Design of miniaturized narrow band filter to consider with cross-coupling effect

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***Abstract*— We have developed a high-temperature superconducting (HTS) receiving filter with narrow bandwidth characteristic for 2 GHz band mobile communication systems. To reduce the filter size and controlled unintended cross coupling, we proposed a stepped impedance resonator (SIR) and separation filter package. This resonator is possible to control the amount of electric coupling and magnetic coupling by changing the length or width the resonator structure. Therefore, the gap between the adjacent resonators can be achieved more compact size. The developed narrow band HTS filter with a fractional bandwidth of 0.25% has 10-pole quasi-elliptic function response for sharp skirt characteristic. This filter separated two packages to reduce unintended cross coupling, and mounted in the front end systems combining this filter together with low-noise amplifier. The measured frequency response agrees reasonably with the desired specifications.**

I. Introduction

Various mobile communication systems have been rapidly adopted in recent years for diverse applications. As a consequence, full and effective use of frequency resources is strongly demanded than ever had been. One prospective approach to address this challenge is to employ low-loss and high-selective filters developed by using HTS. HTS devices have been extensively studied for use in microwave applications because of their low loss characteristics. The surface resistance of HTS is two or more orders of magnitude smaller than that of copper even at 2 GHz band [1]. In particular, these devices expect to be applied as the receiving filters of mobile-telecommunication base stations [2]. A high-sensitivity receiver can be realized using a superconducting filter, which has low insertion loss and a narrow-band characteristic [3-5].

In this paper, we developed a narrow bandwidth HTS receiving filter for mobile-telecommunication base stations. The filter has SIR [6] to reduce size of resonator and controlled amount of coupling coefficient between resonators. The developed narrow band HTS filter with a fractional bandwidth of 0.25% has 10-pole quasi-elliptic function response for sharp skirt characteristic. This filter separated two packages to reduce unintended cross coupling, and mounted in the front end systems combining this filter together with low-noise amplifier.

II. Design of Resonator

Fig. 1 shows a comparison of the configuration and dimensions of a microstrip half-wavelength resonator in a hairpin [7] and that of a proposed C-L-C stepped impedance resonator (SIR) at 2 GHz band. The SIR resonator each contains two patch capacitors connected by a meander-line inductor in a microstrip structure. It is found that the total area of the SIR is reduced to about three-quarter as that of the hairpin resonator, and the width of the SIR is reduced to about one-third of the length of the hairpin resonator. Fig. 2 shows current distribution and equivalent circuit of the SIR. In fig. 2 (a), W_C indicates the width of patch capacitor and W_L indicates the length of meander-line inductor, and the shade of the color indicates current distribution; green indicates high-density, blue indicates low-density. Therefore, the equivalent circuit consist of two shunt capacitors and parallel inductor and capacitor.

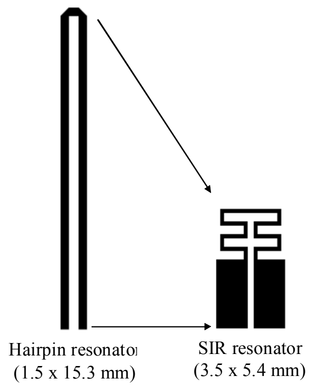
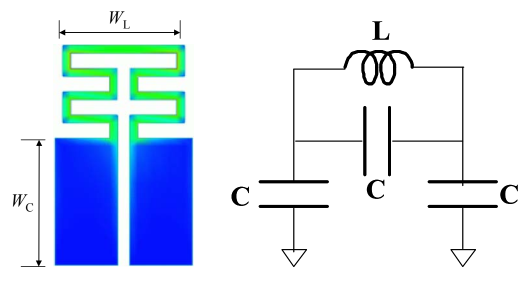


Fig. 1 Structure of 2GHz band hairpin resonator and proposed SIR.



(a) Current distribution (b) Equivalent circuit

Fig. 2 Current distribution and equivalent circuit of proposed SIR.

