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A new type of HTc superconducting film comb-shape resonator for radio frequency superconducting quantum interference devices

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Abstract A new type of HTc superconducting film comb-shape resonator for radio frequency superconducting quantum interference devices (RF SQUID) has been designed. This new type of superconducting film comb-shape resonator is formed by a foursquare microstrip line without a flux concentrator. The range of the center frequency of this type of resonator varies from 800 MHz to 1 300 MHz by changing the length of the teeth. In this paper, we report on simulating the relationship of the value of the center frequency and the length of the teeth, and testing the noise of HTc RF SQUID coupling this comb-shape resonator.

Keywords resonator, HTc superconducting film, RF SQUID

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1 Introduction

The desired resonator for use with a radio frequency superconducting quantum interference device (RF SQUID) should have high unloaded and loaded quality factor (Q_0 and Q_L). The frequency of the resonator should match the frequency of the electric circuit outside. Zhang *et al.* have de-

signed some coplanar resonators and substrate resonators. The size and the structure of these resonators can be adjusted conveniently in order to achieve different frequencies [1–3]. At the same time, the resonators with a flux concentrator at the same substrate [1, 2] and the resonators without a flux concentrator [4, 7] have been fabricated. Xie *et al.* have also designed an HTc superconducting film comb-shape resonator shown in Fig. 1 [5]. In fact, it is an LC resonance circuit. The foursquare microstrip comes into being inductance (L) and the crossed tooth inlaying the microstrip product capacitance (C). The resonant frequency (f_0) can change in a large range easily if the length (l) of the teeth changes. The HTc superconducting film surrounded by the microstrip (see Fig. 1) is a flux concentrator of RF SQUID. The unloaded quality factor of the resonator designed by Xie *et al.* can achieve several thousands when f_0 is 300 MHz and 800 MHz. The best white flux noise they obtained was below $2 \times 10^{-5} \Phi_0 / \text{Hz}^{1/2}$ when the resonator served as a tank circuit for sidestep junction RF SQUID, here Φ_0 is the flux quantum. We have developed HTc RF SQUID, where f_0 is 1 300 MHz.

Serving as a tank circuit for this 1 300 MHz HTc RF SQUID, the resonator is the superconducting film coplanar resonator. However, superconducting film comb-shape resonator can also be used for the 1 300 MHz HTc RF SQUID. In order to increase the f_0 to 1 300 MHz, we decreased the length of the teeth of the superconducting film comb-shape resonator. Unfortunately, our experiments have proved that the resonant frequency (f_0) increases to 1.04 GHz when the length (l) of the teeth drops to 300 μm . The f_0 changes only a little even while the length drops to zero (increases to 1.05 GHz) [6]. The reason, we think, is that there is considerable distributed capacitance between the superconducting microstrip serving as LC circuit and the superconducting film as a flux concentrator surrounded by the microstrip. While the length of the teeth becomes shorter

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and reaches a certain value, the value of the capacitance produced by the crossed tooth is smaller than one of the distributed capacitance. Therefore, decreasing the length of the teeth has no effect on the increase of the f_0 .

We have developed a superconducting film comb-shape

resonator formed by one foursquare superconducting film microstrip with crossed comb-shape tooth and without concentrator surrounded by the microstrip (see Fig. 2). This structure can eliminate the distributed capacitance between the microstrip and the concentrator.

