Coupling Suppression in Microstrip Lines Using a Bi-Periodically Perforated Ground Plane

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***Abstract*—A perforated ground plane is used to suppress the coupling between adjacent and intersecting transmission lines. Experimental results indicate 40-dB suppression of broadside coupling between two adjacent 50-Ω lines. A new option in the design of circuit routing schemes is proposed by demonstrating 28-dB coupling reduction between two intersecting 50-Ω lines.**

***Index Terms*—Coupling, crosstalk, photonic bandgap (PBG).**

I. INTRODUCTION

A major limitation in realizing high-density monolithic microwave integrated circuits is the parasitic coupling and crosstalk that arise between neighboring transmission lines. There have been several studies aimed toward alleviating these problems. One approach involves thinning the substrate under signal lines to facilitate quasi-TEM mode propagation, but this requires an involved etching process [1].

This paper introduces a coupling-reduction scheme for high-density circuits that allows adjacent lines to lie closer or even intersect each other. We address a specific case of transmission-line coupling that occurs when the lines carry different frequencies, as in a transmit/receive module routing different uplink and downlink frequencies.

Coupling suppression is achieved with planar photonic-bandgap (PBG) structures that function as a form of planar filter residing in the normally unused ground plane. This avoids additional top-layer filtering circuitry, thus saving valuable chip real-estate area. PBG structures for microwave transmission lines have been proposed for use in compact filter design, circuit-size reduction due to its slow-wave nature and for numerous other applications [2]–[7]. One of the earliest demonstrated PBG structures for microstrip transmission lines consists of a square lattice of etched circles in the ground plane [2]. The lattice period is approximately half of a guided wavelength at the stopband center frequency. As a result, this topology is very design friendly, requiring little or no electromagnetic simulation to predict the stopband frequency.

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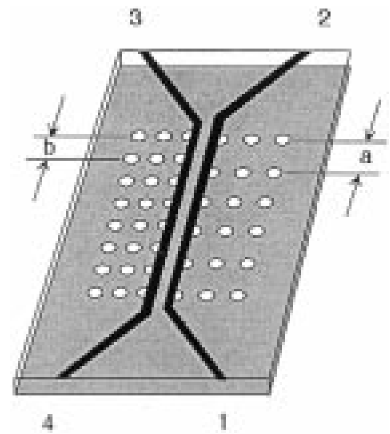

Fig. 1. Coupling reduction scheme for adjacent microstrip lines carrying different frequencies. Perforations in the ground plane serve as photonic-bandgap structures to suppress coupling between adjacent transmission lines.

This letter demonstrates how the perforated ground plane structure is employed in two different circuit topologies to reduce unwanted coupling and crosstalk in high-density circuits. The first example consists of a pair of closely spaced microstrip lines, one carrying a Ku-band signal and the other an X-band signal, which would be the scenario in a fully integrated transmit/receive module routing different uplink and downlink frequencies. In the second example, the PBG suppression concept is used for two intersecting lines that are each designated to carry a specific frequency band, adding an interesting degree of freedom in interconnect layout design.

II. ADJACENT MICROSTRIP LINES

Fig. 1 shows two adjacent 50-Ω microstrip lines separated by 1 mm. The lines are printed on a 0.71-mm-thick RT/Duroid substrate with $\varepsilon_r = 2.2$ and incorporates a perforated ground plane for coupling suppression. Line A connecting Ports 1 and 2 is intended to guide a Ku-band signal, while Line B connecting Ports 3 and 4 is intended to guide an X-band signal. In the ground plane of the Ku-band line is a PBG structure that has a stopband at X-band, and vice-versa, for the other line. This allows the Ku-band signal to propagate unimpeded on its intended line, but also suppresses the coupling of the X-band signal from the neighboring line.

