MEASUREMENT APPARATUS FOR SUPERCONDUCTING QBITS IN GHZ RANGE

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1. Introduction

Superconducting qubits are solid state electrical circuits fabricated using classical techniques known from conventional integrated circuits. They are based on the Josephson tunnel junction, which is a non-dissipative, strongly non-linear circuit element [1].

Superconducting qubit coupled to a high quality superconducting coplanar wave guide resonator, within a simple circuit on a single microelectronic chip can be used to perform cavity quantum electrodynamics experiments on a chip. Such architecture has been suggested [2] and demonstrated [3]. In the dispersive regime of the qubit-resonator system the resonant frequency of the resonator is depending on the qubit state which is lower or higher for qubit being in its ground or excited states, respectively. Using this dependency and measuring either the amplitude or the phase of a probing signal at one of the frequencies of the resonator, the state of the qubit can be measured. To carry out these experiments a cryogenic experimental set up with good noise and interference isolation is required. In this paper we present realization and characterization of an experimental set up in He^3 refrigerator.

2. Experimental

The scheme of the measurement setup for 2.2-3 GHz frequency range built in Oxford cryogen-free He^3 refrigerator HelioxAC-V with lowest base temperature ~300 mK is shown in Fig.1.

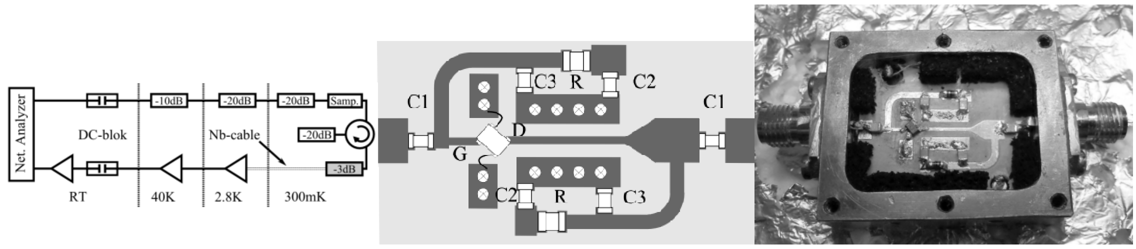

Fig. 1: *Scheme of the setup in He^3 refrigerator on the left and the layout and photo of the cryogenic amplifier on the left.*

The thermal white noise reduction on the input lines is done by 10dB, 20dB and 20dB attenuators thermally anchored to 40K, 2.8K and 300mK temperature stage of the refrigerator. The resultant effective noise temperature of input lines seeing by the sample corresponds to 335mK.

On the output lines in-band filtering without attenuation is provided by circulator. It is a three-port device which allows microwave transmission in one direction only. The sample is irradiated by the noise coming from a thermalized attenuator on the third port of the circulator, while the noise power coming down the line from higher temperatures is dissipated in the same attenuator. About 15dB isolation can be obtained between the sample and the noisy lines.

Amplification at low temperatures is done by two, one-stage, low power cryogenic amplifiers mounted to the 40K and 2.8K stage of the refrigerator (Fig.1). The amplifiers are based on commercially available ATF35143 pHEMT transistor from Agilent. The design of the amplifier, based on Pospieszalski's model of HEMT transistor, was numerically simulated by freely available microwave library Supermix.

To achieve minimal attenuation of the signal from the sample and thermal isolation between the amplifier and the sample superconducting niobium coaxial cable is used between them.

The samples are mounted in a copper box with a 50Ω coplanar waveguide printed circuit board fixed on a sapphire plate by epoxy. The outer perimeter of the printed circuit board is electrically connected to the copper box by indium. From the center of the printed circuit board a slot is cut out and the sample is fixed on the sapphire plate by GE 7031 varnish and wire bonded to the PCB with 50μm aluminum wires (Fig.2).

