URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Overview of Substrate-Integrated Waveguide Dual-Band and Multiband Bandpass Filters

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Invited

Abstract

The method of implementing various substrate-integrated waveguide (SIW) dual-band and multiband bandpass filters (BPFs) are reviewed and summarized, which can be basically classified as three categories. A comprehensive overview of numerous technical approaches and diverse design methodologies are narratively described, including parallel-connecting method, split-type method, and dual-mode method. Future prospects for SIW dual-band and multiband BPF developments are also presented and discussed in this paper.

1 Introduction

With emerging and advanced wireless communication systems under development embracing various key performance indexes (KPIs) in connection with engineering design matrices such as low-cost, high-performance, high-density integration, high-reliability, and high signal integrity, high-quality and highly integrated dual-band and multiband bandpass filters (BPFs) are stringently required in response to current 5G and other wireless sensing system developments. Generally, those BPFs are either responsible for both transmission and reception in transceiver front-ends or for realization of multi-function, multi-standard, and multi-engineering electronic systems.

As a renowned technological platform for microwave and millimeter-wave communication and sensing applications, substrate-integrated waveguide (SIW) technology has provided an effective solution for high-quality and self-packaged dual-band and multiband BPFs benefitting from its inherent merits of low-cost, low-loss, high-power handling capability, and high-density integration, as compared in Figure 1. As the conceptual illustrations in Figure 2, the methods of implementing various SIW dual-band and multiband BPFs are examined and summarized in this paper, mainly including parallel-connecting method, split-type method, and dual-mode method, which would be comprehensively reviewed and described.

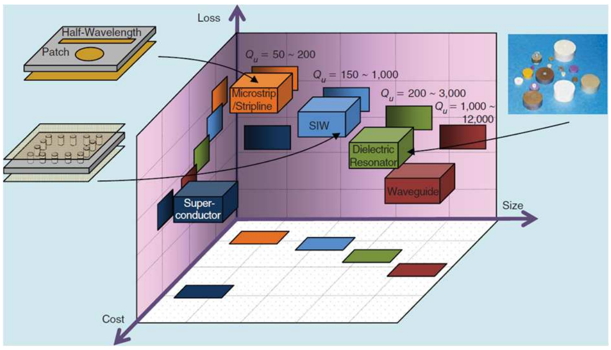

Figure 1. Relationships of costs, sizes, and losses among various microwave resonators.

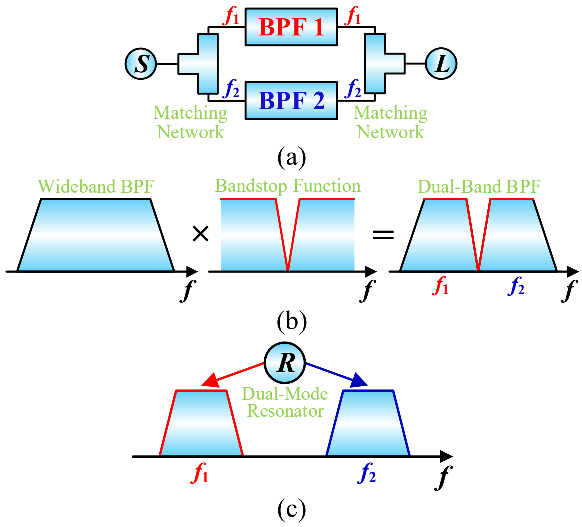

Figure 2. Conceptual illustrations of the three methods for implementing SIW dual-band and multiband BPFs. (a) Parallel-connecting method. (b) Split-type method. (c) Dual-mode method.

2 Overview

Parallel-connecting method: Intuitively, a straightforward solution to implement SIW dual-band or multiband BPFs is to connect two or multiple individual single-band BPFs in parallel with specifically designed wideband or multiband impedance matching networks [1, 2]. Alternatively, complementary split-ring resonators (CSRRs) can also be loaded on SIW top or bottom surfaces to construct multiple passbands [3, 4]. Simple and independent features can be created and characterized for SIW dual-band or multiband BPFs using this scheme. Nevertheless, the circuits usually suffer from larger sizes and higher insertion losses (ILs) in most practical applications.

