Measurement of in-RF and out-RF band saturation of SIS mixer

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***Abstract*—In this article we answer experimentally the question of how much spurious signal power level (relative to LO power) can be tolerated by an SIS mixer. Spurious signals that are inside and outside of the signal sideband have been considered. It is demonstrated that about –20 dBc of in-RF-band spurious level can be tolerated. For out-of-RF-band spurious, on the other hand, a level of about –15 to –10 dBc can be tolerated depending on the frequency separation between the LO and the spurious signal.**

***Index Terms* — Heterodyne detection, saturation, spurious signals, SIS mixer, Local Oscillator, sub millimeter wavelengths**

I. Introduction

THE instantaneous RF bandwidth of SIS-based mixers is limited by the relatively high capacitance of SIS junctions. Recently, significant progress has been achieved in extending the RF bandwidth of SIS mixers either using multiple junctions designs [1] or making use of high current density AlN barrier junctions [2], [3]. At the same time progress has been achieved in generating tuner-less LO power by all solid state sources [4]-[7]. These sources typically consist of microwave multipliers and amplifiers (F < 120 GHz) followed by a set of Schottky multipliers. Although providing enough power these sources often emit an unwanted combination of harmonic signals which can fall into the large RF band of state of the art SIS mixers and potentially disturb their nominal operation.

This article answers experimentally the question of how much spurious signal power (relative to LO power level) can be tolerated by an SIS mixer in two cases:

1) The spurious signal frequency falls in the input RF band of the mixer and it appears at the IF output, i.e. classical saturation by a narrow band signal. This case was previously discussed in [8], [9].

2) The spurious signal frequency falls in the instantaneous RF bandwidth of mixer but outside the input RF band and it does not appear at the IF output. This was discussed for lower frequency in [10].

In order to measure the tolerable spurious signal power level an experimental set-up has been created which allows to apply simultaneously two narrow band signals as well as a calibrated 300K/80K calibrator to an input of ALMA band 9 SIS mixer. Additionally, the output power of one of the narrow band sources can be varied by a rotating grid. The output power of the sources is strong enough that both can pump the SIS mixer and, thus, both can be calibrated with respect to each other.

We have performed standard hot/cold measurements while varying the power of one of the sources and using the other as LO. The frequency plan was such that a variable “spurious” signal source was kept fixed 642 GHz and several sets measurements were performed at different LO frequencies. It is demonstrated that about –20 dBc in-RF band spurious level can be tolerated. On the other hand, when out-of-RF-band is considered, about –15 to –10dBc can be tolerated depending on the frequency separation between the LO and the spurious signal.

II. Measurement set-up and methods

A. SIS mixer

An ALMA band 9 SIS mixer has been used in this work [11]. It uses a waveguide coupling scheme. An input F/2.5 signal beam is coupled to the main waveguide mode by means of a corrugated horn. A reduced size waveguide couples the RF signal to a single SIS junction fabricated on quartz substrate. An Nb-SiO2-Nb integrated tuning structure together with a fixed back short cavity tunes out the SIS junction’s parasitic capacitance and provides an optimum input match.

The SIS junction is of the Nb-AlOx-Nb type with an area of approx 1 μm^2, an R_nA value of 30 $\Omega\mu m^2$, a quality factor of 20 and a gap voltage of 2.8 mV at the physical temperature of 4.2 K. It was manufactured at TuDelft facilities following a standard SIS process [12]. The junction and integrated tuning circuit dimensions have been defined using e-beam lithography process. The Josephson effect noise has been suppressed during operation by means of a magnetic coil integrated into the mixer block.

B. Receiver layout

The optics layout of the main experiment is shown in

Manuscript received May 1, 2007. This work was supported in part by the research funding from the European Community's sixth Framework Programme under RadioNet R113CT 2003 5058187 JRA AMSTAR, and Netherlands Astronomy Research Shool (NOVA)

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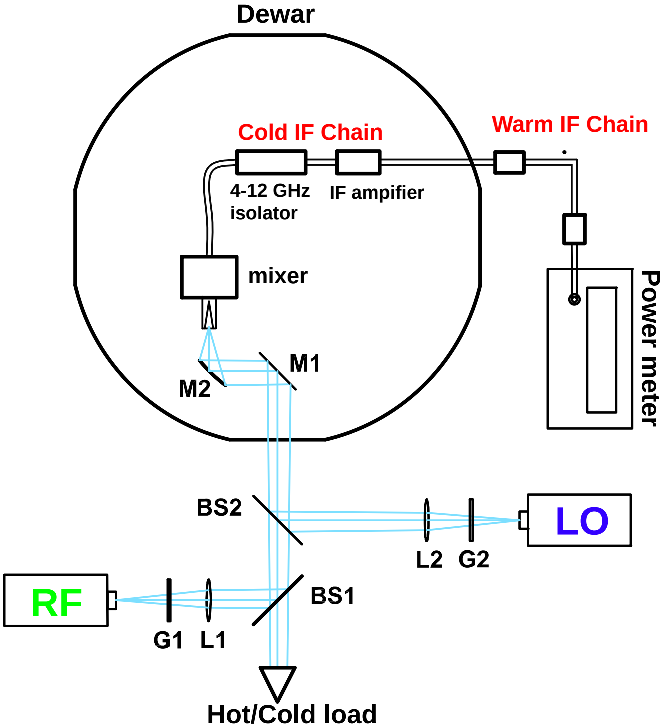

