New Advances in HTS Microstrip Filter Design

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Abstract — **This paper presents a new filter design technique. By using the concept of primary and secondary couplings between a pair of resonators, greater flexibility in the control of sequential couplings and cross couplings can be achieved. A 6-pole 0.1% filter is shown as an example. It was designed for YBCO thin-film on 0.020" MGO substrate. Excellent measured responses demonstrate the validity and potential of this new technique.**

I. INTRODUCTION

Microstrip filters have the advantages of small size and low cost manufacturing. However, microstrip filters with conventional metals suffer much higher loss than other technologies such as waveguide, dielectric resonator, combline, etc, especially in very narrow band filters. With high-temperature superconductor (HTS) thin film technology, microstrip filters can achieve extremely low loss, for example, [1-3]. It is particularly useful for very narrow band filters.

Using microstrip technology for narrow band filter design, the spacing between the resonators determines the amount of coupling between them: the larger the spacing, the smaller the coupling, and therefore the narrower the bandwidth. For very narrow band filters, the spacing between resonators can be quite substantial. Techniques have been developed to reduce the spacing, for example, [2] for lumped element type resonators, and [3] for distributed element type resonators. Those techniques can effectively reduce the spacing between resonators for very narrow band filters.

To reach higher filter rejection performance while keeping a minimal number of resonators, additional couplings between non-adjacent resonators can be applied to realize transmission zeros as for example, [4-5]. These transmission zeros can be placed at strategic locations to achieve optimal filter out-of-band rejection performance. Besides actual cross coupling value, the precise transmission zero location depends on the phase of these cross couplings, i.e., whether it is positive or negative cross couplings.

This paper explores the concept of primary and secondary couplings between a pair of resonators. Applying such concept, large or small bandwidth filters can be made without very small or very large resonator spacing. In addition, the same cross coupling layout configuration may be designed to achieve either positive or negative coupling results. A 0.1% bandwidth filter design will be shown to illustrate the concept.

II. NEW DESIGN TECHNIQUE

Consider resonators 1, 2 and the coupling strip in Figure 1. Without changing the resonator geometries, the primary coupling F_1 is a function of S_1, and the secondary coupling F_2 realized by the coupling strip is a function of S_{2a}, S_{2b}, L_{2a} and L_{2b}. The total coupling between Resonator 1 and Resonator 2, F, is

$$F = F_1(S_1) + F_2(S_{2a}, S_{2b}, L_{2a}, L_{2b}) \quad (1)$$

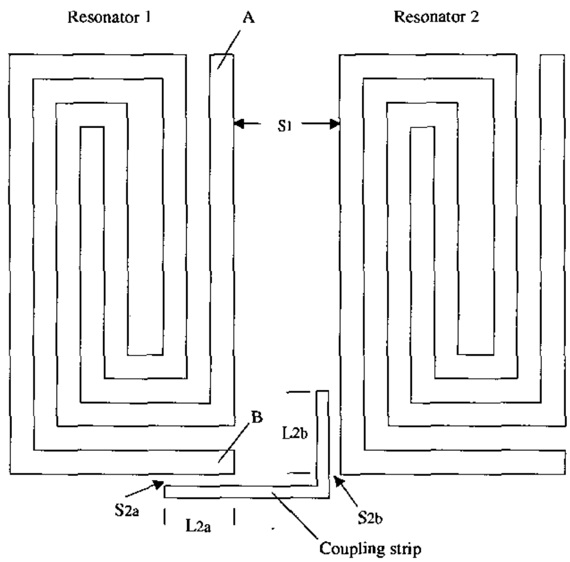

Figure 1, Illustration of primary coupling and secondary coupling between a pair of resonators.

At resonant state, the current flow towards the two ends of the resonator is always at opposite direction. In other

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words, the electric charges at the two ends are opposite in sign. As shown in Figure 1, if current is flowing towards end **A** of Resonator 1, current must be flowing out of end **B** of Resonator 1 at the same time. This is due to the nature of such microstrip resonators.

