Power handling capability of transmit HTS stripline filter
With shuttle-shape resonators

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Abstract

The power handling capability and frequency response of transmit high-temperature superconducting stripline filter with shuttle-shape resonators were investigated. A cascaded quadruplet (CQ) design is used to produce a pair of attenuation poles for obtaining sharp cutoff characteristics. The shuttle-shape resonators improve power handling and out-of-band rejection. An electromagnetic simulator based on the moment method was used to design a four-pole SL CQ filter with shuttle-shape resonators (5.0-GHz center frequency and 100-MHz bandwidth). The filter was fabricated using YBa2Cu3O7-d thin films on an Al2O3 substrate and was formed Au ground plane. The filter showed good frequency response. From the result of the power-handling capability, the filter showed a linear property until 7.9 W.

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Keywords: HTS filter; Transmit filter; Cascaded quadruplet; Stripline structure; shuttle-shape; patch conductors

1. Introduction

High-temperature superconducting (HTS) microwave receive filters have low loss and sharp skirt characteristics, making them practical for use in the receiving systems of mobile telecommunication base stations. HTS microstrip transmit filters are also potentially suitable for systems that require high power handling capability. Thus, interest in HTS transmit filters has been increasing [1-10].
The high-power filters that have been reported use various types of resonators, such as bulk resonators [1-2], dual-mode resonators [3-5], and modified microstrip line (MSL) resonators [6-8]. Although bulk and dual-mode resonators have high-power handling capability, their use makes it difficult to design a practically sized filter. One approach to overcoming this size problem is to use MSL resonators. Guo et al. reported an HTS two-pole MSL filter with shuttle-shape resonators [6]. The distribution of magnetic energy on a shuttle-shape resonator is more even, so the peak current density in the resonator is lower. The filter thus has better power handling capability than a conventional MSL straight-line filter.

We previously reported a miniaturized HTS cascaded quadruplet (CQ) transmit filter with a stripline (SL) structure [9]. The SL structure reduces the spurious unwanted couplings between nonadjacent resonators due to their weak coupling property, which makes it easier to obtain sharp cutoff characteristics. However, the filter has small unwanted cross coupling between nonadjacent resonators due to electrical coupling around open-end of resonators, resulting in degradation of out band rejection level. To overcome this problem we reported a four-pole SL CQ transmit filter with shuttle-shape resonators [10]. We revealed in the simulation that the shuttle-shape resonators improve not only power handling capability but also out-of-band rejection. Using shuttle-shape resonators in the CQ design should reduce the unwanted coupling between nonadjacent resonators due to the small electrical coupling at the open end of the resonators. This improves the out-of-band rejection of the CQ filter. The maximum current density of the shuttle-shape filter was 19% less than that of the straight-line filter, due to more even distribution of magnetic energy using the shuttle-shape resonator.

In this work, we present the experimental results of frequency response and power handling capability of the four-pole SL CQ transmit filter with shuttle-shape resonators.

2. Filter design

We previously proposed the basic concept of a four-pole SL CQ transmit filter with shuttle-shape resonators [10]. The shuttle-shape resonator is longer than a conventional straight-line resonator with the same resonance frequency. This is because the series inductance around the center of the resonator must be increased to recover the smaller shunt capacitance at the open-end of the resonator. Thus, the distribution of the magnetic energy on a shuttle-shape resonator is more even, resulting in improved power handling. We designed and analyzed the filter by using electromagnetic (EM) analysis software (Sonnet EM), which is based on the moment method [11]. The design specifications were a center frequency of 5 GHz, a bandwidth of 90 MHz, and a passband ripple of 0.1 dB for an elliptic response, and attenuation poles at 4.9 and 5.1 GHz. Cross-section of the SL structures is shown in Fig.1 (a). We assumed Al₂O₃ was used for the substrate and that the substrate had a dielectric constant of 9.9 and a thickness of 2.0 mm. The filters consisted of four half-wavelength shuttle-shaped resonators. The configuration of the

![Fig. 1 (a) Schematic side view of stripline structure. (b) Configurations of filter. (c) Frequency response of filter.](image-url)
designed filter is shown in Fig. 1(b). In the filter with shuttle-shape resonators, strong electrical coupling cannot be achieved with a conventional waveguide due to the small electrical coupling and narrow open-end of the resonators. We thus propose using two waveguides to achieve a strong electrical coupling between resonators 2 and 3. Figure 1(c) shows the simulated frequency response of the filter. The center frequency and bandwidth of the filter were in reasonably good agreement with the design parameters.

3. Fabrication and measurement

3.1. Fabrication of filter

The layout of the filter is shown in Fig. 2(a). The L1 substrate had only a ground plane on the upper side. The L2 substrate had nothing on its upper and lower side. The L3 substrate had the designed filter on its upper side. The L4 substrate had only a ground plane on the lower side. The size of the L3 and L4 substrates were $25 \times 25 \times 0.5$ mm and the L1 and L2 ones were $20 \times 25 \times 0.5$ mm. The L1 and L2 substrates were made a little shorter than the L3 and L4 one to enable contact between the SMA (SubMiniature version A) connector and feed line circuit. The filter was fabricated using 0.3-μm YBa2Cu3O7−δ thin film deposited on an Al2O3 substrate. The ground planes were Au thin film. The filters were patterned using a conventional photolithography technique and dry etching. Figure 2(b) shows a photograph of the fabricated filter on the L3 substrate. To test the filter, we mounted the layers on test fixture featuring a top crossbar bolted to the body of the fixture so as to allow tight contact between the layers comprising the filter. The S-parameters were measured with a network analyzer (E5071B, Agilent Technologies).

3.2. Measurement of filter

Fig. 2(b) shows the measured frequency response of the filter at 40 K. The filtering property is clearly observed. The filter has a center frequency of 5.08 GHz and a 3dB-bandwidth of 98 MHz. The slight differences in the center frequency from the designed value may have been due to the difference in the dielectric constant between the simulated and effective values. A redesign using appropriate simulated dielectric constants might eliminate these differences. The spurious resonance is appeared at 5.25 GHz due to discontinuous part at microstrip-to-strip transition. The experimental insertion loss of the filter is 2.2 dB, and the return loss is 20 dB. The large insertion loss is expected due to normal conductor ground planes and discontinuous part at microstrip-to-strip transition.

The power handling capability of the filters was examined using measurement system illustrated in Fig. 3(a). The input signal was a 5.08 GHz continuous wave (CW) which was generated by a synthesized CW generator.

![Fig. 2 (a) Schematic side view of filter. (b) Photograph of fabricated filter. (c) Measured frequency response of filter.](image-url)
Fig. 3 (a) Schematic diagram of system used to measure power handling capability. (b) Measured power handling capability of filter.

(SG: HP 83711B). The isolated CW signal was amplified at the RF power amplifier (PA: R&K A4951-4546R). The gain of the PA was 45 dB, and the maximum output power was 40 W. The input signal levels were adjusted by using the SG and were calibrated using thru cables and a spectrum analyzer (SA: Rohde & Schwarz). The input and output power of the device under test, which included semi-flexible cable with SMA connectors in the vacuum chamber, were monitored by SA.

Figure 3(b) plots the measured input vs. output power characteristics of the filter. The power levels entering the filter varied from 0 to 40 dBm. As a result, power handling capability of the filter over 39 dBm (7.9 W) was observed.

4. Conclusion

A HTS four-pole transmit filter with shuttle-shape resonators was designed and fabricated. A stripline structure and cascaded quadruplet design were used for the filter. The measured frequency response of the filter agreed well with the designed one. The measured power level was over 39 dBm.

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