Design of a Vivaldi Antenna with EBG Structure for Wi-Fi Application

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***Abstract*— A design of a Vivaldi Antenna with Electromagnetic Band Gap (EBG) structure. The Antenna is proposed at a height of 0.51 mm from the substrate Rogers RT/Duroid®5870 with nine squares of EBG structure. The EBG structure is placed at ground plane with copper cladding of 0.0175 mm. The patch antenna structure was designed to resonate at frequency of 5.6 GHz. This work is focused on designing the best Vivaldi antenna by collecting the best simulation result in terms of return loss, (S_{11}), bandwidth (BW), gain of farfield, directivity and VSWR. The work is proceeded by combining Vivaldi antenna with EBG structure. This combination is to investigate the EBG structure characteristic in antenna design in order to increase the performance of antenna in term of return loss (S_{11}), bandwidth (BW), gain of farfield, directivity, VSWR and minimizing the size of antenna as possible. Simulations and measurements have been carried out to verify the performance of Vivaldi antenna with and without EBG structure. All the simulation and measurement work is done by Computer Simulation Technology (CST) CAD Package software and Vector Network Analyzer (VNA) respectively.**

***Keywords*—Vivaldi antenna, Electromagnetic Band Gap (EBG) structure, CST CAD Package, Vector Network Analyzer (VNA), S_{11}, bandwidth, gain of farfield, directivity and VSWR.**

I. INTRODUCTION

The Vivaldi antenna sometimes referred to as or the Vivaldi notch antenna, and also known as the tapered slot antenna (TSA), is easy to fabricate on a circuit board, and can provide ultra-wide wide bandwidth where Peter Gibson invented the Vivaldi antenna in 1978, in the UK [1]. Ultra wideband (UWB) is a radio technology for transmitting large amount of data over a wide frequency band with very low power for a short distance [2]. A Vivaldi antenna is a co-planar especially use as broadband antenna, which is made from a substrate with dielectric plate metalized on both sides and one side act as ground. Their broadband characteristic which is suitable for UWB became one of the advantages of Vivaldi antennas [3]. Broadband service can provide higher speed of data transmission and allow more content to be carried through the transmission or sometimes called pipeline. Broadband commonly use in internet streaming and radar application. On the other hands, the advantages of this antenna are their easy manufacturing process using common methods for PCB production which is involving etching process and their easy impedance matching to the feeding line using microstrip line modeling methods.

Because of revolution and development the Vivaldi antenna can be classified as an end-fire tapered slot antenna [4]. This type of antenna can change beamwidth by varying the shape, length, and dielectric thickness or producing a symmetrical beam in the E-field and H-field. So far the Vivaldi antenna mostly applied to the radio telescope, remote sensing, satellite communication and radar application [5].

Recently, in order to suppress the surface wave and improve the radiation performance of the antenna there has been considerable research effort of electromagnetic band gap (EBG) structure for antenna application and still undergoing monumental developments [6]. Generally speaking, electromagnetic band gap structures are defined as artificial periodic or sometimes non-periodic objects that prevent or assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states [7]. Today, many antennas are required to be small and broadband and to achieve that circumstance the patch antenna must fabricated on a thick piece of high permittivity substrate. This cause unwanted substrate modes begin to form and propagate towards the edges of the substrate, which bring adverse effect on the antenna radiation pattern. In the 1990s, the introduction of an electromagnetic band gap structure into the printed antenna substrate is suggested, which saw the capability of removing unwanted substrate modes [8]. Two commonly employed configurations namely the perforated and metallodielectric structures are the type of this EBG. The effectiveness of the perforated structure relies on the high refractive index contrast between the air-columns and the relative permittivity of the dielectric material and the type of the lattice to use like honeycomb-lattice [9]. The metallodielectric structure is more appropriate if the substrate has a high relative permittivity simply because they are usually easier to manufacture and have wide range of applications. They consist of periodic metalized elements etched usually on the same layer as the microstrip antenna with metal vias connecting the periodic patches on the ground. In most cases, vias are necessary to prevent waves with non-zero vertical electric field component to travel between patch array and the ground [10].

In order to overcome the disadvantages of Vivaldi antenna, EBG structures were proposed. EBG or photonic band gap (PBG) materials can stop the propagation of electromagnetic waves in certain directions, within certain frequency bands.

