Hyperspectral Microwave Atmospheric Sounder (HyMAS) Architecture and Design Accommodations

L.M. Hilliard and P. E. Racette

(NASA Goddard Space Flight Center)

W. Blackwell, C. Galbraith, E. Thompson

(MIT Lincoln Laboratories)

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Outline

- **Overview**

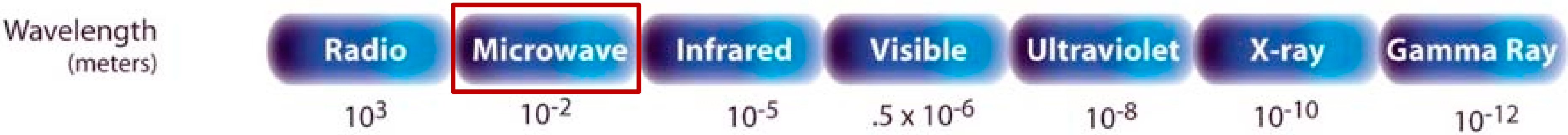
- **HyMAS frontend architecture/frequency plan/design**
- **Prototype IF processor Design and Mechanical Accommodation**
- **Interoperable Remote Component (IRC) and the Scanhead Computer**
- **Summary and Next Steps**

Background

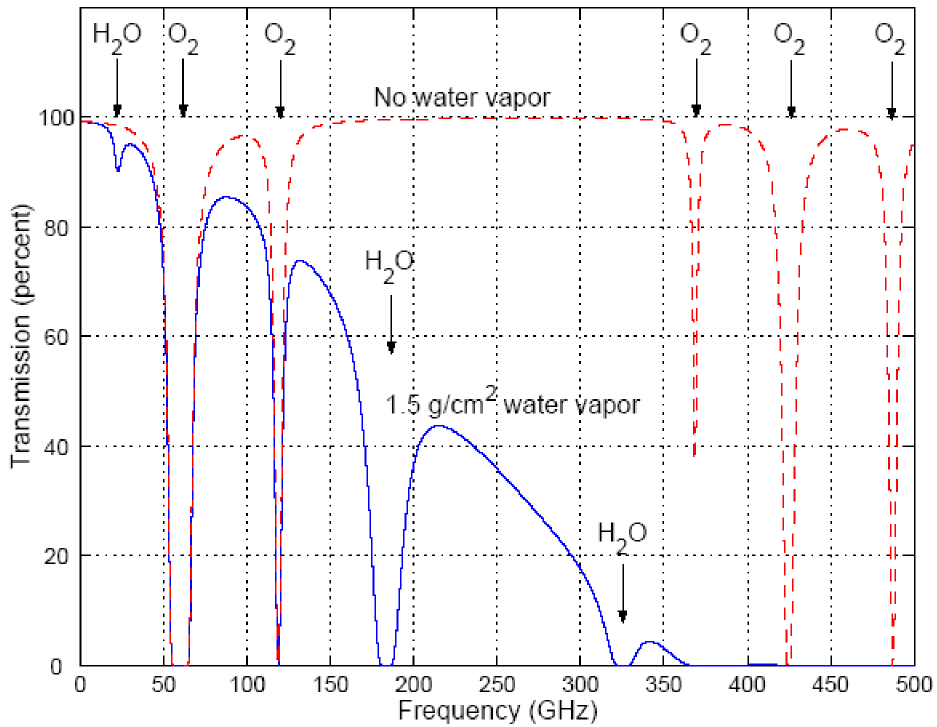
- **"Hyperspectral" measurements allow the determination of the Earth's tropospheric temperature with vertical resolution exceeding 1km**
  - **~100 channels in the microwave**
- **Hyperspectral infrared sensors available since the 90's**
  - **Clouds substantially degrade the information content**
  - **A hyperspectral microwave sensor is therefore highly desirable**

- **Several recent enabling technologies make HyMW feasible:**
  - **Detailed physical/microphysical atmospheric and sensor models**
  - **Advanced, signal-processing based retrieval algorithms**
  - **RF receivers are more sensitive and more compact/integrated**
- **The key idea: Use RF receiver arrays to build up information in the spectral domain (versus spatial domain for STAR systems)**

Microwave Atmospheric Sensing



Cloud Penetration

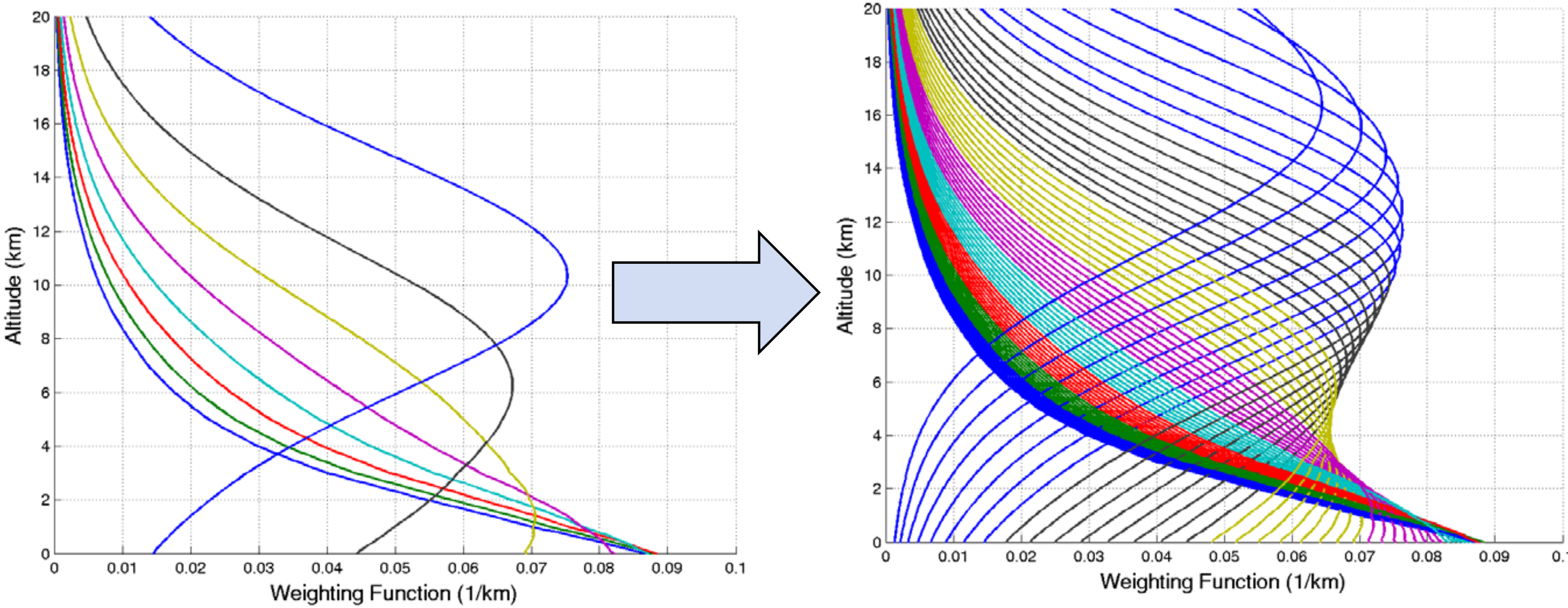


The frequency dependence of atmospheric absorption allows different altitudes to be sensed by spacing channels along absorption lines

HyMAS Overview

- HyMAS comprises multiple receivers at 118.75GHz (oxygen absorption line) and 183.31 (water vapor absorption line)
- Independent RF antenna/receiver arrays sample same volume of the earth's atmosphere at slightly different frequencies
- Yields a set of dense finely spaced vertical weighting functions via frequency multiplexing
- HyMAS will be integrated into a scanhead compatible with the NASA GSFC Conical Scanning Microwave Imaging Radiometer (CoSMIR) to facilitate demonstration and performance characterization
- Limited volume of the existing CoSMIR scanhead requires an ultra compact receiver system
  - Ultra compact 52-channel IF Processor (Key technology development)

Hyperspectral Microwave Operation



- **Hyperspectral microwave operation is achieved by replicating an 8-channel receiver multiple times with slight frequency shift**
- **Channel center frequency is shifted by 70MHz**
- **Template weighting function of single receiver replicated into an aggregate set of eight receivers**

