A NOVEL MICROWAVE HIGH-TEMPERATURE SUPERCONDUCTING REACTION-TYPE TRANSMITTING FILTER FOR MOBILE BASE STATIONS

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Abstract

A novel split open-ring reaction-type construction technique to achieve high power-handling capability for High-temperature superconducting (HTS) filters is presented. The purpose of this filter is to suppress the adjacent noise generated by transmitting power amplifiers for mobile base stations. First, it is explained that reaction-type filters are suitable for high power transmission. Secondly, novel split open-ring resonators, which reduce the maximum current density while maintaining high Q-factors are proposed. Current density dispersion effects are evaluated under the same coupling coefficient. Finally, a 5 GHz three-pole reaction-type filter using split open-ring resonators is designed. The frequency characteristics of the filter are investigated by using the method of moments. The results predict that the filter realizes both a higher power-handling capability than that of transmission-type filters and a better skirt property than existing HTS filters using dual-mode resonators.

Introduction

The microwave thin-film filters employing superconducting materials enable extremely high-Q performance with small sized planer structure circuit construction in comparison with existing room temperature devices. High-Temperature Superconducting (HTS) filters for low-power applications such as receiving filters have been developed and are used practically. On the other hand, transmitting filters for practical applications have not been realized so far. One of the substantial reasons for this is their low power-handling capability caused by high surface-current concentrations on the superconducting devices. Research and development of HTS transmitting filters have been concentrated mostly on dual-mode filters employing patch resonators for the dispersion of surface-current and hence low current densities [1], [2]. Dual-mode filters have difficulties to realize sharp cutoff and miniaturization at the same time since it requires considerably large resonator size to construct. HTS reaction-type filter consisting of novel split open-ring resonator enables both higher power-handing capability than transmission-type filters and sharp cutoff characteristics compared with dual-mode filters. In this paper, a 5 GHz HTS reaction-type filter using split open-ring resonator is discussed. First, concepts and advantages of the reaction-type filters are explained. Secondly, edge-current density dispersion effects of the novel split open-ring resonators are discussed. Finally, the frequency characteristics of the filter are estimated using numerical analysis.

Applications of reaction-type filter

A reaction-type filter is a bandstop filter employing reaction-type resonators. The resonators applied to these types of bandstop filters do not resonate most high-power fundamental transmission signals. Only stopband signals are absorbed or reflected. This reaction-type filter is assumed to be operated at mobile communication base stations. The reaction-type filter is designed to apply for next generation IMT-Advanced mobile base stations' transmission filter. Technical specifications for IMT-Advanced are under consideration and not available at the moment. In this paper, specifications for the current third-generation communication systems are considered.

IMT-2000 (W-CDMA) specifications indicate that adjacent channel leakage ratio (ACLR), a requirement of adjacent channel leakage spurious suppression level, is 45 dBc lower than the carrier power at 1.16 MHz away from the transmission band edge [3]. For example, an adjacent channel leakage noise power, which needs to be suppressed by the filter, is 80 mW, 30 dBc below the 80 W fundamental signal powers. HTS materials' power-handling capability and cryocooler cooling capacity (2-3W) can handle these levels of noise power.

Split open-ring resonator

One of the problems with HTS reaction-type filters arises when high-power fundamental signals pass through a feed line. Although fundamental signals are within the passband of the filter, they are very close to the stopband. These signals induce currents on the resonators, which exceed HTS critical current density. To solve the problem, the novel split open-ring resonators are proposed. It is widely recognized that split microstrip lines, which

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are divided parallel to the edges, allow the edge-current to decrease [4]. The proposed resonator enables reduction of the maximum current density while maintaining high Q-factors based on this idea.

