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A MINIATURIZED BANDPASS FILTER WITH CONTROLLABLE HARMONIC BY USING SPLIT IMPEDANCE RESONATORS

J.-Y. Li and W.-J. Lin

Department of Electrical Engineering
Institute of Microelectronics
National Cheng-Kung University
No. 1 University Road, Tainan City 701, Taiwan, R.O.C.

D.-B. Lin

Institute of Computer and Communication Engineering
National Taipei University of Technology
1, Sec. 3, Chung-hsiao E. Road, Taipei 10608, Taiwan, R.O.C.

L.-S. Chen

Department of Electronic Engineering
I-Shou University
No. 1, Sec. 1, Syuecheng Road., Dashu Township
Kaohsiung County 840, Taiwan, R.O.C.

M.-P. Houng

Department of Electrical Engineering
Institute of Microelectronics
National Cheng-Kung University
No. 1 University Road, Tainan City 701, Taiwan, R.O.C.

Abstract—In this paper, a miniaturized bandpass filter with controllable harmonic by using split impedance resonators is proposed. The proposed split impedance resonator is based on the theories of the basic parallel impedance formula and stepped impedance resonators (SIRs). In this way, the split impedance resonator can be effectively designed to obtain good coupling for reducing the insertion loss. Furthermore, a miniaturized bandpass filter with controllable spurious frequency is proposed. The proposed bandpass filter not only has

Corresponding author: M.-P. Houng (mphoung@eembox.ncku.edu.tw).

good passband characteristics but also obtains miniaturization around 21.87% versus the traditional SIR bandpass filters.

1. INTRODUCTION

Many methods have been proposed for controlling the spurious resonance frequencies of microstrip bandpass filters. In 1980, Makimoto and Yamashita verified that controllability of the spurious resonance frequencies can be realized by using different impedance ratios [1, 2]. Hong also proposed that stepped impedance resonator bandpass filter can achieve the harmonic suppression to improve the stability of the system [3, 4]. In recent years, the stepped impedance resonator has been frequently applied to control the harmonic to be the second passband [5, 6] or improve the out-of-band performance [7–10]. However, the coupling between two different impedances has been a common problem for traditional stepped impedance resonators.

In this paper, based on the theories of the basic parallel impedance formula and stepped impedance resonators, the split impedance resonator is developed and then applied to implement a miniaturized bandpass filter with controllable harmonic.

2. SPLIT IMPEDANCE RESONATOR AND FILTER DESIGN PROCEDURE

2.1. Split Impedance Resonator

To design the split impedance resonator, the basic structure of a traditional half wavelength stepped impedance resonator is shown in Fig. 1, under condition of $K < 1$ ($K = Z_2/Z_1$). It is composed of two lower-impedance sections Z_2 and one higher-impedance section Z_1 between the two lower-impedance ones.

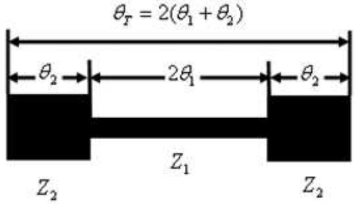

Figure 1. Basic structure of a traditional half wavelength stepped impedance resonator ($K < 1$, $K = Z_2/Z_1$).

An electrical parameter which characterizes the SIR is the ratio of the two transmission line impedances Z_1 and Z_2, which are defined by Equation (1). The overall electrical length of the SIR, represented by θ_T, is expressed as, $\theta_T = 2(\theta_1 + \theta_2)$. Thus, for a direct analysis, input admittance Y_i seen from an open-end must be obtained, in this case given as (2),

$$K = Z_2/Z_1 \tag{1}$$

$$Yin = jY_2 \frac{2(K\tan\theta_1 + \tan\theta_2)(K - \tan\theta_1\tan\theta_2)}{K(1-\tan^2\theta_1)(1-\tan^2\theta_2) - 2(1+K^2)\tan\theta_1\tan\theta_2} \tag{2}$$

Resonance conditions are obtained by taking $Y_i = 0$, thus given as (3). Making $\theta_2 = \theta_1$, in this case given as (4), the controllable spurious frequency f_{S1} was verified as (5).

$$K = \tan\theta_1 \tan\theta_2 \tag{3}$$

$$\theta_1 = \tan^{-1}\sqrt{K} = \theta_0 \tag{4}$$

$$\frac{fs_1}{fo} = \frac{\theta s_1}{\theta o} = \frac{\pi}{2\tan^{-1}\sqrt{K}} \tag{5}$$

Consequently, spurious resonance frequency is obtained and shown as Equation (4), and relationship between impedance ratio and normalized spurious resonant frequencies is shown in Fig. 2.

