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Superconducting Matching Circuits for an Oscillator and an SIS Mixer in the Subterahertz Frequency Range

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Abstract—At present, microwave transmission lines are characterized by a strong frequency dependence of loss in the subterahertz range. This work is aimed at development, research, and optimization of superconducting integrated circuits designed for matching the impedances of a long Josephson junction oscillator (a so-called “flux-flow oscillator”) and a superconductor–insulator–superconductor (SIS) detector in the subterahertz frequency range. The goal of this study is to improve and approve the numerical calculation methods, which make it possible to describe correctly experimental superconducting structures in a wide frequency range. Numerical calculations of integrated circuits have been performed in order to optimize the topology and parameters of transmission lines. The main parameters of the transmission lines and their influence on the signal propagation are determined. The results of optimization of integrated matching circuits in the range of 450–700 GHz have been experimentally confirmed. Optimization and improvement of transmission lines allow one to design new-generation integrated superconducting detectors and investigate tunnel SIS junctions more thoroughly (including shunted ones) and the properties of heterodyne oscillators based on long Josephson junctions.

Keywords: integrated matching circuits, long Josephson junction, superconducting devices, subterahertz oscillator

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INTRODUCTION

The lack of solid-state sources of cw THz radiation with a possibility of fine frequency tuning (which is especially pronounced in the frequency range from 500 GHz to 1.5 THz) is stimulating studies on their development and analysis. Improvement of integrated matching circuits (microwave transmission lines) will make it possible to design and investigate terahertz sources based on an array of synchronous junctions providing frequency tuning in a wide frequency range. In addition, such circuits will be applied for designing new-generation integrated subterahertz detectors. The progress in technologies of generation and detection of terahertz radiation is urgent for not only scientific research in various fields of physics, astronomy, metrology, and biology, but also for some applied problems (e.g., in medicine and security systems).

The niobium integrated circuits under study are designed to operate in the frequency range of 200–700 GHz. Their upgrade includes optimization of the topology of components and fitting of the transmission line parameters, such as thickness and material of the dielectric layer, geometric sizes of the structural elements, detector characteristic, and temperature. The structures are optimized in the device design stage using known models taking into account the penetration of a magnetic field into the superconductor and loss in niobium electrodes in the near-gap voltage region. The main purpose of this study is to develop and approve numerical calculation methods, which make it possible to describe correctly experimental superconducting structures in a wide frequency range from 200 to 700 GHz and to optimize matching circuits in a required frequency range.

INTEGRATED MATCHING CIRCUITS

A microwave flux-flow oscillator (FFO) oscillator based on the long Josephson junction and a superconductor–insulator–superconductor (SIS) detector are located on the same substrate and connected by a transmission line. A micrograph of an experimental sample is given in Fig. 1.

Each element of the transmission line is characterized by geometric sizes, which affect significantly the impedance matching coefficient for the oscillator and the detector and, accordingly, the signal transfer between them.

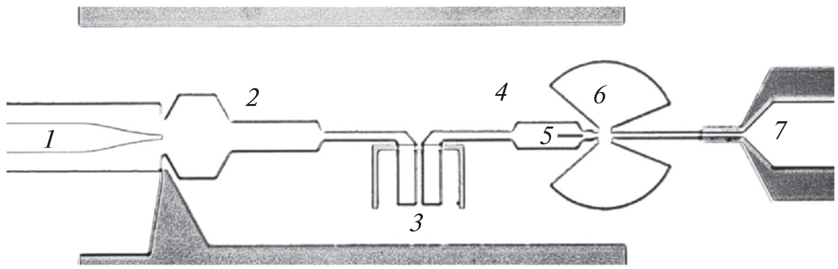

Fig. 1. Integrated matching circuit. (*1*) FFO oscillator, (*2*) three-step impedance transformer, (*3*) DC-block, (*4*) two-step transformer, (*5*) SIS detector, (*6*) radial stub, and (*7*) output coplanar line.

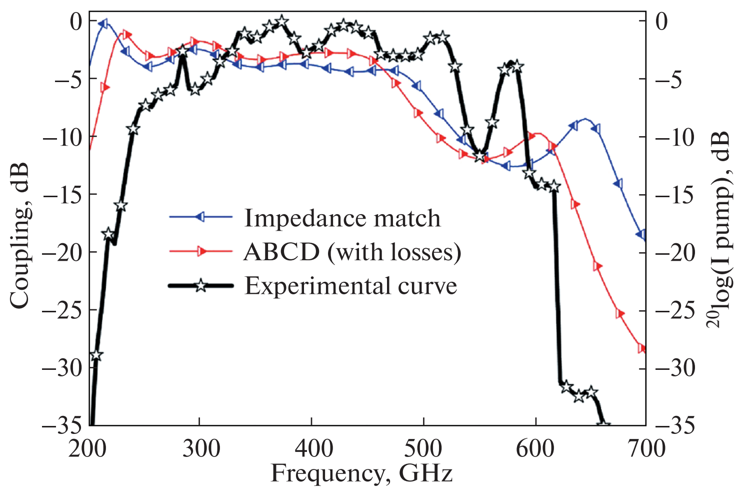

Fig. 2. Comparison of the experimental data and the calculation results.

