Development of High-Speed Tuning System for HTS Filters

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***Abstract*— We developed a high-speed tuning system for HTS microstrip line (MSL) filters using a dielectric tuning plate, dielectric trimming rods, and conducting trimming rods. The tuning plate has windows through which the dielectric and conducting trimming rods pass. It was designed for a 3-pole filter with 5 GHz center frequency (f_c) and 100 MHz bandwidth (BW) using a 3-dimensional electromagnetic simulator. We simulated the shift of the f_c to frequencies below 500 MHz using the tuning plate with a dielectric constant of 45 and improving the insertion loss (IL), the pass-band ripple, and the BW of the filter responses by adjusting the positions of the ceramic and copper (Cu) trimming rods. In the experiment, the positions of the plate and the rods above the filter were adjusted by using high-resolution stepping motors, which function at room temperature. The minimum step of moving the plate and the rods was 0.001 mm. We found that the f_c was shifted to 500 MHz while retaining the IL, pass-band ripple, and BW by experimental evaluation. The time taken by the 500 MHz tuning was less than 1 second. These results indicate that our method and system will be useful for the next generation of wireless communication systems.**

***Index Terms*— high-speed tuning, HTS filter, trimming rods, tuning plate**

I. Introduction

HIGH-temperature superconductor (HTS) filters show low insertion loss and sharp skirt rejection. They are useful for mobile telecommunication systems [1-3]. Also, a microwave filter with a tunable pass-band would be of great use in a variety of applications. Moreover, HTS filters with wide-ranging frequency tunability could provide a solution for fabrication software-defined radio systems. To change the resonant frequency, one must vary either the capacitance or the inductance in a resonant line. Several approaches have recently been demonstrated in HTS systems, including the use of a ferroelectric materials to vary the capacitance [4-6], a magnetic field to vary the Josephson inductance in superconducting junctions [7-9], laser trimming [10], and also mechanical tuning of HTS filters by using a dielectric plate is well known [11-21], however, usually leads to degradation of the filter characteristics and difficulty in obtaining reproducible results at high speeds.

In this paper, we will focus on mechanical tuning method by using a high-speed automatic tunable system.

II. Experimental Setup

A. Design and Fabrication of the Filter

We chose to focus on a three-pole Chebyshev-type microstrip band-pass filter for ease of fabrication and modeling.
EM Sonnet Software was used to simulate frequency responses and distribution of the current density. We found that at the open part of the resonators corresponds to the strong level of the electrical field. Those parts are sensitive to be controlled by trimming screws. To obtain the good responses, controlling and regulating the distribution of the electromagnetic field is important. Because of the strong level of the electric field, dielectric trimming rods (DTR) were placed on the edge of the resonators, as shown in Fig. 1(a).

The filter was designed using a Sonnet EM electromagnetic simulator and a Microwave Studio (MWS) 3-dimensional

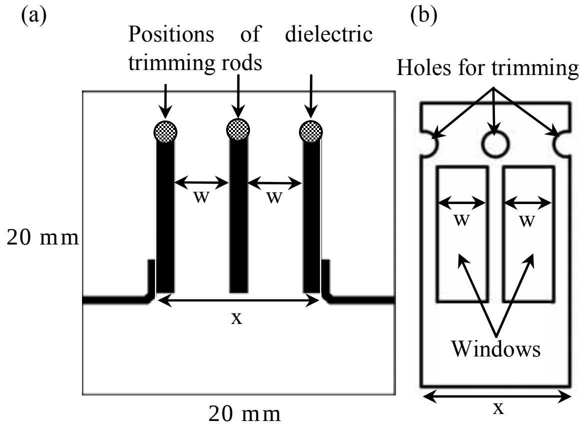

Fig. 1. (a) Layout of the 3-pole band-pass filter using half λ_g straight type resonators. (b) Schematic top view of optimal dielectric tuning plate.

