Miniaturized Extended-Stopband Microstrip Ring Resonator Bandpass Filter Using Uniplanar Compact Photonic Bandgap (UC-PBG) Structures

HEBA B. EL-SHAARAWY (1, 2), FABIO COCCETTI (1), ROBERT PLANA (1, 2),
MOSTAFA EL-SAID (3) and ESSAM A. HASHISH (3)

(1) Laboratoire d'Analyse et d'Architectures des Systèmes at the Centre National de la Recherche Scientifique (LAAS-CNRS),
7 Avenue du Colonel Roche, 31077,
TOULOUSE, FRANCE.

(2) University of Toulouse,
TOULOUSE, FRANCE.

(3) Electronics and Communications Dept., Faculty of Engineering,
Cairo University,
CAIRO, EGYPT.

Abstract: - This paper addresses a modified bandpass ring resonator filter providing compact size, low insertion-loss, wide bandwidth, sharp rejection and suppressed higher order modes. The filter enhancement follows a threefold approach. First, UC-PBG structures are used to suppress the higher order passbands yielding an upper stopband that reaches 4.7 GHz, beside offering a further advantage in terms of size reduction. Second, the use of internal folded stubs allows the exploitation of the internal area of the ring resonator, which translates into an overall size reduction of 84.5%. Finally, a solution employing via holes to replace the tuning stubs is explored in order to extend the lower stopband. EM simulation, equivalent circuit model, as well as measurement results validate the followed design approach and are in excellent agreement within each other.

Key-Words: - photonic bandgap, ring resonator, bandpass filter, fractional bandwidth, stopband, insertion loss.

1 Introduction

The increasing development of wireless applications introduces new requirements for transceiver architectures that feature excellent microwave performances (linearity, spurious rejection, noise figure and bandwidth) and enhanced integration density that is achieved through miniaturization of modules as well as the introduction of multi standard functionalities. All these requirements translate to the need for miniature filters with low passband insertion loss and high stopband rejection.

It has been demonstrated that ring resonator based filters feature attractive behavior [1], [2] but they suffer from two drawbacks that limit their implementation in real applications. The first one is their large size due to the two tuning stubs, while the second deals with the existence of higher order modes which limit the out-of-band rejection. Both issues degrade the whole system performance and need to be assessed to find solutions to overcome these drawbacks.

This paper aims to propose some solutions to reduce the size and increase the rejection of the stopband of the ring resonator filter, while keeping its overall performances with respect to its wide bandwidth, sharp rejection and low insertion-loss. In order to do so, two different design approaches are considered. The first is at the wave propagation level, through the exploitation of UC-PBG structure properties [3], while the second is at the filter layout level, through a space saving redesign of the tuning stubs [2].

To our knowledge, the work reported to date has used the PBG structures to suppress only the second order harmonic of multistage coupled ring resonator filter by etching the ground plane of the output feeding line [3]. The use of this technique yields general detrimental effects as; on the one hand it increases the filter size and the filter insertion loss while on the other it decreases the filter bandwidth due to the coupling of different stages. In the work presented here, by changing the type of the PBG structure and placing it directly under the ring resonator, the second, third and forth harmonics are suppressed with a reduction in the filter size reaching 45.52 % of the ring resonator without PBG structures.

For more size reduction, a space saving redesign of the tuning stubs of the ring resonator filter with the UC-PBG structures etched beneath the whole filter is demonstrated. The reduction in the filter area reaches 84.5 %, while keeping its overall performance with respect to its low insertion loss, wide bandwidth and sharp rejection.

Finally, for the further enhancement of the filter response, the introduction of a transmission zero at zero frequency is eventually considered. This is done by replacing the two tuning stubs by via holes [4].

All filters are fabricated on Teflon substrate (CER 10-0250 CH/CH) of dielectric constant ε_r=9.5, dielectric thickness h=0.635mm and loss tangent 0.0035. Measurements show very good agreement with simulation results.

