METAMATERIAL PATCH ANTENNA WITH ELECTROMAGNETIC BANDGAP (EBG) FOR WLAN APPLICATION

Wan MohdJazliAzri Bin Wan MohdJailani
Faculty of Electrical Engineering (Communication)
UniversitiTeknologi MARA, Malaysia

Email:jazli4zri@gmail.com

***Abstract* –This paper presents a rectangular microstrip patch antenna with electromagnetic band gap (EBG) structures at the ground plane is applied for wireless local area network (WLAN).The antenna is designed to resonate at the 5GHz frequency. The combination of the rectangular microstrip patch antenna is fabricated on top of the substrate Rogers RO5880 with dielectric constant of 2.2 and substrate thickness is 0.508mm.Simulations and measurements have been carried out to verify the performance of EBG structures in patch antenna. All the simulation and measurement work is done by using Computer Simulation Technology (CST) software.The designsare divided into twocategories that are a conventional antenna without EBG and real antenna with EBG. Furthermore, this work is mainly focused on improving the performance of patch antenna and reducing the size of antenna by applying EBG structures. All the calculation, simulation result and measurement regarding this design also provided.**

***Index Terms* –Metamaterial, rectangular patch antenna, electromagnetic band gap(EBG),and return loss.**

I. INTRODUCTION

The advanced development of wireless communication systems required a very effectiveand smart patch antenna. Microstrip patch antenna plays a very important role. Furthermore, this antenna is commonly used as printed antennas in practice. The advantages of patch antenna meet the specification for WLAN application. This antenna is very low profile, inexpensive, light weight, simple and comfortable to planar or nonplanar surface [1].

However, microstrip patch antenna had its weakness, like low gain and directivity, small bandwidth, small wavelength and the signals will reflect back to the source. This will produce side lobe and back lobe [2].There are methods that can overcome this problem, like increasing the height of the substrate to increase efficiency and bandwidth. Due to this action, the pattern and polarization of antenna degrades [1]. In order the overcome this problem, metamaterial is the best way to applied as its characteristic can improve the antenna [3].

Metamaterial are sometimes referred as left-handed materials or negative refractive index materials. Metamaterial is a macroscopic composite of periodic or non-periodic structure, whose function is due to both the cellular architecture and the chemical composition. In nature, most materials have permeability μ_o and permittivity larger than ε_o.The metamaterial open a door to realize all possible materials properties by designing different cellular architectures and using different substrate materials [4]. Negative permittivity means that the materials are physically unique, have unusual realizable response functions and may not be easily found in nature [5]. Victor Veselago, a Russian Physicist was the first person responsible for discovering the concept of metamaterials in 1967 [6]. The Veselago's intuition remained silent for 29 years until 1996 when Prof J.B Pendry proposed his design of Thin-Wire (TW) structure that exhibits the negative value of ε and the Split Ring Resonator (SRR) with a negative value of µ. Based on this discovery, Dr. Smith combined the two structures which represented the first experiment left-handed metamaterial (LH MTM) prototype [7].

This paper proposed metamaterial patch antenna with electromagnetic band gap (EBG) structure to study reducing size. Themain focus is directly to the effects on gain, directivity, bandwidth, efficiency, and return loss.

When improving the thickness of substrate, the mutual coupling between the elements of patch antenna array has increased which also affects the bandwidth of the antenna. Mutual Coupling losses are one of patch antenna array limitation. However, this limitation can be reduced by applying electromagnetic band gap (EBG) [8]. Electromagnetic band gap (EBG) structures also referred as photonic band gap (PBG) structures have a periodic pattern and useful as electromagnetic wave can be attenuated by properly designing their lattice periodicity. Unlike normal conductors, these new surfaces do not support propagation surface wave and reflect incident waves with no phase reversal. As it know, printed antenna suffer from surface wave effect. Therefore, if an EBG arrangement is used to suppress these waves, the antenna, printed over them, will have better performance. Antenna gain, efficiency and bandwidth can be improved and the scan blindness for phased arrays can be eliminated [9].

