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A BROAD BAND LOW NOISE SIS RADIOMETER

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Abstract—**A new type of ultra broad band SIS low noise radiometer has been developed. The SIS receiver instantaneous band of about 30% is significantly increased compared to traditional designs. We avoid a restriction related to the limited band of the Intermediate Frequency (IF) low noise amplifier by using a multifrequency heterodyne power source. In this regime the frequency mixing is performed simultaneously in a big number of the subbands and the IF signals are combined in a common amplifier. A low noise operation in this regime is possible due to the quantum nature of the frequency mixing in SIS quasi particle tunnel junctions.**

The SIS receiver covers 25 GHz band centered at 90 GHz with an equivalent noise temperature of about 50 K. The receiver uses a fixed tuned SIS mixer with Nb/Al Ox/Nb junctions. The critical Josephson current density is about 2.6 KA/cm^2 and the junction area is of about 1.5 μm^2. The limits to further improvement of the radiometer and the possibilities for extension of the technique to the sub millimeter band are discussed.

I. INTRODUCTION

The development of ultra low noise millimeter wave broad band radiometers is required for several different applications, particularly for the detection of weak radiation of distant objects in radio astronomy. The sensitivity ΔT of a radiometer may be characterized by a relation:

$$\Delta T_{\mathrm{Rec}} = T_{\mathrm{Rec}} \sqrt{\frac{1}{2\tau B}} \qquad (1)$$

where *Trec* is an equivalent receiver noise temperature, *B* is the receiver bandwidth and τ is the integration time. Optimizing the operation of a radiometer according to (1), one has to try to increase the receiver bandwidth B and to reduce the receiver noise *Trec*.

During the last decade the best receiver noise at short mm and sub millimeter wavelength was obtained using SIS heterodyne receivers [1], achieving a noise temperature close to $2h\upsilon/k$ [2,3].

There are two main limitation to the bandwidth of an SIS receiver. The input SIS receiver bandwidth is limited due to a large SIS junction capacitance. The output receiver bandwidth is limited by the bandwidth of the low noise IF amplifier.

Normally the problem of a relatively broad band coupling of the SIS junction with the signal source may be solved, using a super conductive integrated matching circuit [4,1]. A real limitation of the SIS receiver bandwidth is imposed by the difficulty of development of a broad band low noise intermediate frequency (IF) amplifier. The problem arises from an increase of the IF amplifier noise with the enlargement of the IF bandwidth.

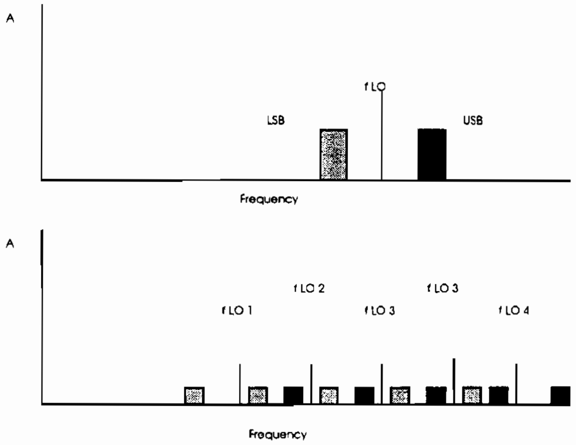

Fig. 1. The frequency diagram of a common heterodyne receiver (upper drawing) with the local oscillator frequency *f lo* and with low and upper side bands (USB and LSB). The lower diagram illustrate the operation of a heterodyne receiver with a multifrequency local oscillator. The bandwidth of the receiver is increased, proportionally to the number of the components in the spectrum of local oscillator.

In this work we present a method of increasing the receiver bandwidth *B* by a factor of 10-100, thus improving the receiver sensitivity wile using a single common IF amplifier chain.

First we discuss the principle of the new mode of SIS receiver operation. Then we describe a fixed-tined SIS mixer developed for this experiment and the test set up. At the end we give the description of the receiver tests and the perspective for further development.

