HTS Filter with Dielectric Rods for Tuning the Center Frequency and Trimming the Passband ripple

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Abstract. Tuneable filters are one of the most essential microwave components for multiband communication systems due to their attractive features. In this study, we developed high-temperature superconducting (HTS) tuneable microstrip line hair-pin resonator filter with dielectric rods for tuning the center frequency and trimming the passband ripple simultaneously. Several dielectric rods are placed above the HTS filter, and the center frequency and passband ripple are controlled by changing the distance between the dielectric rods and the resonators. Two dielectric rods are used for each resonator; one is located on the center of the resonator for tuning the center frequency and trimming the pass-band ripple, and the other is located on the open end of the resonator to tune the center frequency. The filter was designed to have a center frequency of 1.4 GHz and a bandwidth of 28 MHz by using an electromagnetic simulator based on the moment method. The HTS filter was fabricated using double-sided YBa₂Cu₃O₇ thin film on a 30×40×0.5 mm Al₂O₃ substrate. The dielectric rods with a dielectric constant of 39 were used. As a result, the tuning range of the filter was about 140 MHz while keeping the all most the same insertion loss with trimming. The measurement data after trimming and tuning have a good agreement with the design specifications.

1. Introduction
In the future, microwave tuneable filters will be useful for wireless communication systems. Also, High temperature superconducting (HTS) filters which have low insertion loss and sharp skirt rejection are great importance for variety of application. For wireless communication systems, HTS tuneable filters need wide-range tunability of the passband with remaining passband ripple. There are several reports on the center frequency tuneable HTS filters and trimming method for improving passband ripple of HTS filters [1]. H. Peng et al. reported the trimming method which improves the passband ripple by adjusting the resonant frequency using dielectric and metallic screws [1]. In addition, Ohshima et al. had developed a high-speed tuning system for HTS microstrip line filters using a dielectric plate for tuning the center frequency, dielectric rods for trimming the passband ripple, and conducting rods for improving the bandwidth [3]. However, the tuning system have to change three parameters such as distance between filter and the dielectric plate, the dielectric rods and the conducting rods for tuning and trimming. Thus, this mechanism is complex to tune the center frequency, trim the pass-band ripple and trim the bandwidth.

In this work, we develop a simple mechanical center frequency tuneable HTS filter. We used dielectric rods for tuning the center frequency and trimming the pass-band ripple simultaneously. To obtain large tuning range of center frequency, two dielectric rods with high dielectric constant is used for each resonator.
2. Center frequency tuning method and pass-band trimming method

We designed a 4 pole Chebyshev-type microstrip bandpass filter. The filter was constructed with stepped impedance hair-pin resonators. The center frequency $f_c$ is set to 1.4 GHz and the bandwidth is set to 28 MHz (fractional bandwidth: 2.0%). The required coupling coefficients ($k_{ij}$) and external quality factors ($Q_e$) of the passband are $k_{12} = k_{34} = 0.019$, $k_{23} = 0.014$ and $Q_e = 43.4$. The coupling coefficients and external quality factors were calculated using design formulas reported elsewhere [8]. The filter was designed using a Sonnet EM electromagnetic simulator and a MW-STUDIO 3-dimensional simulator.

2.1. Tuning of the resonant frequency

Dielectric rods can change the resonant frequency by changing the shunt capacitance to the ground [1]. To have a great influence on the resonant frequency, the rods are placed above the resonator where the electric field is concentrated. Figure 1 shows the layout of the resonator with dielectric rods. As shown in Figure 1(b), the rods were placed above the center of the resonator (Rod A) and the edge of the resonator (Rod B). We used the Rod A with a diameter of 2.35 mm and the Rod B with a diameter of 4.0 mm. Using Dielectric rod which has low dielectric loss (tanδ = 0.00005) and a high dielectric constant ($\varepsilon_r = 39$) enable to be low loss and a wide frequency tuning range. We used two rods for the resonator to increase the tuning range.

Figure 2(a) and (b) show the simulated tuneable resonant frequencies using the Rod A and Rod B independently when distances $h_A$ and $h_B$ shown in Fig. 1(c) were changed. As shown in Fig. 2(a), when the Rod A was used, the frequency tuning range was 54.0 MHz. As shown in Fig. 2(b), when the Rod B was used, the frequency tuning range was 79.0 MHz. The frequency tuning range using Rod B is larger than one using Rod A. This is because the large electric field is concentrated at the open-end of the resonator. To achieve a large frequency tuning range, we used the Rod A and Rod B at the same time. Figure 3 shows the simulated tuneable resonant frequencies using the Rod A and Rod B at the same time. The obtained frequency tuning range is 123 MHz.

![Image](image_url)

**Figure 1.** Layout of the resonator with the dielectric rods. (a) resonator only (b) surface (c) side
The filter combines stepped impedance hair-pin resonators and waveguides to adjust coupling coefficient. We previously reported that an additional waveguide placed between the comb-line coupled resonators is an effective way to adjust the total coupling coefficient [9]. Figure 4(b) shows the position of the dielectric rods which were placed above the filter. Figure 5(a) and Figure 5(b) shows simulated frequency responses of the filter before and after trimming. To trim the passband ripple, the heights of the Rod A and A (as shown in Figure 4(b)) were changed. It was shown the passband ripple was improved dramatically from 0.048 to 0.023 dB. Figure 5(c) shows simulated frequency responses of the filter before and after tuning center frequency and trimming passband ripple. We adjusted the height of the Rod A for both trimming passband ripple and tuning center frequency and Rod B for tuning center frequency. The maximum tuning range of the filter was approximately 145 MHz (11.0%) from 1.389 to 1.244 GHz remaining the passband ripple less than approximately 0.10 dB. Finally, based on the simulated frequency responses of the filter, we can use the dielectric rods for both tuning and trimming.

