Progress and Outlook for a Future Hyperspectral Microwave Sounder

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First, An Important Distinction: There Are Really Two Separate Issues

- <u>Wideband, Digital Back-ends</u>: WE SHOULD ABSOLUTELY MOVE IN THIS DIRECTION
  - It is a better solution (lower SWaP and performance) than analog back-ends
    - COTS digital spectrometer ASICs now available with <1W/GHz @ ~8 GHz bandwidth
  - It would permit configurable bandpasses, channel sets, etc.
  - It would enable RFI mitigation
  - It would enable "hyperspectral microwave" operation, if that is deemed a useful thing to do

- <u>"Hyperspectral Microwave"</u>: What is it and do we need it?
  - The term "Hyperspectral Microwave", if taken literally, is borderline nonsensical
    - Microwave absorption features are generally very broad and easily resolved with relatively few channels
  - Microwave weighting functions are inherently broad (vertically), so hyperspectral schemes tend to require a deconvolution of a densely-spaced set of broad weighting functions
    - This is a very noisy operation, and reasonable/realistic noise/correlation modeling is ABSOLUTELY CRITICAL
  - HOWEVER, there is a significant amount of unused spectral content in the MW sounding bands (typical channel sets are non-contiguous)
    - Tapping into this unused spectrum could offer a performance benefit

Some History

Hyperspectral Microwave Atmospheric Sounding

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***Abstract*—We introduce a new hyperspectral microwave remote sensing modality for atmospheric sounding, driven by recent advances in microwave device technology that now permit receiver arrays that can multiplex multiple broad frequency bands into more than 100 spectral channels, thus improving both the vertical and horizontal resolutions of the retrieved atmospheric profile. Global simulation studies over ocean and land in clear and cloudy atmospheres using three different atmospheric profile databases**

high cloud-penetrating capability at microwave wavelengths and the relatively sharp weighting functions at infrared wavelengths, particularly in the short-wave region near 4 μm where Planck nonlinearity further increases temperature sensitivity. Infrared spectrometer technology has advanced markedly over the last 15 years or so to allow the simultaneous spectral sampling of thousands of bands spaced along narrow atmospheric absorption features [3]. The Atmospheric InfraRed Sounder

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Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

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of the data sets and physical models used in the simulation is provided. We next point out that opacity due to water vapor continuum absorption is a fundamental limitation of conventional millimeter-wave sounding and show how a hyperspectral millimeter-wave approach can be used to overcome this

- **HyMAS simulation study published in TGRS 8/9/2010**
- **Used a 10-element receiver array and analog filters to realize an 88 channel system (60 and 183 GHz)**
- **Temperature and moisture profiling performance of HyMAS beat AIRS+AMSU in clear air and in overcast conditions in the lower troposphere**
- **We proposed a HyMAS technology demonstrator to NASA ESTO ACT and were selected (GSFC partner)**