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HyMAS Block Diagram

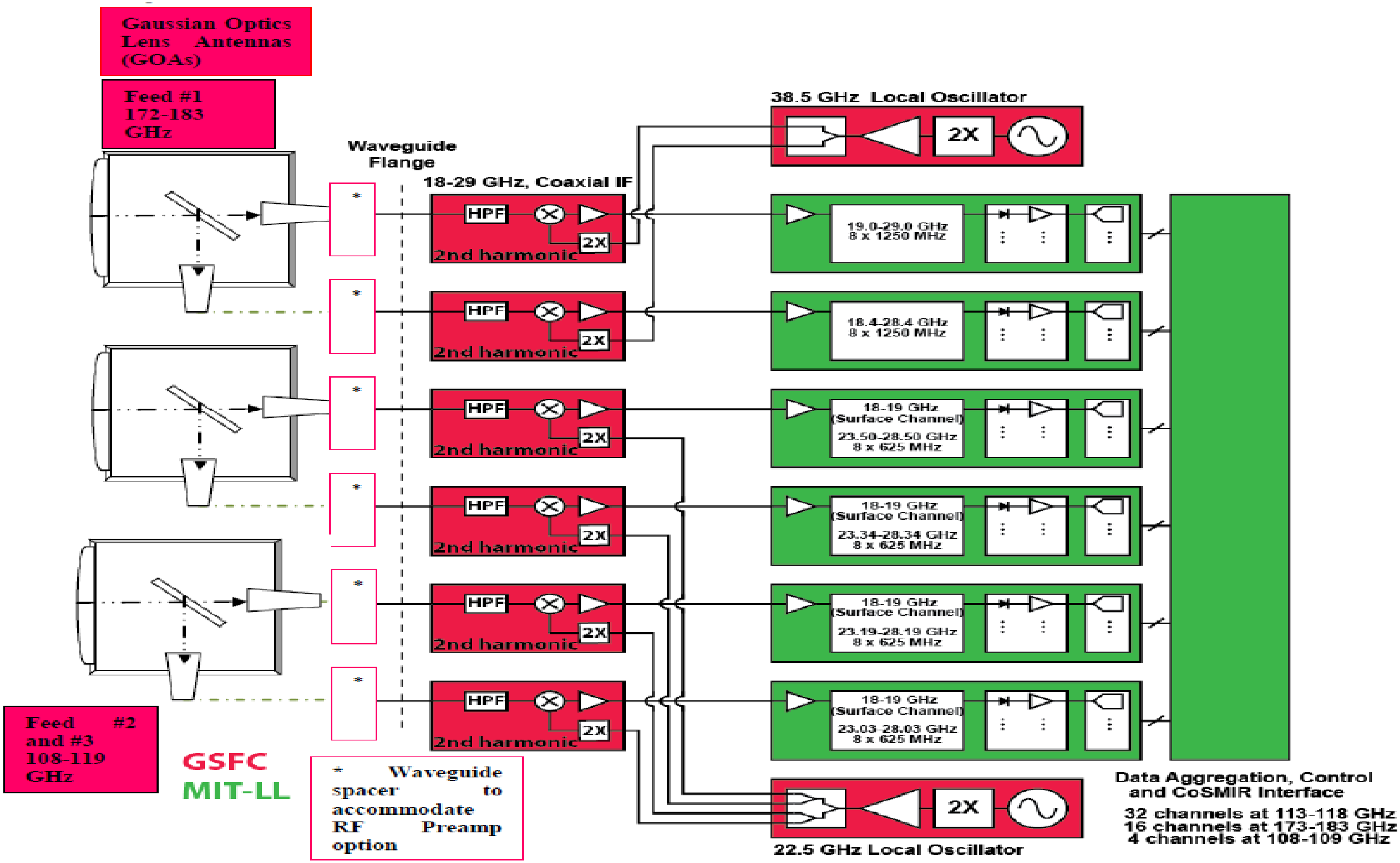


Figure 1 – Block diagram showing both the HyMAS RF electronics and core technology in the IF filter bank

HyMAS Antenna Subsystem

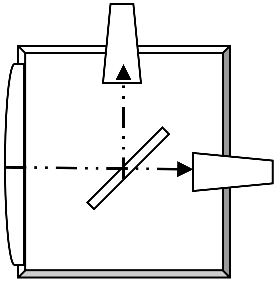
Three antennas

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

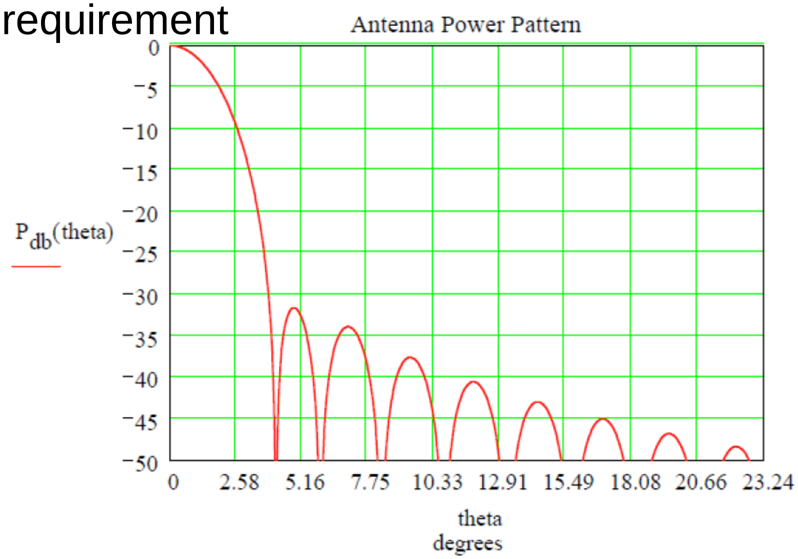
Two at 118 GHz
- Bandwidth   108-119 GHz
- Beam width: 3.1 – 3.3 degrees over the bandwidth
- Side lobes: 30 dB below main lobe
- VSWR: <1.5:1
- Polarization: dual linear

Photo/Information courtesy of Millitech Inc.

Gaussian optic antenna with wire grid to separate polarizations

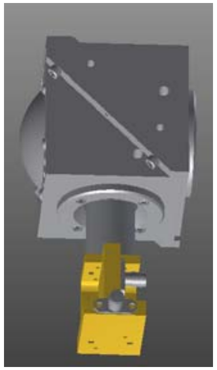


Antenna pattern analysis using 16 dB aperture taper achieves sidelobe requirement

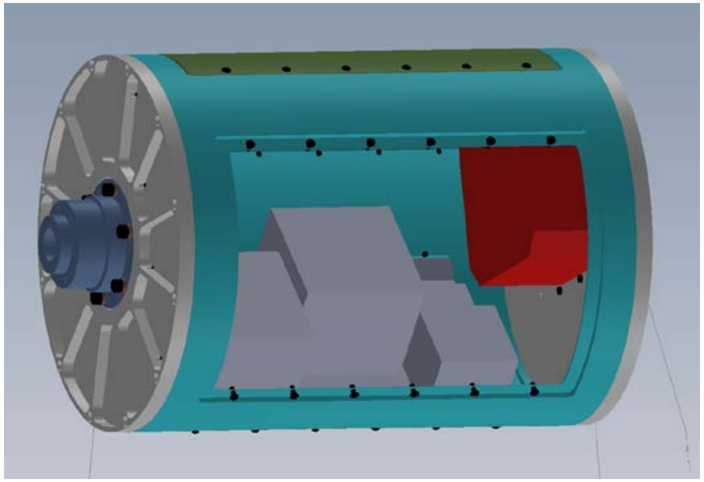


HyMAS Antenna Patterns must be well matched and co-aligned

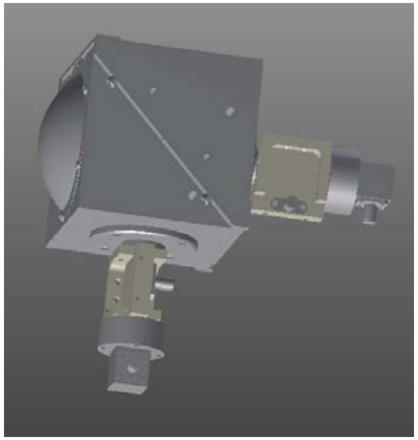
183 GHz GOA antenna and receiver (1 shown but dual linear Polarization are planned)



HyMAS drum and placement of GOAs in wall

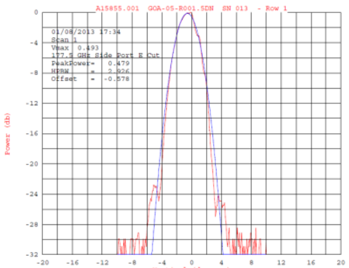


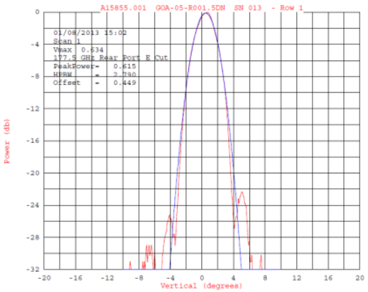
118 GHz GOA (2) & receivers(4)



