Multiple-Frequency-Tuned Photonic Bandgap Microstrip Structures

Miguel A. G. Laso, Txema Lopetegi, Maria J. Erro, David Benito, Maria J. Garde, and Mario Sorolla

***Abstract*—Photonic bandgap (PBG) structures in microstrip technology have been recently proposed as efficient Bragg reflectors. The periodic patterns employed until now were formed by a distribution of nonconnected holes (cermet topology) etched in the ground plane or drilled in the dielectric substrate, giving rise to single-frequency-tuned band reflectors. In this letter, a novel pattern that follows a continuous profile (network topology) is proposed to simultaneously reject multiple frequency bands. It is formed by the addition of various sinusoidal functions tuned at the design frequencies. Measurements performed for two- and three-frequency-tuned PBG microstrip prototypes show that multiple deep and wide stopbands can be obtained using these novel devices.**

***Index Terms*—Electromagnetic crystal, filter, microstrip technology, network topology, photonic bandgap (PBG).**

I. Introduction

NOWADAYS, there is an intensive research effort on the topic of electromagnetic crystals within the microwave and millimeter wave community. They are the microwave- or millimeter-wave-scaled counterparts of photonic crystals, the new devices that have attracted interest of optical domain researchers in recent time [1]. These devices are periodic structures in which propagation of electromagnetic waves is not allowed in some frequency bands or directions. The proper terminology in the microwave domain, either periodic structures, photonic crystals, electromagnetic crystals, photonic bandgap (PBG) structures or even artificial dielectrics is still of great controversy and under discussion [2]–[4]. It is desirable that a full agreement on this matter could be reached soon.

Until now, undesired frequencies in microstrip technology have been usually filtered using short-circuited stubs, one half-wavelength long, tuned at the frequency to be rejected. Alternatively, a chip capacitor placed to provide a transmission zero at the undesired frequency has been employed. These techniques have the drawback of being narrowband and of consuming valuable circuit layout area. Recently, PBG microstrip structures have been proposed as a novel way to accomplish this filtering providing a broad rejected band. Furthermore, they can be easily integrated with other microstrip components to miniaturize the circuit configuration [5], [6].

One of the easiest ways proposed to implement a PBG structure in microstrip technology consists on etching a periodic pattern of circles in the ground plane [7]. This way, deep and wide stop bands are obtained while employing a technique compatible with the monolithic technology. Two-dimensional (2-D) periodic patterns were first used, although taking advantage only of the periodicity along the conductor strip direction (effective one-dimensional (1-D) structures). In fact, due to the high confinement of the fields around the conductor strip, it is possible to use 1-D periodic patterns [8] obtaining similar behavior as the 2-D structures, while reducing the transversal dimension of the device.

In some designs, it is needed to eliminate more than one frequency. One interesting example is the tuning of the second and third harmonic in power amplifiers [5] or oscillators. To accomplish it, various cascaded PBG microstrip structures, each one tuned at a different frequency, have to be used [6]. The drawback of this solution is that the longitudinal dimension is notably enlarged. To overcome this problem, in this letter, a novel pattern to be etched in the ground plane of the microstrip line is proposed, obtaining a multiple-frequency-tuned structure that performs simultaneously all the undesired-frequencies rejection.

Until now, all the proposed microstrip PBG structures presented a periodic frequency response, as corresponds to conventional periodic devices. This fact can constitute a problem in some filtering applications. However, we can eliminate the replicas of the response at the harmonics of the design frequency by employing novel continuous patterns that follow a sinusoidal law [9], [10]. These sinusoidal patterns etched in the ground plane of the microstrip line can be seen as a continuous perturbation of the wave velocity in the scattering structure. From the topological point of view this perturbation can be classified as a network topology, where the scattering structure is connected forming a continuous network running throughout the whole structure [11]. In contrast with it we have the cermet topology (conventional PBG microstrip devices) where the scattering material consists of isolated regions each of which is totally surrounded by the host material.

The structure proposed in this letter has a network topology but it is a much more sophisticated case than the previously presented that followed a sinusoidal law. In some sense, it can be considered a continuous (network topology) PBG structure where continuous defects have been placed to modify the bandgap structure properties.