Therefore, $F_1(S_1)$ and $F_2(S_{2a}, S_{2b}, L_{2a}, L_{2b})$ can have different signs, which is determined by how the secondary coupling $F_2(S_{2a}, S_{2b}, L_{2a}, L_{2b})$ is constructed. It is of particular interest that $F_1(S_1)$ and $F_2(S_{2a}, S_{2b}, L_{2a}, L_{2b})$ have different signs. In such a case, the total coupling between Resonator 1 and Resonator 2 can have either the same sign as F_1 or as F_2, depending on the relative magnitude of F_1 and F_2.

For example,

$$F \approx F_1(S_1),\ for\ |F_2| << |F_1| \qquad (2)$$

$$F = 0,\ for\ |F_2| = |F_1| \qquad (3)$$

And

$$F = sign(F_2)\ |F_1|,\ for\ |F_2| = 2\ |F_1| \qquad (4)$$

A wide range of possible couplings between the two resonators, especially the ability to change signs, provides more flexibility and greater potential for filter designs.

III. EXAMPLES

Figure 2 shows a 6-pole thin-film HTS filter layout. The filter center frequency is 1757.9MHz with 1.8MHz bandwidth, or 0.1% bandwidth. The coupling matrix we chose for this filter is,

0.0	0.7568	***-0.3088***	0.0	0.0	0.0
0.7568	0.4478	0.5416	0.0	0.0	0.0
-0.3088	0.5416	0.0	0.5763	0.0	0.0
0.0	0.0	0.5763	0.0	0.5416	***0.3088***
0.0	0.0	0.0	0.5416	-0.4448	0.7568
0.0	0.0	0.0	***0.3088***	0.7568	0.0

where the input and output terminations are 0.9535.

This is a 6-pole configuration with two tri-section cross-couplings, M_{13} and M_{46}. The negative M_{13} creates a transmission zero at lower side of the passband, while the positive M_{46} creates a transmission zero at higher side of the passband [5].

There are six coupling strips, ***a***, ***b***, ***c***, ***d***, ***e*** and ***f*** shown in Figure 2. Coupling strips ***a*** and ***b*** are designed to implemented M_{13} and M_{46}, respectively. Coupling strips ***c***, ***d***, ***e*** and ***f*** are included to introduce secondary couplings between resonators 1 and 2, 2 and 3, 4 and 5, and 5 and 6, respectively, as illustrated in Figure 1. They are used here to provide opposite couplings between two adjacent resonators.

From (1), F_2 introduced by strips ***c***, ***e*** and ***f*** between resonators 1 and 2, 4 and 5, and 5 and 6 are used to reduce the total coupling, i.e.,

$$|F_2| < |F_1| \qquad (5)$$

such that spacings between the resonators can be much reduced for this extremely narrow 0.1% bandwidth. F_2 introduced by strip ***d*** satisfies

$$|F_2| > |F_1| \qquad (6)$$

Therefore, the coupling between resonators 2 and 3 has an opposite sign compared to the coupling between resonators 4 and 5.

The two cross coupling strips ***a*** and ***b*** for M_{13} and M_{46} as shown in Figure 2 are almost identical in shape, length and location. However, we achieved a negative M_{13} and a positive M_{46}, because of (5) and (6). Without strip ***d*** satisfying (6), M_{13} and M_{46} will be both positive and will generate two transmission zeros both at higher side of the filter passband.

We used IE3D [6] for EM design simulation. The filter was built on 20mil thick MGO substrate with double sided YBCO HTS thin films. Figure 3 shows the measured response of this filter, which clearly demonstrates the validity of this design technique. In addition, the use of HTS thin film technology achieves excellent filter insertion loss considering its 0.1% bandwidth.

Applying the same principle, we have developed a 17-pole filter with 4 pairs of transmission zeros for WCDMA band using thin-film HTS on 20mil MGO substrate. Because of the ability to control the signs of sequential couplings, it significantly simplifies the filter layout effort for the cross couplings. Figure 4 shows the measured response of this filter.

III. SUMMARY

This paper has presented a new filter design technique, particularly suitable for microstrip type filters, which explores the concept of primary coupling and secondary coupling between a pair of resonators. While the secondary coupling can have different magnitude, it can have the same phase or opposite phase as the primary coupling. With different combinations, large or small bandwidth filters can be made without very small or very large resonator spacing. The same cross coupling layout configuration may be designed to achieve either positive or negative results. Excellent experimental results have shown great potential for this technique.