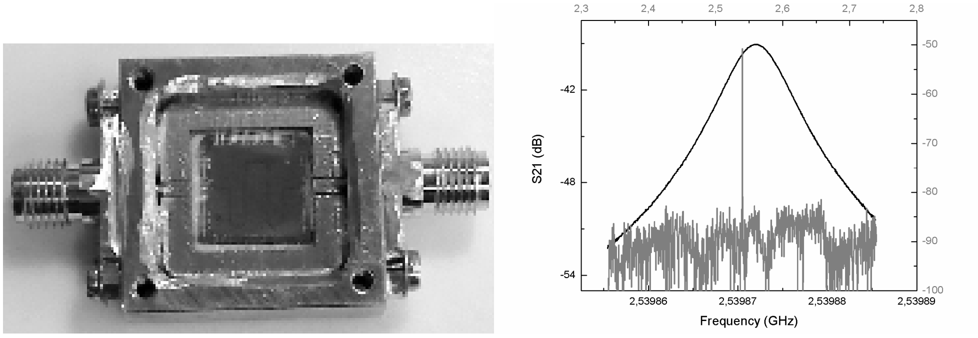

Fig.2: *Coplanar waveguide resonator in copper box and wire bounded on the left and measured resonant curve for niobium resonator with quality of 360 000 at 300mK on the right.*

Two identical circular magnetic coils are placed symmetrically on each side of the sample box constituting Helmholtz coils to produce nearly uniform bias of magnetic field for the qubits. The biasing lines of the coils are filtered by a carbon powder filter to reduce the fluctuations of the field.

The phase sensitive measurement can be carried out either by a commercial network analyzer, or by a quadrature demodulator AD8347 from Analog Devices [4] suitable for frequencies from 0.7GHz up to 2.7GHz (Fig.3).

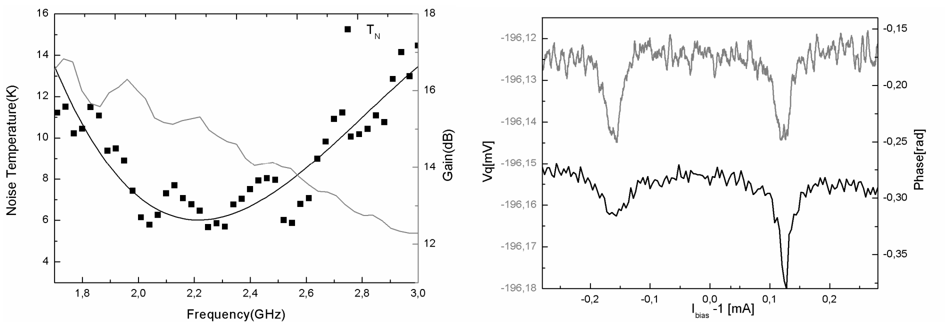

Fig.3: *Gain and noise temperature of the amplifier (left) mounted on the 2.8K stage of the refrigerator and comparison of qubit measurement carried out by network analyser(upper black line) and quadrature demodulator AD8347(gray line). Experiments carried out in 10 mK dilution refrigerator at IPHT Jena, Germany*

3. Results

The noise temperature and gain of the amplifier constructed according to the numerically optimized design was measured in the cryogenic free refrigerator. The noise temperature was determined by a variable temperature load measurement using an additional attenuator thermally anchored to He3 pot as a noise source. The measured noise temperature at 2.5GHz is around 6K and does not exceed 9K from 2GHz up to 2.65GHz (Fig. 3). The estimated gain is 14.5dB at 3,7mW power consumption.

A precise measurement of the niobium coplanar waveguide resonator with quality of 360 000 at 300mK (Fig. 2) demonstrates the sensitivity of the constructed apparatus and the proper working of the refrigerator proves the sufficient thermal isolation of the stages and also the sufficiently low power consumption of the amplifiers.

4. Conclusion

The low noise and good thermal isolation properties of the presented cryogenic experimental set up mounted in He^3 refrigerator enabled us to carry out experiments on high quality coplanar wave guide resonators in the 2.2-3 GHz frequency range at 300mK.

At the same time, we have demonstrated that pHEMT ATF34153 transistors are suitable for very low noise and low power cryogenic amplifiers required for installation in cryogen free refrigerators.

Acknowledgement

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[4] datasheet available at: www.analog.com/static/importedfiles/data_sheets/AD8347.pdf