Over the last few years EBG structures have attracted increasing research interests because of their desirable electromagnetic properties which cannot be observed in natural materials. It is also seen that EBG structures can improve the microstrip patch antennas radiation patterns, increase their gain. EBG also acts as a perfect magnetic conductor (PMC) at a certain frequency band, and reflects the electromagnetic waves with a near zero degree reflection phase. So placing an EBG underneath a radiation element will reflect the electromagnetic wave back in phase, and reduce the size lobe and back lobe levels [11].

Wi-Fi (also spelled Wifi or WiFi) is a popular technology that allows an electronic device to exchange data wirelessly (using radio waves) over a computer network, including high-speed Internet connections [12]. The Wi-Fi Alliance defines Wi-Fi as any wireless local area network (WLAN) products that are based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. Wi-Fi enabled devices (laptops or PDAs) can send and receive data wirelessly from any location equipped with Wi-Fi access. Access points, installed within a Wi-Fi location, transmit an RF signal to Wi-Fi enabled devices that are within range of the access point, which is about 300 feet. The speed of the transmission is governed by the speed of the pipeline fed into the access point [13]. Wi-Fi can be less secure than wired connections (such as Ethernet) because an intruder does not need a physical connection. Web pages that use SSL are secure but unencrypted internet access can easily be detected by intruders. Because of this, Wi-Fi has adopted various encryption technologies. The early encryption WEP, proved easy to break. Higher quality protocols (WPA, WPA2) were added later.

Reviewing on the literature, the author proposes to design a Vivaldi antenna with and without EBG structure at frequency of 5.6 GHz. The Vivaldi antenna with and without EBG structure should be able to maintain a good return loss (S_{11}), bandwidth (BW), gain of farfield, directivity and VSWR as to show the improvement when using an EBG structure.

II. ANTENNA DESCRIPTION

The proposed Vivaldi antenna is designed using the substrate Rogers RT/Duroid®5870 with dielectric constant, ε_r= 2.33 while the height of the substrate, h is 0.51 mm. To design the microstrip antennas over EBG ground plane, it is required to design a conventional antenna to compare the impedance bandwidth parameters. Therefore, a conventional antenna and Vivaldi antenna with EBG structure are designed as shown in Figure 1 and Figure 2 respectively. The design Vivaldi antenna with and without EBG structure were simulated using Computer Simulation Technology (CST) CAD Package software.

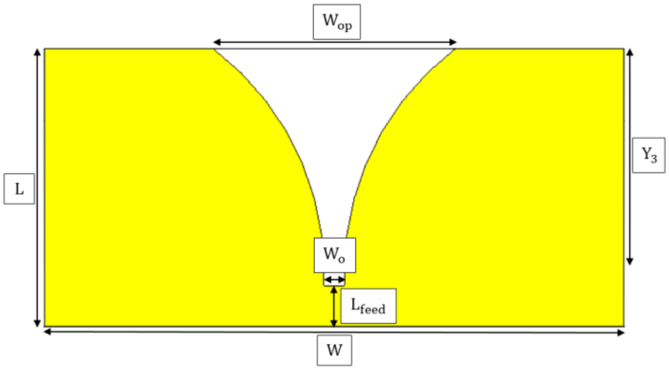


Figure 1: Dimension of conventional Vivaldi antenna.

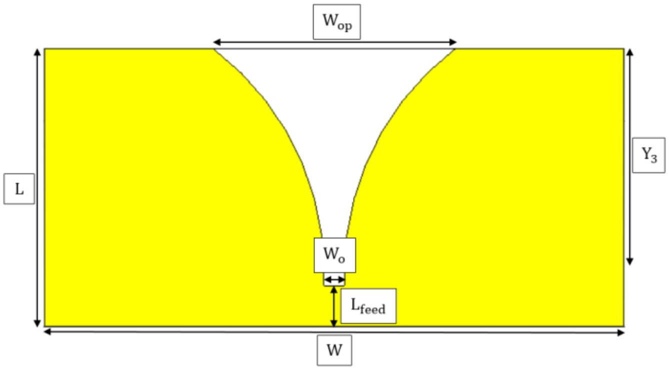


Figure 2: Dimension for Vivaldi with EBG structure.

