INTEGRATED RECEIVING STRUCTURE COMPRISING COMPLEMENTARY SPIRAL ANTENNA AND TUNED PARALLEL BIASED SIS ARRAY

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Abstract Integration of SIS junction arrays with planar wide band antenna allows to increase instantaneous bandwidth of receiver up to octave in comparison with rather narrow-band traditional waveguide mixers with SIS junction arrays or planar antennas with integrated single microstrip transformer and single SIS junction. Integrated receiving structure comprising self-Babinet-complementary spiral antenna, array of SIS junctions connected in series as seen by the RF but are parallel DC-biased through the same inductors that provide the tuning for the SIS junctions capacitance has been designed and experimentally studied. Array was designed for 80-160 GHz wave band and consists of 5 SIS junctions 1.5 μm^2 area each, 6 inductive short-ended slotlines and 2 decoupling capacitances. Effective direct detector bandwidth of such structure with quantum efficiency equals unity has been estimated as wide as 70 GHz. Noise temperature of heterodyne mixer has been measured in three-lens Gaussian beamguide by means of hot/cold loads method, yielding receiver DSB noise temperature 80 K. IF mixer port load bandwidth and thermal background radiation influence on IV curve and saturation of SIS mixer have been studied.

I. INTRODUCTION

The best SIS mixer noise temperatures has been achieved using waveguide horn based receiver systems [1,2]. Method of series RF and parallel DC-biasing through the same inductors that provide tuning-out SIS junction capacitance is very useful for such mixers [1]. The advantages are that all SIS junctions have the same bias voltage, thus reducing the uniformity constraints on the manufacturing tolerance of the array, and that the IF impedance of the mixer, just as for the DC-bias, is a parallel circuit of the individual IF impedances of the SIS junctions, thus making it possible to design the array to have an IF output impedance of about 50 Ω. Such method allows to achieve good matching in millimeter wave band.

The waveguide type SIS mixers signal frequency increasing over achieved values ~500 GHz [2] is connected with increasing problems of mechanical elements fabrication tolerances and increasing with frequency losses in waveguides and plungers. From radioasronomy point of view much easier is to use quasioptical methods of focusing and transmission of initial signal which is presented at the output of radio telescope as a gaussian beam.

Combining of quasioptical beamguide and wide bandwidth planar antenna allows to design more broadband than waveguide type receiver system with conversion gain and noise temperature close to the best achieved in waveguide type mixers [3]. Among disadvantages of quasioptical systems may be mentioned the absence of tuning elements and possibility of antenna-substrate interaction, which can lead to beam pattern distortion at some frequencies.

Advantages and drawbacks of both mentioned methods leads to conclusion about combining series-parallel arrays and integrated planar antennas in order to obtain effective mixer matching in wide bandwidth and increasing of central frequency up to 700 GHz and higher. In such system problems of external broadband thermal radiation on mixer parameters and its saturation should be carefully studied.

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II. INTEGRATED STRUCTURE

In our experiments we use equiangular self-Babinet two-arm spiral antenna similar to [3] with shape according to relation $r=R_0 exp(a\phi)$ where r and ϕ - polar coordinates, a and R_0 - constants (see Fig. 1a). Value of a=0.36 was chosen as compromise between

