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# Waveguide receiver design prototypes for the 211-275 GHz and 790-950 GHz frequency ranges

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## Abstract

Superconductor-insulator-superconductor (SIS) mixers are the most sensitive heterodyne receivers for mm and submm wavelengths. SIS mixers are installed on all state of the art submm observatories such as the Atacama Large Millimeter array (ALMA) and the Atacama Pathfinder Experiment (APEX). Recently, an improved type of Nb/AlN/NbN SIS junction has become available that combines higher gap voltage with high current density. This opens new parametric space for further improvement of the SIS mixer's performance and bandwidth both for frequencies higher and lower than the gap frequency of Nb (700 GHz). In this contribution we will describe designs of SIS mixers based on a new type of SIS junction, both for high (~900 GHz) and low (~200 GHz) frequencies.

## 1. Introduction

We have calculated, designed, fabricated and measured a superconductor heterodyne receiver operating in the 790-950 GHz frequency range, based on twin SIS tunnel junctions integrated in a NbTiN-Al microstrip line wiring. The bottom NbTiN microstrip line electrode has a thickness of 300 nm and the top Al microstrip line electrode is 500 nm thick. The electrodes were separated by a 250 nm thick $SiO_2$ dielectric layer. The mixer structure is placed on a 80 μm quartz substrate which is installed across a 300x75 μm waveguide as shown in Fig. 1. Manufactured SIS mixers have a gap voltage of 3.2 mV for the high current density (about 30 kA/cm$^2$) SIS junctions. The receiver demonstrates a noise temperature of 180 K at the lower part of the frequency range and 350 K for higher part. We assume this increase could be due to additional losses in NbTiN microstrip material.

After analysis of the twin junction mixer design in [1,2], we have optimized, fabricated and measured a new design based on a single SIS junction. We expect a further decrease of the noise temperature while still covering a wide frequency range. The first experimental results demonstrate a decrease in the noise temperature in the part of the 790-950 GHz frequency range for this design [1]. The submicron SIS junction critical current suppression can be a problem through variations in the SIS area between junctions. According to the theory, critical current suppression depends on magnetic field. A twin junction sample has only one source of magnetic field which can not be adjusted individually for each junction. Consequently, small deviations between the SIS areas strongly influence critical current suppression. Using a single junction design allows to avoid the problem mentioned above. However, the twin junction design is more stable with respect to manufacturing tolerances.

For the low frequency range, we have made a single-ended DSB mixer design for the 211 – 275 GHz atmospheric window (band 6 ALMA). It is intended to be used within a waveguide quadrature hybrid 2SB design, which is conceptually based on the successful ALMA band 9 design [3,4]. The mixer is based on a Nb/AlN/Nb junction embedded in a Nb microstrip line. In order to achieve an RF bandwidth of 64 GHz, we will use an AlN barrier. The microstrip line electrodes are separated by a 250 nm $SiO_2$ dielectric layer. We optimized waveguide sizes, substrate thickness and high frequency filters by CST using parameters for the SIS junction and metallization technology described in [2].

## 2. 790-950 GHz mixer designs

In order to make a wide band design we made a twin junction design (0.5 μm$^2$ for each SIS, using critical current of about 30 kA/μm$^2$). However, after our analysis [2], we made a single junction design [5]. A tuned twin structure is matched with a probe by a λ/4 microstrip line transformer. A wideband low-pass filters based on repeated λ/4 transformers and lumped capacitors to cut off the waveguide mode.

The single SIS junction design used the same low-pass filters, a probe, a waveguide and type SIS junction. The SIS junction was matched to the probe by a microstrip line transformer and was tuned by parallel inductance. Microfotos of the designs are shown in Fig. 2 and Fig. 3. Fig. 1 illustrates a double junction CST model.