III. COUPLING COEFFICIENT BETWEEN RESONATORS

A coupling coefficient between two resonators is one of important parameters for design of bandpass filter (BPF), because the coupling values affect the bandwidth of the filter directly. The narrow band filter demanded of weak coupling coefficient. These couplings have been classified into three types, electric coupling k_e, magnetic coupling k_m and mixed electromagnetic coupling [8] as shown fig. 3. Generally, many coupled resonator structures are electromagnetic coupling, both electric and magnetic coupling exist. The electromagnetic coupling k is expressed as

$$|k|=|k_e-k_m| \quad (1)$$

which means k is expressed as the subtraction of k_e and k_m.

To control the behaviour of the electromagnetic coupling, we used a SIR coupling structures. Fig. 4 shows a coupling structure of C type microstrip resonators with large patch capacitors and short meander-line inductor. This coupling model is dominant electric coupling k_e. The adjacent patch capacitor is strongly coupled each other. Therefore, the calculated coupling coefficient k as a function of gap g is shown fig. 5. Fig. 6 shows a coupling structure of L type microstrip resonators with small patch capacitors and long meander-line inductor. Fig. 7 shows calculated coupling coefficient k as a function of gap g. As a results, it would seem that the electric coupling is dominant for g<1.15mm, whereas the magnetic coupling becomes dominant for g>1.15mm. As shown above, the SIR is possible to control the amount of electric coupling and magnetic coupling by changing the length of meander-line or width of patch size. To cancel the k_e and k_m each other, we achieve a weak coupling value around gap of 1.15mm. Therefore, the gap between the adjacent resonators can be achieved more compact size.

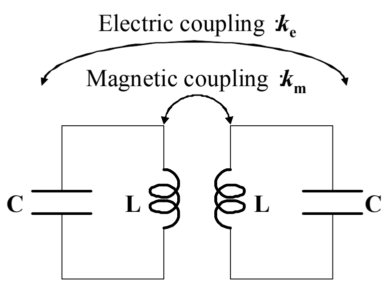


Fig.3 Equivalent circuit of electromagnetic coupled resonators

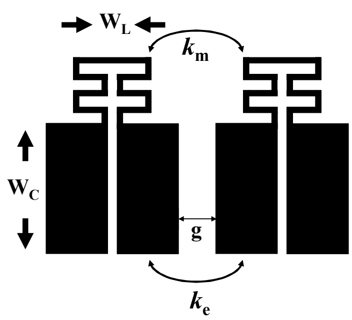


Fig. 4 Coupling structure of C-type microstrip resonators with large patch capacitors.

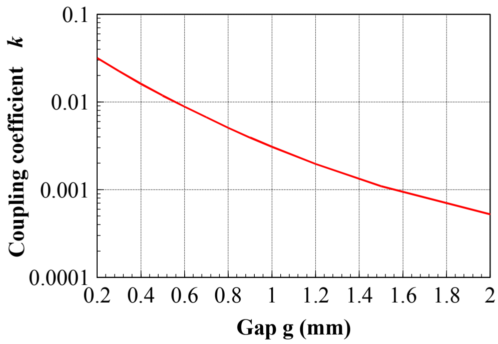


Fig. 5 Simulated coupling coefficient k between C type resonators as a function of gap g.

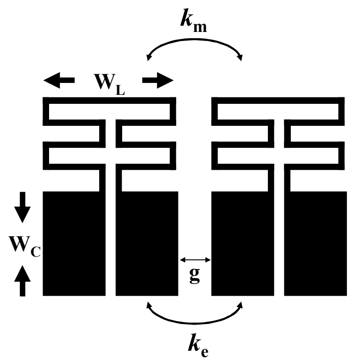


Fig. 6 Coupling structure of L type microstrip resonators with long meander-line inductor.

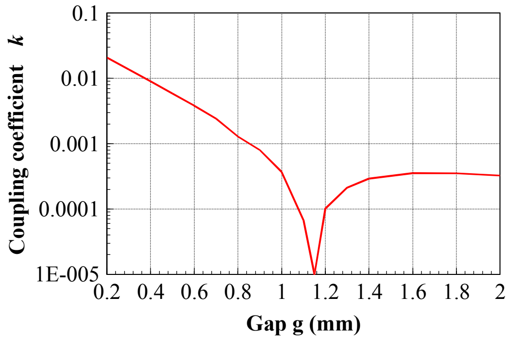


Fig. 7 Simulated coupling coefficient k between L type resonators as a function of gap g.

