# Sensitive Broadband Receivers for Microwave Limb Sounding

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***Abstract*** **− We present the measured performance of a sensitive new broadband receiver developed for a future microwave limb sounding instrument to map chemical species in the upper troposphere. This receiver will downconvert thermal emission spectra in the 180-280 GHz band using superconductor-insulator-superconductor (SIS) heterodyne mixers. The high spectral resolution achieved with heterodyne detection enables precision measurement of the profiles of pressure-broadened lines. Broad instantaneous bandwidth (24 GHz for a single mixer) enables multiple species to be measured simultaneously. The high sensitivity of this receiver and resulting short integration times, when combined with a novel optical configuration, will enable rapid horizontal and vertical scanning of the limb, resulting in three-dimensional maps of a large number of key chemical species in the trophosphere measured five to nine times per day over nearly the entire planet.**

## I. INTRODUCTION

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].

The Global Atmospheric Composition Mission (GACM) (Fig. 1) was recently recommended by the National Research Council Decadal Survey as one of the priority orbital earth observation missions for NASA to implement in the next decade. GACM will address crucial issues on how changes in atmospheric composition affect the quality and well-being of life on earth, providing data that will be essential for governments to make informed policy decisions on issues related to regional and global air quality and climate change [3]. We are developing a new class of highly-sensitive broadband receivers for a next-generation microwave limb sounder aboard GACM that scans the limb in elevation and azimuth to generate a 3-D map of atmospheric composition (Fig. 1, 2). Sensitive receivers are needed to reduce integration times to allow the addition of rapid horizontal 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 (Fig. 3). 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.

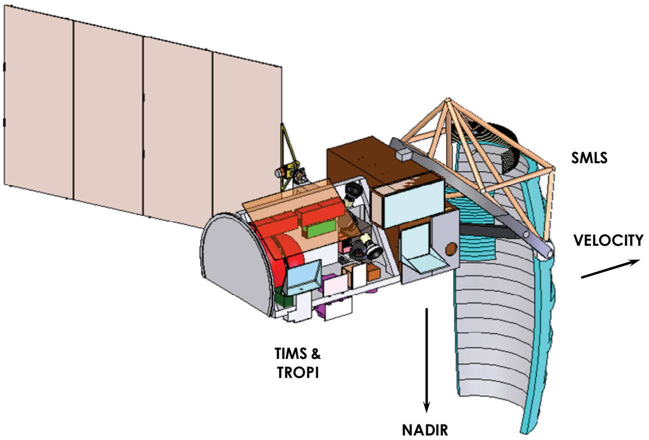

Fig 1. A concept for the Global Atmospheric Composition Mission (GACM). The large primary mirror is axially symmetric to allow rapid horizontal scanning of the atmospheric limb.

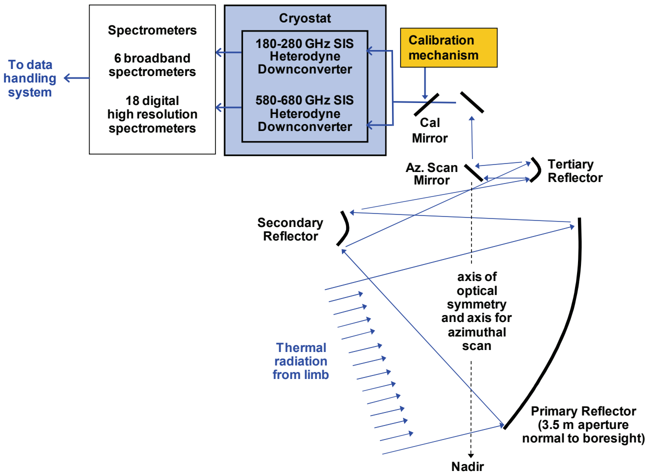

Fig 2. Configuration of the microwave limb sounder instrument on GACM. The primary, secondary, and tertiary reflectors are cylindrically symmetric to enable rapid azimuthal scanning through wide angles about the axis of optical symmetry by rotating a small scanning mirror.

