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Tri-band superconducting filter using stub-loaded stepped-impedance resonators

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ABSTRACT

A stub-loaded stepped-impedance resonator (SLSIR) with three resonant modes is proposed to design a tri-band bandpass filter (BPF). The couplings between adjacent resonators at different resonant modes can be controlled independently by properly selecting the geometric parameters of the resonator. A dual-feeding structure is used to realize the required external couplings of the three passbands simultaneously. A fourth-order tri-band BPF with the passbands centered at 1.73, 2.40 and 3.45 GHz, respectively, is successfully designed and fabricated with superconducting thin films. The measured results exhibit high performance and agree well with the simulated ones.

1. Introduction

With the rapid development of multi-frequency and multi-function wireless communications systems, multi-band microwave devices are urgently demand. Tri-band bandpass filters (BPFs) are one kind of essential building blocks for such applications. Generally, there are two approaches to design tri-band BPFs. The first approach is to combine three single-band sub-filters or a dual-band and a single-band sub-filters in parallel [1–6]. This approach is simple and direct, but it often has a large circuit size. The second approach is to use multi-mode resonators (MMRs), such as stepped-impedance resonators (SIRs) [7], stub-loaded resonators (SLRs) [8], and ring resonators [9–11]. However, it is difficult to adjust the external couplings and interstage couplings of these MMRs to meet the requirements of three passbands simultaneously, which leads to low pole numbers and unsatisfactory return losses [7–11]. So far, design methods for high-order tri-band BPFs with high design flexibility, compact size, and high performance are still scarce.

In this letter, a compact stub-loaded stepped-impedance resonator (SLSIR) is presented. The SLSIR has the advantages of both SIR and SLR, such as controllable resonant frequencies, high harmonic suppression, and well-established design methods. The required coupling coefficients between the SLSIRs for each passband can be easily achieved, which is important for the design of high-order tri-band BPFs. A dual-feeding structure is proposed to meet the requirements of external couplings of the three passbands. A fourth-order tri-band BPF centered at 1.73, 2.40 and 3.45 GHz is designed and fabricated. The insertion losses are significantly reduced by using high-temperature superconducting (HTS) thin films [2,6]. The measured results exhibit high performance and agree well with the simulated ones.

2. Properties of the SLSIR

The proposed SLSIR consists of a horizontal stepped-impedance section loaded with two vertical stepped-impedance stubs, as depicted in Fig. 1a. The even- and odd-mode analysis method can be applied to investigate the resonance properties considering the resonator is symmetrical vertically, as shown in Fig. 1b and c, respectively. The even-mode resonant frequencies can be reduced, from the resonance condition ($Y_{L,even} + Y_{L,odd} = 0$), as:

$$\frac{2Z_5}{Z_2}\frac{1+R_1\cot\theta_1\tan\theta_2}{R_1\cot\theta_1-\tan\theta_2}+\frac{1+R_2\cot\theta_3\tan\theta_6}{R_2\cot\theta_3-\tan\theta_6}+\frac{1+R_3\cot\theta_4\tan\theta_5}{R_3\cot\theta_4-\tan\theta_5}=0 \quad (1)$$

where R_1, R_2 and R_3 are the impedance ratios and are defined as:

$$R_1=Z_1/Z_2, R_2=Z_3/Z_5, R_3=Z_4/Z_5 \quad (2)$$

The even-mode resonant condition can be obtained as:

$$\tan\theta_1\tan\theta_2=R_1 \quad (3)$$

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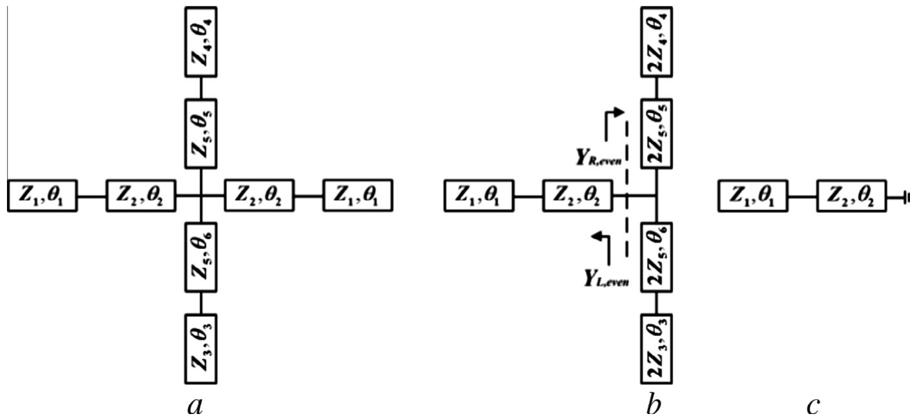

Fig. 1. Structure of the proposed resonator. (a) Stub-loaded stepped-impedance resonator (SLSIR). (b) Even-mode equivalent circuit of the resonator. (c) Odd-mode equivalent circuit of the resonator.

