A 665 GHz WAVEGUIDE RECEIVER USING A TUNED $0.5\mu m^2$ Nb/AlO$_x$/Nb SIS TUNNEL JUNCTION.

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Abstract

We report recent results on a 580-740 GHz SIS heterodyne receiver employing a tuned $0.50\mu m^2$ Nb/AlO$_x$/Nb SIS tunnel junction. The receiver has been successfully installed at the Caltech Submillimeter Observatory, Hawaii. Results of an untuned device in the same waveguide block were presented at the fifth International THz Conference.

Since the mixer is meant to be operated near the superconducting gap frequency of niobium ($2\triangle/h \approx 690$ GHz), special has been taken to minimize the absorption loss in the rf matching network. To this effect we propose the use of a RF matching network that constitutes a hybrid between the well know "end-loaded" stub and radial stub matching networks.

We have measured uncorrected DSB receiver temperatures as low as 160K from 680- to 702 GHz, 200K at 725GHz and 120K from 585-640 GHz. The uncorrected mixer noise temperature at 702 GHz is about 125K, of which 62K can be directly contributed to the front end optics loss. Mixer conversion loss at 702 GHz is 7dB, of which $\approx$ 0.9dB is due to the absorption loss in the Nb film. This results in a corrected mixer noise temperature of 63K, $\approx$ 1.7 times the quantum noise limit.

INTRODUCTION

The results discussed here were achieved by using a $0.56\mu m^2$ Nb/AlO$_x$/Nb SIS tunnel junction with high quality circular non-contacting backshort and E-plane tuners[1-3] in a full height waveguide mount. The heterodyne receiver has been successfully installed at the Caltech Submillimeter Observatory (CSO) on Mauna Kea in Hawaii.

The "end-loaded" RF matching network has been used very effectively below 600 GHz[4-7]. The "end-loaded" stub puts a small section transmission line in series with the junction. This results in the transformation of the complex junction admittance, to the real axis of the Smith Chart, R_s. As the frequency increases the stub length approaches $\pi/4$, which reduces R_s to very small values [2]. This is a serious drawback of the "end-loaded" stub. For frequencies above 500 GHz it gets more and more difficult to transform R_s to match the probe impedance over a reasonable bandwidth (Fig. 1).

An alternative approach is the Radial Stub matching network[2, 8]. It places an inductance in parallel with the junction which resonates out the large junction capacitance. It's simplicity makes it low loss but unfortunately quite narrow band as well.

Since the mixer is meant to be operated near the superconducting gap frequency of niobium ($2\Delta/h \approx 690$ GHz), special has been taken to minimize the absorption loss in the rf matching network. To this effect we propose the use of a RF matching network that constitutes a hybrid between the well know "end-loaded" stub and radial stub matching networks.

In figure 1 we show a photograph of the actual device.

