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High-temperature superconducting band -pass filters for digital cellular communication system

J. H. Lee [a], Y. H. Do [a], J. S. Kwak [a], C. O. Kim [a], J. P. Hong *,[a],
K. L. Lee [b], S. K. Han [b], K. Char [b]
[a] *Hanyang University, Seoul, Korea*
[b] *RFtron Inc, Seoul, Korea*

고온 초전도체를 이용한 이동통신 기지국용 영역통과 필터에 관한 연구

이종현[a], 도영호[a], 곽준식[a], 김채옥[a], 홍진표*,[a],
이경림[b], 한석길[b], 차국린[b]

Abstract

Extremely selective high temperature superconducting (HTS) band-pass filters were developed for the base transceiver station applications of Digital Cellular communication Service (DCS). The filters have a bandwidth of 25 MHz at a center frequency of 834 MHz. There are 12 resonators which have spiral-meander microstrip-line structures in order to reduce far-field radiations with a reasonable tunability. As a result, the size of filters is 5 mm × 17 mm × 41 mm. Device characteristics exhibited a low insertion loss of -0.4 dB with a -0.2 dB ripple and a return loss better than -10 dB in the pass-band at 65 K. The out-of-band signals were attenuated better than 60 dB about 3.5 MHz from the lower band edge, and 3.8 MHz from the higher band edge.

Keywords : Band-pass filter, HTS, RF, resonator, out-of-band

I. Introduction

These days, digital cellular communication system (DCS) demand extreme performance in sensitivity and selectivity in order to support mass-growth in multi-media services, expanding area of mobile telecommunication services, and larger numbers of subscribers. In general, conventional filters have lots of limitation for applying to the next generation communication systems. To solve these problems, the smallest insertion loss is required that can reduce the signal to noise (S/N) ratio and increase selectivity [1]. Therefore, many researchers and groups have been engaging in studies on the development of high T_C superconducting (HTS) filters with narrow bandwidths and sharp skirts in order to make much more attractive microwave devices [2]-[10]. Among great merits of the HTS filters is high selectivity in a base transceiver system or communication systems

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*Corresponding author. Fax : +82 2 2296 3738
e-mail : jphong@hanyang.kr

with effective exclusion of interfering signals in an available RF frequency spectrum.

In this paper, extremely selective band-pass filters with HTS $YBa_2Cu_3O_{7-\delta}$(YBCO) on $LaAlO_3$ substrate are mentioned. The aim of this work is to realize a highly selective HTS filter with very low pass-band loss at a central frequency of 834 MHz. The filter consists of 12 half-wavelength resonators of spiral type meander line structures. Frequency responses of real filters are compared with those of simulated filters using a full wave electromagnetic (EM) simulator "IE3D^{EM}" so as to investigate the experimental properties of HTS filters.

II. HTS filter design

The HTS band-pass filters with high selectivity are designed for half-wavelength meander line resonators having the multiple coupled microstrip line structures. Specific layouts and characteristics of a half-wavelength resonator used in a filter are shown in Fig. 1, The resonator was initially designed to have the center resonant frequency at 834 MHz. As shown in Fig. 1, the whole resonator structure represents a large coupling patch and inductively spiral meander line. With the EM simulator, the former is kept to have low internal impedance for reduction of peak currents at coupling edges as possible and the latter is determined and optimized in order to make the resonators compact and minimize far-field radiation. In addition, the whole characteristic impedance of the resonator is set to 50Ω and it is matched to 50 Ω input and output feed lines for electrical contact to the SMA. Therefore, the resonator has a compact size such of 2.15 mm × 10.9 mm.

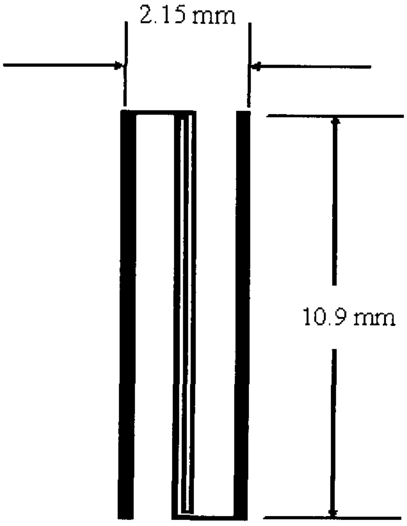


Fig. 1. Layout and dimension of the HTS microstrip resonator using a spiral meander line structure.

In order to meet the requirements of filter specification, firstly, the coupling coefficients K of a pair of resonators are calculated as a function of spacing width between two resonators with the EM simulator. The method how to calculate is to make two peaks which are tuned by the EM simulator have equal insertion loss value, and the valley between two peaks is set to be under -10 dB at least.

The coupling coefficient K of a pair of resonators is determined as

$$K = \frac{2|f_2 - f_1|}{f_2 + f_1} \tag{1}$$

where f_1 and f_2 are two resonant frequencies [12].