The optimized parameter dimensions of radiating patch element for both design antennas are tabulated in Table 1.

Table 1
Comparison of patch dimension between conventional Vivaldi antenna and Vivaldi antenna with EBG structure

Dimension parameters	**Conventional Vivaldi Antenna**	**Vivaldi Antenna with EBG**
Width, W (mm)	41.6191	41.8111
Length, L (mm)	19.5204	19.499
Opening width, W_{op} (mm)	20.5556	20.42
Opening length, Y_3 (mm)	16.778	16.788
Feed line width, W_o (mm)	0.2	0.2
Feed line length, L_{feed} (mm)	2.7424	2.711

Figure 3 illustrates the configuration of the proposed antenna. A Vivaldi antenna that is fabricated on Rogers RT/Duroid®5870 substrate using copper, Cu layer with EBG structure at the ground plane is set to resonate at 5.6 GHz.

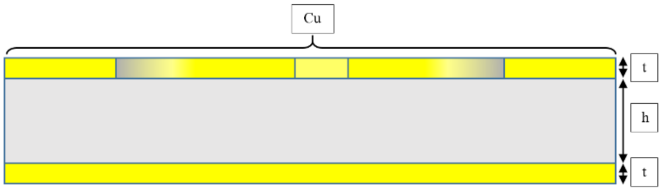


Figure 3: A cross-sectional view of the Vivaldi antenna.

Characteristics of Rogers RT/Duroid®5870 substrate is tabulated in Table 2.

Table 2
Rogers RT/Duroid®5870 substrate characteristics.

Characteristics	Value
Permittivity	2.33
Thickness, h	0.51 mm
Copper cladding, t	0.0175 mm

Figure 4 below shows the periodic structure of the square holes (EBG structure). The square holes dimensions are optimized to get the best results. The position of the highest H-field is identified in order to investigate the accurate position for EBG structure. After that, the antenna was optimized to get the best return loss, S_{11}.

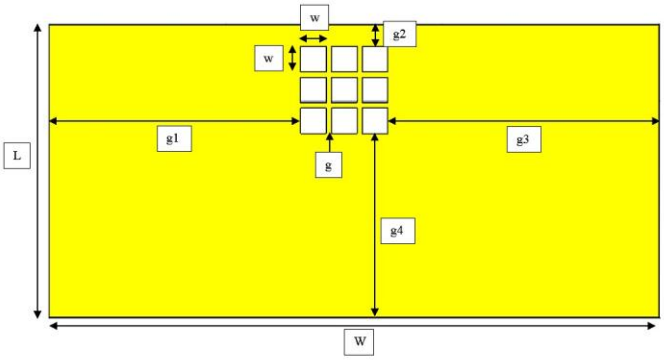


Figure 4: Periodic structure of the square holes (EBG structure).

The dimension of EBG structure and substrate are tabulated in Table 2.

Table 2
Dimension for EBG structure and substrate.

Parameters	Value (mm)
W	41.8111
L	19.499
w	2.27
g	0.5
g1	17.0006
g2	0.859
g3	17.0006
g4	10.83

III. METHODOLOGY

The approaches of the project design are represented in the flow chart in Figure 5.

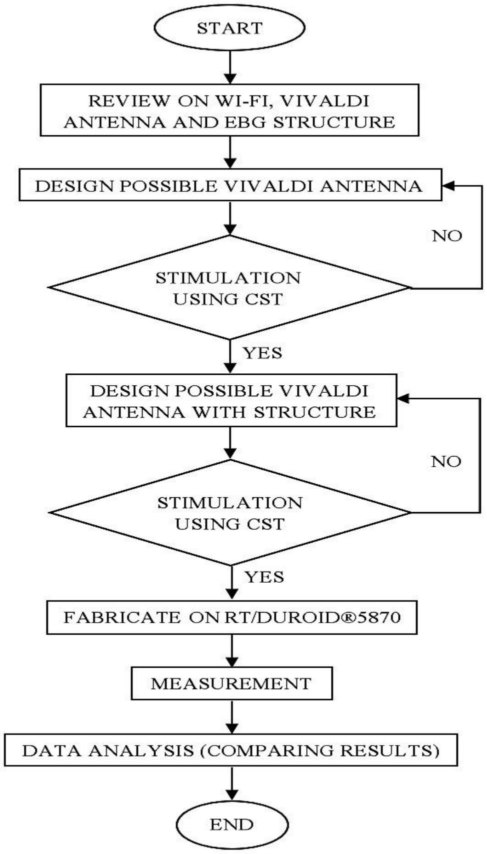


Figure 5: Flow chart of the project design.

