A 547 GHz SIS RECEIVER EMPLOYING A SUBMICRON Nb JUNCTION WITH AN INTEGRATED MATCHING CIRCUIT

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1. INTRODUCTION

The most sensitive heterodyne receivers used for millimeter wave and submillimeter wave radioastronomy employ superconductor-insulator- superconductor (S1S) tunnel junctions as the nonlinear mixing element, Good performance has recently been reported for S1S junctions used in planar mixer circuits [1] and waveguide mixers [2] from about 400 GHz to 500 GHz. In general, however, very few S1S mixers have been demonstrated at these high frequencies. We have developed a submillimeter wave S1S heterodyne receiver for observing the ground state transition of $H_2{}^{18}O$ at 547 (3117 in the interstellar medium. This receiver is based on a waveguide mixer with an adjustable backshort and H-plane tuner [3]. The mixer uses a high current density, submicron area Nb-AlO_x-Nb tunnel junction. The large capacitive susceptance of the junction at high frequencies will shunt the signal away from the nonlinear conductance and hence must be properly tuned for optimum performance, This is accomplished here through the use of a carefully designed superconductive microstrip transformer to match the complex impedance of the junction to the available tuning range of the waveguide mount. The receiver performance has been measured over the frequency range 520 GHz -550 GHz. A DSB receiver noise temperature as low as 370 K has been achieved at 521.5 GHz. This is the best result reported to date at this frequency.

11. SIS JUNCTIONS WITH INTEGRATED TUNING CIRCUITS

The S1S tunnel junctions were fabricated using a recently developed Nb-AlO_x-Nb trilayer process [4] and patterned to an area of 0.25μm^2 by electron beam lithography. The **current density is near** 10 kA/cm^2, the normal state resistance is around 110 Ω, and the specific capacitance is estimated to be 85 fF/μm^2. The integrated tuning circuit is defined by the Nb counter electrode on a 2000Å thick SiO insulating layer.

The integrated tuning circuit consists of a ?-section microstrip transformer as shown in fig. 1. The first section of superconducting microstrip line transforms the S1S junction complex impedance to a low real impedance. This impedance is then transformed to 50 Ω with a 2-step Chebyscheff transformer. The superconductive microstrip line is a slow wave structure due to the penetration of the magnetic field, A penetration depth of 750 Å [5] is used in calculating the phase velocity and impedance of the line.

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111 RECEIVER DESIGN AND MEASUREMENT TECHNIQUES

The S1S tunnel junction, integrated tuning circuit, and low-pass rf filter arc fabricated cm 50μm thick quartz which is cut to a width of 150 pm, This substrate is installed into the waveguide mixer mount and wire bonded to the 50 Ω IF output connector. The waveguide mixer was designed using a low-frequency model to maximize the accessible region of impedances on the Smith chart over an equivalent frequency range of 500 GHz to 600 GHz [3]. This mixer has an adjustable backshort and n-plane tuner which provide a wide range of impedances to the S1S junction. Radiation is coupled into the waveguide mount by a dual-mode conical horn.

Figure 2 shows a block diagram of the receiver. The local oscillator (1.0) source consists of two whisker-contacted frequency multipliers (x2x3) driven by a Gunn oscillator at 92 GHz. The signal and 1.0 are combined in a folded Fabry-Perot diplexer and injected into the cryostat through a mylar vacuum window. Fluorogold far IR filters on the 77 K and **4 K stages** block room temperature radiation from saturating the mixer. An off-axis elliptical mirror reflects the combined radiation into the mixer which is installed on the 4K stage of the cryostat, The 1.4 GHz IF output of the mixer is transformed to the required 50 Ω input impedance of the low-noise 1 HEMT amplifier by a microstrip transformer. The 1 F is further amplified by two high gain room temperature amplifiers. The bandwidth for noise measurements is 300 MHz. A superconducting magnet is used to suppress unwanted Josephson interference and thus improve receiver performance.

The total receiver noise temperature is determined by the Y-factor method using hot (297K) and cold (77K) loads. The reference plane of these measurements is the input of the diplexer (see fig. 2). Due to the very high frequency of this receiver, wc have calculated the correct radiation power from the loads using the full Planck expression,

IV RESULTS AND DISCUSSION

Figure 3 shows the unpumped and 1.0 pumped IV curves of the S1S tunnel junction at about 546 GHz. The unpumped curve shows very low subgap current and a sharp gap structure near 3 mV. The photon step is clearly seen on the pumped 1 V curve. Also shown in this figure is the IF output power from the receiver for both hot and cold loads as broadband signal sources at the rf input, It can be seen that the IF power is very low near zero voltage which indicates that the Josephson current has been almost complete] y suppressed, Also there is no structure in the IF power curves corresponding to rf induced Josephson steps.