Fig. 2 plots coupling coefficients K_s of a pair of resonators with various coupling gap spacing as a summary. The simulated curve indicates comparable coupling strength that we have calculated using normalized low-pass prototype values. This curve allows the filter response in our experiment to be realized. Therefore, in all of the measurement, much

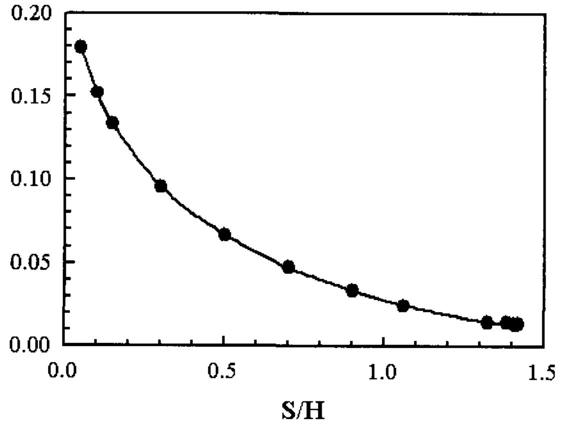


Fig. 2. Simulated coupling coefficients of a pair of resonators versus ratio of a substrate thickness and coupling gap spacing.

attention is paid to the K values with high accuracy since use of many standard K_s with different dimensions would result in more accurate curve and thus more accurate fitting would be possible. With the aid of these coupling coefficients, Ks, the HTS filter is designed to have a bandwidth of 25 MHz at a center frequency of 834 MHz for the DCS on the receiver side in base transceiver system.

Fig. 3 (a) presents the filter layout that consists of twelve poles meander line resonators discussed as above. The physical size of the filter in ladder form is only 17 mm × 41 mm, which can provide at least two filters in a 2 inch wafer. For the best filter simulation, the phenomenological model of HTS thin film is at first used as a simulation factor of full wave EM simulation [14] and then the optimization procedure is applied to improve the performance of the filter with the benefits of the fitting curve presented in Fig. 2.

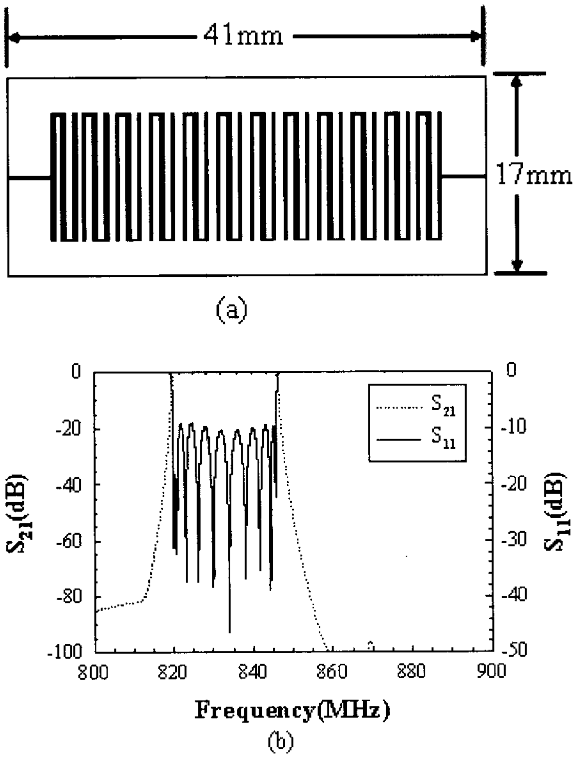


Fig. 3. (a) Layout and dimension of the 12-pole highly selective band-pass filter. The size of filter was 17 mm × 41 mm. (b) Simulated frequency response of the 12-pole HTS band-pass filter using full-wave EM simulator.

