

Sensitive Broadband Receivers for Microwave Limb Sounding

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Scanning Microwave Limb Sounder

- **The purpose of this research is to develop tunable receiver front-ends for a new generation of high-resolution spectrometers to enable a future space-borne mission to measure and monitor the composition of the atmosphere.**
- SMLS is one of 3 instruments on the Global Atmospheric Composition Mission (GACM) called for in the decadal survey.
- GACM provides atmospheric data needed to address important global issues, including air quality, climate change, global circulation, and ozone layer stability.
- SMLS will measure water vapor, cloud ice, and trace gases at altitudes from 8 to 50 km
- High sensitivity SIS receiver front ends will enable SMLS to reduce measurement integration times relative to Aura MLS by more than a factor of 100 while improving measurement precision.
- A novel optical design allows SMLS to take advantage of this improved sensitivity to scan the limb both vertically and horizontally.
- Broad instantaneous and tunable bandwidths allow for simultaneous measurements of key constituents such as ozone, water, carbon monoxide, NO, and acetone.
- Sideband separation critical for studying strongly broadened tropospheric lines and to achieve accurate calibrations.

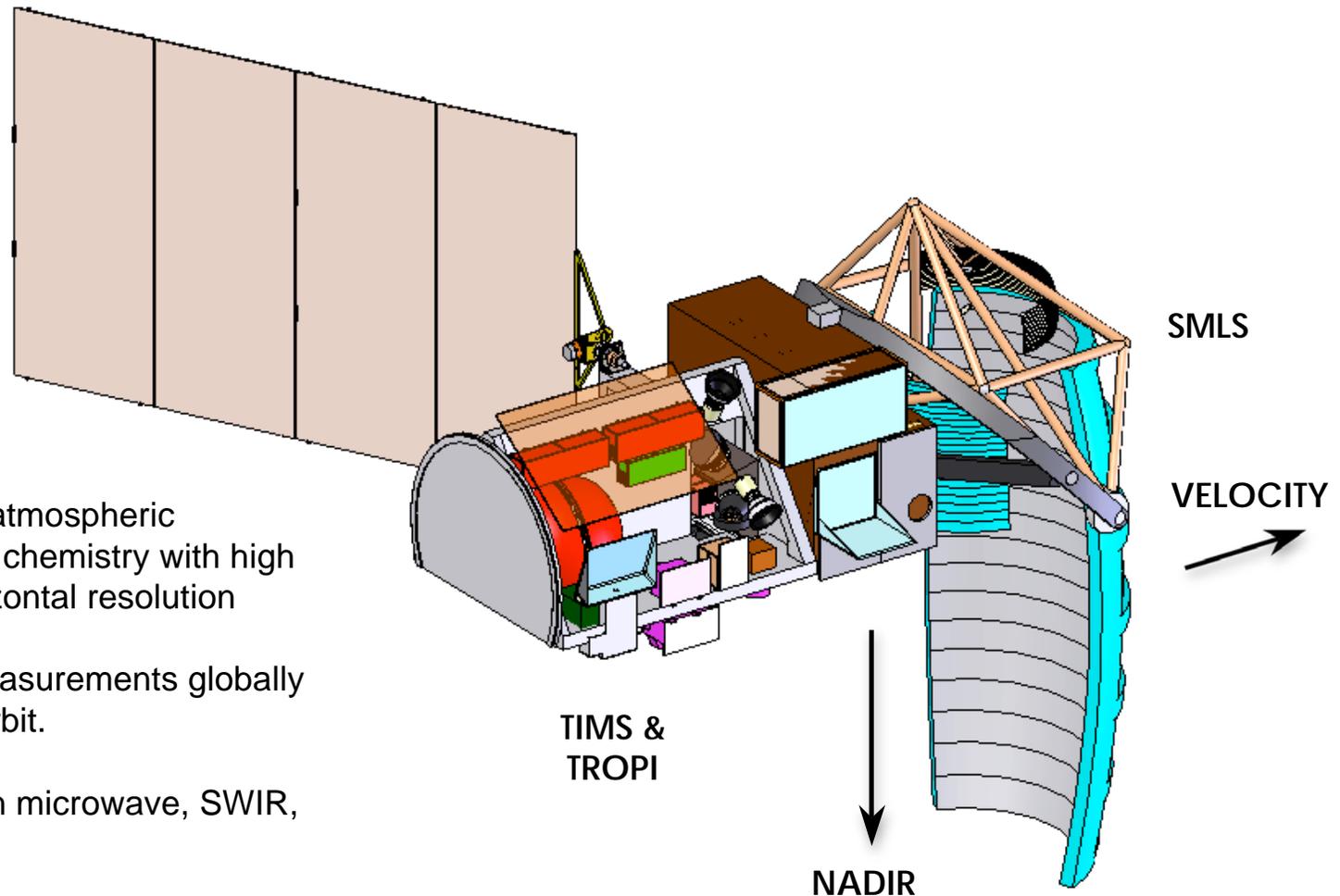
Global Atmospheric Composition Mission

Goals:

Measure global atmospheric composition and chemistry with high vertical and horizontal resolution

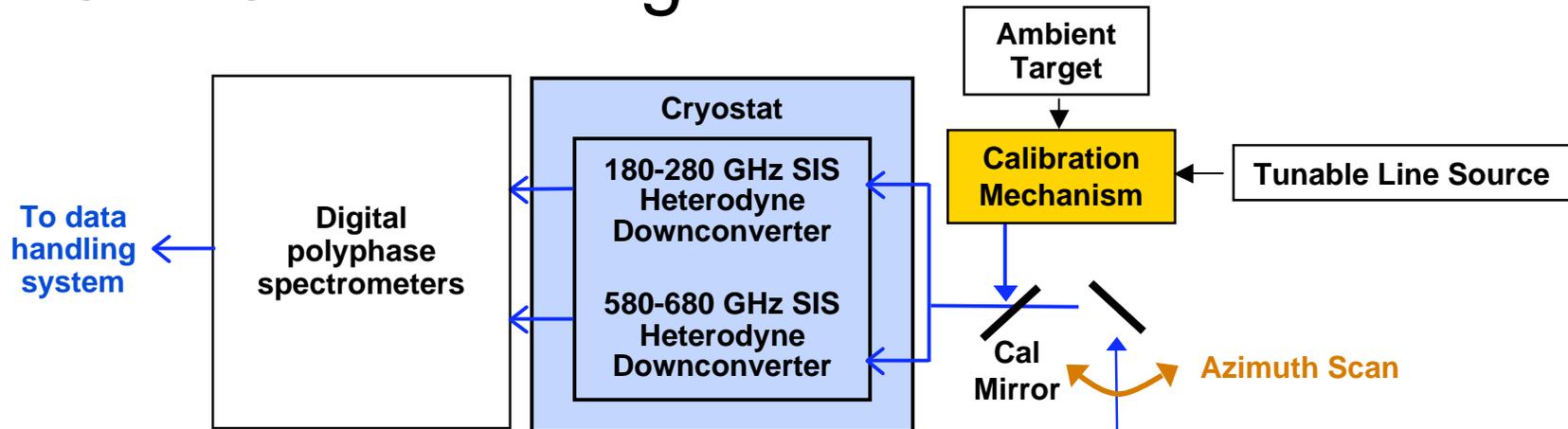
Multiple daily measurements globally from low earth orbit.

Measurements in microwave, SWIR, and UV.