Fig. 1. Layout of the saturation experiment.

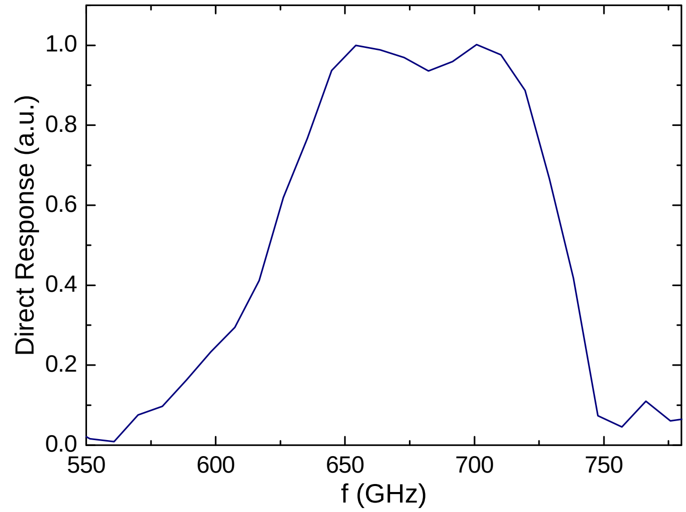

Fig. 2. Measured Fourier Transform Spectrometer response of SIS mixer showing an instantaneous bandwidth.

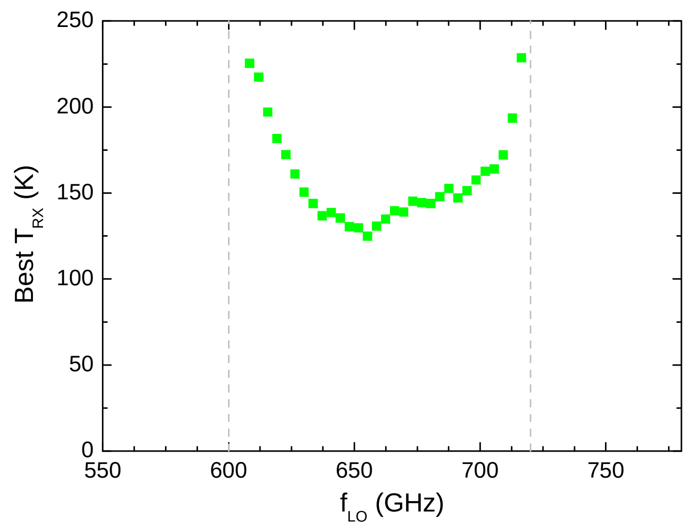

Fig. 3. Measured receiver noise temperature of SIS mixer. Measurements were done while RF source (see Fig. 1) was switched off.

Fig. 1. A Gunn diode oscillator (100-120 GHz) followed by a Schottky diode doubler and tripler has been used to simulate a spurious signal. It has been coupled to the input beam by means of a 12 micron thick Mylar beam splitter (BS1) and a HDP lens (L1). The output frequency of the RF source has been fixed throughout whole experiment at 642 GHz and its output power adjusted regulated by means of a polarizing grid mounted in a computer controlled rotating fixture. The peak output power of several tens of microwatts can be regulated to approximately -40 dB relative power level referred to the input of the mixer.

An ALMA band 9 prototype has been used as a tunable frequency LO source. This LO is a combination of power amplifiers and frequency multipliers with a final stage of ×6 (integrated 2×3) multiplier with output frequency range of 600-712 GHz. This source has been made at NRAO in Charlottesville. The output power of the LO has been adjusted by a grid polarizer (G2) and coupled to a receiver beam by means of a 12 micron Mylar beam splitter (BS2) and a HDP lens (L2). It was possible to achieve an optimum pumping level of the SIS mixer throughout whole ALMA band.

RF and LO signals that pass through beam splitters or reflect from grids (G1, G2) were terminated in signal absorbers (not shown in the figure).