Furthermore, as shown in Equation (6), the impedance Z_2 was presented as Z_1/N, when impedance Z_2 was divided as numerous impedance Z_1. Letting $\theta_2 = \theta_1$, in this case, the Equation (7) is given from Equation (4), and the controllable spurious frequency f_{S1} is verified as Equation (8). In this paper, Equations (6) and (8) were

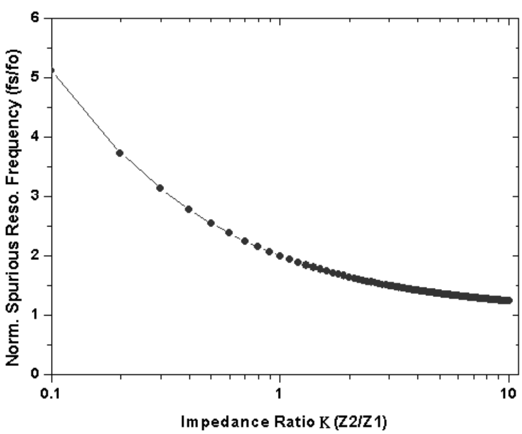

Figure 2. Relationship between Impedance ratio K and normalized spurious resonant frequency f_{S1}/f_0.

not yet be proposed and applied to other reference sources. Thus, Fig. 3 shows the relationship of spurious resonant frequency f_{S1} and frequency ratio f_{S1}/f_0 versus the numbers of split impedance section (N). Then, the proposed split impedance bandpass filter was realized based on Equations (6), (8), and Fig. 3. Relative discussion is shown in the next paragraph.

$$K = Z_2/Z_1 = \frac{(Z_1/N)}{Z_1} = \frac{1}{N} \tag{6}$$

$$\theta_1 = \tan^{-1}\sqrt{\frac{1}{N}} = \theta_0 \tag{7}$$

$$\frac{fs_1}{fo} = \frac{\theta s_1}{\theta o} = \frac{\pi}{2\tan^{-1}\sqrt{1/N}} \tag{8}$$

2.2. Filter Design Procedure

In this paragraph, based on the theories of the basic parallel impedance formula, the lower-impedance sections of traditional stepped impedance resonator were transferred to numerous higher impedance sections by using the proposed Equations (6), (8), and Fig. 3. Fig. 4 shows the proposed bandpass filter composed of two-order split impedance resonators on $50\,\Omega$ feed lines. The total size of the filter was $10.25\,\text{mm} \times 59.5\,\text{mm}$.

To illustrate the performance, center frequency was chosen as

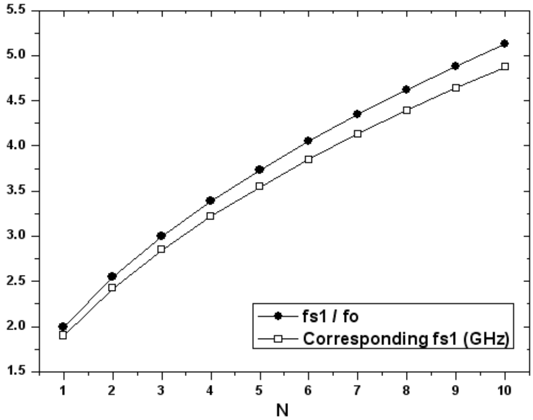

Figure 3. Relationship of spurious resonant frequency f_{S1} and frequency ratio f_{S1}/f_0 versus the numbers of split impedance section (N).

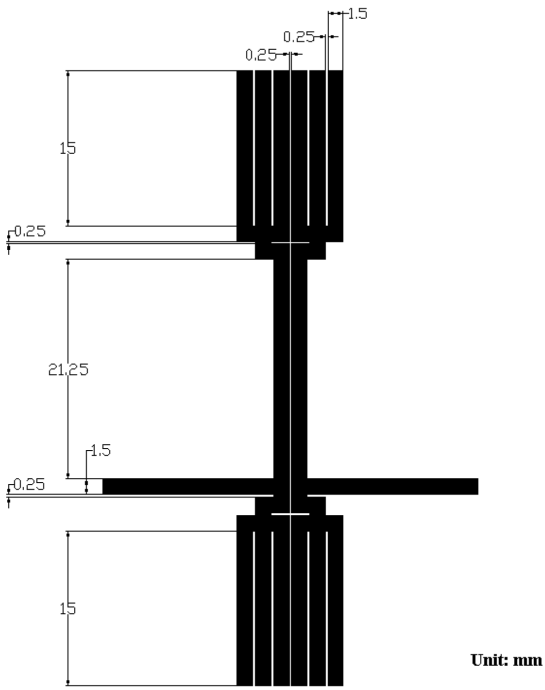

Figure 4. Configuration of the proposed bandpass filter.