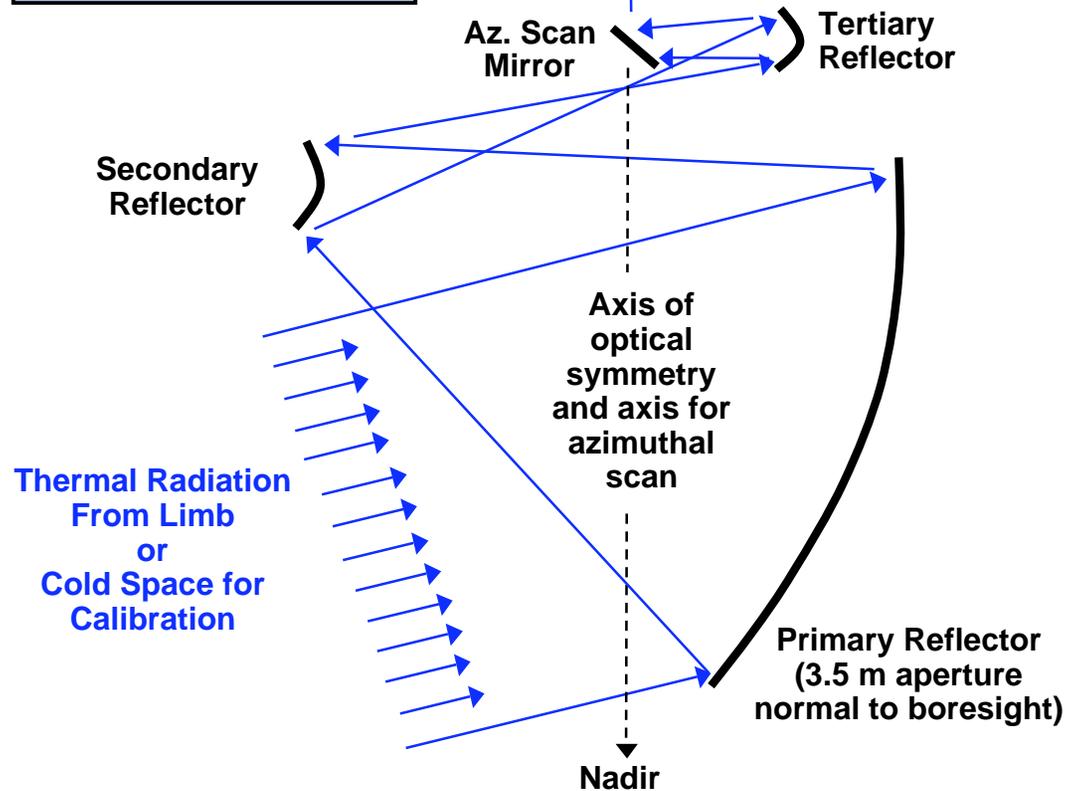
GACM incorporates much of the CAMEO mission concept that was submitted to the decadal survey. LEOMAC was a mission study performed at Goddard in response to the decadal survey.

SMLS Block Diagram



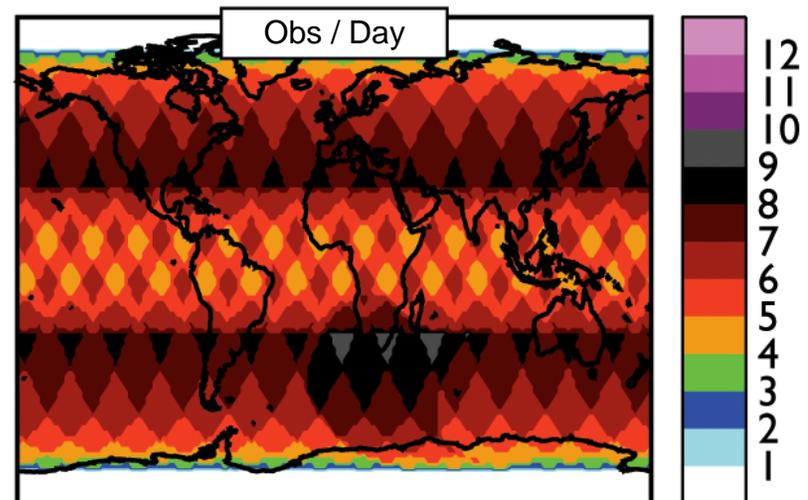
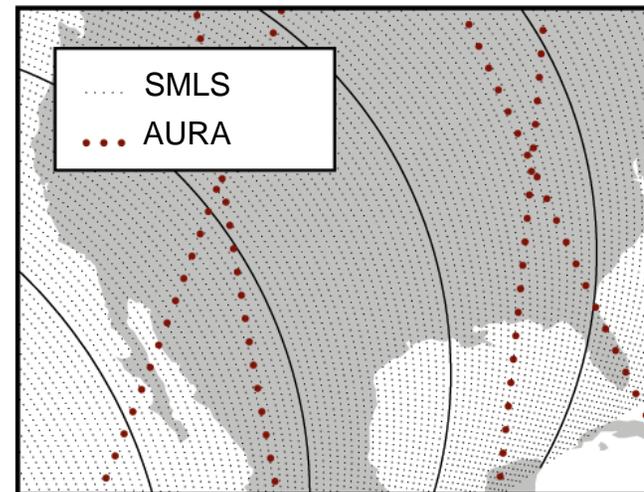
Elevation scan rate:
 $\approx 1^\circ$ every 10 s

The primary, secondary, and tertiary reflectors are cylindrically symmetric about the axis of optical symmetry



SMLS Coverage

- High sensitivity enables rapid scanning of limb
- Scanning both vertically *and* horizontally
- Near-global measurements many times per day enables studying impact of fast processes in atmosphere
- 2 km vertical sampling
- 50 km horizontal sampling
- 52° inclination 800 km orbit

