A BANDPASS FILTER WITH COMPACT SIZE AND EXTENDED STOPBAND USING CLOSED-LOOP TRANSMISSION-LINES AND SHORT-CIRCUITED STUBS

J. A. Escobar[*], J. L. Olvera-Cervantes, A. Corona-Chávez, and H. Lobato-Morales

Department of Electronics, Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), México

Abstract—A novel 3-pole bandpass filter (BPF) based on microstrip loaded ring resonators (LRRs) is proposed. Each resonator comprises a closed-loop transmission line and a short-circuited stub. By properly adjusting the impedance and the electrical length of each resonator, the proposed circuit may be made compact (over 93.7% smaller than a conventional ring resonator) and its stopband may be extended simultaneously. Each resonator exhibits an area of $0.0727\lambda g \times 0.079\lambda g$, where λg is the guided wave length. A BPF at the center frequency of $f_0 = 1.9\,\text{GHz}$ with stopband extended up to $7.8\,\text{GHz}$ $(= 4f_0)$ is developed showing good agreement between simulation and experimental results.

1. INTRODUCTION

In microwave systems, high performance and small size bandpass filters are essentially required to enhance the system performance. Ring resonators have been widely studied in the literature for filter applications. A ring resonator consists in $360°$ closed-loop transmission line, where a full-wavelength standing wave is excited. Due to the large size of these resonators, different techniques have been suggested in the literature to achieve miniaturization. In [1], a miniaturization technique is proposed where the size reduction is about 50%; this is accomplished by means of a via to ground, that forces, the resonant mode, to have a voltage minimum at one end of the resonator. In [2],

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* Corresponding author: Johanny Alberto Escobar-Pelaez (johannyescobar@hotmail.com).

the size filter reduction is accomplished with the use of additional coupling structures (Double U-type Coupling Structure, DUCS); these structures reduce the required spacing for an established coupling factor between each pair of resonators; in consequence, smaller filters can be achieved. In [3], metamaterial lines are used to obtain a 90% size reduction for a conventional ring resonator. In [4], is presented a very compact filter with the use of reduced size conventional quarter wavelength resonators. By other side, in this context, microstrip resonators are structures that do not resonate for an unique frequency value; this way, filters based on these resonators may present more pass bands than just the desired one. For this reason, many efforts have been made along the recent years, in order to obtain farthest spurious from the fundamental resonance frequency. In [5], was presented the use of SIR (Stepped Impedance Resonators) with dissimilar frequency response in order to attenuate the magnitude of the spurious in the total filter. In [6], the use of CSRR (Complementary Split Ring Resonators) was showed to improve the frequency response of conventional Hairpin resonators; spurious around 2.5 times the resonance frequency were obtained. Finally, in [7] with the use of DGS (Defected Ground Structures) it is achieved the suppression of the second and third harmonic for Hairpin resonators.

In this paper, a new compact resonating structure is introduced. The resonator is 93.7% smaller than a conventional ring resonator, presents low sensitivity to substrate thickness and increased spurious frequency (over four times the resonance frequency for the first spurious). It is important to notice that the improvement in the frequency response is accomplished without the use of complementary structures.

The remainder of this paper is organized as follows. In Section 2, the resonating structure and the design of a 3-pole chebyshev filter is presented. Simulations and experimental results for the prototype filter are shown in Section 3. Finally, the main conclusions of this work are highlighted in Section 4.

2. THE RESONATING STRUCTURE AND THE DESIGN OF A 3-POLE CHEBYSHEV FILTER

The proposed 3-pole BPF, illustrated in Figure 1, comprises three LRRs. Each resonator has different characteristics impedances Z_{CL} and Z_S and different electrical lengths Θ_{CL} and Θ_S, where the subscripts CL and S denote the closed loop transmission line and the short-circuited stub, respectively. Is worthy to mention that the stub is short-circuited by means of a via to ground.
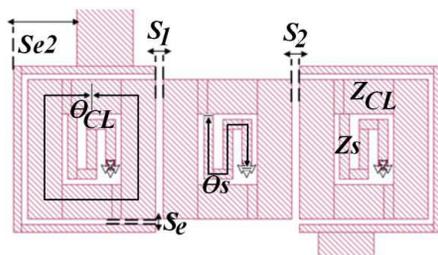
Figure 1. Layout of a prototype at 1.85 GHz.

The resonating frequency for the proposed structure is determined when the denominator of the input impedance given in (1) is zero.

$$Z_{in} = \frac{1 + Z_{LS}Y_X}{Z_{LS}\left(\frac{2}{Z_{CL}}\right)^2 + Y_X} \tag{1}$$

In (1), $Z_{LS} = jZ_S \tan(\Theta_S)$ and $Y_x = -2j\cot(\Theta_{CL})$. By properly adjusting the impedances and the electrical lengths, the circuit may be made compact and its stopband may be extended simultaneously. For the present resonator the impedances were set as $Z_{CL} = 65\,\Omega$ and $Z_S = 108\,\Omega$, and the electrical lengths as $\Theta_{CL} = 70°$, and $\Theta_S = 30°$. Thus the area of each resonator is $0.0727\lambda g \times 0.079\lambda g$; therefore, the new resonator is 93.7% smaller than a conventional ring resonator. A single resonator was designed at the center frequency of 1.9 GHz, on a substrate with a thickness $h = 1.5$ mm, a dielectric constant $\varepsilon_r = 4.34$. The layout of the resonator and its simulated response are shown in Figure 2; where $W_S = 0.5$ mm, $W_L = 1.8$ mm, $W_r = 6.7$ mm and $H_r = 7.3$ mm. From this figure, it can be seen that the fundamental resonating frequency f_0 was successfully obtained and the first spurious harmonic was pushed to a higher frequency such as 7.8 GHz $(= 4f_0)$.

