12. Devices and Applications

Compact Electromagnetic Bandgap Structures for Notch Band in Ultra-Wideband Applications

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***Abstract* — This paper introduces a novel approach to create notch band filters in the front-end of ultra-wideband (UWB) communication systems based on electromagnetic bandgap (EBG) structures. The design presented here can be implemented in any structure that has a microstrip in its configuration. The EBG structure is first analyzed using a full wave electromagnetic solver and then optimized to work at WLAN band (5.15-5.825GHz). Two UWB passband filters are used to demonstrate the applicability and effectiveness of the novel EBG notch band feature. Simulation results are provided for two cases studied.**

I. INTRODUCTION

In recent years there has been a lot of interest in investigating electromagnetic bandgap (EBG) structures for various kinds of applications at microwave frequencies. EBG structures proposed over the past few years have been used primarily to enhance the functionality of antennas [1], but other applications − such as filters and baluns at microwave frequencies − have also been explored [2]. Moreover, the EBG structures have inherent features that can be used to reduce or suppress completely electromagnetic interferences (EMI) that can occur in electronic systems leading to electromagnetic compatibility (EMC) issues [3]. 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. However, in this work we focus on a slightly different application of these structures. Consider the design of a notch band structure that can be used in ultra wideband (UWB) radio systems and can be easily integrated with microstrip circuitry fabricated with printed circuit board (PCB) technology. Since February 2002, when the Federal Communication Commission (FCC) released the 3.1-10.6GHz band for commercial communication usage, UWB has been receiving a lot of attention from both academia and industry. Unlike other existing wireless communication standards, which are narrowband, UWB has a very wide bandwidth, 7.5GHz wide to be precise. However, the UWB emission power is limited to a maximum of −41.3dBm/MHz therefore it can co-exist with other narrow band services that occupy the same spectrum. One such service is the 802.11a WLAN that is located at 5.15-5.45GHz and 5.725-5.825GHz. Recent work has shown that the effect of the 802.11a interference on UWB can be harmful and, depending on the probability of signal overlap and the relative distance between the two transceivers, the 802.11a interference can cause significant signal degradation of the attainable throughput of the UWB system [4]. Therefore it is very important to incorporate means that can mitigate the effects of 802.11a in an UWB front end. Different types of structures for the physical layers and techniques for the MAC layers have been suggested recently. The previously proposed notch filter solutions are very specific to certain types of filters or antennas, therefore they cannot be easily integrated in a different design [5, 6, 7]. In this paper we propose a more general approach that can be implemented in any physical design that has at least a microstrip structure in its front end.

II. THE EBG STRUCTURE

As mentioned in the Introduction, EBG structures have been used for different types of applications in the past few years. The most popular mushroom like EBG structure was first introduced by Sievenpiper in 1999 [1]. The physical mechanism of the mushroom like EBGs can be explained by a simple equivalent LC parallel resonant circuit. However, more recently the EBG structures have been used to suppress the noise propagating in parallel plate waveguide structures, such as the power planes of high speed electronic systems. In this environment the equivalent circuit that can be used to explain the EBG behavior is somewhat different to the initial LC parallel resonant circuit used by Sievenpiper to explain the behavior of the EBGs in an open environment. Due to the EBG's proximity to the two metal planes in this set-up, the capacitances to the plane above and bellow the mushroom are much higher that the capacitance between the edge of the adjacent mushrooms. Therefore these capacitances will now dominate the response of the EBG structure.

