

Design Scheme of Miniaturized Circuits Configuration for 5 GHz Band Coplanar Filters

High-temperature superconducting filters are proposed for use in mobile communication base station receivers for the purpose of achieving efficient frequency utilization and improving the receiver sensitivity. In this article, we focused on coplanar waveguide high-temperature superconducting filters because of the low cost of forming superconducting films and simple manufacturing processes involved, and investigated a design scheme for configuring miniaturized circuits for the filter; we then validated the design by numerical and experimental investigations based on 5-GHz band coplanar waveguide high-temperature superconducting filters. This research was conducted jointly with the Kobayashi laboratory (Professor Yoshio Kobayashi), Department of Electrical and Electronic Systems, Faculty of Engineering, Saitama University.

Kei Satoh, Daisuke Koizumi and Shoichi Narahashi

1. Introduction

Using high-temperature superconducting materials with critical temperatures around the boiling point of liquid nitrogen (77K), it is possible to construct multi-pole filters with low losses even in the microwave band (high-temperature superconducting filters). Consequently, it is possible to keep the insertion loss in the passband extremely low, yet at the same time achieve both sharp cut-off characteristics at the passband edges and significant attenuation in the stop band. These characteristics lead to improved reception sensitivity and frequency selectivity of receivers in mobile communication base stations, resulting in active R&D of high-temperature superconducting filters in universities, research institutes and corporations inside and outside Japan [1] [2].

We examine microwave band high-temperature superconducting filters, focusing on CoPlanar Waveguide (CPW) configurations. This is because the CPW configuration is advanta-

geous in simplifying the fabrication process and in reducing the depositing cost of superconducting films, since it requires only one side of the substrate to be deposited with superconducting film [3]. Specifically, we assigned quarter-wavelength CPW resonators sequentially on a dielectric substrate with a width of 5.4 mm and a length of 30.5 mm to achieve a performance almost equivalent to the filter design values without pre- and post-tuning. When constructing multi-pole filters of this type, however, we ran into the issue that the dielectric substrate had to be extended by approximately 6.4 mm, which is the length of a resonator, for each extra pole. This article presents the results of designing, constructing and evaluating filters that avoid this increase of substrate area caused by the increased number of pole by assigning the quarter-wavelength CPW resonators in a parallel as well as in interdigital patterns [4] [5].

2. Filter Design and Production

Table 1 shows the filter design specification. The filters are designed by using simulation results both via equivalent circuits and by an electromagnetic simulator [4]. **Figure 1** shows the

Table 1 Filter design specification

	Specification
Transmission line structure	Coplanar
Transfer function	Chebyshev
Resonator length	/4
Number of poles	5
Dielectric substrate materials	MgO
Thickness	0.5mm
Dielectric constant	9.68@77K
Loss tangent	<10 ⁻⁷
High-temperature superconducting materials	Y-Ba-Cu-O
Thickness	0.5μm
Critical temperature	86.5K
Center frequency	5GHz
Equal-ripple bandwidth	160MHz
Ripple within passband	0.01dB

Y-Ba-Cu-O: An oxide-based superconducting material, also known as YBCO, Y-123 and so on.

filter structure and major dimensions and **Table 2** shows the principal calculated characteristics of the designed filter, out-of-band attenuation amount and 3-dB bandwidth.

We fabricated the filters using the dielectric substrate and high-temperature superconducting materials shown in Table 1 by means of photolithography^{*1} processing, which corresponds to (1) to (3) and (6) to (8) in the fabrication process shown in **Table 3**, and ion-milling^{*2} processing, which corresponds to (4) [6]. **Photo 1** shows the completed interdigital filter. The exter-

*1 Photolithography: A process in which a fine structure is transcribed onto substrate using light whose wavelength is equal to or shorter than that of ultraviolet rays.

*2 Ion-milling: A processing method in which substrate surface material is removed by ions, generated from gas, accelerated with a strong electric field.

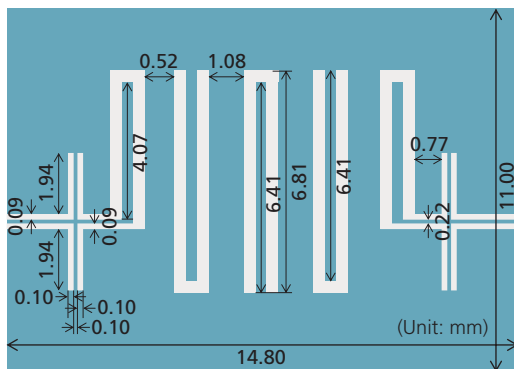


Figure 1 Filter structure and major dimensions

Table 2 Filter characteristics design results

	Equivalent circuit	Calculated value (electromagnetic field simulator)
Attenuation outside passband (dB/10 MHz)	Lower side	2.83
	Higher side	4.68
3-dB bandwidth		
Center frequency (GHz)	5.004	4.996
Bandwidth (MHz)	207	204