As in [2], the ground-plane PBG structure consists of a square lattice of circles with a radius of 2 mm. The radius of the circles influences the depth, width, and roll off of the stopband and,

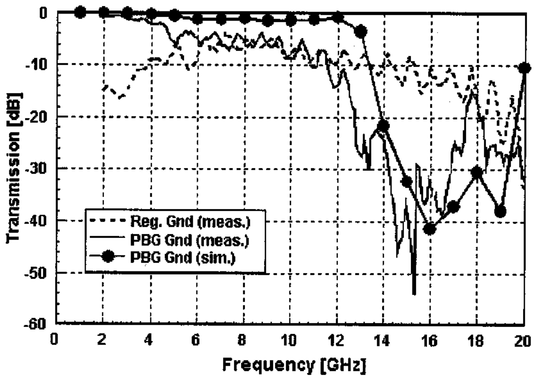

Fig. 2. Measured and simulated transmission coefficient (S34) of Line B for the adjacent-line structure of Fig. 1.

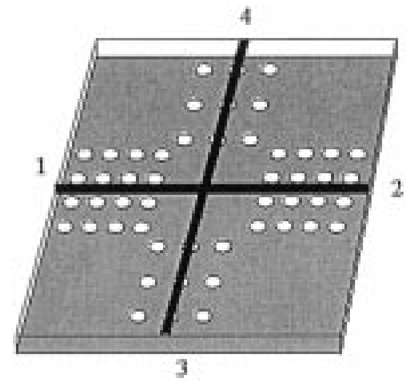

Fig. 4. Coupling reduction scheme for intersecting microstrip lines.

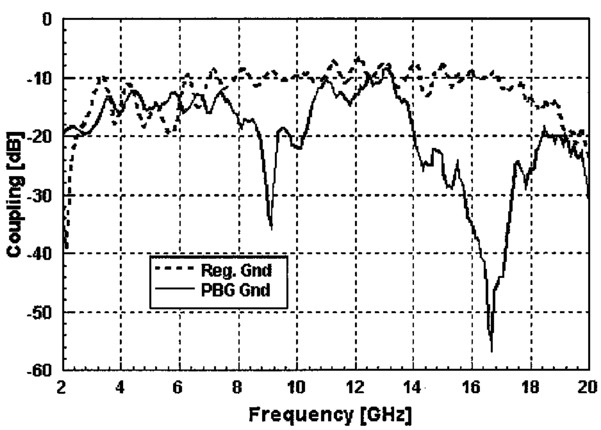

Fig. 3. Measured coupling reduction (S14) between Lines A and B for the adjacent-line structure of Fig. 1.

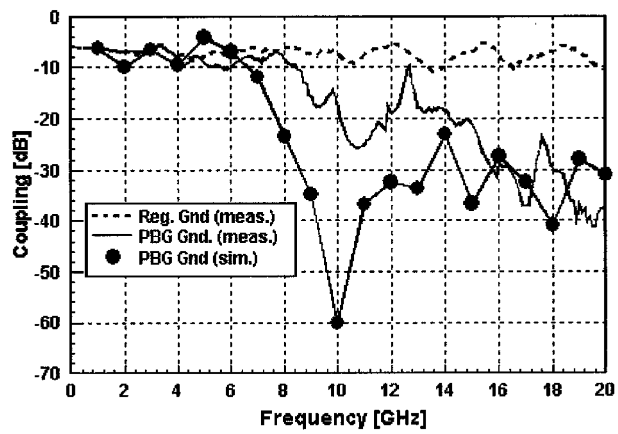

Fig. 5. Measured and simulated coupling reduction (S23) between Lines A and B for the intersecting-line structure of Fig. 4.

therefore, must be optimized to achieve the desired attenuation level and frequency separation of the two signals. The lattice periods are $a = 9.8$ mm for Line A and $b = 6.1$ mm for Line B. These spacings are approximately half of a guided wavelength at the stopband frequency of each respective line.

Fig. 2 compares the measured and simulated transmission coefficient (S34) of Line B, which is designed to reject Ku-band signals while allowing other frequencies to propagate unimpeded. The simulations were performed using Sonnet *em*. Both the measured and simulated data show a wide stopband in the Ku-band ranging from 13–18 GHz. At X-band, the insertion loss is comparable with the same adjacent line structure on a regular solid ground plane, as expected.