Computer Simulation Technology (CST) CAD Package software has been used for all the simulation. Microsoft Excel software has been used for comparing the results between Vivaldi antenna with and without EBG structure for the proposed design.

A. Conventional Vivaldi Antenna Design

Conventional patch antenna are designed to compare the performances in term of return loss (S_{11}), bandwidth (BW), gain of farfield, directivity, VSWR and sizes with Vivaldi antenna with EBG structure. The conventional Vivaldi antenna equations were calculated first and optimized in order to get the best results. Dimension of the Vivaldi antenna has been calculated using equation below;

i. Minimum opening width, W_{min} is:

$$\lambda_g = \frac{c}{F\sqrt{\varepsilon_r}} \qquad (1)$$

Where,
c = Speed of light ($3x10^8$)
F = Center of frequency
ε_r = Dielectric constant (2.33)

So,

$$W_{min} = \frac{\lambda_g}{2} \qquad (2)$$

ii. Maximum opening width, W_{max} is:

$$W_{max} = \lambda_g = \frac{c}{F\sqrt{\varepsilon_r}} \qquad (3)$$

B. EBG Structures Design

In Novel [14], EBG structure was tuned in designing the desired frequency band of the antenna to minimize the thickness of the antenna. This EBG structure was inserted as new ground plane and made possible to reduce the total thickness of antenna more than 71%, therefore obtaining a low profile antenna compared with the reference antenna. The new type of structure proposed was much less complicated and comprise similar performances as those obtained in the case of Mushroom-like.

In this paper, the EBG structure is designed by etching 9 holes on the ground plane of the Rogers RT/Duroid®5870. The EBG structure that designed was squared in shape. The width and the length of the squares were optimized until the desired results are obtained based on the following equation;

$$w = 0.10\lambda, g = 0.02\lambda \qquad (4)$$

IV. RESULTS AND DISCUSSION

A. Simulation Results

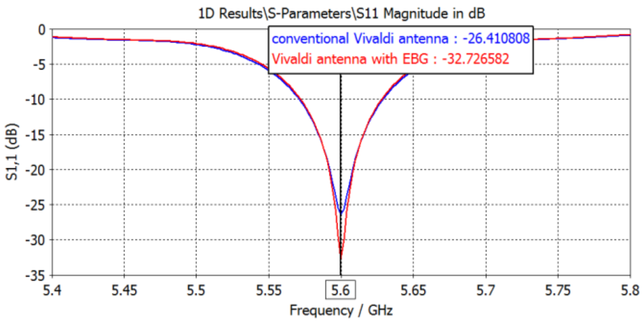


Figure 6: Return loss for combination of conventional Vivaldi antenna and Vivaldi antenna with EBG structure.

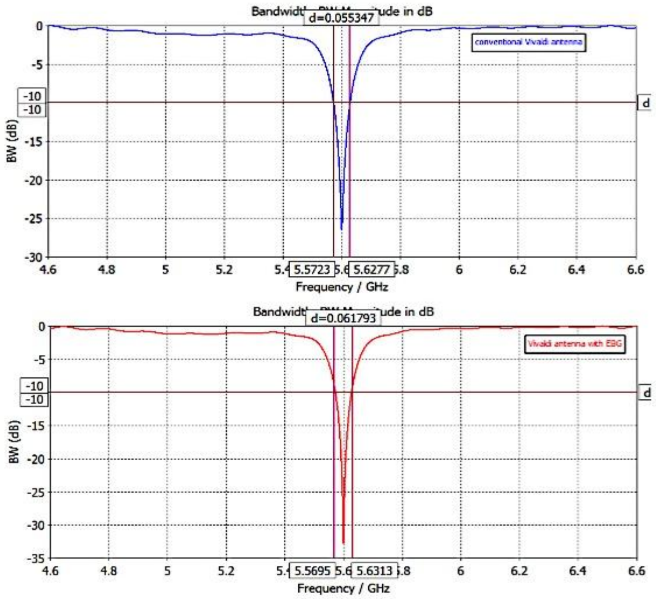


Figure 7: Bandwidth for combination of conventional Vivaldi antenna and Vivaldi antenna with EBG structure.