Table 3 Filter fabrication processes

No.	Process	
(1)	Photoresist coating	Formation of circuit patterns
(2)	Exposure (transfer circuit patterns)	
(3)	Development	
(4)	Ion-milling	
(5)	Cleaning (peeling off photoresist)	
(6)	Photoresist coating	Formation of electrode pad
(7)	Exposure (transfer circuit patterns)	
(8)	Development	
(9)	Evaporation of electrode materials	
(10)	Lift-off	
(11)	Dicing	

Lift-off: To peel metal off from areas where photoresist remains by soaking the object in organic solvent.

nal dimensions of the filter are made slightly larger than the space in the waveguide cavity, so that they may be installed more easily in a metal case: 11.6 mm width and 15.4 mm length. The dimensional deviation of the fabricated filter structure from the design dimensions was within 2 μm, which demonstrates that the filter structure developed in this study was fabricated with sufficient processing accuracy.

3. Filter Characteristics and Evaluation

3.1 Measurement Environment

Figure 2 shows a cross-sectional structure of the case used in the filter frequency characteristics measurement. The 0.5 mm thick MgO substrate was placed such that there is 4.5 mm and 3.0 mm of space above and below the substrate, respectively. The case was made from oxygen-free copper and its entire surface was coated with gold. A coplanar microwave probe was used for measurement. The measurements were made upon calibrating at the probe edge and placing the probe directly in contact with the metal pad areas on both edges of the filter.

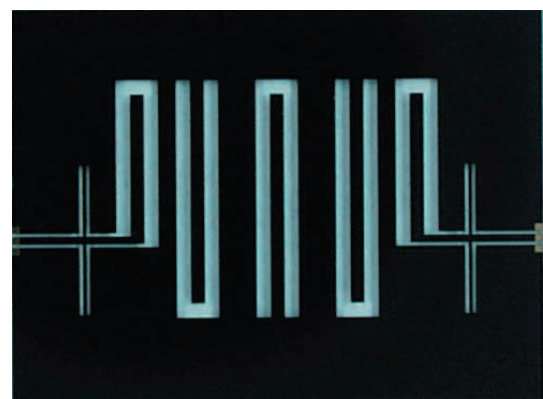


Photo 1 Interdigital-type filter

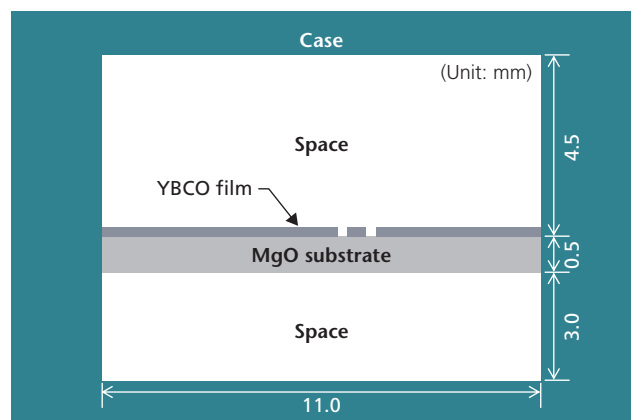
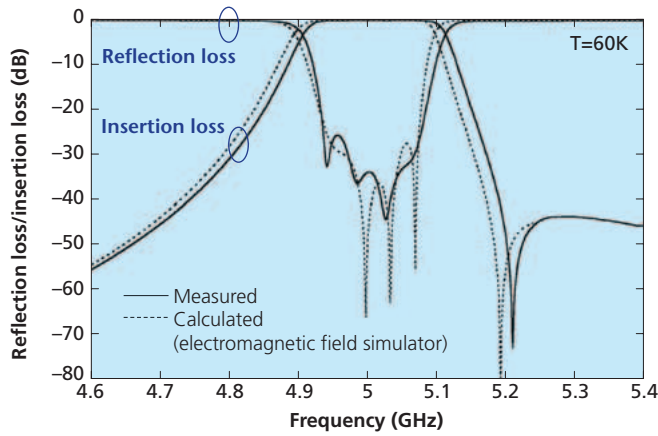
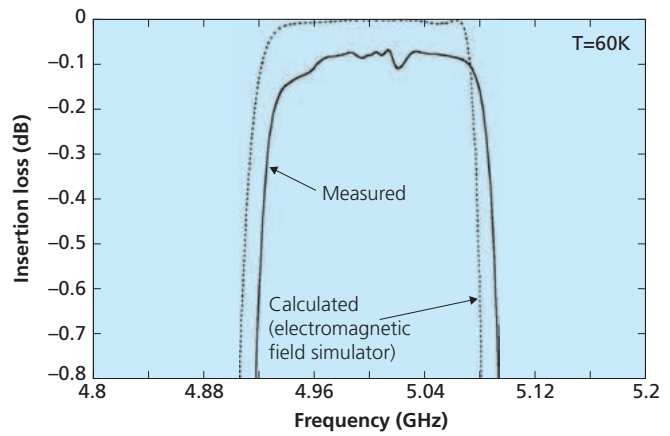