The receiver performance has been measured over an LO frequency range from 520 GHz to 550 GHz. Figure 4 shows the DSB receiver noise temperature as a function of the 1.0 frequency. The mixer, 1.0 level, and bias voltage arc optimized at each frequency. The best value is T_R = 370 K at 521 GHz which is state-of-the-art performance at this frequency. in addition, by subtracting the contribution of the IF system, we estimate the mixer loss to be L = 11 dB and the mixer noise temperature as T_m = 240 K.

We can clearly see in Fig. 4 a large increase in the apparent receiver noise temperature close to 560 GHz. This is expected due to the strong absorption in the signal path by atmospheric water vapor at 557 GHz. Thus this increase is not due to any intrinsic properties of the receiver. We have in fact estimated this absorption by analyzing the apparent change in receiver noise temperature by placing the hot/cold load at two different reference planes. This yields 0.045 dB/cm at 546 GHz and 0.11 dB/cm at 552 GHz which is the correct order of magnitude for our laboratory conditions.

ACKNOWLEDGEMENTS

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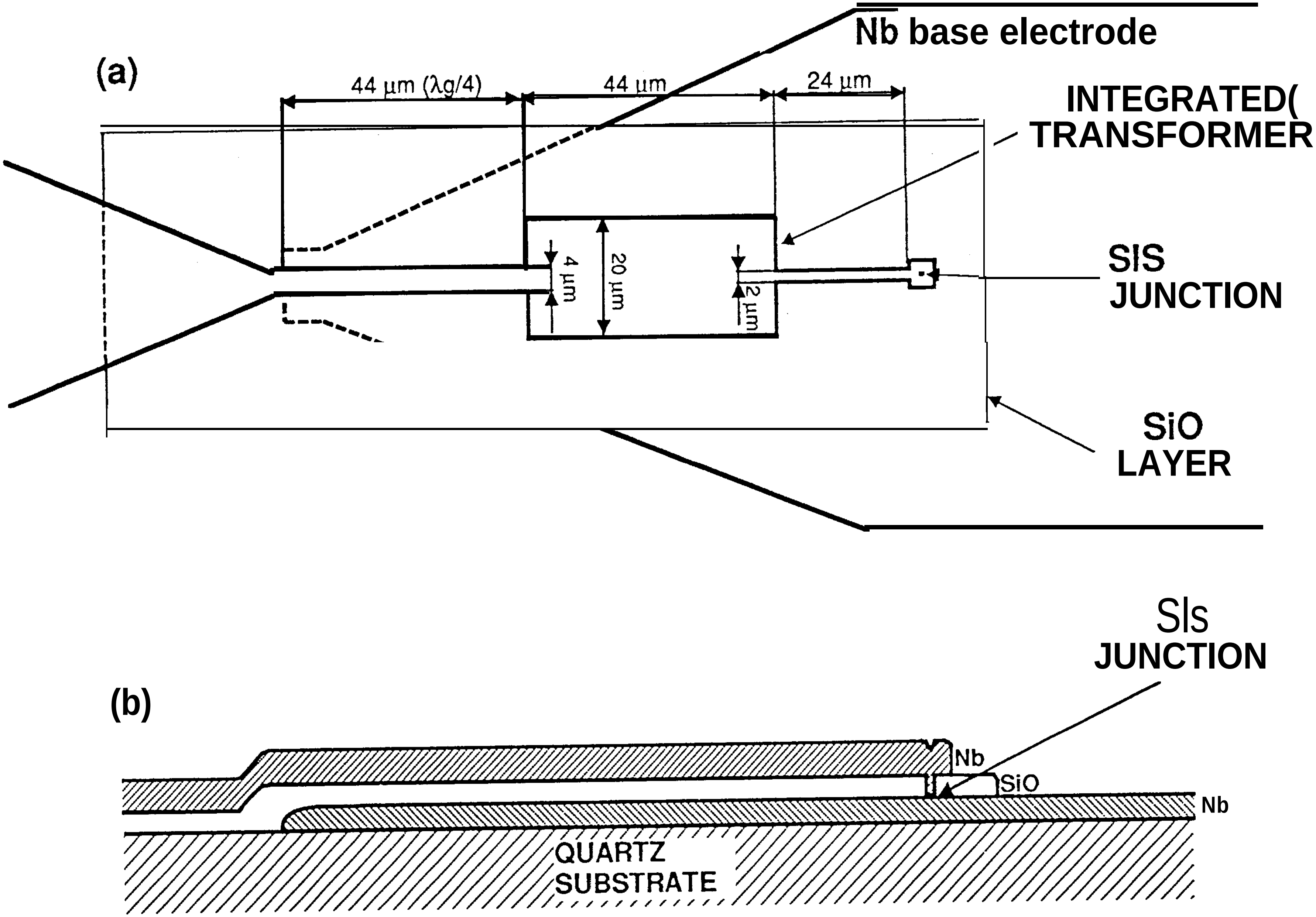

