Coplanar Waveguide Periodic Structures with Resonant Elements and Their Application in Microwave Filters

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Abstract — **Coplanar waveguide (CPW) periodic structures with resonant elements on ground plane have been investigated for lowpass and bandstop filter applications. The resonator is constructed by etching out redial shapes on the ground plane. The use of resonant elements allows larger attenuation in the stop band to be obtained with less number of periodic structures as compared with conventional photonic bandgap (PBG) structures. A theoretical study of this type of periodic structure has revealed some useful information for designing filters. Two filters of this type, one for lowpass application and the other for bandstop application have been designed, fabricated and tested. The results are presented.**

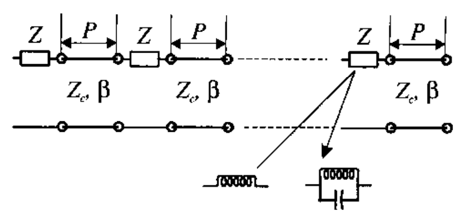
I. INTRODUCTION

Recently there has been an increasing interest in microwave applications of photonic band gap (PBG) structures [1]-[10]. In general, the so-called PBG structure in a microwave transmission line is a periodic structure, which can be implemented in many ways. This type of periodic structure exhibits frequency regions in which electromagnetic waves cannot propagate. Therefore, a direct application of such frequency selective characteristics is in microwave filters [1], [5]-[6], [10]. However, little attention has been drawn on how to design filters using PBG structures. Furthermore, it would seem most reported PBG structures and filters are for microstrip implementation. Since coplanar waveguide (CPW) has become attractive too for microwave monolithic integrated circuits (MMIC), micro-electro-mechanic systems (MEMS) and other technologies, it would be desirable to develop CPW filters using PBG structures.

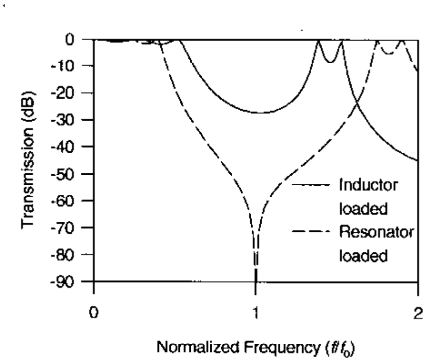
In this paper, we report a recent investigation into CPW periodic structures with resonant elements on ground plane for lowpass and bandstop filter applications. The resonator is constructed by etching out redial shapes on the ground plane. The use of resonant elements allows larger attenuation in the stop band to be obtained with less number of periodic structures as compared with conventional photonic bandgap (PBG) structures. In the next section, a theoretical study of this type of periodic structure is presented, which leads to some useful information for designing filters. Section III demonstrates two filters of this type, one for lowpass application and the other for bandstop application. The measured performance is illustrated. Finally, a conclusion is followed.

II. CIRCUIT MODEL

For our study, a circuit model for a 1D periodic structure in a transmission line with periodically loaded lumped elements is used as shown in Fig. 1(a), where Z is the impedance of lumped element, Z_c and β are the characteristic impedance and propagation constant of transmission line, and P is the period.



(a)



(b)

Fig. 1. (a) Circuit model for a periodic line structure with loaded lumped elements. (b) Frequency response with 3 cells.

The series impedance Z may result from different type of reactive element, here we only consider a single inductor L or a parallel LC resonator as indicated in Fig. 1(a). This is because both the elements can easily be realized in CPW. The frequency response of the circuit can be obtained using network analysis. For the same number of periods (cells) and similar inductive loading, the periodic structure loaded with resonators exhibits a better stop band characteristic with larger attenuation and wider stop band than the periodic structure loaded with inductors only. This is demonstrated in Fig. 1(b) for the case of 3 cells, where f_0 is a reference frequency. Although using larger inductance can improve the stop band, it is more difficult to realize in a lumped or quasi-lumped form. Increasing the cell number can improve stop band too, but at the cost of larger size and larger loss in the pass band. For these reasons, the PBG structure with resonant elements appears more attractive for filter applications.

