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A self-equalized HTS filter for future mobile communication applications

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Abstract

A 10-pole self-equalized high-temperature superconducting (HTS) filter is presented in this paper. The filter has a fractional bandwidth of 0.51% at 1955 MHz, simulated in Sonnet, and is fabricated using double-sided $Tl_2Ba_2CaCu_2O_8$ film on 0.5 mm thick $LaAlO_3$ substrates. The filter consists of 10 novel quasi-lumped resonators and an additional microstrip which is used to realize the real-axis transmission zeros (TZs). The simulated group delay ripple over the central 55% of the filter's passband is 5.6 ns, and a close result of phase response is achieved in laboratory test. The measured insertion loss of the filter is less than 0.2 dB, the out-of-band rejection is better than 75 dB and the slope is better than 22 dB MHz^{-1} at band edge.

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Keywords: HTS; Filter; Self-equalization; Group delay

1. Introduction

There is considerable interest in high-temperature superconducting (HTS) filters for mobile communications applications [1–5], since they can significantly improve the selectivity and sensitivity of base transceiver stations (BTS's), and consequently benefit the mobile communication systems with higher capacity and data transmission rates. Compared with GSM networks, the quality of the next-generation mobile communication system based on CDMA technology is more sensitive to the phase distortion of the receiver subsystem. Hence, HTS filter for that application should have a small or even no group delay ripple over the central region of its passband, as well as high-frequency selectivity. However, most reports about HTS filters have only concentrated on high selectivity and good out-of-band rejection, while paying little attention to improving linear phase response or equalizing group delay.

In this paper, we report a 10-pole self-equalized HTS filter. Its design and fabrication procedure is described. The filter is simulated in Sonnet and fabricated using double-sided $Tl_2Ba_2CaCu_2O_8$ films on $LaAlO_3$ substrates. In laboratory test, a good phase response together with high-frequency selectivity is achieved.

2. Filter design

As is well known, a minimum phase filter (e.g., maximally flat delay, Chebyshev, etc.) has no zeros in the right half-plane. The amplitude responses and phase responses are uniquely related through the Hilbert transform [6]. Consequently, ideal amplitude and linear phase response are not compatible requirements for that kind of filters.

There are two approaches which can be implemented to reduce group delay distortion of a filter [7]. The first one is

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usually called external equalization, which uses a reflection-type equalizer attached to the output of the filter via a circulator or 3-dB hybrids; the other one is called self-equalization, which equalizes group delay of a filter by introducing additional in-phase cross couplings in the filter structure. The self-equalized filter structure requires no cascading devices (circulator or 3-dB hybrids). What's more, it shows a better performance consistency over temperature variation. Therefore, it is more applicable for HTS filters.

This type of filter is referred to as a self-equalized or linear phase filter, and can be realized by locating the finite transmission zeros (TZs) in a pair with symmetry on the real axis [8], or by locating a complex conjugate quadruplet of TZs with quadrantal symmetry on the complex S-plane. The simplest form of the self-equalized filters only consists of a single in-phase cross coupling, and has almost flat group delay over the central 55% of its passband. In this paper, we focus on this type of filter.

To obtain the coupling matrix of this type of filter, a novel synthesis method based on optimization has been developed. The scattering parameters of this type of filter can be defined as a ratio of two polynomials [9]:

$$S_{11} = \frac{F(s)}{E(s)} \tag{1}$$

$$S_{21} = \frac{P(s)}{\varepsilon \cdot E(s)} \tag{2}$$

Here, ε is a scale factor related to the passband ripple. S_{11} and S_{21} share a common denominator $E(s)$, and the polynomial $P(s)$ contains the real-axis TZs.

Similarly, the scattering parameters can be defined from coupling matrix [9]:

$$S_{11} = 1 + 2\mathrm{i}r_1[\mathbf{A}]_{11}^{-1} \tag{3}$$

$$S_{21} = -2\mathrm{i}\sqrt{r_1 r_n}[\mathbf{A}]_{n1}^{-1} \tag{4}$$

Here, $\mathbf{A} = \mathbf{R} + \mathbf{M} \cdot \mathbf{R}$ is a matrix whose nonzero entries are $R_{11} = r_1$ and $R_{nn} = r_n \cdot \mathbf{M}$ is the coupling matrix.

According to (1)–(4):

$$T(s) = \frac{S_{11}}{S_{21}} = \frac{\varepsilon \cdot F(s)}{P(s)} = \frac{1 + 2\mathrm{i}r_1[\mathbf{A}]_{11}^{-1}}{-2\mathrm{i}\sqrt{r_1 r_n}[\mathbf{A}]_{n1}^{-1}} \tag{5}$$

From (5), an object function based on the relation between the polynomial coefficients of $P(s)/\varepsilon \cdot F(s)$ and those of the right-hand side of (5) from the coupling matrix is established. The coefficient of polynomial $F(s)$ can be generated by a recursive technique, which is described in detail in [9], and then the coupling matrix can be obtained by optimization. We have developed a gradient-based optimization tool and a genetic algorithm (GA) tool to solve the optimization problem.