Figure 1: S1S tunnel juction with an integrated microstrip matching circuit. (a) Top view showing transmission line dimensions. (b) Cross section view showing film topology.

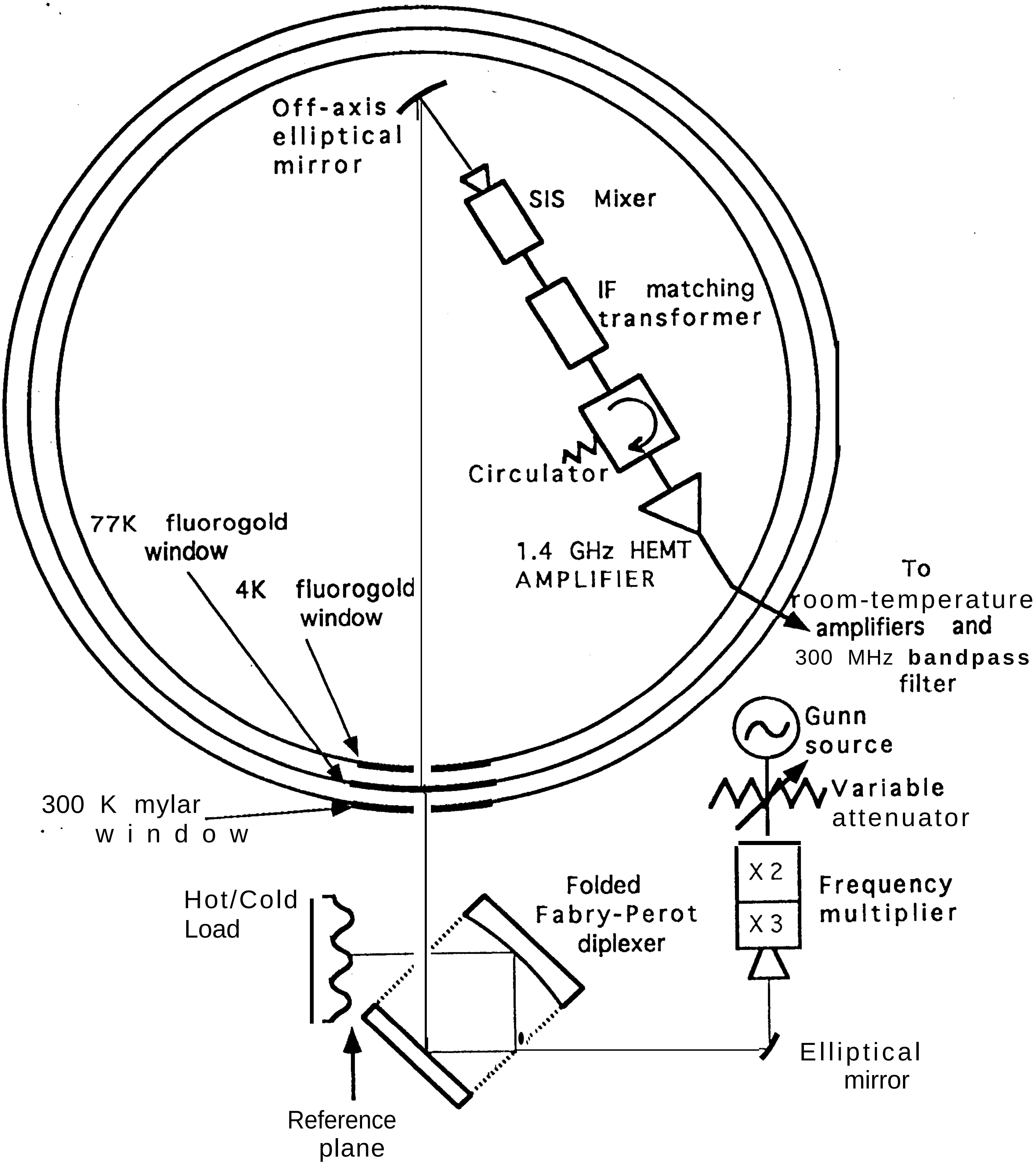

Figure 2. Block diagram **of S1S heterodyne receiver. Noise measurements are referred to the reference plane.**