side

rear

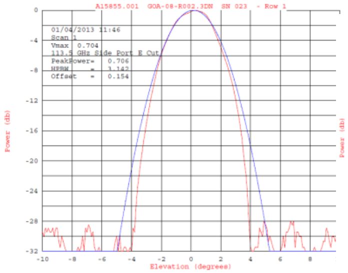


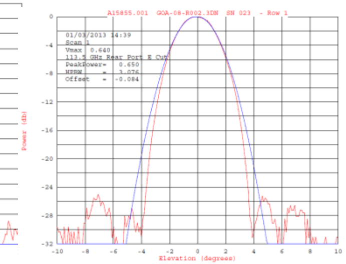


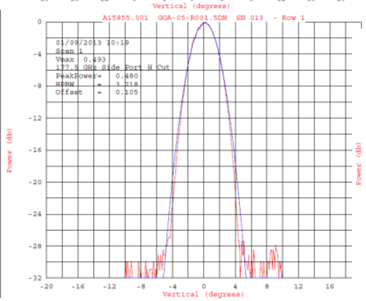
E-plane cuts

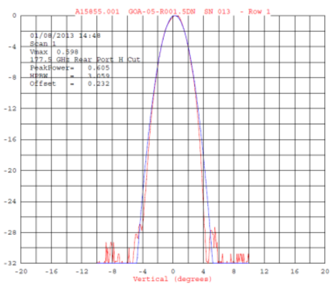
side

rear

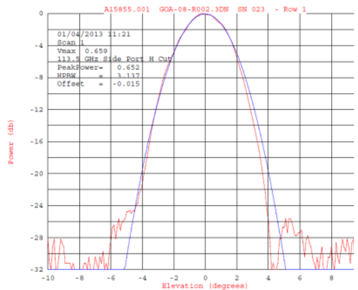


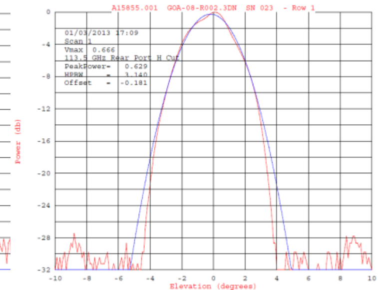






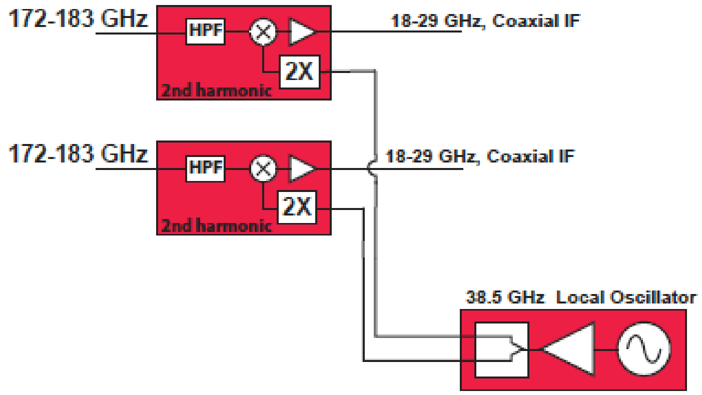
H-plane cuts

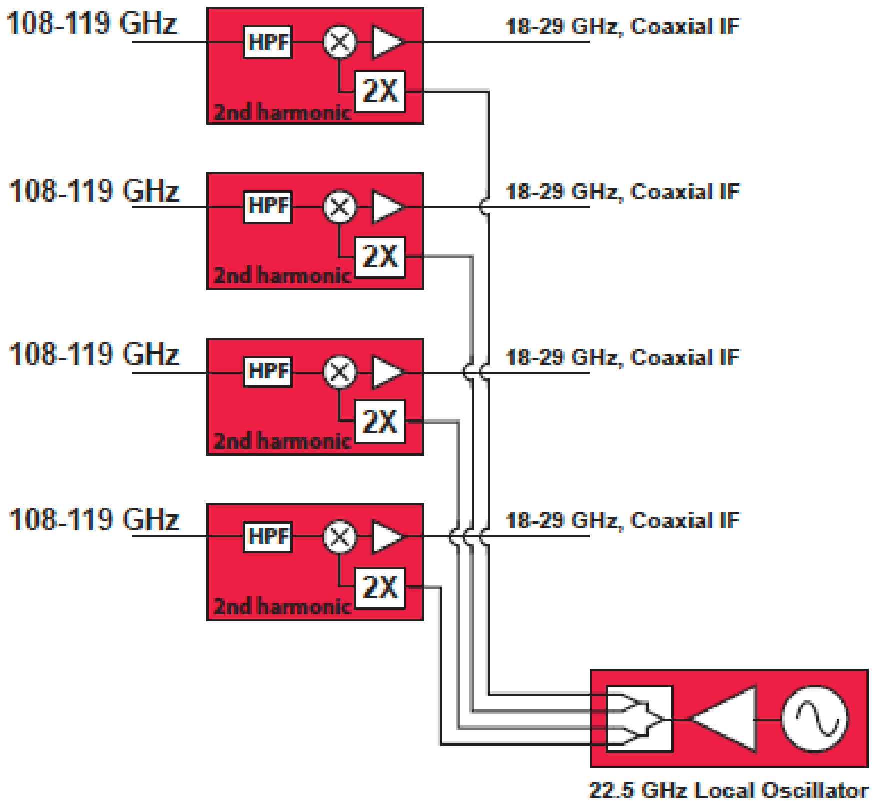


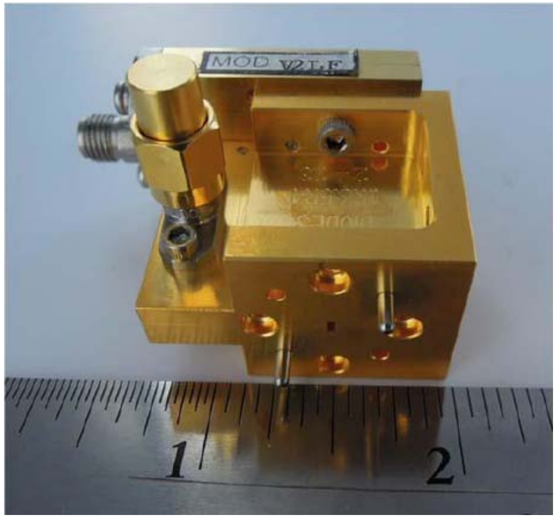


Photo/Information courtesy of Millitech Inc.

HyMAS Receiver Front End







Integrated mixer amplifier
(photo courtesy of Virginia Diodes Inc.)

- **Receiver Front End being designed and fabricated by NASA Goddard Space Flight Center**

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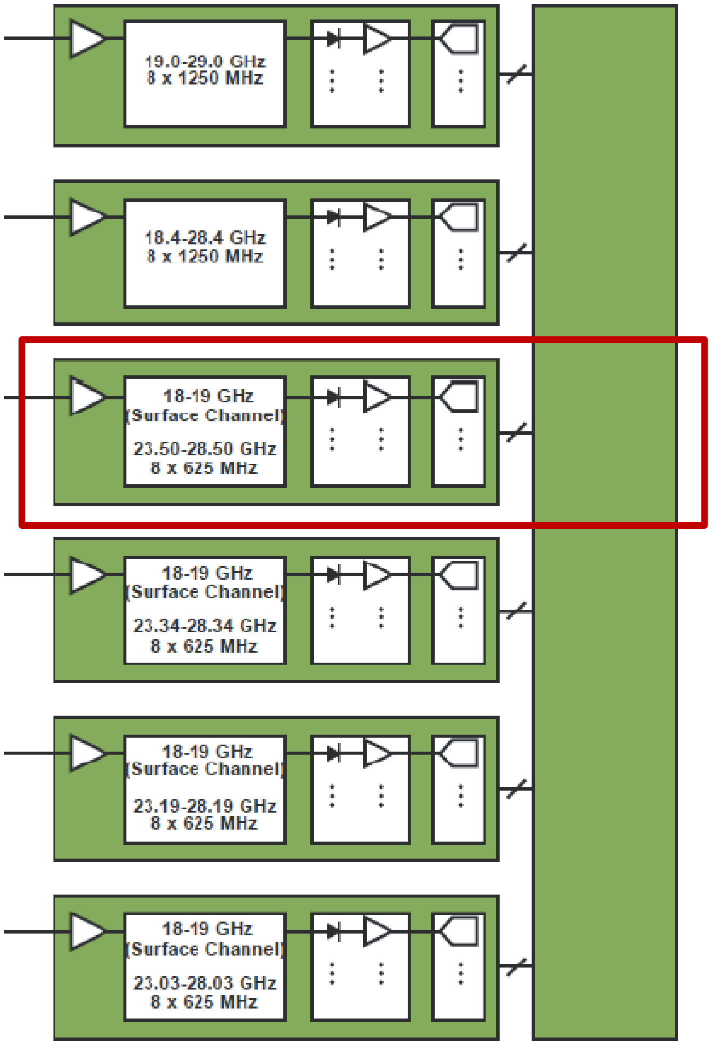
IF Processor Design

- IF processor "back-end" functions
  - Amplify, channelize and detect 18-29 GHz IF band
  - Post-detection filtering, A/D conversion, data processing
- COTS parts for availability, low cost
- K-connector (18-29 GHz) input from Receiver front-end
- 18-29GHz COTS amplifier
- Multiplexer channelizes IF band
  - LTCC SIW filters for high performance, small size
- Detectors detect power at output of each channel
- Op-amps amplify detector output, anti-alias filtering, drive ADC
- Microcontroller sequences data flow