In this paper, a 10-pole self-equalized HTS filter for future mobile communication applications is considered. The specifications are:

Passband frequencies: 1950–1960 MHz
Passband return loss: −23 dB
Finite transmission zeros (TZs): ±0.73

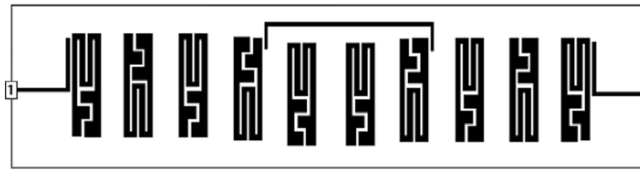

Fig. 1. The layout of the simulated HTS filter.

The coupling coefficients obtained from above-mentioned method are:

$M_{1,2} = M_{9,10} = 0.00441$ $\quad M_{2,3} = M_{8,9} = 0.00309$
$M_{3,4} = M_{7,8} = 0.00284$ $\quad M_{4,5} = M_{6,7} = 0.00268$
$M_{5,6} = 0.00203$ $\quad M_{4,7} = 0.00073$

The HTS filter is simulated by a well-known method [10] in Sonnet's *em*. The layout of the filter is shown in Fig. 1. The filter consists of 10 novel quasi-lumped resonators

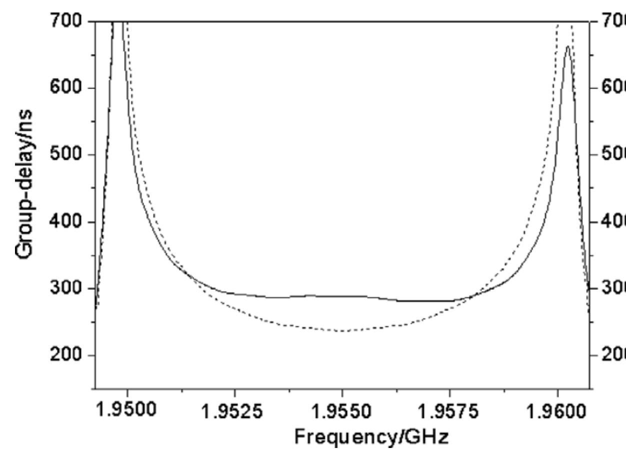

Fig. 2. The simulated group delay of the HTS filter and a 10-pole Chebyshev filter.

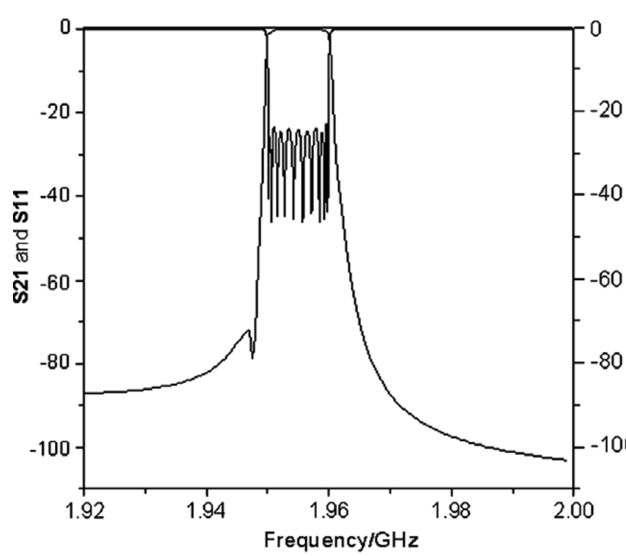

Fig. 3. The simulated response of the HTS filter.

which have been carefully designed to minimize spurious unwanted coupling between nonadjacent resonators on $LaAlO_3$ substrate. A microstrip line is added between resonator 4 and 7 to produce in-phase cross coupling. The amplitude of the coupling can be adjusted by changing the width of the microstrip line and/or the gap between the microstrip line and resonators, and finally, a group delay ripple of 5.6 ns over the central 55% of the filter's passband is achieved, while a Similar specification of Chebyshev filter would have a group delay ripple of 43 ns over 55% of its passband. Their group delay responses are depicted in Fig. 2, and the simulated frequency response of the filter is shown in Fig. 3.

3. Filter fabrication and test

The filter is fabricated using double-sided $Tl_2Ba_2CaCu_2O_8$ film on 0.5 mm thick $LaAlO_3$ substrate [11]. The thin film has a thickness of 500 nm and a characteristic temperature of 103 K [12]. Permittivity of the substrate corrected through experiments is 23.846. The structure of the filer is patterned using standard photolithography and ion-milling processes. The superconducting ground plane is evaporated with gold to make electrical contact to the packaging. Ten sapphire Screws are used for tuning the HTS filter.