A switchable hot/cold load with temperature levels of 80 K (liquid nitrogen) and 300 K (room temperature) has been used to measure receiver noise temperature and gain under different conditions.

The SIS mixer, its associated cold optics (M1, M2) and cold IF components have been mounted in a vacuum space of a Infrared Labs HDL-8 liquid helium cryostat at 4.2 K. Two GoreTex® sheets of 1 mm thickness were used as 4 K and 80 K infrared filters and high performance anti-reflection coated quartz plate was used as vacuum window of the cryostat.

The cold IF coupling scheme uses a 4-12 GHz cryogenic isolator [13], and an InP type 4-12 GHz IF amplifier [14] of 30 dB gain and 4.6 K noise temperature. The warm IF chain consisted of two MITEQ IF amplifiers, a set of attenuators, a computer controlled tuneable YIG filter (with a bandwidth of 40 MHz) and an Agilent power meter. Particular care was taken to avoid saturation of the IF amplifier chain at all input conditions by choosing an appropriate attenuation level. This set-up allowed us to measure gain and noise temperature of the mixer versus IF frequency.

C. *Experimental method and signal source power calibration*

During the experiment, the receiver was tuned first to a given LO frequency and an optimum pumping level was chosen. Then, for each RF spurious source power the receiver output power has been recorded as a function of IF frequency

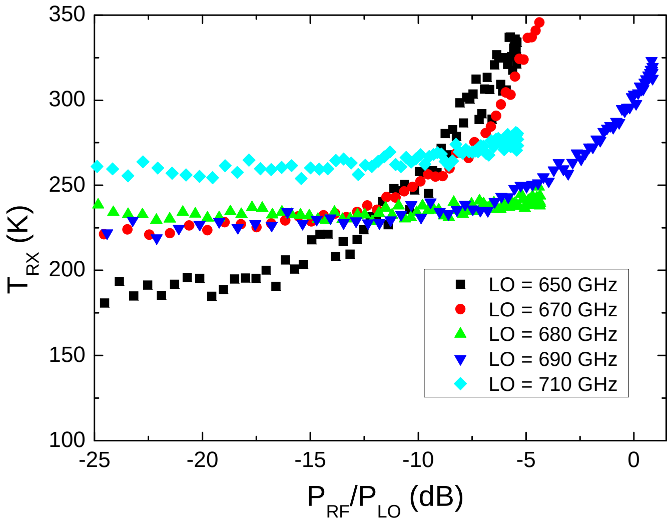

Fig. 4. Measured receiver noise temperature of SIS mixer vs. RF source power for several LO frequencies. Signal frequency was kept at 642 GHz.

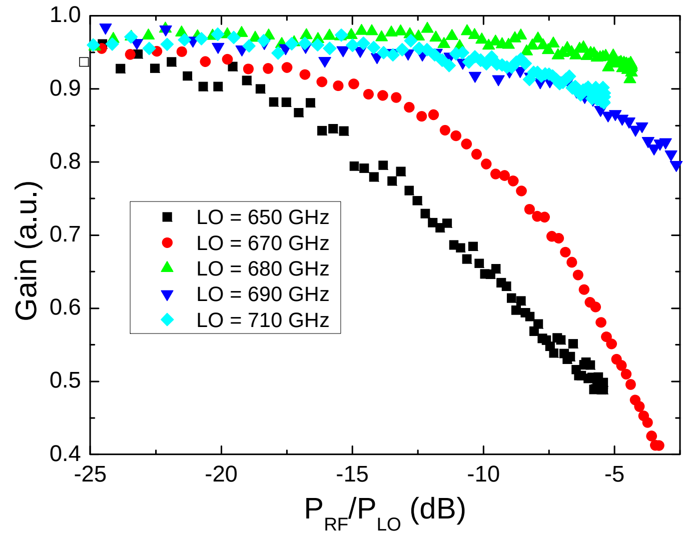

Fig. 5. Measured receiver gain of SIS mixer vs. RF source power for several LO frequencies. Signal frequency was kept at 642 GHz.

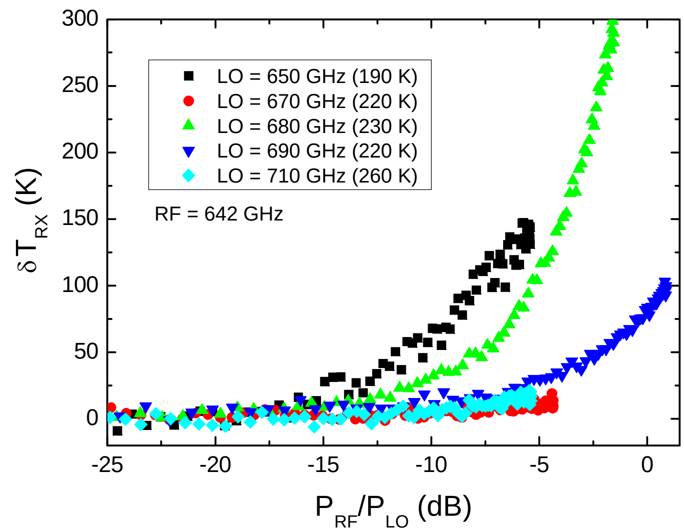

Fig. 6. Receiver noise temperature with receiver noise at zero RF power subtracted. Data are taken from fig. 4