IV. FILTER DESIGN

In order to realize the sharp cut-off and small size filter, we use L type resonator to get weak coupling values compared with C type resonator. The 10-pole quasi-elliptic function structure shown in Fig. 8 was adopted. Numbered circles indicate the resonators. Solid lines indicate the external-Q Q_e and the coupling factor k_{mn} between of resonator m and n. Quasi-elliptic function is realized by coupling between the 2nd resonator and the 5th resonator and between the 6th resonator and the 9th resonator [9]. k_{25} and k_{69} couplings for the quasi-elliptic function filter are added in the design theory of the Chebyshev filter [10]. These couplings produce two transmission zeros at both sides of the desired frequency band. Therefore the Quasi-elliptic function filter is able to realize the sharp-cut around filter pass-band compared with Chebyshev filter. Fig. 9 shows a calculated ideal transfer function response of the 10-pole quasi-elliptic filter with high unloaded Q (Qu) resonator of 60000 by means of a circuit simulation. In this figure, green line indicates spectrum mask. The receiving filter is demanded high-selectivity at center frequency in order to reduce interference between adjacent channels. The specification of this receiving filter, the center frequency is 2.14 GHz. The bandwidth of this filter is 4.2 MHz and the fractional bandwidth is 0.25%. The insertion loss is less than 1.0dB at centre frequency (f_0) and 60dB attenuation bandwidth is less than 5.0 MHz.

In fig. 10, frequency response of the 10-pole quasi-elliptic function filter calculated by the momentum method (solid red line) is shown and compared with an ideal transfer function model (dashed line). From the solid lines, it is seen that the design specifications of the filter are satisfied at in band, but the lower side of the passband is not satisfied spectrum mask caused by unintended cross-couplings among the resonators. To check the amount of unintended cross-coupling values, fig.11 shows simulated coupling coefficient k as a function of gap g. In fig.11, we get the unintended cross-coupling coefficient value is about 1×10^{-6}.

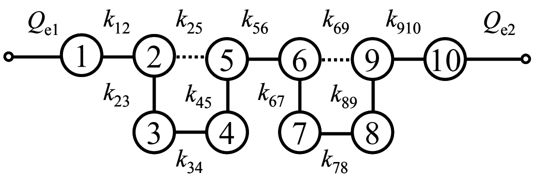


Fig.8 Coupling structure of 10-pole quasi-elliptic function filter.

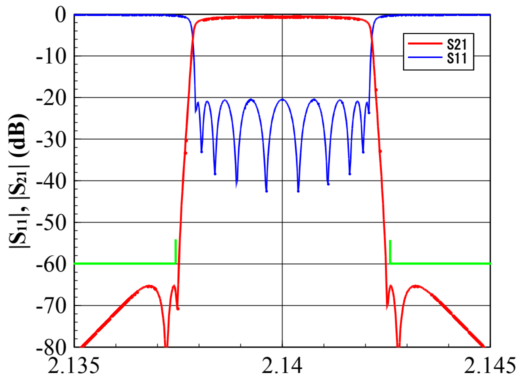


Fig. 9 Calculated transmission response of the 10-pole quasi-elliptic function filter by means of circuit simulation.

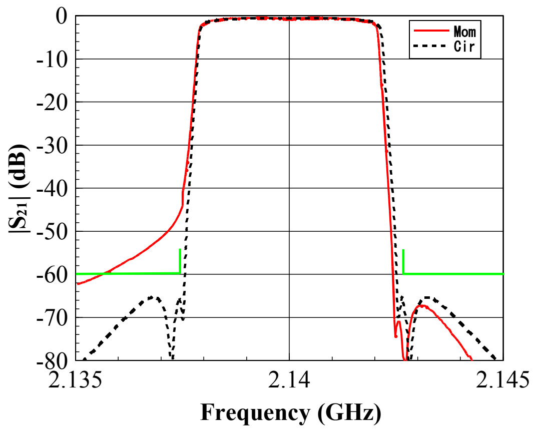


Fig. 10 Frequency response of filter calculated by the momentum method.

