PLANAR X-BAND SQUID-GRADIOMETER DESIGN FOR HTS APPLICATIONS

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ABSTRACT

An RF-SQUID gradiometer integrated in a $\lambda/2$ length microstrip resonator is described. The device was realized with low temperature superconductors (LTS) using a shunted NbN/MgO/NbN SIS junction as the active element. Various measurement results are given. Measurements of the complex reflection coefficient show clearly a periodic dependence on an applied dc flux.

Due to the fully planar design, the SQUID is an apporopriate basic element of a one chip magnetometer including flux transformer. Work is under way to realize the circuit in high temperature superconductors (HTS).

INTRODUCTION

One of the most interesting devices made of superconductors are superconducting quantum interference devices (SQUIDs). Because of the availability of high temperature superconductive (HTS) films with very low loss at microwave frequencies, planar designs are most convenient for these new materials.

HTS-SQUIDs at microwave frequencies have already been demonstrated. A 9.57 GHz/14.17 GHz SQUID with $\lambda/2$ length microstrip resonator has been proposed in reference /1/. The Josephson junction was realized by a precise weak link microbridge geometry. A disadvantage is that the SQUID consists of two separate chips. A single chip gradiometer with low temperature superconductors has been proposed in reference /2/. The device was sucessfully operated at 3 GHz, although the design is somewhat abstruse concerning the microwave part of the device.

In this paper a very elegant solution is described to integrate a gradiometer into a $\lambda/2$ length microstrip line. The new design was verified experimentally with an LTS device. The device is fully planar and appropriate for a realization with high temperature superconductive thin films.

DEVICE MODELING

The device was modeled as a $\lambda/2$ length microstrip resonator with a flux dependent quality factor Q. To model the losses due to an applied dc flux, the josephson junction was replaced by a flux dependent concentrated resistor. The overall length of the strip is $\lambda/2$ at 10 GHz and is divided into the coupling section to the feeding line, a homogeneous microstrip section, a coupling section to the josephson junction and a second homogeneous microstrip section as sketched in Fig.1.

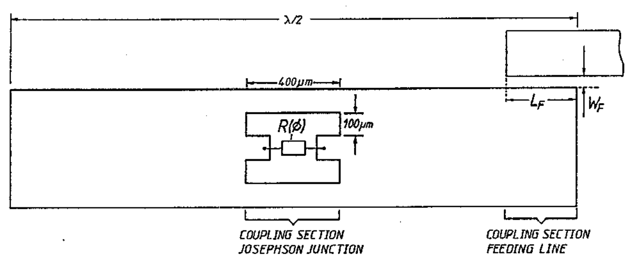

Fig.1
Model of RF-SQUID.

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The design assures that for reasonable values of effective loss resistances, critical coupling can be achieved by adjusting the gapwidth W_F and length L_F of the coupling section to the feeding line. The embedding of the josephson junction is modeled by three coupled microstrip lines. Fig.2 shows the coupling of the gradiometer to the microstrip resonator through the two magnetic fields H1 and H2. The flux through the first SQUID hole caused by the magnetic field H1 causes an RF current through the josephson junction. Mutatis mutandis an RF current in the same direction is caused by the second magnetic field H2.

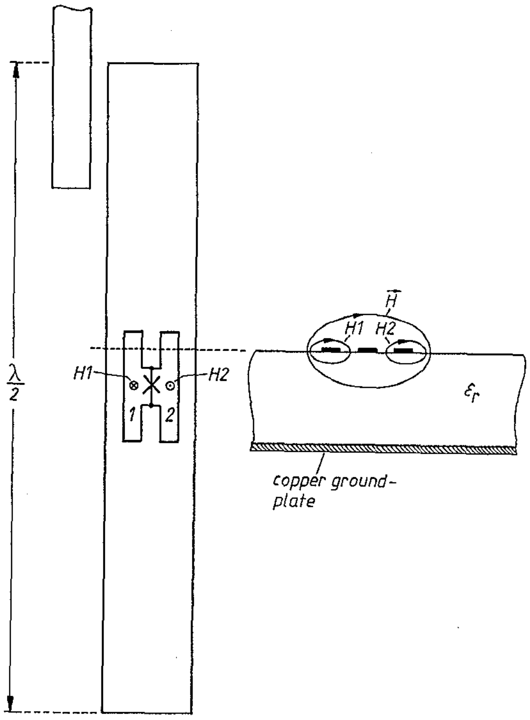

Fig.2
Layout of RF SQUID and RF coupling.

PRACTICAL CONSTRUCTION

The practical device including coupling section to the feeding line is sketched in Fig.3. The coupling section was implemented as a coaxial probe guided in parallel to the strip. The coupling of the cooled device can be adjusted from outside. To protect the experiment from dc magnetic fields and microwave radiation, the device is enclosed in a superconductive lead cylinder, a cylinder made from high permeability material and a brass cylinder.