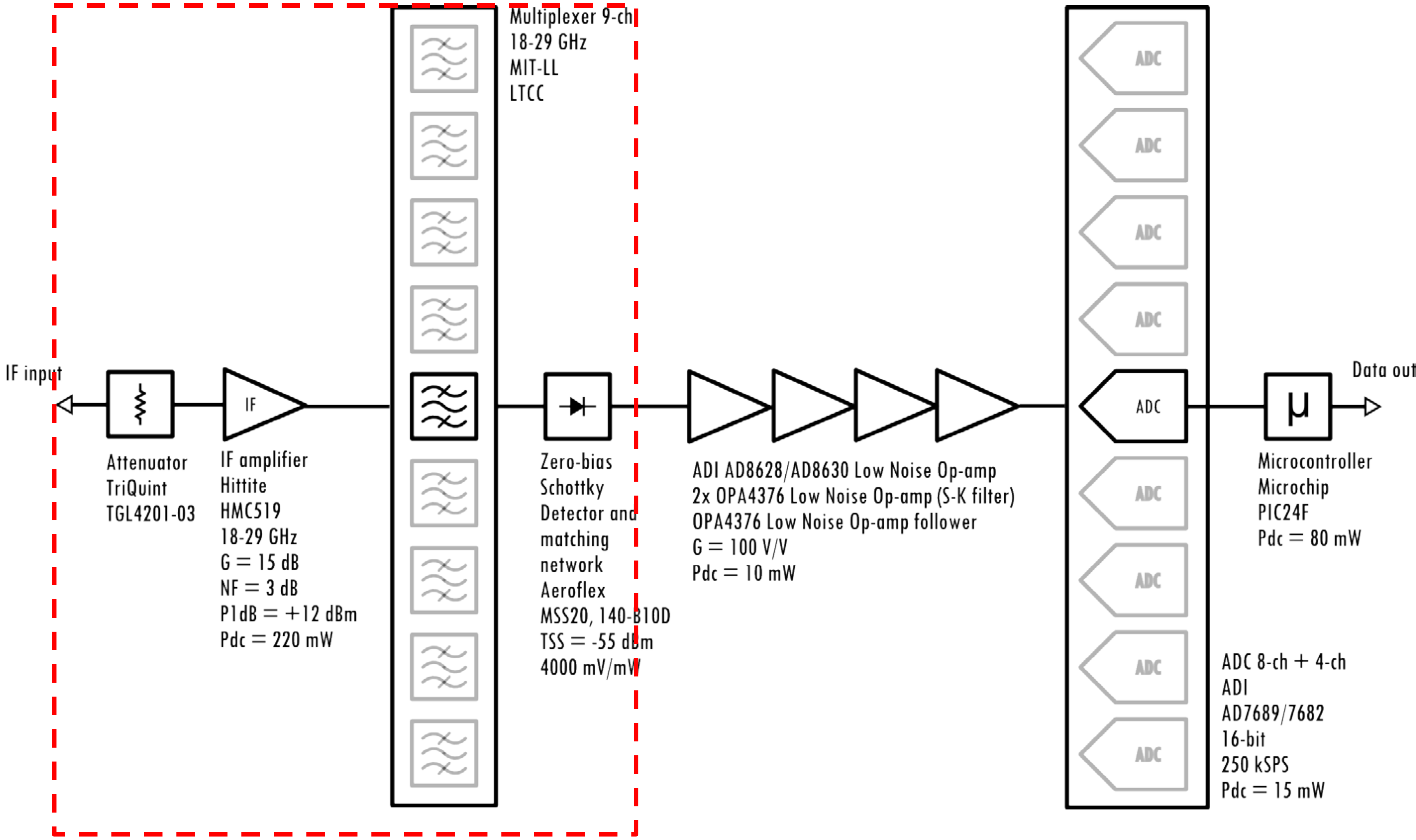
HyMAS IF Processor Prototype



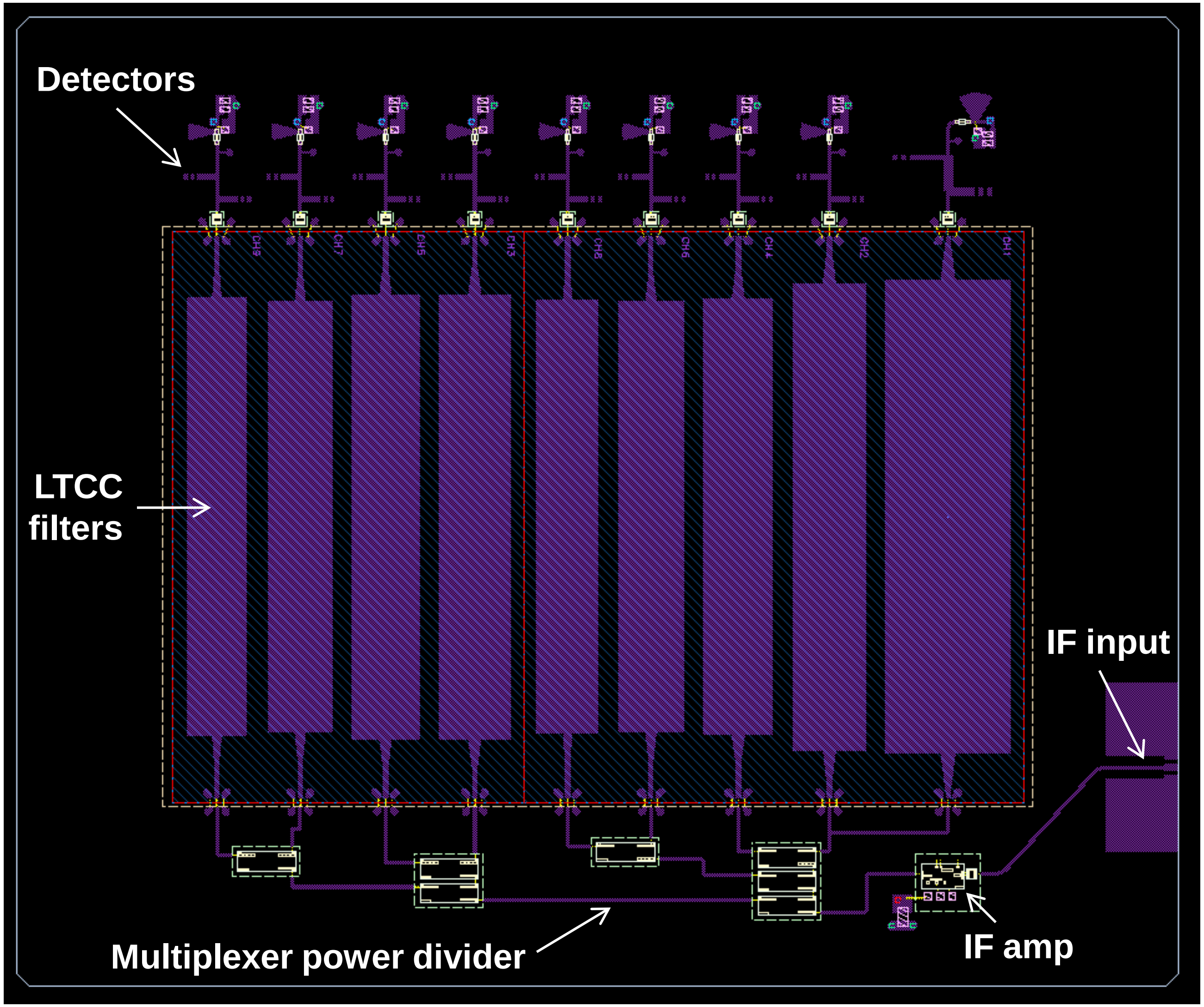
- **52 HyMAS channels designed using 6 filter banks**
- **Each filter bank implemented via “horizontal resonator” architecture**
- **Filter design implemented such that a stackable (vertical) implementation of the 6 filter banks is possible to mitigate volume constraints**
- **A 9-channel bank of filters selected for fabrication as a proof-of-concept**