II. Multiple-Frequency-Tuned PBG Microstrip Structure Design

A conventional PBG structure is realized in microstrip technology by etching a 1-D array of circles in the ground plane

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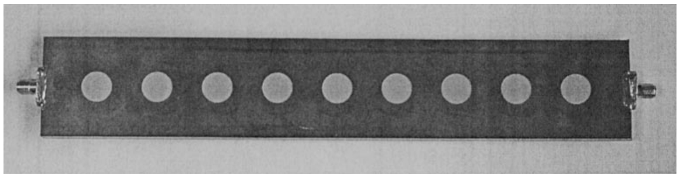
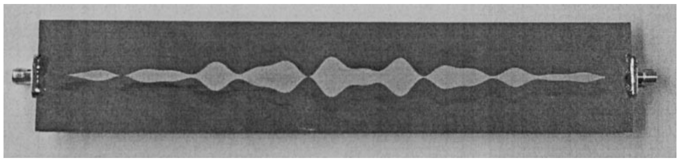


(a)



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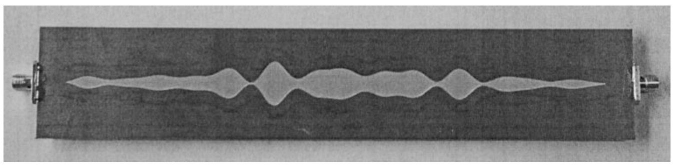

(c)

Fig. 1. Photograph of the ground plane of: (a) conventional (one frequency tuned) PBG microstrip structure. (b) Double-frequency-tuned PBG microstrip structure. The pattern is formed by the addition of two Hamming-windowed raised sines of periods $a_1 = 23.9$ mm, $a_2 = 14.8$ mm and peak amplitude to period ratio $t/a = 0.2$. (c) Triple-frequency tuned PBG microstrip structure. The pattern is formed by the addition of three Hamming-windowed raised sines of periods $a_1 = 23.9$ mm, $a_2 = 19.35$ mm, $a_3 = 14.8$ mm and peak amplitude to period ratio $t/a = 0.15$.

parallel to the upper conductor strip. The distance between the centers of adjacent circles is kept constant and it fixes through the Bragg condition [12] the center frequency of the rejected band [Fig. 1(a)].

Until now, to reject different frequencies, various conventional PBG structures with different periods had to be cascaded. Using the novel pattern that we propose the different frequencies will find tuned periodic perturbations and hence all of them will be rejected.

It is well known in optics that for a weak periodic perturbation of a waveguide, the frequency response in reflection of the device is given, in a first estimation, by the Fourier transform of the coupling coefficient resulting from the perturbation [13]. Even though a complete description of the coupling coefficient of the microstrip waveguide with part of its ground plane removed is not available, this coupling coefficient is strongly related to the geometry of the perturbation in the ground plane. Hence, as a first approximation, the frequency response of the device could be estimated with the Fourier transform of the perturbation geometry. As the Fourier transform of a sinusoidal function is composed of a single frequency, the microstrip with a raised sine pattern etched in its ground plane will have a frequency response with a prominent rejected band at the design frequency and with strongly reduced rejection at the harmonics of it [9], [10]. In the same way, the microstrip with an etched pattern formed by the addition of multiple raised sines is expected to have a response basically composed of rejected bands at the frequencies of the sinusoidal functions. This novel design approach gives rise to the claimed multiple-frequency-tuned PBG microstrip structure.

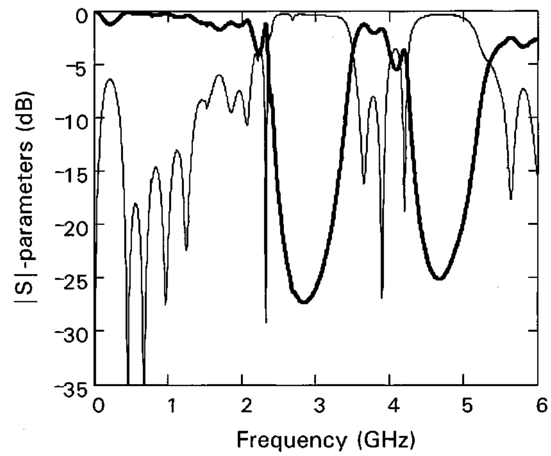

Fig. 2. Measured S_{11} (thin line) and S_{21} (thick line) parameters for the double-frequency-tuned PBG microstrip structure, as shown in Fig. 1(b). The two Hamming-windowed raised sines have periods $a_1 = 23.9$ mm, $a_2 = 14.8$ mm and peak amplitude to period ratio $t/a = 0.2$. The total length of the device is 215.1 mm.

