HTS dual-band bandpass filter using stub-loaded hair-pin resonators with independently controllable bandwidths

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Abstract

We have developed a high-temperature superconducting (HTS) dual-band bandpass filter (BPF) using stub-loaded hair-pin resonators with independently controllable bandwidths. The proposed dual-band BPF is composed of five stub-loaded hair-pin resonators with H-shaped waveguides placed at the center in the spaces between them. The resonator enables independent control of the first and second band resonant frequencies. The main advantage of the proposed filter was to enable independent control of the bandwidths of the first and second band. The coupling coefficient of the second one was controlled by the distance between the resonators, which did not affect the coupling coefficient of the first one. On the other hand, the coupling coefficient of the first one was controlled by the H-shaped waveguide, which did not affect the coupling coefficient of the secondone. An electromagnetic simulator was used to design and analyze the filter. The filter was designed at 3.5 GHz with a 70-MHz (2%) bandwidth for the first band and at 5.0 GHz with a 250-MHz (5%) bandwidth for the second band. The filter was fabricated using YBa$_2$Cu$_3$O$_y$ thin film on a CeO$_2$-bufferd Al$_2$O$_3$ substrate. The measured results agree well with the simulated ones.

Keywords: HTS filter; Dual-band bandpass filter; Stub-loaded resonator; hair-pin resonator; H-shaped waveguide

1. Introduction

Future mobile communication systems will require wideband transmission in order to support high-speed and high-capacity data transmission. This has led to an increasing demand for dual-band bandpass filters (DBPFs). Many DBPFs with a normal conductor and various types of dual-band resonators have been reported [1-8]. The dual-band BPF constructed using high-temperature superconducting (HTS) materials can enhance mobile communication systems due to the low insertion loss and sharp skirt rejection. However, there have been a few reports on dual-band BPFs with HTS materials [9-11].

Wang et al. used quarter-wavelength stepped-impedance resonators (SIRs) to tune the second harmonic of HTS dual-band BPF [9]. The SIRs are usually used on dual-band BPF when the two bands are quite far from each other. Since dimensions of the SIR have an important impact on both frequencies, the dual-band BPF design with them is complicated, and can hardly extend to high-order filters. To overcome this problem, Heng et al., proposed a HTS DBPF

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using stub-loaded resonator with controllable coupling and feeding structure [11]. The DBPF provides high design flexibility and can satisfy various passband specifications. However, there have been few reports on effective design methods for DBPF with improved design flexibility.

We previously reported a novel HTS DBPF by using inter-digital coupled stub-loaded hair-pin resonators and H-shaped waveguide [12, 13]. The main advantages of the filter are to allow independent control of the center frequency of the first and second bands and easy to realize high-order DBPF. We designed the filter with H-shaped waveguide which can be flexibly controlled of bandwidth. The second band bandwidth can be easily tuned by changing the distance between resonators while keeping the first band one basically the same. However, it is difficult to keep the second one basically the same while tuning the first band one by using the waveguide. Furthermore, the strong coupling property of the resonator with the waveguide for the second one needs large space between them so that it makes the filter large.

In this study, we proposed a HTS DBPF by using combline coupled stub-loaded hair-pin resonator and H-shaped waveguide. In particular, we described the newly proposed method for independently adjusting the coupling coefficient for two bands by using combline coupling and changing the position of the waveguide from the DBPF reported in [13].

2. Design of dual-band bandpass filters

We used the Sonnet EM software to design and analyze a five-pole HTS DBPF with combline coupled stub-loaded hair-pin resonators and H-shaped waveguides [14]. The designed center frequencies of the first and second bands were set to 3.5 and 5.0 GHz. A lowpass prototype Chebyshev response with a 0.05-dB ripple was used. The designed bandwidth of the first band and second band were set to 70-MHz (2%) and 250-MHz (5%). The coupling coefficients and external quality factors for the two passbands were obtained using design formulas reported elsewhere [15]. The required coupling coefficients were $K_{12} = K_{45} = 0.017$ and $K_{23} = K_{34} = 0.0126$ for the first band and $M_{12} = M_{45} = 0.0427$ and $M_{23} = M_{34} = 0.0315$ for the second band, respectively. The DBPF was fabricated using 300-nm YBa$_2$Cu$_3$O$_y$ (YBCO) thin film on a 25 $\times$ 25 $\times$ 1.0 mm Al$_2$O$_3$ substrate with a dielectric constant of 9.9. The back of the substrate was also YBCO coated for the ground plane.

We used the stub-loaded hair-pin resonator for the DBPF. We previously reported the detail design method in [13]. The resonator has two resonance modes of odd (first band) and even (second band) modes. The resonant frequency of two modes can be independently tuned while keeping the other one basically the same.