Blackwell MSJA # MS-62264B, MS-69280

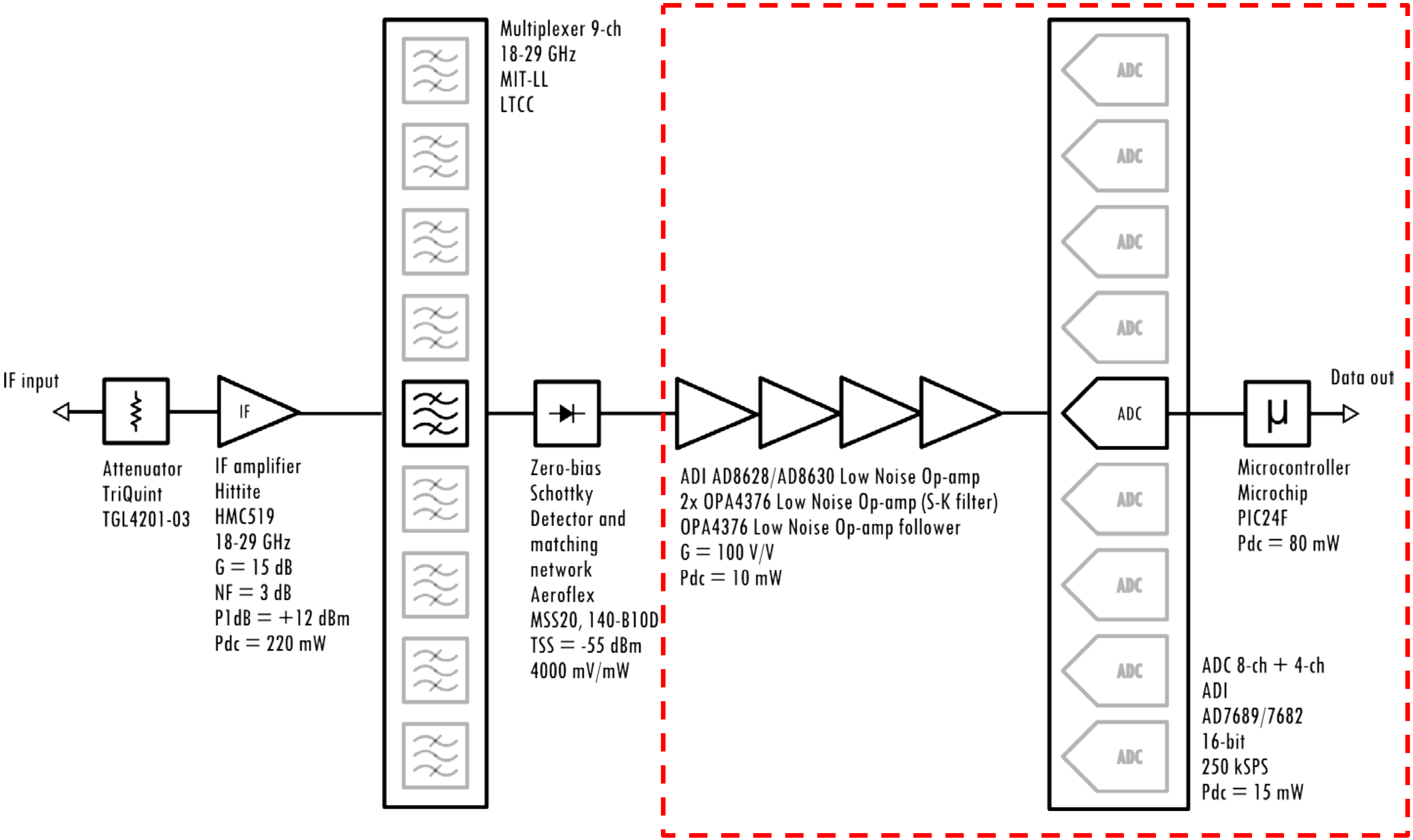
9-ch IFP Prototype Block Diagram



RF Board Layout



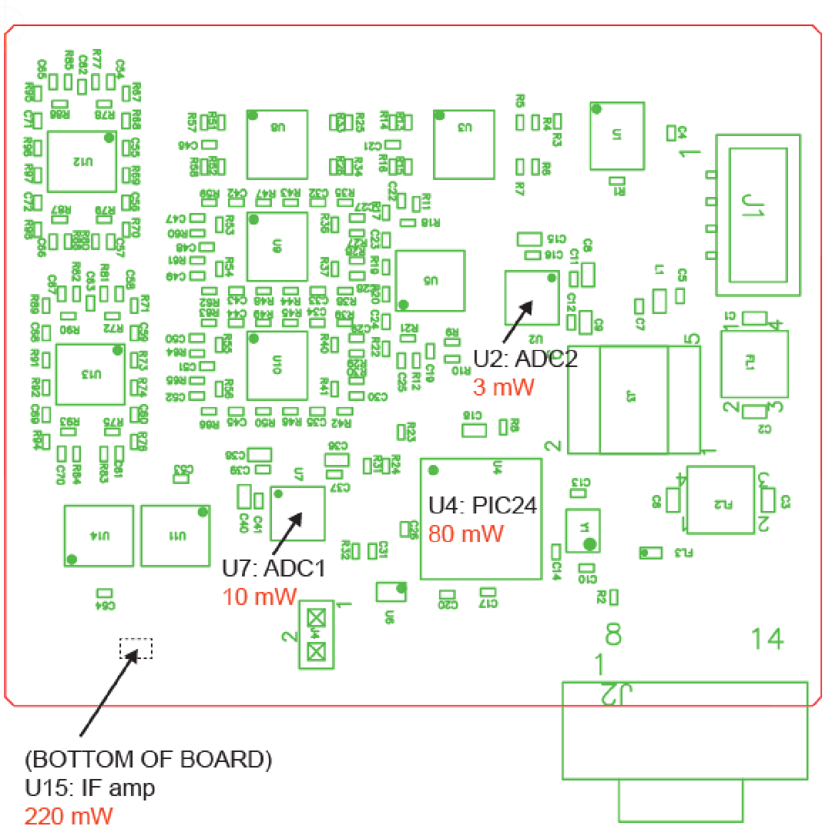
9-ch IFP Prototype Block Diagram



IFP Board – Power Dissipation Contributors

- **Beginning thermal analysis of IFP board**
  - **Major power dissipation contributors identified and modeling is underway**
- **Foresee no difficulty with metal enclosure providing heat sink**

IFP Printed Circuit Board Assembly (TOP VIEW)

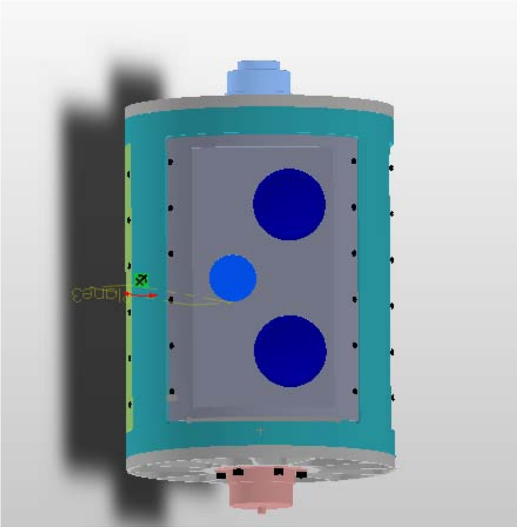


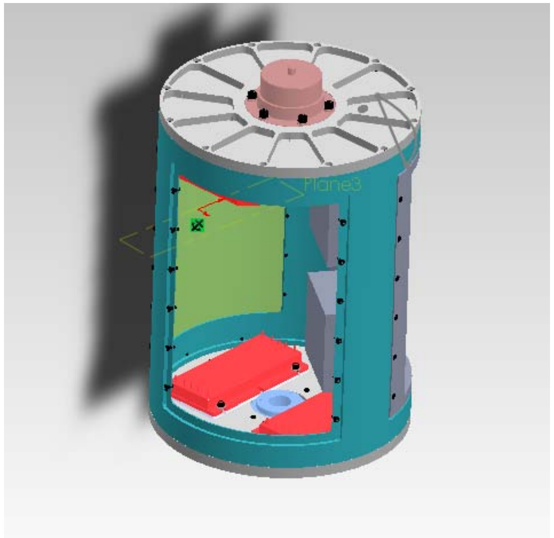
Mechanical Design

Mechanical drawings of the CoSMIR/CoSSIR scanhead have been stripped and a new model for the HyMAS has been created

Scanhead will contain
- Two 118 GHz and One 183 GHz antenna
- Four 118 GHz receivers
- Two 183 GHz receivers
- MIT-LL IF processor
- Two-card PC104 Stack
- Power conditioning and temperature sensors

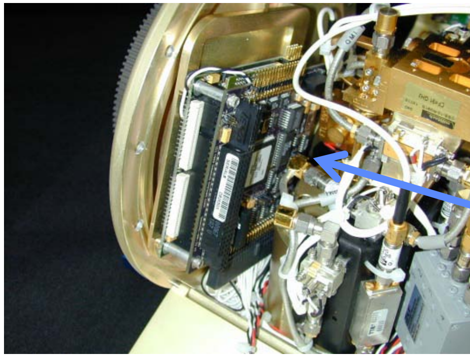
Initial layout with faux components help identify packaging challenges and constraints on component designs