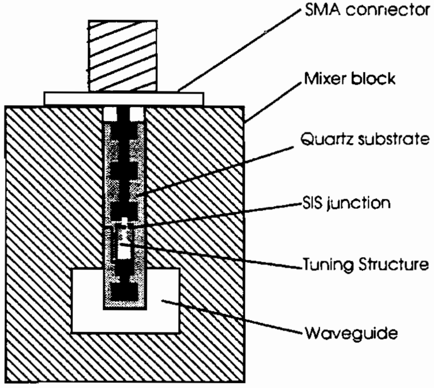

Figure 2. A fixed tuned SIS mixer design. It is a single backshort mixer block with a full height 2.3×1.15 mm waveguide. The printed circuit is coupled to the waveguide with a matching probe in the 70 - 130 GHz band. The non contacting backshort position once adjusted remains fixed in the waveguide.

II. APPROACH

We propose a new mode of broad band operation of a mixer with a SIS quasi particle tunnel junction using simultaneous mixing of the signal with the local oscillator having a multiline spectrum. In this way the effective receiver RF bandwidth is increased by the number of the components in the spectrum of the local oscillator (Fig. 1). There the upper drawing represents the operation of a receiver in a common mode, with a monochromatic local oscillator signal. Below is presented frequency diagram of the proposed receiver. A new approach allows one to use a relatively low intermediate frequency in a broad band SIS radiometer and to benefit from the low noise of an ultra low noise cryogenically cooled HEMT amplifier. This mode of operation is not efficient with a classical mixer, where one needs to increase significantly the total power of a local oscillator to keep a sufficient amplitude of each component of the local oscillator.

An efficient multifrequency mixing in SIS junction is possible due to a quantum nature of the mixing mechanism. The non linear properties of an SIS quasi particle tunnel junction do not strongly depend on the amplitude of the local oscillator, but on the photon energy. At the each frequency of the local oscillator the power may be low, providing a sufficiently large conversion gain.

For example, in our experiment the monochromatic local oscillator of a broad band fixed tuned SIS receiver is replaced by a harmonic generator. Using a 1.2-1.8 GHz IF band and a 2 GHz spacing of the local oscillator frequencies across the 75-120 GHz frequency range we obtain the operation of a receiver with the RF bandwidth increased 22 times, of about 27 GHz in total.

III. SIS MIXER DESIGN

The waveguide mixer design is presented in Fig. 2. The SIS mixer comprises a microstrip Nb circuit with SIS junction

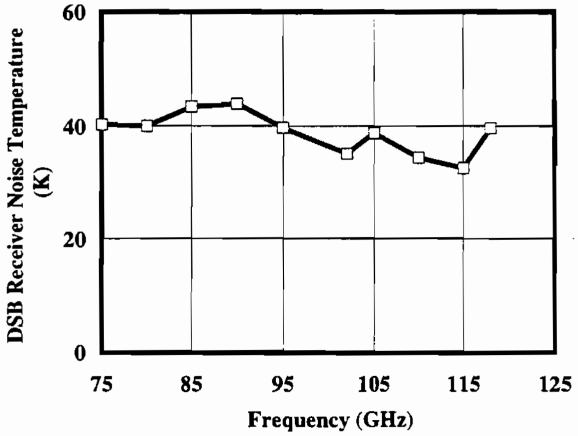

Figure 3. Fixed-tuned SIS mixer operation with a monochromatic local oscillator. The 1.2 - 1.8 GHz band of the intermediate frequency amplifier defines the limits of the receiver bandwidth.

printed on a 0.2 mm thick quartz substrate and a mixer block. The mixer block uses a single backshort in a full height 2.3×1.15 mm waveguide. The printed circuit is coupled to the waveguide with a matching probe in the 70 - 130 GHz band [5]. The non-contacting backshort position once adjusted remains fixed in the waveguide.

