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Development of miniature HTSC microwave bandpass filter with multi-zigzag line structure

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Abstract **On YBCO/$LaAlO_3$/YBCO substrate with the dimension of 10 mm × 20 mm, a miniature HTSC (high temperature superconductivity) bandpass filter with multi-zigzag line structure is developed. At 77 K, the center frequency is 1.2 GHz, the bandwidth is 50 MHz, and the insertion loss is 0.12 dB.**

Keywords: HTSC, microwave, filter, bandpass, multi-zigzag line.

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The HTSC films have very low microwave surface resistance, which is 3—5 orders lower than normal conductor in L and S bands, and they are widely used in microwave devices. In microwave field, the application of the HTSC films will improve the development of other technologies such as communication, radar system, electrical countermeasure, etc. As one of the most important devices in HTSC microwave application, HTSC filters and filter banks are used in mobile communications and satellite communications for their high-selectivity, low loss, small volume, light weight, and the properties easily integrated with other microwave solid circuits.

There are many relative study works in HTSC filters[1—3], and many technologies have been developed for designs and fabrications, especially on the filters' miniaturization and their high-selectivity[3]. In this report, some novel multi-zigzag line structures are developed to miniaturize the structure of the filter, and the EM (electromagnetic) full-wave analysis tool——the momentum method is used to simulate the circuits' electromagnetic properties. Combined with traditional synthesis technologies, this method can be used to simulate the complex tuning procedure in a computer before the fabrication of the filter, and the coupling properties between multi-zigzag resonators are also simulated as the design reference in this report.

1 Design of multi-zigzag line filter

(i) Multi-zigzag line resonators. At microwave low frequencies (such as L and S bands), as the key element of microstrip filters, the length of microstrip resonators is too long to be used in miniature filters. For example, at 1.2 GHz, property impedance is 50 Ω, the resonating length of a half-wavelength resonator is 22.5 mm on high relative permittivity substrate (ε_r = 23, thickness is 0.5 mm). By means of traditional quarter-wavelength or hair-pin coupling, this kind of filters with the resonator number of more than 3 will become too big to be used. In addition, in the design of narrow-band filters, the conventional quarter-wavelength coupling method will make the coupling distance between resonators too wide and it is unfavorable to miniaturize the filters. Hence, some zigzag microstrip structures have been reported in recent distributions (Fig. 1)[1—3].

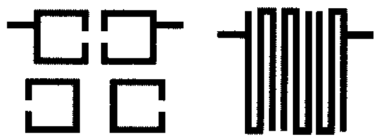

Fig. 1. Two structures of reported zigzag microstrip filters.

As shown in Fig. 1, for the filters' miniaturization, the quarter-wavelength coupled structures have been completely abandoned, and some novel multi-zigzag line resonators (Fig. 2) are developed for smaller structures than Fig. 1.

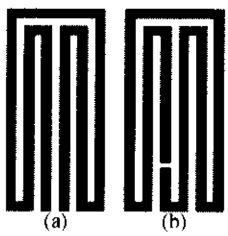

Fig. 2. Novel multi-zigzag line resonators.

(ii) Synthesis of multi-zigzag line of HTSC filter using the full-wave method. When these resonators in Fig. 2 are used as elements of bandpass filters, because of the complexity of their structures, the coupling between resonators is complex. The momentum method (one of the EM full-wave methods) is used to realize the synthesis design of filters, then it is used in tuning analysis and designed to approach the desired filter properties.

According to the traditional synthesis procedure, the prototype network of coupled resonators filter can be described as in Fig. 3[4].

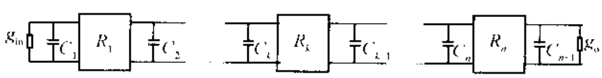

Fig. 3. Prototype network of coupled resonators filter.

Here, g_{in} and g_{out} are input and output admittances, C_k (k = 1, 2, .., n; n is the order of resonators) is the coupling reactance, and R_k (k = 1, 2, .., n; n is the order of resonators) is the kth resonator. By the traditional synthesis technology, the coupling coefficients $k_{k,k+1}$ between two closed resonators can be deduced, then the design of the filter can be completed. The correlation curves between two resonators' coupling distance and coupling coefficients can be approached by the momentum method.

