Microstrip Dual-Mode Bandpass Filter Using CPW-Fed Triangular Loop Resonator with Controllable Attenuation Pole

Xu-Guang Wang #1, Young-Ho Cho #2, Kuk-Jin Chun #1, Sang-Won Yun #4

#1Department of Electronic Engineering, Sogang University
1 Shinsu-dong, Mapo-gu, Seoul, 121-742, Korea
#2jonathan@sogang.ac.kr
#3kchun@snu.ac.kr
#4xgwang@sogang.ac.kr

Abstract — Novel microstrip dual-mode bandpass filter (BPF) based on the triangular loop resonator with coplanar-waveguide (CPW) feeding structure is presented. The novelty of this design is to use two forms of perturbation, the isosceles triangle shape of microstrip loop resonator and the open stub element, both of which contribute to the coupling between two degenerate modes. By making a various combinations of these two parameters, it is possible to design both narrow and wide band filters and to control the attenuation pole frequency simultaneously. Moreover, the issue of harmonic suppression using dumb-bell-shaped defected ground structure (DGS) cells integrated at each input/output port is also investigated. Experimental results show a good agreement with the simulated ones, which validates the proposed design.

Index Terms — Defect ground structure (DGS), dual-mode bandpass filter, harmonic suppression, triangular loop resonator.

I. INTRODUCTION

In recent years, compact, high-performance, and low-cost components for radio frequency (RF) applications have been the focus of a great deal of research and industrial pursuit. Microstrip dual-mode resonators are attractive because a single dual-mode resonator can be utilized as a doubly tuned resonant circuit and, hence, resulting in a compact filter configuration. Since the first presentation of the dual-mode ring BPF by Wolff [1], various innovative designs have been proposed including the dual-mode microstrip patch and loop resonators with circular or square shape [2]-[5]. However, so far, the study of microstrip dual-mode BPF using triangular resonator has received little attention. More recently, a primary development of the dual-mode microstrip triangular patch resonator BPF was reported in [6], and the dual-mode BPF based on the microstrip triangular loop resonator was proposed in [7]. These proposed designs with edge-coupling scheme can only obtain narrow fractional bandwidth due to their natural properties and the high external quality factors resulting from the loose coupling strength between the feeding lines and the resonator. Moreover, few papers have been published regarding the attenuation pole frequency control of a dual-mode triangular resonator BPF.

In this paper, novel microstrip dual-mode BPF using CPW-fed triangular loop resonator is proposed. The employment of the CPW feeding scheme can eliminate the restriction of limited external quality factor tunable range. At the same time, the coupling coefficient between two degenerate modes can also be controlled within a wide range by attaching an open stub to the inner edge of the triangular loop hemline as additional perturbation element. Therefore, the proposed filter configuration can provide sufficient degrees of freedom to satisfy various requirements of external quality factors and coupling coefficients and then can be applied to both narrow and wide band designs. Different from the reported conventional design, the coupling between two degenerate modes in this study is provided as the total effect of the isosceles triangle shaped resonator and the stub perturbation. By making a various combinations of these two parameters, it is possible to control the attenuation pole frequency while keeping the bandwidth constant. In addition, the method to improve the stopband performance using embedded dumb-bell-shaped DGS cells is also studied. Three types of such compact dual-mode BPFs, with narrow bandwidth of 8.3%, with wide bandwidth of 20.8%, and the modified version of the first narrow band design with enhanced stopband performance, respectively, were fabricated and measured to validate this novel dual-mode BPF configuration.

II. CPW-FED DUAL-MODE TRIANGULAR LOOP RESONATOR

As illustrated in Fig. 1 (a), the conventional dual-mode triangular loop BPF adopts edge-coupling feeding structure, causing the bandwidth restriction. And the coupling between two degenerate modes is only dependent on the shape of the triangular loop resonator.

Fig. 1 (b) shows the configuration of the proposed CPW-fed dual-mode BPF using microstrip triangular loop resonator. The input/output CPW feeding lines and open square stubs are fabricated on one side of the dielectric substrate to feed the triangular loop resonator at the left and right lower corners. The resonator is on the opposite side and is simply a guided wavelength long isosceles microstrip triangular loop with an open stub attached to the inner edge of its hemline. The coupling between two degenerate modes depends on the total effect of the triangle shape and the stub perturbation.
Therefore, this coupling scheme has wide tunable range of coupling coefficient and moreover it is possible to control the attenuation pole frequency with a constant bandwidth by making a various combinations of these two parameters. The coupling coefficient can be controlled by relative values of the height and length of the hemline, as well as the stub length (h, p, and a in Fig. 1 (b)), as calculated using

\[ k = \frac{f_{o2}^2 - f_{o1}^2}{f_{o2}^2 + f_{o1}^2} \]  

(1)

where \( f_{o1} \) and \( f_{o2} \) are the resonant frequencies of the two degenerate modes, respectively.

By adopting the broadside-coupling mechanism, the coupling strength between the feeding lines and resonator can be conveniently tuned within a wide range, resulting in a wide tunable range of external quality factor (\( Q_e \)). A full-wave EM simulator can be used to extract the \( Q_e \) as [8]

\[ Q_e = \frac{f_0}{\Delta f_{\pm 90^\circ}} \]  

(2)

where \( f_0 \) denotes the resonant frequency, and \( \Delta f_{\pm 90^\circ} \) is the bandwidth over which the phase shifts \( \pm 90^\circ \) with respect to the absolute phase at \( f_0 \).

