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The research of parallel-coupled linear-phase superconducting filter

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ABSTRACT

This paper presents a research on the mechanism of a linear phase filter constructed with parallel-connected sub-networks, considering that linear phase characteristic of a filter can be achieved when the group delays of sub-networks compensate each other. This paper also gives several coupling and routing diagrams of linear phase filters with different parallel-connected networks, and then the coupling matrixes of three 8-order filters and one 10-order filter are synthesized. One of the coupling matrixes is utilized to design a 8-order parallel-connected network high temperature superconducting (HTS) linear phase filter with two pairs of transmission zeros, so as to verify the correctness of theory data and the feasibility of the circuit design for the proposed 8-order and higher order parallel-connected network linear phase filter. The HTS linear phase filter is designed on YBCO/$LaAlO_3$/YBCO superconducting substrate, at 77 K, the measured center frequency is 2000 MHz with a bandwidth of 30 MHz, the insertion loss is less than 0.3 dB and the reflection is better than -12.5 dB in passband. The group delay is less than ±5 ns over the 60% passband, which shows that the filter has a good linear phase characteristic.

1. Introduction

Nowadays, HTS filter has been widely used in mobile communication system, satellite space communication system and radar receiver system, etc. [1–6]. One important reason is that the HTS filter has very low insertion loss and sharp out-of-band rejection, which can improve the sensitivity of receiver front-end and suppress the out-of-band interference signal effectively. In order to ensure the signal to be transmitted efficiently without distortion, the communication network should have a good linear phase (flat group delay) characteristic in passband. As for the communication network, the group delay characteristics of the filter in passband play a decisive role on the bit error rate of the system and the communication quality of the entire system. Especially, as the selectivity of HTS filter is much better than that of the conventional metal filter, the group delay fluctuation of HTS filter is obviously larger in the passband; therefore, when designing a HTS filter, it not only needs to satisfy the amplitude–frequency characteristic, but also needs to consider the requirements of flat group delay. Up till now, researchers have done a lot of work on the HTS linear phase filter; there are two main models: external equalization and self-equalization [7–13].

The paper [14] firstly proposed a self-equalization linear phase filter model with a parallel-connected two-port network, but with only one coupling matrix of a 6-order filter. In previous work [15], our research group studied a planar double-coupling structure and designed a 6-order parallel-connected network HTS linear phase filter with the coupling matrix from [14]. Obviously, as for this kind of parallel-connected network, the signal mainly has two paths from the input port to the output port, and the linear phase characteristic of the filter can be achieved through mutual group delay compensation of the two paths. Based on this result, a further analysis on the mechanism of the parallel-connected network linear phase filter is presented in this paper. Considering the overall network can be divided into a number of sub-networks, and linear phase characteristics can be achieved if the group delay of sub-networks compensate for each other in the passband. Furthermore, several parallel coupling and routing diagrams for higher order linear phase filter are also given, the corresponding coupling matrix is synthesized, and one of the prototypes coupling and routing diagrams and coupling matrix is utilized to complete the design of an 8-order HTS parallel-connected network linear phase filter to verify the correctness of theory data. Lastly, the feasibility of the actual circuit is proved by the production and measure of the sample.

2. The mechanism analysis of parallel-connected network linear phase filter and the synthesis of coupling matrix

In a previous work [14], a coupling matrix was provided for a six-order linear phase filter. The coupling and routing diagram for the six-order filter is shown in Fig. 1(a), where *S* and *L* represent external ports, and each node with a number represents a resonator. The dashed line between Resonator 1 and Resonator 6 in

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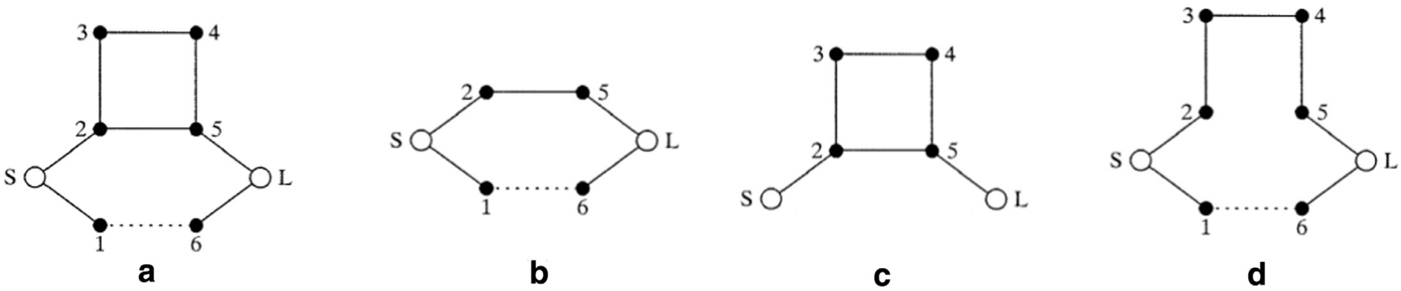

Fig. 1. The coupling and routing diagram. (a) Six-order linear phase filter, (b) Sub-network 1, (c) Sub-network 2, (d) Sub-network 3.

