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High-Temperature Superconducting Reaction-type Transmitting Filter Consisting of Novel Split Open-ring Resonators

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Abstract — **High-temperature superconducting (HTS) reaction-type transmitting filter consisting of novel split open-ring resonators is presented. 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 three-pole reaction-type filter using split open-ring resonators is designed. The frequency characteristics and current distributions of the filter are investigated by the method of moments. The results predict that the filter realizes both a higher power-handling capability than transmission-type filters and a better skirt property than existing HTS dual-mode filters.**

Index Terms — **current density, High-Temperature Superconductor, power-handling capability, reaction-type filter, split open-ring resonator.**

I. Research Background

The microwave thin-film filters employing superconducting materials enable extremely high Q performance with small sized planer circuit construction in comparison with existing room-temperature devices. Low power applications such as receiving High-Temperature Superconductor (HTS) filters have been developed and are used practically. However, transmitting filters for practical applications have not been realized so far. This is because of their low power-handling capability caused by high surface-current concentrations on the devices. Research and development of the HTS transmitting filters are carried out mostly on dual-mode filters employing patch resonators for dispersion of surface-current densities [1], [2]. Although dual-mode filters have benefit of current density dispersion, it is difficult to realize sharp cut-off and miniaturization because of considerably large resonator size. As an alternative, HTS reaction-type transmitting filter consisting of novel split open-ring resonator is proposed.

II. Application of the Reaction-type Filter

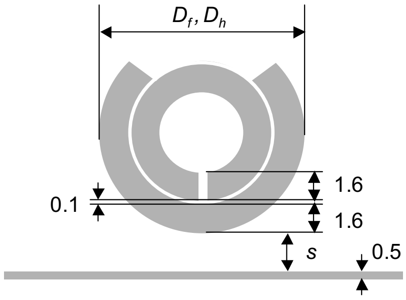
A reaction-type filter is a bandstop filter employing reaction-type resonators. The resonators applied for these types of bandstop filters do not resonate most high-power fundamental transmission signals. Only stopband signals are absorbed or reflected. This reaction-type filter is assumed to be operated 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 power. Power-handling capability of HTS materials and cryocooler cooling capacity (2-3 W) can handle these levels of noise power.

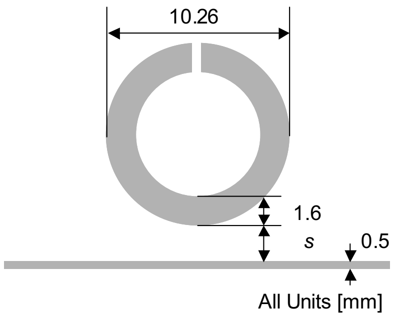
III. Split Open-Ring Resonator

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 well known that split microstrip lines, which 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.

For basic considerations, the novel split open-ring resonator is designed at 2 GHz band. The geometry of the split open-ring resonator is shown in Fig. 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.



(a) Split open-ring resonator



(b) Open-ring resonator

Fig. 1. Structure of the resonators.

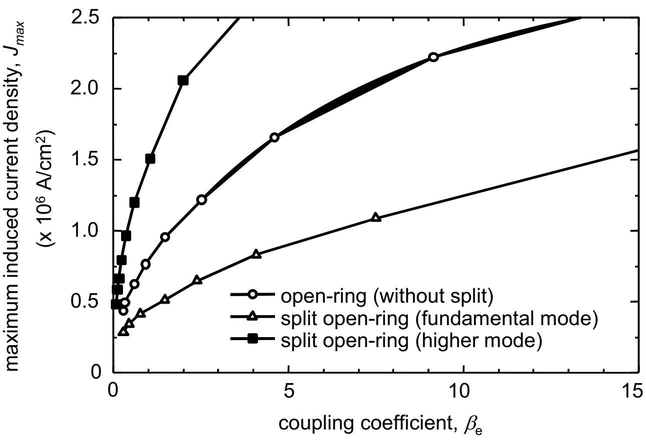
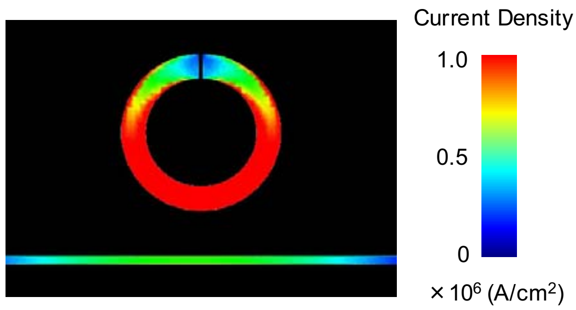


Fig. 2. Resonator coupling coefficients β_e against maximum induced current densities.

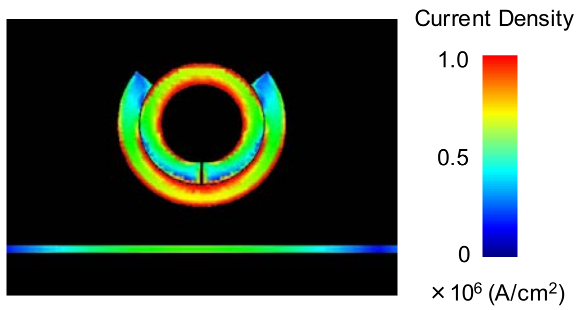
Substrates are assumed as MgO with ε_r = 9.7, tand = 5.5 x 10^{-6} and d = 0.5 mm, and HTS thin-film materials have perfect conductivity. A 50 Ω microstrip line is used as the input and output feed lines. As the split open-ring resonator is a coupling of two resonator elements, it has two resonant frequencies: lower resonant frequency (fundamental mode) and higher resonant frequency (higher mode).