Figure 2 Cross-sectional structure of case used in filter measurement



(a) Characteristics in the vicinity of the passband



(b) Characteristics of insertion loss within passband

Figure 3 Frequency characteristics of filters at temperature of 60K

3.2 Evaluation of Frequency Characteristics

Figure 3 (a) and (b) show the measured frequency characteristics of the fabricated filter at a temperature of 60K, along with the values calculated using the electromagnetic field simulator. Table 4 compares the main characteristics numerically. The electromagnetic field simulator indicated a bandwidth of 204 MHz and a center frequency of 4.996 GHz for the 3-dB band, and the attenuation outside the passband on the low and high frequency sides were calculated to 2.83 dB and 4.68 dB, respectively. For comparison, the measured bandwidth and center frequency were 205 MHz and 5.010 GHz for the 3 dB band, respectively, while the measured attenuation outside the passband on the low and high frequency sides were 2.90 dB and 4.29 dB, respectively; as can be seen, results that agree well with the calculated values could be obtained without any tuning. Since the conductor comprising transmission lines of the filter is assumed to be lossless in the simulation, it is not appropriate to compare the calculated and measured insertion loss directly. Looking only at the measurement data, however, it was found that the average insertion loss in the band was 0.10 dB, a very low loss. Moreover, when estimating the unloaded Q-factor^{*3} of the individual resonators composing the filter based on the minimum insertion loss of 0.08 dB, high values of over 10,000 were obtained.

Figure 4 shows measurements of the spurious characteristics of the filter, along with the values calculated using the electromagnetic simulator. The measured and calculated values agree well across the entire frequency spectrum measured; the validity of the filter structure and design scheme was thus con-

Table 4 Various characteristics of filters at temperature of 60K

	Calculated (electromagnetic field simulator)	Measured
3-dB bandwidth		
Center frequency (GHz)	4.996	5.010
Bandwidth (MHz)	204	205
Insertion loss (dB)		
Minimum value	—	0.08
Average within passband	—	0.10
Attenuation outside pass-band (dB/10 MHz)		
Lower side	2.83	2.90
Higher side	4.68	4.29

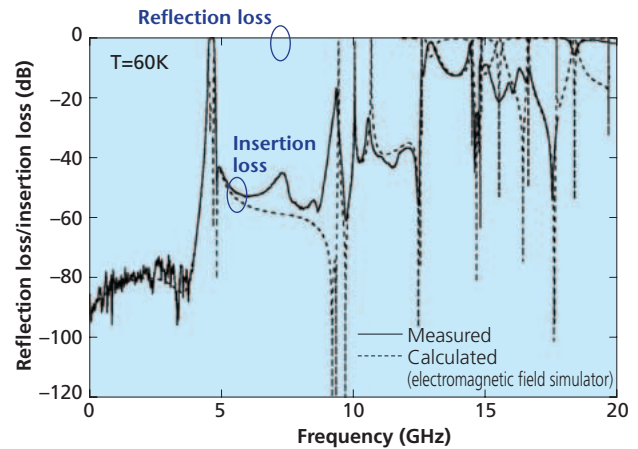


Figure 4 Spurious characteristics of filters

firmed. However, undesirable resonances were observed around 10 GHz in the measured and calculated data. This seems to be caused by the half-wavelength resonance of the short-circuited stubs comprising the conductor between adjacent two resonators in Fig. 1. Several resonances were also observed in the frequency band above 13 GHz. These are considered to be caused by the resonant mode of the rectangular waveguide cavity, in other words, the metal case shown in Fig. 2.

*3 Unloaded Q-factor: A characteristic value for power loss inside a resonator. When this value is high, filters with low insertion loss and high frequency selectivity characteristics can be configured.