The geometry of the novel split open-ring resonator is shown in Figure 1 (a). Unlike other existing split open-ring resonators, two resonator elements are adjusted to equal length in a way that realizes dispersion of edge-current density. Substrates are assumed as MgO with $\varepsilon_r = 9.7$, $\tan\delta = 3.3 \times 10^{-6}$ and thickness $d = 0.5$ mm, and HTS thin-film materials have conductivity of 6.5×10^{12} S/m. In addition, shield box shown in Figure 2 is taken into account. A 50 Ω microstrip line is used as the input and output feed lines. As the split open-ring resonator is a coupling of two resonator elements, it has two resonant frequencies: lower resonant frequency (fundamental mode) and higher resonant frequency (higher mode). Because fundamental mode enables to have both high Q-factor and high current dispersion effect due to relatively strong coupling between two resonator elements, only fundamental mode is considered. The gap between two resonator element is varied from g = 0.010 mm to g = 1.500 mm. The resonator outer diameter D is chosen to resonate at 4.950 GHz. The width of the undivided open-ring resonator shown in Figure 1 (b) is adjusted its width to minimize the induced current density. To obtain the same coupling coefficient β_e between the resonators and the feed line, the spacing s is varied.

Full-wave electromagnetic analysis software Agilent ADS Momentum which uses the method of moments is employed for current density estimation because of its ability to model the planer structure with considerable accuracy. As the fundamental signal is close to the stopband, a 1.0 V peak-to-peak sinusoidal wave 1.0 MHz away from the resonant frequency center (1.0 MHz offset) was excited on the feed line. The maximum induced current density and unloaded Q-factor is shown in Figure 3. The maximum induced current density of the split open-ring resonator (g = 0.500 mm) is 1765 A/m, decreased by 25.0 % at β_e =10, when compared with 2353 A/m of the undivided open-ring resonator. In addition, the unloaded Q-factor of the split open-ring resonator (g = 0.500 mm) is 51000, which is not decreased the value of 47800 for the open-ring without split, as shown in Figure 3. Furthermore, the split open-ring resonator enables low radiation energy from the surface of elements. Radiations are reversed with opposite direction currents on two resonator elements. As shown in Figure 4, radiation energy is rapidly decreased when resonator gap g become narrower. We can find that the split open-ring resonator with g = 0.300 mm achieve both 24.4 % of current density dispersion effect and one third of radiation energy, compared with the undivided open-ring resonator.

Design of the reaction-type filter

To confirm the sharp cutoff characteristics of reaction-type filters, a 5 GHz three-pole reaction-type filter is designed and analyzed. The split open-ring resonator with g = 0.300 mm is employed in this filter, its advantage being its current density dispersion effect and low radiation energy. The filters are designed to have a stopband center frequency f_0 = 4.950 GHz, 3 dB bandwidth of 1.5 MHz (FBW = 0.030 %) and a three-pole Chebyshev response with 0.01 dB ripple. The geometry and frequency characteristics of the filter are shown in Figure 5 and Figure 6, respectively. Calculated results are f_0 = 4.950 GHz, 3 dB bandwidth of 1.42 MHz with maximum attenuation –30.25 dB, which are almost the same as the design values.

Conclusions

The HTS reaction-type transmitting filter consisting of novel split open-ring resonator has been presented. The split open-ring resonator enables a 25 % reduction in the maximum induced current density and low radiation energy. The 5 GHz three-pole reaction-type filter using the split open-ring resonator has been designed and analyzed. Frequency characteristics of the filter show very sharp cutoff characteristics. These results predicted that the filter realizes both a higher power-handling capability and a better skirt property than existing HTS filters. Fabrications of the resonators and filters are going on. The experimental results of their frequency characteristics, power-handling capability and nonlinear characteristics will be shown in the congress.

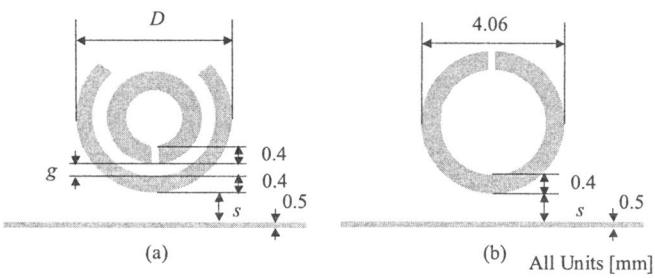

Fig. 1. Structures of split open-ring resonator and the open-ring resonator.

