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A high-T_c L-band SQUID amplifier combined with superconductive thin-film filters

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Abstract

An experimental investigation of high-temperature dc SQUID amplifier connected in series with a high-T_c superconductor (HTS) thin-film band-pass filter is presented. The SQUID amplifiers are designed with microstrip input coils and fabricated on bicrystal substrates of zirconia and sapphire with different misorientation angles of 24° and 37°. SQUID parameters are optimized to attain 50-Ω input impedance for the 1500 MHz central frequency range. The maximum power gain of the amplifier with six turn input coil was measured to be 6 dB at 800 MHz and 4.5 dB at 1750 MHz. Thin-film HTS YBCO filters are based on a band-pass quasi-elliptic prototype consisting of a set of parallel tank circuits connected to a shunt and separated by admittance inverters. The central frequency of the band-pass filter was adjusted close to 1750 MHz amplifier frequency with 4% bandwidth. The natural combination of a high-T_c SQUID amplifier with a HTS band-pass filter allows the reduction of out-of-band noise and optimization of amplifier performance, and demonstrates compatibility with practical components of front-end receiver subsystems. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: dc SQUID; RF amplifiers; High-T_c superconductor filters

1. Introduction

Low-noise RF amplifier based on a dc SQUID (SQA) is a promising candidate for different applications in front-end receiver subsystems where low-noise and low power consumption are essential [1]. In general, SQA can be viewed as a peculiar type of non-linear parametric amplifier and thereafter can produce intermodulation harmonics [2]. The improvement of SQA-based systems with respect to selectivity is the key problem. The standard solution is utilizing of a band-pass filter inserted in front of low-noise amplifier (LNA) to avoid saturation. The preselect filter also

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sufficiently rejects out-of-band spectral components and serves thus to eliminate conversion into in-band frequency components via intermodulation due to non-linearities in the LNA [3]. Within the recent years, significant progress has been achieved in developing of high-T_c superconductor (HTS) band-pass filters exploitable in receivers for base telecommunication stations. The low surface resistance of HTS materials allows fabrication of band-pass filters with low insertion loss. The elliptic-type filters exhibit minimum stop band attenuation of 70 dB with midband insertion losses less than 0.1 dB at 1700 MHz central frequency and 1% bandwidth [4].

In a previous work, we investigated a possibility to implement HTS dc SQUID for RF amplifier [5,6]. The main problem in design of such amplifier is effective matching of the microwave signal into SQUID washer at high frequencies. There are different approaches used previously in Nb dc SQUID RF amplifiers to solve this problem. In our work we introduced microstrip type input coil placed above SQUID washer designed to get desirable impedance matching at frequencies about 1500 MHz. Although the SQUID was far from its optimal performance, power gain of about 5–6 dB at frequencies between 900 and 1700 MHz was observed.

The combination of the HTS SQA and HTS band-pass filter can provide additional information about SQUID performance and brings possibility to perform accurate noise temperature measurements. The main goal of this work is qualification of combination HTS SQUID amplifier and band-pass filter.

2. HTS band-pass filter design and properties

HTS band-pass filter represents a parallel array of coplanar lines [7]. A three-pole filter with Chebyshev characteristic was designed for central frequency 1775 MHz and consists of $n + 2$ resonators. The sketch of the filter is depicted in Fig. 1. To provide strong coupling with the feeding lines the ground plane between two adjacent coplanar lines at the input and output was removed. Two air bridges were added to suppress undesirable slot modes, black rectangles in Fig. 1.

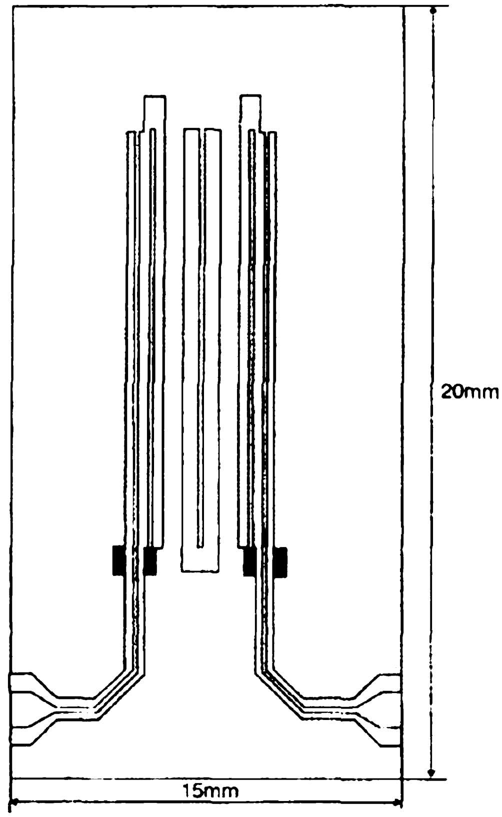

Fig. 1. Layout of a three-pole co-planar waveguide filter.