2 Microstrip Ring Resonator Bandpass Filter with UC-PBG Structures

The ring resonator bandpass filter consists of a ring resonator directly connected to a pair of two orthogonal tuning stubs and two orthogonal feeding lines as shown in Fig.2 (a). The circumference of the ring resonator ℓ_r is chosen according to the following expression:

$$\ell_r = n\lambda_g \quad (1)$$

where n is the mode number and λ_g is the guided wavelength. Each tuning stub is equal to one quarter of a wavelength designed at the center frequency and placed at the center of each side of the ring resonator. And to increase the bandwidth of the stopbands of the filter, a square stub is added at the corner of the filter [1].

A filter using the previously discussed technique is designed at 1.5 GHz. In order to investigate the behaviour of the filter, the transmission line model proposed by [1], the EM simulation (Zeland IE3D) and measurement results are used.

It was found that the filter suffers from other passbands due to the higher order modes at 3 GHz and 4.45 GHz, representing the second and third harmonics of the resonant frequency, consequently the filter 10-dB upper stopband is only 0.4612 GHz.

The use of PBG structures is hereby exploited to improve the harmonic rejection of the filter. The PBG structures enable higher order mode suppression through the introduction of a wide stopband in the frequency response of the filter, and on the other hand introduce slow wave effect which translates in the reduction of the electrical length and hence the overall filter dimensions [5]. Following the original interpretation and analysis made by Yoblonovitch [6] this stopband is produced by the coupling between the forward and backward propagating waves due to periodic variations in the refractive index of the medium.

The PBG structure selected here is the UC-PBG structure of [5], Fig.1 (a). This structure can be represented by the equivalent circuit given in Fig.1 (b), where the parallel inductor (L) and capacitor (C) accounts for the transmission zero at the resonance frequency, while the resistance (R) accounts for the different types of losses [7]. The dimensions of the UC-PBG structures are a=12 mm, b=10.968 mm, g=1.4 mm, s=1.032 mm and h=2.926 mm. The circumference of the ring resonator ℓ_r= 60 mm, the length of each tuning stub is 13 mm and the thickness of the line is 0.9354 mm corresponding to a 50Ω line.

Fig.2 shows a photograph of the fabricated ring resonator filter with UC-PBG structures etched in the ground plane and Fig.3 shows the simulated and measured responses of the ring resonator filter with PBG structures. All filter specifications are found in Table 1.

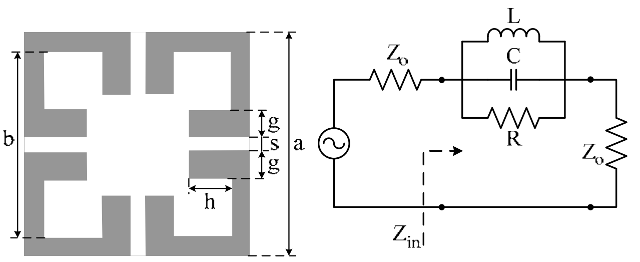


Fig.1. (a) One cell of the UC-PBG lattice.
(b) Equivalent circuit of a unit cell of the UC-PBG.

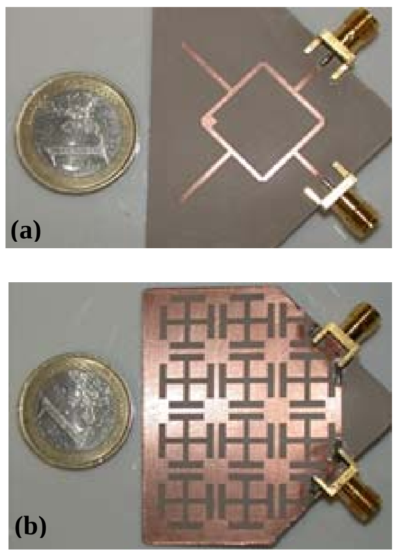


Fig. 2. Photograph of the fabricated ring resonator BPF with UC-PBG structures in the ground plane
(a) Top view, (b) bottom view.