Figure 6 shows the simulation results for return loss, S_{11} for conventional Vivaldi antenna and for Vivaldi antenna with EBG structure. S_{11} for conventional Vivaldi antenna is -26.4108 dB while for Vivaldi antenna with EBG structure is -32.7266 dB which is about 23.91% improved. Besides that, the bandwidth is also enhanced about 11.65% from 55.347 MHz to 61.793 MHz as shown in Figure 7. These proves that Vivaldi antenna with EBG improve the performance than conventional Vivaldi antenna.

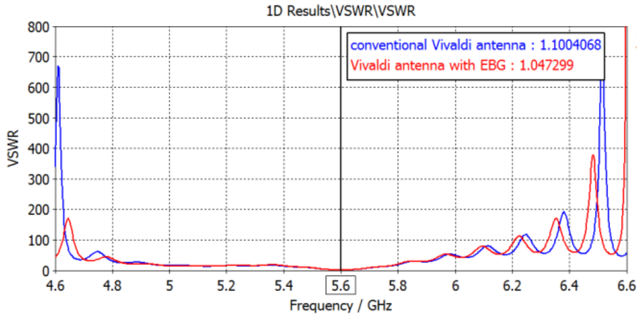
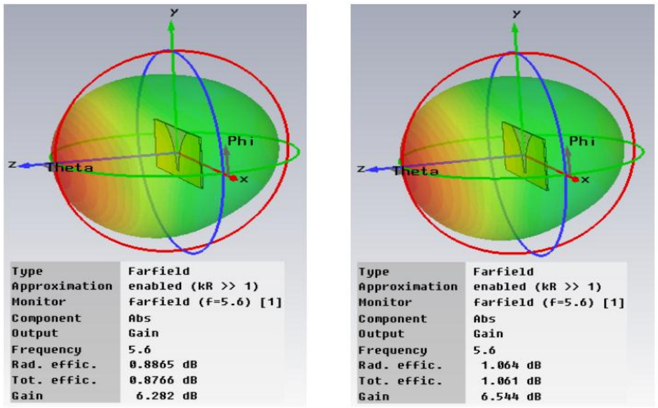


Figure 8: VSWR for combination of conventional Vivaldi antenna and Vivaldi antenna with EBG structure.

Figure 8 above represent the voltage standing wave ratio, VSWR for conventional Vivaldi antenna and for Vivaldi antenna with EBG structure. The VSWR value for conventional Vivaldi antenna is 1.1004 while for Vivaldi antenna with EBG structure is 1.0473. This show that the Vivaldi antenna with EBG approaching more to value 1 which is desired value of VSWR.

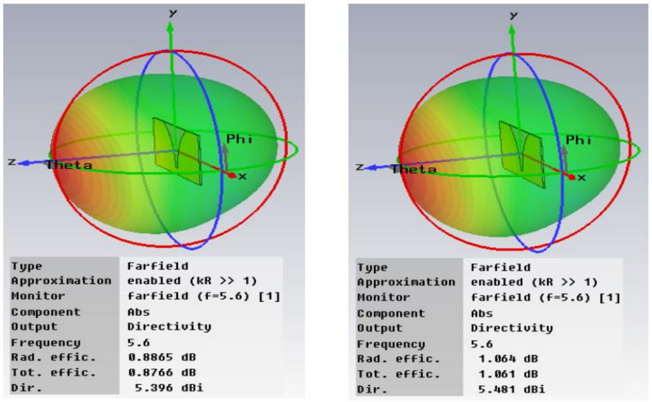


```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=5.6) [1]
Component       Abs
Output          Gain
Frequency       5.6
Rad. effic.     0.8865 dB
Tot. effic.     0.8766 dB
Gain             6.282 dB
```

```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=5.6) [1]
Component       Abs
Output          Gain
Frequency       5.6
Rad. effic.      1.064 dB
Tot. effic.      1.061 dB
Gain             6.544 dB
```

Figure 9: Gain for (a) conventional Vivaldi antenna, (b) Vivaldi antenna with EBG structure.

