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A compact HTS bandpass microstrip filter with novel coupling structure for on-chip integration

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ABSTRACT

A compact low-complexity high-selectivity high-temperature superconducting (HTS) microstrip bandpass filter is presented in this paper, which consists of only three half-wavelength resonators. A novel coupling scheme is used to provide a pair of transmission zeros outside the passband, so that the selectivity of the filter is improved. The filter is fabricated on an MgO substrate with $YBa_2Cu_3O_{7-x}$ (YBCO) coating. Measurement result shows an in-band insertion loss at 0.5 dB, a sharp slope, and a stopband rejection better than 20 dB. The compactness and high-selectivity features make the filter suitable for on-chip integration of HTS receiver front-ends.

1. Introduction

High-temperature superconducting (HTS) passive devices, such as filters and resonators, have been well developed and applied for wireless and microwave communications in the recent years [1–7]. Owing to extremely low surface resistance, the resonators and filters made of the HTS materials demonstrated superior performance such as high quality factor, low insertion loss, high off-band rejection and very sharp skirts. These features make them attractive for application in wireless communication systems. The HTS front-end receivers based on a hybrid of the HTS passive components such as resonators and filters, and semiconductor active devices such as amplifiers, oscillators and mixers, have been demonstrated [6,7]. Recently, progress has been made towards developing a monolithic HTS receiver front-end comprising both HTS filters and Josephson junction devices [8–10]. Compared with hybrid front-ends, such an HTS system-on-chip integration improves the circuit compactness and coupling efficiency between the components.

The performance of the previous reported HTS frequency down-converters [8–10] can be further improved if the filters have lower insertion loss, better selectivity and compactness. There are several ways to realize sharper roll-off at the edge of the passband. Increasing the orders of resonator can improve the selectivity, but the dimension and insertion loss will also increase. Defected ground structure (DGS) can sharpen the slope [10], but they are not suitable for HTS filters which need perfect grounding for thermal conductance. Introducing bypass or cross-coupling between non-adjacent resonators can produce transmission zeros, which is a feasible way to improve the selectivity, but it has a particular requirement of the coupling scheme [11], which might complicate the on-chip design. In this paper, an HTS three-order half-wavelength microstrip bandpass filter is proposed. A novel coupling scheme is used to produce transmission zeros outside the passband. Therefore, the filter achieves high selectivity with only three resonators. The modeling, simulation and experimental results of the HTS bandpass filter are presented.

2. Coupling scheme and filter design

Fig. 1 shows the coupling scheme of the proposed filter consisting of three resonators. The two transmission zeroes in the S21 between the source and the load are introduced by the coupling between the source and resonator 2. The corresponding coupling matrix is given by [12]:

$$M = \begin{pmatrix} 0 & M_{S1} & M_{S2} & 0 & 0 \\ M_{S1} & 0 & 0 & M_{13} & 0 \\ M_{S2} & 0 & 0 & M_{23} & M_{2L} \\ 0 & M_{13} & M_{23} & 0 & 0 \\ 0 & 0 & M_{2L} & 0 & 0 \end{pmatrix} \quad (1)$$

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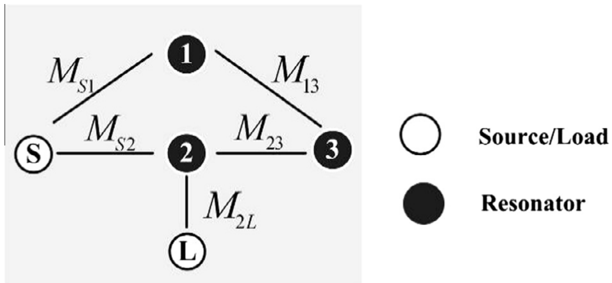

Fig. 1. Coupling scheme of the proposed filter.

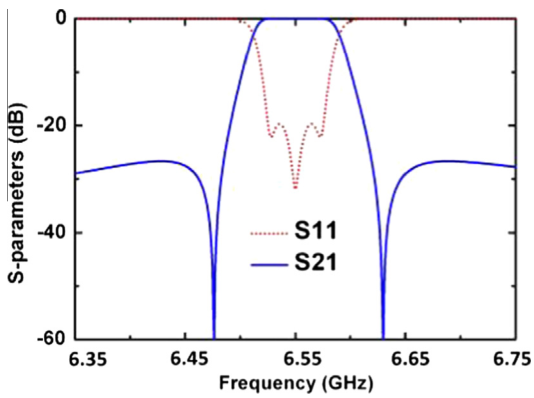

Fig. 2. Simulated *S*-parameters of the coupling matrix.