both for 80 K and 300 K black body loads at the input. This information permitted to calculate the receiver Y-factor, noise temperature and gain, which is then compared to an RF power off situation. The LO frequencies were chosen such that the spurious frequency fell in and out of the receiving sideband of the SIS mixer.

The RF source power referred to the SIS junction was calibrated by measuring the height of a 1st photon assisted tunneling step as function of the grid G1 rotation angle when LO source was off. The detected power has been calculated based on Tucker's theory and was in a good agreement with a cosine to the power fourth law, since both mixer and RF source are highly polarized. The maximum RF power was enough to pump the SIS mixer. The same method was used to measure the available LO power at the SIS junction at a given LO frequency. Using this method we can express the RF signal power in dBc relative to the LO power at the SIS junction at a given LO frequency. This allows us to exclude the influence of the frequency dependence of the input matching network throughput from consideration.

III. Measurement Results and Dicussion

A. *Standard FTS and heterodyne characterization*

A standard direct response of the mixer, as measured with a Fourier transform spectrometer, is presented in Fig. 2. It demonstrates good coverage of ALMA band 9 and an instantaneous RF coverage from 620 to 720 GHz. This response is typical for ALMA band 9 mixers of preproduction series design. The measured receiver noise temperature as function of the LO frequency with the RF source power set to zero is presented in Fig. 3. When compared with measurements performed within an ALMA band 9 cartridge, the noise temperature performance is worser as in the cartridge the LO source is at 80K. Nevertheless, these results demonstrate the adequate noise band coverage, and that this SIS mixers is good choice for further saturation level measurements.

B. *Saturation measurement results and discussion*

Receiver noise temperature and gain as function of the RF signal power for different LO frequencies are shown in Figures 4 and 5 respectively. The respective LO frequencies are indicated on the inset. When f_{LO} = 650 GHz, the response from the 642 GHz RF signal is present at an IF of 8 GHz. This IF frequency was excluded from the noise temperature and gain calculations. For other LO frequencies the RF frequency lies outside the nominal detection bandwidth. As it is demonstrated in Figs. 4-6 the receiver gain is the quantity which is the most sensitive to the presence of an RF signal. It becomes saturated for lower RF source powers than the receiver noise temperature and thus will be used as criteria for evaluation of allowable spurious signal power. The in-RF band spurious signal also has more effect (as can be intuitively expected) than the out-of RF band spurious signal. The −20 dBc in-RF band and −15 to −10dBc of out of RF band spurious signal relative power level can be tolerated in this particular receiver, based on these experimental results.

One should note that noise temperature and gain calculations were done under the assumption that the mixer is pumped by a single LO source and signal from hot/cold is only converted to IF from the $f_{LO} \pm f_{IF}$ frequency range. However, as it can be seen from the power range (x-axis) of Figs. 4-6, the RF signal power can also be sufficient to pump the SIS mixer and, at these conditions, the RF signal is not a weak anymore and the SIS mixer operates under two LO signals simultaneously. This situation may give rise to a parasitic down conversion of frequencies around f_{RF}: $f_{RF} \pm f_{IF}$ which would modify our gain and noise temperature estimate. We believe, however, that this effect does not affect our conclusions as saturation effects begin to show already at relatively low RF power levels, where this parasitic down conversion is expected to be small. An additional narrow band low power signal source at frequency $f_{LO} \pm f_{IF}$ can be used to calibrate the strength of parasitic down conversion. We plan to carry out this experiment in the near future.

IV. Conclusion

In conclusion, we have directly measured the power level of in-RF band and out-RF band spurious signals that can be tolerated by a single junction SIS mixer operating in the 600-720 GHz frequency range. An strong test signal was presented at the receiver input to simulate the presence of a spurious signal. Based on these experimental results, a −20 dBc of in-RF band and a −15 to −10dBc of out-of-RF band spurious signal relative power level can be tolerated in this particular receiver.

Acknowledgment

Authors would like to thank E. Bryerton, W. Wild, B. Jackson and J. Kooi for useful discussions. This work has benefited from research funding from the European Community's sixth Framework Programme under RadioNet R113CT 2003 5058187 JRA AMSTAR.

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