Figure 9 represents the 3D plot of antenna gain for both conventional Vivaldi antenna and Vivaldi antenna with EBG structure respectively. From the both (a) and (b), the antenna with EBG produced higher gain with a value of 6.544 dB compared to the conventional Vivaldi antenna with a value of 6.282 dB which is about 4.17% of increment.

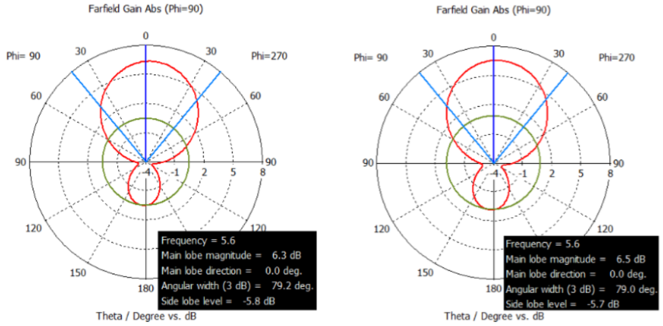


```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=5.6) [1]
Component       Abs
Output          Directivity
Frequency       5.6
Rad. effic.     0.8865 dB
Tot. effic.     0.8766 dB
Dir.             5.396 dBi
```

```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=5.6) [1]
Component       Abs
Output          Directivity
Frequency       5.6
Rad. effic.      1.064 dB
Tot. effic.      1.061 dB
Dir.             5.481 dBi
```

Figure 10: Directivity for (a) conventional Vivaldi antenna, (b) Vivaldi antenna with EBG structure.

Figure 10 deputizes the 3D plot of antenna directivity for both conventional Vivaldi antenna and Vivaldi antenna with EBG structure respectively. From both figures, the Vivaldi antenna with EBG structure produced higher with a value of 5.481 dBi compared to the conventional Vivaldi antenna with a value of 5.396 dBi which is about 1.575% increased. Directivity measures the power density the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal isotropic radiator (which emits uniformly in all directions) radiating the same total power.



```
Frequency = 5.6
Main lobe magnitude =   6.3 dB
Main lobe direction =   0.0 deg.
Angular width (3 dB) =  79.2 deg.
Side lobe level =  -5.8 dB
```

```
Frequency = 5.6
Main lobe magnitude =   6.5 dB
Main lobe direction =   0.0 deg.
Angular width (3 dB) =  79.0 deg.
Side lobe level =  -5.7 dB
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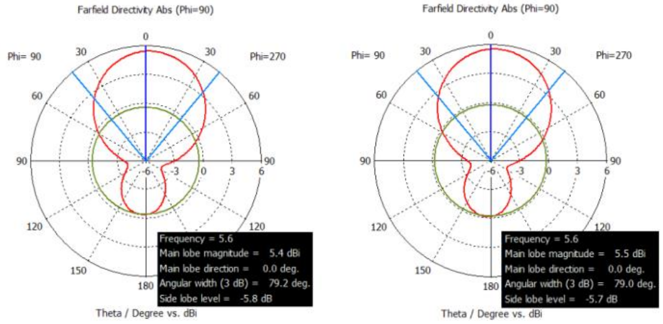
Figure 11: Radiation pattern of gain for (a) conventional Vivaldi antenna, (b) Vivaldi antenna with EBG structure with phi=90.



```
Frequency = 5.6
Main lobe magnitude =   5.4 dBi
Main lobe direction =   0.0 deg.
Angular width (3 dB) =  79.2 deg.
Side lobe level =  -5.8 dB
```

