New Periodic-Loaded Electromagnetic Bandgap Coplanar Waveguide With Complete Spurious Passband Suppression

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***Abstract*—In this letter, coplanar waveguides (CPW) periodically loaded with shunt capacitances and periodically perturbed by varying the distance between the central strip (of constant width) and ground planes are studied. It is demonstrated that the multiple spurious passbands above the Bragg frequency, inherent to the presence of the reactive elements, can be completely and efficiently rejected by means of very simple geometry perturbation. This result is in contrast to previous works, where the rejection of multiple frequencies requires complex layout patterns and reveals that the elimination of spurious frequency bands in periodic loaded CPWs can not be merely estimated from the Fourier transform of the perturbation geometry.**

***Index Terms*—Coplanar waveguide (CPW) technology, electromagnetic band gap (EBG), microwave filters.**

I. Introduction

COPLANAR waveguide (CPW) technology has recently attracted much attention for the fabrication of transmission lines periodically loaded with reactive elements, the main advantage being the single metallization level required for signal and ground, which eases device grounding and limits line to line coupling. Microwave and millimeter wave low-pass filters, phase shifters [1], and frequency multipliers [2] are some of the applications of this technology that can be achieved by loading CPWs with shunt capacitances. Key to these applications is the presence of the reactive elements, which introduce periodicity and dispersion. The consequence is the presence of passband-stopbands in the frequency response and thus the filtering properties of the structure. If the shunt capacitances are replaced by varactor diodes, propagation velocity can be tailored by means of an external bias and operation as a phase shifter results. Finally, under large signal conditions, nonlinearity and dispersion combined give rise to soliton-like propagation [3], and harmonics of the fundamental frequency are produced. The relevant parameter for the design of these devices is the Bragg frequency (which delimits the first frequency band). It gives the cutoff of the structure operating as a low-pass filter and determines the operating bandwidth in phase shifters and frequency multipliers. However, due to periodicity, the presence of undesired spurious passbands above the Bragg frequency is unavoidable. In this work, we propose a method to reject these spurious passbands which is based on the electromagnetic band gap (EBG) concept [4] and consists of periodically perturbing the wave impedance of the line.

It has been previously demonstrated that a periodic perturbation of the wave impedance of a transmission line produces Bragg reflection in some frequency bands. According to coupled mode theory [5], [6], these rejected bands are roughly given by the spectrum of the coupling coefficient, which is closely related to the spatial variation of wave impedance and, hence, line geometry. This method has been successfully applied to the elimination of spurious bands in distributed passband filters by periodically modulating device footprint [7]. Also, EBG structures have been used to enhance efficiency in broad-band power amplifiers by harmonic tuning [8], to cite some examples of EBG applications. In this work, we explore the application of EBG structures to CPWs periodically loaded with shunt capacitances with an eye toward the rejection of the spurious passbands above the Bragg frequency. To this end, the distance between the central strip (of constant width) and ground planes will be periodically varied [9] (different types of geometry modulation in CPWs have been recently proposed [10], [11]). As will be shown, the combination of shunt capacitors and geometry modulation enhances the reflection properties of the structure being possible the rejection of all spurious bands with very simple geometry perturbation.

II. Design of Periodic Loaded EBG-CPW Structures

For comparison purposes, we have fabricated two structures: one of them with geometry perturbation (from now on referred to as PL-EBG-CPW) and the other with uniform lateral dimensions (PL-CPW). Both structures have been designed to be fabricated on a Rogers RO3010 substrate ($\varepsilon_r = 10.2$, thickness $h = 1.27$ mm) and to exhibit a Bragg frequency of $f_B = 0.7$ GHz. This frequency has been chosen relatively small to be clearly separated from the self-resonant frequency of loading devices (2.2-pF phicom capacitances disposed in parallel pairs), which is in the vicinity of 3 GHz. For the design of the PL-CPW, it is also necessary to set the lower frequency of the first spurious band. A value of 1.2 GHz has been selected in order to ensure that the resonant frequency of capacitors lies above the second

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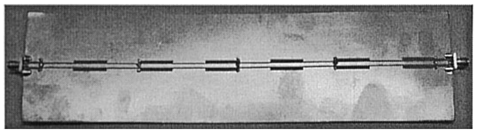


Fig. 1. Fabricated PL-EBG-CPW structure with five capacitor pairs.