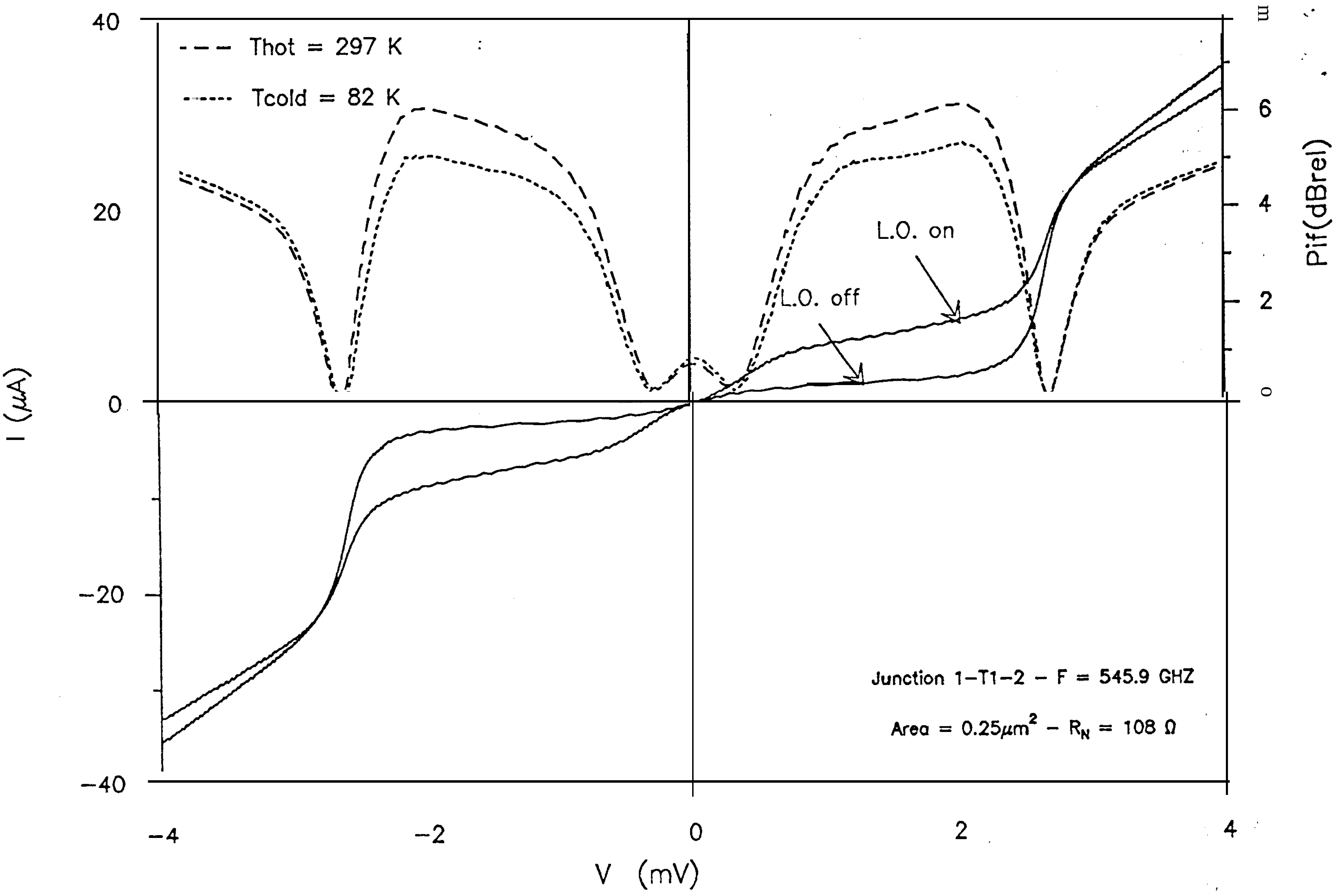

Figure 3. Current vs voltage characteristic (solid lines) for SIS tunnel junction with and without LO power applied at 546 GHz. Receiver IF output power, Pif, (dashed lines) for broadband hot and cold load signals at the rf input.

