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Design of asymmetrical resonator for microstrip triple-band and broadband bandpass filters

Ko-Wen Hsu, Wen-Hua Tu *

Department of Electrical Engineering, National Central University, Jhongli, Taoyuan 32001, Taiwan

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ABSTRACT

This paper presents two triple-band bandpass filters (BPFs) and one broadband BPF by using asymmetrical resonators. The asymmetrical resonator consists of three branched microstrip sections with different electrical lengths. For the first triple-band BPF (Filter I), by adjusting the stub length of the resonator, the first three resonant modes can be moved to the required center frequencies. For the second triple-band BPF (Filter II), the two sets of asymmetrical resonators are designed with the characteristic of the same center frequencies and staggered higher-order modes to achieve a wide stopband. For the broadband BPF (Filter III), the multi-mode resonances and inherent transmission zeros of the asymmetrical resonator are utilized to design the wideband response with sharp passband selectivity. It has the advantages of compact size and harmonic suppression.

1. Introduction

Bandpass filters (BPFs) are essential components, which are usually used in both receivers and transmitters filtering signal based on frequencies. Planar filters are popular structures because they can be fabricated using printed circuit technology and are suitable for commercial applications due to their small size, lower fabrication cost, and high passband selectivity [1]. Thus, the quality of BPFs is extremely important. Many applications of planar filters have been widely used in microwave communication systems. Recently, multi-band BPFs and broadband BPFs have attracted a lot of attention for circuit design.

To achieve multi-band performance, many methods on designing triple-band BPFs are implemented and fabricated such as stepped-impedance resonator (SIR) [2–8], short stub loaded resonator [9,10], split-ring resonator (SRR) [11,12], defected ground structure (DGS) [13], and dual-mode resonator [14]. In [2,3], one way to design the triple-band BPFs is to cascade three single-band bandpass filters. The SIR has been presented by adjusting the impedance ratio and electrical length ratio to design the harmonic modes. In [4], two sets of quarter-wavelength SIRs are combined and use the same via hole to simplify the filter structure. The SIR with symmetrical structure and three different characteristic impedances was presented in [5,6]. While the three section electrical lengths are the same, the variation of the three sections characteristic impedances can control the ratios of the second and third mode frequencies to the first mode frequency. Thus, the first three modes of the triple-band BPF can be decided based on the single set of resonators. In [7,8], the SIRs and half-wavelength uniform-impedance resonators (UIRs) are assembled to construct the triple-band BPF. In [9], the short stub-loaded resonator consists of a half-wavelength UIR tapped open stub and short stubs simultaneously. For the high design freedom, two sets of short stubs and one set of half-wavelength UIRs are combined to cascade the three passband response [10]. In [11,12], the split-ring resonators (SRR) and complementary split-ring resonators (CSRR) are realized to cascade the three single-band filters to develop the triple-band performance. A class of dual-mode BPF attached four open stubs was proposed [13]. With the coupling feeding of 45° and 135°, the ring resonator provides the first and third passband response. While the four open stubs were attached to the ring resonator, the second passband response can be excited. In [14], the dual-mode defected ground structure resonator (DDGSR) is presented to design the triple-band BPF. To avoid interfering the commercial standard such as C-band (4–8 GHz) and X-band (8–12 GHz) frequencies, a broad upper stopband is required. Recently, many literatures of triple-band BPF were presented showing good performance [15–17].

On the other hand, most research papers of broadband BPFs concentrate on the wider passband bandwidth, passband selectivity, and compact size design. In [18], to achieve a high-selectivity filtering characteristic and enhance the group delay with only a few resonators, a short-circuited stub broadband BPF with input–output crossed coupling is introduced. By using the transversal resonator and asymmetrical interdigital coupled lines, a broadband microstrip BPF with a good harmonic-suppressed response is proposed [19]. The transversal signal-interference filtering sections are employed for the broadband BPF with two transmission-line segments connected in

* Corresponding author. Tel.: +886 3 4227151; fax: +886 3 4255830.
E-mail address: whtu@ee.ncu.edu.tw (W.-H. Tu).

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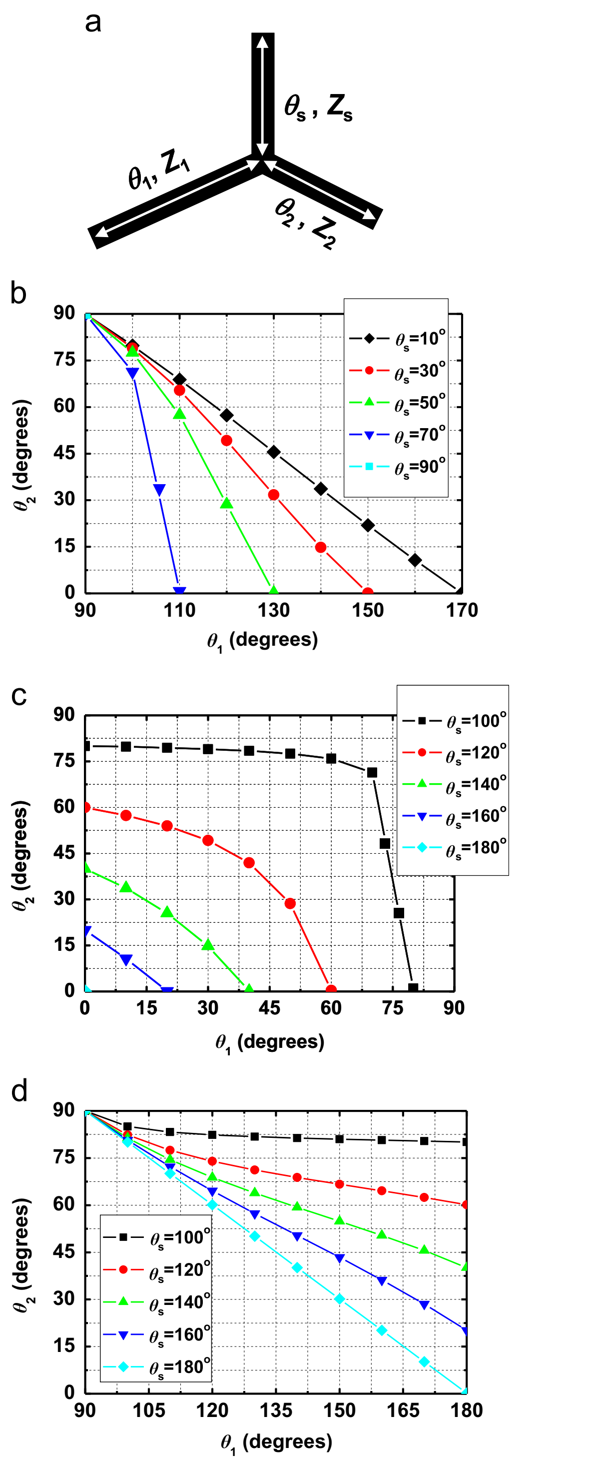

