Characterization of the IF output impedance of SIS mixers

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***Abstract*— We report on the development of a measurement setup to characterize the IF output impedance of a SIS mixer. The measurement method and the details of the test setup are described.**

***Index Terms*—SIS mixer, IF impedance, DSB and SSB tuning, VNA measurements.**

I. INTRODUCTION

MODERN low noise Superconductor-Insulator-Superconductor (SIS) receivers for mm- and sub-mm radio astronomy operate over very wide instantaneous Intermediate Frequency (IF) bands. For example, the current generation of the IRAM Plateau de Bure Interferometer (PdBI) mm-wave dual polarization receivers is being upgraded for the NOEMA (Northern Extended Millimeter Array) project [1] from backshort-tuned Single Side Band (SSB) mixers delivering one 4 GHz wide IF band (across 4-8 GHz) [2]-[3] to Sideband Separating (2SB) mixers delivering two ~8 GHz wide IF bands (across ~4-12 GHz) [4]-[5].

A cryogenic isolator is often used at the single IF output of a SSB mixer (or at each of the two IF outputs of the 2SB mixer) to decouple the SIS mixer IF output impedance from the input impedance of the following IF cryogenic low noise amplifier (LNA): by employing an IF isolator matched to 50 Ω in a SSB receiver chain, a constant 50 Ω impedance is presented at the LNA input independently of the output impedance of the SIS mixer and, at the same time, a constant 50 Ω impedance is presented at the mixer output independently of the input impedance of the LNA. This allows the LNA, which is typically optimized to deliver minimum noise on a 50 Ω input, to operate at its optimum input impedance and the SIS mixer to be optimized to provide best receiver performance (simulated using Tucker's theory of quasi-particle mixing [6]) when its IF output is connected to a 50 Ω load. In short, the optimization of the performance of a SIS receiver chain can be optimized more easily by decoupling mixer and LNA through an isolator.

However, isolators have large mechanical size and non-negligible insertion losses which contribute to increase the receiver noise temperature. Removing the isolator from the chain is essential for the development of closely packed receivers in a focal plane array, for which a miniaturized footprint on their RF and IF sections is required. Moreover, the direct connection of SIS mixer with cryogenic amplifier through a suitable network, offers potential for improvement of the receiver performance.

The IF output impedance of a SIS mixer, Z_{IF}, depends on several parameters, among which the RF embedding impedance of the SIS junctions, the bias condition, and the Local Oscillator (LO) pumping level. Such IF output impedance plays an important role in the performance of a receiver chain and must be known accurately to allow optimization of the receiver performance across its RF and IF bands. This is particularly true when the SIS mixer and following IF low noise amplifier are directly connected without isolator. Therefore, the design of modern wide IF band SIS receiver can strongly benefit from experimental data on the SIS mixer IF output impedance, which can be used for verification and optimization of the following cryogenic IF receiver section.

Here, we describe a measurement system to characterize the IF impedance of SIS mixers, present experimental results, and compare electromagnetic simulations combined with three-port Tucker's theory of quasi-particle SIS mixing with laboratory data. The SIS junction, biased at three different voltages of its unpumped IV characteristic, is used to obtain three known calibration impedances that allowed calibrating the measurement up to the on-chip SIS junction plane (including the SIS junction specific capacitance).

II. TEST SETUP OF SIS MIXER IF IMPEDANCE WITH A VNA

A. *Synoptic diagram of measurement setup*

A synoptic diagram of the measurement setup, utilizing a Vector Network Analyzer (VNA) and an SIS mixer cooled at 4 K inside a cryostat, is shown in Fig. 1. The synoptic shows the reference measurement plane situated at the on-chip SIS junction. The commercial VNA in its base configuration (Agilent PNAx N5244A 43.5 GHz) would not have enough dynamic range to measure the reflection coefficient of the SIS mixer at IF frequencies, Γ_{IF} (or equivalently Z_{IF}). Indeed, the incident power at the VNA output must be very low, of order -85 dBm, to avoid SIS mixer saturation. If the base VNA configuration were used, a coupler internal to the VNA system would replace the combination of circulator and low noise amplifier (LNA) shown in Fig. 1: the coupler would inject a fraction of the power reflected back from the mixer into the

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return-wave VNA receiver. However, the combination of the high-noise of the return-wave VNA receiver with the loss of power due the internal coupler would strongly reduce the detectable signal. The combination of circulator plus amplifier allows at the same time to couple the required power to the return-wave VNA receiver with minimum loss while masking its noise. The bandpass filter situated after the LNA reduces the noise bandwidth and suppresses higher harmonics.

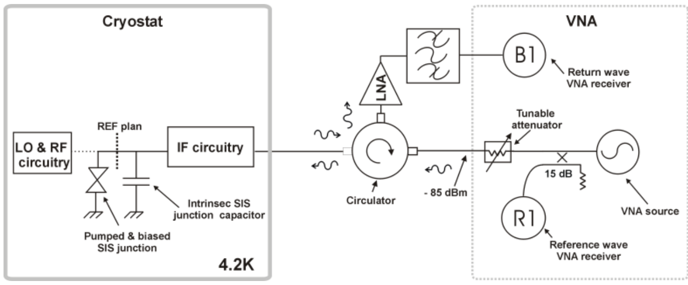

Fig. 1. Synoptic of SIS mixer IF impedance measurement system. The cryostat and the VNA are shown on the left and on the right sides, respectively. In the middle, the paths of the incident and backward waves from the VNA, as well as the connections of the circulator with the cryostat and the VNA are shown.