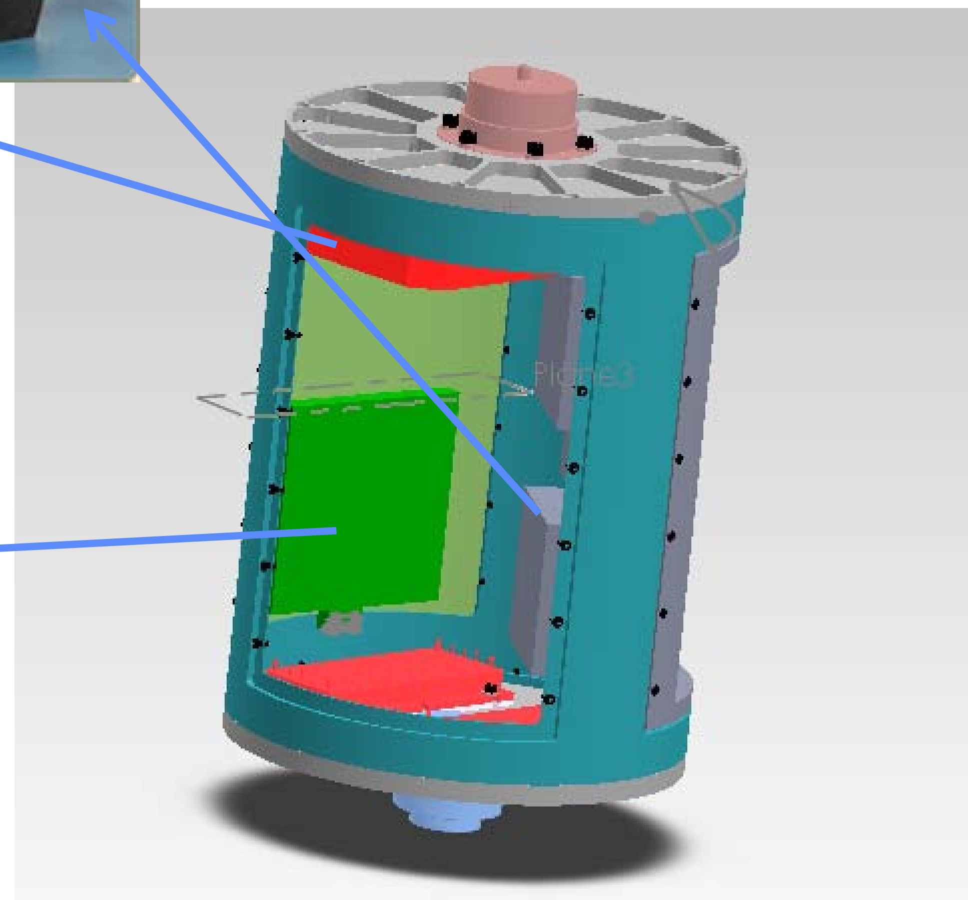


Mechanical Layout

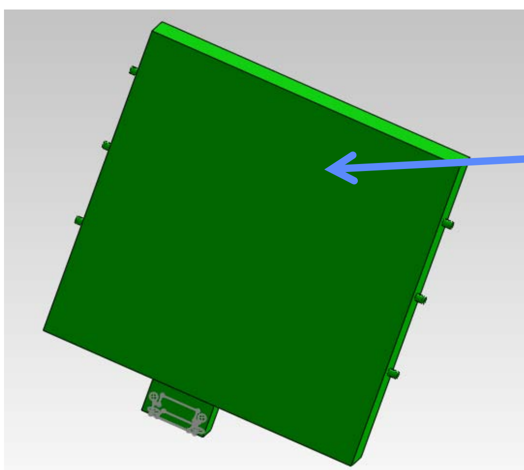
PC104 Computer



One 183 GHz and two 118 GHz antennas



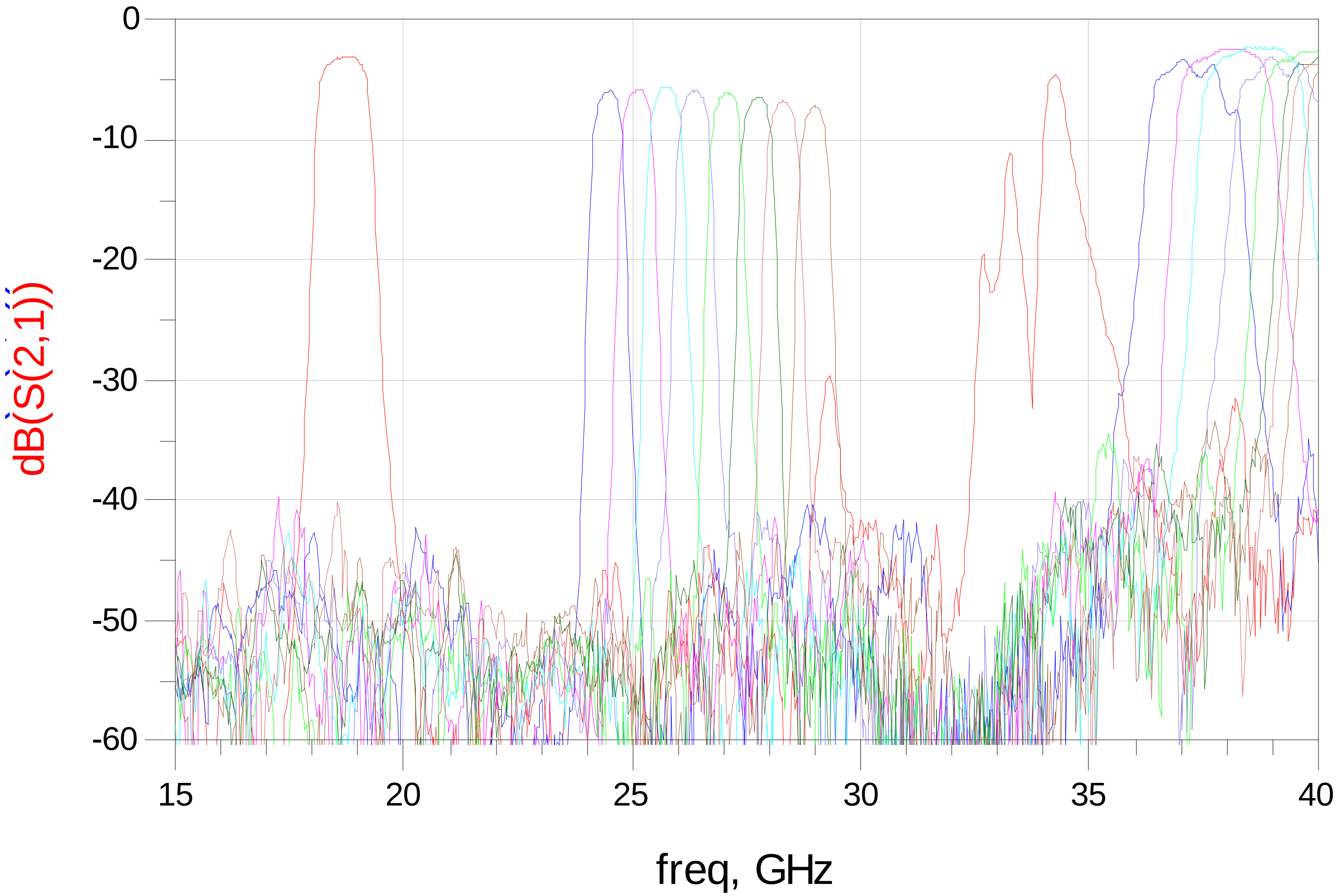
IF Processor (10cm x 10cm x 1cm)



IF Processor Requirements

Requirement		Tests
Size	< 1cm x 1cm x 0.1 cm	None
DC Power	< 650 mW	Swept frequency, power
Channel isolation	> 40 dB	Swept frequency
Channel passband ripple	< 1.5 dB	Swept frequency
Channel amplitude balance	< 1 dB	Swept frequency
Total gain, from input to diode detector input	5 dB < G < 10 dB	Swept frequency, power
DC Power Noise	< 100 mV p-p ripple	Swept frequency, power
Temperature, operational	-40 °C < T < +85 °C	Swept frequency
Data interface	SPI bus	System test

SIW Filter Measurements – S21 wideband



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The PIC24 processor puts 52 channels in a serial stream

