Examination of the Resonator Structure for a Superconducting Transmitting Filter

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Abstract. We studied a resonator structure to reduce the current concentration at outer edge of a microstrip line. We developed a new microstrip line consisting of many parallel pieces separated by gaps. Electromagnetic simulations indicated that the current concentration of the outer edge of the sliced microstrip line was lower than that of a conventional microstrip line. We made a 3-pole filter of YBCO thin film using a sliced microstrip line and measured its power handling capability. The power handling capability was better than that of a conventional filter. We also examined other resonator structures to increase the power handling capability, for example, an S-type structure and a wide hair-pin structure. These resonator shapes had better power handling characteristics than a conventional microstrip resonator.

1. Introduction
Superconducting band path filters have advantages such as a high frequency selection, small insertion loss, and a large out-of-band rejection [1-5]. Consequently, such filters have been put to practical use in receiving systems of base stations for wireless communications in the U.S.A and China. The superconducting band path filter has only been used in receiving systems in which small amounts of electric power flow. If the power handling capability of the filter can be improved, it could be used as a transmitting filter, and hence its range of use could be expanded. Some studies on tunable filters for mobile communications exist [6-7]. There are reports on making resonator shapes that enable a large power handling capability, for example, patch-type [8-11] and wide microstrip resonators [12]. However, multi-resonator filters using such a resonator shape are quite difficult to design. These filters do not have a large out-of-band rejection property, which would otherwise be the biggest advantage of a superconducting filter. This problem may be overcome if a resonator with a large power handling capability can be designed using a microstrip line. With this goal in mind, we tried to reduce the current concentration on the edge of a microstrip line. S. Ye and R. Mansour [13] reported a resonator structure with a lower current concentration on the edge of the line. They used a split-resonator to reduce the current concentration close to the outer edge. They calculated the current concentration on the edge of the sliced line and found that the current concentration could be decreased by splitting the microstrip line. They also showed that the power handling capability of the split-resonator filter would be higher. However, it is difficult to design a multi-resonator filter with this structure. In this paper, we show the optimal sliced-line shape to decrease the current concentration of the microstrip line and show experimental results on the power capability of a comb-line filter using a sliced line. We also describe other resonator shapes to reduce the current concentration at the edge of the microstrip line.
2. Design of the optimal sliced line and filter
A new microstrip line to reduce the current distribution on the outer edge of the microstrip line is shown in the inset of Figure 1. We examined the optimal number of the parallel pieces to reduce a current concentration on the outer edge by using an electromagnetic simulation. We used a gap width \( g \) between the parallel pieces as a parameter. Figure 1 shows the relationship between a slice number and the maximum current concentration on the outer edge of the microstrip line as a parameter of a gap. The microstrip line width is a constant 500 \( \mu \)m. Because of software problems, we couldn’t calculate the current distribution of the microstrip line for \( g \) values less than 10 \( \mu \)m. Therefore, we varied \( g \) value between 10 to 80 \( \mu \)m and found that the maximum current on the outer edge point decreases rapidly with increasing number of slices and that the downward tendency is dependent on \( g \). We need more than six divisions in a 500-\( \mu \)m-wide microstrip line.

To make a resonator using a sliced microstrip line, we have to examine the optimal resonator shape. Figure 2 shows the three kinds of microstrip line division; (a) is a both-ends open type (BOT), (b) is a single-sided short type (SST), (c) is a double-sided short type (DST). We simulated the filter properties of a comb-type filter using BOT, SST and DST microstrip lines (Figure 3). The filters designed by BOT and DST microstrip lines have satellite bandpass properties except for the main band pass property at 5 GHz. These filters are not suitable as a band pass filter for the base stations of

![Maximum current density on sliced strip line versus number of slits as calculated by an electromagnetic simulator.](image1)

**Figure 1.** Maximum current density on sliced strip line versus number of slits as calculated by an electromagnetic simulator. \( g \) is an interval value between the slit line (the unit is mm), and c.p. is the calculation point of the maximum current density.