Filter structure was fabricated in 0.2 μm thick YBCO film deposited on 25×25 mm^2 LAO substrate by the means of ion-beam etching in Ar^+. YBCO film produced by PRIMA TEC was deposited by on-axis magnetron sputtering with radiative substrate heating. The filter revealed maximal insertion loss of 0.6 dB, better than 11 dB reflection loss, 60 dB attenuation and 4% bandwidth at 1725 MHz central frequency (see Fig. 2).

3. High-T_c dc SQUID amplifier

The high-T_c dc SQUID design is based on the idea of open-ended microstrip input coil suggested recently in Ref. [8]. According to the design, microstrip input of the high-T_c SQUID amplifier consists of a single layer spiral coil made from

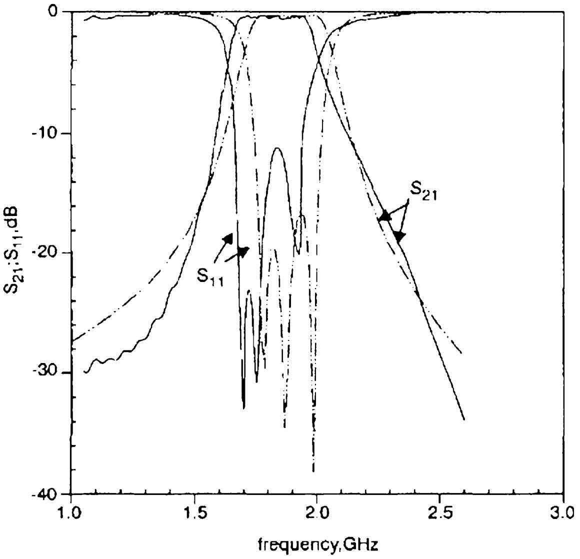

Fig. 2. Frequency characteristics of a three-pole co-planar CPW filter at 77 K.

normal metal (gold) with thickness between 100–200 nm situated above SQUID washer and separated by thin insulator film. Material of the dielectric was chosen with the aim to provide better adhesion and minimum influence on HTS film during fabrication. We found amorphous 9.5%-Y stabilized zirconia deposited by laser ablation technique at room temperature is most suitable for this purpose. To avoid short circuits between top metal layer and HTS film, it is well known problem for any multilayer device, we made a lot of efforts to decrease YBCO film roughness by means of deposition parameters optimization. In general, it is very complicated task in relation with ZrO_2 substrates especially with keeping high quality film on the boundary. We fabricated YBCO films with better roughness of about 30 nm but for all that leakage resistance between Au layer and superconductor film found not less than 10^6 Ω. A microphotograph of the SQUID amplifier on bicrystal ZrO_2 substrate with 37° misorientation angle is shown in Fig. 3. 180 nm YBCO film was deposited by conventional laser ablation technique with excimer KrF mixture laser ($\lambda = 248$ nm), buffer oxygen pressure 0.3 mbar and $T = 745$ °C. Au film was deposited both by e-beam and magnetron sputtering. SQUID structure was patterned

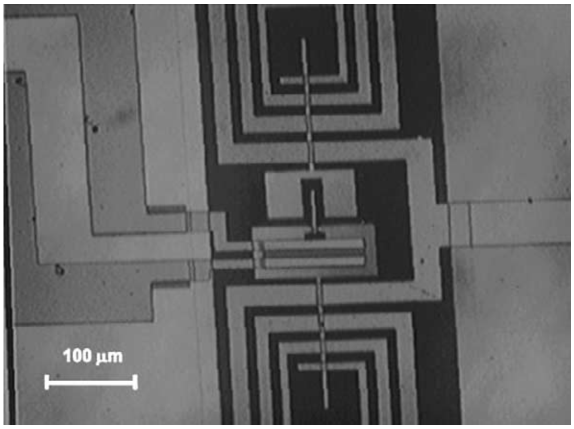

Fig. 3. Photo of high-T_c dc SQUID RF amplifier with gradiometric configuration.

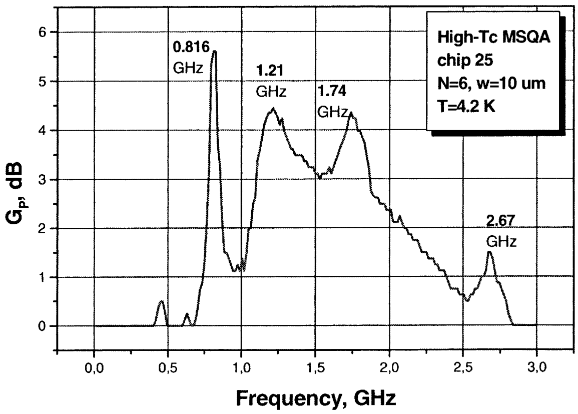

Fig. 4. Measured power gain of the high-T_c dc SQUID RF amplifier.

with optical photolithography and ion-beam etching in Ar^+ ions with energy 250 eV and current density 0.2 mA/cm^2.

