Dual Electromagnetic Bandgap CPW Structures for Filter Applications

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***Abstract*—A novel coplanar waveguide (CPW) low pass filter based on electromagnetic bandgaps (EBG) with double periodicity has been designed and fabricated. The device consists on a CPW with T-shaped loading capacitances at periodic positions and slot width modulation. By properly choosing the ratio between the two periods of the structure, a huge band gap (more than five times the bandwidth) is obtained through the suppression of spurious frequencies. The fabricated prototypes also exhibit very sharp cutoff, very low insertion loss in the passband and slow wave effect.**

***Index Terms*—Coplanar waveguide (CPW), electromagnetic bandgap (EBG), microwave filters.**

I. Introduction

THERE IS A growing interest for periodic structures in the microwave and millimeter wave community. Key to this interest is the capability of these structures to inhibit signal propagation in certain frequency bands or directions. Because of the similarity of their frequency selective behavior to carrier transport in semiconductors, these structures have been usually referred to as electromagnetic bandgaps (EBGs). For planar circuit applications, most EBG-based structures have been fabricated in microstrip technology, where periodicity has been implemented by strip width modulation, ground plane etching or by drilling holes in the substrate. In all cases, wave impedance modulation results and, hence, Bragg reflection in some frequency bands. Intrinsic spurious suppression in band pass filters [1], [2], optimization of radiation patterns in microstrip patch antennas [3], phase noise reduction in oscillators [4] and efficiency optimization in broadband power amplifiers [5] are some representative applications of EBGs in microstrip technology. However, coplanar waveguides (CPWs) present some key advantages for the design of EBG-based devices. At the one hand, a single metal level is required for signal and ground. This eases shunt connections and capacitive coupling between conductor strip and ground planes, which can be of interest for the design of frequency selective slow wave structures. On the other hand, the fact that the lateral dimensions (strip and slot width) are not univocally determined by the characteristic impedance of the line, offers major design flexibility and the possibility to achieve significant wave impedance modulation. This is important to obtain high rejection levels at the frequency gaps of the structure. Uniplanar EBG-CPW filters and resonators based on the perturbation of line geometry have been recently proposed [6]. Also, miniaturized low pass filters have been recently fabricated by periodically patterning signal strip and ground planes to enhance capacitive and inductive coupling [7].

In this work, a new EBG-CPW low pass filter with double periodicity is proposed. The device consists on a capacitive loaded CPW periodically perturbed by varying the width of the signal strip. To avoid the presence of lumped reactances, shunt connected capacitances are implemented by branching the center conductor to ground by means of a T-shaped geometry. The capacitive coupling at periodic locations is responsible for the filtering properties and slow wave effect of the structure. By perturbing the strip width, a very broad stop band is achieved through the suppression of spurious passbands inherent to distributed structures. The result is a compact low pass filter with a sharp cutoff and a stop band at least five times wider than the pass band. It is also worth mentioning that filter design is very simple provided the dimensions of the T-shaped capacitances are small compared to their separation and, under these conditions, the lumped element approach of periodic loaded transmission lines can be applied [8].

II. Design of Dual EBG-CPW Filters

A typical layout for the dual EBG-CPW filter is depicted in Fig. 1. Device design requires the determination of the distance between adjacent capacitances, l, the period of the perturbation, λ_{T}, the lateral dimensions of the high/low impedance sections, the geometry of the T-shaped capacitors and the number of cascading stages. To this end, a two step process is followed. In the first step, the geometry of the unperturbed periodic loaded CPW structure (also shown in Fig. 1) is determined from filter specifications, i.e., the cutoff (Bragg) frequency, f_B, the impedance of the loaded line (or Bloch impedance), $\mathrm{Z_L}$, and the impedance of the unloaded line, $\mathrm{Z_o}$. Under the assumption that the lumped element equivalent circuit of the periodic loaded line is valid (Fig. 2), these parameters are given by:

$$f_B = \frac{1}{\pi\sqrt{L(C+C_{\mathrm{ls}})}} \tag{1}$$

$$Z_{\mathrm{L}} = \sqrt{\frac{L}{C+C_{\mathrm{ls}}}} \tag{2}$$

$$Z_{\mathrm{o}} = \sqrt{\frac{L}{C}} \tag{3}$$

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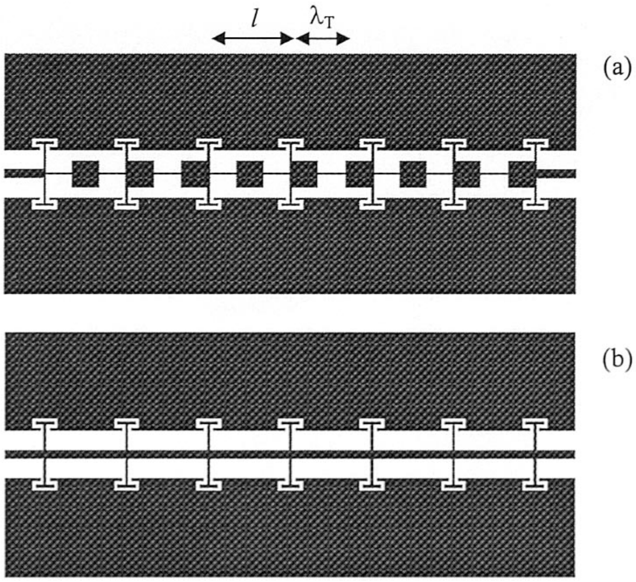

Fig. 1. Layout of the dual EBG-CPW filter (a) and T-shaped (without strip width modulation) filter (b).

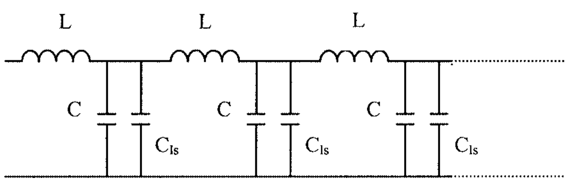

Fig. 2. Lumped element equivalent circuit of a capacitive loaded transmission line.

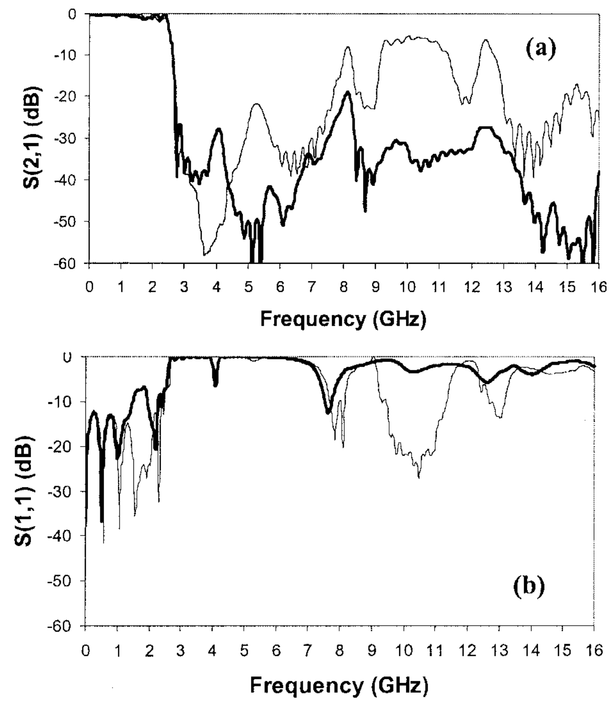

Fig. 3. Simulated insertion (a) and return (b) losses for the T-shaped filter (thin line) and dual EBG-CPW filter (bold line).

where L and C are the per-section inductance and capacitance of the line, respectively, and C_{ls} is the capacitance of the T-shaped capacitor pairs. To avoid mismatching at the input/output ports, the Bloch impedance is set to $Z_L = 50\ \Omega$, while Z_o must be high enough since the stop band of the filter increases with the ratio Z_o/Z_L. This means that $C_{ls} > C$, a necessary condition for the validity of the lumped element approximation [8]. T dimensions much smaller than the cell size is the other condition that the approximation requires. The prototype device has been designed according to (1)–(3) to exhibit a cutoff frequency of $f_B = 2.5$ GHz and a characteristic impedance (unloaded line) of $Z_o = 95\ \Omega$. With these specifications, the parameters of the equivalent circuit model can be isolated and, by means of a transmission line calculator, the lateral dimensions of the CPW (unperturbed) structure and the distance between consecutive reactances can be obtained. The parameters of the Rogers *RO3010* substrate ($\varepsilon_r = 10.2$, thickness $h = 1.27$ mm) have been considered. It has been found that strip and slot widths of $W = 1.5$ mm and $G = 3.15$ mm, and a cell size of $l = 13.3$ mm fit the previous specifications. To obtain the geometry of the T-shaped capacitor pairs, full wave *em* simulations with parameter variation have been carried out until the nominal value of capacitance ($C_{ls} = 2.3$ pF) has been achieved. The layout of the structure (with 7 capacitor pair stages) is depicted in Fig. 1(b). In the second step, perturbation is introduced to reject the spurious frequencies present above the Bragg frequency and thus improve the stop band of the structure. It has been demonstrated in a previous paper, where the distance between ground planes is perturbed, that by choosing $\lambda_T = 2l/3$, attenuation in all spurious bands occurs [9]. This relation between λ_T and the distance between adjacent capacitances, l, has been determined according to the Bragg condition to reject the first spurious band. However, the presence of capacitors in the line enhances its reflection properties and all undesired bands can be attenuated [9]. To obtain an efficient suppression of these undesired frequencies, significant wave impedance modulation is necessary. In this work, this is achieved by means of strip width modulation with a perturbation degree corresponding to symmetric variations of $\Delta Z_o = 35\ \Omega$ up and down the nominal value of wave impedance ($Z_o = 95\ \Omega$). By maintaining the same distance between ground planes as in the unperturbed case, the width of the central strip has been found to alternate between $W = 0.4$ mm and $W = 4.4$ mm. The layout of the structure is that shown in Fig. 1(a).