0.95 GHz with fractional bandwidth (FBW) of 15%, and expected harmonic frequency was designed moving to $3f_0$, 2.85 GHz. In this way, the number of split impedance section N was chosen as 3 by Equation (8), and the proposed filter was simulated and fabricated on FR4 substrate (permittivity = 4.4, thickness = 0.8 mm). The element values of the low-pass prototype filter were found as $g_0 = 1$, $g_1 = 2.034$, $g_2 = 0.662$, and $g_3 = 3.070$. To determine the physical dimensions of the filter, the coupling coefficients need to be calculated. It turned out that $M_{12} = 0.12$ [11, 12]. Thus, Fig. 5 plots the simulated coupling coefficients versus the gaps between two proposed split impedance resonators. According to Fig. 5., we know that coupling coefficient 0.12 can be obtained when the gap is chosen as 0.25 mm.

3. IMPLEMENTATION AND EXPERIMENTAL RESULTS

The bandpass filters are realized and verified by full-wave EM simulation. An Agilent E8364A network analyzer is employed for

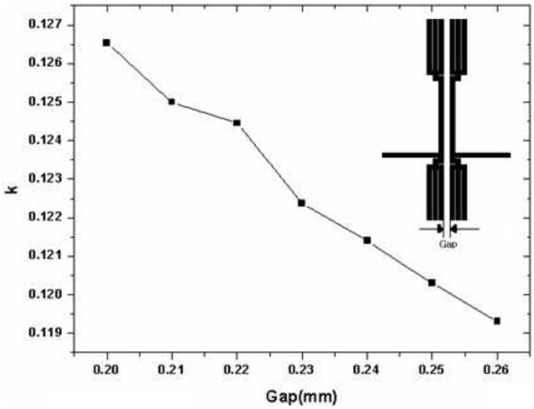

Figure 5. Coupling coefficients k versus the gaps between two resonators in loose coupling.

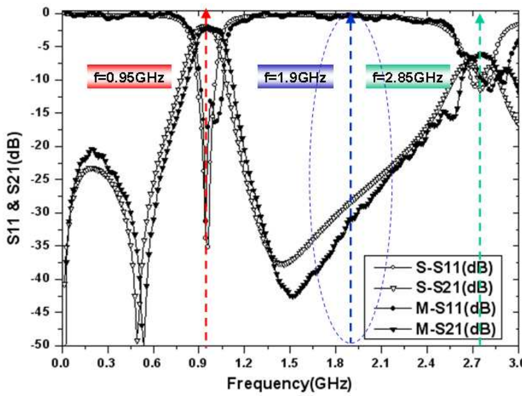

Figure 6. Simulated and measured S-parameters of the proposed split impedance bandpass filter.

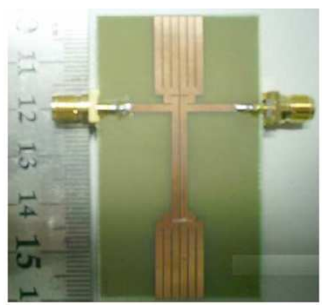

Figure 7. The photograph of the fabricated filter.

the measurement of S-parameters. The simulated and measured S-parameters of the proposed spilt impedance bandpass filter was shown in Fig. 6, and the photograph of the fabricated filter is shown as Fig. 7. Experimental results of the fabricated filter were in agreement with the expected specification. The measured insertion loss was 2.24 dB, and return loss was better than 31.3 dB at the center frequency 0.95 GHz. Finally, this filter effectively moved the harmonic frequency 1.9 GHz to $3f_0$, 2.85 GHz. Then, from 1.15 to 2.29 GHz, the suppression is better than 20 dB.

4. CONCLUSION

A split impedance bandpass filter with controllable harmonic was theoretically verified and proposed in this paper. The proposed bandpass filter not only has good passband characteristics but also obtains miniaturization around 21.87% versus the non-split impedance bandpass filter.

ACKNOWLEDGMENT

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