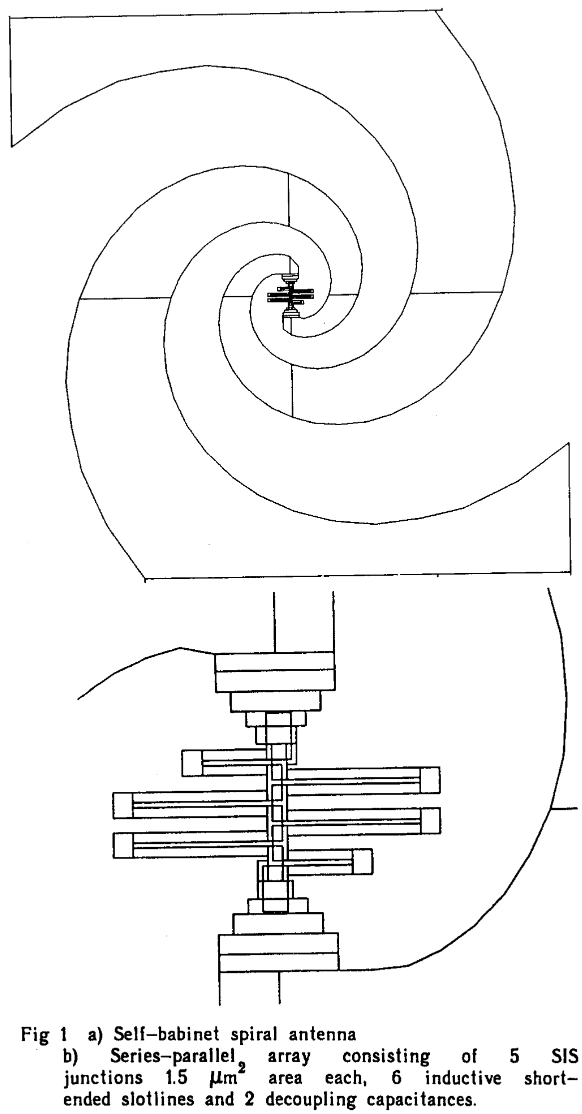

Fig 1 a) Self-babinet spiral antenna
b) Series-parallel array consisting of 5 SIS junctions 1.5 μm^2 area each, 6 inductive short-ended slotlines and 2 decoupling capacitances.

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two cases of wider beampattern with lower and more elliptical beampattern with higher values. Impedance of such antenna placed on quartz hyperhemisphere corresponds to relation $Z_{ant}=Z_0/(0.5+0.5n^2)^{1/2}\approx114\ \Omega$ in more than decade frequency band.

SIS junction array (Fig. 1b) consists of five junctions. Six sections of end-shorted slotlines were used for parallel connection of junctions and capacitances tuning out. The central sections are 140 μm long and outer sections are 70 μm long. Area of each junction is 1.5 μm^2 and the whole structure designed for central frequency 115 GHz is equivalent to single junction of 0.3 μm^2 area.

Such integrated circuit operates without additional choke filters in IF channel preventing signal leakage because spiral antenna itself has a useful property of automatic currents cutoff which means that only central part of antenna takes part in signal receiving. The length of such active part of antenna not exceeds the signal wavelength, i.e. 2–3 mm in our case.

III. STUDIES OF BEAMPATTERNS AND BEAMGUIDE ADJUSTING WITH BISMUTH BOLOMETERS INSTEAD OF SIS ARRAY

In order to make direct measurements of antenna beampattern and to precisely adjust 3–lens beamguide at room temperature we fabricated similar structures with golden antenna of the same shape and bismuth microbolometer instead of SIS array. Bolometers were made of Bi film 200 nm thick, 30 $\Omega/\square$ resistance, 3 μm width and 9–16 μm length. Beampatterns of bare antenna on quartz substrate, the same on quartz hyperhemisphere lens and also with counterreflector behind antenna are shown in Fig. 2. Data presented in Fig.2 are normalized to maximal signal corresponding to the last case.

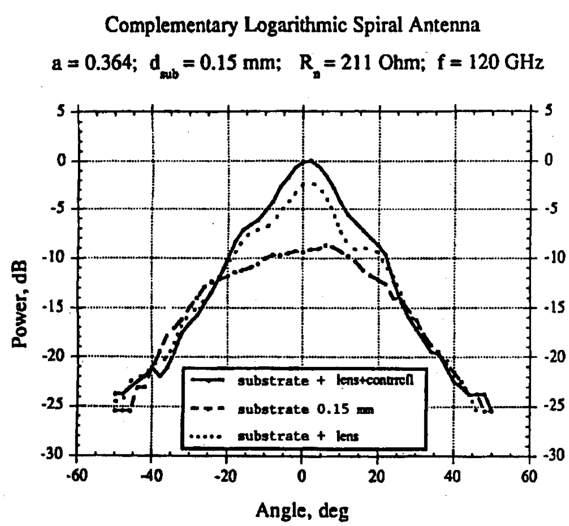

Fig 2 Beampatterns of spiral antenna on quartz substrate, the same on quartz hyperhemisphere lens and with counterreflector.