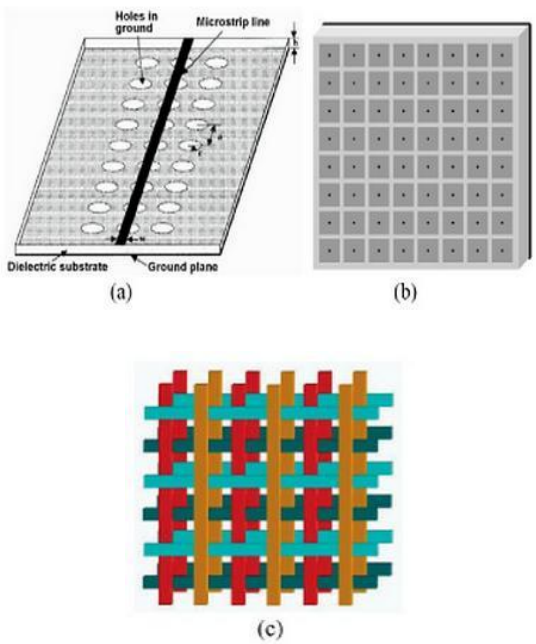


Figure 1: Various electromagnetic band gap structures: (a) a one-dimensional EBG transmission line, (b) a two-dimensional mushroom like EBG surface and (c) a three-dimensional woodpile EBG surface [10].

There are various types of EBG structure. They can be categorized into three groups according to their configuration. Figure 1 showed the different type of EBG structure.

II. DESIGN METHODOLOGY

A. *Flow Chart*

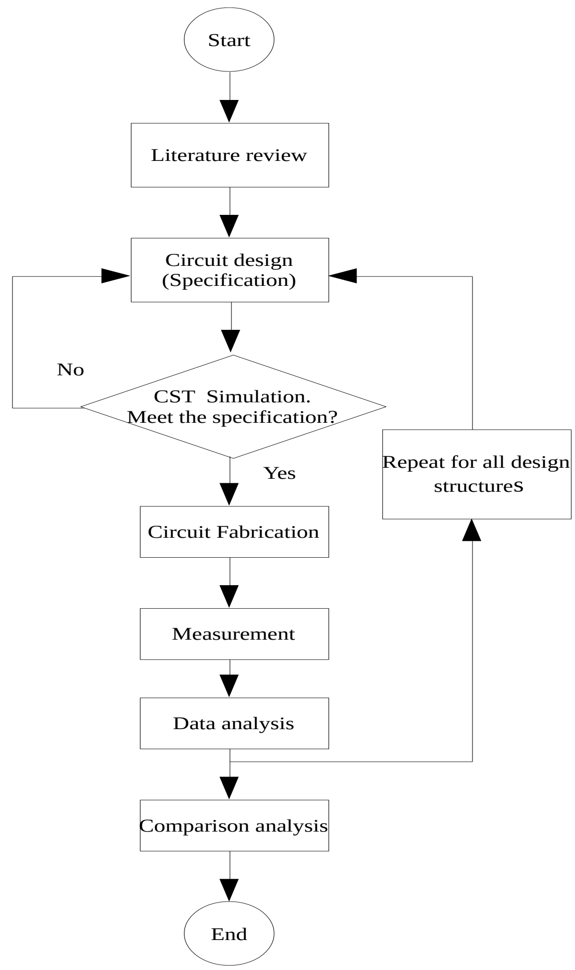


Figure 2: Design methodology flow chart

B. *Metamaterial Design*

Metamaterial is designed at the ground plane of the antenna usingelectromagnetic band gap (EBG).The type of EBG structure used is one-dimensional EBG transmission line. Squares shape matrix (3x3) is created at the ground plane. The main purpose of this EBG is to create metamaterial features. The 50 ohm line impedancewas placed above the substrate with the EBG structure at ground plane. The combination was thentested by simulating using Computer Simulation Technology (CST) to find the meta point.

