Technology Development for a Hyperspectral Microwave Atmospheric Sounder (HyMAS)

W. Blackwell, C. Galbraith, L. Hilliard, P. Racette, and E. Thompson

ESTF

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Outline

• HyMAS: Motivation and Overview
• Intermediate Frequency Processor (IFP)
• Receiver Front-End Electronics
• Airborne Instrument Accommodations
• Current and Future Work
Project Summary and Key Objectives

- Hyperspectral microwave (HM) sounding has been proposed to achieve unprecedented 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.

Ready for future AITT.
HyMAS System Components
Roles and Responsibilities

Scan Head Assembly

10-channel CoSMIR

38.5 GHz Local Oscillator

Waveguide Flange

18-29 GHz, Coaxial IF

2nd harmonic

HPF

2X

19.0-29.0 GHz
8 x 1250 MHz

18.4-28.4 GHz
8 x 1250 MHz

18.19 GHz
(Surface Channel)
23.56-28.50 GHz
8 x 625 MHz

18.19 GHz
(Surface Channel)
23.34-28.34 GHz
8 x 625 MHz

18.19 GHz
(Surface Channel)
23.16-28.10 GHz
8 x 625 MHz

18.19 GHz
(Surface Channel)
23.03-28.03 GHz
8 x 625 MHz

22.5 GHz Local Oscillator

Data Aggregation, Control and CoSMIR Interface
32 channels at 113-118 GHz
16 channels at 173-183 GHz
4 channels at 108-109 GHz

GSFC
MIT-LL

Presentation Name - 4
Author Initials MM/DD/YY

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
<table>
<thead>
<tr>
<th>HyMAS Technology Infusion Examples</th>
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</thead>
<tbody>
<tr>
<td><strong>MicroMAS</strong></td>
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<tr>
<td>3U cubesat with scanning 118-GHz radiometer</td>
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<tr>
<td>9 channels for temperature profiling and precipitation imaging</td>
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<td>July 13, 2014 launch</td>
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</table>

| **MiRaTA**                        |
| 3U cubesat with 60, 183, and 206 GHz radiometers and GPS radio occultation |
| 10 channels for temperature, moisture, and cloud ice measurements |
| July 2016 launch expected          |

| **DOME**                          |
| Constellation of high-performance cubesats for high-revisit observations of severe storms |

| **NAST-M**                        |
| Radiometer upgrade funded by NOAA to include IFP back end |
| Substantial performance improvement at > 10X SWaP reduction |

IFP enables ultracompact, high-performance radiometry
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IFP – Overview

• IF processor functions
  – Amplify, channelize and detect 18-29 GHz IF bands
  – Post-detection filtering, A/D conversion, data processing

• Scalable in number of channels, processing capability

• LTCC microwave filters for high performance, small size
  – Assess state of technology for more aggressive (frequency, bandwidth) designs and more compact structures

• COTS parts for availability, low cost
  – Microwave MMICs
  – Analog/digital ICs and passives

• Ultra-compact form factor (10 x 10 x 1 cm³) and low DC power requirement (<100 mW/ch) drives the architecture and design
  – Leverage high performance miniature microwave filters, COTS MMICs, electronics packaging
Single IF Channel Architecture

Gain Budget – 118 GHz channels

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<th>P (W)</th>
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Detector driven at -24.6 dBm with conservative loss estimates and 21 dB of additional IF gain reserve

To RF Front-end (K-conn.)

[Diagram of signal flow with components and specifications]

Multiplexer 8/9-ch 18-29 GHz MIT-LL L1CC

Quad Op-amp, zero-drift ADI AD8630 (4-ch) x2 G = 10 V/V Pdc = 40 mW

Zero-bias Schottky Detector and matching network Aeroflex NSS20, 140-B10D TSS = 55 dBm 4000 mV/mW

Zero-bias Schottky Detector and matching network Aeroflex NSS20, 140-B10D TSS = 55 dBm 4000 mV/mW
IFP 9-Channel Prototype Summary

• Demonstrated 9-channel IF processor
  – Scalable to larger numbers of channels
  – RF MMIC amplifiers and detectors
  – Post-detector analog processing and noise characterization
  – Data conversion and processing and software
• High frequency LTCC technology characterized for microwave filters
  – Tolerances within expectations confirming viability of representative circuits up to ~ 30 GHz
  – Very good measured SIW filter results
• PCB is composed of FR4 and Rogers RO4350B material
• Top: digital, low frequency analog (post-detector), DC power filtering
• Bottom: 18-30 GHz RF (IF) amplifier, multiplexer, and detectors with cavities for LTCC filters, MMICs, and GaAs passives
Hybrid Manifold Technique

- Requires pairs of identical filters
- Accommodates arbitrary number of channels, any channel characteristics, bandwidth determined by coupler response

Hybrid coupler is key building block: Need wideband (18-30 GHz) with good amplitude and phase balance

“Unit cell”
• Optimized line lengths
• Coupler amplitude and phase mismatch causes reflections

Simulated Multiplexer Response
8/9-Channel LTCC IF Module Layout (top)