When the two resonators with the same resonating frequency are coupled together, their resonating frequencies will be split by the coupling[5]. This procedure is simulated as in Figs. 4 and 5 (here, the coupling distance between the two resonators is S). Fig. 4 is the current distribution on the two resonators. In this figure, the red part means the high current density, and from red to blue the current density is decreased. Fig. 5 is the frequency response of Fig. 4, f_{p2} and f_{p1} are the split higher and lower resonating frequencies respectively, and from this two frequencies the coupling coefficients can be calculated by eq. (1)[5].

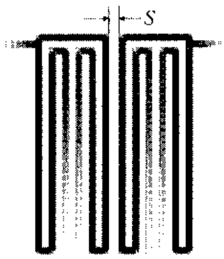

Fig. 4. Current distribution of the two coupled multi-zigzag line HTSC resonators.

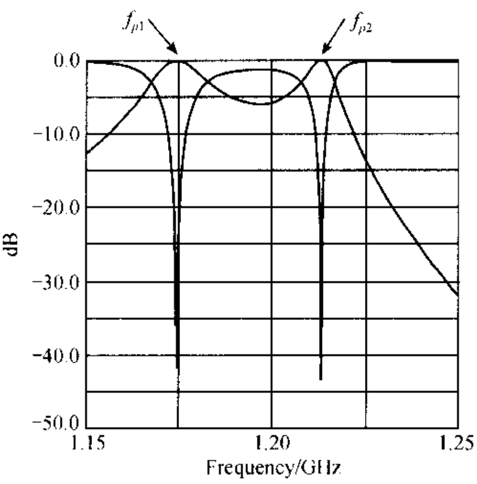

Fig. 5. Split resonating frequencies.

$$k_{k,k+1} = \frac{f_{p2}^2 - f_{p1}^2}{f_{p1}^2 + f_{p2}^2}. \tag{1}$$

From this, the coupling relation curve of the novel resonators is acquired in Fig. 6, and the simulation is on $LaAlO_3$ substrate (ε_r=23, its thickness is 0.5 mm).

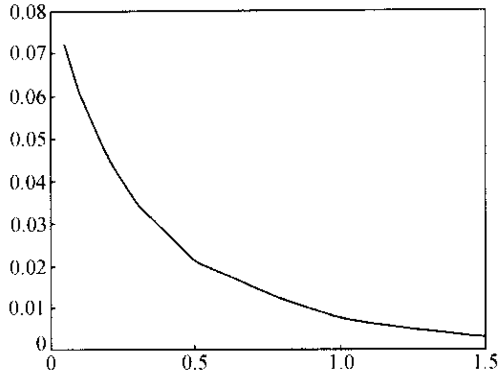

Fig. 6. Correlation curve of coupling coefficients and coupling distances.

When the curve in Fig. 6 is used to design the filters, because it is obtained by curve fitting, some errors may be included. So the tuning procedure must be followed to optimize the filters' responses. When the resonator is resonating, the current distribution on half-wavelength resonator can be roughly regarded as sinusoid (this can be calculated by the momentum method). Because the coupling of the microstrip line is mainly capacitive, there are different couplings between the different parts of the same resonator, and from this point the filter is designed as Fig. 7. Different resonators are used in the filter, and the coupling between resonators can be tuned by the end point of each resonator. By this method the tuned coupling is much less than the conventionally modified coupling by tuning the distance between the resonators. Therefore, the so-called "micro-tuning" procedure can be easily realized, and the external Q-factor of the filter can also be easily modified by this procedure (when the output resonator is

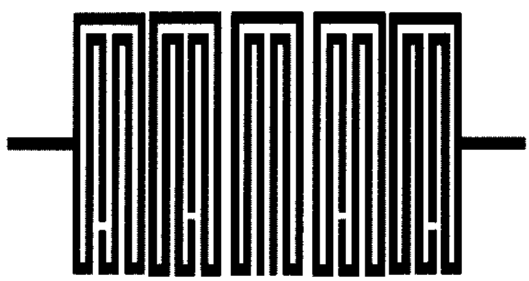

Fig. 7. Circuit top of designed filter.

tuned). Meanwhile, the parasitic passband can be controlled since different resonators have different high order modes.