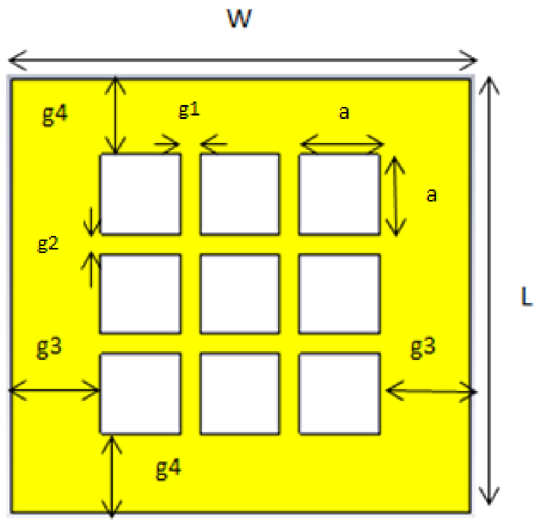


Figure 3: Matrix (3x3) of square shape EBG structures

The geometry of the square EBG structure is shown in Figure 3. The EBG structural is placed on the ground of Rogers substrate RO5880. This type of substrate was chosen due to several factors such as lowest electrical loss, low moisture absorption, isotropic, and have uniform electrical properties over frequency [11]. Characteristic of this substrate is shown in Table 1 whereas the dimensions of EBG structure and substrate are tabulated in Table 2.

Table 1: RO5880 substrate properties

Properties	Values
Permittivity, ε_r	2.2
Permeability, μ_r	1.0
Substrate Thickness, *hs (mm)*	0.508
Copper Thickness, *hc (mm)*	0.035

Table 2: Dimension of EBG structures

Parameters	Values (mm)
W	27.6636
L	26.8802
a	5
g1	1
g2	1
g3	5.3318
g4	4.9401

The EBG structure is designed by drilling holes on the ground plane of the substrate. In this design, metamaterial features with negative permittivity and permeability is defined at frequency of 5GHz. Nicholson-Ross-Weir (NRW) technique is used in this project as a conversion approach. Both permeability and permittivity is obtained from S-parameter using this approach [12]. NRW method is as follows:

$$\Gamma = X \pm \sqrt{X^2 - 1} \quad (1)$$

$$X = \frac{s_{11}^2 - s_{21}^2 + 1}{2s_{11}} \quad (2)$$

$$\mathrm{T} = \frac{s_{11} + s_{21} - \Gamma}{1 - (s_{11} + s_{21})\Gamma}. \quad (3)$$

where;

Γ = reflection coefficient of the circuit

X = correct root

T = transmission coefficient

S_{11} = reflected signal

S_{21} = transmitted signal

The value of *S11* and *S21* can be obtained from CST simulation. The magnitude value of the reflection coefficient of the circuit (Γ) must be less than one (Γ<1) in order to find the correct root (X) which is in form of S-parameters.

$$\ln\left(\frac{1}{\mathrm{T}}\right) = \ln\left(\frac{1}{\mathrm{T}}\right) + j(\theta_{\mathrm{T}} + 2\pi n) \quad (4)$$

$$n = \frac{L}{\lambda_g} \quad (5)$$

where;

n =number of root (0, ±1, ±2…)

L = material length in cm

λ_g = wavelength in cm

θ_T = phase of transmission coefficient in radian

After equation (6) and (7) has been solved, the value of n can be obtained. Then equation (7) is then substituted into equation (5). The n must be rounded up to nearest integer to find actual root number.

$$\frac{1}{\Lambda} = -\frac{1}{\lambda_o}\sqrt{\varepsilon_r^o \mu_r^o - \left(\frac{\lambda_o}{\lambda_c}\right)^2} \quad (6)$$

$$\left(\frac{1}{\Lambda}\right) = \frac{1}{\lambda_g} \quad (7)$$

where;

Λ = complex number of wavelength

ε_r = initial guess of material permittivity

μ_r = initial guess of permeability

λ_0 = wavelength in free space

λ_c = cut-off wavelength

Value obtained from equation (4) is substituted into equation (8).

$$\frac{1}{\Lambda^2} = -\left[\frac{1}{2\pi L}\ln\left(\frac{1}{\mathrm{T}}\right)\right]^2 \quad (8)$$

Equation for permeability (μ_r) and permittivity (ε_r) are set as follows;

$$\mu_r = \frac{1+\Gamma}{(1-\Gamma)\Lambda\sqrt{\frac{1}{\lambda_o^2} - \frac{1}{\lambda_c^2}}} \quad (9)$$

$$\varepsilon_r = \frac{\lambda_o^2}{\mu_r}\left[\frac{1}{\lambda_c^2} - \left[\frac{1}{2\pi L}\ln\left(\frac{1}{\mathrm{T}}\right)\right]^2\right] \quad (10)$$