```
Frequency = 5.6
Main lobe magnitude =   5.5 dBi
Main lobe direction =   0.0 deg.
Angular width (3 dB) =  79.0 deg.
Side lobe level =  -5.7 dB
```

Figure 12: Radiation pattern of directivity for (a) conventional Vivaldi antenna, (b) Vivaldi antenna with EBG structure with phi=90.

Referring to Figure 9 and 10, it is proven that Vivaldi antenna with EBG structure improved the radiation pattern of gain and directivity. This radiation patterns shows how the main and side lobe was improved. The main lobe magnitude of gain is increased by 0.2 dB from 6.3 dB to 6.5 dB. The 3 dB beam width of Vivaldi antenna with EBG structure is better than conventional Vivaldi antenna from 79.2° to 79.0° which decline about 0.2°. The side lobe level of directivity is decreased from -5.8 dB to -5.7 dB with main lobe direction directivity from 5.4 dBi to 5.5 dBi after using EBG structure on Vivaldi antenna. From both radiation patterns of gain and directivity, both Vivaldi antenna with and without antenna radiate more on front patch than back patch. If the radiation lobe is wide, the antenna has wider coverage area and if otherwise, the antenna can radiate in long distance. Based on the radiation pattern of simulation and measurement results, it shows that both Vivaldi antennas with and without EBG structure has wider coverage area which is the main feature of Wifi application.

Table 3
Comparison between simulation performances of conventional Vivaldi antenna and Vivaldi antenna with EBG structure.

	Conventional Vivaldi Antenna	**Vivaldi Antenna with EBG**	**Percentage Difference (%)**
Return loss, S_{11} (dB)	-26.4108	-32.7266	23.91
BW (MHz)	55.347	61.793	11.65
Patch area, W *x* L (mm^2)	41.6191 *x* 19.5204	41.8111 *x* 19.499	0.35
Gain (dB)	6.282	6.544	4.17
Directivity (dBi)	5.396	5.481	1.575
VSWR	1.1004	1.0473	4.82

Comparison between simulation performance of Vivaldi antenna with and without EBG structure is depicted in Table 3. Overall parameters showed improvement but the parameter only can be stated as improved when the increment percentage is more than 10 % and in this case only return loss and bandwidth can be considered improved which 23.91% and 11.65% respectively. For the other parameters like gain, directivity and VSWR, showed increment in value but below 10%.

B. *Measurement Results*

Figure 11 shows the fabricated conventional Vivaldi antenna which is (a) represent the front view of antenna while (b) is the back view of antenna.

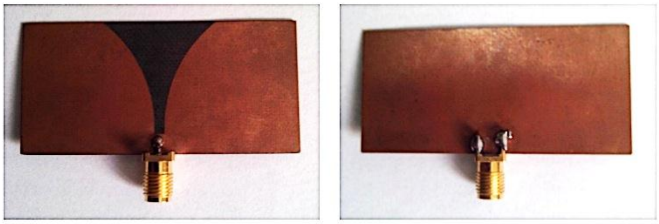

(a) (b)

Figure 11: Fabricated conventional Vivaldi antenna; (a) front view, (b) back view.

Figure 12 depicts the view of Vivaldi antenna with EBG structure. Figure (a) and (b) shows the front view and back view with square shaped EBG structure on the ground plane respectively.

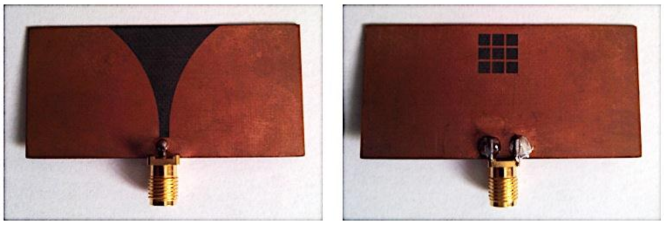

(a) (b)

Figure 12: Fabricated Vivaldi antenna with EBG structure; (a) front view, (b) back view.

Based on these figures, the size of Vivaldi antenna with EBG structure is variance with the conventional Vivaldi antenna. Vivaldi antenna in Figure 12 is much smaller than Vivaldi antenna in Figure 11. From the measurement result, it is also show improvement in Vivaldi antenna with EBG structure compared to the conventional antenna.

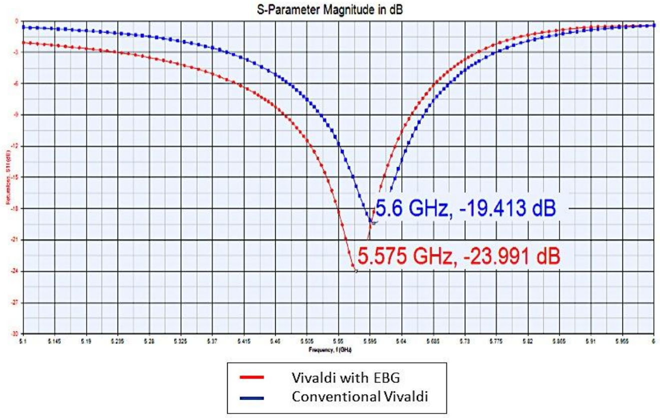


Figure 13: Measurement result of return loss, S_{11} for Vivaldi antenna with and without EBG structure.