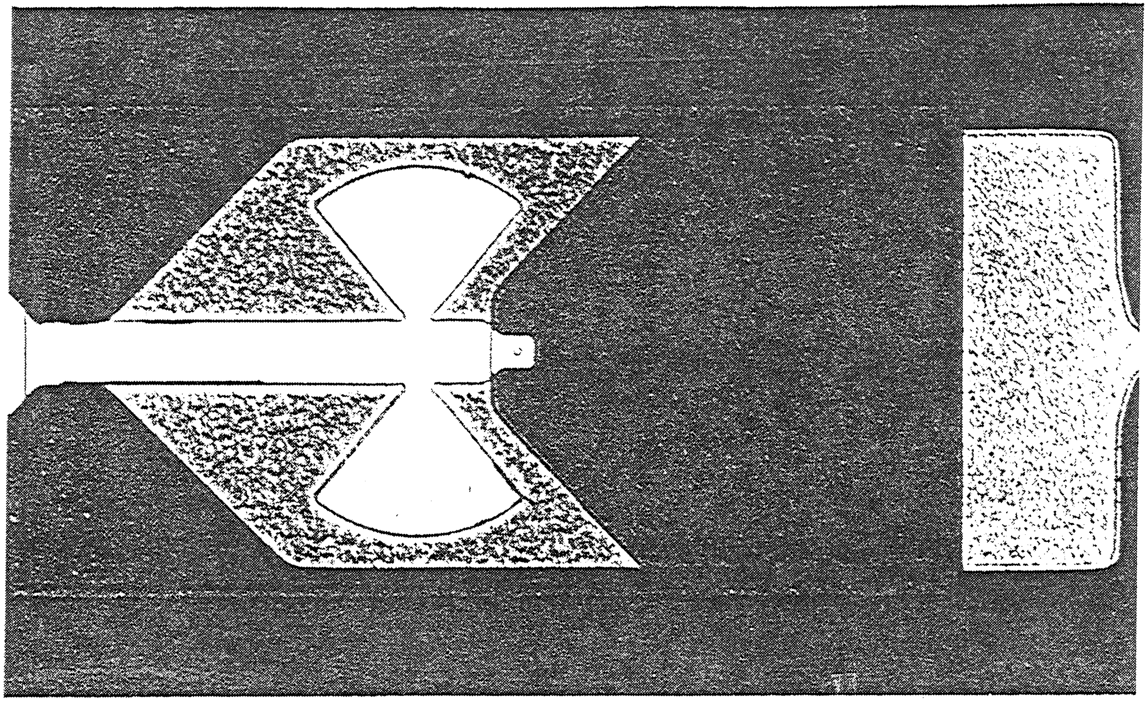
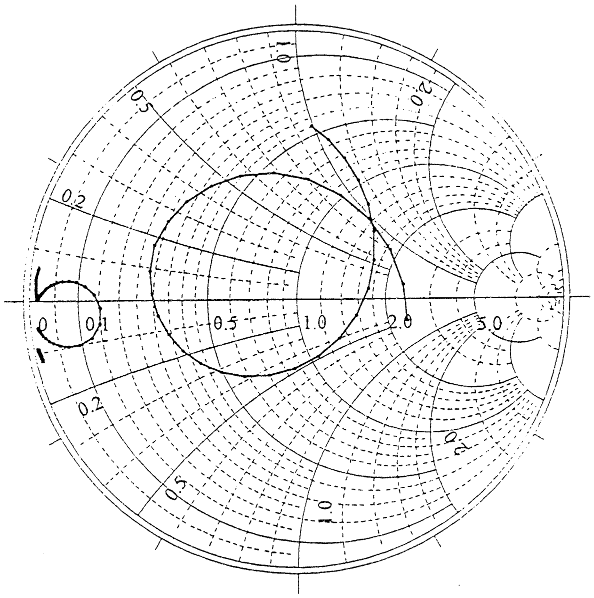


Fig. 1. 1000 X photograph of the junction and 'butterfly' matching network. The junction size is 0.75 μm on a side.

Instead of transforming the junction impedance to the real axis of the Smith chart, as is done with the 'End-Loaded' stub, we purposely oversh~~oo~~t the real Axis. This makes the transformed impedance slightly inductive, which when presented with a shunt capacitance (Parallel Radial stubs) transforms the impedance to $\approx$ 3.5 Ohm. A one section quarter wave transformer is then used to transform it to the desired waveguide embedding impedance. We hope to present a more detailed analyses in a future paper.

The advantages of this kind of matching scheme are several. First, The 'End-loaded' stub length can be extended beyond $\pi/4$, which eases the constraints on the photolithography. Secondly, There is no large discontinuity as with the traditional 'End-loaded' stub matching network at these frequency's. The latter greatly simplifies RF circuit models. And lastly the circuit performance of both the 'End-loaded' stub and 'Butterfly' matching networks are very similar, as one might expect (calculated, but not shown in this paper).

650 GHz Butterfly Matching Network



580-740 GHz

Fig. 2. 'Butterfly' impedance plot normalized to 50 Ω.

$580 - 740 GHz\,GHz$ *Results and Discussion*

The 702 GHz pumped/unpumped I-V curves and hot(295K)/cold(80K) total power response are shown in Figure 3. The Shapiro steps were carefully suppressed by adjusting the magnetic field. Highest sensitivity is achieved by operating of the first Josephson null. With the receiver tuned for maximum total power, the slope of the pumped I-V curve is nearly zero indicating that the junction capacitance is effectively tuned out. The IF coupling efficiency in this case is quite poor however, which is readily observed by the IF passband ripple. De-tuning[9] the receiver to get a positive sloped I-V curve and subsequent finite IF impedance improves the receiver noise temperature by as much as 15%.