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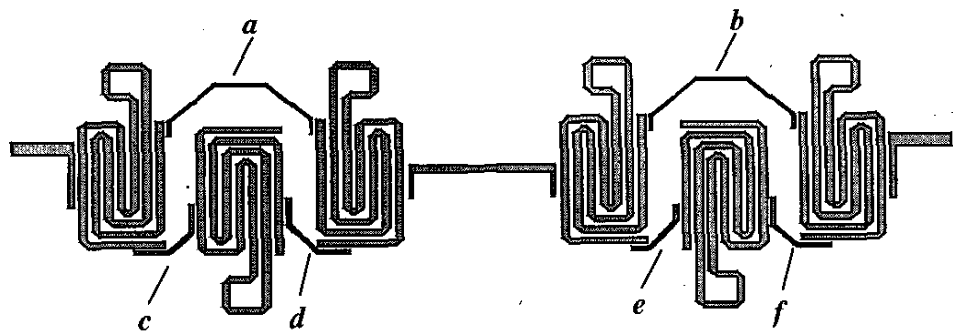

Figure 2, A 6-pole thin-film HTS filter layout, which is designed for 1757.9MHz center frequency and 0.1% bandwidth using 0.020" MGO substrate.

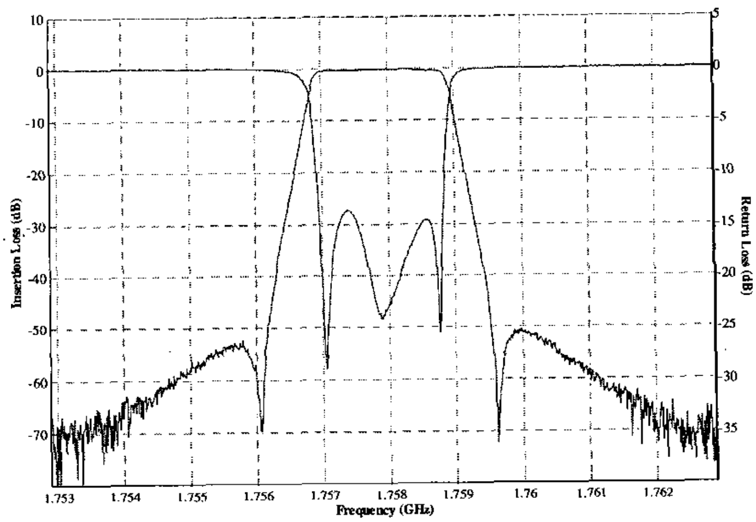

Figure 3, Measured response of the 6-pole thin-film HTS filter shown in Figure 2.

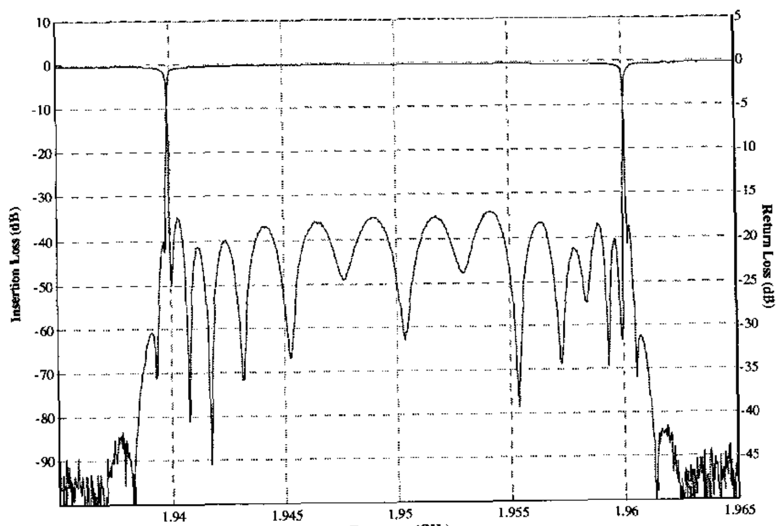

Figure 4, Measured response of a 17-pole thin-film HTS filter designed for WCDMA band using 0.020" MGO substrate.