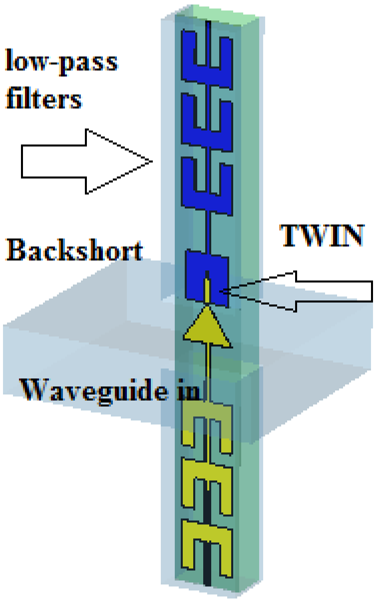

**Figure 1** A 3D sketch of the double junction twin mixer as used in the CST model.

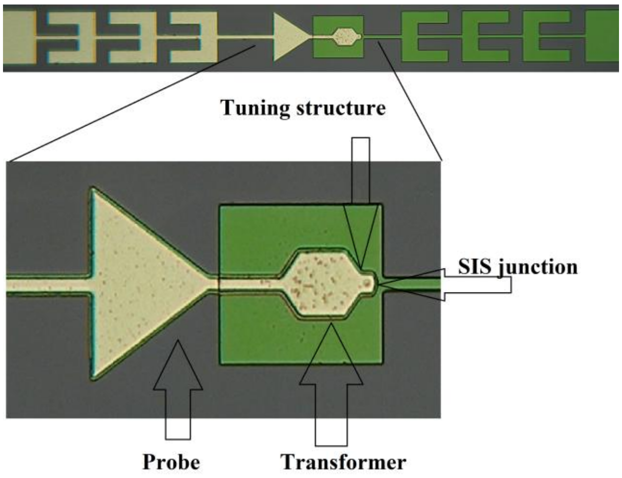

**Figure 2.** A photo of the 1 SIS mixer. Including the waveguide probe and filters.

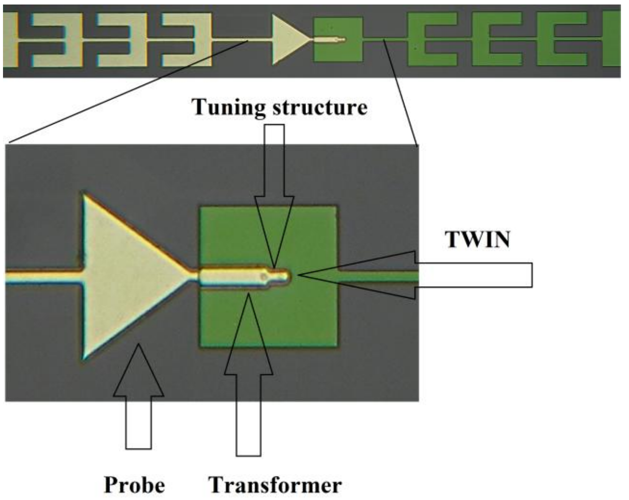

**Figure 3.** Photo of the two junction mixer substrate. Including the waveguide probe and filters.

The tuning structure for the single junction SIS mixer is short and comparable with possible photolithography technology deviations. The twin design also has a short tuning structure but the distance depends on mask plate resolution and it can not be changed by mask offsets during the lithography process. This leads to less sensitivity to manufacturing deviations than the single junction SIS mixer. High dimensional sensitivity of single junction design lead us to focus on twin design measurements. We improved the used technology to achieve an excellent SIS junction quality factor and correct NbTiN layer thickness. Fig.4 shows corrected noise temperatures of the latest mixer batch. Different color corresponds to different twin junction design structures. As there are different estimations for AlN SIS junction specific capacitance, $C_{sp}$ [6,7,8], we have made a set of designs optimized for $C_{sp}$ 100, 150, 200 fF/μm$^2$ .

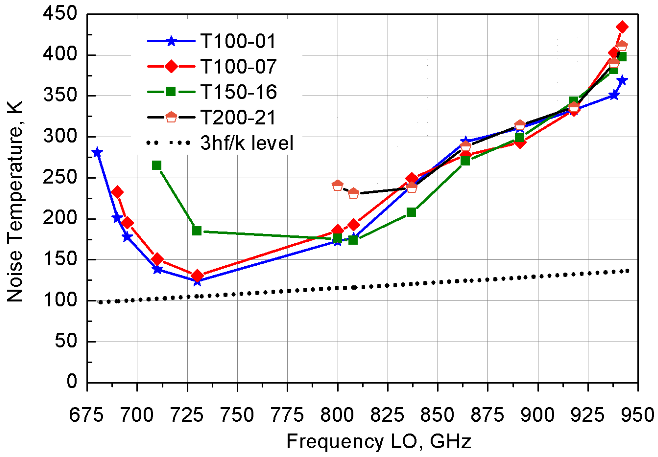

**Figure 4.** Corrected DSB noise temperature, shown for 3 different designs (t100, t150, t200).

## 3. 211-275 GHz mixers design

We calculated two types of designs. For both designs, substrates were placed across a rectangular waveguide of 460x920 µm as shown in Fig. 5. The microstructure is placed on a 125 µm thin quartz substrate. The mixers are based on SIS junctions embedded in 200 nm Nb wiring and separated by 250 nm $SiO_2$ layer.

The first design is based on a single Nb/AlN/Nb SIS junction with 1 $\mu m^2$ area and Rn = 15 Ohm normal resistance. We made the modeling in CST Microwave Studio. The sample location is shown in Fig.5 in 3D CST modeler.

Optimal coupling between the waveguide probe and the SIS junction is achieved by using a lumped elements transformer. A microstrip and a CPW line between the probe and the SIS act as a lumped element capacitance and inductance. Another CPW line between the SIS junction and a trapezoidal stub can be considered as a lumped inductance. Using a triangular stub in this case is more optimal than a radial stub to match it with low-pass filters. We use high current density (Rn = 10-15 for 1 $\mu m^2$ SIS area) SIS junctions so it is possible to achieve good matching between input and the junctions using only microstrip structures. An the other hand, for lower frequencies a design based on CPW and microstrip lines is more compact which leads to a wider IF frequency range. After an analysis [9, 10] we decided to use an orthogonal probe as shown in Fig. 5. Using the orthogonal probe led to a more complicated matching process for wide frequency range than parallel [10], but this orientation reduces many difficulties associated with installation of a parallel probe. The high frequency low-pass filters are based on CPW lines interleaved with lumped capacitors in a top wiring and on choke structures in the bottom wiring. Optimization in CST shows wide IF frequency range. Fig.6, Fig.7 and Fig.8 illustrate numerical estimations for the probe impedance, the IF wide frequency range and matching between the input waveguide and the SIS junction, respectively.