Figure 13 indicate the measurement result of return loss, S_{11} for conventional Vivaldi antenna and Vivaldi antenna with EBG structure. It is shown that the resonant frequency for EBG structure is slightly shifted. The conventional Vivaldi antenna resonate at exactly at the proposed frequency which is 5.6 GHz while for Vivaldi antenna with EBG structure resonate at 5.575 GHz which is shifted to the left by 25 MHz. The difference between simulation and measurement result may due to disturbance or interference that affect the circuit in an open air environment. It is also occurred due to corrosion of copper during fabrication process. However, measurement result also show improvement of S_{11} when using EBG structure. Return loss for conventional antenna is -19.413 dB which is decrease by -6.9978 dB from simulation result while for antenna with EBG structure is -23.991 dB which is decease by -8.7356 dB from simulation result. This show that the simulation result is better than measurement due to losses in equipment.

Figure 14: Measurement result of VSWR for Vivaldi antenna with and without EBG structure.

Figure 14 represent the measurement result of voltage standing wave ratio, VSWR for conventional Vivaldi antenna and Vivaldi antenna with EBG structure. It is show that VSWR value is taken from the center frequency from measurement result of return loss, S_{11} which is 5.6 GHz for conventional Vivaldi antenna and 5.575 GHz for Vivaldi antenna with EBG structure. The value of VSWR of conventional antenna is 1.24 while for Vivaldi antenna with EBG structure is 1.221. Both antennas meet the characteristic of VSWR value which is approaching to 1. The approaching value of VSWR to 1 is needed to produce the antenna which is less signal loss due to reflected power transmit. In this case the Vivaldi antenna with EBG structure show the better VSWR value than conventional Vivaldi antenna by 0.019.

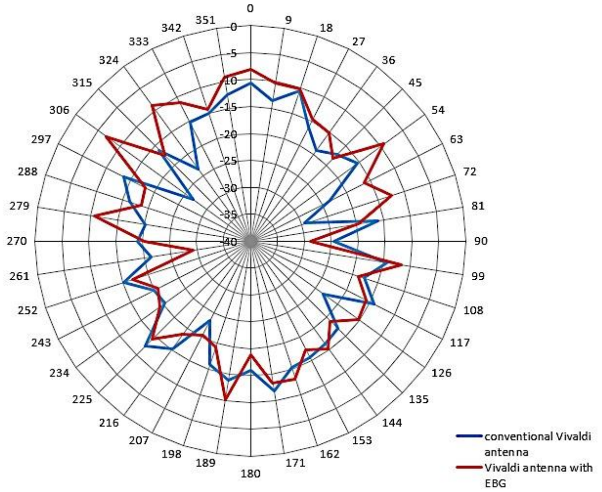


Figure 15: Measurement result of radiation pattern of gain and directivity for Vivaldi antenna with and without EBG structure.

Figure 15 depicts the measurement result of gain for Vivaldi antenna with and without EBG structure. The figure show the overall gain and directivity of conventional Vivaldi antenna is improved by EBG structure. The results seem slightly difference from simulation result but both antennas produces good gain and directivity.

V. CONCLUSION

In this paper, it is demonstrated that the overall EBG structure improved the performance of Vivaldi antenna. The concept has been successfully simulated, fabricated and measured. The experiment results show good settlement with the theoretically and numerically. The improvement of antenna can be prove through return loss and bandwidth value which is increased about 23.91% and 11.65% respectively.

VI. FUTURE RECOMMENDATION

Future research should investigate on how to improve more on antenna performance. The EBG structure might be designed using different shape and dimensions. Other alternative might be different type of antenna such as dipole or array antenna. The EBG structure also can be become a reflector instead of a ground plane such as in this project. The other technique also might be used beside EBG structure like Defected Ground Structure (DGS) in order to improve the performance results. Besides that, the meta-material concept might also be included in antenna to improve some basic antenna features such as impedance matching, gain, bandwidth and efficiency.

VII. ACKNOWLEDGEMENT

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