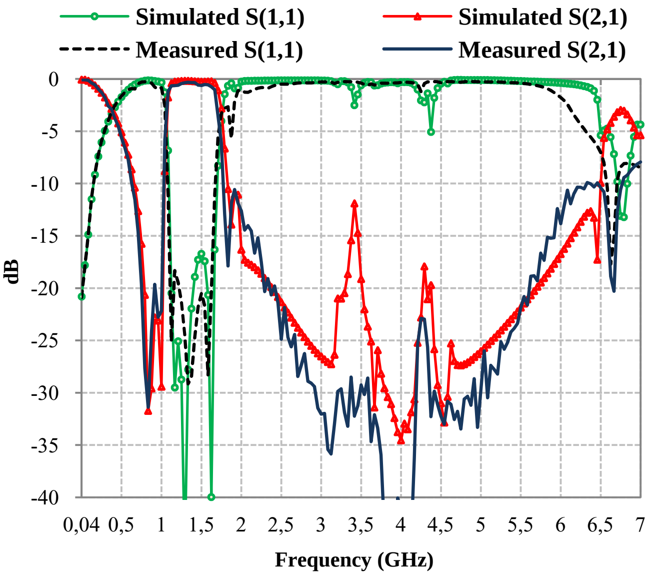


Fig. 3. Simulated and measured responses of the ring resonator filter with UC-PBG structures.

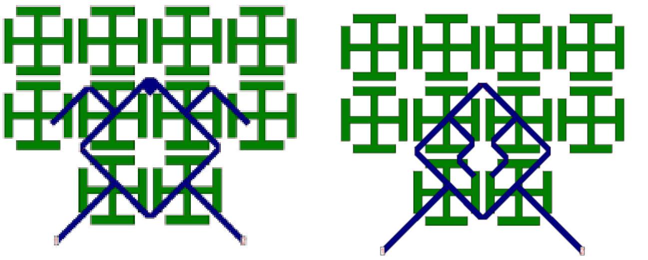
The etching of UC-PBG structures in the ground plane solves the two problems of the original filter simultaneously. Referring to the filter dimensions given in Table 1, the size of the filter is reduced by 45.52% due to the slow wave effect introduced and the stopband of the filter has increased from 0.46 GHz to 4.7 GHz suppressing the second, third and forth harmonics introduced by the original filter design. In addition, the insertion and return loss values of the filter are enhanced due to the suppression of surface waves provided by the UC-PBG structures. Compared to the results reported in [8], obtained by using circle defected ground structures (DGSs) on the same ring resonator filter, the DGSs introduces a size reduction of only 25.75 % and a narrower stopband of 2.44 GHz.

Although that the size of the filter is reduced, the filter still suffers from the large occupation area of the two tuning stubs, as they occupy 72% of the total area.

3 Size Reduction Using External Bent Stubs and Internal Folded Stubs

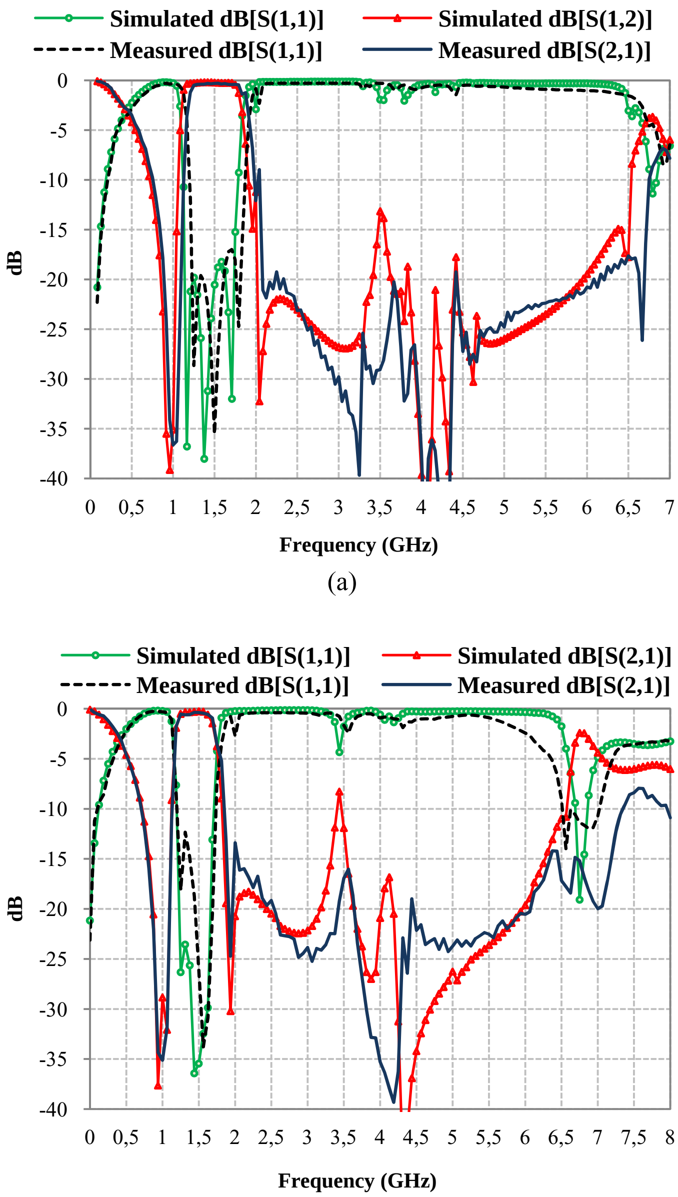
In order to reduce the area occupied by the filter, a more compact design of the two stubs has been previously considered [2]. The disadvantage of the stub structure introduced before is its complex orientation and design parameters.

