Comparison of power handling capabilities of sliced and conventional microstrip line filters

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Abstract. We examined a high power filter using a sliced microstrip line. We simulated the current distribution in the microstrip line by using electromagnetic field analysis software. The current flowing along the outer edge of the sliced microstrip line was less concentrated than in the conventional microstrip line. The electric test power of the sliced microstrip line filter was larger than that of the conventional filter. The electric proof power of the filter can be estimated from the current flowing along the outer edge of the microstrip line.

1. Introduction

High-temperature superconducting bandpass filters have small insertion loss, large out-of-band rejection and high frequency selection. Such filters have been put to practical use in base station receiver systems for cellular telephony in the United States and China. However, the filters are only used in receiving systems at low levels of electric power. For base stations, it is quite important to develop a transmitting bandpass filter with small insertion loss and large out-of-band rejection. Therefore, it is important to have a filter that can handle large amounts of electric power.

There are several reports on superconducting filters that can handle a large amount of power. The first report was a wide-width microstrip line filter. To adjust the impedance of the microstrip line to 50Ω, its width usually cannot be increased. However, the filter resonator need not be matched to a 50Ω-impedance. Guo-Chun Liang et al. [1] reported a band-pass filter with a wide-width microstrip line and capable of handling 10 W. The second report was the unique shape of the filter. The current distribution in the resonator can be simulated by using an electromagnetic field simulator and the current can be reduced by changing the shape of the resonator. Xubo Guo et al. [2] designed a filter in this way and succeeded in making a filter with good power handling characteristics. The third report was a patch-resonator filter. Thomson et al. [3], Setsune and Enokihara [4], Yamanaka et al. [5] and Saito et al. [6] reported dual-mode patch-resonator filters. They obtained a power-handling capability exceeding 10-100 W. However, it is difficult to reduce the size of the disk resonator filter and to make a multi-resonator.

We have examined a filter capable of handling high power by using a resonator with a special shape [7-8]. Here, we propose the sliced microstrip line filter. From an electromagnetic simulation, we found that the current concentration on the outer edge of the microstrip line could be reduced by using the sliced microstrip line. Accordingly, we should be able to improve the power handling capability of an
HTS bandpass filter by using sliced microstrip line resonators. We experimentally demonstrated the power handling capability of HTS filters with sliced microstrip line resonators and analyzed the relationship between current concentration on the outer edge of the microstrip line and the power handling capability of the filter.

2. Experimental Procedure

2.1. Electromagnetic simulation of current concentrations in a microstrip line

It is the concentration of current flowing along the outer edge of the microstrip line that determines the electric power handling capability of the microstrip line. When the current on the outer edge exceeds the critical current, the superconducting state of the microstrip line is lost. Therefore, it is very important to examine how the current on the outer edge of the microstrip line can be reduced. We simulate the current distribution in the microstrip line by using the electromagnetic field analysis software package SONET EM. We examined how parameters such as the number of slices and the interval division affect the results of the simulation.

2.2. Design of bandpass filter

We designed a forward-coupled resonator filter with sliced microstrip lines and conventional microstrip lines with SONET EM. In our earlier report [8], we showed three kinds of microstrip line division: (a) the both-ends open type (BOT); (b) the single-sided short type (SST); and (c) the double-sided short type (DST). We found that the SST resonator was the best at reducing unnecessary resonating characteristics. Therefore, we designed bandpass filters based on the SST microstrip. The center frequency was 5 GHz, the bandwidth was 100 MHz and the ripple in the band was less than 0.1 dB. The filter material was double-sided YBCO thin film.

2.3. Measurement of filter power handling capability

We used a vector network analyzer to measure the power handling capability of the YBCO thin-film filter. The experimental setup was reported in our previous paper [13]. While measuring the output characteristics as a function of input power, we checked the relationship between the input and output of the filter. We define the electric power proof of the filter as the power at which the curve stops being linear. The temperature was varied between 50 and 80 K.

3. Results

3.1 Simulation results for the current concentration near the outer edge of the microstrip line resonator

Figure 1 shows the configuration and current concentration of 3-pole forward coupled filters made from sliced and conventional microstrip lines. (a) Sliced microstrip line filter: line width (w) 0.05mm; sliced line gap (g) 0.04mm; total width 1.13mm. (b) Conventional microstrip line filter: width 1.13 mm. The numerical values in the figure are currents in the electromagnetic field simulation. The current flowing on the outer edge of the sliced microstrip line and conventional microstrip line is larger than the current flowing in the middle of the microstrip line. The difference in the conventional line is especially large: only 8.6% of the current flows in the middle. In addition, the current near the edge of the conventional line is larger than the current near the edge of the sliced microstrip line. Because of this, a filter made with a sliced microstrip line can handle more power than the conventional one. The difference between electric power proofs of these filters, as calculated from the concentrated current values, is about 4 dB. Figure 2 shows the configuration and current concentration for 7-pole forward coupled filters based on sliced and conventional microstrip lines. The current indicated is the current in the fifth resonator of the filter. The current in the fifth resonator is larger than the currents in the other resonators. The concentrated current in the sliced microstrip line is smaller than in the conventional resonator.
The concentrated current on the outer edge of this resonator based on sliced microstrip lines is 66% smaller than in conventional microstrip lines. This result means the filter using the sliced microstrip line has a large electric power proof. Moreover, this is true for the other resonators in the filter.