Frequency dependence of power gain of the high-T_c dc SQUID RF amplifier made on 37° YSZ bicrystal substrate with $N = 6$ turn input coil is presented in Fig. 4.

4. Measurements

Qualification of HTS SQUID amplifier with band-pass filter was performed in specially equipped helium cryostat. SQUID was mounted on an assembly with RF inputs and placed on the

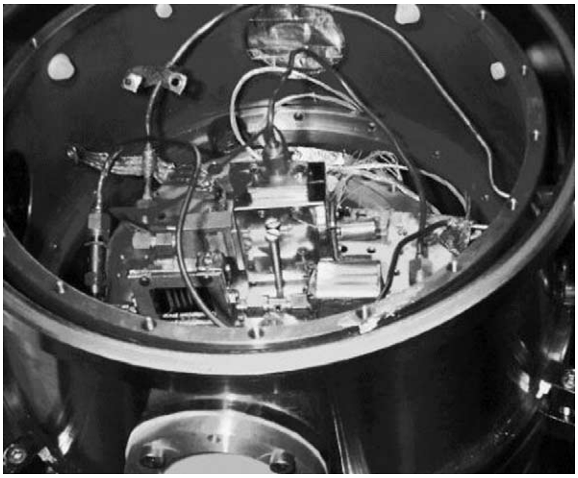

Fig. 5. Inside of the helium cryostat with SQUID and filter installed.

cryostat cold plate, see photo in Fig. 5. Optional attenuators and cooled FET preamplifier with gain 20 dB and 0.3–3 GHz bandwidth can be mounted on the cold plate. For RF qualification we used room temperature WILTRON sweep oscillator model 6659A combined with scalar network analyzer model 560A or microwave power detector RLC Electronics model CR133A (0.01–12.4 GHz). A series of room-temperature amplifiers Narda AFS4-20 with total gain 40 dB was connected to the output. The schematic of the measurements system is shown in Fig. 6.

The high-T_c dc SQUID fabricated on 36.8° YSZ bicrystal substrate (sample #25b) with Josephson junction of 1.5 μm width was used. It had critical current 25 μA, normal resistance 20 Ω at 4.2 K providing $I_C R_N$ value about 0.5 mV.

Filter characteristic appeared at temperature according 65 K on the cold plate, and SQUID IVC was observed starting from 50 K. Filter bandwidth and attenuation did not undergo substantial changes down to 4.2 K while SQUID critical current risen from 3 up to 25 μA. The frequency characteristic of the SQUID and filter combination measured at 35 K is presented in Fig. 7. The central frequency of the system is in good correspondence with filter characteristic, but midband attenuation level is significantly smaller presumably due to interference with cryostat surroundings placed close to the filter structure.

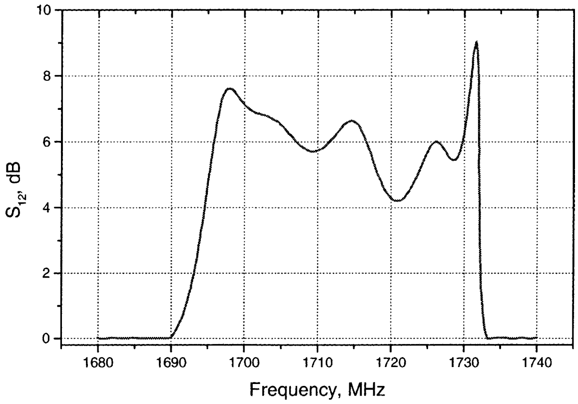

Fig. 7. Frequency characteristic of SQA and band-pass filter combination at $T = 35$ K.

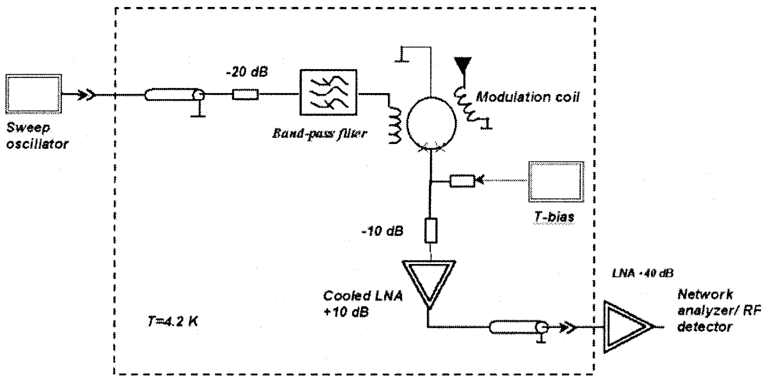

Fig. 6. Schematics of the measurements system.

5. Conclusion

The combination of band-pass filter and LNA is essential part of any front-end receiver system. In our work we demonstrated practical operation of high-temperature dc SQUID L-band amplifier with YBCO CPW band-pass filter. Both amplifier and filter were centered for frequency 1750 MHz with ultimate bandwidth of 4%. The following step is the noise measurements of the high-T_c SQUID amplifier in such a configuration.

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