Novel method to improve power handling capability for coplanar waveguide high-temperature superconducting filter

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Abstract. This paper proposes a novel method to improve the power handling capability of a coplanar waveguide (CPW) high-temperature superconducting (HTS) filter. The noteworthy point of the proposed method is that it is based on the concept that the power handling capability is improved by reducing the maximum current density of the filter. Numerical investigations confirm that a CPW HTS filter using 66-Ω characteristic impedance resonators (66-Ω CPW HTSF) reduces the maximum current density compared to that using conventional 50-Ω resonators (50-Ω CPW HTSF). We fabricated 5-GHz band four-pole Chevyshev CPW HTSFs based on the proposed and conventional methods. The fabricated 66-Ω CPW HTSF exhibited the third-order intercept point (TOI) of +61 dBm while the 50-Ω CPW HTSF exhibited the TOI of +54 dBm, both at 60 K. These results indicate the effectiveness of the proposed method.

1. Introduction
High-temperature superconducting (HTS) filters were proposed for use in mobile communication base station receivers from the standpoint of efficient frequency utilization and improving the receiver-sensitivity [1], [2]. This is because HTS filters achieve low insertion loss and have sharp cut-off characteristics. These filters were investigated in various configurations including the microstrip line, stripline, and coplanar waveguide (CPW) configurations. In particular, the CPW configuration is advantageous in simplifying the fabrication process and in reducing the cost of the HTS filter because it requires the use of only one side of the superconducting film [3], [4].

The development of HTS filters with a high-power handling capability is also of great importance in improving the system performance of mobile communications. However, the current concentration and critical current density in the HTS filters limit the input signal power level of the HTS filters. There are several ways to improve the power handling capability reported so far [5]-[7]. These ways employ approaches from a circuitry-mechanism standpoint such as preventing current concentration in the resonators. It seems to be much more practical for the HTS filters to reduce the current non-uniformity or to reduce the maximum current density, than to develop a new HTS material that has a higher critical current density [8].

This paper proposes a novel method that improves the power handling capability of a CPW HTS filter by employing resonators that have higher characteristic impedance than 50 Ω in order to reduce the maximum current density. A 5-GHz band, four-pole, CPW HTS filter is also fabricated to investigate experimentally the advantages of the proposed method.
2. Filter design concept
Four approaches are considered to reduce the maximum current density of the CPW HTS filters: 1) increase the characteristic impedance of the line by using a wider spacing between ground planes; 2) increase the center-conductor width; 3) reduce the non-uniformity of the current at the edge of the resonator; and 4) increase the film thickness. This paper employs approaches 1) and 2) as the first step in improving the power handling capability of the CPW HTS filters.

Figure 1 shows the normalized maximum current density versus the characteristic impedance of the line for a single CPW quarter-wavelength resonator on a Magnesium Oxide (MgO) substrate at 5 GHz. The maximum current density decreases as the characteristic impedance of the line increases. These results suggest that the current density of the CPW HTS filter will decrease by properly setting the distance between the ground planes and the center-conductor width. Figure 2 shows the normalized maximum current density versus the ratio, $k$, of the center-conductor width to the distance between ground planes. These results show that the $k$ of around 0.4 (point T) minimizes the current density.

3. Filter pattern and current density
Figures 3(a) and 3(b) show a schematic of the designed circuit pattern with the substrate dimensions of the CPW HTS filters employing quarter-wavelength resonators, which have the line characteristic impedance of 50 $\Omega$ (50-$\Omega$ CPW HTSF) [9] and 66 $\Omega$ (66-$\Omega$ CPW HTSF). The details of the fundamental design method for the 50-$\Omega$ CPW HTSF and 66-$\Omega$ CPW HTSF are described in [9]. The specifications of these CPW HTSFs are summarized in Table 1. They are designed to be a four-pole Chebyshev bandpass filter with the center frequency of 5.0 GHz, a 3.2-% (160 MHz) bandwidth, and 0.01-dB ripple. The dimensions of the gaps (e.g., $g_1$ and $g_2$) and the length of the quarter wavelength resonators ($l_1$ and $l_2$) are determined such that they satisfy the specification by using a SONNET em simulator [10]. Typical dimensions are given in Table 2.