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simulator was also used for checking the tunability of the filter. The center frequency of 5 GHz and the bandwidth of 100MHz were obtained from the simulation using Sonnet EM simulator. The filter was patterned from a single layer of YBCO film on a 20 × 20 mm^2 MgO substrate with a 30 Ω characteristic impedance with the input and output feed line impedances of 50 Ω. For the sake of simplicity, the ground plane consisted of a thin layer of Au on the reverse side of the substrate. Figure 1 (a) shows the layout of the 3-pole band-pass filter using half λ_g straight-type resonators. The dielectric tuning plate was designed for the 3-pole band-pass filter (Fig. 1 (b)). The width of the tuning plate (x) was the same as the distance between the edge of the 1st and the 3rd resonators to decrease the effect on the external quality factor (Q_e) of the filter. Two windows with a width of w were also made to decrease the effect upon the coupling coefficient of the filter. Additionally, three holes were made in the plate in order to place the DTRs on the upper edge of the respective resonator [19]. The dielectric constant (ε_r), and the thickness of the dielectric tuning plate were 45 and 1.7 mm, respectively. The ε_r, the diameter, and the height of the DTRs were 39, 1.6 mm, and 4 mm, respectively.

B. Tuning System

Measurements were taken using the acquisition tuning system depicted in Fig. 2 (a). The system consists of a moving module (six gear transform type step motors mounted on top of the chamber and six sensors for checking the position of the tuning screws. The resolution of each step motor is 1μm/1pulse), a chamber, a small pulse tube refrigerator with 2.5W@70K power and a control box for controls the movement of the step motors via a programmable OMRON CP1h board.

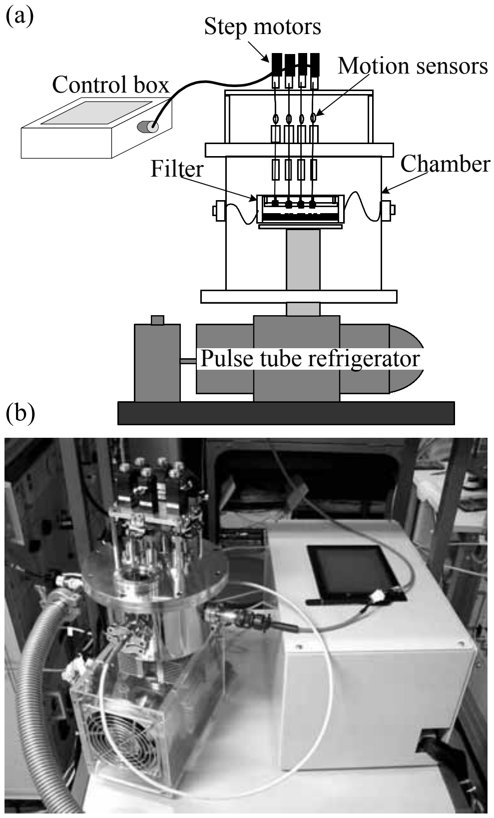

Fig. 2. (a) Schematic, and (b) photograph of automatic tuning system.

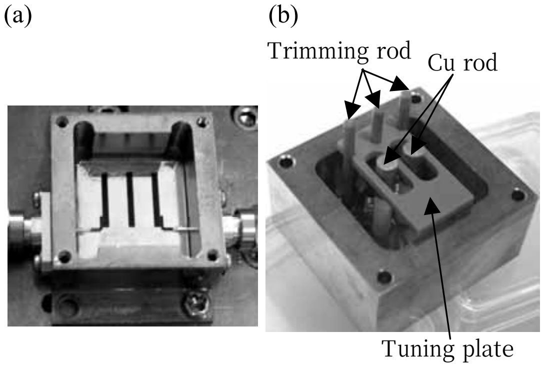

Fig. 3. (a) Photograph of 3-pole band-pass filter mounted in Cu cavity. (b): Photograph of upper cavity with tuning mechanism.