Fig. 3 shows the coupling between the two adjacent lines (S14). For a regular ground plane, the close proximity of the two lines results in a nominal coupling of 10 dB across a wide band. In contrast, the perforated ground plane results in a 40-dB coupling reduction at 17 GHz and a 26-dB reduction at 9 GHz. It must also be noted that, because the filtering affect of the ground plane perforations is mainly due to the etched circles directly under the transmission line due to the high field concentration in that area, a single row of circles in the signal propagation direction may be used to achieve even higher circuit density at the cost of slightly lower coupling reduction levels as compared to a complete square lattice of circles.

III. Intersecting Transmission Lines

Multilayer architectures are sometimes used in high-density circuits in which a transmission line on one layer must be routed across another transmission line on a second layer. Fig. 4 proposes an alternative single-layer architecture consisting of two intersecting, frequency-selective microstrip lines. Here, Line A (connecting Ports 1 and 2) is intended to guide an X-band signal and has a PBG ground plane designed to prevent coupling of Ku-band signals traveling on Line B (connecting Ports 3 and 4). This scheme permits new options in the layout of integrated millimeter-wave circuits. For example, in addition to the space saving and simplified architecture offered by intersecting two lines, the microstrip line section residing over the PBG circle lattice need not be straight, but may also bend [2], increasing the potential overall circuit size reduction. Although a specific intersection angle is presented here, this is not believed to be a limitation of this approach as in integrated optics, where two optical waveguides can intersect each other with minimal coupling only at the so-called magic angle [8].

Fig. 5 compares the simulated and measured cross coupling between Lines A and B printed on a ground plane with PBG lattice dimensions identical to the ones discussed in Section II. For a regular ground plane, the coupling is between 6–8 dB. For the perforated ground plane, reductions of 20 dB at 11 GHz and 28 dB at 17 GHz were observed.

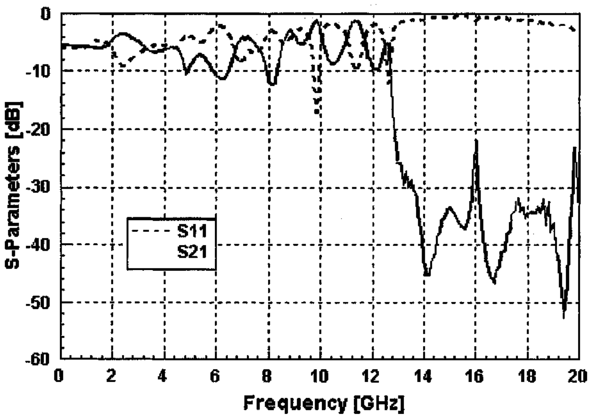

Fig. 6. Measured reflection (S11) and transmission (S21) coefficients of Line A for the intersecting-line structure of Fig. 4.

The full two-port S-parameters characterizing Line A are shown in Fig. 6. A clear stopband is observed at Ku-band, but more importantly we see that signals are able to pass unimpeded at certain X-band frequencies. The X-band windows arise from the spacing between the cross-junction and the edge of the X-band PBG lattice, which is purely reactive within the stopband. The Ku-band line is thus shunted by this reactive loading, resulting in the resonance effect seen in Fig. 6. Ideally, we would like to realize a parallel infinite impedance at the cross-junction for complete transmission.

IV. Conclusion

This letter demonstrated a coupling-suppression scheme using a perforated ground plane for use in high-density circuits. The approach is valid in cases where microstrip lines support signals at different frequencies, as in a transmit/receive module. For two adjacent transmission lines, broadside coupling was suppressed by as much as 40 dB. For two intersecting lines, coupling was reduced by as much as 28 dB. Together with the slow-wave propagation effect inherent in PBG structures, this coupling-suppression approach offers new possibilities in circuit layout and transmission-line routing, potentially increasing circuit and system-level integration.

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