Hyperspectral Microwave Atmospheric Sounder (HyMAS) - new capability in the CoSMIR/CoSSIR scanhead

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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

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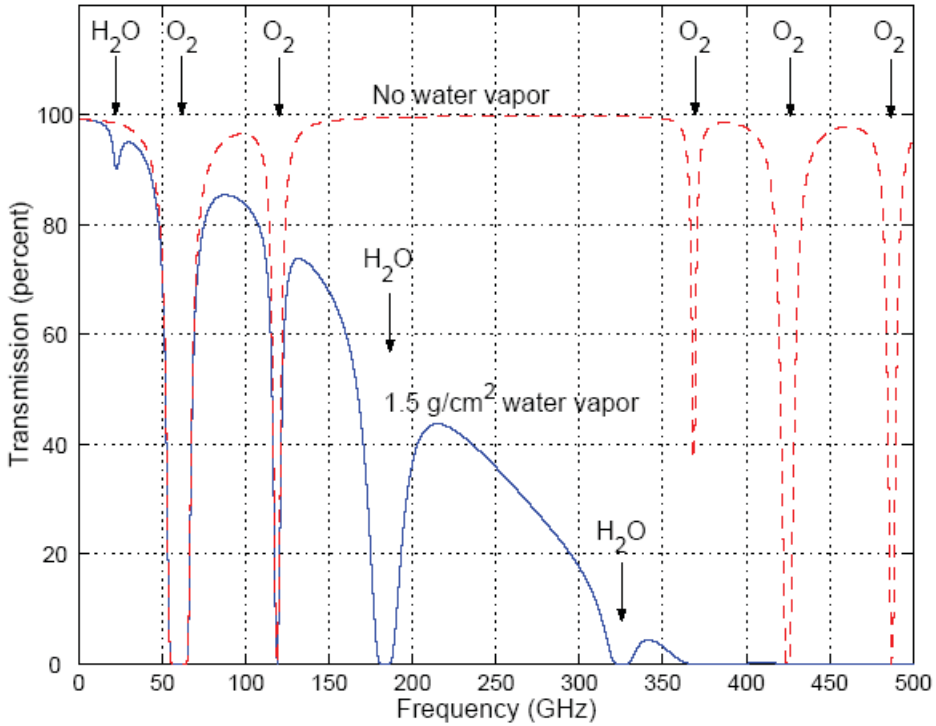
- Several recent enabling technologies make HyMW feasible:
  - Detailed physical/microphysical atmospheric and sensor models
  - Advanced, signal-processing based retrieval algorithms
  - RF receivers are more sensitive and more compact/integrated
- The key idea: Use RF receiver arrays to build up information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

Microwave Atmospheric Sensing

Cloud Penetration

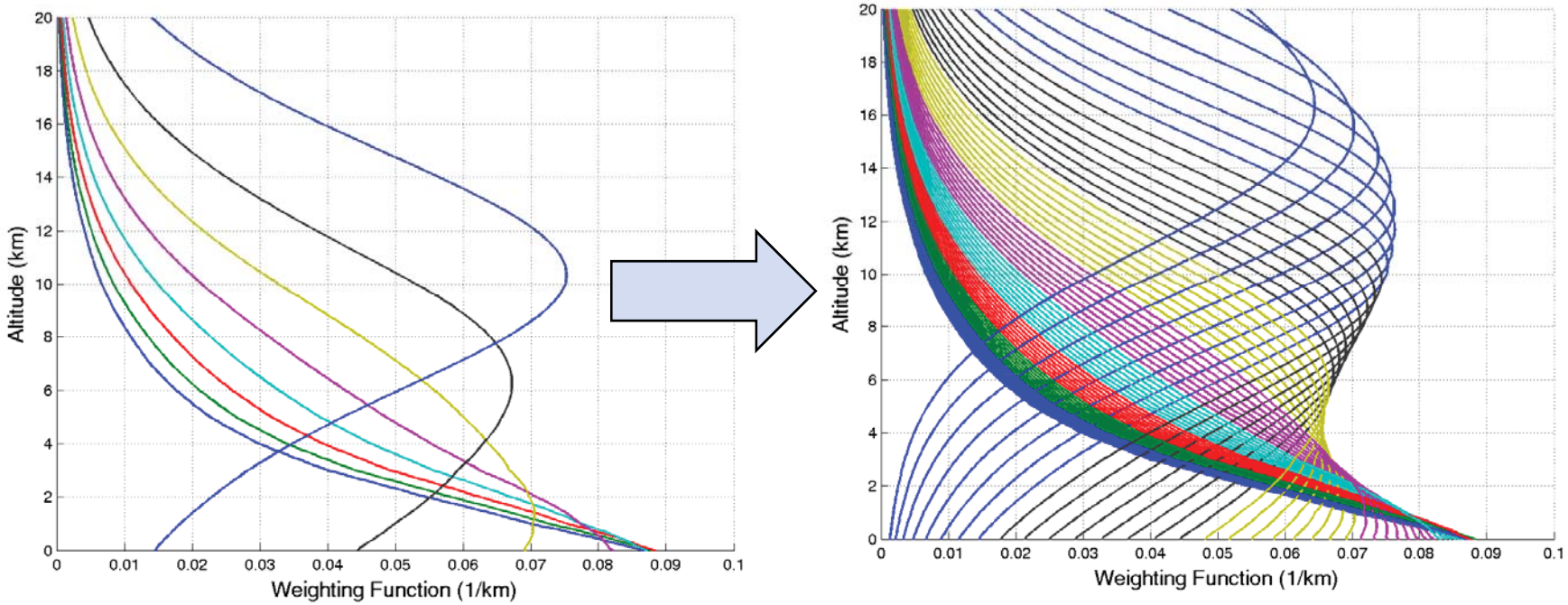


The frequency dependence of atmospheric absorption allows different altitudes to be sensed by spacing channels along absorption lines

