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Application of Modified Electromagnetic Band Gap (EBG) Structures for Notch Band in Ultra-WidebendAntennas

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ABSTRACT: *This paper introduces a novel approach to create notch band within ultra-wideband (UWB) communication systems based on a modified mushroom electromagnetic bandgap (EBG) structures. The concept presented here can be implemented in any structure that has a microstrip in its configuration. The modified edge-located vias EBG structure is characterized and analyzed using Computer Simulation Technology (CST) Microwave Studio full wave electromagnetic solver and then optimized to work at WiMAX band (3.3 – 3.7 GHz). A double layer Antipodal Vivaldi Antenna (AVA) is used to demonstrate the applicability and effectiveness of the novel EBG notch band feature. Simulation results achieved a band notch at 3.18 GHz – 3.80 GHz within the 2.78 GHz to more than 12 GHz operating band of the antipodal Vivaldi antenna which demonstrated the effectiveness of the proposed structure.*

KEYWORDS: *Antipodal Vivaldi Antenna, Dielectric Substrate, Reflection Coefficient, Ultra wideband*

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I. INTRODUCTION

The increased popularity of wireless communication systems and devices coupled with the enormous advances in antenna design over the past decades has continued to open new frontiers in the electromagnetic field which results in the demand of more advanced or special type of electromagnetic materials for high-performance applications. Thus there is growing interest in studying electromagnetic bandgap (EBG) structures for applications at microwave frequencies.

To enhance the functionality of antennas, therefore, new EBG designs have been primarily used(Kim, 2018). Other applications, such as filters and balunshave also been explored (Bezerra, Lira, Campos, Gomes Neto, & da Silva, 2021). Additionally, the EBG structures also possesses features that can be used to reduce or suppress electromagnetic interferences (EMI) that occur in electronic systems leading to electromagnetic compatibility (EMC) issues(Mohan, Esther Florence, Vimal Samsingh, & Ahmed, 2021). The EBG structures suppress the propagation of surface waves over specific frequency bands that directly depend on the dimensions and types of materials used to fabricate the EBGs. A number of studieshave equally shown that electromagnetic band gap (EBG) structure can be used to improve the gain of the antenna, eliminate mutual coupling due to surface wave generation as well as block or allow certain band of frequencies to pass through it.

The Federal Communications Commission (FCC) has specified 3.1 – 10.6 GHz UWB frequency spectrum for commercial use (Yimdjo Poffelie et al., 2016).Unlike other existing wireless communication standards, which are narrowband, UWB has a very wide bandwidth of 7.5 GHz. However, the UWB emission power is limited to a maximum of −41.3 dBm/MHz, therefore it can co-exist with other narrow band services that occupy the same spectrum. These wireless technologies including IEEE 802.16 WiMAX standard at 3.5 GHz and the IEEE 802.11a WLAN standard at 5.5 GHzcan 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.Perturbation techniques have mostly being used to filter out these frequencies from the UWB spectrum. However, these techniques mostly degrade the radiation pattern and efficiency of the UWB antenna.Other techniques such as using capacitive loaded loop (CLL) resonator (Yao et al., 2016)and loading resonant parallel strip (RPS) (Yang et al.,2017)have also being used which generally impacts the design complexity of the antenna.

This paper proposed a simple but effective and efficient design of a modified EBG structure for isolating these interfering narrow band frequencies within the UWB spectrum without negatively affecting other radiation characteristic parameters of the antenna. The EBG structure was be designed and characterized to operate at the intended notched frequencies using the method of suspended transmission line technique before been integrated in to a double layer AVA to demonstrate its notch band capability.

II. THE EBG STRUCTURE

The discovery of today's metamaterial started as far back as the nineteenth century with the experiment on twisted media or artificial chiral element(Verma, 2012)later extended to lightweight microwave lenses which resulted in tailoring the effective refractive index of the artificial media. Research on artificial complex material continued ever since, and after the theoretical investigation by Veselago in 1967 (Alam et al., 2013)the effort was strengthened with the development of the theory of metamaterial (Kubacki et al., 2017)with the study of the electromagnetic properties of 3D periodic structures referred to as "Yablonovite" in 1987 which was further investigated byBowden et al. in the early 1990s.

The initial discovery was realized by mechanically drilling holes into a block of dielectric materials and was found to prevent the propagation of microwave radiation in any 3D spatial direction within the band gap. The concept follows the idea of photonic band gaps (PBG), from optics in solid state physics and optical domain, where photonic crystals with forbidden band-gap for light emission were proposed. However, in order to distinguish these artificially engineered materials of the optical domain from the microwave domain, the term electromagnetic band gap (EBG) was used for the microwave domain(Wang & Liu, 2016). Figure 1 illustrated the metamaterial classification (Kim, 2018).