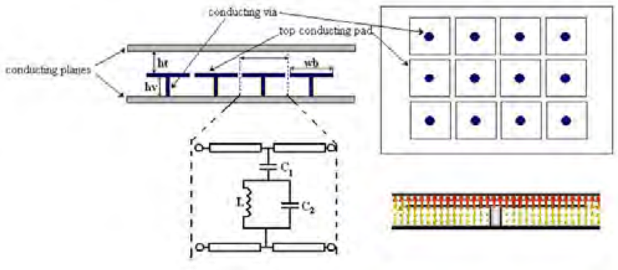

Fig. 1. EBG embedded between two metal planes and its equivalent circuit

In this configuration the EBG behaves like a stop band filter for the electromagnetic wave propagating in the parallel plate waveguide. The center of the stop band frequency and the bandwidth of the stop band are determined by C_1, C_2 and L, where C_1 is the capacitance between the top conducting pad and the above metal structure, C_2 is the capacitance between the pad and the bottom metal plane and L is the inductance of the via connecting the bottom metal plane to the pad. The capacitances of the structure C_1 and C_2 are determined by the size of the pad, the distance from the top and bottom planes and the dielectric material between the two planes. The inductance of the structure L is determined by the size of the via (length, diameter) but also by its position with respect to the center of the patch. As the distance between the two parallel plates is much smaller than the size in the *xy* direction, it can be assumed that the only mode travelling in this wave guide is a TEM mode. Therefore it is expected that, if the EBG structure is embedded within another wave guiding structure supporting a TEM mode, a similar response will be obtained. This has been confirmed through simulation of a microstrip line run above the EBG. As previously, the observed behavior can be explained by the circuit in Fig.1. The return loss of the microstrip routed above one mushroom has a zero at frequency f_1 and a pole at f_2, where f_1 and f_2 are:

$$f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_2)}} \quad \text{and} \quad f_2 = \frac{1}{2\pi\sqrt{LC_2}} \tag{1}$$

Hence the stop band appears at the frequency f_1. Another interesting behavior of this circuit is that the relative band width of the circuit is proportional to $\sqrt{(C_1 + C_2)/L}$; therefore by controlling the size and the design of the EBG element one can tune frequency of the stop band as well as its bandwidth. This behavior has also been confirmed through numerical simulation.

The size of the EBG structure is critical when it has to be integrated into a practical design. Unfortunately the size of a mushroom EBG to be integrated into a practical substrate such as FR4 is quite large (4.4x4.4mm) if for example the 5.5GHz is chosen as the resonant frequency. Another drawback of the mushroom structure is the fact that its inductance is very small while C_1 and C_2 are much bigger; therefore the bandwidth of the stop band is relatively large and may not be useful for a notch filter application. A compact and novel EBG element based on small planar inductor is introduced to solve the above problem. The design and optimization of the size and shape of the inductor based EBG is done using a full wave simulation software. The numerical tool (CST-Microwave Studio) used for this work is based on Finite Integration Technique (FIT) [8]. Through this approach a much smaller EBG structure is obtained, only 2x2mm for a FR4 substrate. Moreover, the corresponding inductance is much higher while the two capacitances are much smaller. However, the design of such structure is not as straightforward as the design of a simpler mushroom structure as its total inductance and capacitances have to be computed through a rigorous three dimensional numerical model. The appropriate ratio between total capacitance and inductance of the structure has to be calculated carefully and an iterative process is necessary to obtain the optimum design.

III. UWB FILTERS WITH EMBEDDED EBG ELEMENT

Using the features described above one can design small structures with notch band characteristics that can be incorporated into existing designs without large and costly modifications. In this section two band pass filters that can be used in UWB applications were modified to incorporate the notch band feature for the WLAN. All the following results were obtained through full wave simulation using CST Microwave Studio.

The first UWB filter studied here is based on the broadside coupling between a microstrip and a coplanar waveguide (CPW). The CPW is on the ground of the microstrip, while the two microstrip lines on the top surface are separated by a small gap. The second UWB filter has two coupled L-shaped microstrips on the top layer and a stepped impedance resonator (SIR) on a defected-ground structure (DSG) on the bottom layer. The UWB filters described above are considered to be built on different types of a substrate. The first design uses a dielectric substrate with a dielectric constant of 2.17 whereas the second filter has a substrate with a constant of 4.4 (FR4).

The simulations results in terms of the magnitude of the insertion loss (|S21|) obtained from the full wave numerical solution are presented in Fig. 2. It can be observed that both designs have a sharp stop band feature in the WLAN band without serious degrading of the passband for the designs with the novel inductor based EBG implemented.

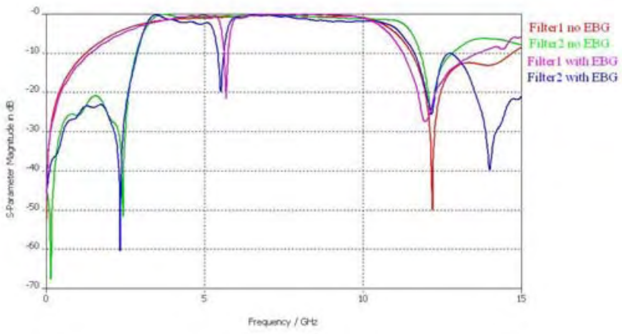

Fig. 2. Magnitude of the return loss for the four cases studied

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