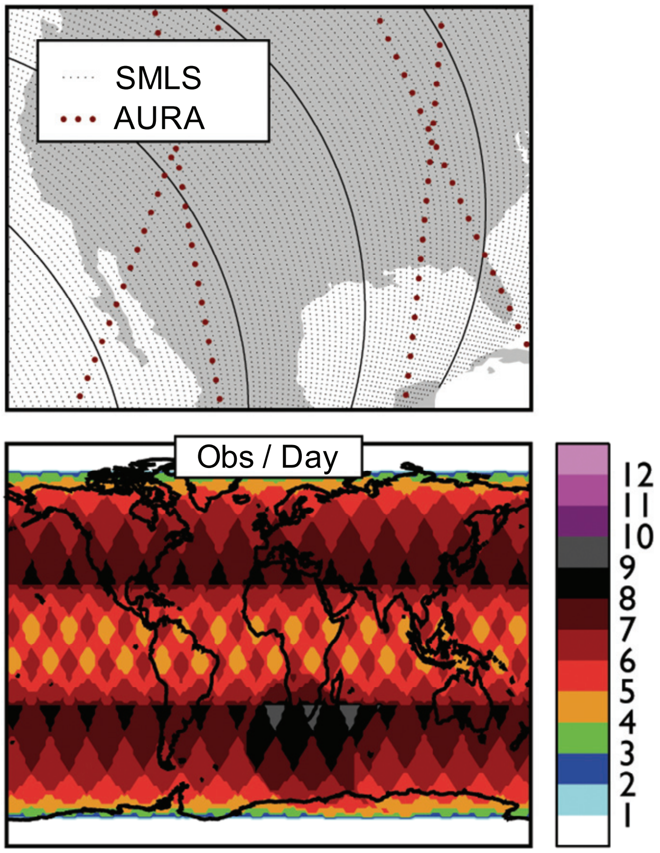

Fig 3. **Top.** Measurement locations for a portion of one orbit comparing the GACM mission concept to the currently operational Aura MLS. **Bottom:** Number of observations per 24 hour period for the GACM SMLS. Note that mid latitudes are mapped 6 to 9 times per day.

Two receivers are being developed for SMLS: a 230 GHz channel will be used to study the upper troposphere and a 640 GHz channel will focus on measurements of the stratosphere. Both receivers feature broad tunable bandwidth (100 GHz each) to enable measurements of many important species including water, ozone, CO, HCN, NO, SO2, and acetone. Each receiver will downconvert the signals using superconductor-insulator-superconductor (SIS) heterodyne mixers [4]. The high spectral resolution achieved with heterodyne detection enables precision measurement of the profiles of pressure-broadened lines. Broad instantaneous bandwidth (up to 24 GHz for each channel) will enable multiple species to be measured simultaneously.

## II. Receiver Configuration

The receiver for the lower-frequency channel features two SIS mixer chips [5] 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 such as those flown on the UARS and Aura microwave limb sounders. The sidebands are separated using a waveguide 180-300 GHz branchline hybrid coupler at the RF input and a 6-18 GHz suspended-stripline hybrid coupler for the IF (Fig. 4). Both hybrid couplers as well as both mixer chips are all integrated into a single waveguide split-block to minimize phase errors and loss (Fig. 5). Fig. 6 shows the completed mixer block. The IF outputs are amplified with two 6-18 GHz single-ended amplifiers [6] (not shown) operated at 4.2 K before being processed by room-temperature microwave spectrometer back-ends.

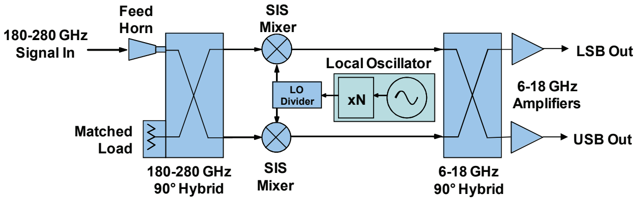

Fig 4. Configuration of the heterodyne downconverter for the lower-frequency channel. Thermal emission spectra from the limb in the 180-280 GHz band are downconverted into two 6-18 GHz bands. Splitting and recombining the signal with 90° hybrid couplers separates the upper and lower sidebands, effectively doubling the instantaneous bandwidth of the spectrometer and improving calibration accuracy.

