CHARACTERIZATION OF A 680–760 GHZ SIS WAVEGUIDE MIXER

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A heterodyne waveguide receiver employing 1 μm2 Nb superconducting tunnel junctions with on chip integrated tuning structures is characterized from 680-760 GHz. Several different types of integrated tuning structures are investigated. Lowest DSB receiver noise temperatures of 310 K at 709 GHz and 400 K at 720 GHz are measured. Analysis of the data shows that the loss of the superconducting tuning structures has a major influence on the overall receiver performance. A 25% reduction in receiver noise temperature is observed if the mixer is cooled from 4.2 K to 2 K, which we attribute to the reduced loss of the superconducting microstrip lines at lower temperatures. The calculated performance of the different tuning structures is shown to be in good agreement with the actual receiver noise measurements.

Keywords: SIS Receivers, Waveguide Mixers, Superconducting Striplines, Sub-Millimeter Receivers.

1 Introduction

Recent progress in the development of heterodyne mixers based on niobium superconducting tunnel junctions, has resulted in upper frequencies of use approaching 1 THz. Astronomical and atmospheric observations in the 600-800 GHz frequency range have been performed both with waveguide and quasioptical systems [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. SIS-mixers are therefore increasingly being operated at frequencies well above the superconducting gap frequency of niobium (~ 700

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GHz) and although the sensitivity of the mixers decreases rapidly above this frequency, the resulting noise temperature is still much lower than state of the art GaAs Schottky diode mixers. Analysis of the measurements shows that Nb based tunnel junctions can be used as mixer diodes above the superconducting gap-frequency and that the main cause for the observed increase in noise temperature above this frequency is the onset of loss in integrated RF-tuning circuits, which are used to tune out the intrinsic high capacity of the Nb tunnel junctions [2, 11]. Design and fabrication of low loss tuning structures is therefore of main importance in the development of SIS-mixers at these high frequencies.

In this paper we present results of measurements with a Nb SIS waveguide mixer with several different types of integrated tuning structures in the 680-760 GHz frequency range. The mixer has a lowest noise temperature (with different samples) of 310 K DSB at 709 GHz and 400 K at 720 GHz (and 1500 K DSB at 840 GHz). The best results obtained with this mixer, measurements at 840 GHz, and the implications for heterodyne mixing above the gap-frequency were previously reported in [1] and [12]. Here we supplement these results with an analysis of the effect of different type of tuning structures (in Section 4) and a comparison with the calculated behaviour (Sections 5 and 6). A detailed description of the receiver is given in Section 2. The various contributions to the total receiver noise and gain are analyzed in Sections 3 and 6. Lowering the ambient temperature of the mixer (from 4.2 K to 2 K) results in a substantial improvement of the receiver performance. The origin of this improvement is analyzed in Section 6.

2 Sample Parameters and Receiver Design

The results reported here are obtained with single Nb junctions or with arrays of two junctions. The specific junction parameters are given in Table 4 in Section 4. Typical junction parameters are a normal resistance of 16 Ohm, a current density of 15 kA/cm² and a (defined) area of 1 μm². The gap of these junctions is 2.7 mV at 2.2 K, corresponding to \( f_{\text{gap}} = 670 \text{ GHz} \) and 2.5 mV at 4.2 K with \( f_{\text{gap}} = 603 \text{ GHz} \). Details of the fabrication process can be found in Ref. [13]

The thicknesses of the Nb layers forming the ground plane and the microstrip of the tuning structures is 200 nm and 600 nm, respectively. The SiO₂ dielectric between these layers is 250 nm thick and has a relative dielectric constant \( \varepsilon_r \) of 3.8. The junctions and the tuning structures are fabricated, together with a band-stop RF-filter, on a 200 μm thick fused quartz substrate. After fabrication the quartz is polished down to 45 μm and diced in widths of 90 μm. The substrates are glued in the substrate channel of the mixerblock, parallel to the sidewall of the waveguide. The mixerblock consists of a full height waveguide with dimensions 300x150 μm and a substrate channel of dimensions 100x100 μm (perpendicular to the waveguide). One end of the waveguide is closed by an adjustable backshort tuner (with a quarter wave choke section to improve the quality of the short) and