Other Subsequent Studies

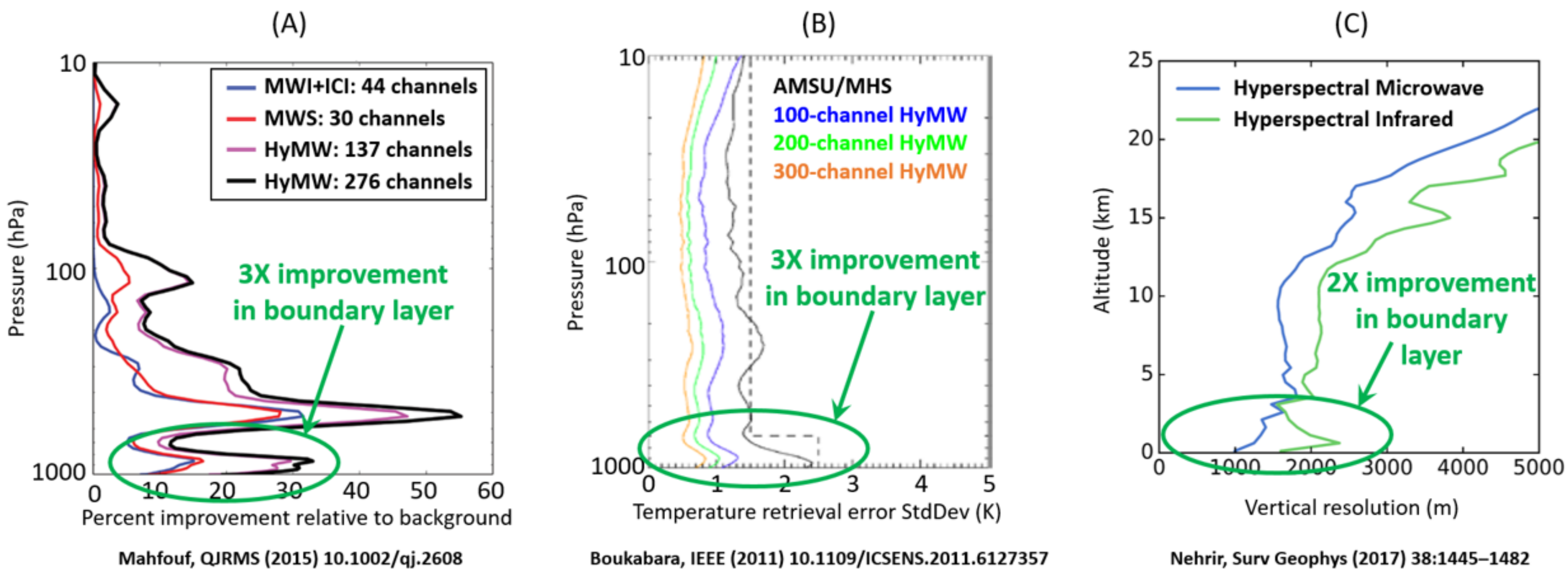
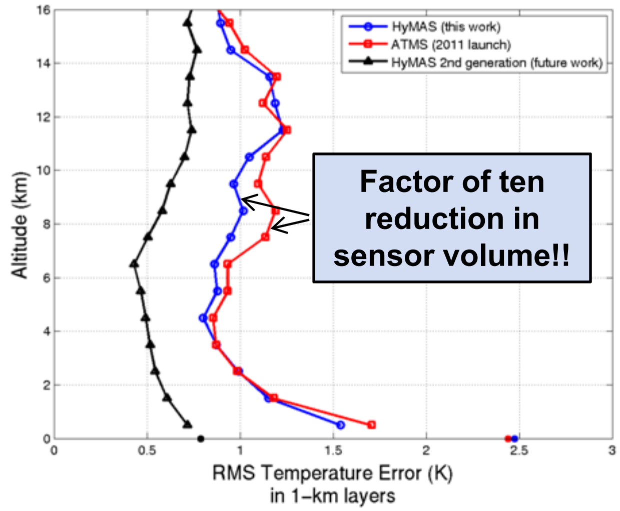
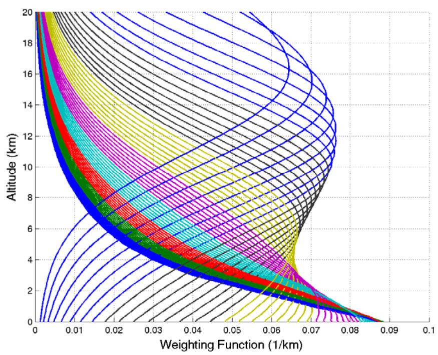


Figure 1. Recent studies have quantified the performance of hyperspectral microwave sensors relative to current state-of-the-art observing systems. The largest performance improvement is evident in the critical boundary layer region, with approximately a factor of three improvement in boundary layer temperature retrieval error (panels A and B) over current microwave sensors and factor of two in boundary layer vertical resolution (panel C) over current hyperspectral IR sensors.

