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A 350 to 700 GHz open structure SIS receiver for submm. radioastronomy

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Abstract: An open structure SIS receiver, used already for astronomy at 345 GHz was tested at 470 and 690 GHz. Receiver noise temperatures considerably better than those of standard systems based on Schottky diode mixers were accomplished. A specific merit of this system is the option to change the range of input frequencies by simply mounting a specific mixer element in a standard mixer block and by exchange of the output horn at the solid state local oscillator.

1. Introduction

The status of submillimeter receiver technology was reviewed recently [1]. Although Niobium superconductor-isolator-superconductor (SIS) junctions should be applicable to twice the gap frequency (1.4THz) in theory [2] it was not clear whether a real system could even approach the gap frequency (~ 700 GHz) with reasonable performance. This and other successful projects working between 600 and 720 GHz [3-6] open the 690 GHz atmospheric window to SIS technology. The atmospheric window around 470 GHz is exploited already by SIS receivers [7,8]. The advent of SIS receivers in a new wavelength range not only provides a sensitivity 5 - 10 times better than that of Schottky mixers, it also means an enhancement in capability as soon as molecular lasers are replaced by solid state sources with 10% tuning range and synthesizer performance as local oscillator.

2. Receiver

At mm wavelengths receivers are built in waveguide technology, coupling with efficient horn antennas to the telescope. At submillimeter wavelength a waveguide mixer is expensive and difficult to make. Open structure mixers, pioneered by [9,10], usually make up in transmission what they lack in coupling efficiency. Beyond that they cover a large range of wavelength. This system (fig.1), used previously at the 30m antenna on Pico Veleta between 290 and 360 GHz [14], was converted to 470 GHz and 700 GHz by adjustments to the dewar windows, the local oscillator (LO) and by a novel mixer element. At frequencies above 400 GHz where LO power from solid state sources becomes scarce and Josephson oscillations start to interfere with LO frequency (fig. 4), a single SIS junction offers a vast advantage over a series array at two junctions.

The mixer element is placed in the focal plane of the elliptical immersion lens. The mixer block and a HEMT-amplifier are mounted in a commercial 3 liter l-He dewar (fig. 3). The solid state local oscillator (LO) consists of a 110 to 120 GHz Gunn oscillator followed by a varistor type frequency multiplier [11,12], which achieves the necessary multiplication factor of 3,4 and 6 in one step. The LO is coupled into the signal path with 20-50 μ m Mylar foils.

3. Mixer element

The mixer element (fig. 2), an antenna coupled SIS tunnel junction of submicron dimensions, has all essential components on a $0.2 \times 0.8 \times 5$ mm substrate. The mixer block with a immersion lens of 1 cm diameter is used from 300 to 700 GHz by exchange of the mixer element, where the dipole feed, the matching circuit and the bandstop filter are scaled to the wavelength. Antenna coupled detectors are getting increasing attention in both coherent and incoherent applications [13,14]. Planar dipoles with a integrated detector are used at frequencies as high as 30 THz [15]. A planar dipole was chosen as a feed antenna because it combines low source impedance with sufficient bandwidth and moderate antenna gain. It can be scaled reasonably well to an environment where the antenna radiates into a halfspace filled with a dielectric medium such as a substrate lens.

Submicron dimensions for the SIS junction are accomplished by crossed resist lines of $0.6 \mu\text{m}$ width [16]. Around 700 GHz, any SIS junction is operated far above its RC limit. Its intrinsic capacitance completely shorts an antenna, unless a circuit is added which essentially removes the shunt capacitance by a resonance. We use a stripline transformer in between junction and antenna because of its simplicity and large error margin [14]. The stripline is implemented using the quartz layer deposited for junction definition as a dielectric. The 320 nm quartz layer, twice as thick as in conventional SIS mixers because of the crossed resist line process, provides a much smaller insertion loss in the matching circuit and a phase velocity, less dependant on the London penetration depth.

A bandstop filter isolates the LO and signal frequencies from the IF and bias circuitry. It consists of two $\lambda/4$ sections of transmission line, the first in coplanar geometry of 120Ω , the second in stripline geometry of 8Ω .