Split-type method: Another scheme is to split a broad passband into two or multiple sub-passbands with inserted finite transmission zeros [5-11]. With this scheme, dual-band responses were realized in [5, 6], and triple-band

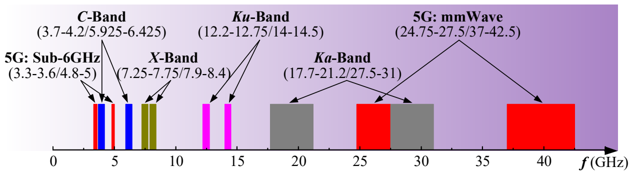

Figure 3. Frequency spectrums of 5G sub-6 GHz and millimeter-wave communications as well as other wireless sensing applications.

responses were implemented and demonstrated in [5] and [7]. To achieve more flexibly allocated passbands, SIW triple-band BPFs are presented by splitting one of the dual-passbands into two [8-10], SIW quad- and quint-band BPFs are proposed by splitting both dual-passbands into two [10, 11] or three [11]. Although smaller circuit sizes and lower ILs could be achieved, the sub-passbands are generally in close adjacency and cannot be allocated or controlled independently.

Dual-mode method: The most commonly used scheme to implement advanced SIW dual-band or multiband BPFs is to exploit the dual-mode or multi-mode properties of SIW cavities [12-27], which generally feature compact sizes and flexibly allocated passbands. In [12-14], SIW dual-mode dual-band BPFs were presented by employing the first dual-modes of TE_{101} and TE_{201} in SIW rectangular cavities. To ease the control of bandwidths, SIW single-mode cavities are added into the above dual-mode dual-band BPFs to achieve wider ranges of bandwidth ratios [15-17]. Furthermore, the first two modes in folded SIW cavity [18], intersecting parallel-plate waveguide loaded SIW cavity [19], dual-capacitively loaded SIW cavity [20], fan-shaped SIW cavity [21], and half-mode SIW rectangular cavity [22] are also exploited to realize SIW dual-band BPFs with widely separated passbands. The orthogonal modes of TE_{102} and TE_{201} in over-mode dual-mode SIW cavity [23, 24] and the first two modes in perturbed SIW square cavity [25] were adopted to achieve closely spaced passbands. SIW triple-band BPFs have been also presented based on perturbed SIW triple-mode cavities and the proposed triple-mode frequency and coupling controlling techniques [26, 27]. Generally, the advantages of flexibly controlled passbands of the parallel-connecting method and small circuit sizes of the split-type method can be preserved for this dual-mode method while circumventing the disadvantages of these two methods.

3 Prospects

Although many state-of-the-art techniques have been reported to date on sophisticated SIW dual-band and multiband BPFs, numerous challenges still remain with respect to front-burner issues. As demonstrated on the frequency spectrum in Figure 3 and illustrated in Figure 4: First, the development of SIW dual-band or quad-band BPFs with frequency ratios larger than 12 for both 5G sub-6 GHz and millimeter-wave communications and other wireless sensing applications is still challenging and difficult. Sec-

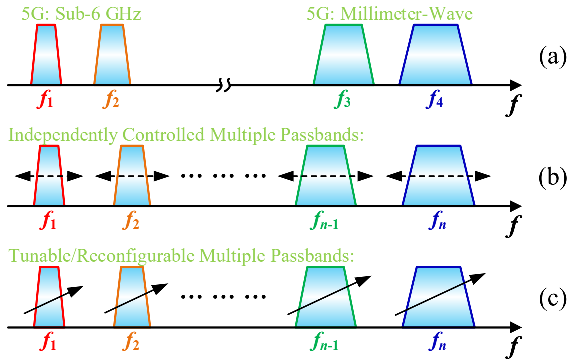

Figure 4. Three future prospects of SIW dual-band and multiband BPFs. (a) Dual- or quad-band BPFs covering 5G sub-6 GHz and millimeter-wave frequency bands. (b) Independently controlled multiple passbands. (c) Tunable/reconfigurable multiple passbands.

ond, it is still a pressing issue to find an effective solution to implement SIW multiband BPFs with all the passbands independently controlled since the sub-passbands in the above-discussed SIW multiband BPFs are always inter-inhibitive. Third, tunable/reconfigurable SIW dual-band and multiband BPFs also present a tough development task because of the difficulty in controlling and tuning the resonant frequencies and mutual couplings of the dual modes or multiple modes independently.

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