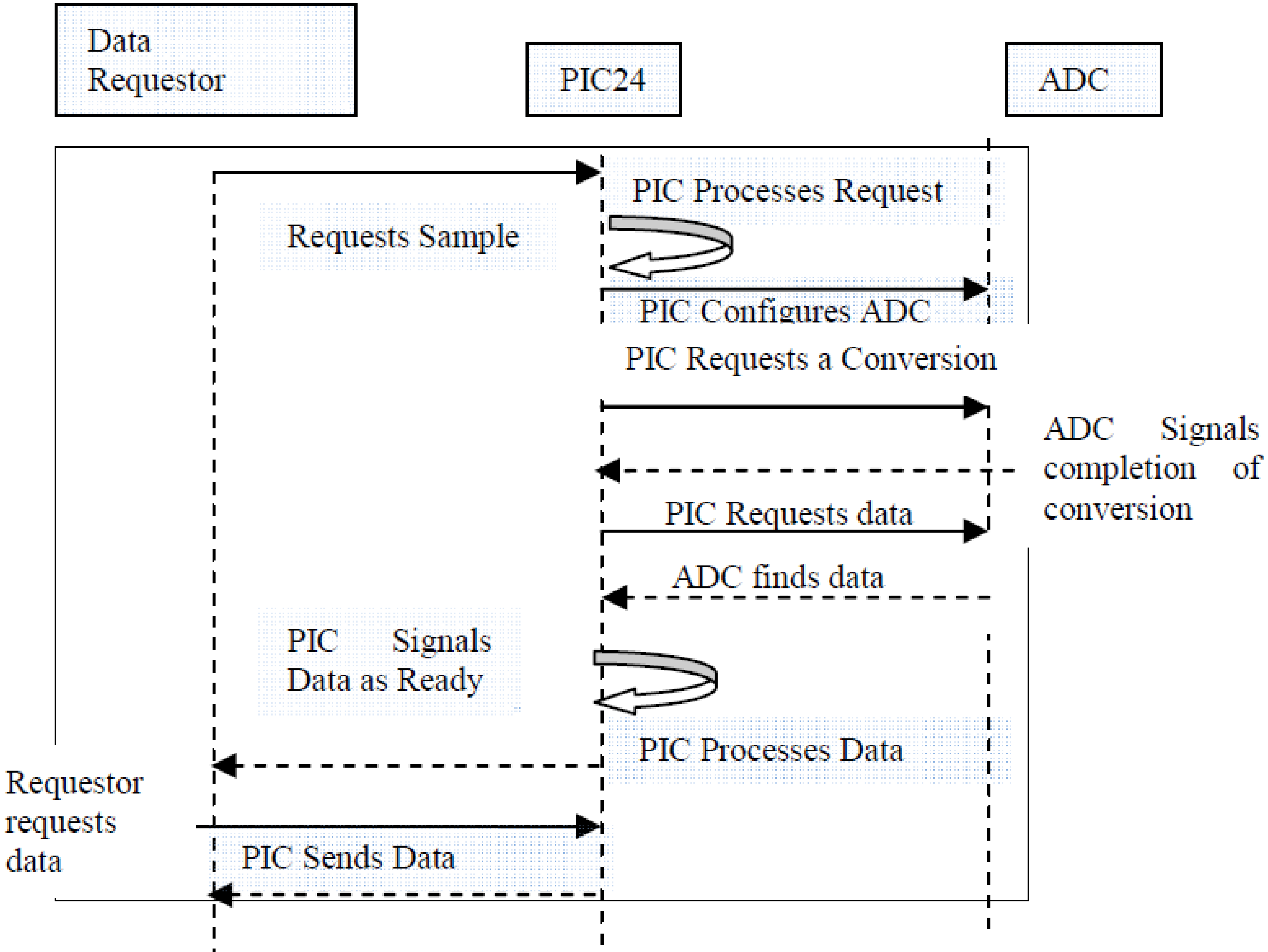

Figure 5c: Hand-shaking between back end components

Interoperable Remote Component (IRC) will update CoSMIR/CoSSIR and accommodate HyMAS

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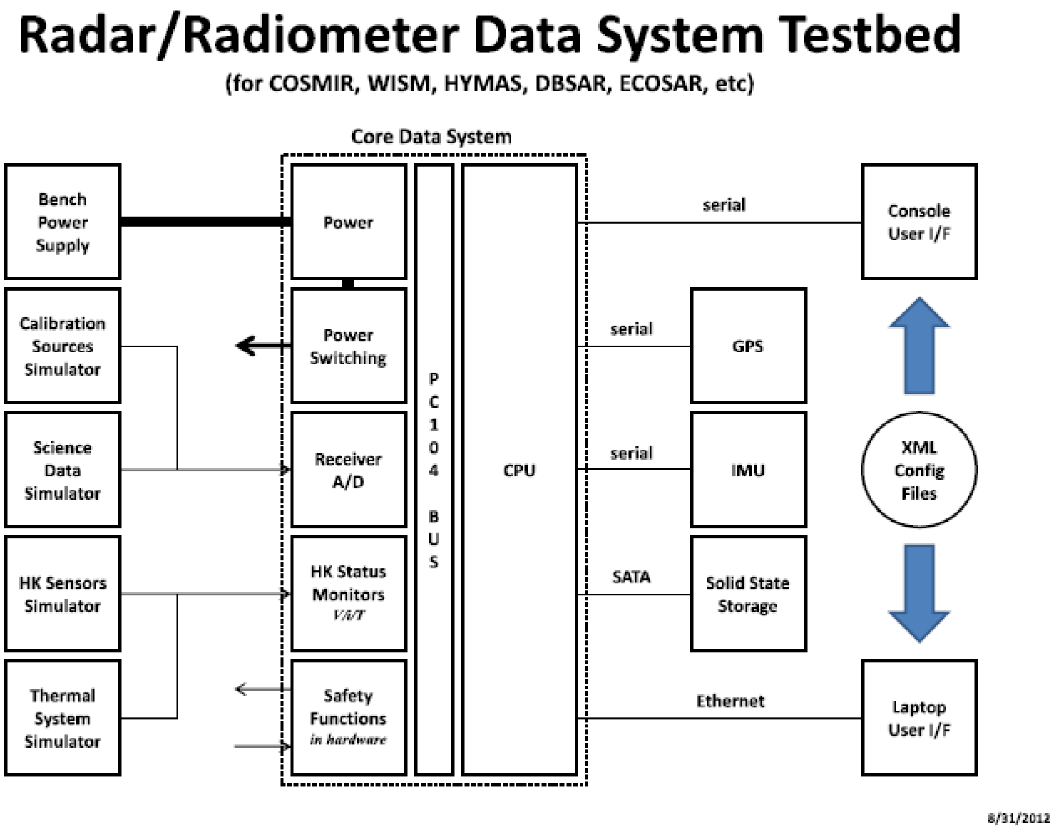

Figure 7: The general IRC test bed being developed for multiple aircraft instruments-*block diagram by Beth Timmons Goddard Science Data Processing Branch*

The additional channels required for HyMAS are not a problem for IRC and the degree of automated operation required for CoSMIR/CoSSIR are lessons learned that the IRC can re-apply for HyMAS.

Hyperspectral IFP and Scanhead Computer Serial Peripheral Interface (SPI)

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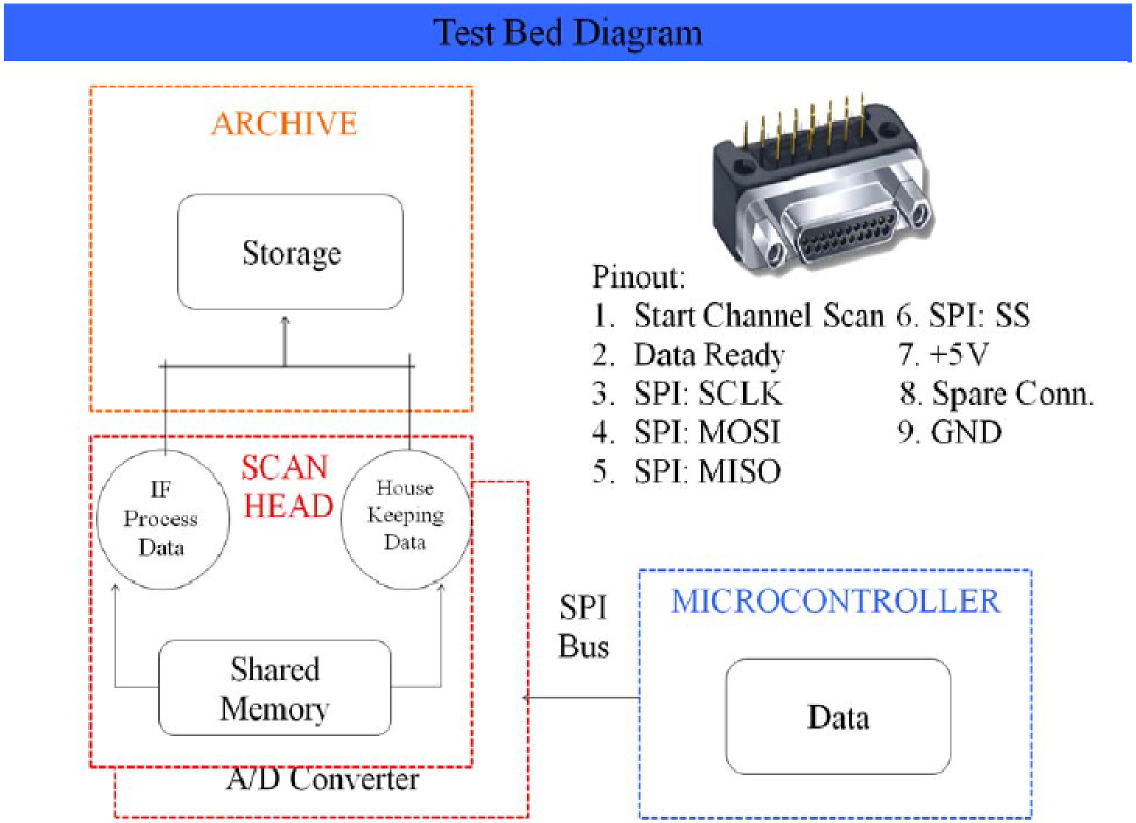

Figure 5b: The Scan head computer will pull the data from the IFP over a serial peripheral interface (SPI)[6]

The HyMAS test bed must simulate the collection and system clock time-tagging of data . The calibration computer and navigation data are also time tagged and archived together for post-flight processing.

