Band-Notched Antipodal Vivaldi Antenna using Edge-Located Vias Mushroom EBG Structure for Ultra Wideband Applications

Saidu A. Adamu, Thelaha Masri, Wan Azlan W. Z. Abidin, Kismet H. Ping

Abstract: ***An Ultra wideband (UWB) Antipodal Vivaldi Antenna operating at 2.78 GHz to more than 12 GHz with dual notch band attributes is designed for application in ultra-wideband. The proposed double-layered antenna is designed on a low cost FR-4 dielectric material with combined thickness of 2.1mm. Two edge-located vias mushroom type EBG metamaterial structures were incorporated within a conventional antipodal Vivaldi antenna (AVA) in between the two substrate layers and below the feeding line, to realize the proposed antenna. Using the band gap property of the EBG structure, two notch bands were created within the ultra wideband frequency range of the antenna for WiMAX IEEE 802.16 application at 3.18 – 3.80 GHz and WLAN IEEE 802.11a application at 5.13 – 5.80 GHz. Simulation results showed a almost stable directional radiation pattern in the entire frequency range except in the two notch bands, having a peak realize gain of 7.69 dBi at 6.5 GHz. Additionally, surface current distribution and far-field radiation patterns are also studied to characterize the achievement of the presented antenna.***

Keywords**:** ***Antipodal vivaldi antenna, Edge located vias, Ultra wideband, Slot edge corrugation, Reflection coefficient.***

I. INTRODUCTION

Rapid increase has being witnessed in the use of the ultra wideband frequency spectrum and quite a number of UWB antenna designs have being proposed in both the academia and the industry following the commercial licensing of the UWB frequency spectrum by the federal communication commissions (FCC) [1]. Thus there has being a rapid increase in the use this spectrum for both military and industrial wireless communication applications. UWB antennas such as Log-periodic, TEM horn, fractal, spiral, bow-tie, conical, and Vivaldi antennas [2, 3] have being investigated and proposed. Desirable electrical features such as planar and simple structure, light weight and low profile, symmetric beam in both radiating planes, conformity with mounting host surfaces [4–7] among others have combined to make the Vivaldi antenna more competitive in UWB applications compared others such as the Log periodic and the Horn antennas which are very bulky and non-planar. The Vivaldi antenna was first proposed as a travelling wave, coplanar tapered slot antenna [8] before being successively improved by [9] and then [10] so as to eliminate the limitations of the initial design.

Unique characteristics of the Vivaldi antenna has enabled its deployment in applications such as detection of cancerous cells and tumors [11, 12], microwave imaging of structures and construction materials [13–16], for high range radar systems [17], see through wall applications [18] and many other such applications. Within the allocated 3.1 – 10.6 GHz UWB frequency band also exists other narrow band wireless technologies including the two standards for WiMAX and WLAN at 3.5 GHz and 5.5 GHz commonly, which might cause possible electromagnetic interference to the UWB applications.

The need thus arise for extra circuitry in the UWB antenna covering the whole range of the UWB frequency band to filter out the band of frequencies that might cause the potential interference to the UWB system operation.

However, due to the non-uniformity of the Vivaldi antenna radiators which are of elliptical or exponential taper shape, precious little investigation of band notched Vivaldi antennas have being reported [19–23] for single or multiple frequencies band-notched. A U and Ω-shaped slots were made on the radiating arms of the AVA in [19] to realize a notch band at 5.5 GHz frequency for WLAN. In the same vain, a capacitive loaded loop resonator [20] was used within a UWB Vivaldi antenna for notch band operation at the same WLAN frequency. Apart from only one notch band being created, using these perturbation techniques to create the band-notch degrades the performance of the antenna due to copper etching. A notch band at 5 - 6 GHz was equally achieved in [21] with an elliptically-tapered miniaturized slot antenna. Though this antenna has small size, it however, only provides a single notch at IEEE 802.11a WLAN band with an undesired H-plane radiation pattern. A band notch for WiMAX application from 3.3 – 3.6 GHz was also obtained using a resonant parallel strip (RPS) loaded AVA [22]. However, the location of the RPS negatively impacts the design complexity of the antenna in addition to only one notch frequency band being realized.