C. Rectangular Patch Antenna

For the rectangular patch antenna, two patch antennas are designed in this research which is rectangular microstrip patch antenna with EBG and without EBG. Dimension of the microstrip patch antenna has been calculated using equation based on Table 3 data;

Table 3: RO 5880 substrate characteristics

Characteristics	Value
Frequency, f (GHz)	5
Type of material	RO 5880
Permittivity, ε_r	2.2
Substrate Thickness, hs (mm)	0.508
Copper Thickness, hc (mm)	0.035

1) Calculation of width (W)

$$W = \frac{c}{2f\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (11)$$

where;

c = the free space velocity of light
f_o= the frequency of operation
ε_r = the dielectric constant and
hs = the height of the dielectric substrate.

2) Calculation of effective dielectric coefficient

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{\frac{-1}{2}} \quad (12)$$

3) Calculation of effective length

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \quad (13)$$

4) Calculation of length Extension

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \quad (14)$$

5) Calculation of actual Length of patch

$$L = L_{eff} - 2\Delta L \quad (15)$$

6) Calculation of ground dimensions

$$Ls = 6h + L \quad (16)$$

$$Ws = 6h + W \quad (17)$$

7) Calculation of inset feed.

$$y = \frac{10^{-4} L}{2} \begin{pmatrix} 0.001699\varepsilon_r^{7} + 0.13761\varepsilon_r^{6} - \\ 6.1783\varepsilon_r^{5} + 93.187\varepsilon_r^{4} - \\ 682.69\varepsilon_r^{3} + 2561.9\varepsilon_r^{2} - \\ 4043\varepsilon_r^{1} + 6697 \end{pmatrix} \quad (18)$$

The conventional antenna is designed based on the calculation. Figure 4 showed the dimension of antenna in the CST software. The antenna is stimulated and optimized to get best result.

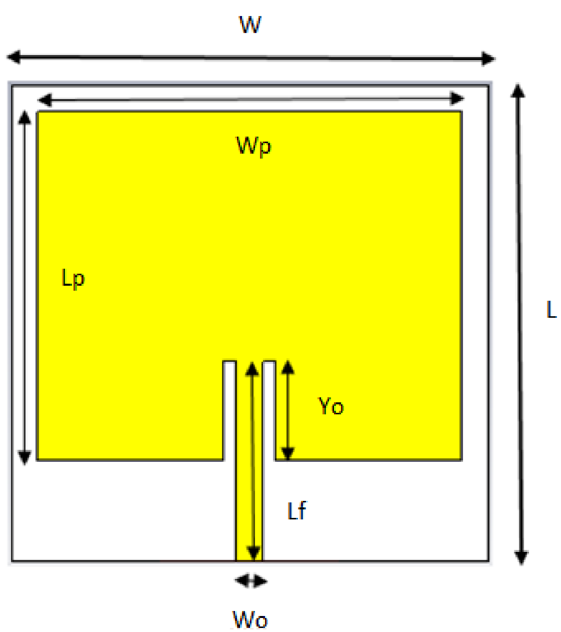


Figure 4: Patch antenna without EBG

In addition, the ground plane of patch antenna is placed with the metamaterials EBG structure. In order to determine the EBG is at negative permittivity and permeability, this antenna with EBG structure need to be simulated and the simulation data were then verified by using NRW formula.The parameter of antenna with EBG structure is modified and different from the conventional antenna as shown in Figure 5.

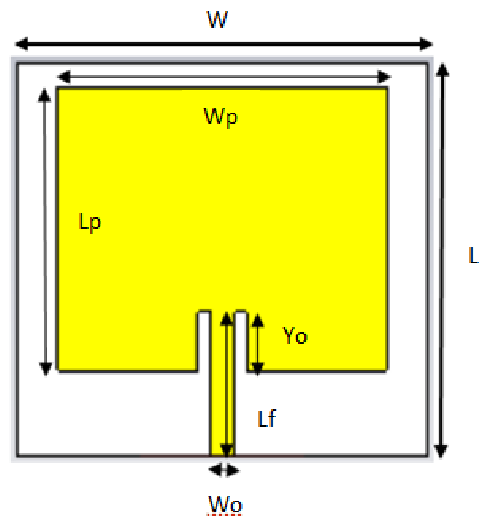


Figure 5: Patch antenna with EBG

Parameters of both antennas are shown and compared in Table 4 and Table 5 below.