Fig. 1. Asymmetrical resonator (a) schematic, (b) design curves of θ_1 versus θ_2 (c) design curves of θ_1 versus θ_2 (d) design curves of θ_1 versus θ_2.

parallel. The transversal section provides the design method of adjusting passband bandwidth and stopband rejection [20]. Liquid crystal polymer (LCP) is used based on its low cost and stable RF performance over the frequency of interest and its ability to act both as a substrate and a package to obtain broadband filter [21]. The microstrip resonant cell dual-band stub (DBS) was used to further reduce the filter size as soon as the two coupled resonator lines were meandered. The proposed resonator provides three transmission poles in the passband and two transmission zeros beside the passband to enhance the broadband BPF [22]. There are several types

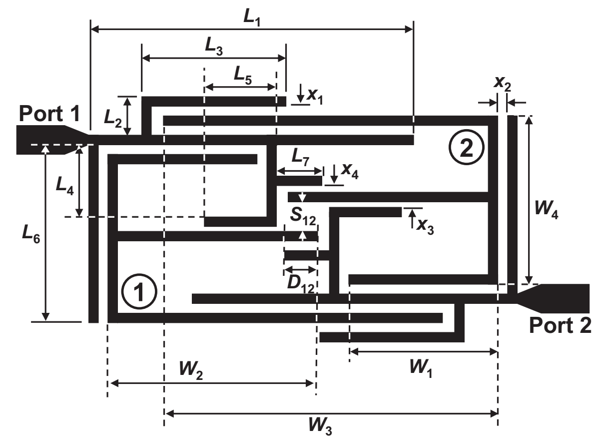

Fig. 2. The layout of the triple-band BPF using asymmetrical resonators.

of broadband BPFs using multi-mode resonator (MMR) reported in the literatures [23–30], in which the resonator consists of a half-wavelength resonator and tapping shunt stubs.

In this study, the asymmetrical resonator with controllable resonant modes and transmission zeros is proposed to design the triple-band BPFs and broadband BPF. For Filter I, the triple-band BPF by means of mixing coupling structure is designed. To improve the stopband response up to high frequency, Filter II is proposed with two sets of resonators, which have the same fundamental frequencies and stagger the harmonics individually. The two triple-band BPFs with operating frequencies of 1.5, 2.5, and 3.5 GHz are implemented. For Filter III, the MMR response and tight coupled structure are used to design the broadband BPF. Moreover, a loaded section design is introduced to provide the edge-coupled effect and adjust the quality factor of the passband. Thus, the characteristic of broadband and harmonic suppression is realized.

2. Asymmetrical resonator

In the past, the asymmetrical resonator was presented to control the stub electrical lengths to design filters. Moreover, the design methods of stub electrical lengths are $\theta_s > 90^\circ$ and $\theta_s < 90^\circ$ to design broadband BPF and dual-band BPF [23,29], respectively. Fig. 1(a) shows the schematic of the asymmetrical resonator. The proposed resonator consists of two microstrip line sections (Z_1, θ_1, Z_2, θ_2) tapped by another stub line (Z_s, θ_s) between the two microstrip lines. The equations of input impedance from the open end can be derived as

$$Z_{in} = \frac{1 - \tan\theta_1(\tan\theta_2 + \tan\theta_s)}{jZ(\tan\theta_1 + \tan\theta_2 + \tan\theta_s)} \quad (1)$$

where $Z_1 = Z_2 = Z_s = Z$ is assumed for simplicity. The resonance condition can be obtained as following:

$$Z_{in} = \infty \quad (2)$$

From (1) and (2), the resonance condition is obtained as

$$\tan(\theta_1) + \tan(\theta_2) + \tan(\theta_s) = 0 \quad (3)$$

Generally, Eq. (3) can be expressed as below

$$\tan(R\theta_1) + \tan(R\theta_2) + \tan(R\theta_s) = 0 \quad (4)$$

where R is the ratio of higher-order modes f_{si} ($i = 1,2,3\ldots$) to the fundamental frequency f_0. It is clear that the proposed asymmetrical resonator has a great freedom in determining the high order modes [27]. Fig. 1(b) shows the relation of the electrical length θ_1 versus θ_2 while $\theta_s = 10^\circ, 30^\circ, 50^\circ, 70^\circ$, and 90° at the fundamental frequency ($\theta_s \leq 90^\circ$). It is clear that there are various solutions to θ_s to achieve the same