Sensitive Broadband SIS Receivers for Microwave Limb Sounding

John S. Ward, Karen A. Lee, Jonathan Kawamura, Goutam Chattopadhyay, and Paul Stek
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA

***Abstract*— We present the measured performance of a sensitive new broadband waveguide sideband-separating superconductor-insulator-superconductor (SIS) heterodyne receiver with very wide IF bandwidth that is being developed for a future space-borne microwave limb sounder to study the earth's atmosphere. The prototype receiver has measured noise temperature below 100 K from 190 to 300 GHz, and features 24 GHz of sideband-separated output. Measured sideband image rejection is typically 13 dB. The receiver features a three-section suspended stripline 6-18 GHz quadrature hybrid coupler integrated into the mixer waveguide block to minimize phase errors and standing waves to provide maximum bandwidth and image rejection. The high spectral resolution achieved with heterodyne detection will enable precision measurement of the profiles of pressure-broadened thermal emission spectral lines. Broad instantaneous bandwidth will enable multiple chemical species in the atmosphere to be measured simultaneously without retuning the receiver.**

I. Introduction And Background

Microwave limb sounding is a proven remote-sensing technique that resolves the spectra of microwave thermal emission along a limb view of the earth's atmosphere against a cold space background. The temperature and composition of the atmosphere as a function of altitude are retrieved by analyzing the spectra returned from a vertical scan of the limb. The Microwave Limb Sounder (MLS) instrument on the NASA Upper Atmosphere Research Satellite (UARS) was the first experiment to study the microwave limb from space [1], and was followed by the current EOS MLS instrument aboard the Aura spacecraft [2].

We are developing a new class of highly-sensitive broadband receivers for a next-generation microwave limb sounder that will scan the limb in elevation and azimuth to generate 3-D maps of atmospheric composition [3]. Sensitive receivers are needed to reduce integration times to enable rapid horizontal and vertical scanning while maintaining high measurement precision. The Scanning Microwave Limb Sounder (SMLS) will sample a 6000 km cross track swath with 50 km horizontal sampling and better than 2 km vertical sampling. This wide swath allows for six or more daily samples for most of the mid latitudes. These frequent measurements, combined with the good horizontal and high vertical resolution of SMLS, are essential to enable the study of fast processes in the upper troposphere affecting chemistry, climate, and air quality.

II. Results

The receiver features two SIS mixer chips [4] arranged in a sideband-separating configuration with 24 GHz of instantaneous bandwidth. Separating the sidebands increases the usable instantaneous bandwidth of the receiver, rejects unwanted flux from the image sideband, and improves calibration accuracy by eliminating the sideband imbalance uncertainty inherent to double-sideband mixers. The sidebands are separated using an eight-branch waveguide 180-300 GHz branchline hybrid coupler at the RF input and a three-section 6-18 GHz suspended-stripline hybrid coupler for the IF (Fig. 1). The local oscillator signal is split with an in-phase power divider [5] and coupled to the mixers using a pair of two-branch 18 dB directional couplers. While weaker coupling would improve performance, it would also complicate fabrication. Both hybrid couplers as well as the other waveguide circuitry and two mixer chips are all integrated into a single compact mixer block to minimize phase errors, loss, and standing waves (Fig. 2). Fig. 3 shows the completed mixer block. The two IF outputs from the mixer block (lower sideband and upper sideband) are amplified using 6-18 GHz single-ended amplifiers [6] operated at 4.2 K before being analyzed by room-temperature microwave electronics.

A prototype receiver was measured at 4.2 K in a liquid helium cryostat. A Gunn diode oscillator [7] driving a Schottky diode frequency multiplier [8] was used for the local oscillator. Three different local oscillators were used to cover the large tunable bandwidth of the receiver. The noise temperature was measured using room temperature and 77 K black body loads. Dark and pumped mixer currents as well as the total IF power are plotted as a function of mixer bias voltage in Figure 4. Image sideband rejection was measured by injecting a weak narrow-line signal into the mixer input horn following the approach given in [9], and was found to be typically 13 dB. After correcting for the cryostat window loss, the measured noise temperature was 60 to 100 K from 190 to 300 GHz (Fig. 5). The noise temperatures plotted in the figure were not corrected for sideband image rejection nor for the loss of three infrared blocking filters, and include noise contributions from the local oscillator and the 6-18 GHz IF amplifiers.