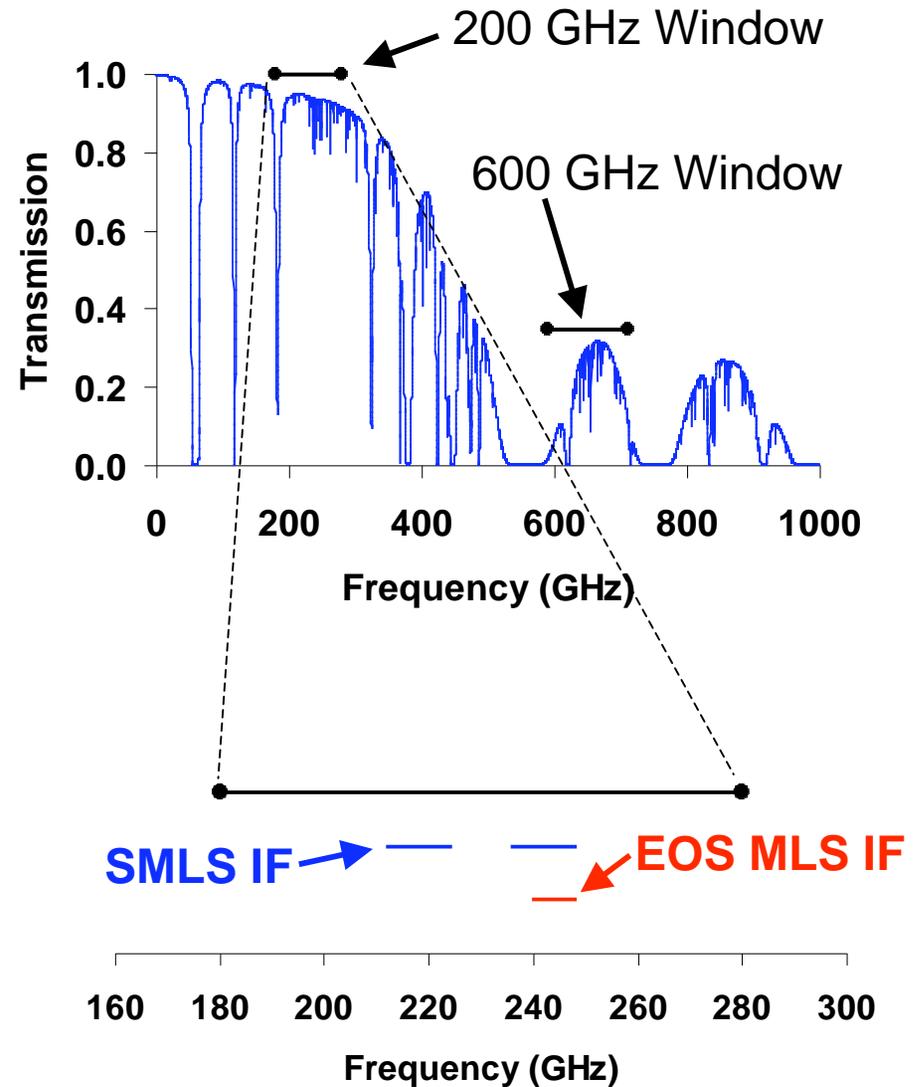


SMLS Windows

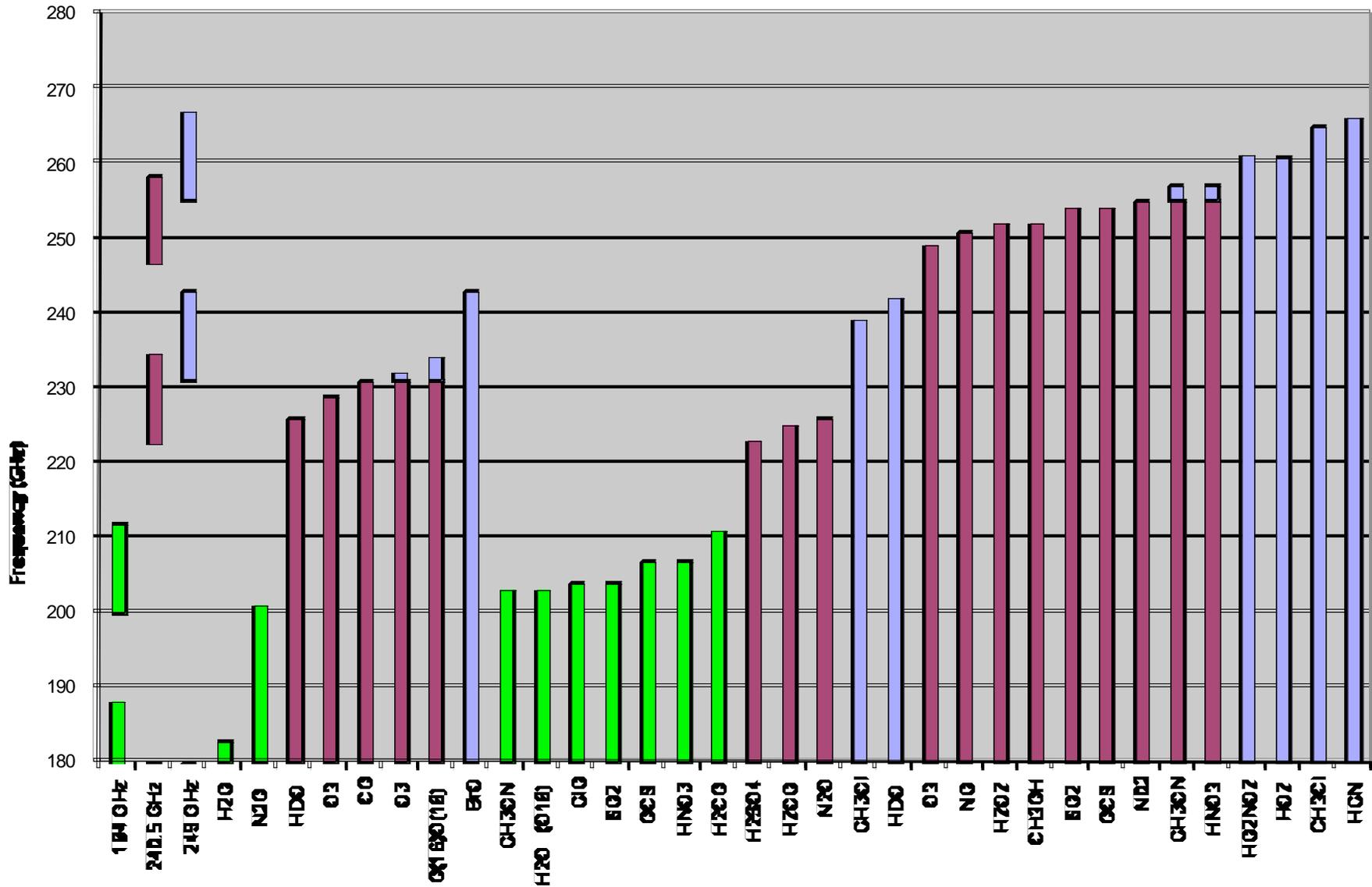
- SMLS windows are 100 GHz wide
- SMLS radiometers must have...
 - High sensitivity for rapid mapping
 - Wide bandwidth to simultaneously measure multiple species

The focus of this effort is to greatly increase instantaneous bandwidth while providing large tunable bandwidth and high sensitivity.

The SMLS 200 GHz radiometer is 20 to 30 times more sensitive than the EOS MLS radiometer, enabling more than 100 times faster integration.

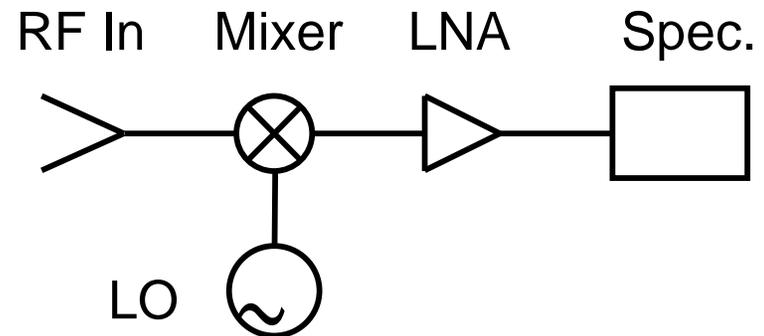
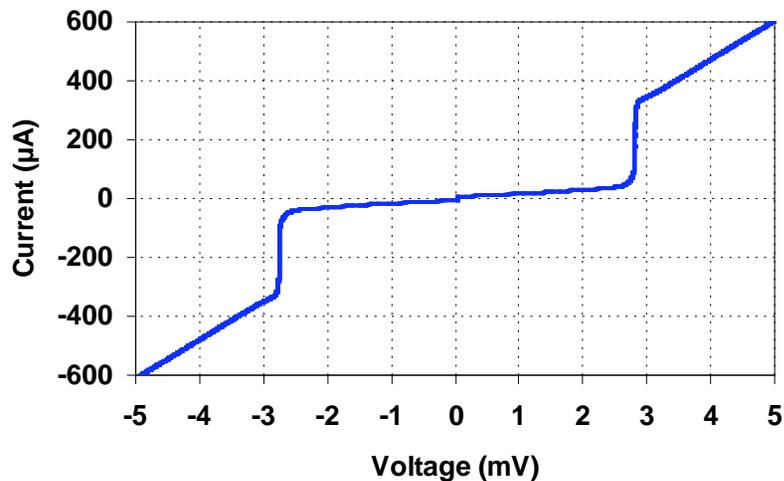


