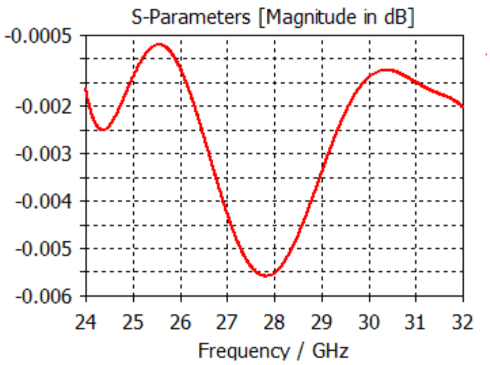

Figure 9: Simulated return loss of a unit of AMC cell

The return losses of all the results are being compiled in the graph so that the dissimilar between can be seen. The comparisons between them are in Figure 10. The antenna without EBG structure shows the better S11 because the value of S11 is lower than -10 dB compared to others which resonate at -15.078 dB at 28 GHz. However, when present of the number of EBG, the value of S11 decreased moderately. The colour of the green line is for two (2) units EBG has been applied to the RLSA antenna has the return loss of -13.616 dB. The blue line colour is for four (4) units EBG has the return loss of -13.961 dB and the return loss of orange line is for eight (8) units EBG is -14.070 dB. When the value of the S11 is below than -10 dB, it shows that the design is good and can be as an antenna. Hence, the power that transmits the signal also has fewer losses, while the value of the s-parameter is lower.

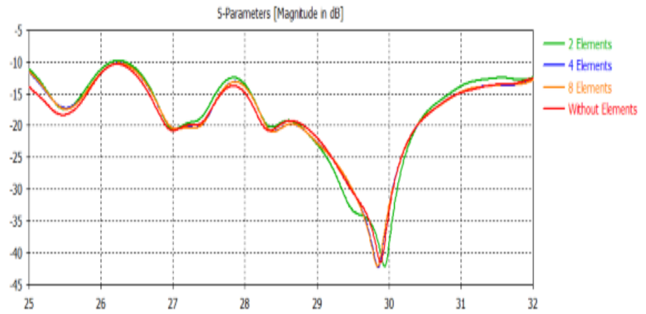

Figure 10: Compilation of return loss from all design

At the back of the antenna which is ground did not attach to any AMC structures. For the result of the return loss which is the S11, the value is -41.628 dB resonant at a frequency of 29.907 GHz. The value shows that the return loss of the RLSA antenna is below than – 10 dB shows that the antenna is above 90% efficiency. The frequency at 28 GHz reaches -14.97717 dB. This RLSA antenna also resonates at a frequency of 30 GHz with wider impedance bandwidth. Figure 11 shows the S11 simulation results for RLSA antenna with various numbers of AMC and without AMC structure.

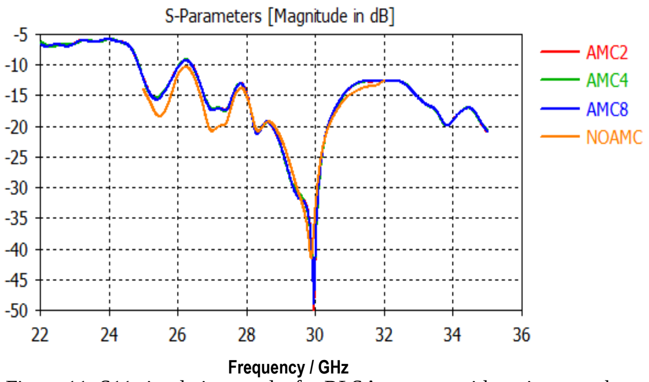

Figure 11: S11 simulation results for RLSA antenna with various numbers of AMC and without AMC structure.

The directivity is one of the fundamentals of an antenna parameter which measured the degree to which the radiation emitted. Based on the simulation result, all the design with return loss, directivity and realized gain are compiled in the table below so that the difference between them can be seen as shown in Table 3 for AMC structure while in Table 4 is for EBG structure attached with the RLSA antenna at 28 GHz.

Table 3
The compilation results of return loss, directivity and realized gain at 28 GHz for EBG structure.

Number of EBG Structure	S11(dB)	Directivity (dBi)	Realized Gain (dB)
RLSA with 2 elements	-13.62	25.62	25.26
RLSA with 4 elements	-13.96	25.60	25.26
RLSA with 8 elements	-14.07	25.60	25.26

Table 4
The compilation results of return loss, directivity and realized gain at 28 GHz for AMC structure.