NASA ACT "HyMAS" Project Selected in 2011
Summary and Key Objectives

- **Hyperspectral microwave (HM) sounding has been proposed to achieve improved performance**
- **HM operation is achieved using multiple banks of RF spectrometers with large aggregate bandwidth**
- **A principal challenge is Size/Weight/Power scaling**
- **Objectives of this work:**
  - **Demonstrate ultra-compact (100 cm^3) 52-channel IF processor (enabler)**
  - **Demonstrate a hyperspectral microwave receiver subsystem**
  - **Deliver a flight-ready system to validate HM sounding**





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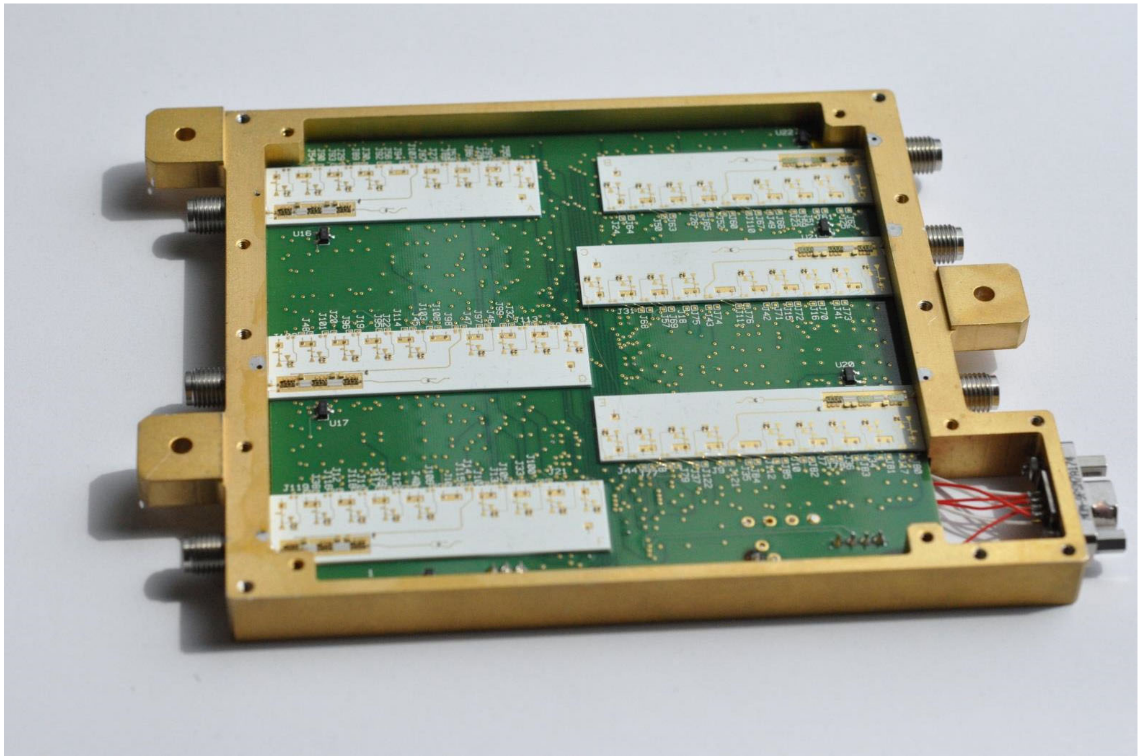
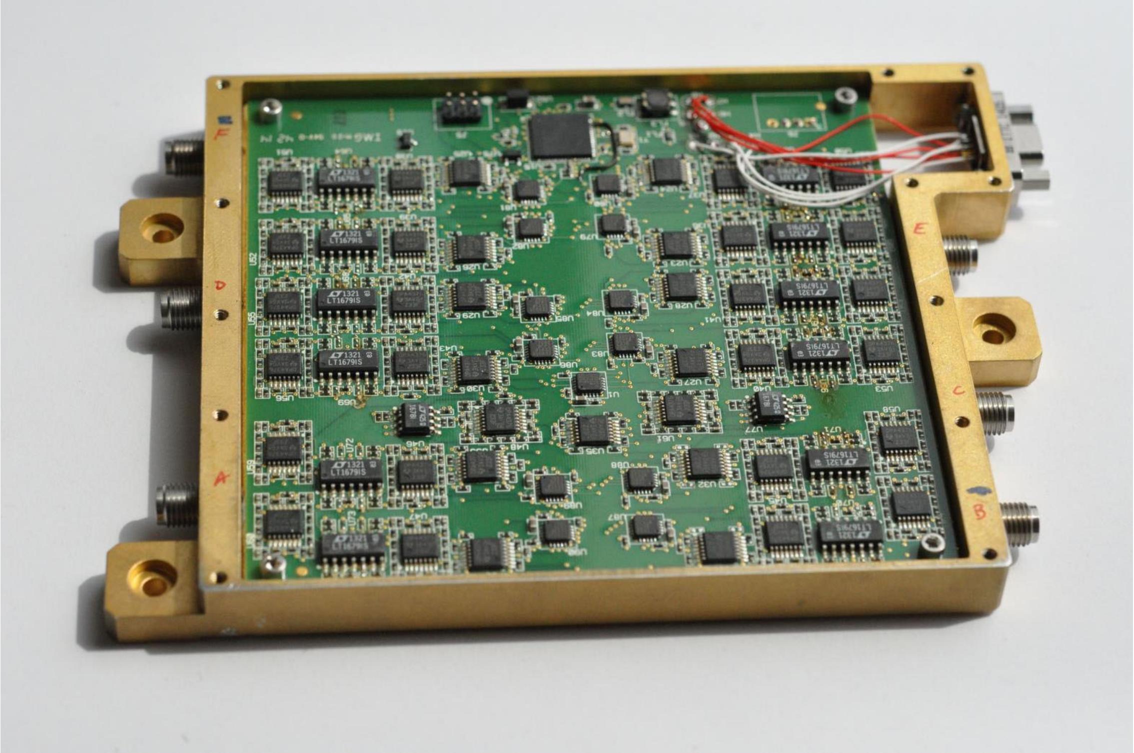
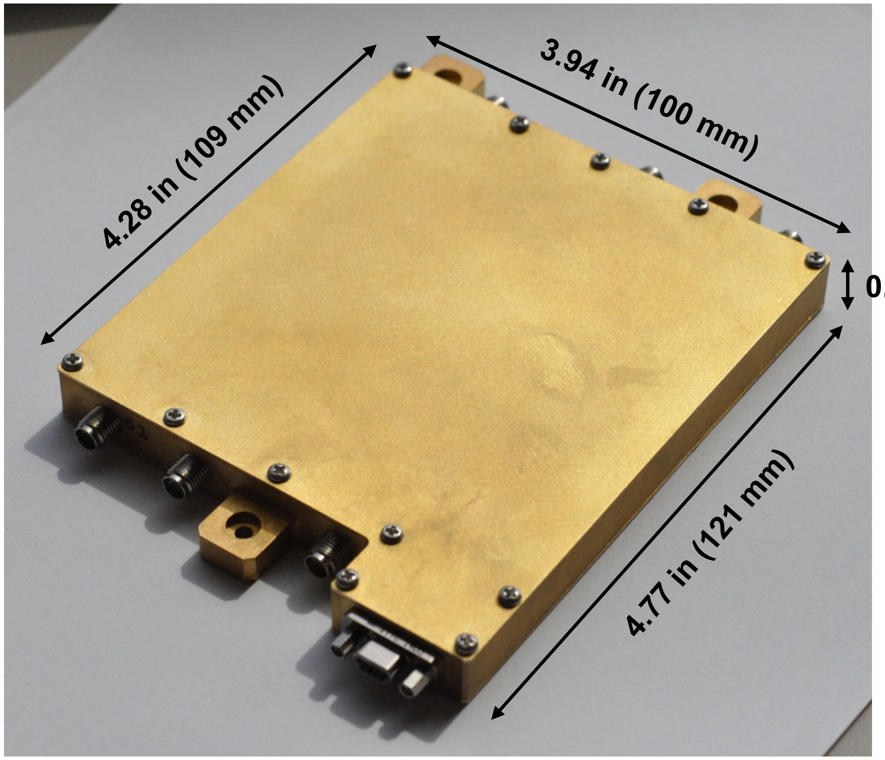
HyMAS Intermediate Frequency Processor RF LTCC/PCB