Example Species in 180-280 GHz Channel



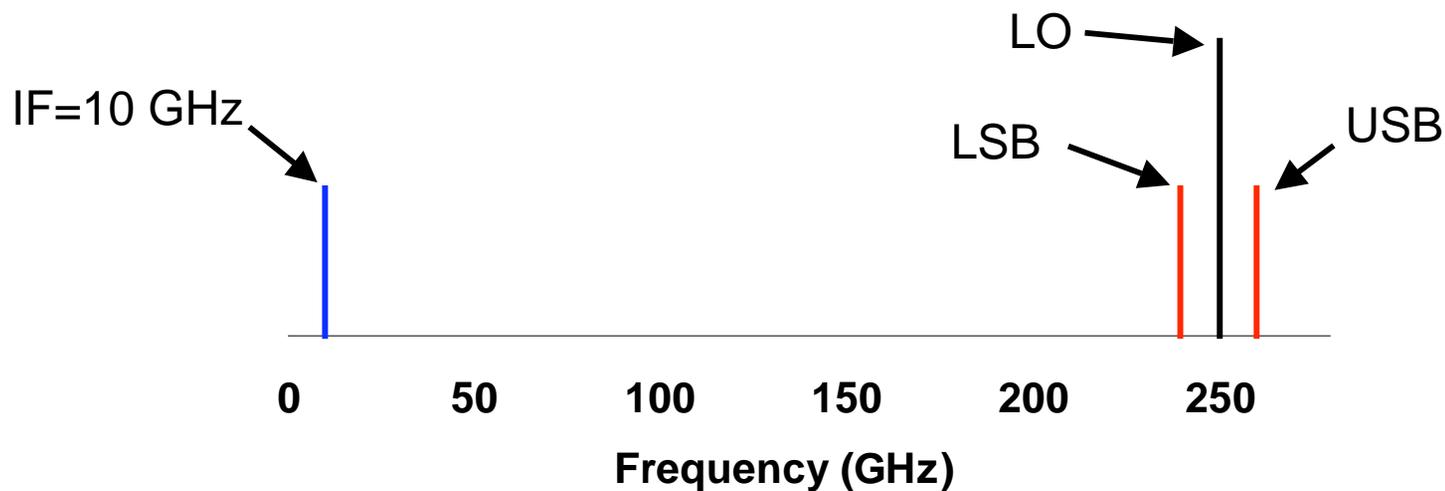
Heterodyne Receivers

- Downconvert signals to lower frequency
- Very high spectral resolution
- Based on non-linear device
 - Current not proportional to voltage
 - Superconductor-Insulator-Superconductor (SIS) junctions provide best sensitivity 100-1000 GHz
- “Mix” two signals to produce difference frequency: $IF = | RF - LO |$
 - Input called the radio frequency or **RF**
 - Output called the intermediate frequency or **IF**
 - RF is mixed with a local oscillator, the **LO**
 - Receiver is tuned by setting the LO frequency



Sidebands

- Recall $IF = |RF - LO|$
- Assume LO is tuned to 250 GHz and IF spectrometer to 10 GHz
- RF=240 GHz is called the lower sideband, or **LSB**
- RF=260 GHz is called the upper sideband, or **USB**
- A double sideband, or **DSB** mixer combines the sidebands
- We are building a sideband separating receiver, to provide two separate outputs for the LSB and USB signals
- Separating sidebands improves sensitivity, calibration, and speed

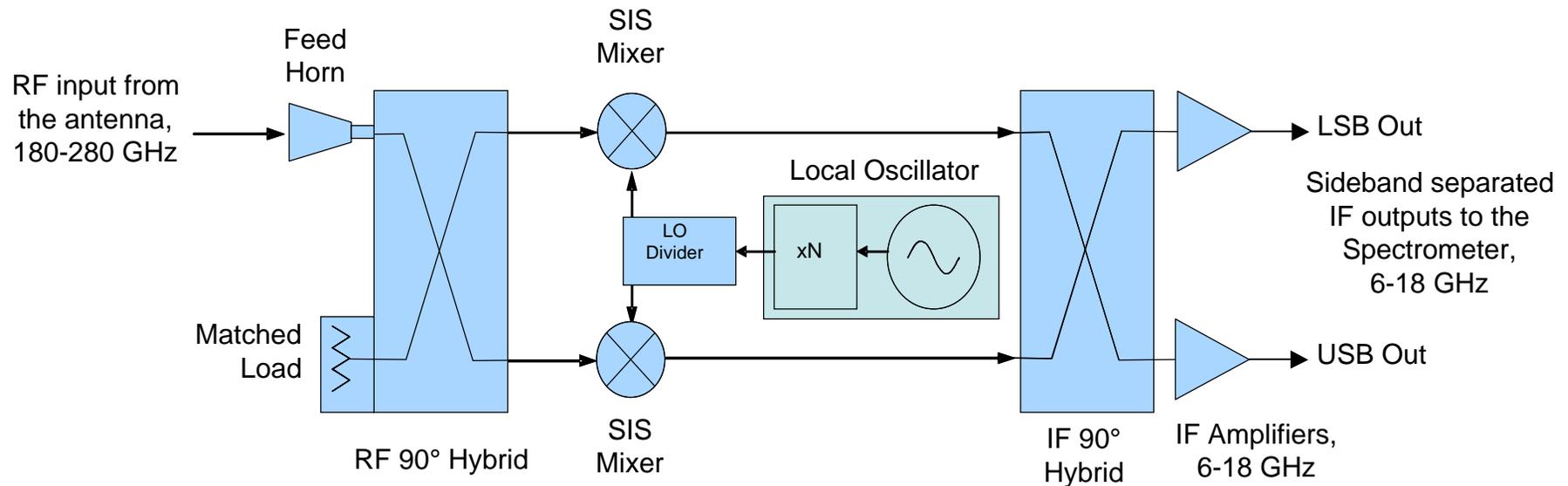


Advantages of Sideband Separation

- Allows for high accuracy on orbit sideband fraction calibration using tone injection and atmospheric lines.
- Reduces interfering signals from opposite sideband improving retrieval accuracy especially of weak species in the presence of strong pressure broadened lines.
- Provides mechanism for characterizing standing waves in optical and calibration system.
- Compared to a quasi-optical bandpass filter, provides twice the usable IF bandwidth while also allowing broad LO tuning.
- Requires additional back-end electronics and increases thermal load on cold head.

