

THE CALTECH AIRBORNE SUBMILLIMETER SIS RECEIVER

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ABSTRACT We have constructed a sensitive submillimeter receiver for the NASA Kuiper Airborne Observatory (KAO) which at present operates in the 500-750 GHz band. The DSB receiver noise temperature is about $5 h\nu/k_B$ over the 500-700 GHz range. This receiver has been used to detect $H_2^{18}O$, HCl, and CH in interstellar molecular clouds, and also to search for C^+ emission from the highly redshifted galaxy ($z = 2.3$) IRAS 10214.

INTRODUCTION

The rotational transitions of many hydride molecules lie in the submillimeter band. These simple molecules play a fundamental role in interstellar chemistry, and may provide important cooling mechanisms for collapsing cloud cores. However, observations from the Kuiper Airborne Observatory (KAO) are often necessary. Over the past two years, we have detected CH at 532 and 536 GHz, HCl at 626 GHz, and $H_2^{18}O$ at 547 and 745 GHz, using our SIS receiver on the KAO; some of these observations are discussed in more detail elsewhere in this volume (Zmuidzinas *et al.* 1994b).

THE CALTECH SIS RECEIVER

Construction of our receiver was started in October, 1991, after our project was approved as a new instrument for the KAO. The first flights occurred in September, 1992, and since then our instrument has flown four additional series. There has recently been a tremendous improvement in the sensitivity of submillimeter receivers which use superconducting (SIS) tunnel junctions. The progress is due to new materials and processes for fabricating robust tunnel junctions and superconducting circuits; novel circuit configurations to cancel the effects of the junction capacitance; and new techniques for coupling the radiation into the device. Figure 1 shows the receiver sensitivity we have obtained to date. Note that these noise temperatures are only a factor of several below those obtained with the pioneering InSb hot-electron bolometer receiver developed by

T. G. Phillips and which flew on the KAO during 1978-1986. However, the SIS receivers enjoy a large multiplex advantage since many frequency channels can be observed simultaneously, whereas the InSb system had a single 1 MHz channel.

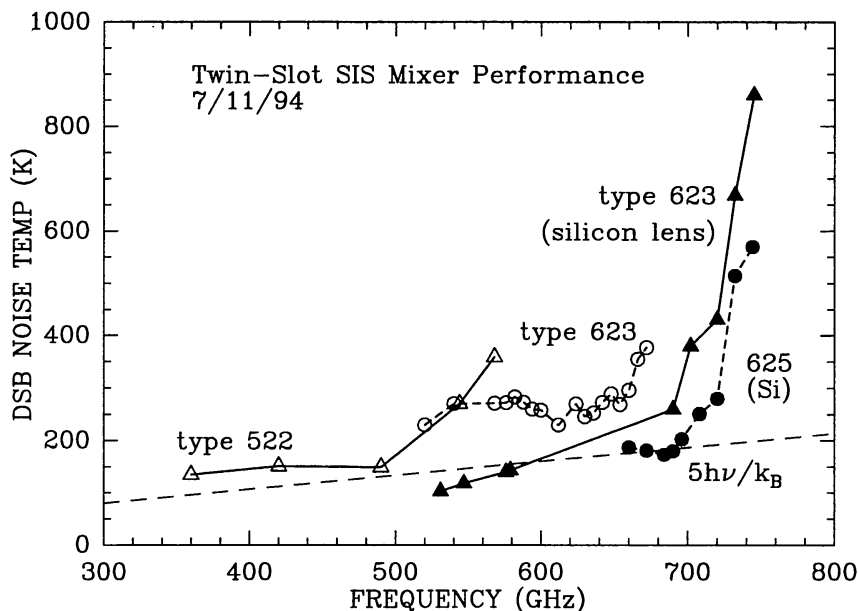


Figure 1. DSB noise temperature vs. frequency for our twin slot antenna mixers.

The local oscillator (LO) for this receiver is provided by a phase-locked Gunn oscillator followed by a waveguide frequency multiplier. Sources are available at present in the following bands: 500-580 GHz, 580-660 GHz, and 660-750 GHz. Switching between these bands requires the substitution of LO sources, but can be performed in flight in about 15-20 minutes.

The intermediate-frequency (IF) output of the receiver is analyzed by a radio-frequency spectrometer to provide a multichannel spectrum. We have constructed a digital autocorrelation spectrometer for our receiver, using the Caltech CSO320 CMOS correlator chip developed by B. von Herzen. Our KAO spectrometer provides a bandwidth of 350 MHz with 160 channels, and uses commercial silicon A/D converters running at a 350 MHz sample rate. To obtain the 350 MHz bandwidth with converters limited to a Nyquist bandwidth of 175 MHz, we use a quadrature mixer to convert the receiver 1.5 GHz IF output to baseband, and measure all four correlation products between the in-phase (I) and quadrature-phase (Q) baseband outputs. A 1 GHz bandwidth acousto-optic spectrometer (AOS) was also loaned to us by A. Betz and R. Boreiko, which allowed us to fly our receiver before the correlator was constructed. The wide bandwidth of the AOS was also necessary for the IRAS 10214 observations.