HyMAS Intermediate Frequency Processor
Mixed Signal/PCB

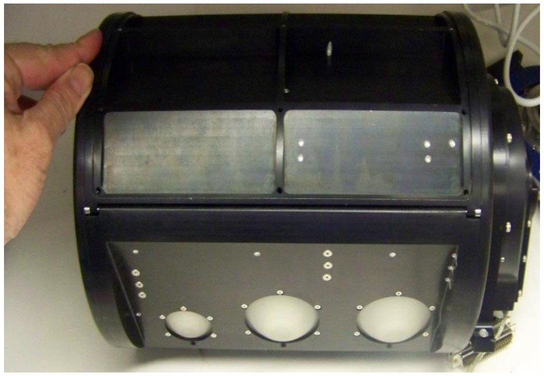


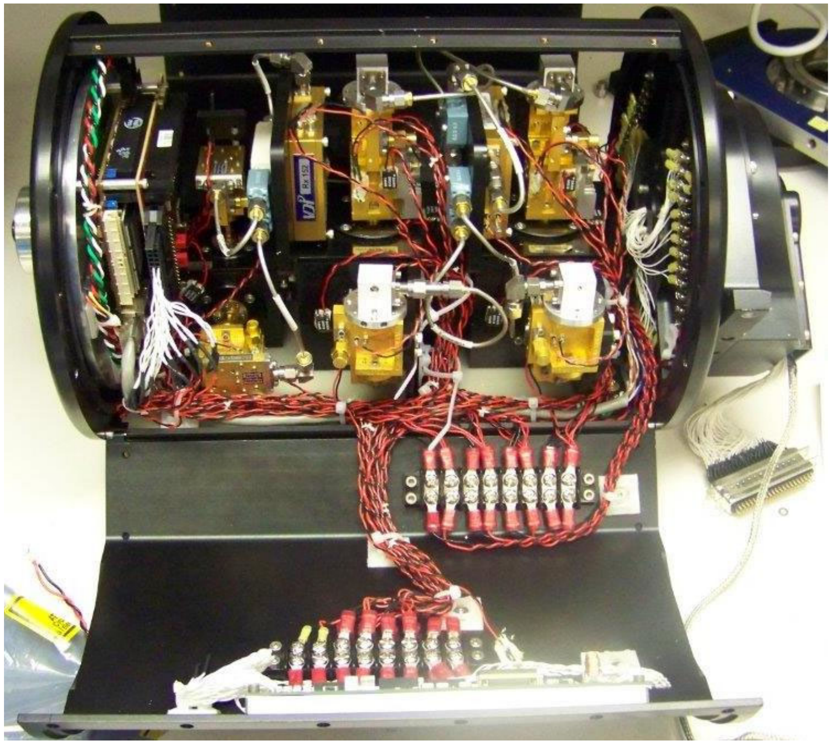
HyMAS IFP Final Assembly



This technology was further developed and flown in MicroMAS-2, MiRaTA, and TROPICS

Completed HyMAS Scanhead





Integrated HyMAS Drum features

- Three Gaussian Optics Lens Antennas
- Four F- Band Low Noise Amplifiers and support brackets
- Six F- and G- Band Mixer/IF Amplifiers receivers and oscillators
- Accommodation for Intermediate Frequency Processor
- Accommodation for G-band RF LNAs

HyMAS technology was successfully developed and subsequently flown on multiple CubeSat missions, but hyperspectral flight demonstration hasn't been funded yet

Summary and Recommendations

- Digital back-end technology appears ready for in-space validation and subsequent mission infusion
  - Many benefits: SWaP, performance, agile spectral response functions, RFI mitigation, …
  - Enables "full spectrum" contiguous observations
  - On-board processing is progressing quickly and offers many clever CONOPS for observing and transmitting data to the ground

- HyMAS (NASA ESTO 2011) demonstrated key technologies, since used for CubeSat sounding missions, but rapidly becoming outdated in the age of digital spectrometers

- HyMS simulations and OSSEs are needed with <u>realistic and complete</u> characterizations of sensor noise/correlation. A flight demonstration is the ultimate proof of concept.
  - Beware of overly optimistic simulations with simplistic noise models