A simpler design is presented here by bending the correspondent transmission lines of the stubs along the filter ring profile in a first design iteration (Fig. 4 (a)), and then reversing the stubs T-junction toward the interior of the ring in a second design iteration (Fig. 4 (b)). In the latter the two stubs need to be bent twice to fit in the ring internal area.



(a) (b)

Fig. 4. Layout of the ring resonator BPF with UC-PBG structures in the ground plane with (a) external bent stubs, (b) internal folded stubs.



(b)

Fig. 5. Simulated and measured responses of the ring resonator filter with UC-PBG structures and (a) external bent stubs, (b) internal folded stubs.

In both cases parameters such as the losses introduced by the bend and the coupling that might take place between the ring resonator and the bent stub need to be considered. To minimize the losses, a mitered bend design has been used. This provides about 0.1 to 0.3 dB losses and does not affect the overall filter performances [9]. The second issue that should be considered is the coupling between the stub and the ring resonator. The design presented here is based on the quasi-TEM mode properties of the coupled microstrip lines [10]. Although these equations produce an error that might reach more than 8% due to the presence of the PBG structures in the ground plane, they were accurate enough to define a distance such that the coupling is below -15 dB.

The two solutions of Fig.4 are designed on the same material mentioned above. The simulated and measured responses are presented in Fig.5 (a) and (b). All filters specifications are shown in Table 1. We can see a great reduction in the size of the filter reaching up to 84.49 % for internal folded stubs (while 68.24% is attained for the external bent stubs), accompanied by very good overall filter performance. This means that bending the stubs has affected neither the very good passband characteristics provided by the ring resonator filter, nor the wide stopband provided by the UC-PBG structures.

4 Suppression of the Lower Passband Using Via Holes

The filter still suffers from a narrow lower stopband and a passband at the DC frequency range. This problem is usually solved using input/output capacitive coupling [2]. The disadvantage of this technique is its high insertion loss and decrease in the bandwidth.

A transmission zero may be obtained by replacing the two tuning open-circuited stubs by two via holes [4]. This should not affect the response at the center frequency required. This may be explained as follows; at the resonant center frequency, the $\lambda_g/4$ open-circuited stub is equivalent to a direct short circuit at the ring-stub interface following the transmission line input impedance equation given by:

$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tanh(\gamma \ell)}{Z_0 + Z_L \tanh(\gamma \ell)} \quad (2)$$

Where Z_L is the load impedance (open circuit in this case), γ is the propagation constant and ℓ is the length of the stub. This short circuit is implemented using via holes. At zero frequency, the circuit acts as if there is a short circuit directly connected at the input, and therefore a transmission zero is obtained at zero frequency.