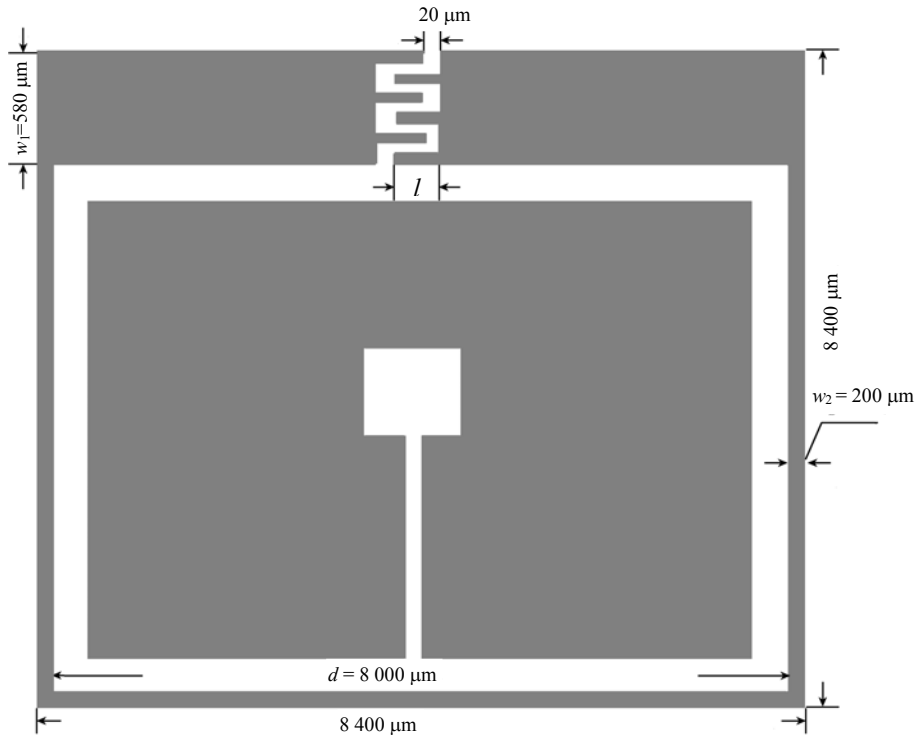


Fig. 1 The structure of the superconducting film resonator with a flux concentrator the black is $\text{YBa}_2\text{Cu}_3\text{O}_7$ thin film.

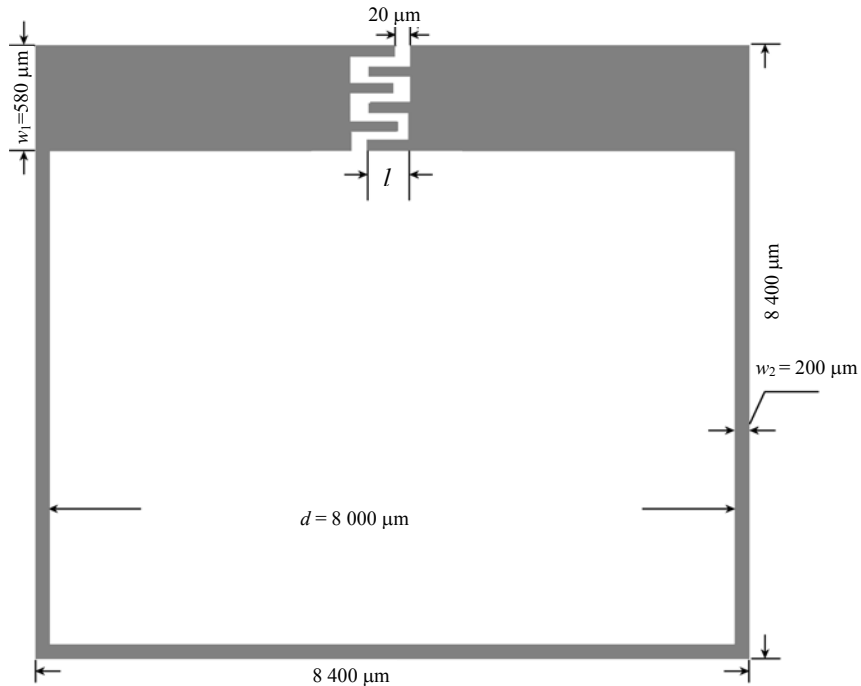


Fig. 2 the structure of a new type of HTc superconducting film comb-shape resonator (without a flux concentrator) the black is $\text{YBa}_2\text{Cu}_3\text{O}_7$ thin film.

The designation of the parameter of capacitance and inductance becomes easier. A comb-shape resonator showed unloaded quality Q_0 was 1 200 (at $f_0 = 873$ MHz) and loaded quality Q_L was 160.