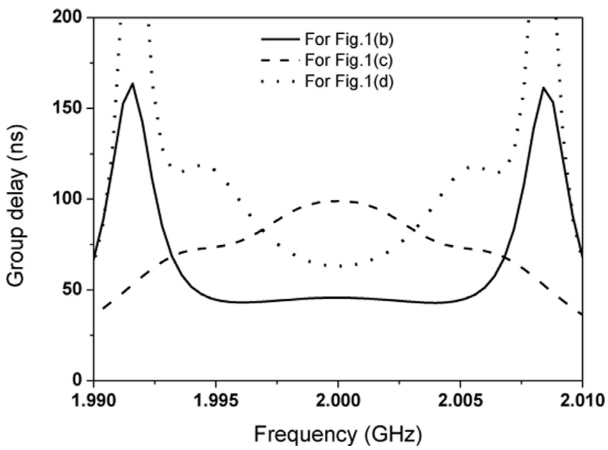

Fig. 2. The group delay of three sub-networks.

Fig. 1(a) is used to distinguish it from the solid line between other resonators for the coupling patterns, that is, if m25 (the normalized coupling coefficients between Resonator 2 and Resonator 5) and m34 refer to positive coupling, then m16 will be negative coupling accordingly. It is known from Fig. 1(a) that each external port must be coupled with two different resonators at the same time. Here, S is coupled with Nodes 1 and 2, L is coupled with Nodes 5 and 6.

Fig. 1(a) can be treated as a combination of the three sub-networks given in Fig. 1(b) –(d) for comprehension. The simulated group delay responses of these sub-networks, utilizing the corresponding coupling matrix given in [14] and assuming a center frequency of 2000 MHz with a 15 MHz bandwidth, are illustrated in Fig. 2. In Fig. 2, the group delay response of three sub-networks can be treated as complementary, which also explains that the three routing diagrams shown in Fig. 1(b)–(d) can be used to achieve the linear phase response. As the structure shown in Fig. 1(c) has already been discussed in detail in [15,16], the studies of new structures shown in Fig. 1(b) and (d) are carried out in the following. For the structure shown in Fig. 1(b), only the value and sign of m25 are tuned to see the tendency of the group delay response and the results are shown in Fig. 3(a). From Fig. 3(a), whether m25 and m16 are of the same sign or not, the phase response of structure in Fig. 1(b) can be either kick-up or kick-down by only controlling the ratio of these two coefficients, which will lead to great convenience when designing linear phase filters. This is also true for the structure shown in Fig. 1(d) , as shown in Fig. 3(b), the group delay response can also be either kick-up or kick-down near the center frequency, by simply adjusting the ratio of these two coefficients. Following the rules discussed above, several parallel-coupled linear phase filters coupling matrixes have been optimized and presented in Tables 1–4.

Using combinations of the sub-networks shown in Fig. 1(b), (c) and (d), higher order parallel coupled filters with linear phase response can be constructed. The coupling and routing diagrams shown in Fig. 4(a) and (b) illustrated 8-order linear phase filter and 10-order linear phase filter, respectively. With the filter structure being determined, a self-written program was used to synthesize the coupling matrix. The synthesized results of structure in Fig. 4(a) and (b) are given in Tables 1 and 2. Different

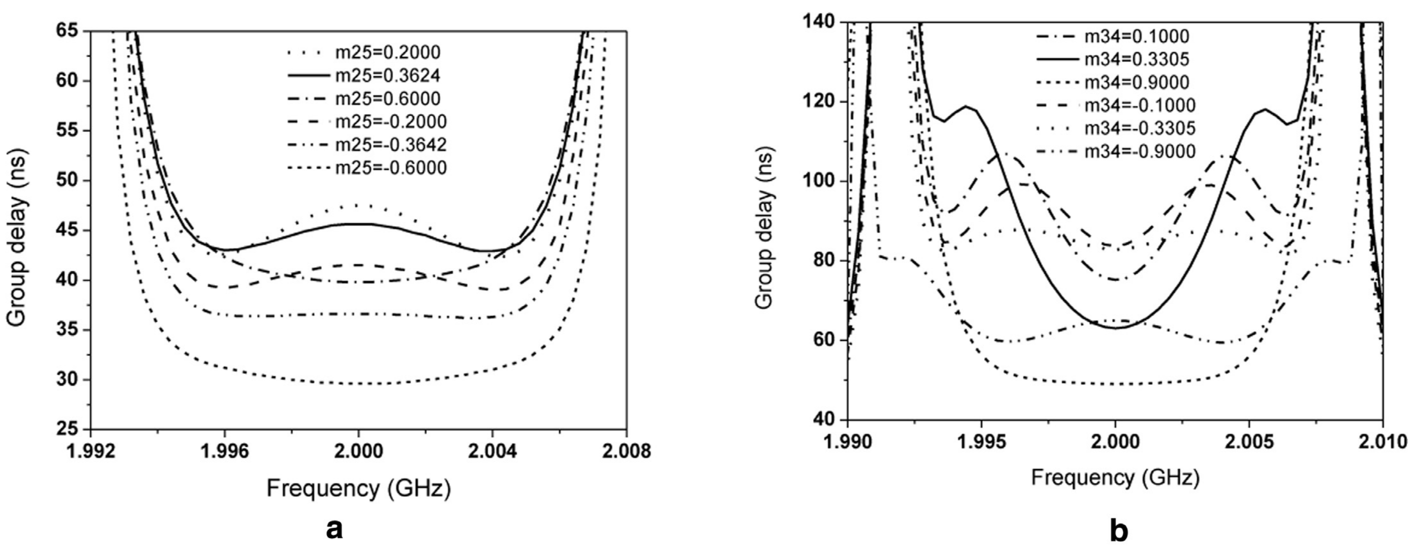

Fig. 3. The changes of group delay. (a) The group delay of Fig. 1(b) changes with m25, and (b) the group delay of Fig. 1(d) changes with m34.