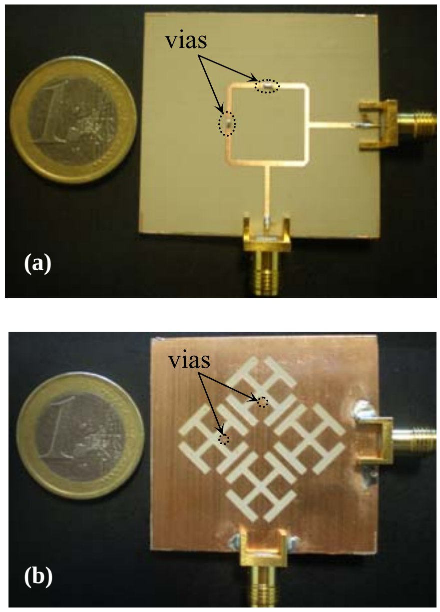


Fig. 6. Photograph of the fabricated ring resonator BPF with UC-PBG structures in the ground plane and via holes (a) Top view, (b) bottom view.

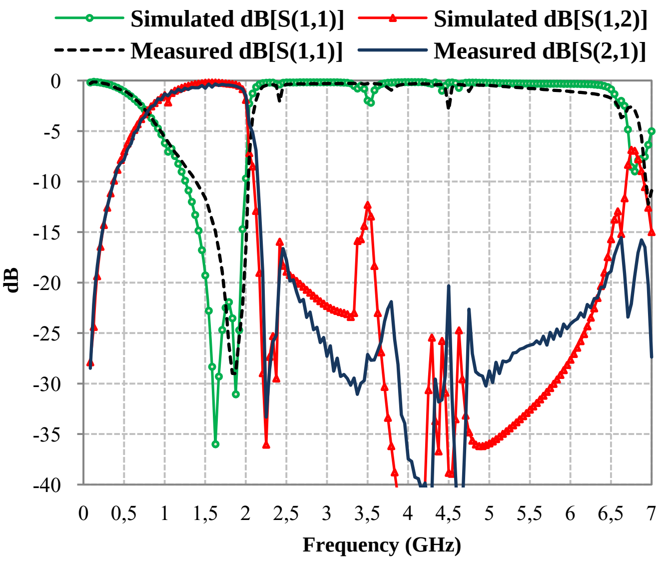


Fig. 7. Simulated and measured responses of the ring resonator filter with UC-PBG structures and via holes.

Fig.6 shows a photograph of the ring resonator filter with via holes and UC-PBG structures. The radius of each via is equal to 0.25 mm. Fig.7 shows the responses of the filter. All filters specifications are shown in Table 1. The basic disadvantage of using via holes is that the rejection in the lower stopband is not sharp enough. This is because the sharp transmission zero produced by the stub has been replaced by that at zero frequency. It should be noted that the sharp upper rejection in this case is produced by the UC-PBG structures.

ISSN: 1790-5109

ISBN: 978-960-6766-94-7

Table 1
Characteristics of the Presented Filters

Filter	Insertion Loss (dB)	Return Loss (dB)	3-dB FBW	10-dB Stopband (GHz)	Size (mm)	Size Reduction
Conventional Ring Resonator Filter	-1.2	-8	60.6 %	0.46	40.5 x 40.5	----------
Ring Resonator Filter with Straight Stubs and UC-PBG	-0.21	-20	46.5 %	4.7	29.9 x 29.9	45.52 %
Ring Resonator Filter with External Bent Stubs and UC-PBG	-0.34	-17	50.73 %	4.66	22.9 x 22.9	68.24 %
Ring Resonator Filter with Internal Folded Stubs and UC-PBG	-0.59	-12.81	40.8 %	5.25	15.9 x 15.9	84.49 %
Ring Resonator Filter with Via Holes and UC-PBG	-0.18	-27	85 %	5.5	13.9 x 13.9	88.135 %

5 Conclusion

A modified ring resonator filter using two tuning stubs was presented. The modifications were implemented following a threefold approach. First, suppression of the higher order modes and size reduction were carried out by the introduction of UC-PBG structures, which enhanced the stopband rejection attaining a level better than -15 dB over 4.7 GHz. In addition, a reduction in the filter size reaching 45.5% was achieved. Second, further size reduction was achieved by the introduction of the inward reversed and twice bent stubs reaching 84.5 % of the original filter size. Finally, via holes are added to replace the stubs providing a transmission zero at zero frequency.

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