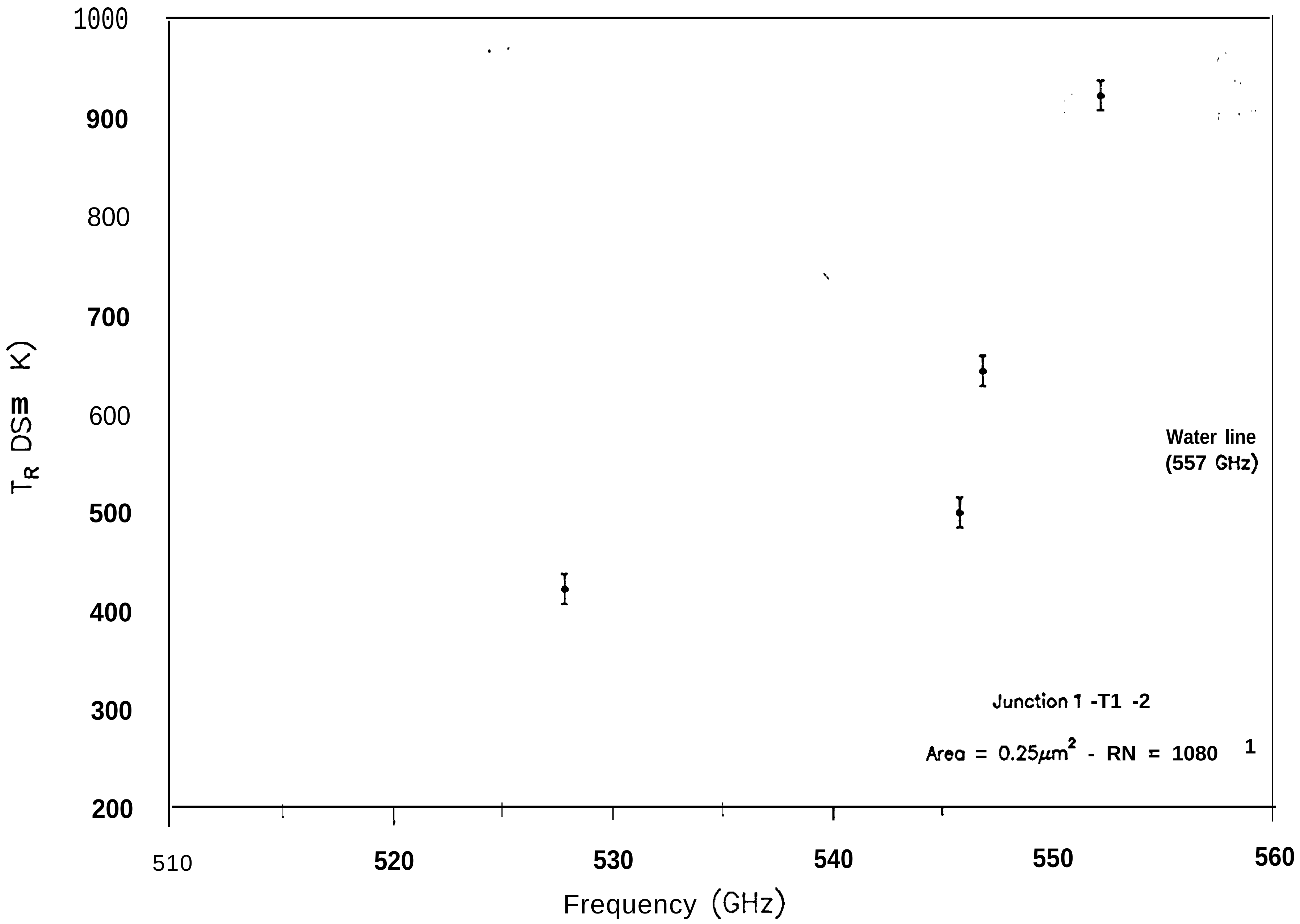

Figure 4. Receiver noise temperature as a function of LO frequency. The best value is 370 K at 521 GHz. Absorption due to atmospheric water vapor increases the apparent receiver noise above 550 GHz.