2.2. Simulated tuning of the center frequency and trimming of the pass-band ripple

Figure 4(a) shows the layout of the designed 4-pole bandpass filter. The filter combines stepped impedance hair-pin resonators and waveguides to adjust coupling coefficient. We previously reported that an additional waveguide placed between the comb-line coupled resonators is an effective way to adjust the total coupling coefficient [9]. Figure 4(b) shows the position of the dielectric rods which were placed above the filter. Figure 5(a) and Figure 5(b) shows simulated frequency responses of the filter before and after trimming. To trim the passband ripple, the heights of the Rod A and A (as shown in Figure 4(b)) were changed. It was shown the passband ripple was improved dramatically from 0.048 to 0.023 dB. Figure 5(c) shows simulated frequency responses of the filter before and after tuning center frequency and trimming passband ripple. We adjusted the height of the Rod A for both trimming passband ripple and tuning center frequency and Rod B for tuning center frequency. The maximum tuning range of the filter was approximately 145 MHz (11.0%) from 1.389 to 1.244 GHz remaining the passband ripple less than approximately 0.10 dB. Finally, based on the simulated frequency responses of the filter, we can use the dielectric rods for both tuning and trimming.
Figure 4. (a) Layout of 4-pole HTS bandpass filter. (b) Layout of 4-pole HTS bandpass filter with the rods.

Figure 5. Simulated frequency responses of the filter with the rods. (a) before and after trimming $S_{11}$ and $S_{21}$. (b) before and after trimming $S_{21}$ (c) After both tuning and trimming.
3. Measurement of the tunable HTS filter

As illustrated in Figure 4(a), the filter was fabricated $\text{Al}_2\text{O}_3$ substrate with double-side-deposited 300 nm YBCO thin film. The size of the substrate is $30 \times 40 \times 0.5$ mm and the relative dielectric constant is 9.9, respectively. The fabrication process is photolithography and ion beam etching. The filter was mounted on a metal carrier and packaged into a metal shield box, as shown in Figure 6(a). We placed the rods above the filter as shown in Figure 4(b). Figure 6(c) shows a schematic view of our tuning system. The gap $h_A$ between resonators and dielectric rods (SG390 from Kyocera) are adjusted by mechanical screws to tune the center frequency and trim the passband ripple. The gap $h_B$ between resonators and dielectric rods (SG390 from Kyocera) are adjusted by mechanical screws to tune the center frequency.

The fabricated HTS filter was cooled to 40 K by using a cryocooler. The measurements were carried out using a network analyser (E5071B from Agilent Technologies). Figure 6(b) shows the simulated and measured frequency responses of the filter. There was good agreement between them. Figure 7 shows the frequency responses of the filter before and after trimming passband ripple. It is found that the passband ripple was improved greatly after trimming by changing height of the Rod A$_2$ and A$_3$ (as shown in Figure 4(b)). The passband ripple was improved approximately 0.07 dB. Figure 8 shows the frequency responses of the filter before and after tuning center frequency. The maximum tuning range of the filter was approximately 140 MHz (10.57%) from 1.394 to 1.254 GHz remaining the passband ripple less than approximately 0.10 dB. The insertion loss of the passband varied from 0.08 to 0.205 dB. This very small insertion loss of the passband was due to the rods which have the small dielectric loss and the trimming the passband ripple. The 3 dB bandwidth of the filter varied from 41.1 to 25.3 MHz. This is because the coupling coefficients of the filter degreased by increasing the electric coupling of the resonator when the height between the rods and resonator was decreased. The measured center frequency, 3 dB bandwidth, insertion loss and return loss before and after tuning center frequency and trimming passband ripple are summarized in Table 1.

Figure 6. (a) Photograph of 4-pole bandpass filter mounted in Cu cavity. (b) Frequency response of designed and measured the filter. (c) Schematic side view of tuning system.
Table 1. Measured center frequency tuning and pass-band trimming results.

|                | Center frequency [GHz] | -3dB Band width [MHz] | Insertion loss [dB] | Return loss [dB] |
|----------------|------------------------|-----------------------|---------------------|------------------|
| Before         | 1.395                  | 41.2                  | -0.08               | -16.5            |
| Trimming       | 1.394                  | 41.1                  | -0.08               | -23.0            |
| Tuning A       | 1.367                  | 39.2                  | -0.11               | -18.9            |
| Tuning B       | 1.324                  | 32.7                  | -0.13               | -18.6            |
| Tuning C       | 1.289                  | 27.4                  | -0.20               | -18.1            |
| Tuning D       | 1.254                  | 25.3                  | -0.21               | -15.8            |

Figure 7. Measured frequency responses of the filter with the rods. (a) before and after trimming $S_{11}$ and $S_{21}$. (b) before and after trimming $S_{21}$

Figure 8. Measured tunability of 4-pole filter before and after tuning. (a) $S_{21}$ (b) $S_{11}$ and $S_{21}$
4. Conclusion
We developed a simple mechanical center frequency tuneable HTS filter. The rods are used for tuning the center frequency and trimming the passband ripple simultaneously. We designed and fabricated a 4 pole Chebyshev-type microstrip bandpass filter. From the measurement, by adjusting the gap between the resonator and the rods which were placed above the center of the resonator, the passband ripple was improved approximately 0.07 dB. The tuning range of the filter was 10.57% remaining the passband ripple less than approximately 0.10 dB by using the dielectric rods which were placed above and edge of the resonators. We obtained small variation of the insertion loss from 0.08 to 0.205 dB before and after tuning. The experimental results demonstrate the successful realization about center frequency tuning and passband ripple trimming by the dielectric rods.

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