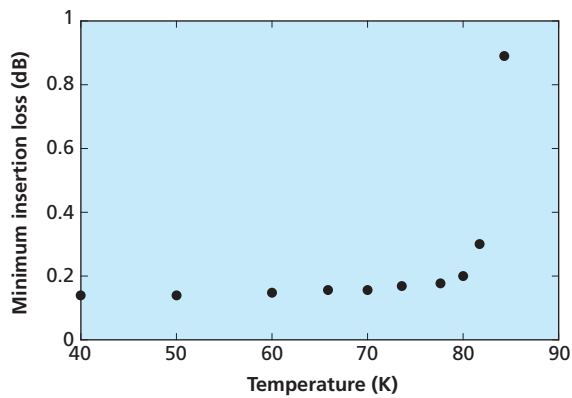


Figure 5 Minimum insertion loss of filters versus temperature

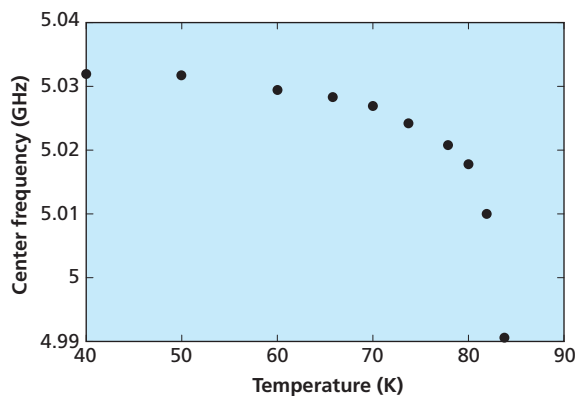


Figure 6 Center frequency of filters versus temperature

3.3 Evaluation of Dependency on Temperature

This section presents the results of evaluating the dependency of the filter insertion loss and center frequency on temperature. It should be noted that we fabricated several filters in this research, and the filter used in this section is different from the one used in previous sections. **Figure 5** shows the results of evaluating the relationship between the minimum insertion loss of the filter and temperature. From Fig. 5, it can be seen that the filter's insertion loss increases as the temperature of the filter increases. This is considered to be caused by increased surface resistance in the high-temperature superconducting film. **Figure 6** shows the evaluation results of relationship between the center frequency of the filter and temperature. From Fig. 6, it can be seen that the center frequency of the filter gradually shifts toward lower frequencies as the temperature of the filter increases. This is considered to be caused by the temperature dependency of both the kinetic inductance^{*4} of the high-temperature superconducting film and the dielectric constant of the dielectric substrate (MgO).

*4 Kinetic inductance: One of the superconducting inductances and a parameter generated by kinetic energy of superconductive carriers.

4. Conclusion

This article presented the results of examination and experimental validation of a configuration method for miniaturized circuits for CPW high-temperature superconducting bandpass filters, which can be used to construct highly efficient receivers for mobile communication base stations. Specifically, we focused on a design scheme for achieving multi-pole filters that do not require a drastic increase in the substrate area by assigning quarter-wavelength CPW resonators in parallel as well as in interdigital patterns, and then fabricated filters in order to experimentally validate the design scheme. We confirmed that the measured and calculated data showed good agreement in the vicinity of the passband as well as in terms of the spurious characteristics. These experimental results confirmed the validity of the interdigital type filter structure as well as the design scheme using a simulation via equivalent circuits and an electromagnetic simulator. Since this filter structure causes little increase in the substrate area, it is highly suited for compact bandpass filters with sharp cut-off characteristics outside the band.

REFERENCES

- [1] A. I. Braginski: "Superconducting Electronics Coming to Market," IEEE Trans. Appl. Supercond. Vol. 9, No. 2, pp. 2825–2836, Jun. 1999.
- [2] T. Nojima, S. Narahashi, T. Mimura, K. Satoh and Y. Suzuki: "2-GHz band cryogenic receiver front end for mobile communication base station systems," IEICE Trans. Commun., Vol. E83-B, No. 8, pp. 1834–1843, Aug. 2000.
- [3] D. Koizumi, K. Satoh and S. Narahashi: "A 5-GHz Band Coplanar-waveguide High Temperature Superconducting Filter Employing T-shaped Input/Output Coupling Structure and Quarter-wavelength Resonator," Technical Report of IEICE, MW2004-25, pp. 55–60, Mar. 2004.
- [4] T. Kawaguchi, Z. Ma, Y. Kobayashi, D. Koizumi, K. Satoh and S. Narahashi: "A 5GHz Interdigital Bandpass Filter using CPW Quarter-wavelength Resonators," IEICE Technical Report, SCE2005-2, MW2005-2, Apr. 2005.
- [5] D. Koizumi, K. Satoh, S. Narahashi, T. Kawaguchi, Z. Ma and Y. Kobayashi: "Experimental Investigation on a 5-GHz Band Interdigital Bandpass Filter using CPW Quarter-wavelength Resonators," IEICE Technical Report, SCE2005-3, MW2005-3, Apr. 2005.
- [6] K. Kawai, K. Satoh, S. Narahashi, H. Suzuki, Z. Ma and Y. Kobayashi: "Characteristics of a 5-GHz Band Coplanar Superconducting Filter," Technical Report of IEICE, SCE2002-8, MW2002-8, Apr. 2002.

ABBREVIATIONS

CPW: CoPlanar Waveguide