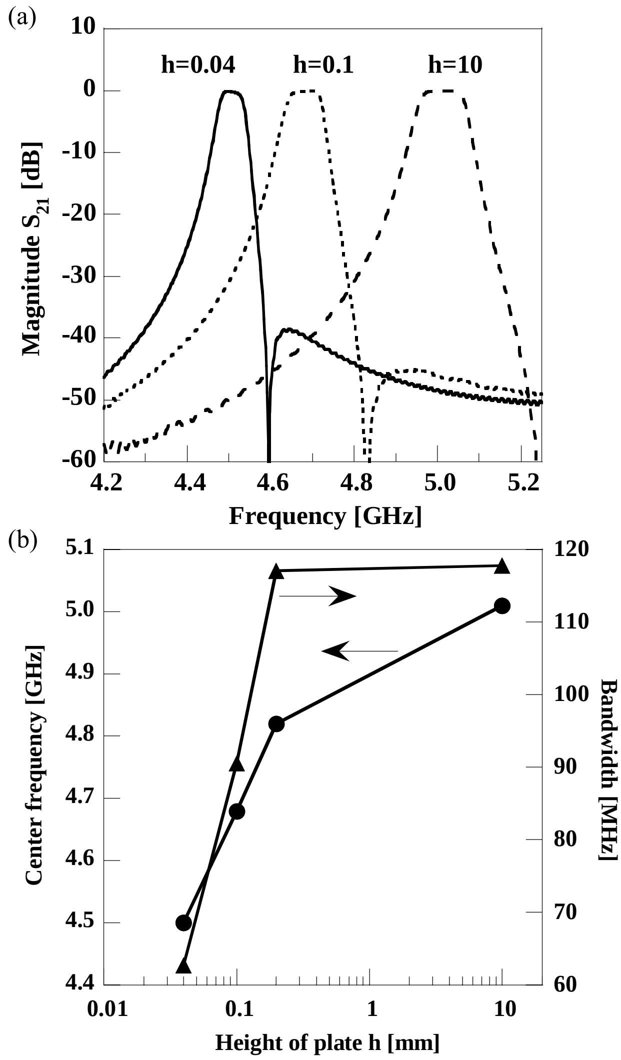

Fig. 4. (a) Simulated frequency responses of tunable filter with dielectric rods under various h. (b) Dependence of f_c and BW of tunable filter with dielectric rods on h.

We can automatically program the step motors with predetermined position values. The system can store four positions of each rod in its memory. Figure 2 (b) is a photograph of the tuning system. Fig. 3 (a) shows a photograph of the 3-pole band-pass filter mounted in the Cu cavity, and fig. 3 (b) shows a photograph of the upper cavity with a tuning mechanism. Tuning is automatic by moving the plate and rods, which are connected to the step motors.

C. *Simulation of tuning characteristics*

Figure 4 (a) shows simulated frequency responses of the tunable filter with the DTRs at various distances from the bottom of the tuning plate to the surface of the filter (h). The filter properties after f_c tuning were improved by adjusting the height of the DTRs. The f_c and BW were 5.01 GHz and 117.8 MHz at h = 10 mm, 4.68 GHz and 90.5 MHz at h = 0.1 mm, and 4.50 GHz and 62.7 MHz at h = 0.04 mm, respectively. Figure 4 (b) shows the dependence of f_c and BW of the tunable filter with dielectric rods on h. The f_c value gradually decreases with h. It was possible to shift the f_c to lower frequencies greater than 500 MHz at h = 0.04 mm. The filter properties after tuning were improved using the DTRs because deterioration of the filter properties was lessened using the tuning plate with windows. However, the value of BW gradually decreases with shifts in the f_c, so we needed to increase the BW after tuning of f_c to obtain the designed BW.

