Design and Analysis of a Hyperspectral Microwave Receiver Subsystem

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Outline

• Project summary, key objectives, and roles/responsibilities
• RF receiver electronics and scan head
• IF processor module
• Next steps
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

Factor of ten reduction in sensor volume!!
HyMAS System Components
Roles and Responsibilities

Scan Head Assembly (GSFC CoSMIR/CoSSIR)

OMT
Feed #1 172-183 GHz
18-29 GHz, Coaxial IF
2nd harmonic
HPF
2X

OMT
Feed #2 108-119 GHz
18-19 GHz (Surface Channel)
23.56-28.50 GHz
8 x 625 MHz

OMT
Feed #3 108-119 GHz
18-19 GHz (Surface Channel)
23.15-28.19 GHz
8 x 625 MHz

GSFC
MIT-LL
22.5 GHz Local Oscillator
38.5 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

Lincoln Laboratory
Massachusetts Institute of Technology
HyMAS (9-channel) IF Frequency Plan

- 18.16 GHz (Surface Channel)
  - 23.50-28.50 GHz
  - 8 x 625 MHz

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

- 13.19 GHz (Surface Channel)
  - 23.19-28.19 GHz
  - 8 x 625 MHz

- 13.19 GHz (Surface Channel)
  - 23.03-28.03 GHz
  - 8 x 625 MHz
IF Processor Description

- K-connector (18-29 GHz) input from RF front-end
- Two IF amplifiers (18-29 GHz)
  - Buffered with attenuators for gain adjustment and matching at IF input/output
    - Provides termination for RF front-end output and multiplexer input
    - Nominally 3 dB at input/output, “0 dB” in between stages
- Multiplexer channelizes IF band
- Detectors detect power at output of each channel
- Op-amp fed by detectors, drives ADC
- Microcontroller sequences data flow
HyMAS – IF Processor
IF Multiplexer

• Single port feeds 9-channels through a corporate feed power splitting network
  – Reduces interaction among contiguous channels
  – Low-risk for initial demonstration

• IF channel filters are LTCC-based substrate integrated waveguide (SIW) cavity types
  – High unloaded Q resonators (500+) in small volume for low insertion loss and sharp filter skirts
  – Probe/bond pads for S-parameter testing and assembly

• First 9-channel design completed and in fabrication
  – Omega Micro Technology (DuPont 9K7), expect parts in 9/2012
HyMAS LTCC SIW Filters

- Substrate Integrated Waveguide (SIW) filters offer lower insertion loss and better filter shape factor than stripline interdigital filters due to their higher $Q$ (> 500) resonators
  - Filters are realized in two-layer LTCC stack with via “fences” creating the waveguide side walls
  - Via “posts” control coupling in between resonator cavities

![HFSS Model](image1)

![HFSS Simulation](image2)
Out of band response to be attenuated by detector roll-off
IF Channel 2 (HFSS)

- **m1**
  - freq = 23.96 GHz
  - dB(S(2,1)) = -6.218 dB

- **m2**
  - freq = 24.50 GHz
  - dB(S(2,1)) = -6.059 dB
IF Channel 3 (HFSS)

freq, GHz

dB(S(2,1))

m1 m2

freq = 24.57GHz
dB(S(2,1)) = -6.197

freq = 25.13GHz
dB(S(2,1)) = -5.964
**IF Channel 4 (HFSS)**

![Graph]

**dB(S(2,1))**

- **m1**
  - freq = 25.16 GHz
  - dB(S(2,1)) = -5.757

- **m2**
  - freq = 25.79 GHz
  - dB(S(2,1)) = -6.092
IF Channel 5 (HFSS)

freq, GHz
dB(S(2,1))
dB(S(1,1))

m1
freq=25.79GHz
dB(S(2,1))=-6.070

m2
freq=26.42GHz
dB(S(2,1))=-6.051
IF Channel 6 (HFSS)

- **m1**
  - freq = 26.46 GHz
  - dB(S(2,1)) = -5.924

- **m2**
  - freq = 26.98 GHz
  - dB(S(2,1)) = -5.833
IF Channel 7 (HFSS)

m1
freq = 27.04 GHz
dB(S(2,1)) = -5.974

m2
freq = 27.65 GHz
dB(S(2,1)) = -5.876
IF Channel 8 (HFSS)

m1
freq=27.68GHz
\( \text{dB}(S(2,1)) = -5.739 \)

m2
freq=28.24GHz
\( \text{dB}(S(2,1)) = -5.522 \)
IF Channel 9 (HFSS)

- m1
  - freq = 28.33 GHz
  - dB(S(2,1)) = -6.070

- m2
  - freq = 28.86 GHz
  - dB(S(2,1)) = -6.134
IF Filter Layout (LTCC)
IF Processor Form Factor 1
Horizontal Resonators

Top View: 8/9-channel Panel

Side View: 52-ch IF Processor

IF amplifiers/splitters
IF Channel Filters
Detectors/ADC/uC/power

RF Input

10.0 cm

5.0 cm

FR4/Duroid
LTCC
IF Processor Form Factor 2
Horizontal+Vertical (Stacked) Resonators

Top View: 26-channel Panel

Side View: 52-ch IF Processor
IF Processor Form Factor 3 (Project Goal)
Vertical (Stacked) Resonators

Top View: 52-channel Panel

Side View: 52-ch IF Processor

10.0 cm

2.92 mm
RF input

DC & Data
Summary

- Hyperspectral microwave sensors could change the landscape of atmospheric sounding for both LEO and GEO systems.

- An intermediate frequency processor fabricated in LTCC technology is a key innovation enabling ultracompact microwave radiometry in a variety of applications with severe constraints on size, weight, and power.

- Fabrication and testing of the hyperspectral microwave receiver subsystem will occur in 2012/2013 with airborne validation in 2014/2015.
Backup
CoSMIR/CoSSIR Scan Head

The scan head provides calibration and control infrastructure and rotates in azimuth and elevation. CoSSIR is shown in the photo at left.

A compact drum houses the radiometer electronics and rotates relative to the scan head.

Flights on the ER-2 have produced many hours of high-quality radiometric data.
Frequency Plan

Example: 36 Channels near the 118.75-GHz oxygen line

<table>
<thead>
<tr>
<th>Channel #</th>
<th>Left edge</th>
<th>Center</th>
<th>Right edge</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>108.0000</td>
<td>108.5000</td>
<td>109.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>2</td>
<td>113.9135</td>
<td>114.2260</td>
<td>114.5385</td>
<td>0.625</td>
</tr>
<tr>
<td>3</td>
<td>114.5375</td>
<td>114.8500</td>
<td>115.1625</td>
<td>0.625</td>
</tr>
<tr>
<td>4</td>
<td>115.1615</td>
<td>115.4740</td>
<td>115.7865</td>
<td>0.625</td>
</tr>
<tr>
<td>5</td>
<td>115.7855</td>
<td>116.0980</td>
<td>116.4105</td>
<td>0.625</td>
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<tr>
<td>6</td>
<td>116.4095</td>
<td>116.7220</td>
<td>117.0345</td>
<td>0.625</td>
</tr>
<tr>
<td>7</td>
<td>117.0335</td>
<td>117.3460</td>
<td>117.6585</td>
<td>0.625</td>
</tr>
<tr>
<td>8</td>
<td>117.6575</td>
<td>117.9700</td>
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<td>0.625</td>
</tr>
<tr>
<td>9</td>
<td>118.2815</td>
<td>118.5940</td>
<td>118.9065</td>
<td>0.625</td>
</tr>
</tbody>
</table>

Channels 2-9 above are shifted by 156.25 MHz per band