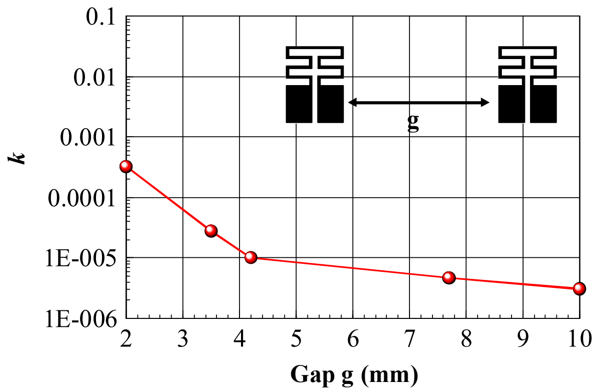


Fig. 11 Amount of unintended cross-coupling coefficient k between L type resonators.

Table 1 shows coupling matrix of the 10-pole quasi-elliptic function filter, and simulated the acceptable unintended cross-coupling value to satisfied spectrum mask. In table 1 and fig.11, the acceptable unintended cross-coupling value required less than 1×10^{-7} at k_{19}, k_{110} et al., but it is difficult of reduce unintended cross-coupling between non-adjacent resonators. Thus, we need another method to reduce the unintended cross-coupling. To achieve this demand, we use separation filter package. Fig. 12 shows the topology of separation packages of 10-pole filter. This package divides the 10-pole filter at the 5th and 6th resonator, to separate the unintended cross-coupling of k_{19} and k_{110}. Fig.13 shows simulated filter responses calculated by the momentum method with separation packages. The frequency response is symmetrical and improves the lower side response compared with fig.10. This response satisfied spectrum mask and agrees reasonably with the desired specifications.

Table 1 Coupling matrix of the 10-pole quasi-elliptic function filter and acceptable unintended cross coupling value.

	1	2	3	4	5	6	7	8	9	10
1		0.0016								
2	0.0016		0.0011		-0.0004					
3	1.E-05	0.0011		0.0014						
4	1.E-05	1.E-05	0.0014		0.0009					
5	1.E-05	-0.0004	1.E-05	0.0009		0.0010				
6	1.E-05	1.E-05	1.E-05	1.E-05	0.0010		0.0010		-0.0003	
7	1.E-06	1.E-06	1.E-06	1.E-06	1.E-05	0.0010		0.0013		
8	1.E-06	1.E-06	1.E-06	1.E-06	1.E-05	1.E-05	0.0013		0.0011	
9	1.E-07	1.E-07	1.E-07	1.E-06	1.E-06	-0.0003	1.E-05	0.0011		0.0016
10	1.E-07	1.E-07	1.E-07	1.E-07	1.E-06	1.E-05	1.E-05	1.E-05	0.0016	

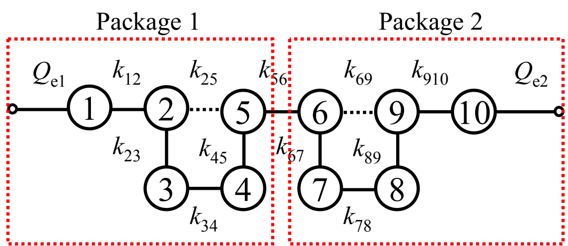


Fig.12 Topology of separation packages of 10-pole filter.