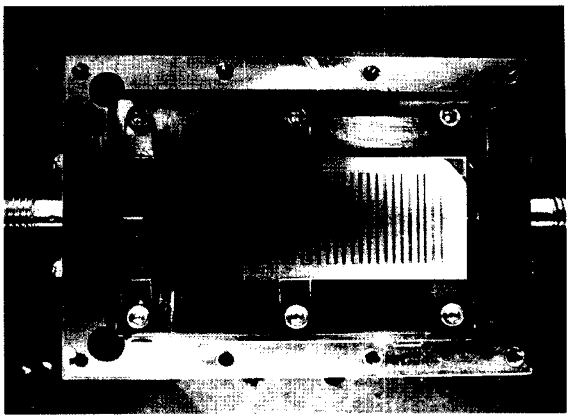


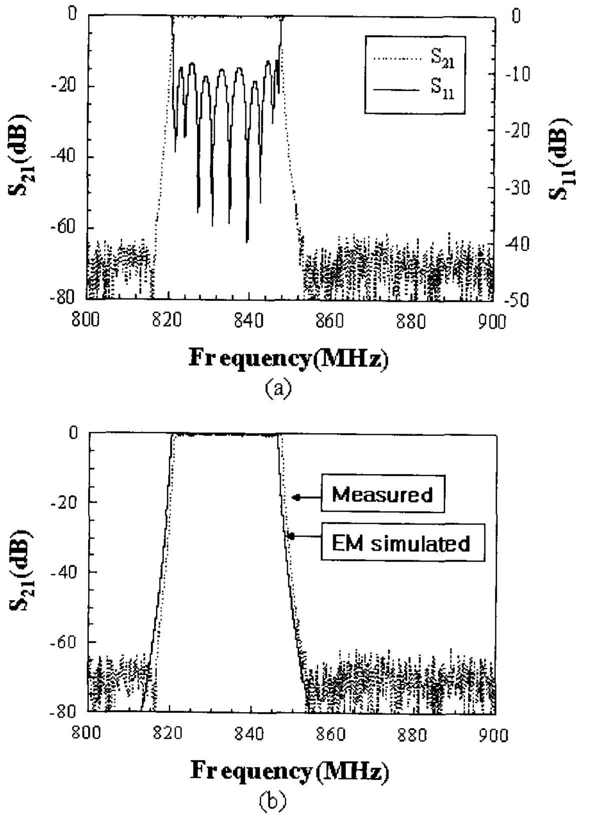
Fig. 4. Photograph of the RF-packaged 12-pole HTS filter.

As showed in Fig. 3 (b), EM simulation data of the filter have a less than -0.1 dB insertion loss and 25 MHz bandwidth at a resonant frequency of 834 MHz. In addition, frequency response of the filter exhibits asymmetrical quasi-elliptic characteristics. The asymmetrical frequency response might be caused by unwanted coupling effects between each resonator or any complex behavior of EM waves in a microstrip line structure. In the simulation, the $LaAlO_3$ substrate is approximated to have a low dielectric loss ($\tan\delta = 1\times10^{-4}$) and a relative dielectric constant of 23.5 at microwave frequency ranges. Fig. 4 shows real photograph of the packaged 12-pole HTS filter.

III. Fabrication and measurements

The HTS filter is fabricated using a double-sided YBCO thin film of a thickness of 600 nm. The diameter of $LaAlO_3$ substrate is 2 inch and the thickness of it is 0.5 mm. The film used in this experiment have the zero resistance at 88.6 K. The filter is mounted in the aluminum test package. All the packages are directly mounted to the cold stage of a closed-cycle cryogenic system for the filter measurement at 65 K. Transmission and reflection parameters of the filter are measured using a HP8510C vector network analyzer with an input power of +10 dBm. The calibrations are performed at room temperature before measurements in the frequency range from 800 MHz to 900 MHz. Fig. 5 (a) shows measured transmission and reflection coefficients of the filter. Although it is highly compact in size, the 12-pole filter presents a very promising performance without any tuning treatment or tuner at 65 K.

The filter exhibits low insertion losses of -0.4 dB and return losses of better than -10 dB in the pass-band, with out-of-band rejection losses of about −70 dB. The out-of-band signals are attenuated better than -60 dB about 3.5 MHz from the lower band edge, and 3.8MHz from the higher band edge without any artificial transmission zeros. In addition, it has small pass-band ripple of about -0.2 dB. The filter also indicates slightly asymmetric frequency responses in two ports, as expected by the simulation. However, it is not certain what the asymmetry in reflection loss response come from at this moment.



(a)

(b)

Fig. 5. (a) Frequency response of the 12-pole filter fabricated by a 600nm thick double-sided YBCO film on a $LaAlO_3$ substrate. The filter was measured using HP8510C with input power of +10 dBm at 65 K. (b) Comparison in transmission coefficients of the HTS filter experimentally measured and simulated by using the EM simulator.

For comparison, experimental and simulated results of the 12-pole filter are shown in Fig. 5 (b). As shown in this figure, the center frequency in the filter performance is slightly shifted down about 1 MHz. The discrepancy in the center frequency is mainly due to non-uniformity in substrate thickness and variation in film thickness [4]. In addition, over etching of the filter pattern during the fabrication process mainly allows the decrease in bandwidth when the pattern is checked. Therefore, since a tolerance in fabrication process can have a considerable impact on the filter performance, resulting in a slightly different coupling effect between coupled resonators, the tuning process is currently under progress. However, up to now, although any tuning procedure is not done, the whole frequency response of the filter do verify the simulated results very well.

IV. Conclusions

Extremely selective HTS band-pass filters, incorporating 12-pole spiral meander line structures were developed for the application of DCS base transceiver systems. Although small size of 0.5 mm × 17mm × 41mm, the filter exhibited very low insertion losses of -0.4 dB and return loss better than -10 dB at a center frequency of 834 MHz. The out-of-band signals were attenuated better than -60 dB about 3.5 MHz from the lower band edge, and 3.8 MHz from the higher band edge at 65 K.

Acknowledgments

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