Then, each mode is adjusted to resonate at 2.000 GHz. The resonator outer diameter is chosen to be D_f = 11.07 mm for fundamental mode, and D_h = 13.25 mm for higher mode, respectively. The width of the undivided open-ring resonator shown in Fig. 1 (b) is adjusted to minimize the induced current density. To obtain the same coupling coefficient be between the resonators and the feed line, the spacing s is varied from s = 0.5 mm to s = 3.0 mm.

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.



(a) Open-ring resonator



(b) Split open-ring resonator (fundamental mode)

Fig. 3. Surface current density distributions on the resonators. (Coupling coefficient: β_e = 10)

TABLE I
CHARACTERISTICS OF THE RESONATORS

types of resonators	radius of resonators, D	maximum induced current density (β_e = 10), J_{max}	unloaded-Q, Q_u
open-ring (without split)	10.26 mm	2.25 x 10^6 A/cm^2	33800
split open-ring (fundamental mode)	11.07 mm	1.25 x 10^6 A/cm^2	77700
split open-ring (higher mode)	13.25 mm	2.78 x 10^6 A/cm^2	7600

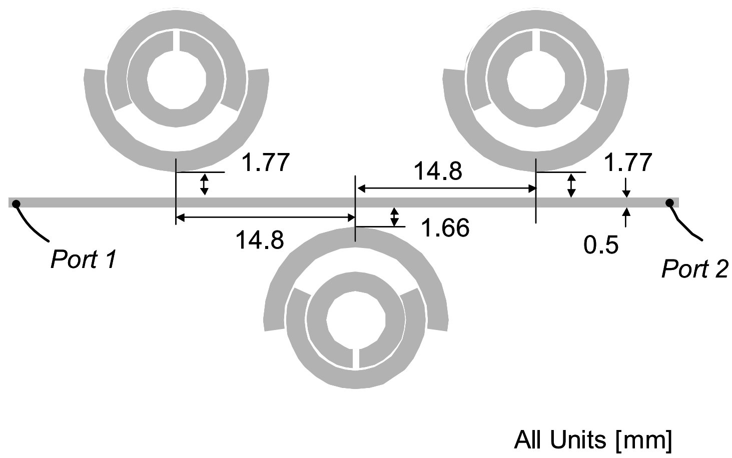


Fig. 4. Structure of reaction-type filter.

The results is shown in Fig. 2, the maximum induced current density of the split open-ring resonator (fundamental mode) decreased by 43 % at β_e = 10, when compared with the undivided open-ring resonator. In addition, Fig. 3 shows surface current distributions on the resonators. These distributions illustrate current density dispersion effects of the split open-ring resonator. Furthermore, the unloaded Q-factor of the split open-ring resonator fundamental mode increased to 77700, which is more than twice the value of 33800 for the open-ring without split as shown in Table I.

IV. DESIGN OF THE REACTION-TYPE FILTER

The three-pole reaction-type filter is designed. The fundamental mode of the three-way split open-ring resonator is employed in this filter with its advantage being its current density dispersion effect and high Q-factor. The filters are designed to have a stopband center frequency f_0 = 2.000 GHz, 3 dB bandwidth of 500 kHz (FBW = 0.025 %) and a three-pole Chebyshev response with 0.1 dB ripple. The geometry and frequency characteristics of the filter are shown in Fig. 4 and Fig. 5 respectively. Calculated results are f_0 = 2.000 GHz, 3 dB bandwidth of 536 kHz with maximum attenuation –33.5 dB, which are almost the same as the design values. The maximum induced current density is 1.26 x 10^6 A/cm^2 when excited with a 1.0 MHz offset 1.0 V peak-to-peak sinusoidal wave. Using this filter as a transmission-type filter and all signals are absorbed in the resonators, maximum current density is 8.92 x 10^6 A/cm^2 under the same signal without offset. The input power-handling capability provided by transmission-type filters is improved by 7.1 times if reaction-type filters are employed instead.

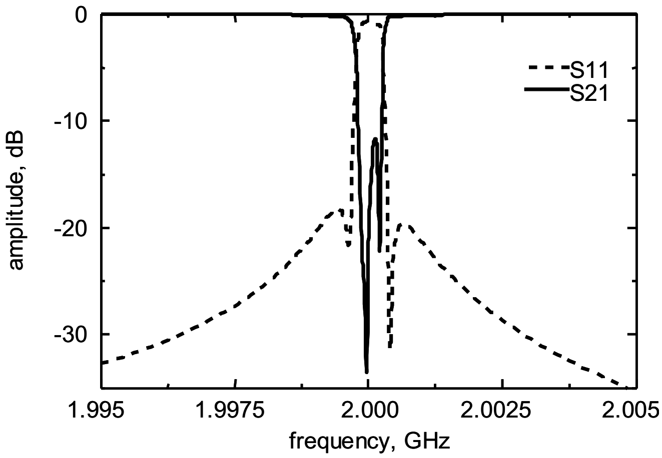


Fig. 5. Frequency characteristics of reaction-type filter.

V. Conclusion

HTS reaction-type transmitting filter consisting of novel split open-ring resonator has been presented. The split open-ring resonator enables a 43 % reduction in the maximum induced current density. The three-pole reaction-type filter has been designed and analyzed. The results predicted that the filter realizes both a higher power-handling capability and a better skirt property than existing HTS filters. The next step will design the filter for more high frequency bands. Then fabrication of the filter and measurement of their power-handling capability and nonlinear characteristics will be conducted.

Acknowledgement

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