- Modules (0.5 in x 1.7 or 1.9 in) contains all amplification, multiplexer filtering, and detection circuits for 8 or 9 channels
- Single 18-30 GHz input, (8) detector (DC) outputs
8/9-Channel LTCC IF Module Layout

- Inner stripline couplers and filters built in 5 LTCC layers
- Multiplexer is divided into two “quadplexers” for additional channel isolation
- Via fences used for isolation and eliminating cavity modes
52-ch IFP Packaging – PCB

- Top of board contains digital, post-detector analog circuit, bottom is mounting platform for LTCC IF modules
- Low cost 6-layer FR4 PCB using ENEPIG finish for soldering/wire-bonding
  - All RF circuits confined to LTCC modules, eliminating need for HF materials, PCB cavities
52-ch IFP Packaging – Enclosure

IFP Enclosure CAD Model

*Connectors not shown

- Overall size 4.5 in x 3.8 x 0.4 in (~103 cm³)
- 2.92 mm (“K”) connectors used for RF connections, “Micro-D” connector used for DC and data
- Aluminum enclosure with top and bottom lids allows access to both sides of PCB for post-assembly tuning (RF and IF gain adjustment)
IFP Flight Unit Status

• LTCC modules and PCB are in fabrication
  – Both expected to ship week of 10/20/2014
• Software 95% complete
  – Code finalized during IFP testing
• Final assembly and testing at MIT-LL to follow fabrication
  – Estimate 3 weeks of effort
  – Functional testing and characterization
  – Adjust IF and video gain to improve system gain flatness
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HyMAS System Overview

Figure 1 – Block diagram showing both the HyMAS RF electronics and core technology in the IF filter bank.
HyMAS Receivers

- Four COTS F-band Receivers (108 – 119 GHz)
  - 9 IF Channels each
  - 22.6 GHz DRO

- Two G-band Receivers (172 – 183 GHz)
  - 8 IF Channels each
  - 38.5 GHz DRO

- Each receiver has integrated IF amplifier with passband 18 – 29 GHz

- Four COTS F-band low noise RF amplifiers (Noise Figure < 5 dB)

- G-band low-noise amplifiers
  - Space allocated in design
  - GSFC internal development
  - SBIR development through Virginia Diodes, Inc.
Three antennas

One at 183 GHz
- Bandwidth: 172-183 GHz
- Beamwidth: 3.1 – 3.3 degrees over the bandwidth
- Sidelobes: ~30 dB below main lobe
- VSWR: <1.5:1
- Polarization: dual linear

Two at 118 GHz
- Bandwidth: 108-119 GHz
- Beamwidth: 3.1 – 3.3 degrees over the bandwidth
- Sidelobes: ~25 dB below main lobe
- VSWR: <1.5:1
- Polarization: dual linear

Gaussian optics lens antenna with wire grid to separate polarizations
Power Board

- Custom PCB Layout
- Input 48 VDC
- Output
  - +8 V @ 2.3A
  - +3 V @ 1.1A
  - 3.3 V @ 1.9A
  - +/- 12 V (future use)
- Computer power
  - 5 V @ 1.75 A
- Heater power
  - 48 V @ 8 A

Power board is integrated and tested with receivers
HyMAS Scanhead Computer Configuration

- **MIT-LL**
- **GSFC**

Elevation Slip Ring

- 10BaseT
- SPI Bus

**Ocelot CPU Board**

**Sensoray I/O**

**HyMAS IF Processor**

- 52 channels radiometer data and 12 channels housekeeping will be transferred through SPI interface. Handshaking will initiate transfer every 10 milliseconds data to scanhead.

- 2-Board PC104+ Stack
- CPU with 10baseT and SPI Bus
- SPI interface to IF processor
- 8-channel temperature sensor board

9-pin D

Final IFP footprint

Surrogate IFP
HyMAS Data Acquisition

- “Surrogate IFP” used to develop communications and electrical interfaces with HyMAS electronics
- Maximum sampling rate from IFP is ~180 data frames per second
  - 52 Radiometer channels
  - 12 Housekeeping
- Time stamp of data using network time protocol (NTP) implemented on CoSMIR – applicable to HyMAS
- GUI development components, laboratory display of real time data

Scanhead computer and surrogate IFP delivered to scanhead I&T

HyMAS Real-time Display

Plot and data display functions for testing HyMAS surrogate IFP using simulated data

Photo of surrogate IFP used to test electrical compatibility of HyMAS electronics
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HyMAS Scanhead Mechanical Integration

- End-view of receivers w/ brackets to support waveguide
- Antennas and receivers fit within drum envelope
- HyMAS Scanhead Assembly

Layout facilitated by computer aided design

Partial assembly of HyMAS electronics
Current and Future Work

- Assemble receiver wiring harnesses
- I&T of data acquisition using IFP and receivers (Nov)
- Thermal testing of scanhead (Nov)
- Functional tests using scan pedestal (Dec)
- Laboratory calibration data collects (Dec)
- Final report (Jan)
- Ready for test flights in 2015