Since the resonator geometry is designed to be symmetrical, it is expected that $M_{13} = -M_{23}$. After optimization, the normalized coupling matrix is obtained as below, with in-band return loss at 20 dB and transmission zeros at ±BW, where BW is the bandwidth of the normalized filter.

$$M = \begin{pmatrix} 0 & 1.02 & 0.15 & 0 & 0 \\ 1.02 & 0 & 0 & 1.1 & 0 \\ 0.15 & 0 & 0 & -1.1 & 0 \\ 0 & 1.1 & -1.1 & 0 & 1.2 \\ 0 & 0 & 1.2 & 0 & 0 \end{pmatrix} \quad (2)$$

The external quality factors, Q_{s1} and Q_{2L} are calculated to be 0.96 and 0.69. The passband frequency of the filter is designed to be from 6.5 GHz to 6.6 GHz, which is used for telecommunication services in Australia. Simulation result according to (2) is shown in Fig. 2, where two transmission zeros are produced.

The layout of the proposed bandpass filter is shown in Fig. 3. It consists of three half-wavelength resonators. The filter is designed to be on a 0.5 mm MgO substrate with a dielectric constant of 9.7. Simulations were carried out using Ansoft High Frequency Structure Simulator (HFSS) to determine the appropriate distance between resonators and length of the feedlines [13]. Fig. 4 shows the normalized coupling coefficient M_{13} and M_{23} as a function of the coupling gap g_{13} and g_{23}. It shows that the coupling becomes weaker as the gap increases. External quality factors Q_{s1} and Q_{2L} are also simulated as shown in Fig. 5(a and b). It is shown that both quality factors are proportional to the gaps and inversely proportional to the length of the feedlines. The source feedline, l_s is in position between resonator 1 and 2. It should be long enough to weaken the cross coupling between resonator 1 and 2, but not overlong to introduce unwanted coupling with resonator 3. A compromise was made resulting in l_s as 3.7 mm and l_l as 3.35 mm.

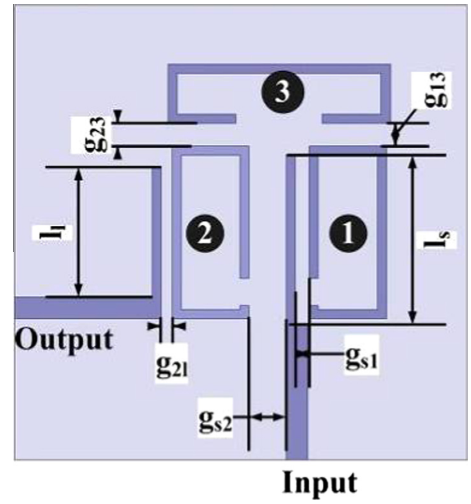

Fig. 3. Layout of the bandpass filter.

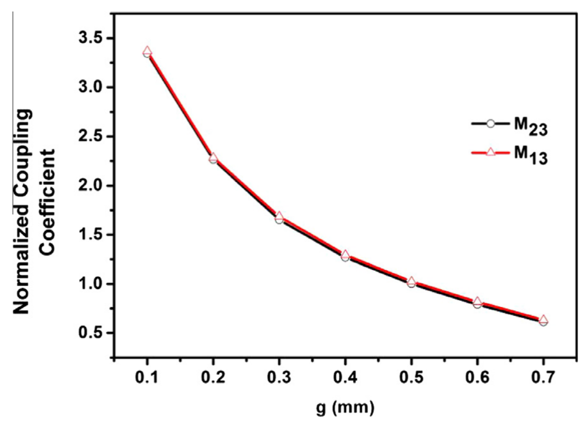

Fig. 4. Simulated M_{13} and M_{23} as a function of *g*.

After all the parameters had been chosen as described above, simulations were done regarding the coupling gap g_{s2} and the position of the two transmission zeros. As shown in Fig. 6, a smaller g_{s2} results in a sharper slope, but a worse suppression outside the passband. In this case, g_{s2} was chosen to be around 0.8 mm in order to achieve a stopband suppression of better than 20 dB.

The final layout of the optimized filter is shown in Fig. 7(a). The total size of the filter is 5.6 mm × 5.27 mm, which is very compact compared with conventional half-wavelength bandpass filters. Fig. 7(b) is a photograph of a fabricated and packaged filter. *S*-parameter simulation results are shown in Fig. 8(a and b). Note that the in-band insertion loss is better than 0.5 dB, and the stopband has a rejection level of better than −20 dB.

3. Fabrication and experimental details

The filter was fabricated on a single-sided $YBa_2Cu_3O_{7-x}$ (YBCO) film and MgO substrate using a photolithographic and Ar ion milling techniques. A 220 nm thick YBCO film with a 50 nm in situ Au on top was deposited by Theva GmbH, Germany. The in situ Au was removed by using gentle Ar-sputtering technique from the filter area except for the contact parts of the feedlines. In-situ Au ensures low contact resistance. A layer of Au was then deposited on the back of the MgO substrate. The fabricated filter was then packaged into a thermal-conducting copper housing (Au coated) as shown in