To sum up, one 5-pole HTSC microwave multi-zigzag line filter is designed as Fig. 7. The center frequency is 1.2 GHz, the bandwidth is 50 MHz, the substrate is: ε_r 23, tg$\boldsymbol{d}$ = 10^{-5}, the thickness of substrate is: h = 0.5 mm, and the measured microwave surface resistance of HTSC film is: R_s 500 μΩ (at 10 GHz, 77 K). The simulated frequency response is shown in Fig. 8.

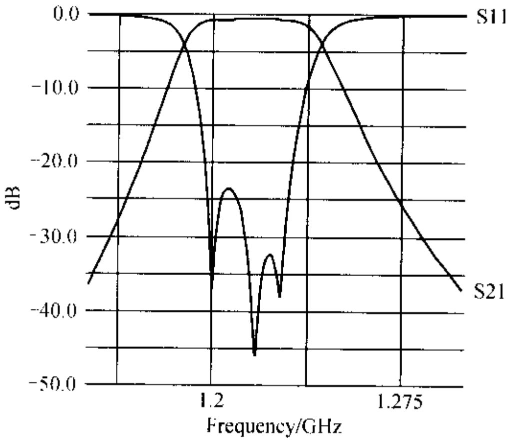

Fig. 8. Simulated frequency response of Fig. 7.

2 Fabrication and test

The HTSC film used in this report is YBCO/$LaAlO_3$/YBCO (double sided film fabricated by the MCI method), and at 10 GHz, 77 K, the surface resistance measured is 0.5 mΩ respectively. In a sealing box, the filter is fabricated on the film by wet chemicaletching, and its output and input connectors are all SMA sealed connector. Fig. 9 is the test system of the filter, and Fig. 10 is the tested frequency response.

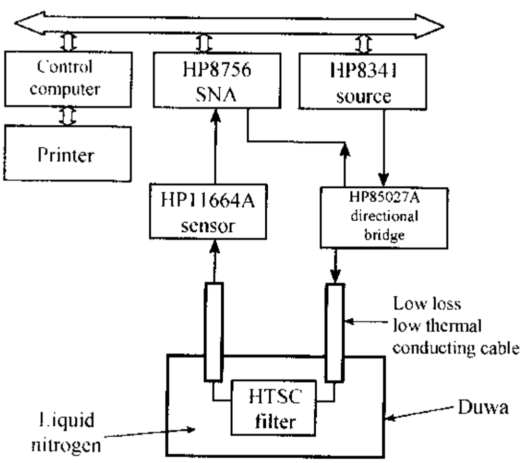

Fig. 9. Test system of the filter.

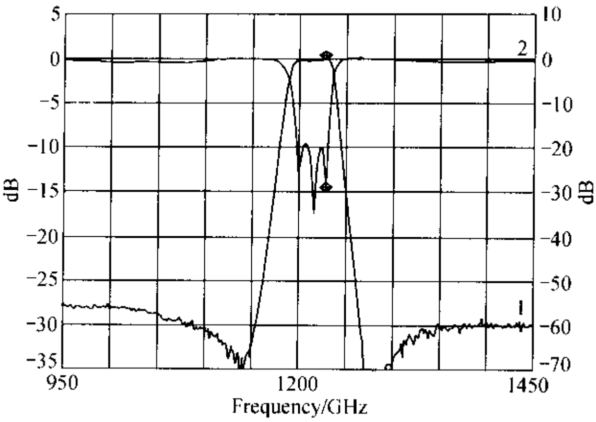

Fig. 10. Tested filter response.

3 Conclusion

This report developed a miniature HTSC (high temperature superconductivity) bandpass filter with a multi-zigzag line structure on 10 mm × 20 mm YBCO/$LaAlO_3$/YBCO substrate. At 77 K, the center frequency is 1.2 GHz, the bandwidth is 50 MHz, the insertion loss in passband is 0.12 to 0.26 dB, and the return loss is less than 20 dB. The design method is described, and this will offer the design guarantee for the following fabrication of the high selectivity filter used in the future mobile system in China.

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