III. Results

Full wave electromagnetic simulations of the T-shaped-CPW and dual EBG-CPW filters have been carried out by means of the commercial software *CST-Microwave Studio*. The results are depicted in Fig. 3 and the experimental results, obtained by means of a *hp-8510C* network analyzer, in Fig. 4. In view of these results, both structures exhibit very low insertion loss in the pass band. Neither losses nor appreciable ripple can be observed in spite of line dispersion, which is due to periodicity. Another relevant feature is the sharp cutoff, which has been achieved with only 7 capacitor stages. This has been found to be more pronounced than that measured in a conventional nine-stage stepped-impedance filter (results not shown). Above

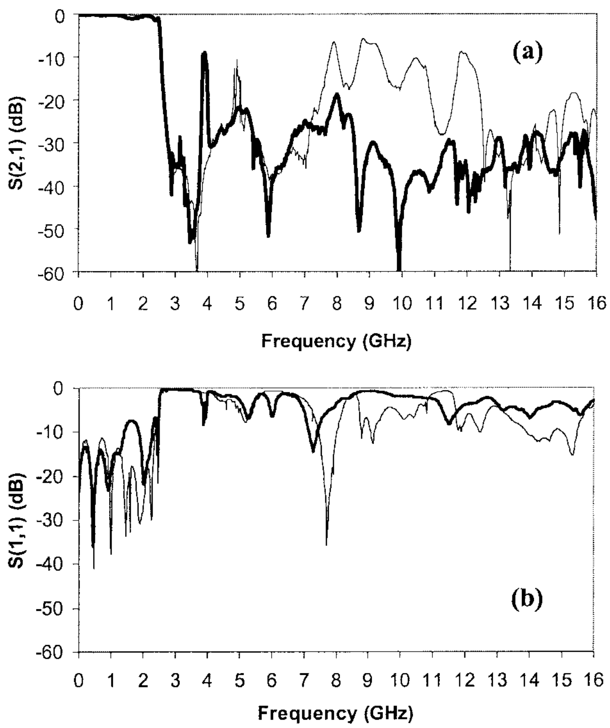

Fig. 4. Measured insertion (a) and return (b) losses for the T-shaped filter (thin line) and dual EBG-CPW filter (bold line).

the Bragg frequency, the frequency parasitics measured in the T-shaped filter are found to be substantially reduced in the dual EBG-CPW filter due to the reflection properties of the combined structure. The result is a frequency response with a wide stop band (more than five times the bandwidth).

Let us finally consider the slow wave effect inherent to the structures and derived from capacitive coupling. This can be estimated from the ratio of the $(\varepsilon_{\mathrm{eff}})^{1/2}$ in the proposed structures to that in a 50 Ω line. In the T-shaped and dual EBG filters, the effective dielectric constant can be indirectly obtained since we know that $\beta l = \pi$ at the cutoff frequency, f_B. In a 50 Ω line, a transmission line calculator directly provides the value of the effective dielectric constant. Following this procedure, the above mentioned ratio has been calculated and has been found to be 2.3. This is equivalent to a compactness factor of more than two for the proposed structures.

IV. Conclusion

In conclusion, a uniplanar EBG-CPW filter with double periodicity has been proposed. The structure combines T-shaped capacitances located at periodic positions with strip width modulation. It has been demonstrated that by choosing the distance between adjacent capacitances 1.5 times the period of the perturbation, a high performance low pass filter with very wide stop band, very sharp cutoff and low insertion loss in the passband results. It is also important to highlight the compactness factor related to capacitive coupling between signal and ground, which has been found to be higher than two. This can be of interest for the design of compact microwave devices operating in the passband of the T-shaped structure.

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