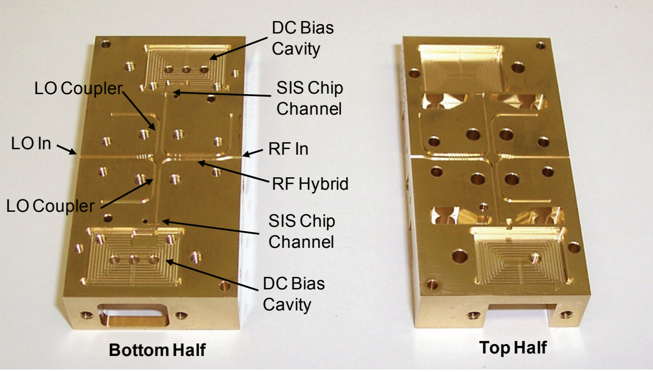

Fig 5. Most of the 180-280 GHz circuit is implemented in rectangular waveguide. The back side of the bottom half (not shown) houses the 6-18 GHz hybrid coupler, producing outputs in two 6-18 GHz band.

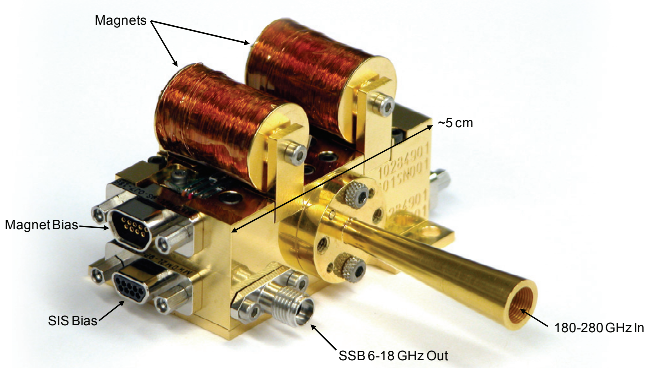

Fig 6. The completed mixer block. The corrugated feed horn input will sit at the instrument focal plane. Two superconducting magnets mounted to the top of the block are used to suppress Josephson noise in the SIS mixer chips. The local oscillator signal is introduced from the back side via a waveguide flange. A second 6-18 GHz output is located on the back of the block.

## III. Measured Results

A prototype 180-280 GHz sideband separating 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 double-sideband noise temperature was measured using room temperature and 77 K black body loads, and image sideband rejection was measured by injecting a weak narrow-line signal into the mixer input horn. This measured image rejection was then used to convert the raw double-sideband noise measurements to true single-sideband (SSB) sensitivities following the approach given in [9]. The measured single-sideband (SSB) noise temperature was 80 to 120 K from 190 to 300 GHz (Fig. 7). The single sideband noise temperatures plotted in the figure were *not* corrected for the loss of the cryostat window and three infrared blocking filters, and also include noise contributions from the local oscillator and the 6-18 GHz IF amplifiers. The measured image rejection, also calculated following the approach given in [9], was typically 13 dB. These results meet the goals required for GACM, which include 100 K SSB noise temperature and 10 dB image rejection.

## III. Discussion

The R2 channel of the EOS microwave limb sounder on the Aura satellite is a double sideband receiver tuned to a center frequency of 240 GHz. Although the R2 double sideband noise temperature is 1,400 K, the spectra being measured are only present in a single sideband, resulting in an effective SSB noise temperature of over 2,800 K for this receiver. Given that the RMS channel noise in the spectrometer drops with the square of the integration time, the new receiver for GACM presented here can match the sensitivity of EOS MLS with at least 100 times shorter integration times. This huge drop in integration time enables the rapid scanning of the GACM SMLS instrument for near-global coverage at high resolution many times per day.

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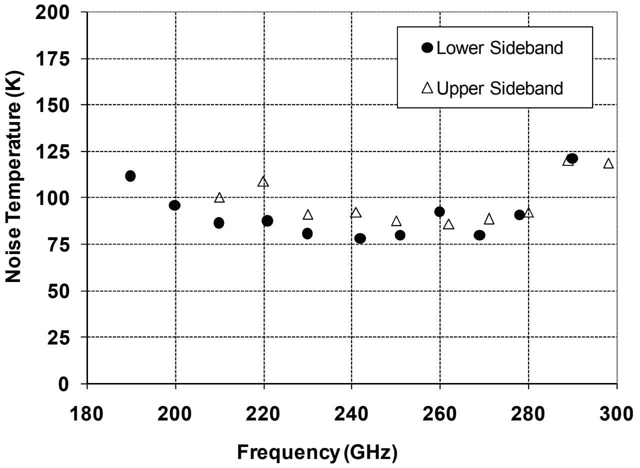

Fig. 7. Measured SSB noise temperature of the sideband-separated broadband receiver. These measurements include the noise contributions from the cryostat window, infrared blocking filters, local oscillator, and IF amplifiers.

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