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Microwave Superconducting Reaction-Type Transmitting Filter Using Novel Split Open-Ring Resonator

S. Futatsumori, T. Hikage and T. Nojima

A microwave superconducting reaction-type filter consisting of novel split open-ring resonators is presented. Novel split open-ring resonators, which reduce the maximum current density while maintaining high Q-factors, are proposed. The frequency characteristics and current distributions of the filter are investigated by the method of moments. The results predict that the filter realises both a higher power-handling capability and a better skirt property than existing high-temperature superconductor filters.

Introduction: Microwave thin-film filters employing high-temperature superconductor (HTS) materials have advantages owing to their low loss, high Q performance and reduction in size and weight, which cannot be achieved with existing room-temperature devices. HTS filters for low-power applications such as receiving filters have been developed and are used practically in cellular base stations. However, transmitting filters for practical applications have not been realised so far. This is because of their low power-handling capability caused by high surface-current concentrations on the devices. Research and development of 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 the benefit of current density dispersion, it is difficult to realise sharp cutoff and miniaturization because of considerably large resonator size. In this letter, a microwave superconducting reaction-type 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. The current density reduction efficacy of the split open-ring resonator is evaluated under

the same coupling coefficient between a feed line and resonators. Finally, a three-pole reaction type filter has been designed. The frequency characteristics and current distributions of the filter are investigated by the method of moments. The results predict that the filter realises both a higher power-handling capability than transmission-type filters and a better skirt property than existing HTS dual-mode filters.

Concept 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 in IMT-2000 (W-CDMA) mobile communication base stations. According to IMT-2000 specifications, adjacent channel leakage ratio (ACLR), a requirement of spurious suppression level, is 45dBc lower than the carrier power at 1.16MHz away from the transmission band edge [3]. For example, a spurious noise power which needs to be suppressed by the filter is 80mW, 30dBc below the 80W fundamental signal power. 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 recognised that currents on a microstrip line are concentrated and have a peak value on the edge of microstrip line. 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 with this idea.

The geometry of the novel 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. Assuming a MgO substrate with $\epsilon_r = 9.7$, $\tan\delta = 5.5 \times 10^{-6}$ and $d = 0.5\text{mm}$, and HTS-thin film materials with perfect conductivity, the dimensions of the resonator are chosen to be $w_s = 1.6\text{mm}$ and $g = 0.1\text{mm}$. A 50Ω microstrip line with a width of $w_L = 0.5\text{mm}$ 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. The resonant frequencies vary depending on the coupling levels of the elements as follows:

$$k = \frac{f_h^2 + f_l^2}{f_h^2 - f_l^2} \quad (1)$$

where k is the coupling coefficient between two resonator elements, f_l and f_h are lower resonant frequency (fundamental mode) and higher resonant frequency (higher mode), respectively. Then, each mode is adjusted to resonate at 2.000GHz. The resonator outer diameter is chosen to be $D_f = 11.07\text{mm}$ for fundamental mode, and $D_h = 13.25\text{mm}$ for higher mode, respectively.

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 1.0V peak-to-peak sinusoidal wave 1.0 MHz away from the resonant frequency centre (1.0MHz offset) was excited on the feed line. The width of the undivided open-ring resonator shown in Fig. 1 (b) is adjusted and the minimum current density and resonant frequency of 2.000GHz are realised when $w_o = 1.6\text{mm}$ and $D_o = 10.26\text{mm}$. To set the same coupling coefficient β_c between the resonators and the feed line, the spacing s of the resonators is varied from $s = 0.5\text{mm}$ to $s = 3.0\text{mm}$. The results, Fig. 2 show that the maximum induced current density of the split open-ring resonator (fundamental mode) decreased by 43% at $\beta_c = 10$, when compared with the undivided 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. 1.

Three-pole reaction type filter: The frequency characteristics and current distributions of the filter are analysed to determine the reason why reaction-type filters using the split open-ring resonators realise both a higher power-handling capability and a better skirt property than existing HTS filters. The fundamental mode of the resonator is used in this filter, its advantages being its current density dispersion effect and high Q-factor. The filters are designed to have a stopband centre frequency $f_0 = 2.000\text{GHz}$, 3dB bandwidth of 500kHz (FBW=0.025%) and a three-pole Chebyshev response with 0.1dB ripple [5]. The geometry and frequency characteristics of the filter are shown in Fig. 3 and Fig. 4, respectively. Calculated results are $f_0 = 2.000\text{GHz}$, 3dB bandwidth of 400kHz with maximum attenuation -26.6dB, which are almost the same as the design values. The maximum induced current density is $1.35 \times 10^6 \text{ A/cm}^2$ when excited with a 1.0MHz offset 1.0V 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 $9.25 \times 10^6 \text{ A/cm}^2$ under the same signal without offset. The input power-handling capability provided by transmission-type filters is improved by 6.9 times if reaction-type filters are employed instead.