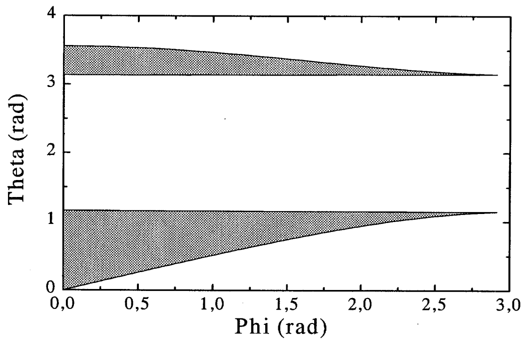


Fig. 2. Dispersion diagram of an arbitrary periodic loaded unperturbed coplanar waveguide (PL-CPW) depicted in a reduced Brillouin zone.

spurious band. By using a commercial transmission line calculator, the geometry of the PL-CPW has been obtained, i.e., the width of the central strip is $W = 2.2$ mm, the distance to ground planes is $G = 1.56$ mm, and the distance between consecutive capacitor pairs is $l = 6.1$ cm. This results in a 50-Ω characteristic impedance for the PL-CPW (i.e., 0-dB insertion loss at low frequencies), whist the wave impedance of the unloaded line is $Z_o = 65\,\Omega$.

For the design of the PL-EBG-CPW, the wave impedance of the line must be symmetrically varied around 65 Ω. Specifically, step variations of 15 Ω up and down have been considered, resulting in a square wave geometry where G alternates between 0.77 mm and 2.52 mm (Fig. 1). As it is well known, the center frequency of the rejected band f_o is related to the period of the perturbation λ_T through the Bragg condition, i.e., $\lambda_T = v_{pL}/2f_o$, where v_{pL} is the propagation velocity of the loaded line. However, the design of the EBG structure necessary to suppress the spurious bands requires some caution since the unperturbed line is very dispersive near and above the Bragg frequency, and v_{pL} is, thus, frequency dependent. Therefore, to determine λ_T, it is necessary to use the dispersion relation of the PL-CPW, which is given by [12]

$$\cos \beta l = \cos kl - \frac{\omega C_{ls} Z_o}{2} \sin kl \tag{1}$$

where k and β are the phase constants of the unloaded and loaded line, respectively, and C_{ls} the loading capacitances. The dispersion relation is depicted in a Brillouin diagram in Fig. 2, where $\theta = kl$ is proportional to frequency and $\varphi = \beta l$. This is a representation in a reduced zone, i.e., $0 \le \varphi \le \pi$. Actually, the first frequency band $(f < f_B)$ corresponds to this interval, while the following passbands are delimited by phase constants given by the intervals $n\pi \le \varphi \le (n+1)\pi$, where $n = 1, 2, 3 \ldots$ enumerates the spurious bands. The passbands of the structure (determined by those frequencies satisfying the condition $|\cos \beta l| < 1$) are very thin above the Bragg frequency. Thus, the rejection of spurious bands is expected to be efficient

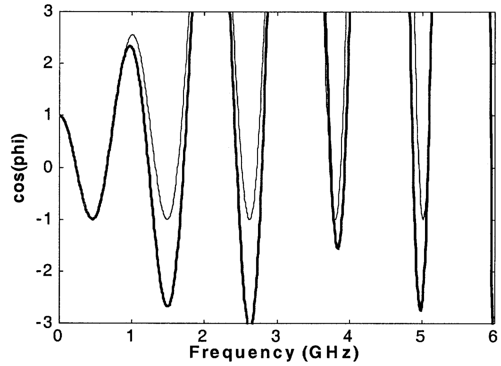
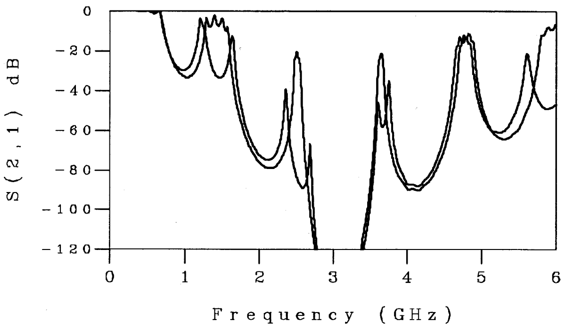


Fig. 3. Representation of $\cos \beta l$ for the fabricated PL-EBG-CPW (bold line) and PL-CPW (thin line) structures. Transmission occurs only for frequencies satisfying the condition $|\cos \beta l| < 1$.