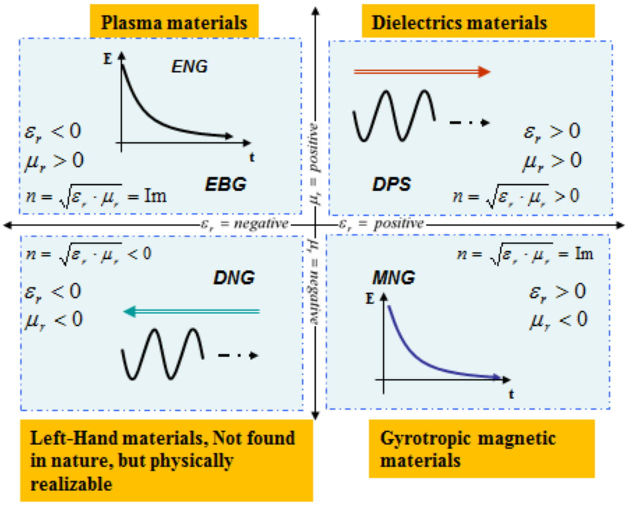


Figure 1: Metamaterial Classification(Kim, 2018).

Metamaterials are classified based on the properties of a material's response to electromagnetic field.These properties are described by defining the macroscopic parameters, permittivity ε and permeability,μ,of the materials(Li et al., 2021). A medium with both permittivity and permeability greater than zero (ε_r>0, μ_r>0) will be designated as double positive (DPS) medium. These include most naturally occurring media (normal dielectrics). A medium such as the Gyrotropic magnetic materials with relative permittivity greater than zero and relative permeability less than zero (ε_r>0, μ_r<0) are designated as mu-negative (MNG) medium. On the other hand a medium with the relative permittivity and relative permeability less than zero (ε_r<0,μ_r<0) is designated as double negative (DNG) medium. Materials belonging to this class are not found in nature but are physically realizable.

The electromagnetic band gap (EBG) is a broad term used to describe materials with ENG property. EBG structures are normally realized by periodic arrangement of dielectric materials and metallic conductors. The EBGs being periodic structures, when they interact with electromagnetic (EM) wave, produces radically distinctive properties at different frequencies. Characteristics such as passing certain frequency bands, rejecting some frequency bands, and behaving like a magnetic conductor in yet another band of frequencies known as the band gap, could be observed(Bezerra et al., 2021). These structures are generally defined as artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states(Lima, Cunha, & da Silva, 2021).

III. NOTCH BAND IMPLEMENTATION

The band gap property is used here to create the frequency band notch of the EBG structure. Therefore, for obtaining the band notches at 3.5 GHz WiMAX band an edge-located vias modified EBG structure is designed and characterize using the full wave frequency solver computer simulation technology (CST) microwave studio. The method of suspended transmission line (MoSTL) is used to analyze the resonant behavior of the EBG cell, where the EBG cell is are positioned under the transmission line in between the two substrates layers as shown in Figure 2.