Number of AMC Structure	S11 (dB)	Directivity (dBi)	Realized Gain (dB)
RLSA with 2 elements	-14.55	26.10	25.80
RLSA with 4 elements	-14.66	26.09	25.70
RLSA with 8 elements	-14.61	26.09	25.80

Based on the result shown in Table 5 below, the present of AMC and EBG structures will affect the main lobe magnitude as it increases the magnitude, angular width and side lobe level. Thus, makes the radiation pattern become more direct and narrower. The main lobe direction also changes drastically from 12.0 dBi to 0 dBi when the AMC structure applied on the ground of the RLSA antenna. Even though the half power beam width fallen from 5.30º without AMC structure to 4.90º with the eight elements of AMC added, while the added EBG structure the angular width is 4.40º . However, the side lobe level reduces from -2.70 dB to -1.7 dB as increases the number element of AMC structures at the H-plane (phi 90). Hence, EBG structure is added to the antenna and got the value of -0.50 dB for the low side lobe level at H-plane with two elements.

Table 5
Comparison of RLSA antenna with a number of AMC and EBG structures

		Element	Main Lobe Magnitude (dBi)	Angular Width (3 dB)	Side Lobe Level (dB)
AMC	Phi 0	2	26.10	4.20º	-8.80
		8	26.10	4.20º	-8.80
	Phi 90	2	7.22	5.00º	-1.60
		8	7.25	4.90º	-1.70
EBG	Phi 0	2	25.60	4.40º	-9.00
		8	25.30	4.40º	-8.90
	Phi 90	2	8.66	5.90º	-0.50
		8	8.39	6.00º	-0.90

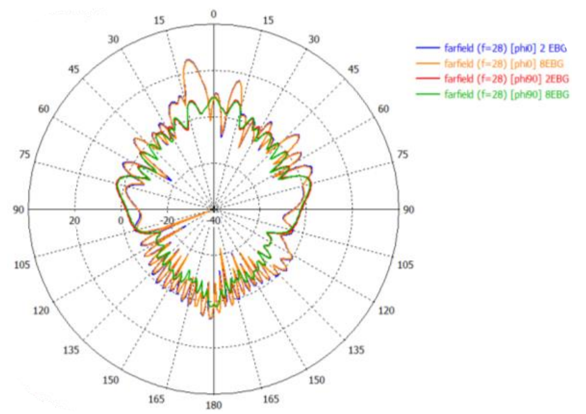

Figure 12: The comparison of the radiation pattern of phi 0 and phi 90 with EBG structures

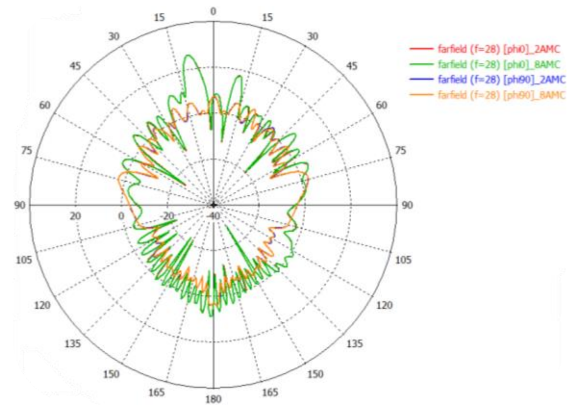

Figure 13: The comparison of the radiation pattern of phi 0 and phi 90 with AMC structures

The radiation pattern is one of the parameters of the results of the antenna. The Figure 12 and Figure 13 have shown the comparison of the lowest is two (2) and the highest is eight (8) elements already applied to the antenna that gave the effect on the radiation pattern. The highest value of the main lobe is 26.10 dBi by applying AMC elements and 25.60 dBi for EBG structures.

The AMC structure has a high value of 26.10 dB main lobe magnitude and has a good result of return loss when added more numbers of the element of AMC which is -14.607 dB. However, the EBG structure has a better result on reducing side lobe level at phi 90 with a value of -0.50 dB. Hence, it reduces the performance of the RLSA antenna before the EBG structure is added. This may be due to eliminating the slots on the radiating plate are the reason for the present number of EBG structures applied to it.

IV. Conclusion

The design of Electromagnetic Band Gap (EBG) and Artificial Magnetic Conductor (AMC) are applied to the RLSA antenna at a frequency of 28 GHz. The antenna with a thickness of cavity $\boldsymbol{\lambda}/4$ and have a dielectric constant 1.13 which are the combination of sthe ubstrate was used FR4 and air gap techniques has successfully designed and simulated. The integration of AMC with RLSA antenna produces the better result compared to EBG with RLSA antenna. By applying the AMC and EBG structures on the antenna there was affect the main lobe magnitude as it increases the magnitude, angular width and side lobe level. This makes the radiation pattern become more direct and narrower.

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