To design this type of filter, we can initially be concerned with only two design parameters, i.e., the period P and the susceptance slope b of the parallel LC resonator, where $b = \omega_0 C$ and $\omega_0 = 1/\sqrt{LC}$. Fig. 2(a) shows the effect of b on frequency response when the P is equal to a half-wavelength of the line. As can be seen, the smaller the b the wider the stop band, hence this type of frequency characteristic is more suitable for lowpass filter applications. If we let P equal a quarter-wavelength, a more compact band gap structure can be obtained. The resultant frequency responses for different values of b are illustrated in Fig. 2(b). It appears that the larger b results in a frequency characteristic which is more attractive for bandstop filter applications.

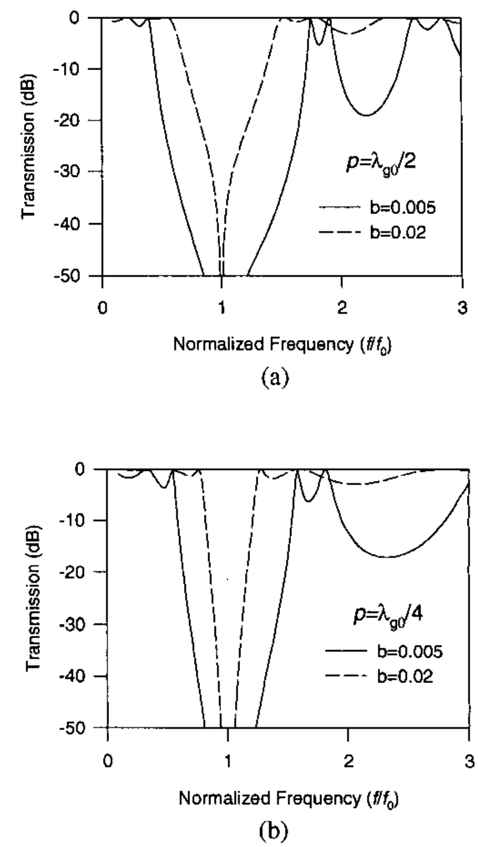


Fig. 2. Frequency characteristics of periodic transmission line structure loaded with resonant elements (3 cells). (a) P = half-wavelength. (b) P = quarter-wavelength.

III. Implementation in CPW

To implement the above periodic structures in CPW, the resonant elements were realized with a defected ground of the CPW as depicted in Fig. 3, where each pair of etched radial shapes functions as a parallel LC resonator in series. This type of resonator has advantages of low loss, easy fabrication and packaging, especially for very high frequency applications. The series susceptance slope of the CPW resonator can easily be controlled by changing the radial shape such as that from Fig. 3(a) to Fig. 3 (b), and/or changing the coupling gap to the main line such as that from Fig. 3(a) to Fig. 3(c).

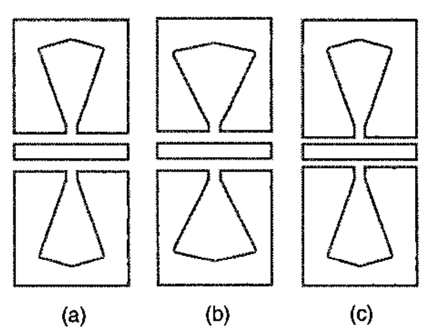


Fig. 3. CPW resonators implementation with defected ground plane.

Fig. 4 plots the full-wave simulated resonant responses of the resonators in Fig. 3. The simulations were preformed using the Sonnet ***em*** [11]. As can be seen the 3-dB bandwidths have been effectively changed from one to another, so do the susceptance slopes as they are inversely proportional to the 3-dB bandwidths. Therefore, one can control the susceptance slope according to the two design guidelines: (i) the larger the radial shape the smaller the susceptance slope, and (ii) the smaller the couplig gap the smaller the susceptance slope.

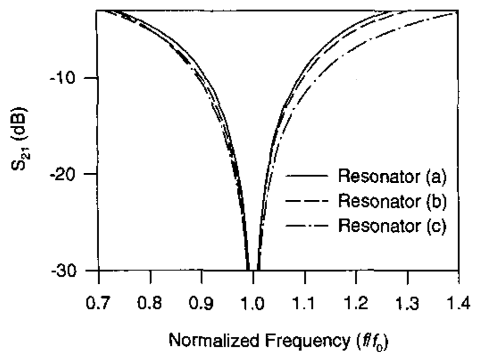
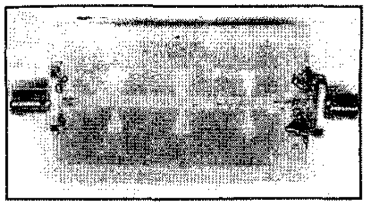


Fig. 4. Full-wave simulated resonant frequency responses of the CPW resonators of Fig. 3.