**Figure 1.** Concentration of current along outer edge of a microstrip line in the middle pole of a forward coupled filter, as simulated with electromagnetic simulation software. (a) sliced microstrip line filter, (b) conventional microstrip line filter

**Figure 2.** Concentration of current along the outer edge of a microstrip line in the fifth pole of a forward-coupled filter simulated with electromagnetic simulation software. (a) Sliced microstrip line filter, (b) conventional microstrip line filter
3.2 Design of a bandpass filter

The optimum filter configuration was determined in an electromagnetic simulation. Figure 3 shows the simulation results for the frequency response of bandpass filters with three resonators based on sliced and conventional microstrip lines. The solid lines show the $S_{11}$ and $S_{21}$ parameters of the sliced microstrip line filter, and the broken lines show those of the conventional filter. The filters have similar frequency response. Because this filter characteristic met our specification, we made a filter based on this shape.

![Figure 3. Bandpass filter properties of sliced microstrip line and conventional microstrip line filters simulated with electromagnetic simulation software.](image)

3.3 Measurement of power handling capability of filters

The electric power handling capabilities of band-pass filters made from sliced microstrip lines and conventional microstrip lines were measured. Usually, heat generated in the joint between the terminal and the power feed becomes a problem when the electric power handling capability of the filter is measured, especially in high power proof filters. Therefore, we used a superconducting film with a small $J_c$. Figure 4 compares the power handling capabilities of the filters. The y-axis shows a power of output minus input. The thickness of the YBCO thin films is about 100 nm. We defined the power proof of the filter as the input power at which the output power becomes 0.5 dBm lower than maximum.

![Figure 4. Power handling capabilities of sliced- and conventional microstrip line filters made with YBCO thin films (100nm thickness)](image)
That point is 19.0 dBm for the conventional filter and 22.8 dBm for the sliced microstrip line filter. That is the sliced microstrip line filter improves the output by about 3.8 dBm.

How many power characteristics improve with a thicker superconducting thin film? We made three-resonator and seven-resonator filters using 300-nm-thick YBCO film. The results are shown in Figures 5(a) and 5(b). When we measured the filters at 70 K, we obtained an electric proof power of 35.5 dBm in the seven-resonator filter and 39 dBm in the three-resonator filter.

Figure 5. Correlation between input power and output power in a forward-coupled bandpass filter with three and seven resonators based on sliced microstrip lines made with YBCO thin films (300 nm thickness). (a) Three-resonator filter (b) Seven-resonator filter

4. Discussion

From the electromagnetic simulation, we obtained the difference between the current concentrations near the outer edges of the microstrip lines. The concentrated current was about 536 A/m in the sliced microstrip line and about 844 A/m in the conventional line, as shown in Figure 1. If this difference directly accounts for the improvement in the power handling capability of the filter, we can estimate the difference in proof power between the sliced and conventional microstrip line filters from the following equation.

\[
P(dB) = 10 \log \frac{844^2 R_r}{536^2 R_r} = 3.9(dB)
\]

Here, \( R_r \) is the resistance of the microstrip line. This estimate agrees quite well with the experimental results, as shown in Fig. 4. Therefore, we conclude that the main factor in deciding the electric proof power of the filter is the concentration of current level along the outer edge of the microstrip line.

The results of Figure 5(a) and Figure 5(b) can be subjected to a similar analysis. A current of 536 A/m flows along the edge in the three-resonator filter, while a current of 761 A/m flows in the seven-resonator filter. As above, we can estimate the difference between the electric proof powers the filters. The value is calculated to be 3 dB. The experimental result was 3.5 dB which is close to the estimated value. Thus, we see that the concentration of current along the outer edge of the microstrip line determines the electric proof power of the filter.
5. Conclusions
In order to increase the power handling capability of HTS band pass filters, we designed a sliced microstrip line, that does not concentrate as much current along the outer edge of the microstrip line. The following results were obtained:
(1) The current flowing along the outer edge of the sliced microstrip line was less concentrated than in the conventional microstrip line.
(2) The electric proof power of the sliced microstrip line filter was larger than that of the conventional filter.
(3) The electric proof power of the filter can be estimated from the current along the outer edge of the microstrip line.

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