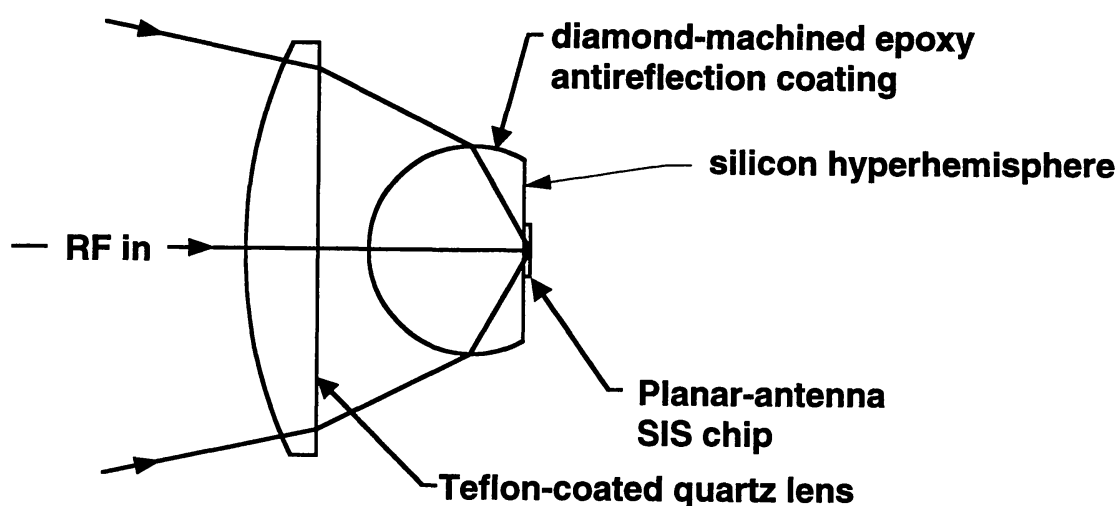


Figure 2. Optical layout of our twin-slot SIS mixer.

QUASIOPTICAL MIXERS

Figure 2 shows the optical layout of our mixer. The SIS chip is mounted on a silicon hyperhemispherical lens, which concentrates the radiation from the telescope onto an antenna fabricated lithographically on the SIS chip. Hyperhemispherical lenses with planar antennas were introduced by Rutledge and Muha (1982), and were first used with SIS mixers by Wengler *et al.* (1985). Another benefit of the hyperhemispherical lens is that the planar antenna radiates preferentially into dielectric material. The use of silicon ($\epsilon_r = 11.7$) as the dielectric results in a forward efficiency (for our antenna design) of 91%, compared to a 9% loss due to backward radiation into free space. To avoid the Fresnel reflection at the surface of the silicon lens, we have developed an anti-reflection coating. The coating material is epoxy loaded with alumina powder, which gives the proper combination of dielectric constant ($\epsilon_r \approx 4$), reasonably low loss ($< 2\%$), adhesion, and cryogenic recyclability. The coating is diamond machined to yield a very smooth coating with precisely the correct ($\lambda/4$) thickness.

Our mixer uses a twin-slot antenna (Figure 3) to receive the radiation. As discussed by Zmuidzinas *et al.* (1992), this antenna has a number of desirable properties, including linear polarization, a symmetric beam with low sidelobes, a low antenna impedance, and an octave bandwidth. The radiation received by the slot antennas is coupled into the SIS junctions with superconducting microstrip lines, and a novel two-junction circuit tunes out the SIS junction capacitance at the frequency of operation (Zmuidzinas *et al.* 1994a). The mixer chip fabrication is performed at the JPL Center for Space Microelectronics Technology, using Nb/Al-Oxide/Nb tunnel junctions.

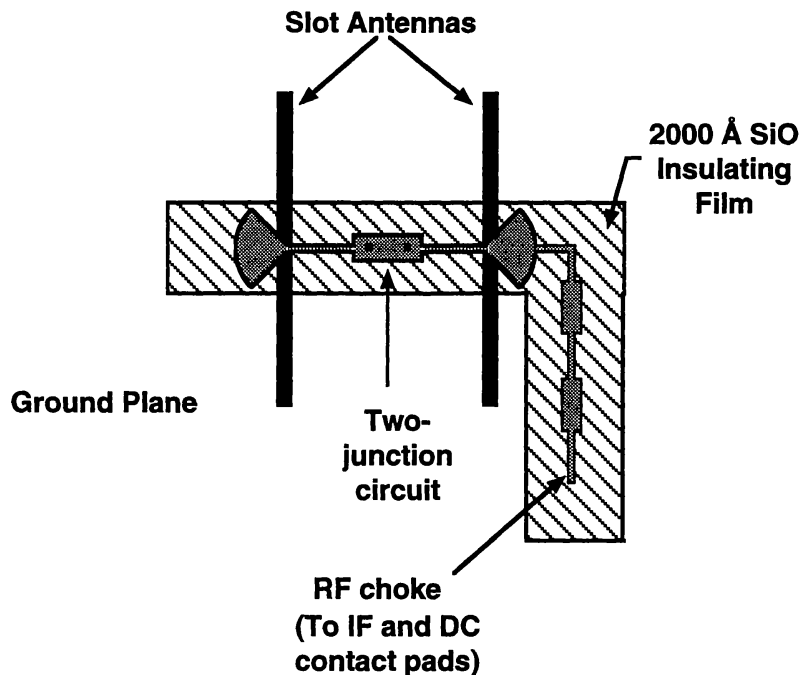


Figure 3. Our twin-slot SIS mixer chip.

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