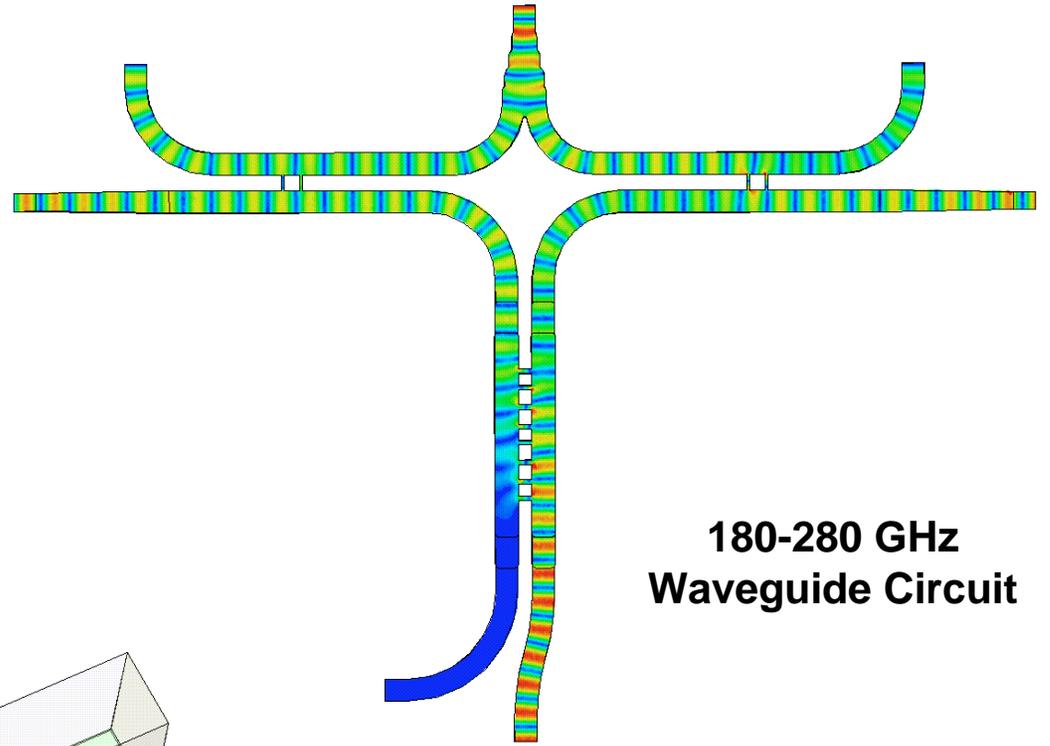
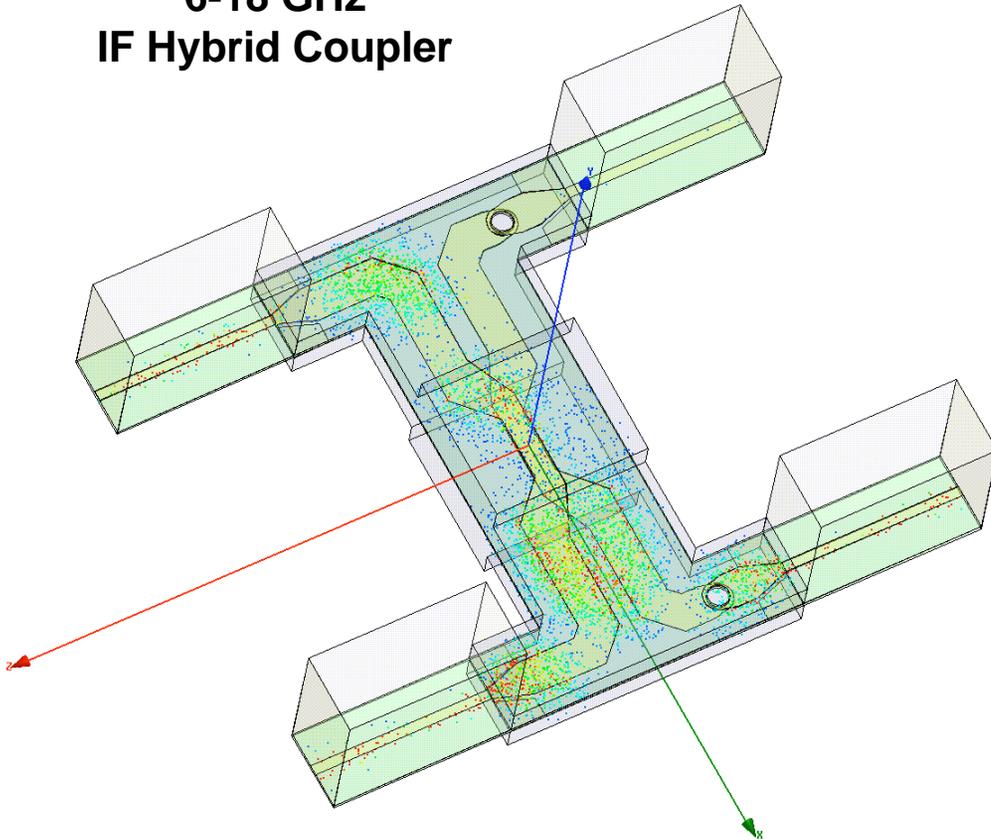
180-280 GHz Receiver Overview

- Sideband-separating
- Output is two 6-18 GHz downconverted bands
- Niobium SIS junctions
- 4.2 K operating temperature
- System noise below 100 K SSB
- Electronically-tuned waveguide circuits
- Corrugated feed-horn input



180-280 GHz Mixer Design

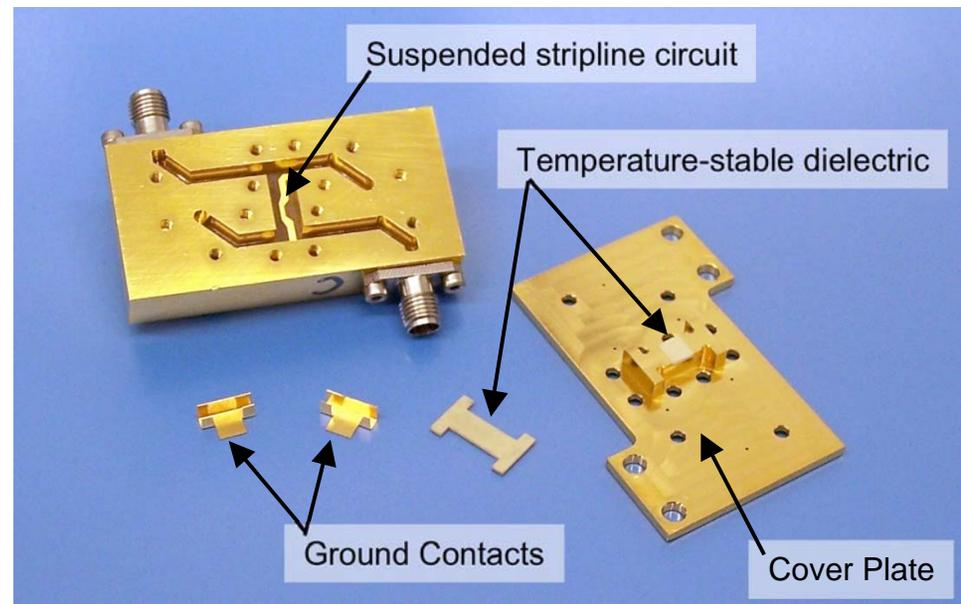
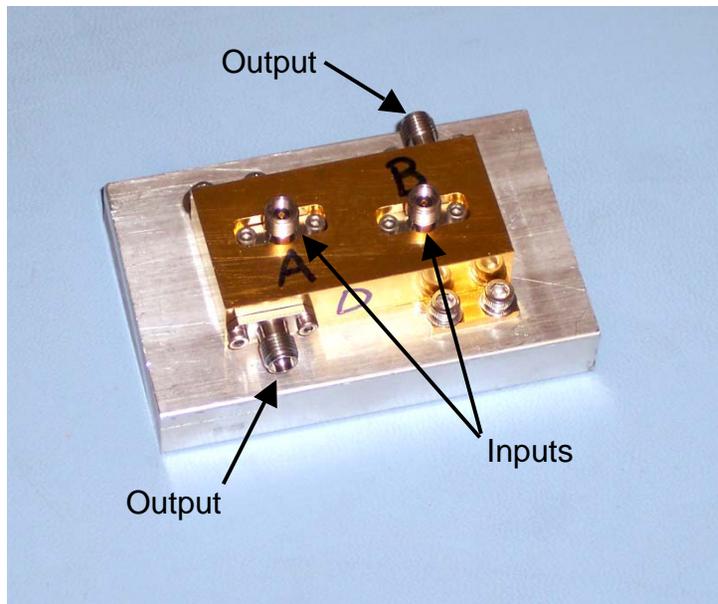
**6-18 GHz
IF Hybrid Coupler**