The printed circuit of the mixer is optimized for the junction normal resistance of about 50 Ohm and $R_N\omega C \approx 4$. The Nb-Aloxide-Nb SIS junction has an area of 1.5 μm^2. The coplanar inductive tuning circuit is connected to the junctions as part of the top electrode layer in the junction fabrication process (Fig. 2). The coplanar design gives a wider operation band and a better tolerance of the manufacturing imperfections of Nb printed circuit [6]. Coplanar line parameters are calculated with GPLINES program and the circuit was developed using the EESOF Libra program. The bandwidth of the SIS junction match in the mixer is expected to be about 50 GHz.

IV. TEST RECEIVER

The receiver comprises a liquid helium cryostat, a SIS mixer, a cooled HEMT IF amplifier, an ambient temperature amplifier and the local oscillator.

In experiment we used two different type of local oscillator. A 3 mm harmonic source pumped with a 2 GHz signal was used for the broad band mode of operation. In the normal mode of operation a Gunn device was used as a local oscillator. The local oscillator power was injected at the mixer input by a cooled waveguide coupler. The cooled intermediate frequency amplifier used in the experiment had about 5 K noise temperature in the frequency range of 1.2-1.8 GHz [7]. An isolator was fitted between the SIS mixer and the first IF amplifier. The receiver input window with anti-reflection grooves is made of polyethylene and an infrared filter of expanded polystyrene foam was fixed to the 77 K shield. The mixer block was at a temperature of about 4.5 K.

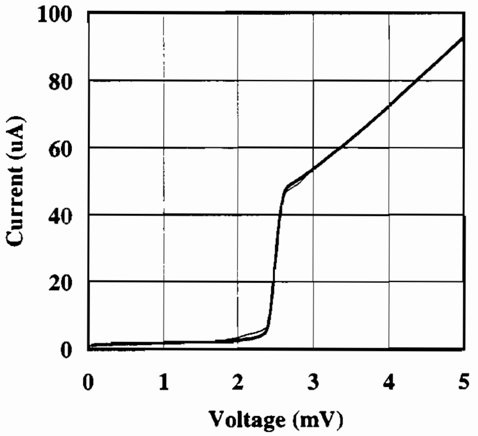

Fig. 4. Current-voltage characteristic of the SIS junction with and without multifrequency local oscillator power.

The design of the test receiver has the same features as a real receiver: the same windows and infrared filters on the way of the signal beam to the SIS mixer, the same amplifier and the same temperature at the mixer block. The receiver performance observed in laboratory may be reproduced without constraints at a radio telescope.

V. FIXED TUNED SIS RECEIVER OPERATION

A. Monochromatic local oscillator

The fixed-tuned SIS mixer was tested first with a monochromatic local oscillator power source. The receiver double sideband noise temperature versus frequency dependence was determined in a standard experiment with the ambient temperature (295 K) and the 77 K liquid nitrogen cooled loads (Fig. 3). The receiver DSB noise temperature of 40 K was nearly constant in the 75 - 118 GHz frequency range.

This confirms the design expectation of a broad, about 50%, bandwidth for the SIS junction coupling to the signal source. The two sidebands of a broad band SIS receiver have to be in balance in a major part of the band. The total receiver bandwidth at each frequency of the local oscillator is limited by the IF chain and is about 1.2 GHz.

B. SIS receiver with a multifrequency heterodyne source

In this experiment we used as a local oscillator a harmonic generator pumped with a 2 GHz signal. Across the 75-120 GHz range the number of the harmonics produced by this source is about 22. In the next subsection we will demonstrate the mixing of a broad band signal with each component of the local oscillator spectrum.