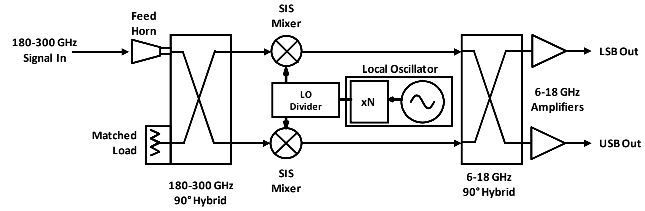

Fig 1. Configuration of the sideband-separating receiver. Spectra in the 180-300 GHz band are downconverted into two 6-18 GHz bands. Splitting and recombining the signal with 90° hybrid couplers separates the upper and lower sidebands, effectively doubling the instantaneous bandwidth of the spectrometer, reducing noise, and improving calibration accuracy.

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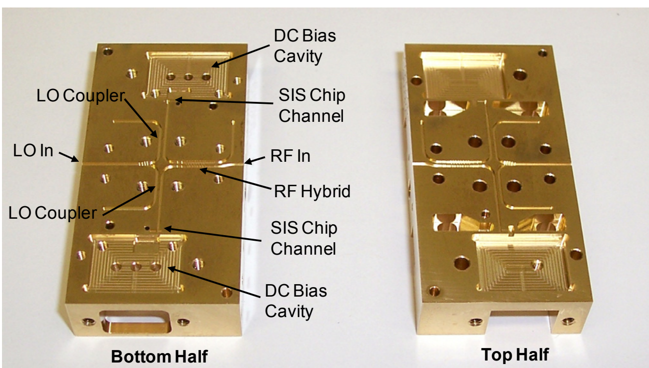

Fig 2. Most of the 180-300 GHz circuit is implemented in rectangular waveguide. The back side of the bottom half (not visible) houses the 6-18 GHz hybrid coupler, producing outputs in two 6-18 GHz band.

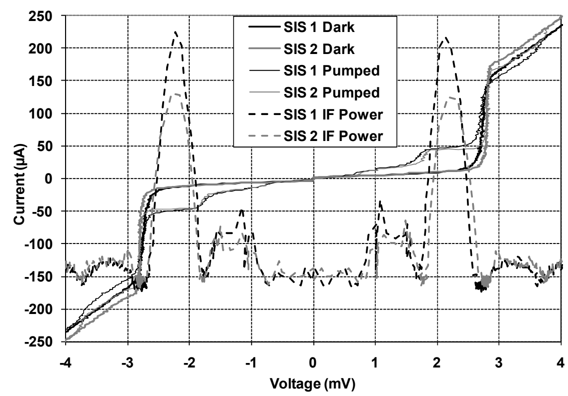

Fig. 4. Measured IV curves and total IF power at an LO frequency of 252 GHz. Total IF power was measured with the receiver beam terminated with a room-temperature load and the other mixer biased above the gap.

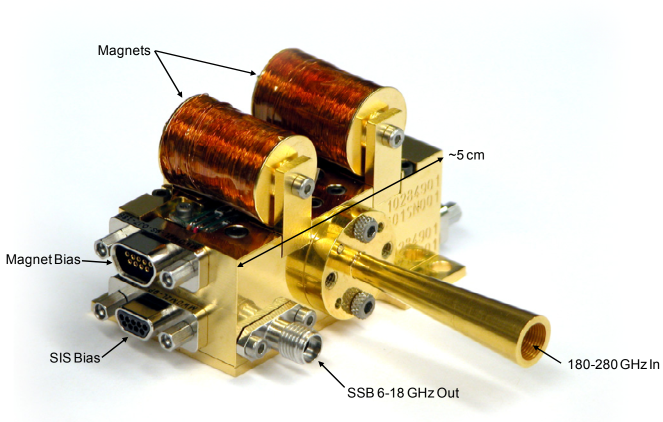

Fig 3. The completed mixer block. Two superconducting magnets mounted to the top of the block are used to suppress Josephson noise in the SIS mixer chips. The local oscillator signal is introduced from the back side via a waveguide flange. A second 6-18 GHz output is also located on the back of the block.

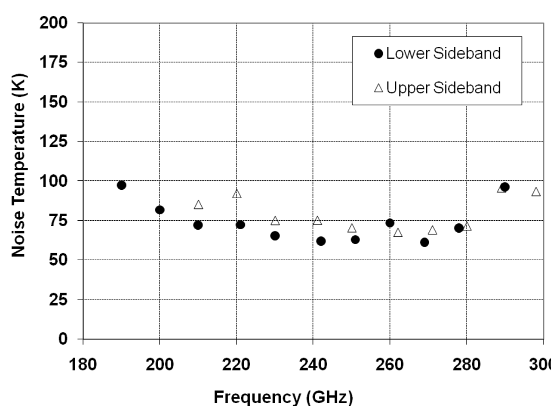

Fig. 5. Measured noise temperature of the sideband-separated broadband receiver. These measurements were corrected for the cryostat window loss. No other corrections were applied, and the results include the noise contributions from the infrared blocking filters, local oscillator, and IF amplifiers.