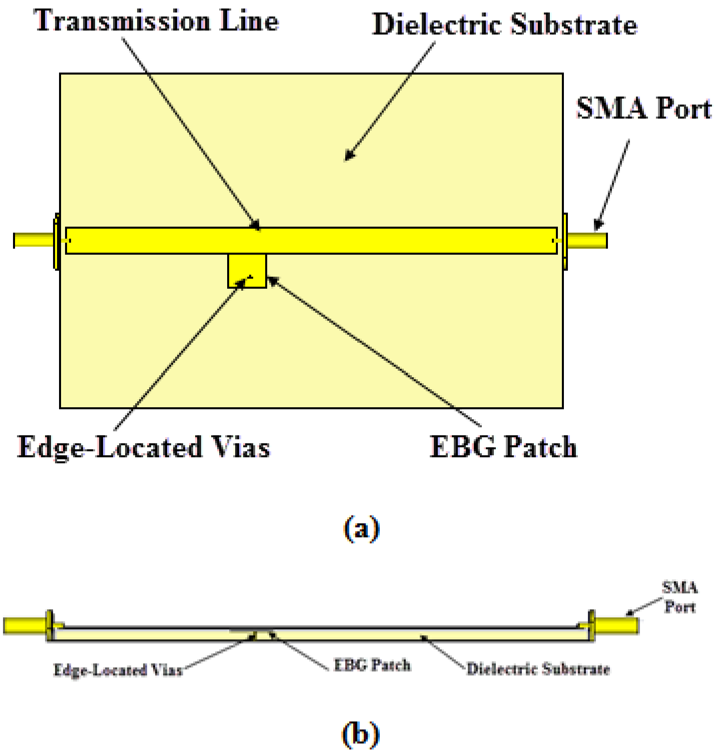


Figure 2: Characterization of the EBG Structure (a) Top View and (b) Side View

From the simulation result of the edge-located vias mushroom EBG structure shown in Figure 3, it can be observed that for the same patch size (7.0×7.0 mm^2), the edge-located vias mushroom EBG has a lower resonance frequency (2.98 GHz) compared to the normal center-located vias mushroom EBG (3.5 GHz). This indicated that the size of the conventional mushroom EBG structure has being miniaturized by moving the vias location to a lateral position without having to change the physical dimension of the structure. Thus moving the vias location to the edge of the EBG structure reduces the size of the structure by **15 %.**

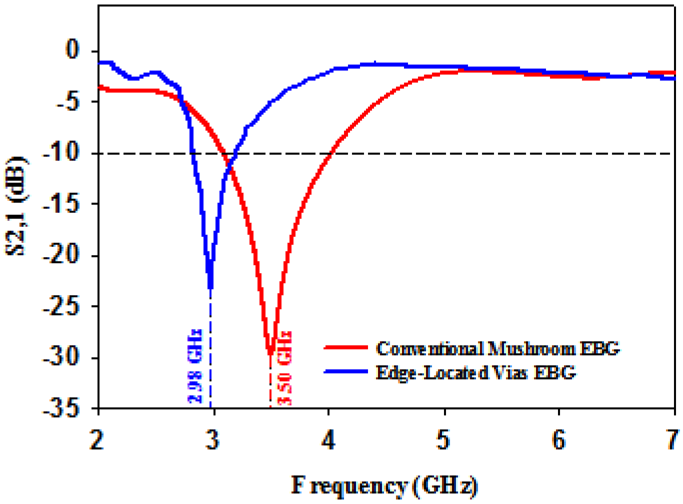


Figure 3: Forward Transmission Coefficient (S_{21}) of Conventional Mushroom EBG and Edge-Located Vias EBG Structures at 7 mm × 7 mm Patch Size

In this configuration the EBG behaves like a stop band filter for the electromagnetic wave propagating in the parallel plate waveguide. The centre of the stop band frequency and the bandwidth are determined by the following equations;

$$f_i = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

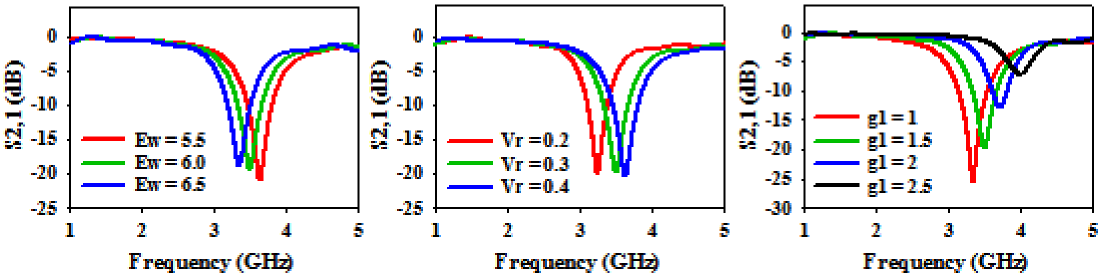
$$BW = \frac{1}{\eta}\sqrt{\frac{L}{C}} \tag{2}$$

Where

$$L = \mu_o h \tag{3}$$

$$C = W\varepsilon_o \frac{(\varepsilon_r + 1)}{\pi} \cosh^{-1}\left[\frac{2W + g}{g}\right] \tag{4}$$

C is the capacitance due to the voltage gradient between the top conducting pad and the bottom metal plane while Lis the inductance of the vias connecting the bottom metal plane to the pad. C is determined by the size of the pad, the distance from the top and bottom planes and the dielectric material between the two planes. L is mostly influenced by the size of the connecting via (length, diameter) but also by its position with respect to the center of the patch.To maintain the resonance frequency of the edge-located vias EBG structure at 3.5GHz a parametric sweep of EBG patch size, Vias radius and the distance between the EBG patch and the feed line was conducted as shown in Figure 4.