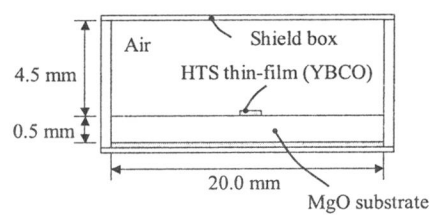

Fig. 2. Structure of shield box (cross-section view).

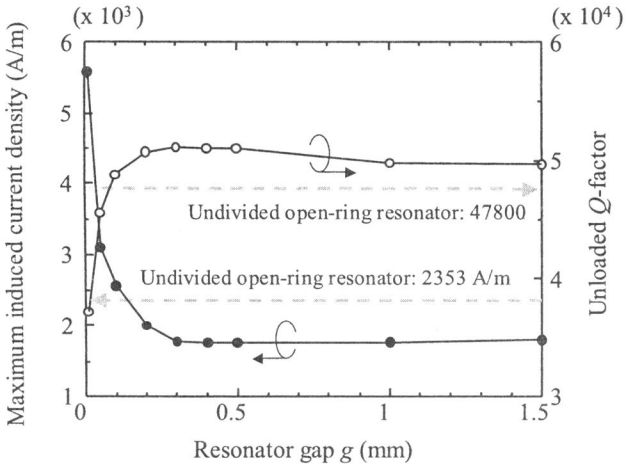

Fig. 3. Resonator gap g against maximum induced current density (coupling coefficient $\beta_e = 10$) and unloaded Q-factor.

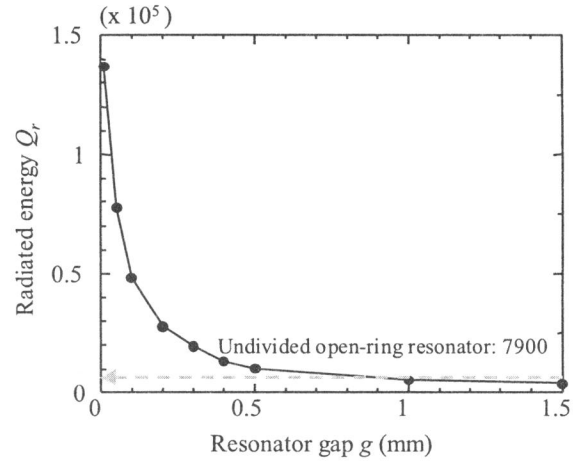

Fig. 4. Resonator gap g against radiated energy Q_r.

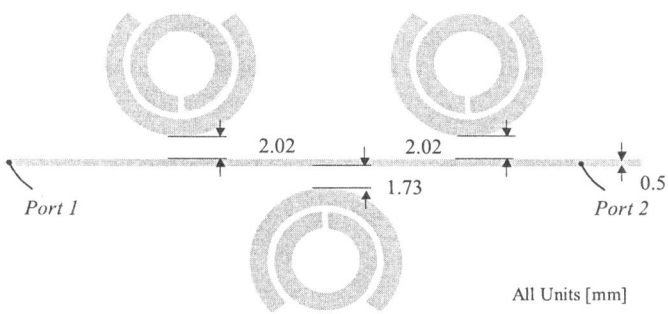

Fig. 5. Structure of 5 GHz three-pole reaction-type filter.

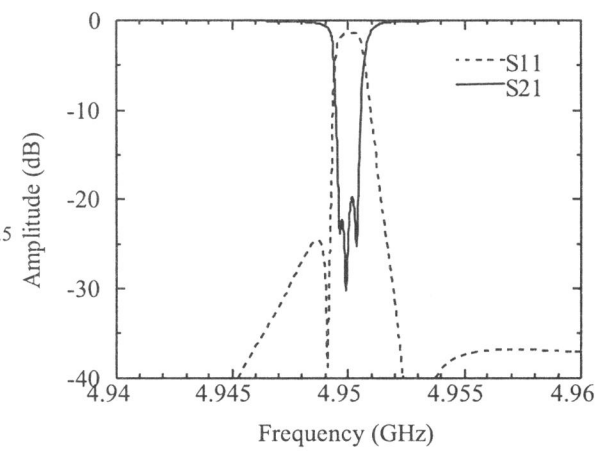

Fig. 6. Frequency characteristics of 5 GHz three-pole reaction-type filter.

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