Measurements at 77 K have been performed by an Agilent 8720 ES network analyzer. The insertion loss in the passband is less than 0.2 dB, the out-of-band rejection is better than 75 dB and the return loss is about 17 dB. The measured bandwidth is 9.94 MHz, which is almost the same as the simulated one of 10 MHz. The measured group delay ripple over the central 55% of the filter's passband is about 11 ns. The slope is 27 dB MHz^{-1} at lower band edge and 22 dB MHz^{-1} at upper band edge. The measured response is indicated in Fig. 4, and the measured group delay of the HTS filter is shown in Fig. 5. We can see that the experimental performance of the HTS filter shows agreement with the simulated data.

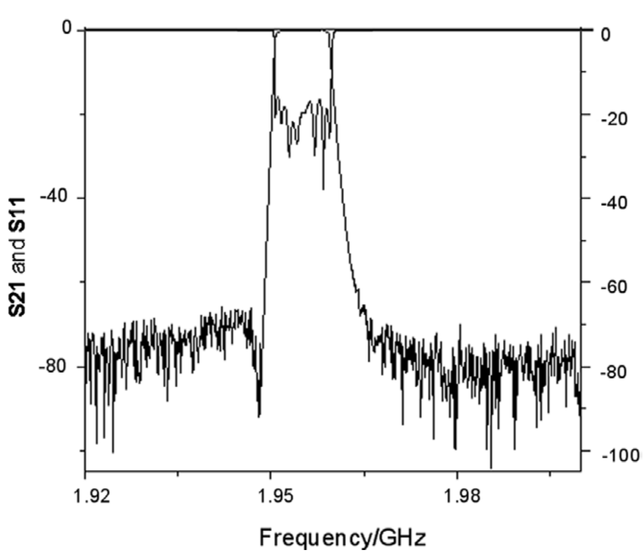

Fig. 4. The measured response of the HTS filter.

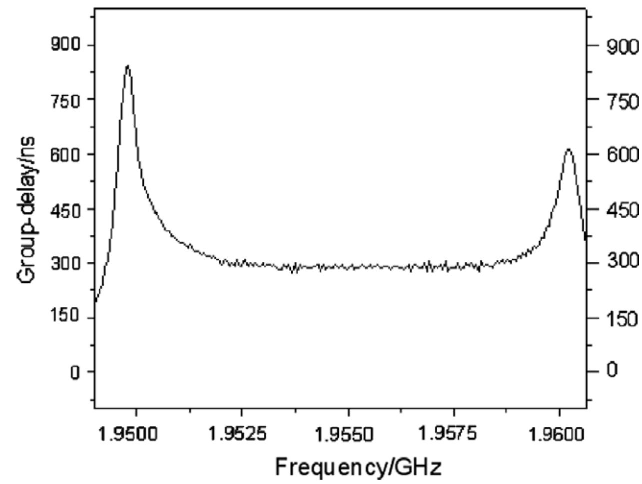

Fig. 5. The measured group delay of the HTS filter.

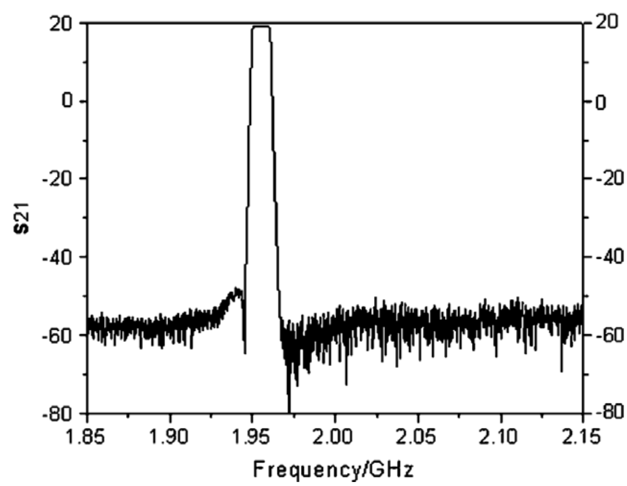

Fig. 6. The measured frequency response of the HTS filter subsystem.

Furthermore, we combine this filter together with a laboratory-made low noise amplifier (LNA) in a cooling device. Fig. 6 shows the frequency response of the filter subsystem in a wider frequency range. Good performance on frequency selectivity is achieved.

4. Conclusion

In this paper, a 10-pole self-equalized HTS filter for future mobile communication applications is presented. The design and fabrication procedure is described. The filter consists of 10 novel quasi-lumped resonators. An additional microstrip line is used to realize the real-axis TZs. The filter is simulated in Sonnet and fabricated using double-sided $Tl_2Ba_2CaCu_2O_8$ films on $LaAlO_3$ substrates. Good group delay response and high-frequency selectivity have been achieved in laboratory test.

Acknowledgments

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