4. Results

Receiver noise temperature (fig. 4) was measured with the LO set to 690.000 GHz which puts the (6-5) line of ^{12}CO into the middle of the upper sideband. As the synoptic input bandwidth of the mixer is >30 GHz [14] and the response of the mixer is flat (fig. 5) at this frequency, the sideband ratio must be 1/1 leading to a single sideband (SSB) noise temperature of <1000 K for the CO line. The IF signal is continual all over the gap apart from one double peaked spike at a bias voltage of 1.427 mV where the Josephson oscillation coincides with the LO frequency (fig. 4). For a single junction the Josephson effect can be suppressed by a magnetic field almost perfectly as shown in fig. 4 where the residual interference raises only 30% over the IF signal from a thermal source.

A noise budget [6] indicates an insertion loss, 8 dB higher at 690 GHz than at 350 GHz for identical LO induced DC mixer current, corresponding to a factor of 6 lost somewhere in the signal path in front of the mixer. Lowering the He bath temperature from 4.2 to 2.5 K has no effect on the mixer gain and LO response at 345 GHz, whereas both parameters are improved by a factor of 1.4 at 690 GHz.

In order to verify heterodyne operation, the (6-5) CO line (fig. 6) was measured. It is difficult to verify a receiver noise temperature with such a test quantitatively. For the experimental setup the signal to noise ratio is consistent with 1000 K single sideband noise temperature measured by the Y-factor method.

The Josephson interference at 1.427 mV bias voltage was used to verify the voltage calibration of the bias circuitry. We find a gap voltage for the junction of 2.81 mV at 2.5 K corresponding to the gap frequency of 680 GHz plotted as a vertical line in fig. 5. As the receiver noise is even somewhat lower above the gap frequency [2] is confirmed. In addition fig. 5 gives noise temperatures at 345 and 470 GHz from scaled mixer elements.

5. Conclusion

Submicron lithography puts the normal resistance and static capacitance of single SIS junctions of high current density in a range of magnitude which can be matched well to a resonant antenna. This progress in junction technology probably makes series arrays of junctions obsolete. Specific advantages of a single junction are high quantum efficiency, low LO power requirement and negli-

gible Josephson interference [6]. Open structure mixers based on a substrate lens are efficient, cost effective and convertible to higher frequency bands. As tuning is not required once the backplane is adjusted, they are a good candidate for array receivers. Keeping in mind that the largest part of the submillimeter range is blocked by atmospheric water vapour, a decisive scientific breakthrough will come from a satellite mission. The status of cryogenics, SIS mixers and solid state oscillators make such a mission feasible now at reasonable costs.

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fig. 1: Left: Mixer block with an aspheric immersion lens of crystal quartz and superconducting coils for suppression of the Josephson effect. Right: Cross section of the mixer.

fig. 2: Microphotograph of the 690 GHz mixer element, an antenna coupled $0.6 \times 0.6 \mu m$ SIS junction.

fig. 3: Left: 350 to 690 GHz SIS receiver with lHe dewar, Mylar coupler and solid state LO above the coupler. Right: Local oscillator with a 350 GHz horn mounted. 470 and 700 GHz horns in the foreground.

fig. 4: i/v curves of the SIS junction with the LO switched on and off. Lower right : IF power (1250 MHz in 50 MHz bandw.) versus mixer bias voltage for reference loads at 290 and 77K and with the LO switched off. The corresponding DSB noise temperature is 485K.

fig. 5: Double sideband (DSB) receiver noise temperature versus LO frequency. Z indicates frequencies measured by a commercial 40 μ W doubler tripler combination [17] and a 8% Mylar coupler. R indicates the varistor multiplier which provides 1 μ W at 700 GHz and requires a 25% coupler.

fig. 6: $(6-5)^{12}\text{CO}$ line at 691.5 GHz measured with a 1m gas cell and a spectrum analyzer. For the second scan the LO frequency was changed by 12 MHz. Each scan was taken in 100s with a resolution bandwidth of 1 MHz and 1.25s integration time. The center frequency is 691.473 GHz.