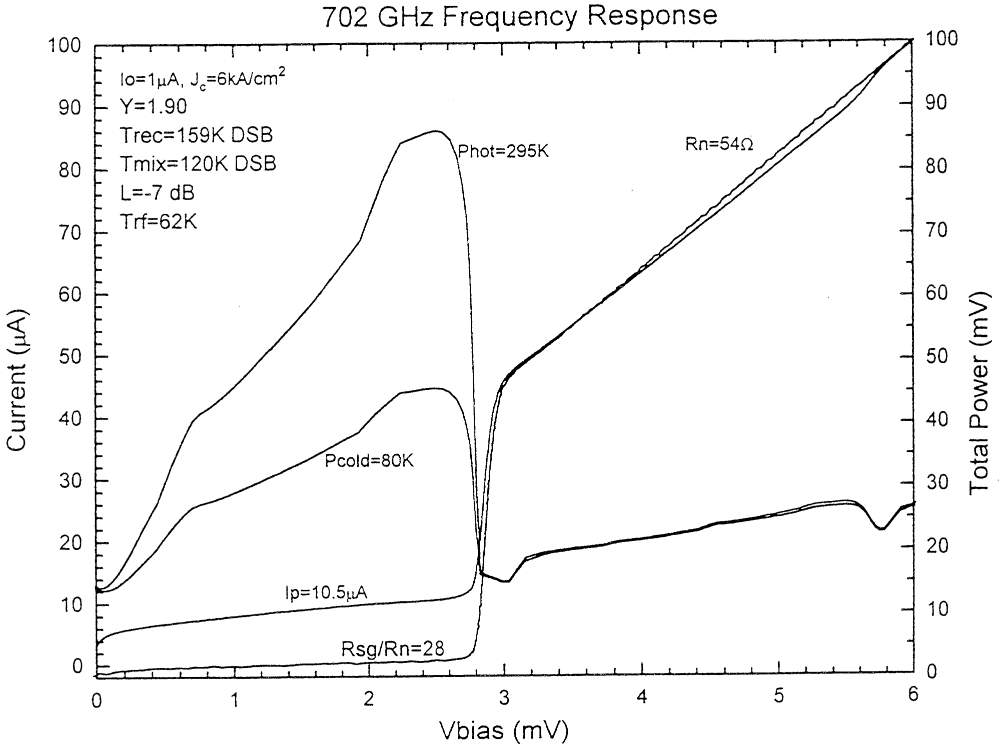


Fig. 3. 702 GHz I-V / Total power response The optimum receiver noise temperature was 160K ± 2K DSB with an corrected mixer noise temperature of ≈ 63K. The mixer exhibits about 7dB of conversion loss, of which ≈ 0.9dB is due to absorption loss in the niobium film.

To further understand the breakdown of the measured 160K DSB receiver noise temperature shown in Figure 3, we employed a technique described by Blundell/Feldman *et al.* [10, 11]. By plotting the total IF power as a function of input load temperature for different values of LO drive level we obtained an equivalent front end receiver noise temperature of 62± 3 Kelvin, Shot noise calculated IF contribution of ≈ 5K and a corrected mixer noise temperature of ≈ 63K, or about 1.7 times the quantum noise limit.

The frequency response of the 665 GHz receiver is shown in figure 4.