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Summary and Next Steps

- LTCC filter prototype bank 1 (of 6) fabricated and tested
  – Very good S-parameter performance
  – Additional tests ongoing
  – "Horizontal resonator" architecture implemented
  – Fabrication tolerances characterized
- Filter "carrier board" with power divider, detectors, signal conditioning, and digital processing fabricated
- Analysis of ultra-compact "vertical resonator" architecture (goal) looks very good; completion of design and fabrication run planned for early 2013.
- Digital firmware for carrier board complete
- Finish Integration in time for Flight Opportunity in Summer of 2014

Thank you

Questions

Back up

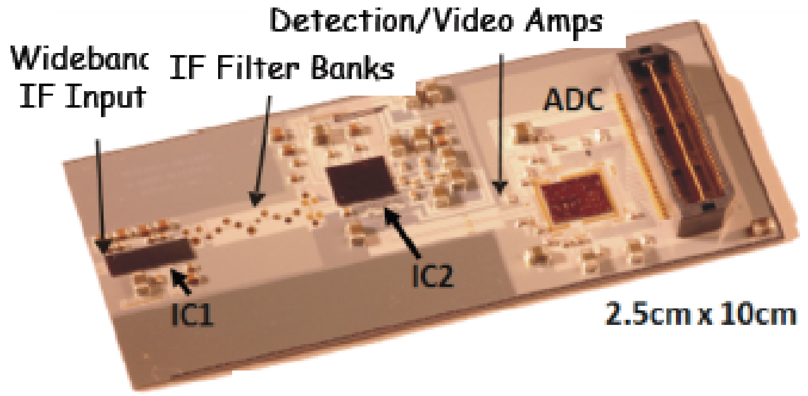
Charts

Demonstration of a Hyperspectral Microwave Receiver Subsystem

PI: William Blackwell, MIT Lincoln Laboratory

Objective

- Develop and demonstrate a new hyperspectral microwave receiver subsystem to support future atmospheric sounding missions such as PATH.
- Achieve an all-weather sounding capability through broadband 118 and 183 GHz receiver subsystems.
  - Core technology effort is an ultra-compact (<100cm³, 500g) Intermediate Frequency (IF) processor module enabling hyperspectral sensing within the mass/volume envelope of current systems.
- Enable smaller sensors with greater reliability, launch opportunities, and performance with the proposed IF technology, together with recent RF advancements.



Ultra-compact LTCC filter bank and digital processor

Approach

- Develop an integrated hyperspectral microwave receiver subsystem in a flight-ready compact package.
  - Low-temperature co-fired ceramic (LTCC) process allows small feature size and multilayer integration.
  - New broadband mixer technology allows many broad channels to be measured across the IF passband.
- Verify performance through ground-based radiometric and thermal testing.

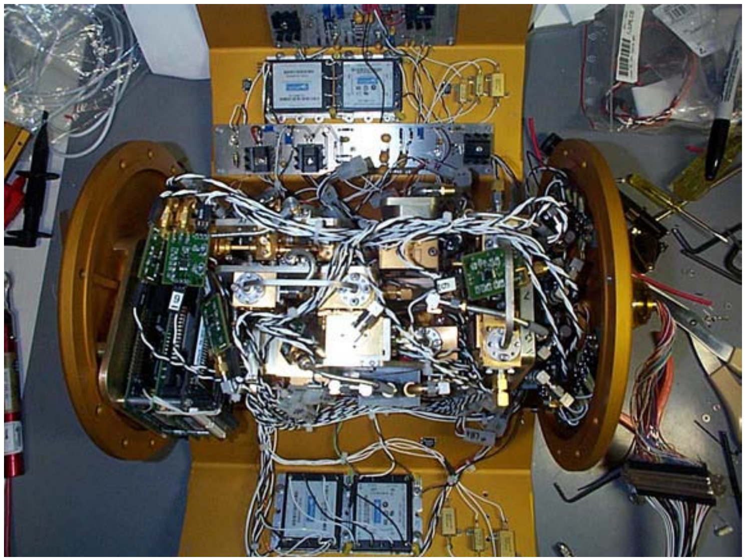
Co-Is/Partners:
Paul Racette, GSFC; Tim Hancock, MIT/LL

Key Milestones

• Develop requirements and interface control document	06/12
• Design review of IF processor module	06/12
• Fabricate prototype IF filter bank	11/12
• Conduct thermal testing of prototype IF filter bank	03/13
• Assemble and test 118 GHz front end	07/13
• Assemble and test 183 GHz front end	11/13
• Fabricate final IF filter bank	11/13
• Complete IF processor module functional testing	11/13
• Complete mechanical integration and thermal testing	06/14
• Complete integrated subsystem environmental testing	11/14

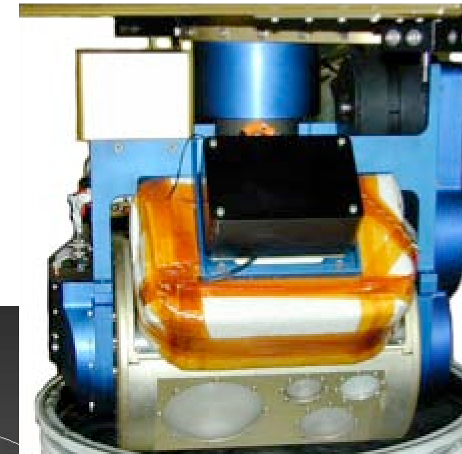
$TRL_{in} = 3$ $TRL_{current} = 3$

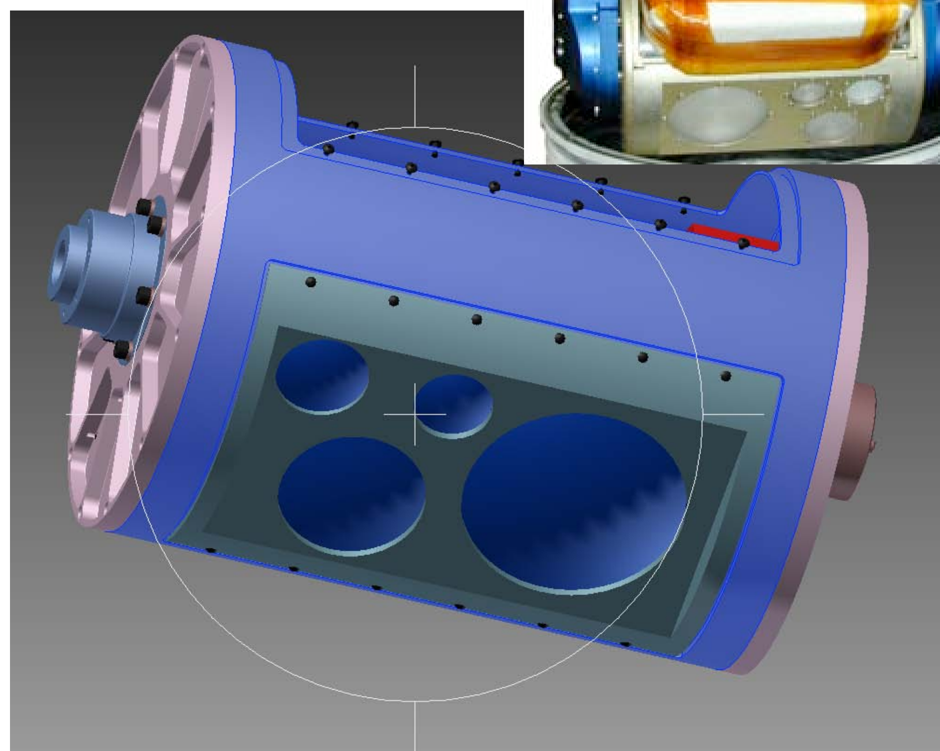
CoSMIR/CoSSIR Scan Head accommodating HyMAS: The work ahead



←- Integrate the inside

Integrate the Outside - →





•Successful Demonstration of high IF 18-29 GHz in front end

•Successful demonstration of 52 Hyperspectral Channels

•Successful Data Collection and metadata collection using the IRC

CoSMIR/CoSSIR/HyMAS Scan Head

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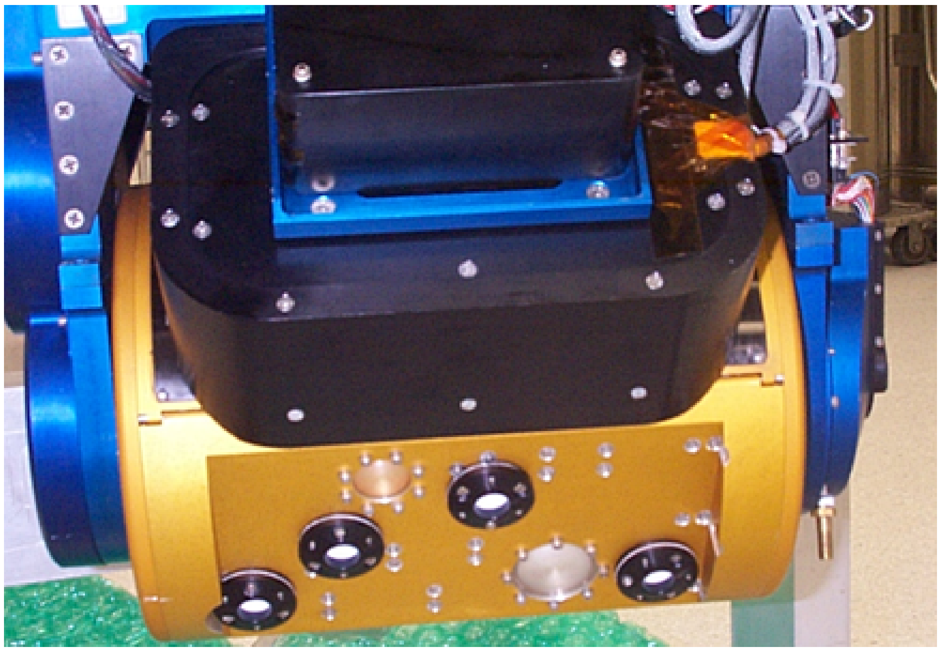

The scan head provides calibration and control infrastructure and rotates in azimuth and elevation. CoSSIR is shown in the photo at left.

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