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Incorporating pairs of two EBG cells along the AVA feed, [23] achieved two band notches for WiMAX and ISM bands from 3.6 – 3.9 GHz as well as 5.6 – 5.8 GHz respectively which however have a wide bandwidth between the stop band and the usable frequency.Presented here is a double-layered double band notched AVA designed with an edge-located via mush room type EBG structure.

By introduction the EBG structure between the two layers within antenna structure a double notch bands from 3.2 to 3.8 GHz as well as 5.1 to 5.8 GHz for WiMAX and WLAN respectively are easily achieved. Flexibility with respect to adjusting the number and location of the stop frequency bands for antennas with non-uniform radiators such as this AVA can be realized using this design methodology.

II. ANTENNA GEOMETRY AND DESIGN

Fig. 1 shows the development of prospective antenna. A conventional AVA Figure 1(a) is constructed on a double-layered inexpensive fire retardant -4 dielectric material permittivity (ε_r) 4.4, tan $\delta = 0.019$ with a combined width (h_1+h_2) = 2.1mm. As a consequence of its simple structure and smooth curvature between radiating flare and feed line and because of its wide impedance bandwidth, the taper of the radiating arm follows the elliptical shape in which the radii of the outer and inner quarter ellipses are defined by

$$a_1 = (S_l - L_f) + k \tag{1}$$

$$a_2 = 0.375a_1 \tag{2}$$

$$a_3 = 0.296a_2 \tag{3}$$

$$b_1 = \frac{S_w + W_f}{2} \tag{4}$$

$$b_2 = \frac{S_w - W_f}{2} \tag{5}$$

$$b_3 = \frac{W_g - W_f}{2} \tag{6}$$

where S_l is the substrate length, S_w as substrate width, W_f as feed line width, W_g ground plane width and L_g as ground plane length respectively. For the ellipses, a_1 , a_2 and a_3 represents the major radii of outer, inner and ground plane ellipses, while b_1, b_2 and $b_3$are the secondary radii of outer, inner and ground plane ellipses respectively. k represents a constant that determines the aperture width.

The upper frequency limit has a theoretically infinite value whereas the width of the antenna at the open aperture determines the lower end frequency limit which was obtained from.

$$f_{\min} = \frac{c}{2W\sqrt{\varepsilon_{eff}}} \tag{7}$$

Where;

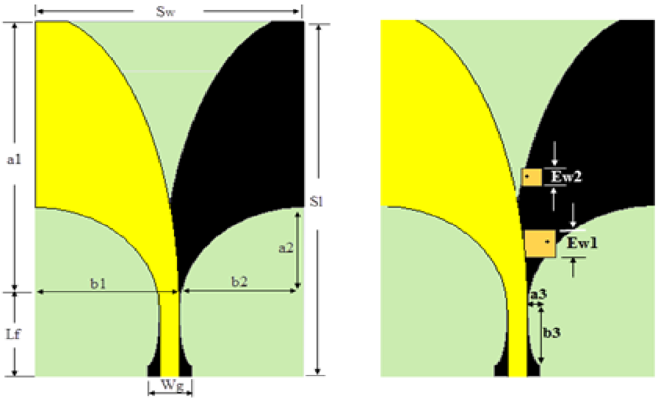
$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-\frac{1}{2}} \tag{8}$$

In which $\varepsilon_{\mathrm{eff}}$ is effective permittivity and W represents the aperture width.

Edge-located vias mushroom type EBG cells were then incorporated in between the two substrate layers and under the feed line of the conventional AVA to realize the prospective antenna as indicated in Fig. 1(b) and achieve the band notch at the specified frequency bands. The optimize parameters of EBG structure and antenna are as given in Table I.