![Sliced microstrip line shapes](image2)

**Figure 2.** Sliced microstrip line shapes
(a) Both-ends open type (BOT), (b) single-sided short type (SST), and (c) double-sided short type (DST).
wireless communications. From the other hand, the filter designed by SST shows excellent band pass filter properties. Therefore, we used the SST microstrip line to make a filter.

Figure 4 shows the configuration of 3-pole comb-filters using conventional microstrip lines and sliced microstrip lines. Design specifications are as follows: center frequency is 5 GHz, bandwidth is 100 MHz, and ripple in band is less than 0.1 dB. We used a wide-width microstrip line in order to raise the electric power-proof characteristic. The width (w) of the two filters is equal to 1.13 mm.

**Figure 3.** Filter property S21 of a three resonator comb-filter designed for the different sliced microstrip line shapes as shown in Figure 2. Main resonating peak is 5 GHz, satellite resonating peaks appear at 2.7 GHz (DST), 5.6 GHz (SST), and 5.5 and 5.9 GHz (BOT).

**Figure 4.** Configuration of three-resonator comb-filters designed with a conventional microstrip line (a) and a sliced microstrip line (b). Sliced microstrip line: microstrip line width (w): 1.13 mm, gap of sliced line (g): 0.04 mm, slit number: 12.
The slice number \( n \) is 12, and the gap width \( g \) is 40 microns. The simulated results of this filter are shown in Figure 5. We found that both filters can meet the specification.

3. Experimental results

The filter was built on a 25 x 25 mm YBCO/MgO film. Figure 6 shows experimental results for \( S_{11} \) and \( S_{12} \) of a conventional and a sliced microstrip line filters measured at 70 K. The filter shape is shown in Figure 4. The measured ripple in the band and \( S_{11} \) values of the both filters are larger than the simulated ones. In order to reduce influence of insertion loss, we chose the measured frequency at which \( S_{11} \) was less than 0.1 dB. Since 4.95 GHz fulfilled the condition, we measured the input and the output characteristics using this frequency.

Figure 7 shows the power dependence of the filter with conventional and sliced microstrip line filters. When the input power is small, the output power becomes large proportional to the input power. However, when input power becomes large, the output power is not proportional to input power. This is because the high-power electric current worsens the superconductivity of the resonators. The linearity of the input-output relation for the filter designed by the conventional microstrip line is lost at the input electric power of 14.5 dBm; the linearity is extended to 19.5 dBm for the filter designed by the sliced microstrip line. That is, the filter using a sliced microstrip line improved by 5 dB with power handling capability.

Next we examined other resonator forms that might improve electric power handling characteristics. An electromagnetic simulation clearly showed that the hairpin type of resonator concentrates electric current at the curved point, therefore, a hairpin resonator seems to have a poor electric power-proof characteristic in this region. The S-type resonator was examined as a means to prevent this. Since the curve point shifts from the voltage maximum point, a resonator of this form should have better electric power-proof characteristics. The EM simulation indicated that the S type resonator could reduce the current concentration. Hence, we plan to fabricate an S type resonator filter using a superconducting thin film and measure its characteristics. We also examined a wide microstrip line filter. We designed a 3-pole hairpin type filter using a wide microstrip line. The power handling capability of the filter increased compare with that of a conventional hairpin filter with a 50-ohm line. These results will be presented in the near future.

Figure 5. Simulation results for conventional and sliced microstrip line filters shown in Fig. 4.

The slice number \( n \) is 12, and the gap width \( g \) is 40 microns. The simulated results of this filter are shown in Figure 5. We found that both filters can meet the specification.
4. Conclusions
We presented a 3-pole comb-filter design for conventional and sliced microstrip lines. The sliced-microstrip line resonator filter improved the power handling capability compared with the conventional-microstrip line resonator filter. We found that the sliced microstrip line is a superior choice for the design of a transmitting filter. We can easily design a multi-pole resonator filter (more than 15 poles), and the resulting filter will have a high power capability and a steep skirt characteristic.

Figure 6. Experimental results for conventional and sliced microstrip line filters shown in Fig. 4. Physical temperature was 70 K.

Figure 7. Power dependence of conventional and sliced microstrip line filters measured at 70 K.
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