The twin junction design uses the same probe and filters as the single junction design. The twin junction design is more stable with respect to technology deviations. Currently the preliminary twin junction design (see Fig.9) is more optimal than the single junction design.

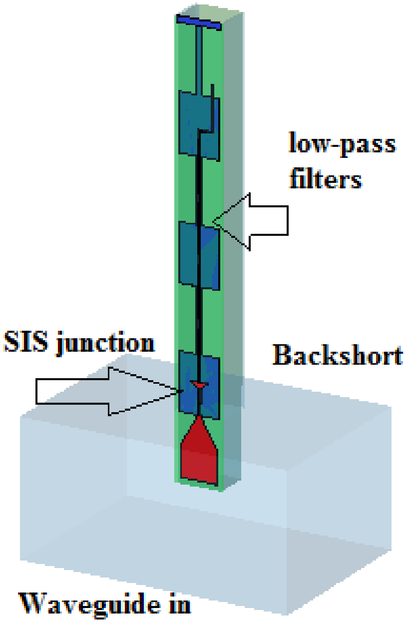

**Figure 5.** A full 3D based on 1 SIS junction mixer CST model.

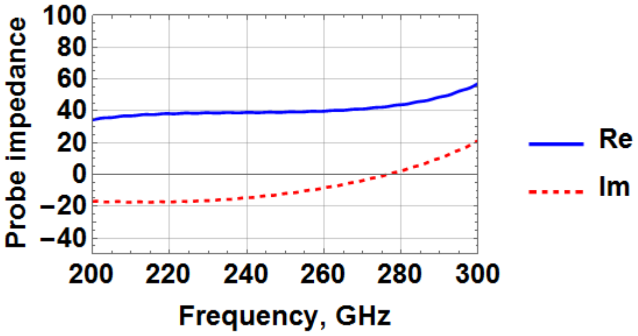

**Figure 6.** Using waveguide probe impedance.

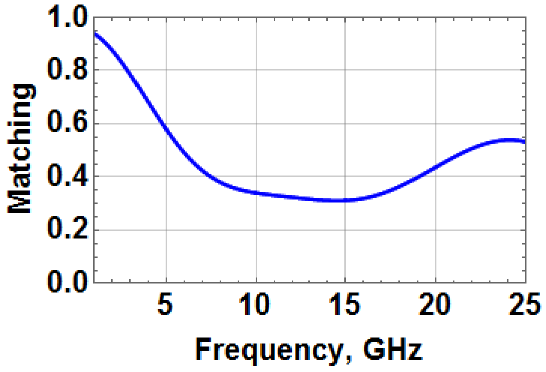

**Figure 7.** An IF choke bandwidth.

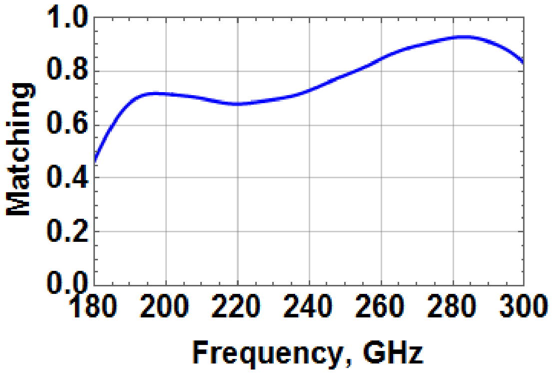

**Figure 8.** Power matching between a SIS junction and a waveguide.

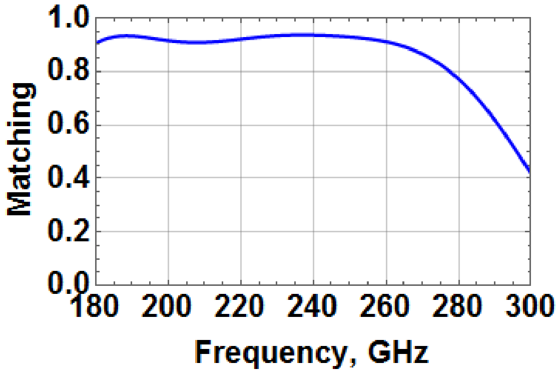

**Figure 9.** Power matching between twin junctions and a waveguide.

## 4. Conclusion

We calculated, fabricated and measurement twin and single junction SIS mixers for 790-950 GHz. The single junction SIS mixer design showed more sensitivity for technology deviation than the twin junction design. The twin junction mixers demonstrated a noise temperature of 120 K at 730 GHz and up to 350 K for the highest frequency. We also made 211-275 GHz mixer design calculations and it will be fabricated in near future.

## 5. Acknowledgements

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