Table 1: Optimized specification of the prospective antennas and EBG structures (mm)

Vivaldi Antenna			
Parameter	**Value**	**Parameter**	**Value**
S_l	90	a_1	75
S_w	60	a_2	26
W_f	4.4	a_3	14
W_g	10	b_1	32.2
L_g	3	b_2	27.8
L_f	17	b_3	2.8
EBG$_1$		**EBG$_2$**	
Ew_1	7	Ew_2	4.5
Vr_1	0.3	Vr_2	0.3
g_1	1.5	g_1	1
g_2	8	g_2	3
x_{dist}	5	x_{dist}	1
y_{dist}	3	Y_{dist}	2.25



(a) (b)

Fig. 1. (a) Conventional AVA (b) Proposed AVA.

III. NOTCH BAND IMPLEMENTATION

As artificial periodic structures, the electromagnetic band gap (EBG), upon interaction with electromagnetic waves produces thrilling phenomenon in the form of pass band, stop band and a band gap where they act as artificial magnetic conductor. Thus the band gap property is used here to create the frequency band notch of the presented antenna. Therefore, for obtaining the band notches at 3.5 GHz WiMAX and 5.5 GHz WLAN bands, two edge-located vias mush room type EBG structure are designed and incorporated to the conventional AVA as shown in Fig. 1(b). Notch frequencies given by

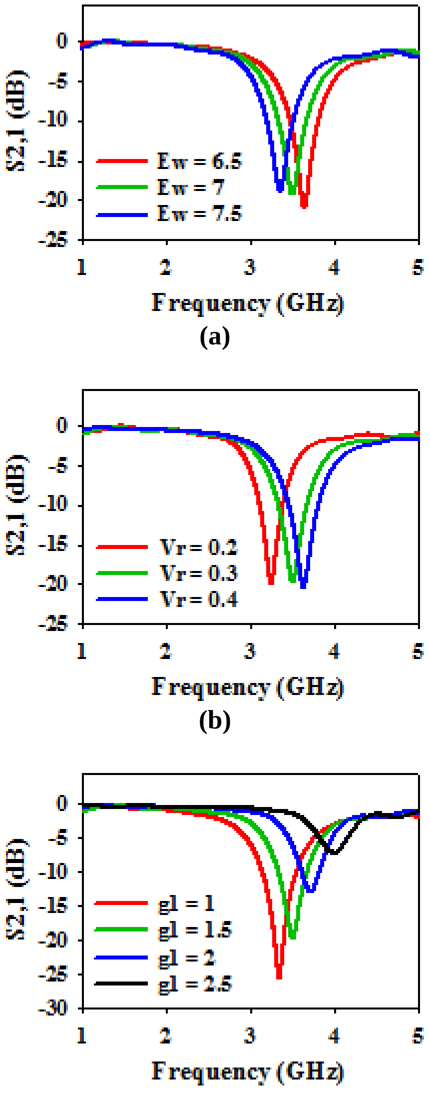
$$f_i = \frac{1}{2\pi\sqrt{L_i C_i}} \tag{9}$$

where i = 1, 2 are produced by the EBG structures in which L_i is the inductance due to the vias current and C_i represents the capacitive effect of the EBG patch with respect to the metallic radiator as ground.

Method of suspended transmission line (MoSTL) is used to analyze the resonant behavior of the EBG cells, where the EBG cells are positioned under the transmission line in between the two substrates layers.

Only one EBG cell is adequate for simulation due to the periodic nature of the cell, hence EBG_1 is used in this analysis for clarity purposes but same is true of EBG_2. Parameter study was done to establish the capacity of the EBG cells to govern the notch frequency.

Fig. 2(a), shows that increasing the patch width E_w, increases the capacitance C_i which result in lowering the resonant frequency from equation (9). On the other hand, from Fig. 2(b), it is observed that an increase in the vias radius V_r, reduces the inductance and hence an increase in resonant frequency from equation (9). Likewise from Fig. 2(c), a decrease in resonant frequency is observed with decrease in gap of transmission line and the EBG patch g_1. This indicates that the more coupling is achieve when EBG patch is close to the feed line, hence a better S_{21} magnitude but at the expense of resonant frequency.



