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Dispersion Analysis and Design of Planar Electromagnetic Bandgap Ground Plane for Broadband Common-Mode Suppression

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***Abstract*—Planar electromagnetic bandgap (EBG) structure designed for broadband common-mode suppression is proposed. A uniplanar compact photonic-bandgap (UC-PBG) structure with periodic center slots is etched on the ground plane to obtain broadband common mode suppression while minimally disturbing the differential signal within the designed bandwidth. Dispersion analysis has been conducted for both common (even) and differential (odd) mode signals. Good signal integrity is observed in both simulated and measured results. The fractional bandwidth of the proposed EBG ground plane is around 80 % with common-mode suppression below –15 dB. The proposed EBG ground planes may be applicable for systems requiring low-cost and simple solutions in designing high-speed differential interlinks operating above 5 Gbps.**

***Index Terms*—Electromagnetic bandgap (EBG), Common -mode suppressor, dispersion diagram.**

Introduction

HIGH immunity to noise, low crosstalk, and low electromagnetic interference (EMI) are some of the intrinsic advantages of differential interconnects. For these reasons, differential signal lines have played an important role in high-speed digital systems. In reality however, undesired common-mode signals may arise due to timing skew or amplitude imbalance between the differential lines. Common-mode noise will degrade the signal or power integrity, and may even radiate when coupled to the I/O cables. Therefore, broad band common-mode suppression is highly desired.

Typically, ferrite cores have been utilized as the solution for suppressing common-mode noise of low-frequency differential interconnects [1]-[2]. However, to improve the signal integrity of gigahertz differential signals, several broadband common-mode filters based on defected-ground planes have been recently proposed [3]-[6]. Selective filtering of the return current path for the differential and common-mode signals determines the level of common-mode suppression. For microstrip coupled lines, the differential signal's return current

Fig. 1. Illustrative sketch of the proposed UC-PBG ground plane with periodic center slots integrated with differential signal lines (a = 140 mil, w = 15 mil, g_3 = 25 mil, and h = 25 mil).

path is through the coupled lines. On the other hand, the ground plane is the return path for the common-mode. To provide common-mode suppression with minimal change to the differential mode, a bandstop filter or high-impedance current path may be integrated to the ground plane. By aligning the high impedance bandgap to the common-mode signal within the frequency band of interest, common-mode noise can be suppressed without significantly affecting the differential mode. Some recent examples that are based on different design methodologies include a bandstop filter integrated into the ground plane that provides over 15 dB of common-mode suppression with ~86 % bandwidth [3], a common-mode filter using metamaterial concepts [4], a common-mode suppressor by means of double-slit complementary split-ring resonators that provide better than 20 dB rejection level with a 41 % fractional bandwidth [5], and a periodic defected ground plane that provides a simple and low cost solution for wideband common-mode suppression [6]. This work is similar to [6]. However, compared to [6], the proposed solution based on the uniplanar compact photonic-bandgap (UC-PBG) ground plane [7] provides wider 20 dB common-mode suppression bandwidth.

The UC-PBG is a two dimensional array of complementary Jerusalem cross metallic structures that behaves as a parallel LC tank, thereby presenting a high impedance path for the currents traveling through the structure. The capacitance and inductance are provided by the thin gap between the adjacent metallic patches and the narrow branches connecting each unit-cell, respectively. UC-PBG ground planes have been incorporated in generating various novel and alternative

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Fig. 2. Eigenmode simulation setup of a unit-cell for obtaining dispersion properties of even and odd mode propagations (a = 140 mil, b = 5 mil, w = 15 mil, g_1 = 10 mil, g_2 = 15 mil, and s = 60 mil).

(a)

(b)

Fig. 3. Dispersion diagram of the differential interconnect with EBG ground plane operating in (a) even and (b) odd modes.

microwave solutions otherwise difficult to realize using conventional microwave devices [7]. For example, UC-PBG ground planes have been utilized in both passive and active devices to suppress intrinsic spurious transmission of microwave filters, LO leakage in mixers, harmonic transmission in power amplifiers, etc. [8]. High impedance surfaces based on various form factors other than UC-PBG have also been extensively researched to improve the signal integrity of high-speed circuits. For example, dispersion engineering has been examined and applied in designing parallel-plate noise suppressors for power ground planes [9]-[11]. In this paper however, we focus our efforts on improving the signal integrity for a particular type of interconnect, differential lines, by using a planar high impedance UC-PBG structure. We utilize selective dispersion engineering of an electromagnetic bandgap ground plane for even and odd mode signals in designing a broadband common-mode suppressor for differential signal lines. A detailed dispersion analysis of the UC-PBG ground plane with periodic center slots for common-mode suppression application is presented in the following section and verified with the measured results to demonstrate excellent differential signal integrity while providing a broad common-mode rejection bandwidth.