2 The structure of the comb-shape resonator and simulation

The superconducting comb-shape resonator, formed by one foursquare microstrip with comb-shape crossed tooth inlaying one of four sides (see Fig. 2), was patterned from a 200-nm-thick *c*-axis oriented epitaxial $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO) film grow on 0.9-mm-thick (001) LaAlO_3 (LAO) substrate. The width of the tooth was 80 μm , the width of the gap between the teeth was 20 μm , and the number of the teeth was 3. These values were all constant. We only changed the length of the teeth (l) to adjust the capacitance of the resonator, in order to change the resonant frequency of these resonator. The length of the teeth (l), we chose, was 50 μm , 200 μm , 340 μm , 420 μm , 600 μm , 700 μm , 800 μm , 1 000 μm , 1 200 μm , 1 400 μm . Correspondingly, the f_0 dropped from 1.34 GHz to 796 MHz. We measured the f_0 of these resonators with different length of teeth by HP8590L. Table 1 shows dependence of the resonant frequency (average value) on the length of teeth, respectively.

Table 1 The different lengths l of teeth and the corresponding resonant frequency f_0 .

$l/\mu\text{m}$	50	200	340	420	600	700	800	1000	1200	1400
f_0/MHz	1344.0	1235.1	1113.5	1077.3	1017.9	1001.2	958.3	867.1	825.0	791.6

The simulation of the dependence of the f_0 on the length of teeth has been made. The inductance of these resonators changed a little and the capacitance changed largely if we adjusted the length of the teeth only. These changes of the inductance can be ignored. The capacitance of these resonators can be obtained from the formula:

$$C = C_0[w_1 + (2N - 1)l] \quad (1)$$

Here, w_1 is the width of one side of the foursquare microstrip with crossed tooth, N is the number of the teeth ($N = 3$), l is the length of the teeth, and C_0 is unit capacitance (the gap between tooth is 20 μm). We obtain expression of the f_0 from formula:

$$f_0 = 1/2\pi\sqrt{LC} \quad (2)$$

Here, C is the capacitance of the resonators, which can be derived from Eq. (1). L is inductance of the resonators, which remains constant. The dependence of $\lg f_0$ on $\lg C$ is linear. The slope parameter (k) is $-1/2$. The value simulation of this slope parameter (k), was $k=0.42$. Figure 3 shows the value of the experiment and the stimulant line. The simulation agrees well with the results of the experiment at low frequencies. The results at high frequencies was not as good as that of low frequencies. Advanced research on these phenomena can be made.

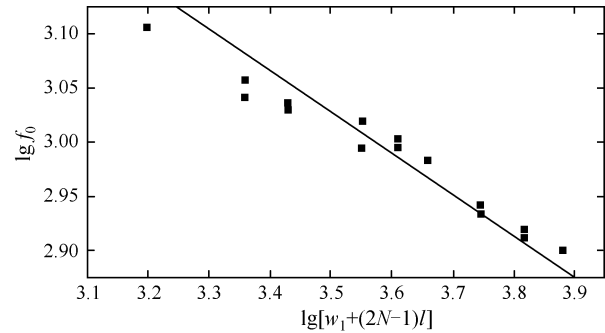


Fig. 3 The relationship of $\lg f_0$ and $\lg[w_1 + (2N - 1)l]$, the black square shows the results of the experiment. The line is a simulative result. The slope of the line is -0.42 .

3 The results of experiment

A resonator ($f_0 = 873$ Hz, $Q_0 = 1\ 200$) was used to serve as a tank circuit for RF SQUID. The superconducting film concentrator with a dimension of 15×15 mm² should contact with the HTc RF SQUID [4, 7] in order for the resonator to couple well with the small area (3×3 mm²) HTc RF SQUID. The RF SQUID washer obtains a larger effective area. The resonator, HTc RF SQUID washer and the superconducting concentrator were placed as shown Fig. 4. The resonant frequency of the RF SQUID magnetometer (Fig. 4) was 900 MHz and the loaded quality factor (Q_L) was 160. We also obtained the triangle wave of the RF SQUID magnetometer (see Fig. 5). The white flux noise spectra of the RF SQUID magnetometer has been tested using HP 35665 dynamic signal analyzer (shown in Fig. 6). The white flux noise ($S_{\phi}^{1/2}$) was about $3 \times 10^{-5} \Phi_0/\text{Hz}^{1/2}$.

