Superconducting Linear Phase Shifter for the Phased Array Antenna

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***Abstract*—We propose a continuous variable phase shifter as a new use of a tunable filter. To obtain a large phase shift, the filter is designed using the ideal transform function of the generalized Chebyshev function with real zero. The generalized Chebyshev function with real zero is realized by 4 resonators and jump coupling between resonators. The phase shifter tunes the center frequency by 4 dielectric rods with a piezoelectric actuator. The resonator uses a step-impedance hairpin microstrip line resonator. The phase shifter uses high-Tc superconducting material, YBCO. Therefore, this tunable filter has a low insertion loss of 0.3dB and constant magnitude. In addition, it showed linear phase change continuously. A maximum tuning phase was 372 degrees in condition of a maximum tuning speed of 2.66 msec.**

***Keywords*—phase shifter; phased array antenna; microstrip tunable filter; Superconducting filter.**

I. INTRODUCTION

High-Tc superconducting (HTS) devices have been extensively studied for use in microwave applications because of their low-loss characteristics. In particular, these devices are expected to be applied as the receiving filters of mobile-telecommunication base stations. A high-sensitivity receiver can be realized using a planar superconducting filter, which has low insertion loss and a narrow-band characteristic [1-4]. And now, we are trying to develop the phased array antenna with high-sensitivity receiver by use of superconducting devices [5-7]. Generally, conventional phase shifters are large-loss devices. Therefore, the phase shifter connects after low noise amplifiers in receiver of phased array antenna. If the phase shifter has a low-loss characteristic, it is expected to realize a new structure for phased array antenna. For example, a high-sensitivity phased array antenna with a single low noise amplifier can be feasible.

In this paper, we propose a continuous variable phase shifter as a new use of a superconducting tunable filter. We use large phase change in filter's band. We developed a narrow-bandwidth HTS tunable filter for a low-loss phase shifter. We have designed a higher-Qu resonator to suppress radiation loss by using a step-impedance hairpin microstrip line resonator. The HTS tunable filter realizes constant magnitude with low-loss and linear-phase-shift characteristics.

II. DESIGN OF PHASE SHIFTER

In order to obtain a large phase shift, the filter functions are compared. Coupling matrix of the 4-poles generalized Chebyshev function filter is shown in figure 1. The filter circuit consists of 4 resonators, couplings of M_{12}, M_{23}, and M_{34}, and jump coupling of M_{14}. This filter in condition of $M_{14}=0$ is conventional Chebyshev function filter (CF). Also this filter in condition of opposite phase between M_{14} and $M_{12}+M_{23}+M_{34}$ is generalized Chebyshev function filter with imaginary zero (IZCF). Finally, this filter in condition of common phase between M_{14} and $M_{12}+M_{23}+M_{34}$ is generalized Chebyshev function filter with real zero (RZCF). Figure 2 shows comparison of phase characteristic for 3 types of 4-poles generalized Chebyshev function filter. The only RZCF has a large phase-shift value over 360 degrees.

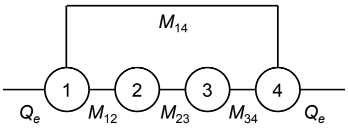


Fig. 1. Coupling matrix of the 4-poles generalized Chebyshev function filter.

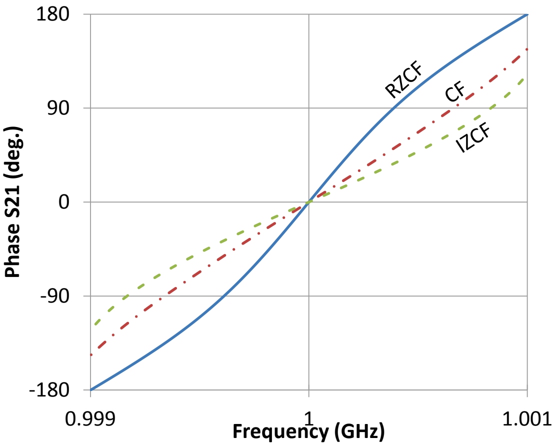
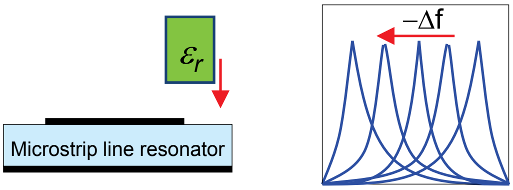


Fig. 2. Comparizon of phase characteristic for 4-poles generalized Chebyshev function filters.

The low-loss phase shifter requires high-Qu resonators. A high-Qu resonator is realized by low substrate loss of MgO, low conductive loss of superconductor, and low radiation loss of a step-impedance hairpin microstrip line resonator. Figure 3 shows basic operation of the tunable method. The dielectric rod is on the maximum electric field point at the edges of the resonator pattern. Tuning of resonant frequency is realized by change of height of the dielectric rod. Closest position is lower resonant frequency. Figure 4 shows the filter layout for the phase shifter and dielectric rod positions. Red circles indicate dielectric rod positions. The common phase condition is realized by the same line length of M_{23} and M_{14}. Therefore, the resonator realizes Qu of over 100000.



(a) Cross-section of resonator (b) Frequency response

Fig. 3. Basic operation of tunable resonator.

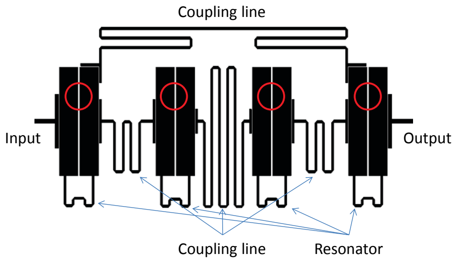


Fig. 4. Filter layout of the RZCF and positions of the dielectric rod for the tunable filter.