Two CPW periodic structures have been developed based on the above discussed design guidelines. The first one was developed for the lowpass filter applications. Fig. 5(a) shows a photograph of the fabricated CPW periodic structure with three resonant elements. The circuit was fabricated on a RT/Duriod substrate with a relative dielectric constant of 10.8 and a thickness of 1.27mm. The separation between adjacent resonators is 14mm, which is about a half of guided wavelength of the 50-ohm line on the substrate. The circuit size as shown in Fig. 5(a) is 53mm by 28mm. Fig. 5(b) plots the measured transmission response of the circuit, showing a lowpass filtering characteristic around a cutoff frequency of 2.5 GHz. The measured attenuation at the bandgap center of this 3-cell CPW periodic structure was 30dB, which was limited by the finite quality factor of the resonators. Even so, the similar performance is difficult to be achieved with conventional 3-element transmission line lowapss filters or 3-cell periodic structures without resonant elements.



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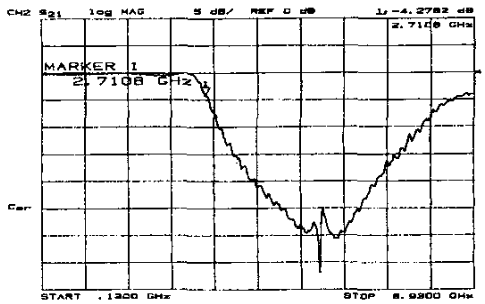
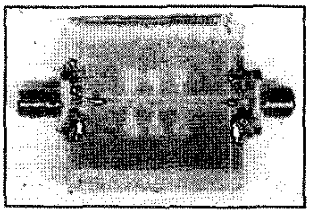


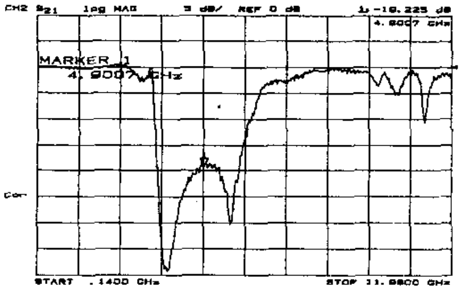
(b)

Fig. 5. (a) Photograph of a fabricated CPW periodic structure with three resonant elements for *lowpass* filter applications. (b) Measured performance.

The second CPW periodic structure developed was aimed for bandstop filter applications. Fig. 6(a) illustrates a photograph of the fabricated device with 3 resonators. Similarly, the device was fabricated on a 1.27mm thick RT/Duriod substrate with a relative dielectric constant of 10.8. However, in this case the separation between adjacent resonators is only about a quarter of guided wavelength of the 50-ohm line on the substrate. Therefore, the device is more compact than that of Fig. 5(a). The measured frequency response of the device in Fig. 6(a) is plotted in Fig. 6(b). The bandgap of this periodic structure exhibits shaper edges as compared with that shown in Fig. 5(b), demonstrating a typical bandstop filtering characteristic. The measured ~20dB bandwidth of the stopband was 2.3 GHz centered at about 4.9GHz. This represents a relative bandwidth of 46%. The ripples in the passband should be reduçed as the designed bandwidth decreases. The performance can further be improved by optimizing or taking into account some other design parameters, such as the line impedance and the coupling between adjacent resonators.



(a)



(b)

Fig. 6. (a) Photograph of a fabricated CPW periodic structure with three resonant elements for *bandstop* filter applications. (b) Measured performance.

V. Conclusion

In this paper we have reported a recent investigation into CPW periodic or photonic bandgap (PBG) structures with resonant elements on ground plane for lowpass and bandstop filter applications. Two CPW filters of this type have been demonstrated, where the resonators are constructed by etching out redial shapes on the ground plane. Our investigation has shown that (i) the larger attenuation can be obtained for a PBG structure with resonant elements; (ii) a half-wavelength separation between adjacent resonant elements with a smaller susceptance slope leads to a PBG structure more attractive for lowpass filter applications; (iii) a quarter-wavelength separation between adjacent resonant elements with a larger susceptance slope leads to a more compact PBG structure which is more suitable for bandstop filter applications.

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