B. Measurement calibration

One of the main challenges in vector network measurements at cryogenic temperatures is the calibration. To avoid calibration uncertainties related to changes of electrical lengths and of impedance discontinuities upon cooling, we have used the properties of the IV characteristic of the SIS junction at 4.2 K to generate the necessary calibration standards: the junction was biased in three different regions of its IV curve to obtain impedances close to the three classical SOLT standards (see Fig. 2): Open Circuit (OC), Short Circuit (SC) and Load. In choosing the SIS junction as calibration kit, the measurement reference plane is necessarily located at the SIS junction itself. Thus, the calibration procedure calibrates out all IF circuitry of the measurement setup (IF coaxial cables, SIS mixer external IF circuit, bias-T etc..) including the on-chip SIS mixer intrinsic capacitance and inductance. This procedure does not require to thermally cycle and open the cryostat to locate and measure three different calibration standards.

C. Backshort-tuned SSB SIS mixer

We carried out measurements across the 4-8 GHz IF band of the IRAM 3 mm band backshort-tuned Single Side Band (SSB) SIS mixers currently installed on the PdBI antennas. The mixer backshort allows to reject the image side band (typical gain ratios G_I/Gs~-10 dB), thus reducing the contribution of the atmospheric noise in the image band and improving the system sensitivity during spectroscopic observations.

The SIS mixer chip used in the measurements is based on two junctions in series, with an equivalent gap voltage at ~5.6 mV. The electrical distance between the two junctions is very small compared to the wavelength and are considered to be located on the same plane (the reference plane).

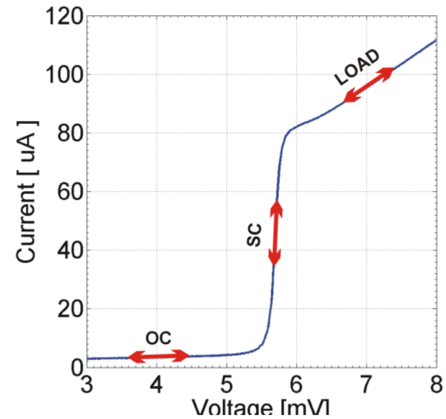

Fig. 2. In blue, the I(V) curve of the SIS junction situated on the mixer chip. The red double arrows show the three different impedance defining the three SOLT (OC, SC, LOAD) calibration standard.

D. SIS IF impedance measurement bench

The IRAM test setup for characterizing the IF impedance of the SIS mixer is shown in Figs. 3 and 4. The mixer is placed inside a laboratory wet cryostat (from Infrared Lab Inc.) in thermal contact with the 4.2 K stage cooled by liquid helium.

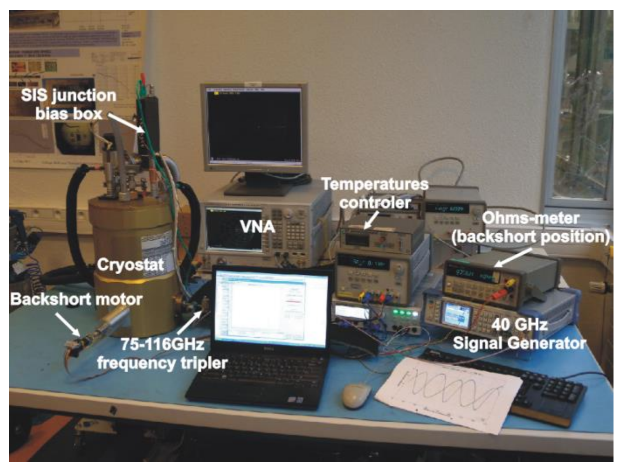

Fig. 3. Overview of the measurement bench showing the VNA, the cryostat to cool down the SIS mixer at the physical temperature of 4.2 K, the backshort motor to tune such SSB mixer in LSB or USB, the SIS junction bias box, the SIS mixer Local Oscillator which is realized by a 40 GHz signal generator combined with tripler and WR10 mechanical attenuator. The system is fully controlled with a computer.

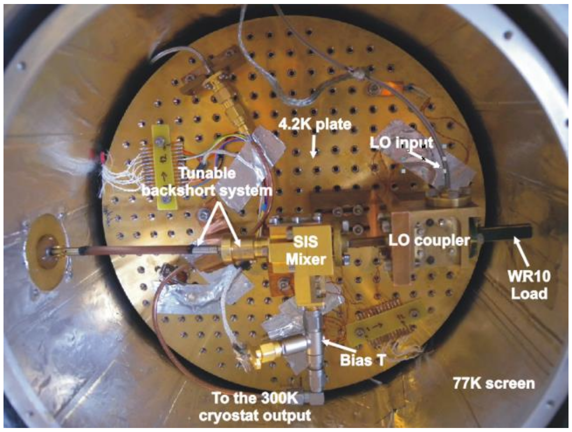

Fig. 4. The cryostat component arrangement is shown. The SIS mixer, located at its center, has is waveguide input connected to a waveguide LO coupler, terminated to a WR10 waveguide load on the signal path, through a WR10 copper waveguide. A WR10 stainless steel waveguide allows to inject the LO signal generated outside the cryostat. The backshort mechanism is connected to a fiberglass rod and controlled from outside the cryostat. The IF SMA output of the SIS mixer is connected to the cryostat IF output through coaxial cables (copper and stainless steel types) through a commercial bias-T.

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