To test the performance of these new devices, double- and triple-frequency-tuned PBG microstrip structures will be designed, constructed and measured. The double-frequency-tuned PBG microstrip structure, Fig. 1(b), is designed with two added raised sines: the first one has nine periods of $a_1 = 23.9$ mm and the second one has 14 periods of $a_2 = 14.8$ mm in order to have the rejected frequencies around 3 GHz and 4.5 GHz, respectively, using a Rogers RO3010(tm) substrate ($\varepsilon_r = 10.2$, thickness $h = 1.27$ mm) and a conductor strip width of $w = 1.2$ mm (corresponding to a characteristic impedance of $Z_0 = 50\,\Omega$ for a conventional microstrip line). Both sines have $t/a = 0.2$, where t is the peak value of the raised sine.

The triple-frequency-tuned PBG microstrip structure is designed with three added raised sines, Fig. 1(c). The first sine has nine periods of $a_1 = 23.9$ mm, the second one has 11 periods of $a_2 = 19.35$ mm, and the third one has 14 periods of $a_3 = 14.8$ mm, to obtain their stopbands centered at 3 GHz, 4 GHz, and 5 GHz, respectively, for the same substrate as above. In all these cases the ratio t/a is fixed to 0.15. It can be noted that the amplitude of each particular sine has been reduced in order to maintain the total amplitude of the ground plane perturbation in such values that the radiation is kept in low levels. It must be also pointed out that in both designs the patterns resulting from the addition of various sines are Hamming-windowed to achieve a low-rippled response at the passband [14].

Low design frequencies have been chosen in order to measure the responses of the devices with our HP(tm) 8753-D network analyzer (up to 6 GHz).

III. Experimental Results

Two prototypes have been studied: 1) a double-frequency-tuned PBG microstrip structure (with a two-added sine pattern), and 2) a triple-frequency-tuned PBG microstrip structure (with a three-added sine pattern) designed as stated in the previous section. The prototypes have been fabricated by means of a numerical milling machine. The measurements are shown in

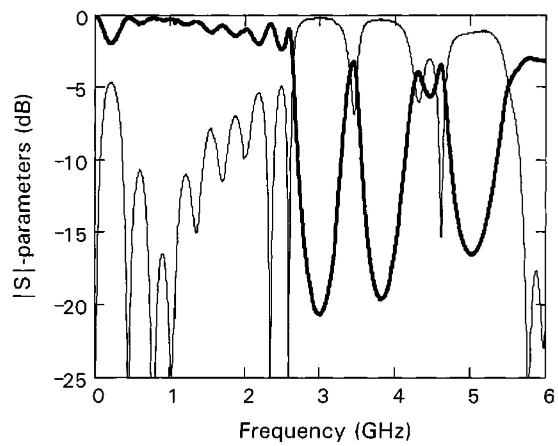

Fig. 3. Measured S_{11} (thin line) and S_{21} (thick line) parameters for the triple-frequency-tuned PBG microstrip structure, as shown in Fig. 1(c). The three Hamming-windowed raised sines have periods $a_1 = 23.9$ mm, $a_2 = 19.35$ mm, $a_3 = 14.8$ mm and peak amplitude to period ratio $t/a = 0.15$. The total length of the device is 215.1 mm.

Figs. 2 and 3, respectively. Both S_{11} and S_{21} parameters are given.

Two rejected frequency bands centered at 2.85 GHz and 4.65 GHz are observed in Fig. 2 for the double-frequency-tuned structure. Rejection levels higher than 25 dB are shown for both stopbands. A flat and low-rippled passband is obtained at frequencies below 2 GHz.