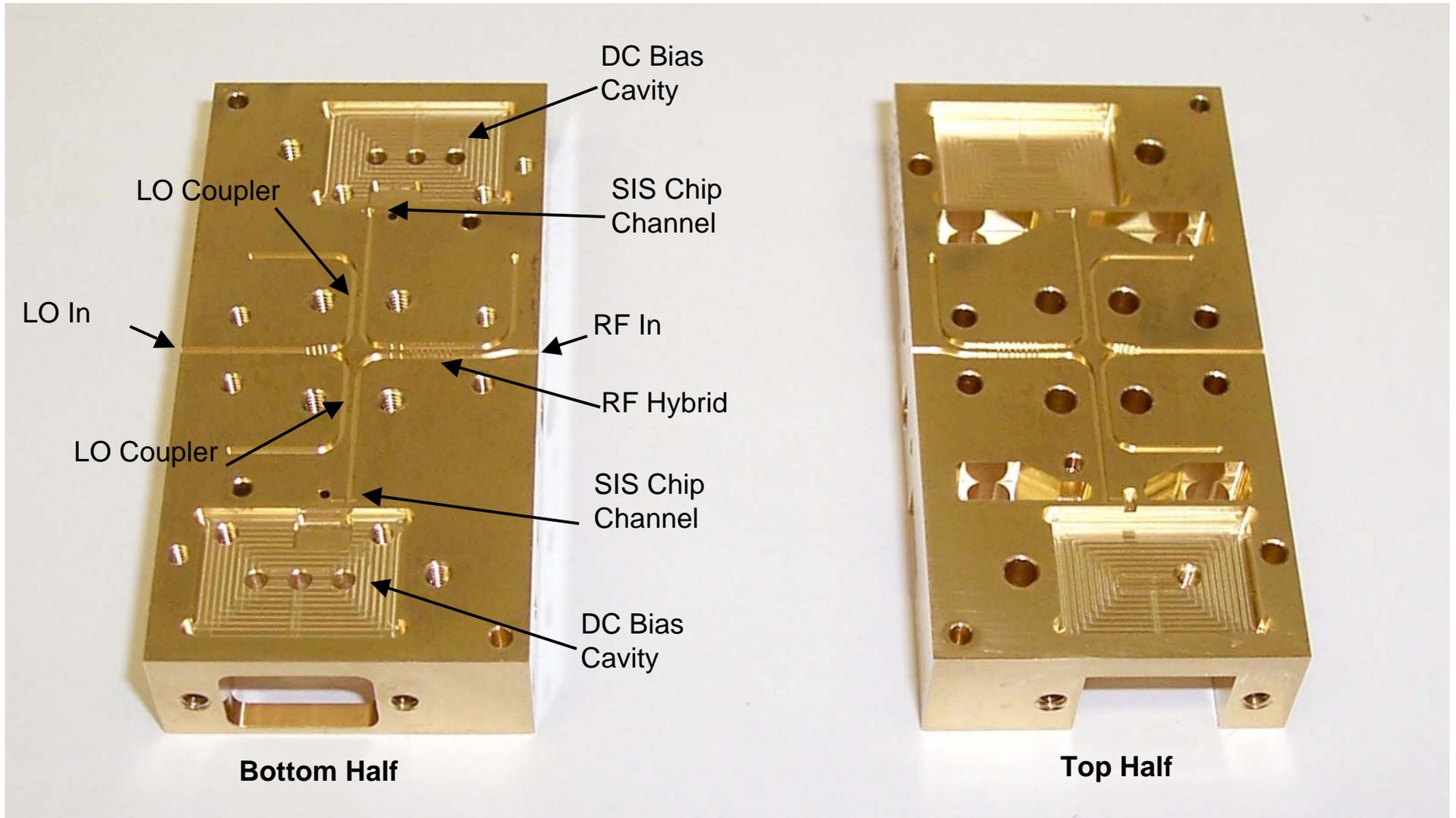
**180-280 GHz
Waveguide Circuit**

IF Hybrid Test Block

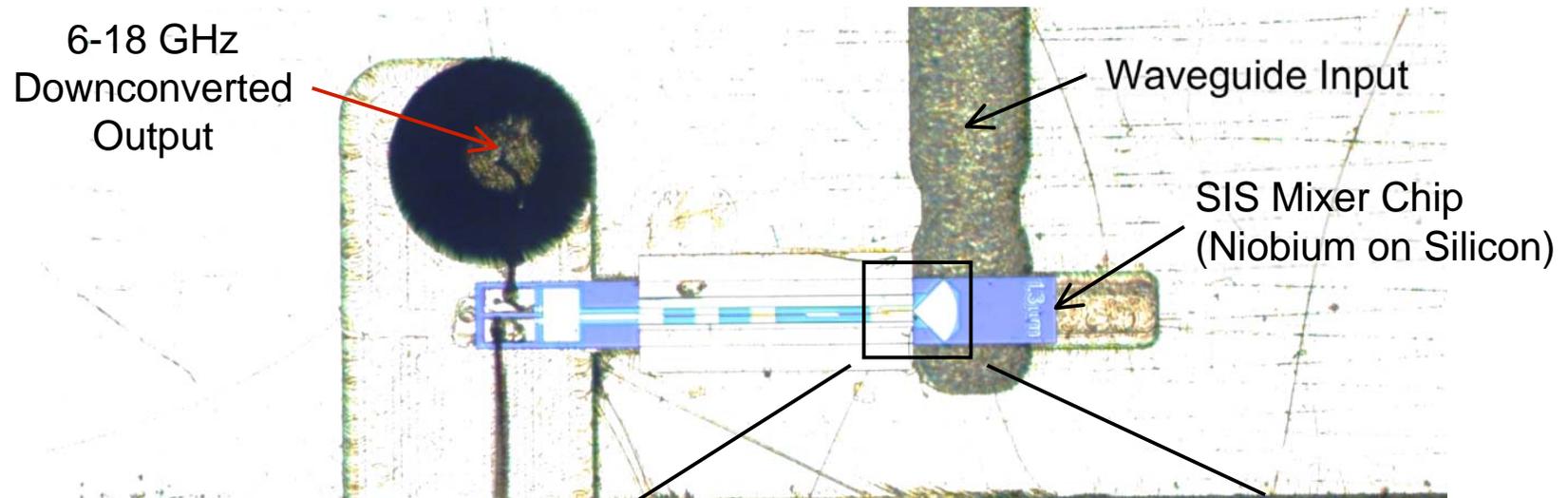
- Completed IF hybrid test block
- Measured performance with vector network analyzer
- Amplitude balance and bandwidth are excellent
- Survived thermal shock tests in liquid nitrogen