Table 4: Dimension of patch antenna with and without EBG

Description	Patch antenna without EBG (mm)	Metamaterials antenna with EBG (mm)
W	27.6636	26.073
L	26.8802	24.2752
Wp	24.6156	21
Lp	19.7124	17.45
Lf	15.5	14
Yo	5.656	3.6
Wo	1.54313	1.542

Table 5: Comparison of area between conventional and metamaterials antenna

Description	Conventional	Metamaterials	Percentages Different (%)
Substrate area (mm^2)	27.66x26.88	26.07x24.27	14.89
Patch area (mm^2)	24.61x19.71	21x17.45	24.48

III. RESULT AND DISCUSSION

In this research, the antenna performances were investigated through simulation and measurement process. The simulation results are obtained from the CST software. The results are showed in simulation and measurement session.

A. *Simulation Result*

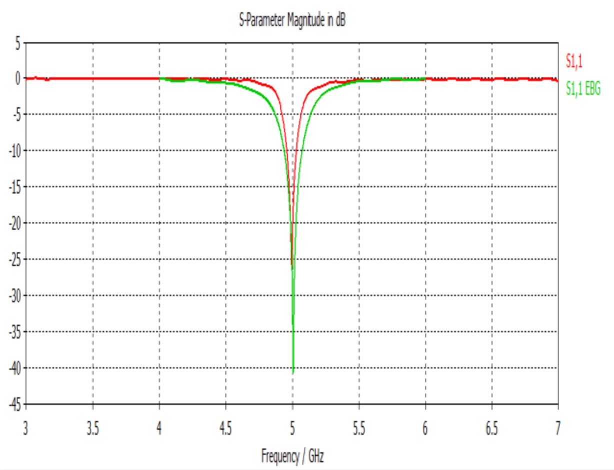
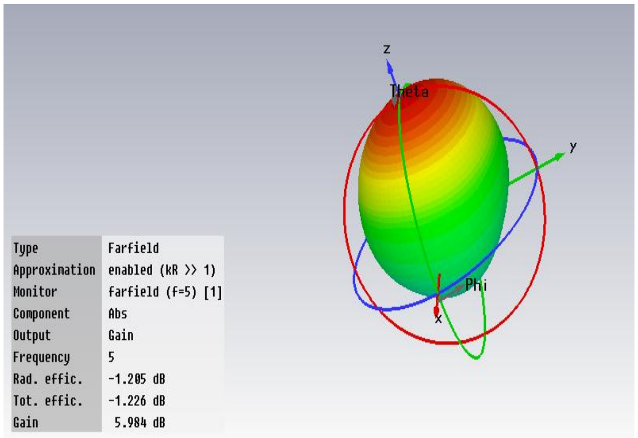


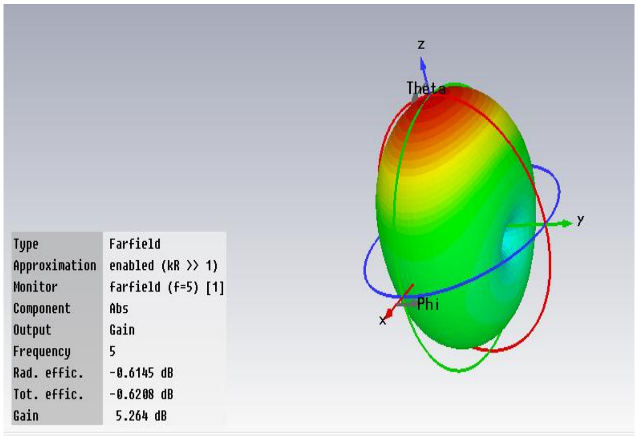
Figure 6: Simulation result of return loss (dB) against frequency (GHz) for patch antenna with and without EBG structure

Figure 6 indicates the simulation results for return loss (S_{11}) for rectangular patch antenna with and without EBG. Based on the graph above, the red graph represent conventional antenna without EBG while the green graph represent the metamaterial antenna with EBG structures. It can be seen that S_{11} for rectangular patch antenna with EBG structure gives better performance which is -40.582413dB compared to the S_{11} of patch antenna without EBG which is just -25.965539 dB. These S_{11} values prove that the metamaterial path antenna with EBG had improved the return loss of the antenna which meets the requirement of less than -10 dB cut off. Based on the figure, antenna with EBG produce higher bandwidth which is 139.96 MHz compared to antenna without EBG that produce only 77.551 MHz bandwidth.