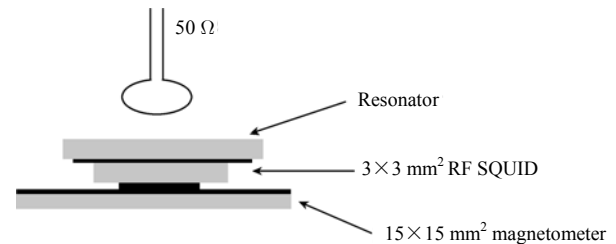


Fig. 4 The structure of a 900 Hz RF SQUID, the black parts are $\text{YBa}_2\text{Cu}_3\text{O}_7$ films.

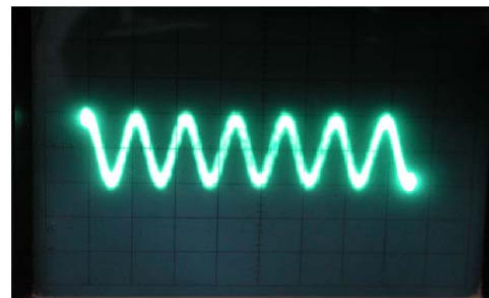


Fig. 5 The triangle wave signal produced by a HTc RF SQUID coupled with a unloaded superconducting film comb-shape resonator, the resonant frequency is 873 Hz.

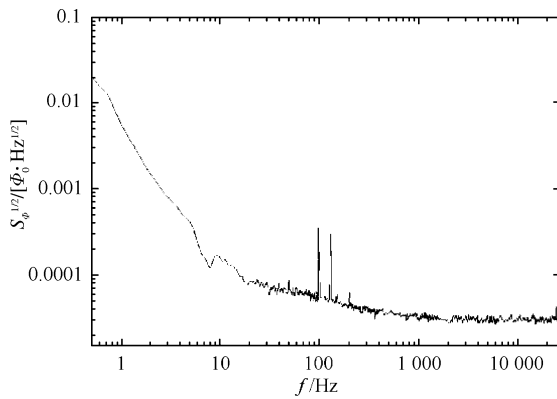


Fig. 6 The noise spectrum of a 900 MHz HTc RF SQUID, the white noise is about $3 \times 10^{-5} \Phi_0 / \text{Hz}^{1/2}$.

4 Conclusions

This new type of superconducting film comb-shape resonators eliminate the distributed capacitance between the superconducting microstrip and concentrator surrounded by the microstrip. We can design the parameter of the capacitance and inductance of the resonator easily. The dependence of $\lg f_0$ on $\lg C$ is well within the theory at low frequencies (Fig. 3), but not at high frequencies. This maybe

because the inductance also changes while the length of the teeth becomes shorter resulting in a drop of the resonant frequency.

References

1. Zhang Y., Zander W., Schubert J., Rüdgers F., Soltner H., Banzet M., Wolters N., Zeng X.H., and Braginski A.I., *Appl. Phys. Lett.*, 1997, 71 (5): 704
2. Yi H. R., Zhang Y., and Braginski A.I., *APPL. Phys. Lett.*, 1998, 73 (16): 2357
3. Zhang Y., Schbert J., Wolters N., Banzet M., Zander W., and Krause H.J., *Physica C*, 2002, 282: 372–376
4. Liu X. Y., Xie F. X., Meng S. H., Dai Y. D., Li Z. Z., Ma P., Yang T., Nie R. J., and Wang F. R., *Chinese Physics*, 2004, 13 (1): 100
5. Xie F. X., Yang T., Ma P., Nie R. J., Liu L. Y., Wang S. G., Wang S. Z., and Dai Y. D., *Proceedings of the 5th Academic Conference of National Superconducting film and Superconductive Electronic Apparatus*, 2000: 227
6. Mao B., Master's thesis of Condensed Matter Physics of Peking University
7. Meng S. H., Deng N., Nie R. J., Xie F. X., Ma P., Liu L. Y., Wang S. Z., and Dai Y. D., *Chinese journal of Low Temperature Physics*, 2002, 24 (3): 179