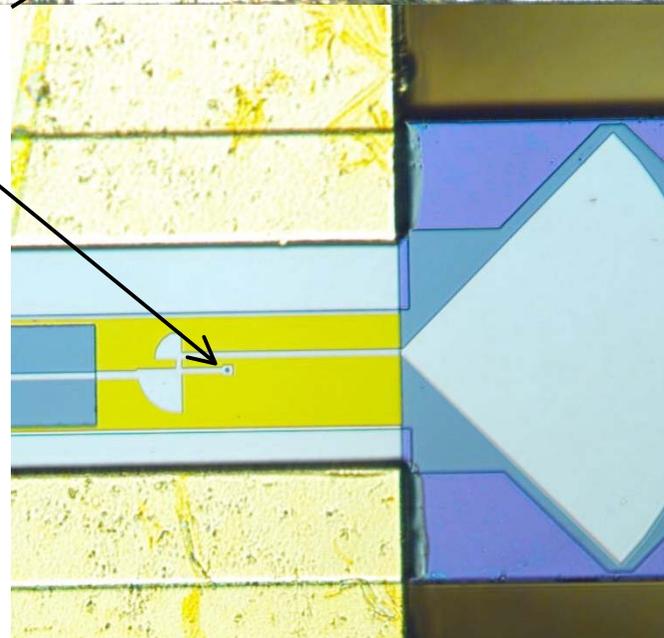
180-280 GHz Waveguide Mixer Block



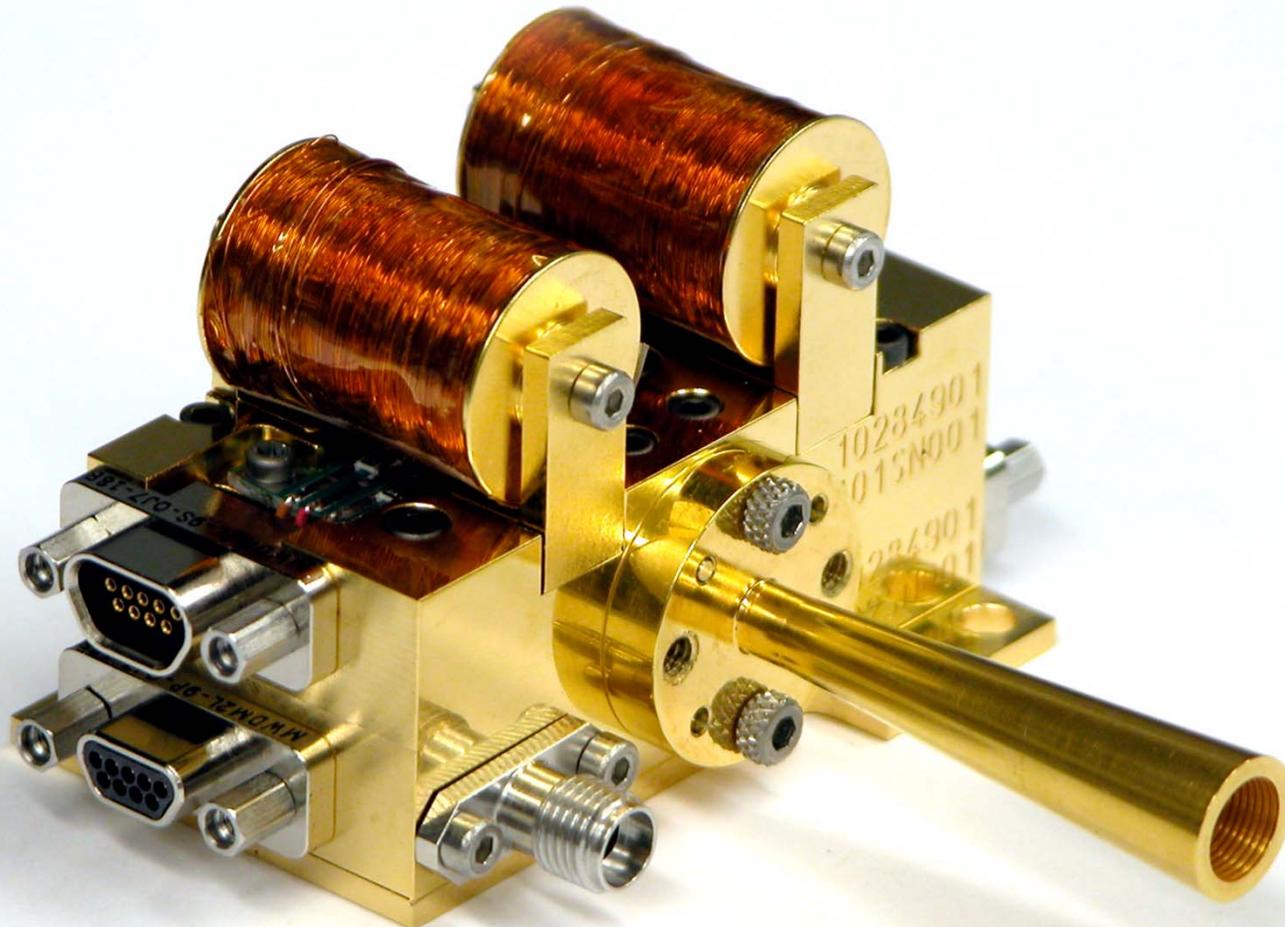
Devices Assembled in Mixer Block



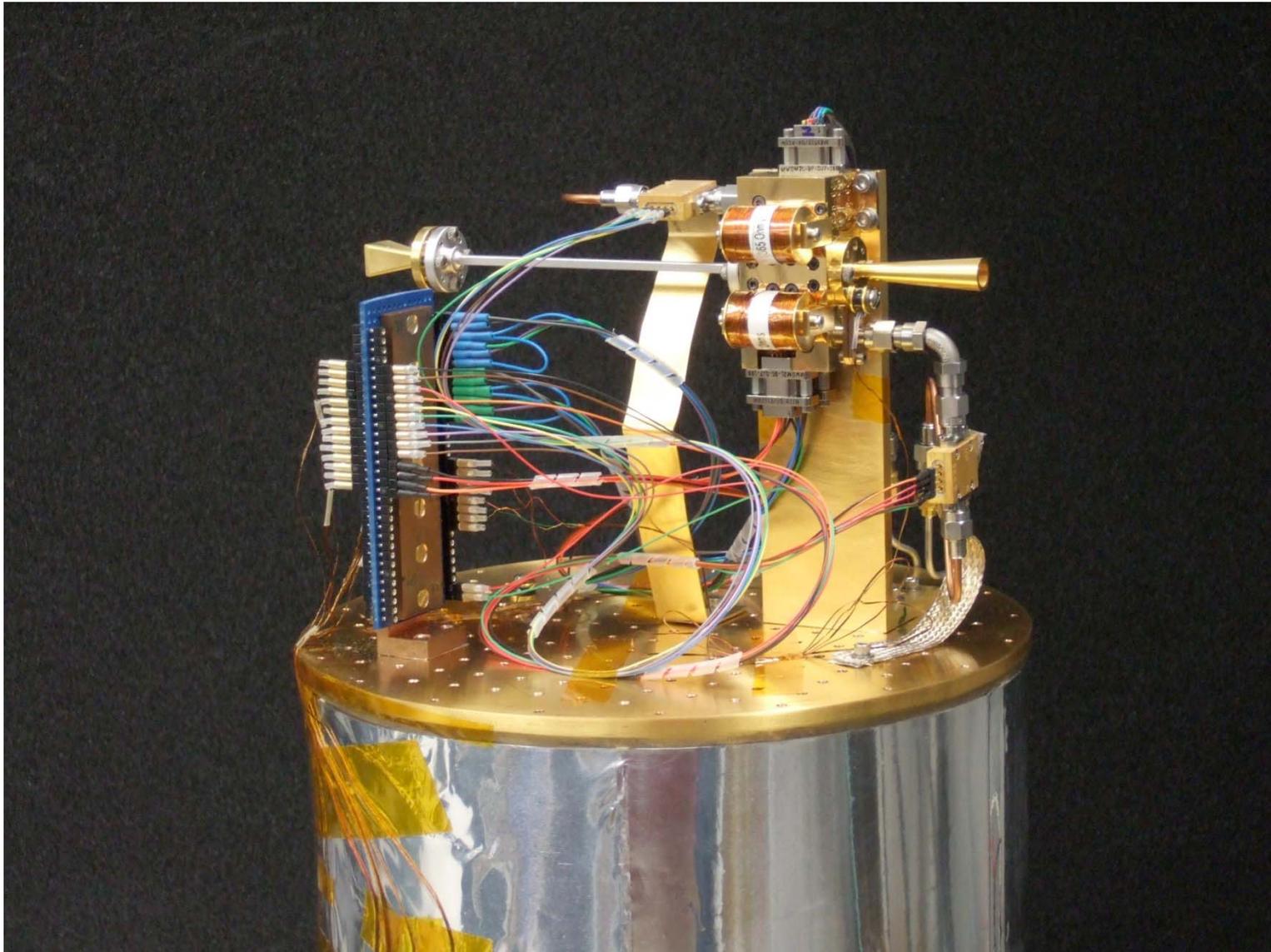
SIS Junction



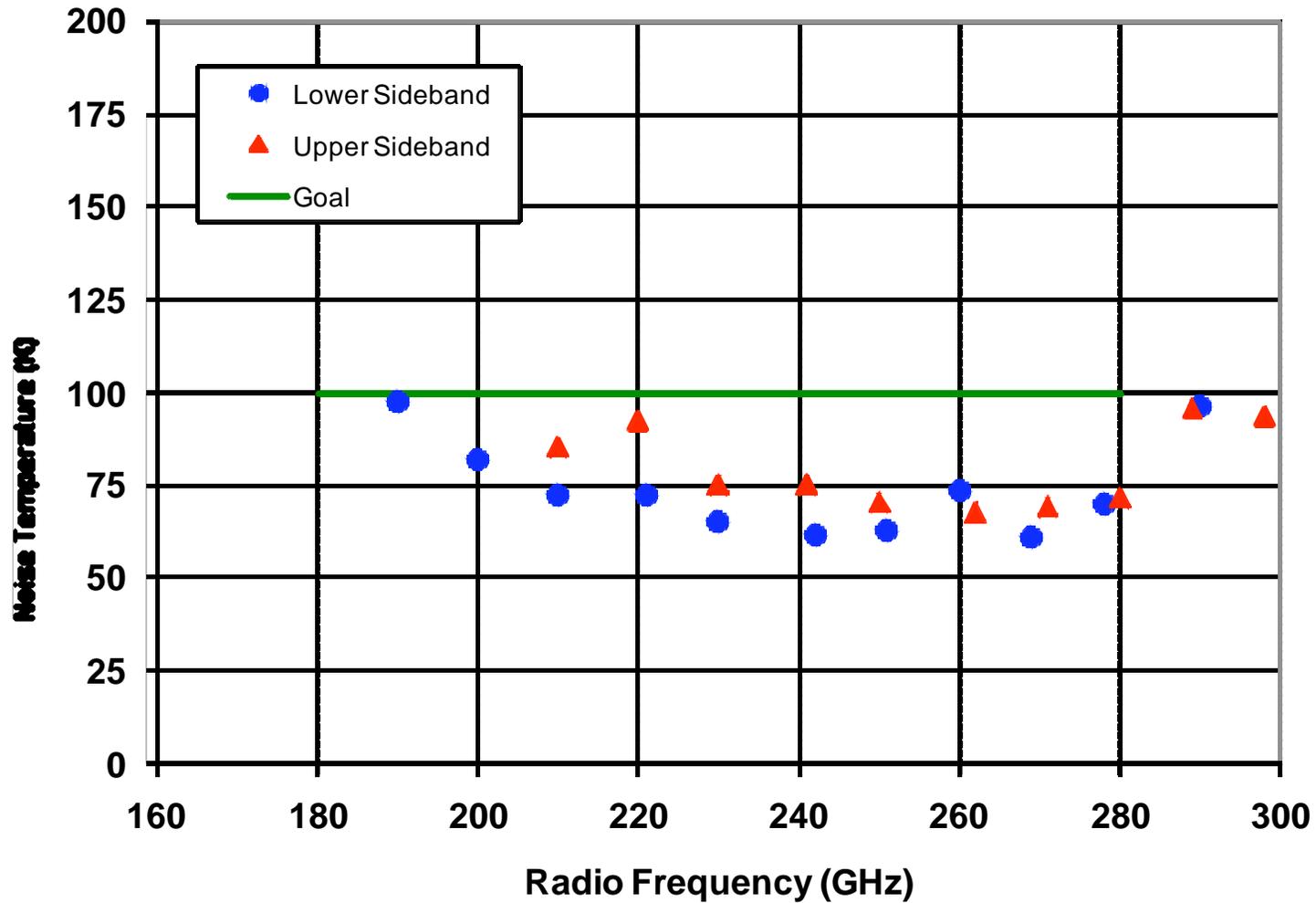
Assembled SSB Mixer Block



SSB Mixer Mounted in Cryostat



Measured Sensitivity



Measured in 6-18 GHz IF band, plotted at IF=10 GHz, corrected for vacuum window

180-280 GHz Measurement Summary

- Sensitivity
 - Plotted sensitivity includes IF system and LO noise
 - Corrected for vacuum window
 - Not corrected for IR filters or image rejection
- Image Rejection
 - Requirement is > 10 dB rejection
 - Measurements averaged 14 dB
- Downconverted (IF) Passband
 - System flat to ± 3 dB and smooth after subtracting cable slope
 - Includes 4 amplifiers and over 20 room-temperature components

640 GHz Channel

- Currently being designed at JPL
- 580-680 GHz tunable band
- 6-18 GHz downconverted IF band
- DSB $T_{\text{sys}} < 200$ K compared with 5000 K on Aura MLS
- First generation will be double-sideband
- First results expected in late 2008
- Planned future generation will separate sidebands
- Primarily for clouds and stratospheric ozone chemistry
 - Greatly improved precision (100x) for BrO, HOCl, HO₂, CH₃Cl, SO₂ and ClO
 - Improved calibration accuracy for HCl, O₃, and HNO₃ if sidebands are separated

Advancing TRLs

- The 240 GHz receiver is an integral part of the Scanning Microwave Limb Sounder IIP (PI Paul Stek) which will demonstrate TRL 6 for the receiver front-end:
 - Both ground and airborne demonstrations of an end-to-end instrument.
 - Testing with a simulated flight-like cryogenics system.
- Both 640 and 240 GHz receivers will be provided to ground and balloon based programs operated by R. Stachnik.
- Additional development needed:
 - Flight-qualifiable, tunable, spur-free local oscillators
 - Sideband separation at 640 GHz

Summary

- Highly sensitive SIS mixer front ends enable huge improvements in bandwidth and sensitivity over Aura MLS
- High sensitivity enables rapid scanning in altitude and azimuth to map the entire planet many times per day
- The 180-280 GHz channel has been assembled and tested, achieving sensitivity goals
- The 580-680 GHz channel is currently in development

The recent demonstration of high sensitivity, broad bandwidth, and high image rejection for a new generation of SIS receiver front-ends enables the scanning microwave limb sounder instrument.