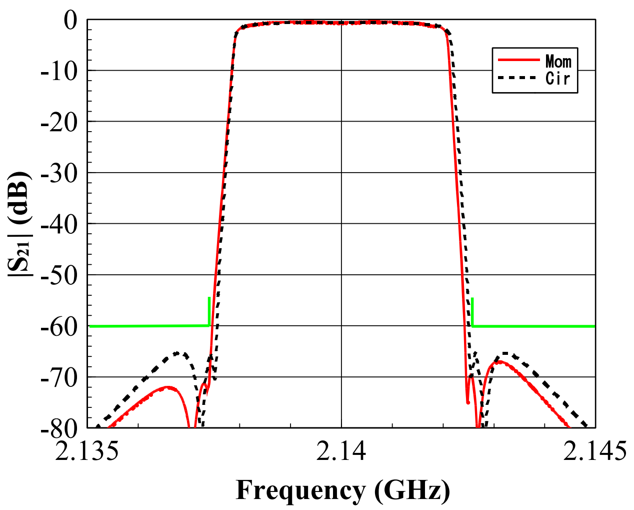


Fig. 13 Frequency response of this filter calculated by the momentum method with separation packages .

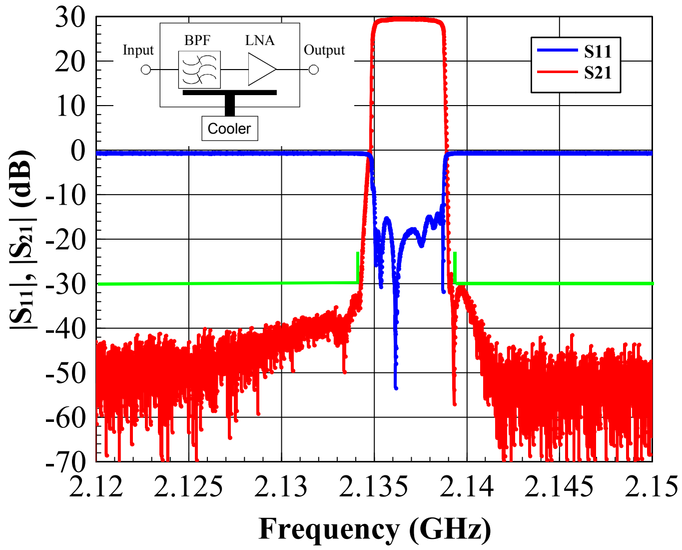


Fig. 14 Measured frequency response of cryogenic front-end systems at 60K.

V. MEASURED RESULTS

The 10-pole filter designed above is fabricated by using HTS YBCO thin films on a sapphire substrate with a photolithography and dry etching process. The 10-pole filter operated at 60K by using cryogenic cooler. The measurement frequency response of the filter is evaluated using a vector network analyzer.

Fig. 14 shows the measured frequency response of cryogenic front-end systems. This front-end system consists of BPF and low-noise amplifier (LNA). The LNA has been specially designed to work at low temperature with gain of 30dB. As a result, the filter response with center frequency of 2.137GHz, insertion loss is lower than 1dB. The Q_u of the SIR reaches a value of about 60,000. The 60dB attenuation bandwidth is 4.8MHz. Moreover, the transmission zeros were obtained on both sides of desirable band and the filter response is symmetrical. Although two transmission zeros at both sides of the transmission band are degenerating, the result is in good agreement with that of the circuit simulation and satisfied specifications. The measured center frequency of the filter is about 2.137GHz, 3MHz lower than the designed value. The reason is assumed that the actual dielectric constant of the sapphire substrate is a little bit larger than the given nominal value.

VI. CONCLUSION

A highly selective superconducting microstrip narrowband filter for mobile-telecommunication base stations has been designed, fabricated and measured. The proposed C-L-C stepped impedance resonator (SIR) can be controlled the coupling values to changing the length of L element meander-line or width of C elements patch size. To cancel the electric coupling and magnetic coupling each other, we achieve a weak coupling value. Therefore, the gap between the adjacent resonators can be achieved more compact. The developed narrow band HTS filter with a fractional bandwidth of 0.25% has 10-pole quasi-elliptic function response for sharp skirt characteristic. This filter separated two packages to reduce unintended cross coupling, and mounted in the front end systems combining this filter together with low-noise amplifier gain of 30dB. The measured frequency response agrees reasonably with the desired specifications and spectrum mask. By using this compact size filter design, the multi channels cryogenic front-end systems can be expected.

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