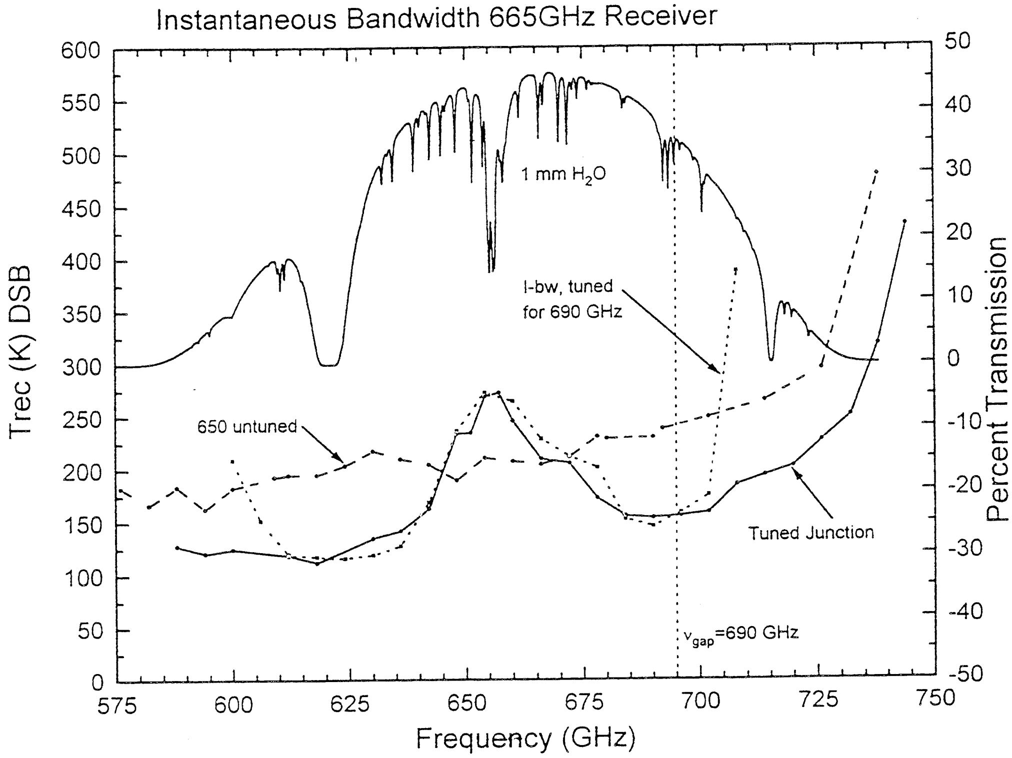


Fig. 4. Frequency response of the 665 GHz receiver discussed (solid). Shown are the receiver noise temperatures (dashed line) for a untuned junction in the same mixer block (1994) and Instantaneous bandwidth (dotted).

Data was taken "in situ" at the Caltech Submillimeter Observatory in Hawaii. A 10μm beamsplitter was used in for all the measurements. The multipliers were provided by RPG-Physics[12]. Unfortunately the SIS devices have a current density 40% lower than the 10kA/cm^2 design value. This has, due to the lower junction capacitance, shifted the resonance up in frequency. The effect of this is twofold. First, the sensitivity is reduced by 3dB at 660 GHz as the tuners can no longer provide a match to the input impedance of the RF matching network (passes through the forbidden region on the Smith chart). And secondly the conjugate input impedance of the RF matching network tracts the embedding impedance of the waveguide mount, which results in a essentially tunerless receiver below 690 GHz.

An upgrade is planned during the August CSO engineering shutdown. It is expected that this will both eliminate the resonance and much reduce the instantaneous bandwidth.

Conclusion

A SIS heterodyne quasi-particle mixer has been developed for the 580-720 GHz submillimeter band. The mixer employs a tuned 0.56 μm^2 Nb/AlO$_x$/Nb tunnel junctions mounted in a full height waveguide mixer.

Above 500 GHz it becomes increasingly difficult to accurately model and fabricated the well known 'End-loaded' stub matching network. In addition, since the mixer is meant to be operated near the superconducting gap frequency of niobium ($2\triangle/h \approx 690$ GHz), special has been taken to minimize the absorption loss in the rf matching network. To solve some of the problems we propose a variation, namely the 'Butterfly' matching network, which is essentially a hybrid hybrid between the well know "end-loaded" stub and radial stub matching networks.

We have measured uncorrected DSB heterodyne receiver noise temperatures as low as 160K from 680- to 702 GHz, 200K at 725GHz and 120K from 585-640 GHz. The uncorrected mixer noise temperature at 702 GHz is about 125K, of which 62K can be directly contributed to the front end optics loss. Mixer conversion loss at 702 GHz is

7dB, of which $\approx$ 0.9dB is due to the absorption loss in the Nb film. This results in a corrected mixer noise temperature of 63K ($\approx$ 1.7 times the quantum noise limit).

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