(a)

(b)

(c)

Fig. 2: Effect of variation of (a) Patch Width E_w (b) Via radius V_r and (c) distance between EBG patch and feed line g_1, against frequency for EBG1.

IV. RESULTS AND DISCUSSION

Results from simulation of the conventional and proposed antennas were compared. Figure 3 indicates plot of S_{11} against frequency for the conventional AVA and the band-notch AVA. The conventional AVA has an impedance bandwidth from 2.78GHz to more than 12GHz. When the two EBG structures were introduced to realize the proposed antenna, a frequency notch at 3.18–3.80 and 5.13 – 5.80 GHz were obtained for WiMAX and WLAN applications respectively. The operational band of the proposed antenna however remains unaffected as a consequence of integrating the EBG structure.

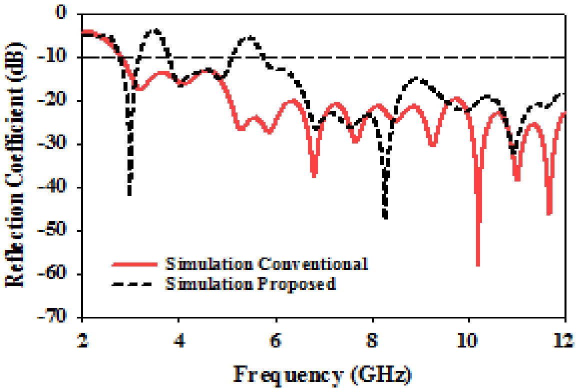


Fig. 3: Antennas Simulated Reflection Coefficient

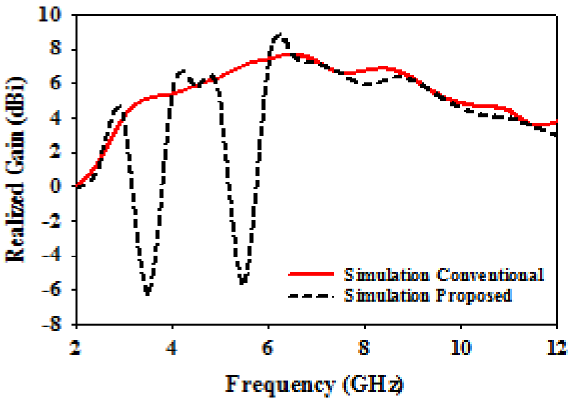
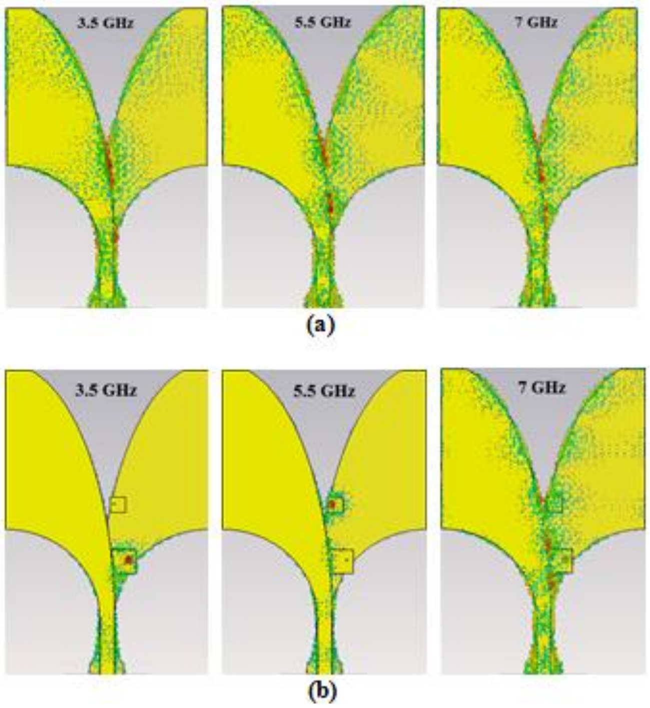


Fig. 4: Antennas Simulated Gain.