(a) **(b)** **(c)**

Figure 4. Effect of variation of (a) patch widthE_w (b) vias radius V_r and (c) distance between EBG patch and feed line g_1, against frequency.

Figure 4(a), shows that increasing the patch width E_w, increases the capacitance C_i which result in lowering the resonant frequency from equation (1). On the other hand, from Figure 4(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 (1). Likewise from Figure 4(c), a decrease in resonant frequency is observed when the gap between the transmission line and the EBG patch $g_1$is decreased.

IV. ANTIPODAL VIVALDI ANTENNA WITH EBG STRUCTURE

A microstrip line fed conventional antipodal Vivaldi antennaof size 55 x 70 mm^2 is designed on a double-layered inexpensive fire retardant-4 (FR4) dielectric substrate having relative permittivity (ε_r) of 4.3, dielectric loss tangent $\delta = 0.025$ and a combined thickness (h_1+h_2) of 2.1mm.The designed edge-located vias modified EBG cell with a footprint of 6 x 6 mm^2 and height of 0.035 mm was then embedded in to the antipodal Vivaldi antenna using the methodology explained in Section 3 as shown in Figure 6.

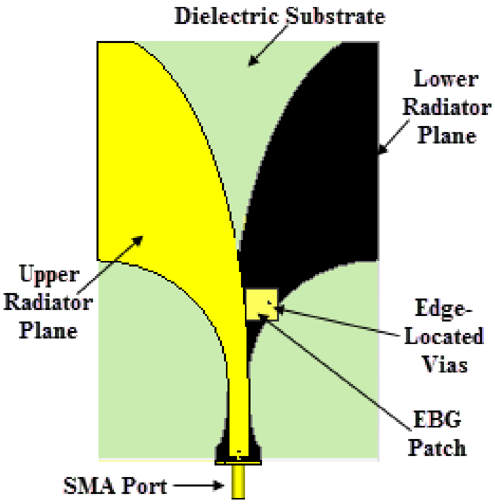


Figure 5. Antipodal Vivaldi antenna with proposed EBG structure

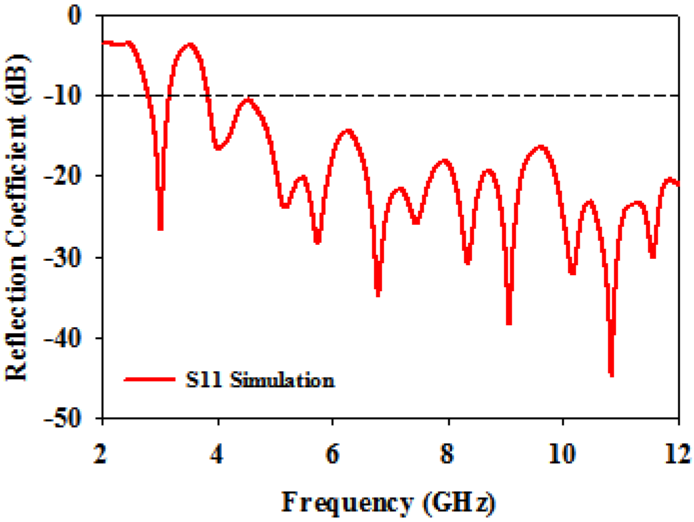


Figure 6. Simulated result to varify the effectiveness of proposed EBG structure

The simulation results of the antipodal Vivaldi antenna incorporated with the proposed EBG structure is shown in Figure 6. From the plot of the reflection coefficient against frequency for the band-notch AVA, the antenna has an ultra-wide impedance bandwidth from 2.78 GHz to more than 12 GHz. When the proposed edge-located vias modified EBG structures was introduced to test its band notch effectiveness, a very sharp notch centred at 3.5 GHz with a rejection frequency notch at 3.18 GHz – 3.80 GHz for IEEE 802.16 WiMAX applications was obtained.

V. CONCLUSION

In this paper a compact modified electromagnetic band gap structure based on the mushroom EBG element coupled to a microstrip line has been investigated theoretically, exploiting its band gap feature to realize a notch band centered at 3.5 GHz for WiMAX applications. A design methodology for the structure has been proposed and implemented, using an ultra-wideband antipodal Vivaldi antenna to demonstrate its ability to govern the notch band. A band notch frequency of 3.18 GHz – 3.80 GHz for IEEE 802.16 WiMAXwas achieved within the 2.78 GHz to more than 12 GHz operating band of the antenna. The new structure is very simple and can be implemented in any design that has microstrip lines; it has the advantage of a small footprint and extensive tune-ability.

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