Tolerances in substrate thickness is the main drawback for mass production of planar filters [8]; for this reason, in order to evaluate the sensitivity of the resonator to substrate thickness variations, the resonator was analyzed in this context following the procedure described in [8], where the changes in the resonance frequency, for a particular resonator layout are determinate for variations in the thickness of the substrate. The analysis showed that the proposed resonator, changed its resonance frequency only 116 MHz when the substrate thickness changed from 1.5 mm to 3.5 mm, this corresponds to a low sensitivity value ($\Delta f = 3\%$/mm), representing an additional advantage of the proposed structure.
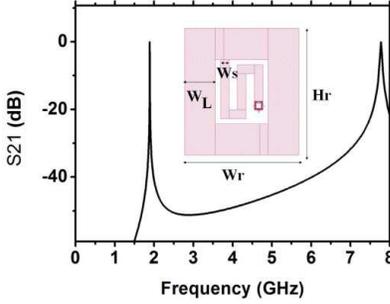
Figure 2. Response of a single uncoupled resonator.
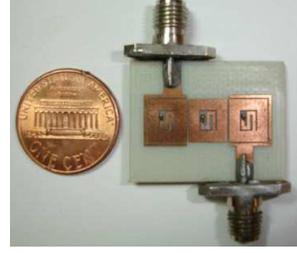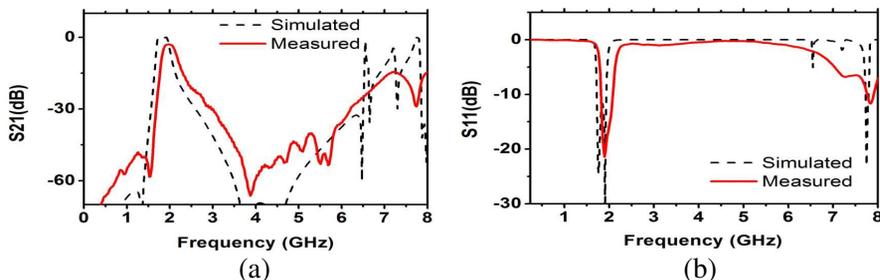

Figure 3. Picture of the fabricated filter.

A BPF can be designed by considering the proposed resonator, the mutual coupling coefficients (coupling between each adjacent pair of resonators), and the Input/Output coupling coefficients (the coupling regarding the feed lines and their adjacent resonators). In this context, the Input/Output coupling coefficients $Q_{ext1,n}$ and the mutual coupling coefficients M_{ij} can be calculated as $Q_{ext1} = g_o g_1 / \text{FBW}$, $Q_{extn} = g_n g_{n+1} / \text{FBW}$ and $M_{ij} = \text{FBW}(g_i g_j)^{-1/2}$ where FBW is the fractional bandwidth and $g_0, \ldots, g_{n+1}$ are the named g-parameters of a lowpass prototype [9]. To design a 3-pole Chebyshev BPF with a ripple of 0.1 dB and FBW = 10.53% the g-parameters can be obtained from [9] as $g_0 = 1$, $g_1 = 1.0315$, $g_2 = 1.1474$, $g_3 = 1.0315$, and $g_4 = 1$ which give $Q_{ext1} = 9.7993$, $Q_{extn} = 9.7993$ and $M_{12} = M_{23} = 0.0968$.

On the other hand, the external quality factors depend on the gap S_e and the length S_{e2} shown in Figure 1. The quality factor may be calculated from (2), where the 3 dB frequency band width Δ_{FBW} and the center frequency f_{0x} are obtained from full wave simulations [9]. For the proposed filter $S_{e2} = 6.2$ mm and $S_e = 0.3$ mm.

$$\text{Q}_e = \frac{f_{ox}}{A_{\text{FBW}}} \tag{2}$$

The mutual coupling coefficient M_{12}, and M_{23} depend on the gap S_1, and S_2, shown in Figure 1, respectively. They can be calculated from (3) where f_1 and f_2 are the corresponding resonant frequencies obtained from full wave simulations [9]. For the proposed filter $S_1 = S_2 = 0.4$ mm.

$$M_{ij} = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \tag{3}$$

Figure 4. Measured and simulated dispersion parameters. (a) Insertion loss and (b) return loss.

3. RESULTS

A picture of the fabricated filter is shown in Figure 3; it can be noticed the compact size of the structure. Simulated and measured S-parameters are shown in Figure 4. Simulated results were obtained by using Sonnet$^{©}$ and the measured results by means a vector network analyzer. Simulated and measured center frequencies are 1.85 GHz and 1.95 GHz, respectively. It was also found that the simulated and measured FBW are 14.67% and 14.72%, respectively. Measured insertion and return loss are 3.3 dB $\pm$ 0.1 dB and better than 10 dB within the measured bandwidth, respectively. The results show that the proposed filter exhibits stopband extended up to 7.8 GHz ($= 4f_0$). Additionally, it can be noticed that the magnitude of the first spurious is attenuated under 15 dB.

4. CONCLUSIONS

A BPF at 1.95 GHz with 14.72% fractional bandwidth was proposed. The filter is based on a new reduced size microstrip resonator that is 93.7% smaller than conventional ring resonator. The presented structure has a compact size, extended stopband, and excellent sensitivity with less than 3 percent variation per millimeter changed in the substrate thickness. The resonator exhibits interesting characteristics that will be exploited, in a future work, to develop chipless tags for RFID systems and very compact balanced BPFs with differential-mode passband, common-mode rejection, and extended common-mode stopbands.

ACKNOWLEDGMENT

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