Conclusions: A microwave superconducting reaction-type filter consisting of novel split open-ring resonators is 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 realises both a higher power-handling capability and a better skirt property than existing HTS filters. The next step will be fabrication of the filter and measurement of its power-handling capability and nonlinear characteristics.

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Figure and table captions:

Fig. 1 Structures of the resonators

- a split open-ring resonator
- b open-ring resonator

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

- open-ring (without split)
- △— split open-ring (fundamental mode)
- split open-ring (higher mode)

Fig. 3 Structure of three-pole reaction-type filter

All dimensions in millimetres

Fig. 4 Frequency characteristics of three-pole reaction-type filter

- - - S_{11}
- S_{21}

Table. 1 Characteristics of resonators

Figure 1

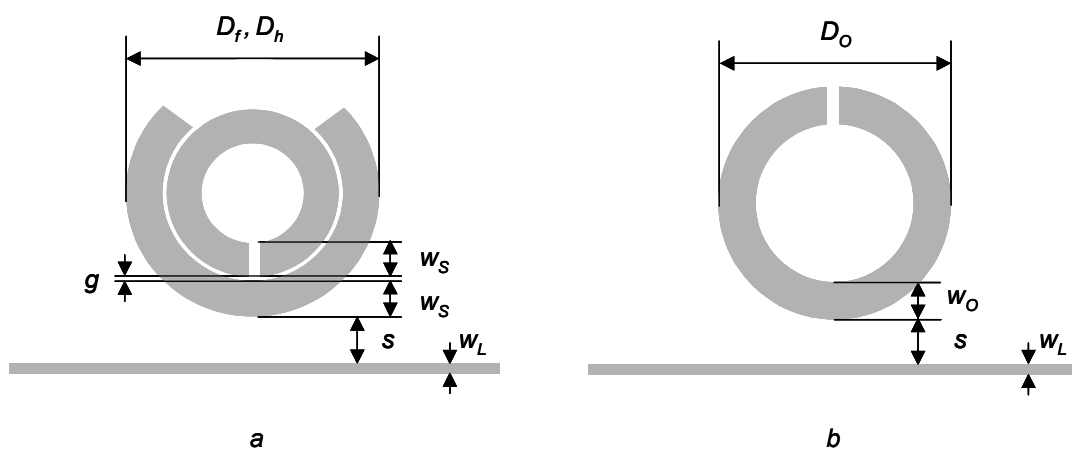


Figure 2

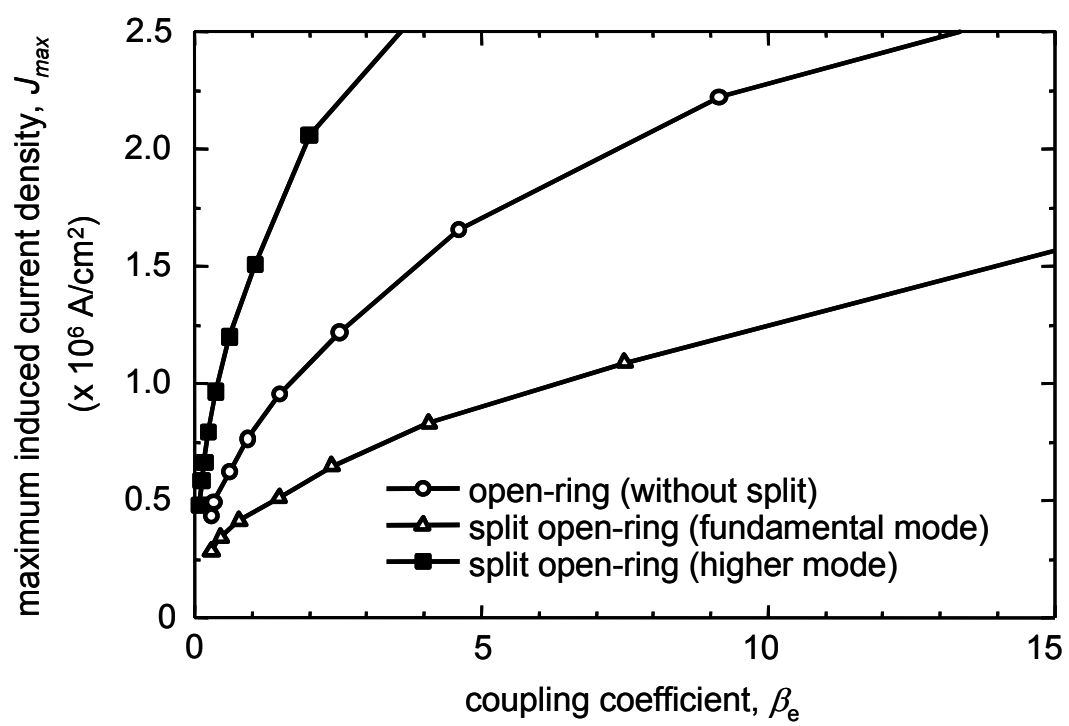


Figure 3

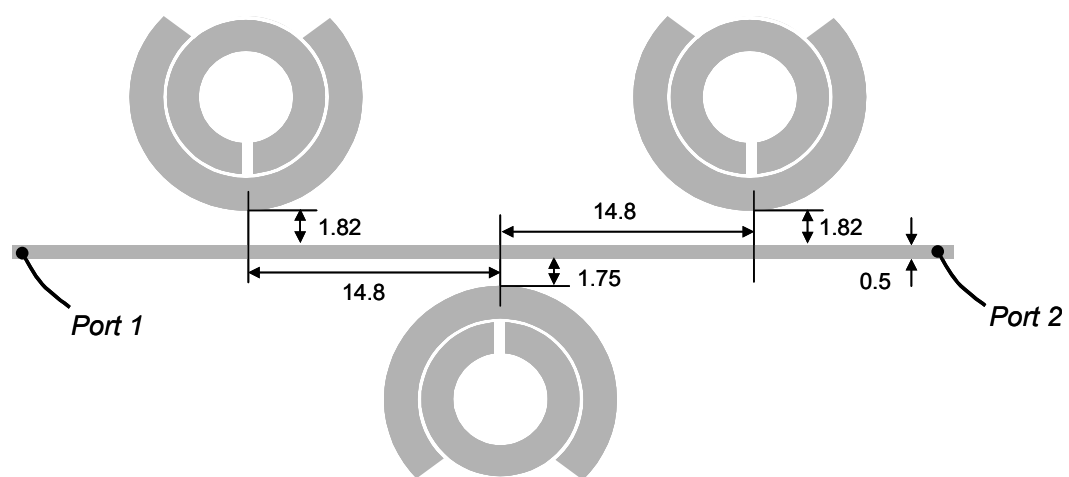


Figure 4

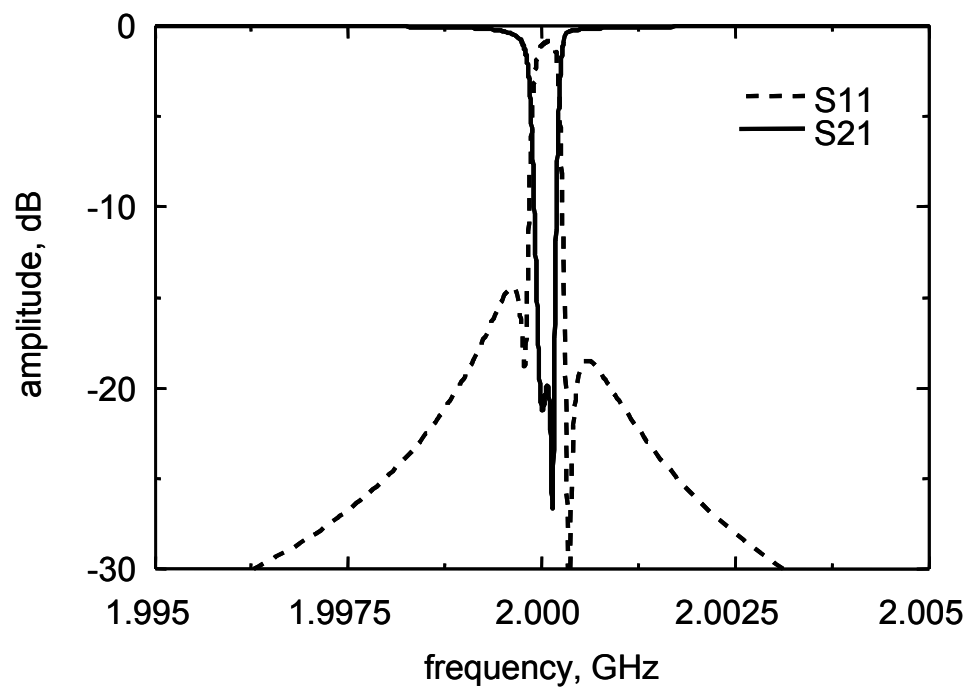


Table 1

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