In Fig. 3 three rejected frequency bands corresponding to the triple-frequency-tuned device can be seen at 3 GHz, 3.85 GHz, and 5 GHz, respectively. The achieved rejection levels are approximately 20 dB for the first and second one, and more than 16 dB for the last one. The reduction observed in the bandwidths and rejection levels compared with the double-frequency-tuned prototype is due to the smaller t/a ratios employed. This filter has also a flat and low-rippled passband below 2 GHz.

IV. Conclusions

Novel patterns consisting in the addition of various sinusoidal functions have been proposed for the PBG microstrip structure ground plane. These continuous patterns can be considered as the network topology counterpart in microstrip, in contrast with the conventional discrete patterns that can be seen as cermet topologies.

Measurements show that the proposed device behaves as a multiple-frequency-tuned band reflector, avoiding the need of cascading conventional PBG devices. A promising application of these novel devices can be the suppression of the second and third harmonic in power amplifiers and oscillators.

References

[1] J. D. Joannopoulos, R. D. Meade, and J. N. Winn, *Photonic Crystals: Molding the Flow of Light*. Princeton, NJ: Princeton Univ. Press, 1995.
[2] A. A. Oliner, "Periodic structures and photonic band-gap terminology: Historical perspectives," in *29th Eur. Microwave Conf.*, vol. 3, Münich, Germany, Oct. 1999, pp. 295–298.
[3] Mini-Special Issue on Electromagnetic Crystal Structures, Design, Syntheis, and Applications, *IEEE Microwave Theory Tech.*, vol. 47, pp. 2057–2150, Nov. 1999.
[4] Special Section on Electromagnetic Crystal Structures, Design, Synthesis, and Applications, *IEEE/OSA J. Lightwave Technol.*, vol. 17, no. 11, pp. 1928–2207, Nov. 1999.
[5] V. Radisic, Y. Qian, and T. Itoh, "Broad-band power amplifier using dielectric photonic bandgap structure," *IEEE Microwave Guided Wave Lett.*, vol. 8, pp. 13–14, Jan. 1998.
[6] I. Rumsey, M. Piket-May, and P. K. Kelly, "Photonic bandgap structures used as filters in microstrip circuits," *IEEE Microwave Guided Wave Lett.*, vol. 8, pp. 336–338, Oct. 1998.
[7] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, "Novel 2-D photonic bandgap structure for microstrip lines," *IEEE Microwave Guided Wave Lett.*, pp. 69–71, Feb. 1998.
[8] F. Falcone, T. Lopetegi, and M. Sorolla, "1-D and 2-D photonic bandgap microstrip structures," *Microwave Opt. Technol. Lett.*, vol. 22, no. 6, pp. 411–412, Sept. 1999.
[9] T. Lopetegi, M. A. G. Laso, M. J. Erro, D. Benito, M. J. Garde, F. Falcone, and M. Sorolla, "New results in microstrip grating technology," in *Invited Conf. 7th Int. Symp. Recent Advances in Microwave Technology (ISRAMT'99)*, Málaga, Spain, Dec. 1999.
[10] ——, "Novel photonic bandgap microstrip structures using network topology," *Microwave Optical Technol. Lett.*, vol. 25, no. 1, pp. 33–36, Apr. 2000.
[11] E. N. Economou and M. M. Sigalas, "Classical wave propagation in periodic structures: Cermet versus network topology," *Phys. Rev. B*, vol. 48, no. 18, pp. 13 434–13 438, Nov. 1993.
[12] M. A. G. Laso, M. J. Erro, D. Benito, M. J. Garde, T. Lopetegi, F. Falcone, and M. Sorolla, "Analysis and design of 1-D photonic bandgap microstrip structures using a fiber grating model," *Microwave Opt. Technol. Lett.*, vol. 22, no. 4, pp. 223–226, Aug. 1999.
[13] E. Peral, J. Capmany, and J. Martí, "Iterative solution to the Gel'Fand-Levitan-Marchenko coupled equations and application to synthesis of fiber gratings," *IEEE J. Quantum Electron.*, vol. 32, pp. 2078–2084, Dec. 1996.
[14] T. Lopetegi, F. Falcone, B. Martínez, R. Gonzalo, and M. Sorolla, "Improved 2-D photonic bandgap structures in microstrip technology," *Microwave Opt. Technol. Lett.*, vol. 22, no. 3, pp. 207–211, Aug. 1999.