The optimal length of hyperhemisphere cylindrical part was found to be a little more than calculated $l=r/2$ and for correction of this length we use two additional quartz substrates of 0.1 mm thickness between the substrate with antenna and the lens.

Antenna with such immersion lens and counterreflector was placed in wet cryostat 3–lens gaussian beamguide insert, which was adjusted with bismuth bolometer instead of SIS array. For such measurements reflector was placed instead of beamsplitter and modulated LO signal was received in lock–in detector mode.

IY. MATCHING, SATURATION AND NOISE IN IF PORT

In IF channel cold amplifier and cold circulator were used to prevent standing waves at the output of the mixer. Such amplifier was matched with SIS array in bandwidth over 0.5 GHz, which may lead to the mixer output saturation. For mixer dynamic range increase it is desirable to make IF band narrower and short–circuit its output out of this band. For this purpose we tested two types of filters. First consists of microstrip line section and decoupling capacitor, and the second – of antenna+leads inductance and capacitor comprising together series resonant circuit.

Matching efficiency at IF was estimated from IF port noise temperature, measured with SIS junction shot noise as noise source. In general current noise in SIS junction corresponds to the relation $I_N^2=2eI\cdot\Delta f\cdot coth(eV/4kT)$ which is reduced to simple shot noise relation $I_N^2=2eI\cdot\Delta f$ for voltages above the energy gap. Illustration of this formula is presented in Fig.3 which corresponds to IF port noise temperature 17 K.

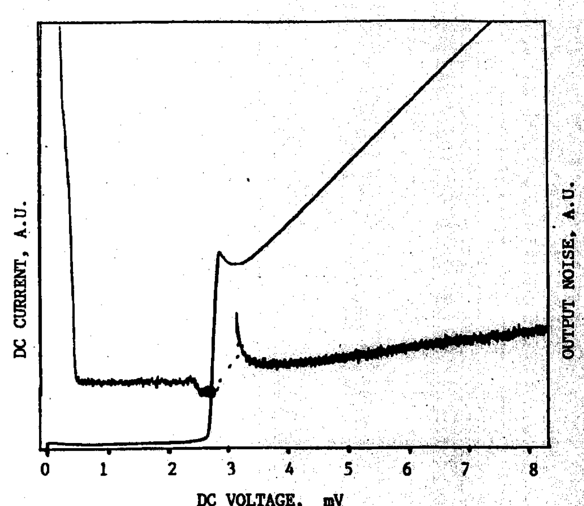

Fig 3 IV curve and IF output noise dependence on SIS junction dc voltage bias.

Y. RECEIVER NOISE TEMPERATURE MEASUREMENTS

Noise temperature of the receiver was measured in DSB mode with hot (300 K) / cold (80 K) loads. In this experiments a sufficient influence of hot/cold switching on IV curve and IF noise was observed even in the absence of LO power for array with dc resistance 20 Ω (Fig.4.). This fact is clear illustration of mixer input saturation by broadband of the order of 100 GHz thermal radiation with effective temperature 300 K. Observed in the same experiment rather high noise temperature 180 K at 108 GHz is due to this saturation effect.

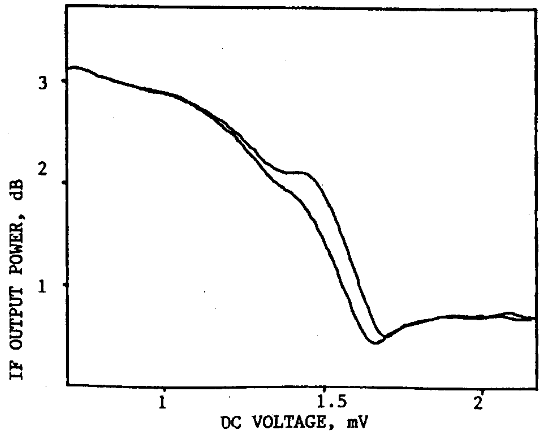

Fig 4 IF noise in the absence of LO power for 20 Ω dc resistance SIS array for hot and cold input loads.