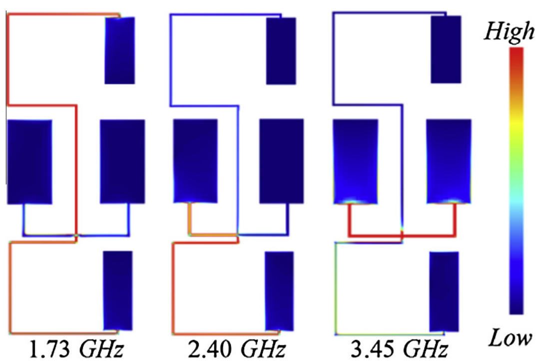

Fig. 2. Simulated current density distributions of the SLSIR at the three resonant modes.

As can be seen from the equations above, the six electrical lengths and three impedance ratios of the SLSIR give sufficient degrees of freedom to tune the three resonant frequencies. The resonant properties of the SLSIR are simulated and adjusted by SONNET full-wave EM simulator. The current density distributions of the SLSIR at the three resonant modes of 1.73, 2.40 and 3.45 GHz, respectively, are shown in Fig. 2. The high-impedance lines in the SLSIR are folded for size reduction.

3. Filter design

Two coupling structures for adjacent SLSIRs are proposed to facilitate the design of a high-order BPF, as shown in Fig. 3a and b. Area 1, 2, 3 and 5 are mainly electric (E) couplings, while 4 and 6 mainly magnetic (M) couplings. According to the simulated current density distributions shown in Fig. 2, the inter-resonator

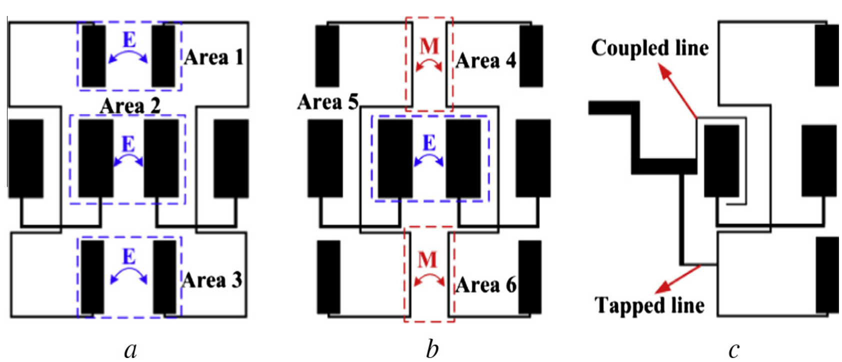

Fig. 3. Coupling structures between adjacent resonators (a and b) and external coupling structure (c).

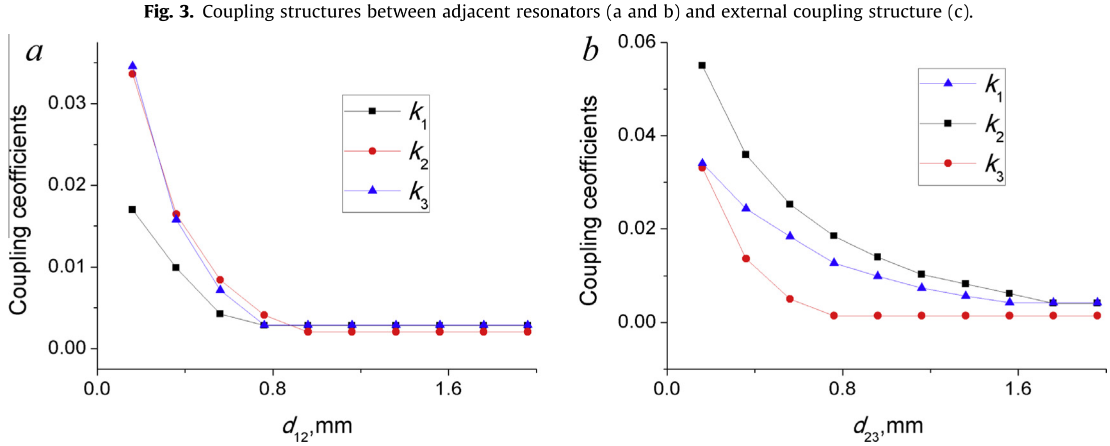

Fig. 4. Simulated coupling strengths as a function of the distance between adjacent resonators. (a) d_{12} represents the distance between the first resonator and the second one. (b) d_{23} represents the distance between the second resonator and the third one.