Figure 7 (a) and (b) showed the 3D radiation pattern of gain for both antenna. Based on both figures, the gain of patch antenna without EBG is 5.984 dB that higher than metamaterial antenna with EBG which is 5.264 dB. The comparison of the simulation results for both antennas is tabulated in the Table 6.



(a)



(b)

Figure 7: 3D plot of radiation pattern for antenna gain in dB; (a) Patch antenna without EBG (b) Patch antenna with EBG.

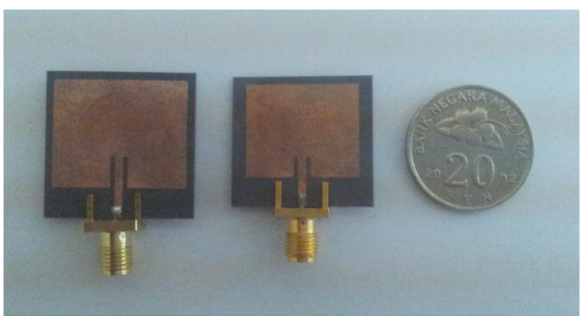
Table 6: Comparison between simulation performance for conventional and metamaterial antenna

	Patch antenna without EBG	Patch antenna with EBG	Percentage Difference (%)
Return Loss, S_{11} (dB)	-25.965539	-40.582413	56.29
Bandwidth (MHz)	77.551	139.96	80.48
Directivity (dB)	7.189	5.879	-18.22
Gain (dB)	5.984	5.264	-12.03

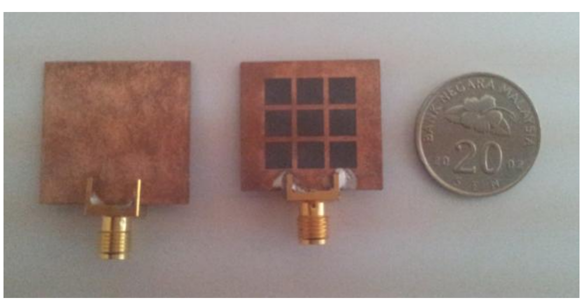
From the comparison performance in Table 6,the metamaterial patch antenna with EBG produced better performance compared to patch antenna without EBG antenna in term of return loss and bandwidth. There is increment of return loss (S_{11}) from -25.965539 dB to -40.582413 dB. The major different between both values was the percentage difference had exceeded half of the reference value that is 59.29%.These indicate thatmetamaterial antenna ismore efficient than conventional antenna. Bandwidth also improved massively by 80.48 % from 77.551 MHz in conventional to 139.96 MHz in metamaterial antenna.

For the directivity, the antenna shows the decrement from 5.984 dB to 5.264 dB after applying metamaterial with EBG structures. Same results also occurred for directivity of antenna where the value reduced up to 18.22%.Increasing the width of rectangular patch increases the directivity [13]. The results also showed that gain is always less than directivity [14].

B. *Measurement* Result



(a)



(b)

Figure 8: Fabrication of the antenna with conventional is located at the left side while metamaterial antenna with EBG structure at the middle; (a) Front View (b) Back View

Figure 8 above represents the conventional and metamaterial antenna with EBG structure that had been fabricated. These antennas were fabricated on Rogers RO5880 substrate. Based on the figure given, metamaterial antenna with EBG structurethat located in the middle issmaller than the conventional antenna. In addition, a coin which diameter of 23 mm is used as reference for the comparison of antenna size. Based on Table 5, the percentage different is 14.89%. Figure 8 (a) shows a front view of antenna. Patch size of metamaterial antenna with EBG is smaller than conventional antenna. From this measurement result, it is also indicates that the metamaterials reduced the antenna size.