Another SIS array with 10 Ω normal resistance was tested with switching on and off additional cold attenuator with losses 3.8 dB. The noise temperature with opened attenuator was 350 K, and with closed attenuator 200 K. For another cold attenuator with 8.8 dB losses the noise temperature was 250 K and 80 K for opened and closed cases correspondingly (Fig.5). These experiments show that the main problem for such very broadband SIS mixers is the output saturation and it may be solved by restricting input and output bandwidths.

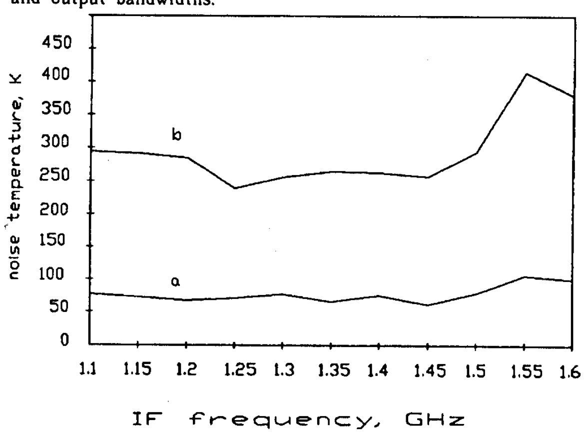

Fig 5 Receiver noise temperature with and without 8.8 db cold attenuator.

YI. THERMAL RADIATION INFLUENCE ON IV CURVE

In Fig. 6 IV curves of 20 Ω SIS array for opened (a) and closed (b) 8.8 dB cold attenuator cases are presented. Noise temperature at mixer input was correspondingly 300 and 45 K. At IV curve are clear seen three characteristic features corresponding to:

–fast response to 45/300 K switching near the energy gap voltage $V \le V_{2\Delta}$ with current amplitude $\Delta I \approx 0.5\ \mu A$,

–fast response of Josephson current with $\Delta I_c \approx 6\ \mu A$,

–slow "bolometric" response in the intermediate voltage region with time constant around 2 s.

Described effect of SIS array IV curve changes

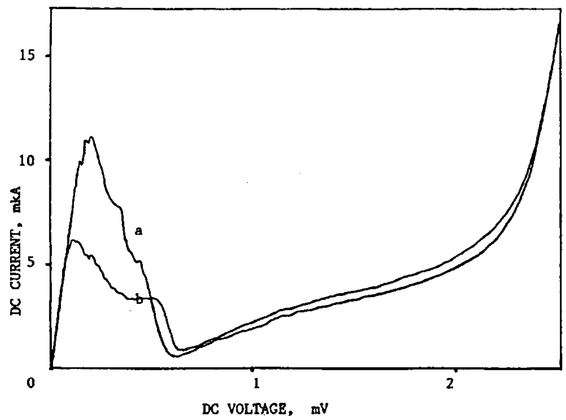

Fig 6 IV curves of 20 Ω SIS array for opened (a) and closed (b) 8.8 db cold attenuator. At low voltages a stray series resistance is seen on IV curve.

due to cold attenuator switching on may be described by simple model of quantum detector response to broadband thermal radiation. In the case of quantum efficiency equals unity $dI/dP=e/hf$ for central frequency 100 GHz, temperature variation ΔT=250 K the observed current variation ΔI=0.5 μA corresponds to 70 GHz matched bandwidth.

Described effect partially may be connected with wide bandwidth thermal IR radiation. Such radiation can be depressed by more then 100 times by cold fluorogold filter [4]. In our experiments insertion of cold fluorogold filter 0.75 mm thick gives rise to 2 dB additional losses at 90 GHz which is too much for practical receiver.

DISCUSSION AND SUMMARY

New type of superconducting receiving element comprising complementary spiral antenna and series–parallel SIS array with individual tuning of each SIS junction has been designed, fabricated and experimentally studied. Optimization of beamguide and its adjusting using bismuth bolometers allow to receive radiation in wide frequency band over 70% of central frequency with quasiparticle detector quantum efficiency close to unity. Josephson detection efficiency was one order higher.

Such wide bandwidth matching leads to saturation of receiving structure by thermal radiation with effective noise temperature over 50 K. In the case of inserting cold attenuator the noise temperature of quasiparticle heterodyne receiver at 85 GHz was 80 K.

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