![Stub-loaded hair-pin resonator](image1)

![Stub-loaded hair-pin resonator](image2)

Fig. 1. Simulated coupling coefficients of the resonators as a function of $d$.

![Simulated coupling coefficients of a pair of proposed resonators with additional microstrip line as a function of $lw$. Distance between proposed resonators $d$ is (a) 3.2 and (b) 3.9 mm.](image3)

The simulated coupling coefficients of the resonators as a function of $d$ are shown in Fig. 1. Note that once the coupling coefficient of one band has been set, that of the other band is determined. Thus, it is very difficult to independently control the coupling coefficients of both bands. This makes it difficult to design a high-pole DBPF.

To overcome this problem, we introduced combline coupled stub-loaded hair-pin resonators and H-shaped waveguides to enable the coupling coefficients to be independently controlled. The idea is to control the second band...
coupling coefficient mainly by adjusting the distance between the combline coupled resonators and to control the first one by adjusting the structural parameters of the H-shaped waveguide while the coupling coefficient of the second band remains basically the same. To achieve the required coupling coefficients of 0.0315 and 0.0427 for the second band, we first set distance $d$ between the resonators to 0.32 and 3.9 mm on the basis of the relationship shown in Fig. 1. To obtain the designed coupling coefficient of the first band, we had to increase the first band coupling coefficient by adding the H-shaped waveguide between combline coupled resonators which did not affect the second band coupling coefficient. We previously reported the relationship between the coupling coefficient and the position of the H-shaped waveguide placed between combline coupled single band resonators [16]. When the waveguide is placed at the center in the spaces between the resonators, its effect is the minimum and the coupling coefficient remains basically the same as without the waveguide. Thus, we placed the waveguide at the center in the spaces between the combline coupled resonators to control the first band coupling coefficient while the coupling coefficient of the second band was hardly changed, as shown in Fig. 2. The coupling between the resonators is controlled by adjusting the waveguide length $l_w$, the gap between the waveguide and each resonator, and the width of the microstrip line. We set the coupling gap to 0.1 mm and the waveguide line width to 0.2 mm. The coupling coefficients of the resonators with the waveguide between them as a function of $l_w$ are shown in Fig. 2. The coupling coefficient of the first band was increased substantially while that of the second band remained basically the same.

Finally we obtained the designed coupling coefficient for both bands. This means that the coupling coefficients can be independently tuned by using the combline coupled resonator and the waveguide.

3. Measurement results

The configuration of the final HTS DBPF and the side view of it are illustrated in Fig. 3(a) and (b). The DBPF was fabricated with two Al$_2$O$_3$ substrates with single-sided-deposited YBCO thin films. The upper substrate had only the designed DBPF on its upper side. The lower substrate had an only ground plane on the lower side. The filter was patterned using conventional photolithography and ion beam milling. Figure 3(c) shows a photograph of the fabricated DBPF. Measurements were done using an integrated RF measurement system consisting of a cryocooler operating and a network analyzer (E5071B, Agilent Technologies).

![Fig. 3](image_url) (a) Configuration of HTS DBPF. (b) Side view of HTS DBPF. (c) Photograph of DBPF.

![Fig. 4](image_url) (a) Simulated and measured frequency response of HTS DBPF at (a) wide band, (b) 3.5 and (c) 5.0 GHz band.
The simulated and measured frequency responses of the DBPF are shown in Fig. 4. As shown in Fig. 4(a), there was good agreement between the simulated and measured frequency responses. The simulated and measured frequency responses of the DBPF at 3.5 and 5.0 GHz band are shown in Fig. 4(b) and (c), respectively. Since the first and second fractional bandwidths were difficult to observe in the measured frequency response, a 3-dB bandwidth was used. The 3-dB bandwidths for first and second band were slightly larger than the designed one. The slight differences in the bandwidths from the designed values may have been due to the difference in the dielectric constant and thickness of the substrate between the simulated and effective values. The minimum insertion losses for the first and second passbands were 0.09 and 0.05 dB.

4. Conclusion

We have proposed a high-temperature superconducting dual-band bandpass filter (DBPF) that uses a pair of newly developed five-pole stub-loaded hair-pin resonators with an H-shaped waveguide between them. The proposed resonator enables independent control of the center frequencies of the first and second bands. The bandwidths can be independently adjusted using the waveguide placed at the center in the spaces between the combline coupled resonators. We designed and fabricated the DBPF using YBa$_2$Cu$_3$O$_y$ thin film on an Al$_2$O$_3$ substrate. The measured frequency response of the filter agrees well with the simulated one.

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References