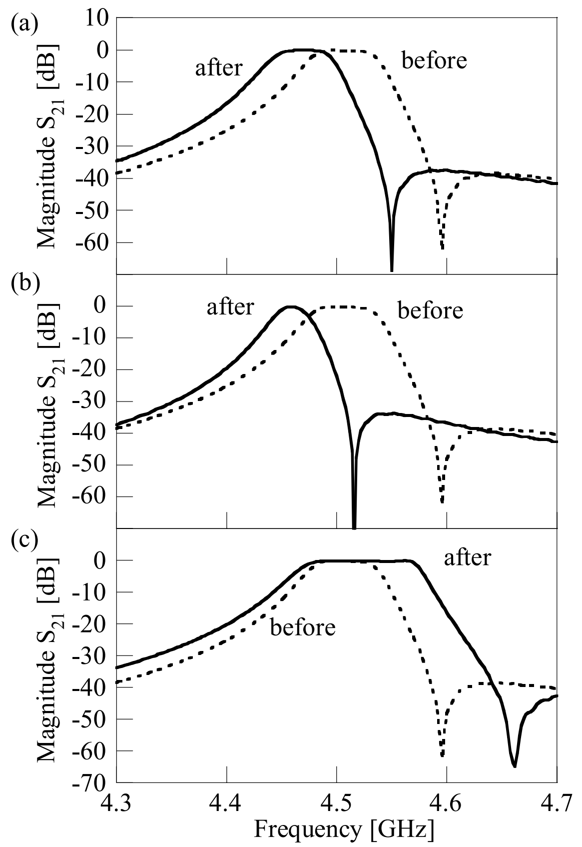

Fig. 5. Frequency responses using (a) dielectric, (b) magnetic and (c) copper rod that are located in spaces between resonators (see Fig. 3(b)).

Figure 5 shows the various kinds of rods located in the spaces between the resonators dependencies on the simulated frequency responses. We used (a) dielectric, (b) magnetic and (c) copper rods for the BW trimming. After BW trimming of the filter, the BW did not so change much by using dielectric rods (less than ~ 5%), however, BW significantly decreased (~ 50%) or increased (~ 80%) by using the magnetic rods or copper rods, respectively. Thus, the decrease, after tuning without Cu rods, in BW can be improved by using the Cu rods with diameter of 3 mm and length of 4 mm. Finally, based on the results of the simulation, if we use a proper tuning plate, DTR, and Cu rods, the tuning plate and the trimming rods would not affect the IL. Therefore, it was possible to simulate 500 MHz tuning using the dielectric plate with windows, DTRs, and Cu rods.

III. Results and Discussions

Figure 6 shows the measured tunability of the 3-pole tunable filter before and after trimming. We found that the filter properties improved greatly as a result of trimming with DTRs, and in particular, the ripple in the pass-band dramatically decreased, and also BW improved after using the Cu rods. Variations in the f_c, BW, IL, pass-band ripple, and maximum return loss (RL_{max}) after tuning and trimming are listed in Table 1. For example, the BW of the filter after BW trimming increased approximately 30 MHz from 72 MHz.

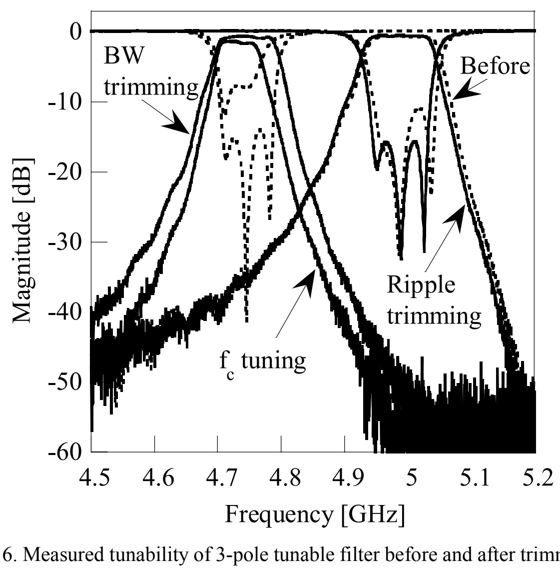

Fig. 6. Measured tunability of 3-pole tunable filter before and after trimming at 70 K.

Table 1. Tuning Properties of F_C, BW, IL, pass-band ripple, and RL_{MAX} after tuning and trimming.

	Before	Ripple trimming	f_c tuning	BW trimming
f_c (GHz)	4.991	4.985	4.733	4.746
BW (MHz)	120.0	116.6	72.1	102.1
IL (dB)	0.42	0.43	1.23	0.52
Ripple (dB)	0.34	0.17	0.39	0.38
RL_{max} (dB)	10.77	15.63	7.52	13.84