Figure 5 shows photographs of a phase shifter and an expanded view of the dielectric rods part. This phase shifter consists of the substrate of HTS filter, piezoelectric actuators, dielectric rods of sapphire, cantilevers, and elastic hinges. Generally, the piezoelectric actuator has highly accurate control and high power. But mechanical change of the piezoelectric actuator is small. The frequency shift by the small piezoelectric actuator is very small. To improve the frequency shift, the mechanical change is expanded by the cantilever and the elastic hinge. In the expanded system, the dielectric rod is changed by the piezoelectric actuator. Maximum changed length of dielectric rod is about 100 μm. As a result, small tunable machinery is realized. This tuning filter module is set in the vacuum chamber to insulate the heat. The HTS filter is fabricated by using HTS YBCO thin films on an MgO substrate (50×56×0.5 mm) with a photolithography and dry etching process. Highly accurate control of each of the 4 dielectric rods is realized by a feedback system using a strain gauge detector. In addition, high-speed control is realized by a lookup table control method.

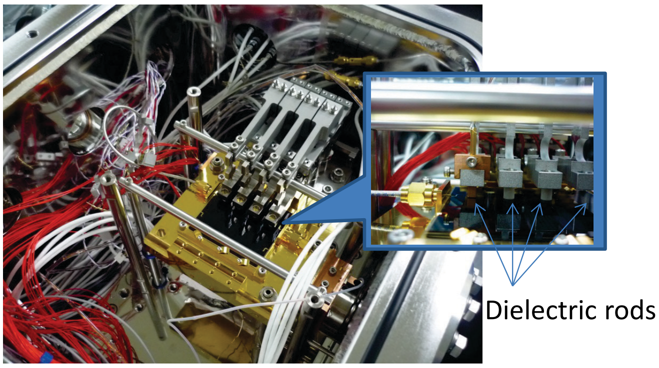
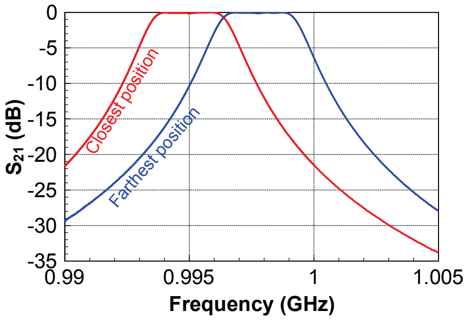


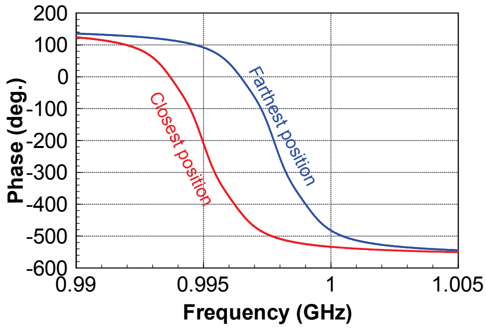
Fig. 5. Photographs of the tunable filter module and an expanded view of the dielectric rods part.

III. MEASURED RESULTS

Figure 6 shows measured results of transmission response and phase characteristic in the condition of closest position and farthest position between the dielectric rod and the substrate. Tuning frequency shift was about 3 MHz. In addition, insertion loss was 0.3dB in both conditions. Fractional bandwidth was 0.2%. Tuning time was less than 2.66 msec. Measured results are in good agreement with the calculated results. This tunable filter can change the center frequency continuously. As a result, transmission phase can change continuously, too. Figure 7 shows normalized phase characteristic at 0.996 GHz. Initial position is the closest position. The maximum phase shift value was 372 degrees. Transmission loss in the condition of 360-degree phase shift was less than 0.3dB.



(a) Transmission response



(b) Phase characteristic

Fig. 6. Measured results of transmission response and phase at the closest position and the farthest position.

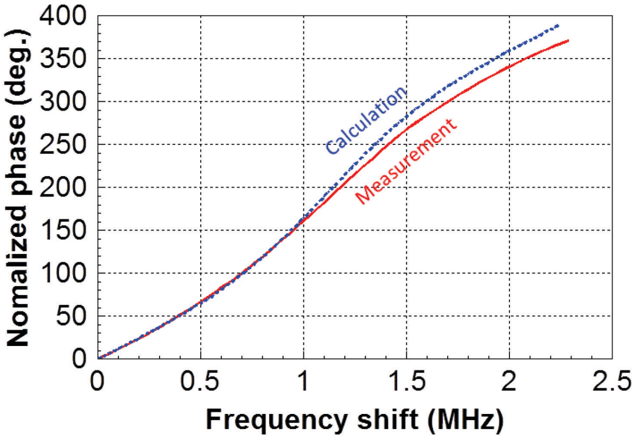


Fig. 7. Measured result and calculation result of normalized phase characteristic at 996 MHz that depends on frequency shift.

I. CONCLUSION

A low loss linear phase shifter using high-speed tunable superconducting filter has been developed. The 4-pole generalized Chebyshev function with real zero realized phase shift over 360 degrees. The phase shifter was realized by a small number of resonators and small tunable machinery with a piezoelectric actuator and an expanded system. Transmission loss in the condition of 360-degree phase shift was less than 0.3dB. In addition, this phase shifter showed linear phase change continuously.

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