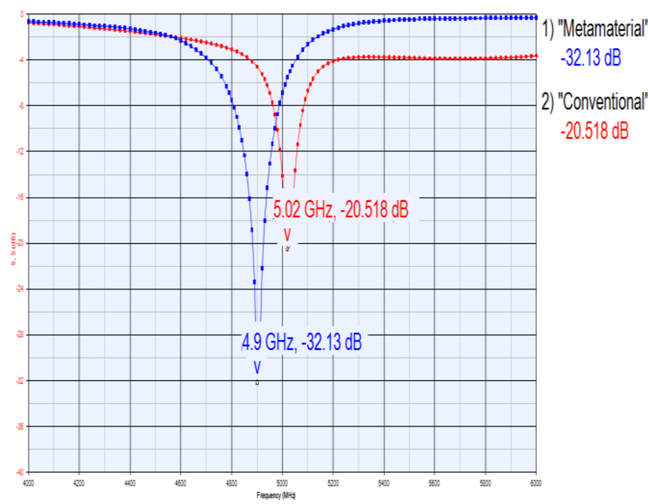


Figure 9: Measurement result of return loss, S_{11} (dB) against frequency (GHz) for conventional antenna and metamaterial antenna with EBG structure

Figure 9shows the measurement resultfor the conventional antenna and metamaterial antenna. From the result, the return loss for conventional antenna is at-20.518 dB and themetamaterialantenna is at -32.13dB.The graph shows a slight shift from the simulation result which resonate at 5GHz.S_{11} value for metamaterialantenna with EBG is shifted to the left which resonates at 4.9 GHz while the value of S_{11}conventional antenna shifted to the right which resonate at 5.02 GHz.This displacement may occur due to the error during fabrication process or loss along Vector Network Analyzer (VNA) cable.Bandwidth value for the conventional antenna is 0.09GHz while the metamaterial antenna value for bandwidth is 0.14GHz. By using metamaterial, the bandwidth increases by 0.05GHz. It verified that metamaterialwith EBG structure enhance the bandwidth of microstrip antenna.

Table 7: Comparison for measurement performance between conventional and metematerial antenna.

Parameters	Conventional antenna	Metamaterial antenna
Return loss, S_{11}(dB)	-20.518	-32.13
Frequency resonate (GHz)	5.02	4.9
Bandwidth (GHz)	0.09	0.14

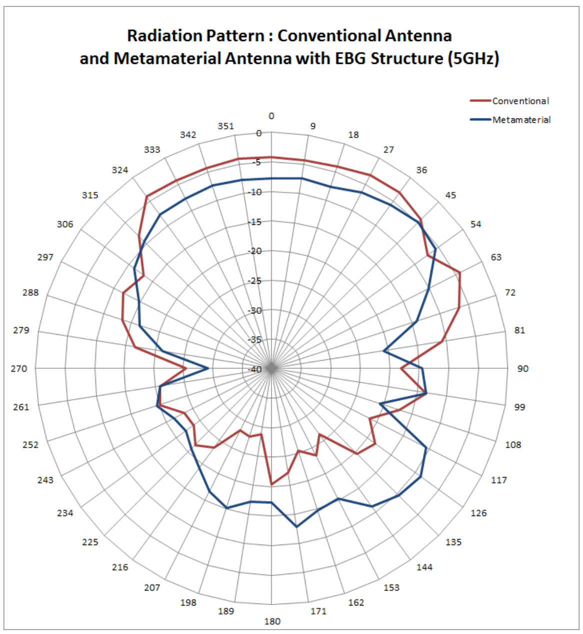


Figure 10: The radiation pattern of conventional and metamaterial with EBG structure

IV. CONCLUSION.

In this paper, the metamaterial patch antenna with EBG structure has been simulated, fabricated and measured. The EBG structure and metamaterial characteristics have been investigated. Both simulated and measured results showed the performance of the EBG structure toward microstrip antenna. The main objective of this project to reduce the antenna size hasaccomplished.It is proven that the metamaterial with EBG structure enhanced the antenna bandwidth, improved return loss and reducedthe antenna size significantly.

V. ACKNOWLEDGEMENT

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