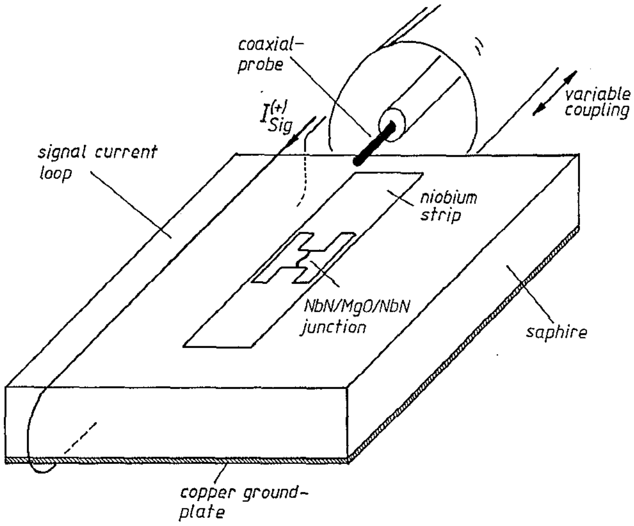

Fig.3
Practical LTS device.

The influences of air and moisture are avoided by evacuating the sample holder. A stainless-steel coaxial airline was used for the feed to minimize phase and amplitude drift during the measurement; thus enabling large averaging factors. The josephson junction is an NbN/MgO/NbN SIS junction shunted with a 10Ω palladium resistor to guarantee a hysteresis free operation. Fig.4 shows a photograph of the junction, the shunt resistor and the coupling holes. The SQUID holes have the same area as in the design in reference /2/ and the critical current of the josephson junction is also 10 μA. This permits to operate the SQUID in the hysteretic mode.

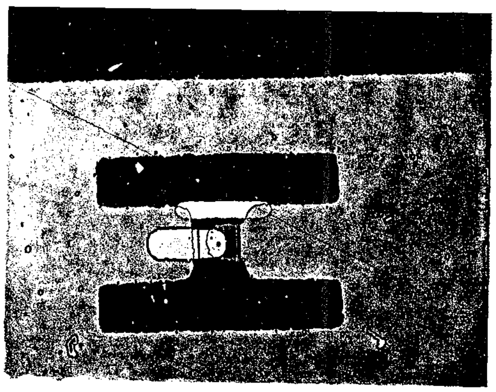

Fig.4
Photograph of SQUID holes, palladium resistor and NbN/MgO/NbN junction.

DC SIGNAL FLUX

In order to operate the SQUID without a flux transformer, a dc flux is produced by a signal current loop as depicted in Fig.3. Fig.5 shows a cross section of the SQUID chip and schematically the corresponding magnetic fields due to the signal currents $+I_{Sig}$ and $-I_{Sig}$. The ground plate is made of copper and has no influence on the dc magnetic fields. In both holes a flux is produced by the positive and negative signal currents. The magnitude of the fluxes produced by the positive signal current $+I_{Sig}$ is larger than that produced by the negativ signal current $-I_{Sig}$ because of the larger distance of the latter one. The two total fluxes through the SQUID holes are different in magnitude because the first hole is closer to the currents.

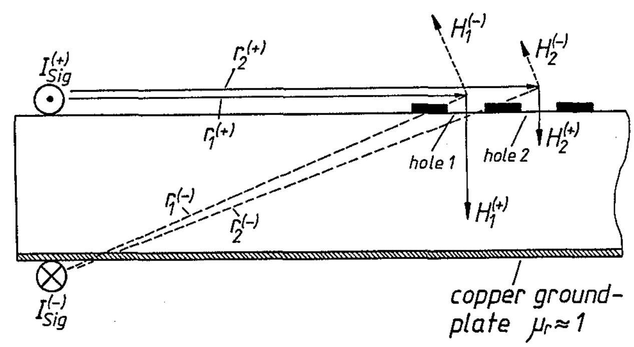

Fig.5
Generation of a dc difference flux by a signal current loop.

MODE OF OPERATION

The setup for the measurements is sketched in Fig.6. The pump signal is applied to the SQUID via a 22dB coupler. A typical input power is 10nW. The reflected signal is amplified by a room temperature HEMT amplifier and then detected by a heterodyne network analyzer.

Firstly, the generator is swept over a frequency band and the coupling is adjusted to nearly critical coupling when no dc magnetic flux is applied. Fig.7 shows measurements over a frequency band for two applied dc fluxes.

In the second step the generator is set to the resonance frequency of the strip resonator and a dc magnetic field is generated by a signal current I_{Sig} parallel to the resonator. The signal current I_{Sig} is varied by an auxiliary output voltage of the network analyzer so that the difference of the fluxes into the two SQUID holes is between about $-2\phi_o$ and $+2\phi_o$. The reflection coefficient is measured both in amplitude and phase.

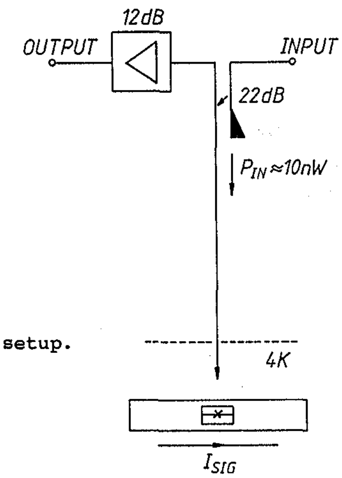

Fig.6
Measurement setup.