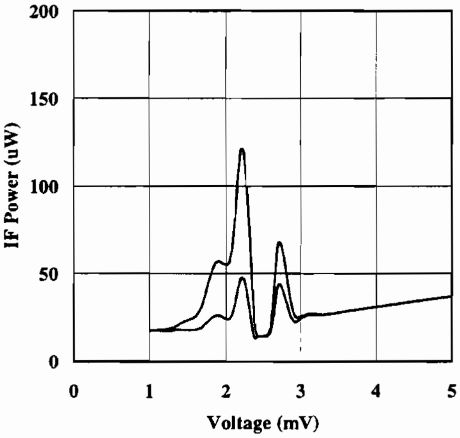

Fig. 5. Receiver IF power versus bias voltage with the multifrequency local oscillator power source. The upper and lower curves are measured respectively with the 295 K and with the 77 K loads in front of the receiver.

The current - voltage characteristics of the SIS junction measured with and without radiation from the multifrequency local oscillator is shown in Fig. 4. The receiver IF power versus bias voltage measured with the multifrequency local oscillator is shown in Fig. 5. The upper and lower curves are measured respectively with the ambient and with the liquid nitrogen temperature loads in front of receivers. The current detected in the SIS junction of about 4.5 μA was lower, compared to the experiments with the monochromatic local oscillator, which was typically about 10 μA. Nevertheless the receiver noise temperature measured in the new regime is only 55 K, close to the receiver noise temperature in a usual narrow band mode of operation.

C. Receiver spectral response with the multifrequency local oscillator

We verified the reality of the simultaneous mixing with a large number of local oscillator frequencies by injecting a signal of a small amplitude from a second harmonic generator (Fig. 6). The harmonic source producing the local oscillator power was pumped with a 2.000 GHz signal. The signal harmonic source was pumped at a frequency 2.030 GHz, producing signals in the upper sideband of the all subbands of the receiver (upper drawing in Fig. 6). The measured response across the IF band is in the lower part of Fig. 6. The number of spectral lines corresponds to the number of the subbands in the receiver.

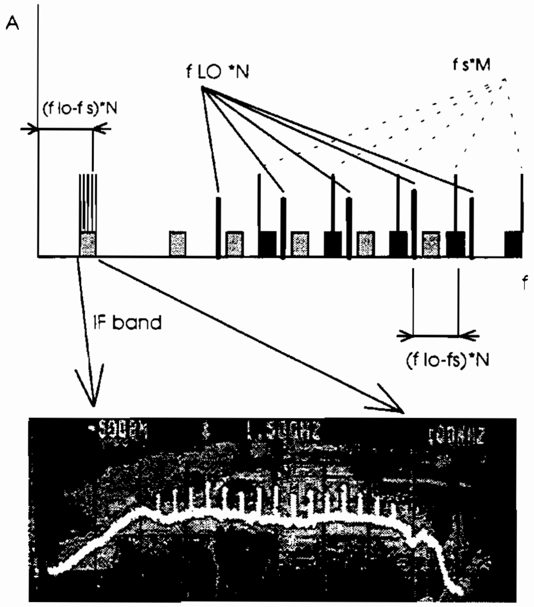

Fig. 6. The receiver with a harmonic source as a local oscillator receive a signal from a second harmonic source, pumped at a slightly different frequency. Upper drawing gives the diagram of the signals, local oscillator and intermediate signal frequencies. Below is a measured IF spectrum. The number of the component in the IF spectrum corresponds to the number of the local oscillator frequencies and confirms the expected mode of receiver operation.

V. SUMMARY

We have demonstrated a possibility of making a low noise SIS radiometer with a detection bandwidth many tens of times larger than in the standard design. The new type of a broad band operation of a mixer with a SIS quasi particle tunnel junction uses the simultaneous mixing at the different frequencies of the local oscillator with a comb type spectrum. This allows one to use a relatively low intermediate frequency in a broad band SIS radiometer. The efficient multifrequency mixing in a SIS junction is possible due to the quantum nature of the mixing mechanism. In the experiment a monochromatic local oscillator of a broad band SIS receiver was replaced by a multifrequency harmonic source. Using a 1.2-1.8 GHz IF band and a 2 GHz spacing of the local oscillator frequencies we obtained an operation of the receiver with a RF 25 - 30 GHz bandwidth around 100 GHz with a 55 K noise temperature.

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