The transmission-line equivalent circuit of the proposed BPF is shown in Fig. 1(c). This symmetrical geometry allows us to explain its operation by even- and odd-mode analysis. For an even mode, the circuit is divided into one-half at the symmetrical plane, where it is open circuited. Conversely, for an odd-mode excitation, this symmetrical plane is short circuited. The existed two propagation paths between the

III. FILTER DESIGN

Based on the discussions above, three compact two-pole microstrip BPFs composed of such a single dual-mode resonator were designed at the center frequency of 2.4 GHz with symmetrical attenuation poles. The design parameters were calculated as follows [8]:

\[ k_{12} = \frac{FBW}{\sqrt{g_1g_2}} \]  

(3)

\[ Q_e = \frac{g_0g_1}{FBW} \]  

(4)

where \( FBW \) is the fractional bandwidth, and \( g_1 \) is the value of the low-pass prototype element. The substrate is Rogers RO3010 with a relative dielectric constant of 10.2, a thickness of 0.635 mm, and tanδ = 0.0023. The filters were simulated using the full-wave EM simulator HFSS.

A. Narrow Band Filter Design

Firstly, such a dual-mode BPF with symmetrical transmission zeros was designed with a bandwidth of 200 MHz (8.3%). It was fabricated with design parameters as follows: \( a = 14.4 \) mm, \( b = 19.8 \) mm, \( s = 3 \) mm, \( w_2 = 1.5 \) mm, \( g_2 = 0.5 \) mm and \( w_1 = 1 \) mm, \( g_1 = 0.33 \) mm for 50 Ω CPW feeding lines.

The measured frequency responses and the simulated ones are shown in Fig. 3. As can be seen, except for the slight shift
towards the lower frequency, measurement agrees well with simulation. The fabricated filter exhibits a low insertion loss of -1.0 dB including the loss from two SMA connectors and good frequency selectivity due to the two transmission zeros at the both sides of the passband. One is at 1.85 GHz, and the other is at 2.9 GHz with attenuation level of -41 dB and -44 dB, respectively. The return loss within the passband is better than -15 dB. The frequency shift may be due to the fabrication tolerance, and can be compensated by simply reducing the size of the triangular loop.

B. Wide Band Filter Design

To show the wide band application, another design example with 500 MHz bandwidth (20.8%) was designed. The bandwidth can be tuned by adjusting the stub length without varying the center frequency. Here, the stub length $p$ is taken as 1.5 mm. Also, a bigger feeding area with length $s$ = 3.5 mm and bigger gap $g_2 = 1$ mm is adopted to satisfy the corresponding required low external quality factor. The other design parameters are same with the filter in subsection A.

Fig. 4 depicts the simulated and measured frequency responses. Again, compared with the simulation, a good agreement can be observed, except for the approximate 100 MHz shift towards the lower frequency. The insertion loss, including two SMA connectors loss, is measured at -0.8 dB and the return loss is greater than -15 dB within passband. The two transmission zeros are at 1.7 GHz with -45 dB attenuation and 3.05 GHz with -43 dB attenuation, respectively. Note that the shape of triangular loop resonator is not adjusted, so the center frequency unchanged and the two transmission zeros are still symmetrical.

C. Improving Stopband Performance Using DGS

The dual-mode BPF usually suffers from the spurious response. In this study, we also did some experiment to improve the stopband performance. Using DGS structure, which is etched off a defect pattern from the ground plane, is a simple method. It is well known that DGS cell displays a rejection band in a certain frequency range [9]. Here, we inserted dumb-bell-shaped DGS cells into the CPW input/output structure. Fig. 5 shows the simulated frequency responses of a single DGS cell and double series DGS cells with the dimensions as follows: $d = 2.5$ mm, $g = 0.2$ mm and $l = 1.7$ mm. As can be observed, such a single cell acts as a bandstop element having the center frequency of 6 GHz and a deep attenuation of -30 dB, while the double series DGS cells can provide wider stopband range to effectively suppress the spurious response.

Fig. 6 (a) gives the final configuration of the proposed dual-mode BPF with double DGS cells integrated at each port. The resonator has same dimensions with the one in subsection A. Fig. 6 (b) plots the simulated and measured results. It can be seen that the out-of-band rejection level is kept below -15 dB up to 10 GHz except for a small frequency range around 4.4 GHz because of a peak with rejection level.
of -10 dB. Meanwhile, the performance around its passband is kept almost the same as the original BPF without DGS. The measured insertion loss is -1.4 dB, 0.4 dB higher than the BPF in subsection A due to the loss of the low-pass section. The return loss is better than -15 dB. The lower and upper transmission zeros also nearly remain unmoved, which generate sharp rejection at 1.9 GHz and 2.85 GHz with attenuation level of -43 dB and -41 dB, respectively. Fig. 7 shows the photograph of practical fabricated BPF sample, which is connected with SMA connectors for measurement.

IV. CONCLUSION

Novel dual-mode BPF using CPW-fed microstrip triangular loop resonator has been demonstrated, which can be applied to both narrow and wide band designs. In addition, such dual-mode BPF can control the attenuation pole frequency without change the bandwidth. Good agreement exists between the experimental and the simulated results. The proposed filters exhibit a good performance including low insertion loss, compact size, novel and simple structure, high selectivity, and easy design and fabrication. This design concept can be an important addition to the dual-mode BPF designs with emphasis in simplicity and design flexibility.

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REFERENCES