Figure 3. Circuit pattern and current density observation point for (a) 50-$\Omega$ CPW HTSF with point R parameter in figure 2 and (b) 66-$\Omega$ CPW HTSF with point T parameter in figure 2.
The current density is maximized at the short-circuited stub because both the 50-Ω CPW HTSF and 66-Ω CPW HTSF employ quarter-wavelength resonators. Figures 3(a) and 3(b) show the observation point of the current density for the 50-Ω CPW HTSF and 66-Ω CPW HTSF, respectively. Figures 4(a) and 4(b) show the current density distribution at the stub of the 50-Ω CPW HTSF and 66-Ω CPW HTSF, respectively. Numerical analysis indicates that the maximum current density of the 66-Ω CPW HTSF is only 1089.3 Amps/meter, whereas that of the 50-Ω CPW HTSF is 2534.0 Amps/meter.

4. Filter fabrication and test results

Figure 5 is a photograph of the fabricated 66-Ω CPW HTSF. This filter is fabricated on Yttrium Barium Copper Oxide (YBCO) film on a MgO substrate. The specifications of the YBCO film and MgO substrate are given in [9]. The procedure for the filter fabrication is described in [9]. Figure 6 and Table 3 show the frequency responses of the fabricated 66-Ω CPW HTSF at 60 K. The solid lines in figure 6 represent the measured characteristics of $|S_{11}|$ and $|S_{21}|$. The dashed lines represent the calculated results from the SONNET em simulator. The measured characteristics agree well with the

| Table 1. Four-pole Chebyshev bandpass filter specifications. |
|-------------------------------------------------------------|
| Center frequency | 5.0 GHz |
| Equal ripple bandwidth | 3.2% (160 MHz) |
| Ripple | 0.01 dB |
| Substrate | 9.68 |
| Dielectric constant | 0.5 mm |
| Thickness | 0.5 μm |
| Superconductor | 0.5 μm |

| Table 2. Typical dimensions of filter pattern in figure 3. |
|----------------------------------------------------------|
| $l_1$ | 6.290 mm |
| $l_2$ | 6.640 mm |
| $g_1$ | 0.885 mm |
| $g_2$ | 0.070 mm |
| $g_3$ | 0.091 mm |
| $g_4$ | 0.018 mm |
| $w_0$ | 0.218 mm |
| $s_1$ | 0.045 mm |
| $s_2$ | 0.685 mm |

| Table 3. Summary of frequency responses at 60 K. |
|------------------------------------------------|
| Measured | Calculated |
| Center frequency | 5.01 GHz | 5.00 GHz |
| Ripple | 0.25 dB | 0.03 dB |
| Equal ripple bandwidth | 203 MHz | 171 MHz |
| (Fractional bandwidth) | (4.1%) | (3.4%) |
| Minimum insertion loss | 0.43 dB | 0 dB |
| Average insertion loss | 0.56 dB | 0.006 dB |

Figure 4. Current density distribution at the stub of (a) 50-Ω CPW HTSF and (b) 66-Ω CPW HTSF.

Figure 5. Photograph of 66-Ω CPW HTSF.

Figure 6. Frequency responses of 66-Ω CPW HTSF.
simulated characteristics.

The power-handling capability is often expressed by the third-order intercept (TOI) point, which is the virtual intersection of the two input-output power lines for the fundamental and the third-order intermodulation frequencies based on a log-log scale. Figure 7 shows the measured TOI of the 50-Ω and 66-Ω CPW HTSFs. The TOI of the 66-Ω CPW HTSF is +61 dBm at 60 K, while the TOI of the 50-Ω CPW HTSF is +54 dBm. This means that the 66-Ω CPW HTSF can handle over four times as much power as that of the 50-Ω CPW HTSF filter at the same temperature of 60 K. Figure 8 shows the temperature dependence of the TOI of the 50-Ω and 66-Ω CPW HTSFs. Degradation in the TOI is observed as the operating temperature increases from 60 K to 80 K. In the HTS filters, reducing the operating temperature leads to an improvement in the power handling capability.

5. Conclusion

A new method for reducing the maximum current density of a CPW HTS filter was proposed in order to improve the power handling capability. A 5-GHz band, four-pole, CPW HTS filter employing the line characteristic impedance of 66 Ω was fabricated for the purpose of investigating the advantages of the proposed method. The experimental results showed that the 66-Ω CPW HTSF handles a higher input power than the 50-Ω CPW HTSF. Aside from circuitry-mechanism based approaches, the invention of new HTS material is also expected to handle high power radio frequency signals.

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