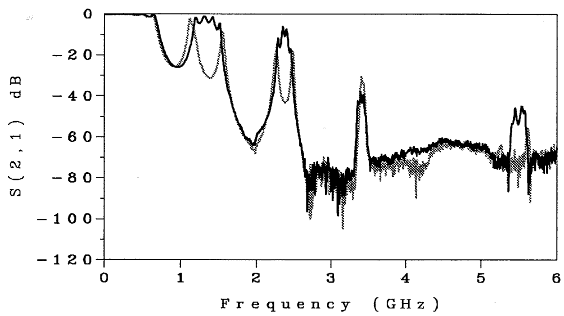
provided the period of the perturbation is determined from the Bragg relation ($\lambda_T = v_{pL}/2f_o = \pi/\beta$) with $\varphi = \beta l$ in the center of the interval corresponding to the spurious band to be suppressed. We have determined λ_T to reject the first $(n = 1)$ spurious band (i.e., $\varphi = 3\pi/2$, or $\lambda_T = 2l/3 = 4.05$ cm). Since a square wave perturbation is applied to the structure, elimination of odd ($n = 3, 5 \ldots$) spurious bands is also expected. However, the presence of capacitors in the PL-EBG-CPW might give rise to interaction effects that can modify the results expected from coupled mode theory, provided this theory does not account for the presence of lumped devices. To analyze the effects of this interaction on the frequency response of the structure, the dispersion relation for the PL-EBG-CPW has been numerically obtained. In Fig. 3, $\cos \beta l$ is depicted and compared to the result obtained for a PL-CPW. As can be seen, both odd and even spurious bands are suppressed in the PL-EBG-CPW, while the first band remains unaltered. This result point out that complete rejection of spurious bands can be achieved in CPWs loaded with reactive elements, by using EBG structures with square-wave geometry perturbation.

III. Results

Fig. 4 shows the simulated (using *ADS-Agilent Technologies*) and measured frequency response for the fabricated PL-EBG-CPW and PL-CPW structures (total length corresponding to five capacitor-pair stages). Rejection levels of the order of 30 dB are obtained for the first two spurious bands (measured response). Above 3 GHz, the presence of shunt capacitors degrades the frequency response due to their resonant frequency and this obscures the effects of the EBG, although these are still visible in the rejection of the fifth band. For comparison, the frequency response of the EBG-CPW structure (i.e., with the capacitors removed) has been also obtained by computer simulation using the *CST Microwave Studio* commercial software (Fig. 5). In the EBG-CPW, the suppression of even order frequency bands is scarcely visible and the magnitude of rejection is considerably smaller when compared to the PL-EBG-CPW. Also, there is a shift in the rejected frequency bands which is due to the absence of capacitors, and hence dispersion. These results clearly point out that the simultaneous presence of capacitors and perturbation in the line give rise to interaction effects that make possible



(a)



(b)

Fig. 4. (a) Simulated and (b) measured frequency responses ($|S_{21}|$) for the fabricated PL-EBG-CPW and PL-CPW structures.

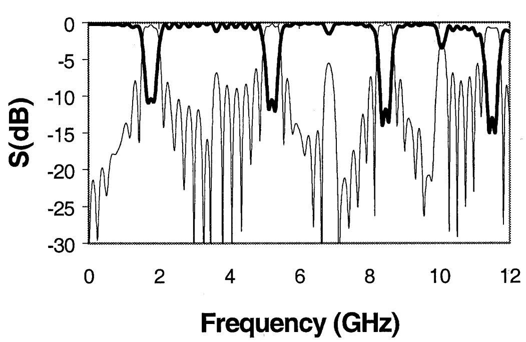


Fig. 5. Simulated S_{11} (thin line) and S_{21} (bold line) for the EBG-CPW with capacitors removed.

an efficient rejection of undesired frequency bands with very simple perturbation geometry.

IV. Conclusion

It has been demonstrated that a complete rejection of spurious frequency bands in CPWs periodically loaded with shunt capacitances can be achieved by using EBG structures. The main conclusion of the work is that both odd and even order bands are simultaneously suppressed by means of a square wave perturbation geometry, avoiding the need of cascading several EBG stages or superposing various perturbation functions tuned at the desired frequencies. The results open the possibility to fabricate CPW-based microwave and millimeter wave filters, phase shifters, and frequency multipliers with a single passband in the frequency response.

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