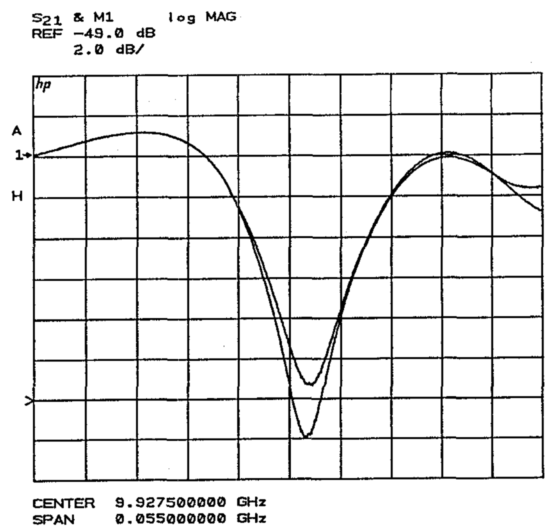

Fig.7
Measurement of reflection coefficient for two applied dc fluxes.

MEASUREMENT RESULTS

Typical measurements for three different input powers are shown in Fig.8. Fig.9 shows amplitude measurements including the trace of the reflection coefficient in the complex plane. The markers visualize a clear periodicity both in amplidude and phase. The corresponding dc flux difference between two consecutive markers is in the range of two flux quanta.

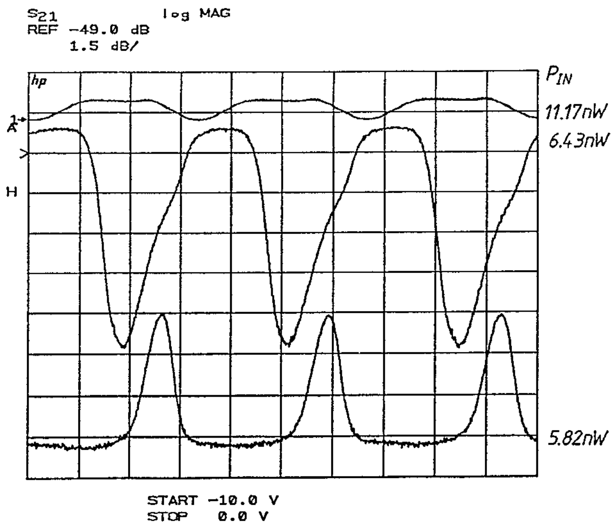

Fig.8
Reflection coefficient over a dc flux range for three input powers.

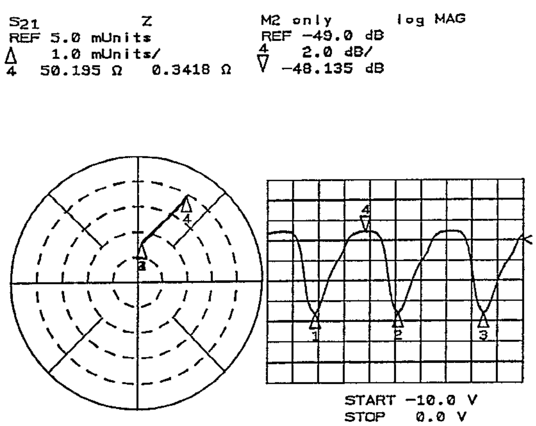

Fig.9
Reflection coefficient over a dc flux range. Amplitude and complex plane.

CONCLUSIONS AND WORKING PROSPECTS

A new SQUID gradiometer design was proposed and successfully realized with low temperature superconductors. Measurements of the complex reflection coefficient show a clear periodicity with an applied dc flux. The device is fully planar and is an appropriate first element of a one chip RF SQUID magnetometer with microwave pump frequencies. Work is under way to realize the structure with YBaCuO on MgO with a sandwich type josephson junction as the active element. A DC-SQUID has already been realized with these junctions (Fig.10) /3/.

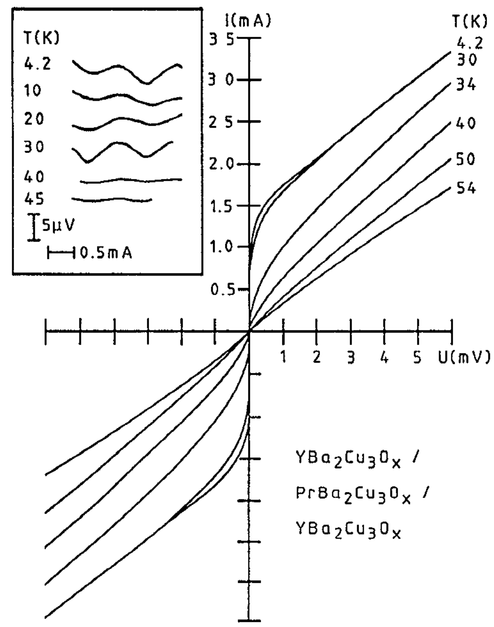

Fig.10
Current-voltage curves of an HTS DC-SQUID for various temperatures. The insert shows the flux modulation of the SQUID versus the current in a modulation coil/3/.

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