Response of the simulated realized gain against frequency of the antennas is shown in Fig. 4. The conventional AVA has a gain of 3 – 7.69 dBi with the peak gain realized at 6.5 GHz. The gain was however suppressed by 11.47dBi (5.16 to -6.31 dBi) within the first notch band central frequency and 12.82 dBi (7.10 to -5.72 dBi) at the second notch band respectively as a result of the EBG structures. The gain of the antenna proposed is 2.86 – 7.68dBi.

From the surface current distribution in Fig. 5, uniform surface current amplitude can be observed at all frequencies along the radiating section of the flared arm of the conventional AVA. On the other hand, the proposed antenna does not radiate any surface current when the EGBs are activated at their respective resonant frequencies of 3.5 GHz and 5.5 GHz commonly thus creating notch band at those frequencies. It can also be noticed that, surface current at 7 GHz for the proposed antenna has strong amplitude indicating the limited effect of the EBG structure at this frequency.

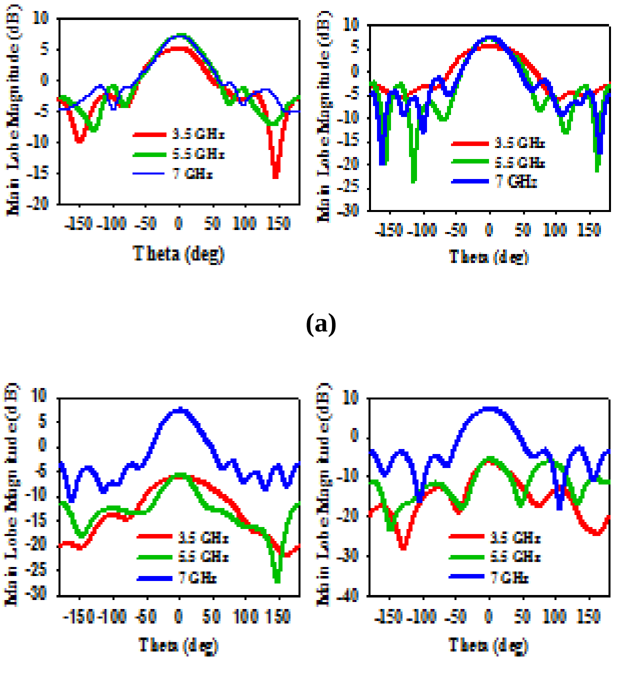


(a)

(b)

Fig. 5: Surface current delivery at 3.5 GHz, 5.5 GHz & 7 GHz (a) Conventional AVA and (b) Prospective AVA.

Simulated far-field radiation patterns in both principal planes at observed frequencies are displayed in Fig. 6. Symmetric radiation pattern is obtained for both principal planes at specified frequencies for the conventional antenna while a clear pattern distortion exist with gain attenuation at the notch band frequencies for the proposed antenna due to the effect of the incorporated EBG structures.



(a)

(b)

Fig. 6: E-Plane and H-Plane Radiation pattern at 3.5 GHz, 5.5 GHz & 7 GHz for (a) Conventional and (b) Proposed Antennas.

V. CONCLUSION

A double-layered band notch antipodal Vivaldi antenna was investigated and proposed in this study for ultra wideband communication systems. With the incorporation of two edge-located vias mushroom EBG structure between the two substrate layers, a dual notch band from 3.18 – 3.80 GHz as well as 5.13 – 5.80 GHz for WiMAX and WLAN applications respectively was achieved. The antenna achieved 2.86 – 7.68dBi peak realized gain with gain suppression of 11.47dBi and 12.82 dBi respectively at the two notch bands. Minimal effect of the EBG structure was also observed on the radiation pattern outside the rejected bands. With uncomplicated design as well as symmetric and balanced directional radiation pattern in the band of operation, the proposed antenna has proved to be a good choice for band notch operation in UWB applications. Proposed antennas prototype will be produced and measured next for simulation results validation.

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