The influence of parameters of individual elements of the matching circuit on the signal transfer can be determined experimentally by preparing sets of samples with different geometries of the matching circuits. However, this approach would be very time-inefficient, because the necessary number of different structures cannot be produced in short time due to technological features of the production process. In this context, the program for calculating transmission lines was developed.

SIMULATION OF TRANSMISSION LINES

The simulation was performed using two models, which make it possible to calculate the character of microwave signal propagation via a transmission line (Fig. 2).

The first model provides calculations of the impedance matching coefficient for the microwave oscillator and the detector in a required frequency range. The impedance conversion function (which is actually performed by a system of impedance transformers, see Fig. 1) can be used to calculate the match between the oscillator and the detector for a specified frequency.

The second calculation model is based on the ABCD matrix method [1]. Each element of the circuit is put into correspondence with the signal transfer matrix. These matrices can be used to calculate the ratio of the power loss at the SIS junction to the power emitted by the oscillator at a specific frequency [2]. A significant advantage of this approach is that the propagation loss in the transmission line can be taken into account. The magnetic field's penetration into superconducting line electrodes and the loss in the line at high frequencies (above 600 GHz) can be taken into account using a modified Mattis–Bardeen theory [3, 4].

Both the described models have the possibility of varying any parameter of each element of the matching circuit, which makes optimization possible.

HIGH-FREQUENCY TRANSMISSION LINES

The obtained models were applied for designing devices operating in the range of 450–700 GHz. The calculation results and the experimental data for the samples under study are compared in Fig. 3. Two matching circuits were implemented, with different

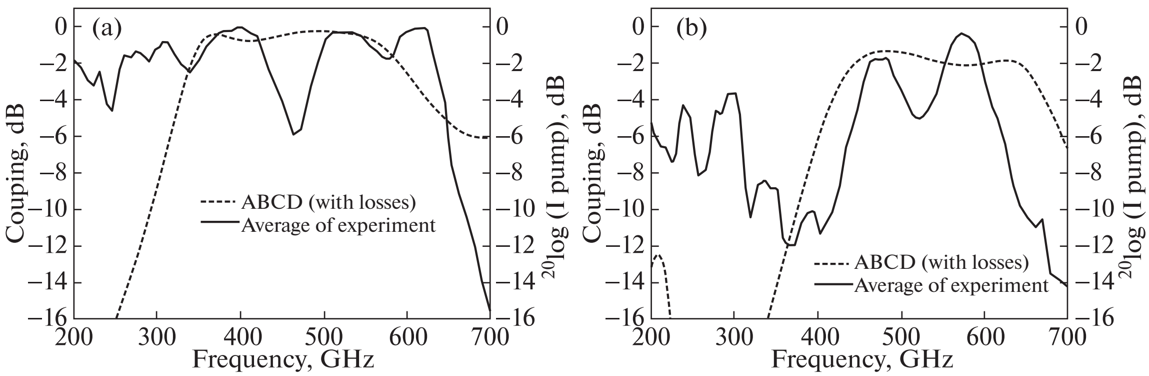

Fig. 3. Frequency dependences of the normalized pump current using (a) a two-step transformer and (b) a one-step transformer.

impedance transformers between the low-frequency blocking element and the SIS detector (element *4* in Fig. 1). For the first circuit, the transformer is conventional (two-step). In the second circuit, a one-step transformer was placed before the microstrip line containing the SIS detector. The power losses range from –6 to –1 dB in the larger part of the range of 450–700 GHz. As was suggested, the version with the one-step transformer has a narrower matching band but provides lower loss, which may be important when operating at close-to-gap frequencies.

CONCLUSIONS

The influence of the main parameters of integrated matching circuits on the microwave signal transfer between an FFO oscillator and an SIS detector in the subterahertz frequency range was determined. The developed and approved models of transmission lines made it possible to optimize the topology of the matching circuits. The calculation results obtained were used to design samples for the frequency range of 450–700 GHz. The performed investigations confirmed the possibility of significant expansion of the matching band for samples with superconductor–insulator–superconductor detectors with high current densities. The influence of the operating temperature on the working frequency range of integrated FFO–SIS structures was analyzed.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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