Dispersion Analysis

Dispersion diagrams for the even and odd modes are presented to understand the passband and bandstop regions for the common-mode (even mode) and differential-mode (odd mode) signals. Even and odd mode propagation are verified by examining the field profiles of the EBG integrated coupled microstrip line. Fig. 2 shows the eigenmode simulation setup of the unit-cell used to obtain the dispersion diagrams. Even and odd mode operation/propagation is enforced with a perfect magneticconductor (PMC) and perfect electric conductor (PEC) symmetry plane, respectively. Periodic boundary conditions are assigned to replicate the periodicity of the unit cell in the wave propagation direction (z-direction) and an impedance surface is assigned to all other surfaces of the unit cell. Corresponding dispersion diagrams for the even and odd modes are shown in Fig. 3. At low frequencies, even and odd signals have a dispersion that hug a linear dispersion as shown with the dash line. As the frequency increases, a slow wave effect of the periodic structure is exhibited for both propagating modes [12]. It is noted that the proposed UC-PBG ground plane generates fundamental mode stop bands above ~3.5 GHz and 9.5 GHz for the even mode and odd mode, respectively. The UC-PBG ground plane resonances are also obtained from the eigenmode solver and are shown with gray dots. The UC-PBG ground plane allows a quasi-TEM mode propagation for differential signals while suppressing the common-mode signal between the frequency range from around 3.5 GHz to 8 GHz. In order to provide broad operational bandwidth, the ground plane should ideally present an open circuited path to the common-mode return current while minimally affecting the differential signal over the desired bandwidth. Although the main portion of the field will be confined between the coupled lines for differential signals, coupling to the ground plane may not be completely avoided, especially for thin substrates. Even weak coupling to these ground plane resonance may add up as the unit-cells are cascaded and create noticeable insertion loss near the natural resonance frequency of the periodic structure. To reduce the ground coupling of the differential signal a small periodic open slot (40 x 85 mil.) is etched in the ground plane directly below the center of the coupled lines. This modified UC-PBG ground plane structure provides broadband common-mode suppression while minimally disturbing the quasi-TEM differential signal transmission within the common-mode suppression bandwidth.

Simulated and measured Results.

To examine the common-mode suppression, ten unit-cells

(a)

(b)

(c)

Fig. 4. Fabricated common-mode suppressors: (a) top view, (b) bottom view for ten unit-cell case, and (c) bottom view for three unit-cell case.

Fig. 5. Scattering parameters of simulated and measured transmission for coupled microstrip lines with a ten unit-cell EBG ground plane.

Fig. 6. Scattering parameters of simulated and measured transmission for coupled microstrip lines with a three unit-cell EBG ground plane.

are cascaded along the coupled microstrip lines. Fabricated circuits are shown in Fig. 4. Coupled microstrip lines are designed to provide Z_{odd} close to 50 Ohm. Using Rogers RT/duroid 6010.2 with ε_r = 10.2, $tan\delta$ = 0.0023, and h = 25 mil an odd impedance Z_{odd} = 51 Ohm and even impedance Z_{even} = 70 Ohm is achieved with the microstrip width of w = 15 mil and spacing of s = 25 mil. The measured common-mode suppression percent bandwidth is around 80 % (3.3 GHz to 8 GHz) for a suppression level below -15 dB and 70 % (3.3 GHz to 7 GHz) for the suppression level below -20 dB, as shown in Fig. 5. The measured insertion loss of the odd-mode signal is maintained above -1.5 dB from DC to 8.5 GHz. Even with only three unit-cells, 20 dB common-mode suppression can be maintained from around 3.5 GHz to 7.5 GHz (Fig. 6). The difference between the simulated and measured results may be due to fabrication and assembly errors.

Conclusion

Broadband common-mode suppressors based on EBG ground planes are designed using dispersion analysis for high-speed differential signal lines. The common-mode suppressor based on the UC-PBG ground plane with open center periodic slots demonstrates broadband operation with good common-mode suppression. This method may be useful in designing low cost differential interconnects operating above 5 Gbps that require broadband common-mode suppression.

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