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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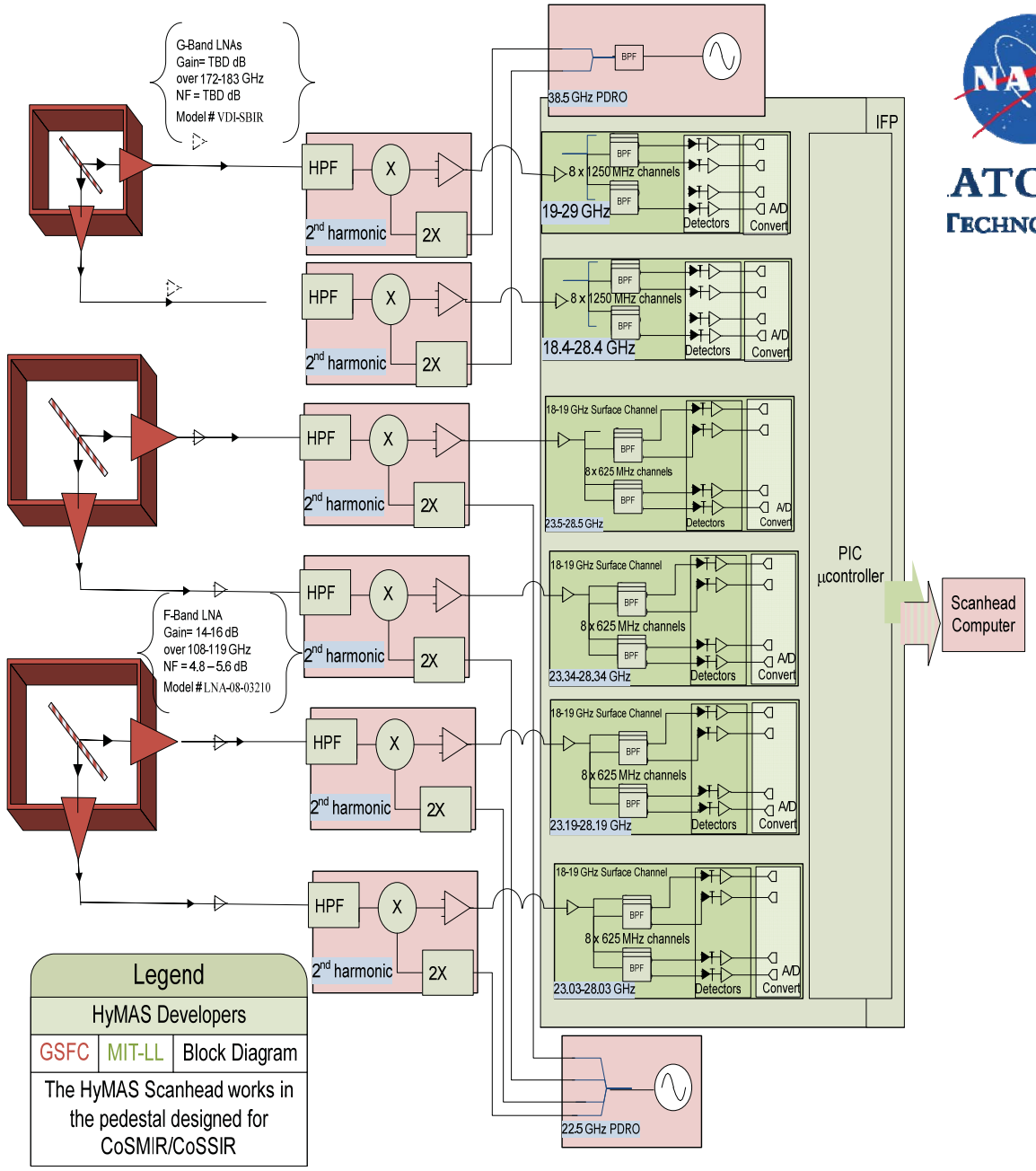
HyMAS Block Diagram



HyMAS Antenna Subsystem

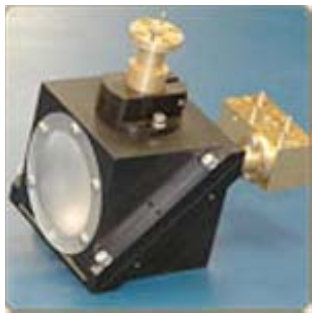
Three antennas

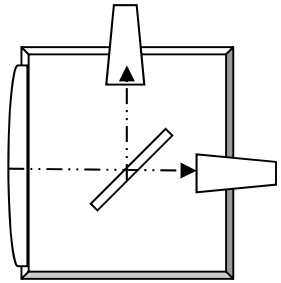
One at 183 GHz
- Bandwidth 172-183 GHz
- Beamwidth: 3.1 – 3.3 degrees over the bandwidth
- Sidelobes: 30 dB below main lobe
- VSWR: <1.5:1
- Polarization: dual linear

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

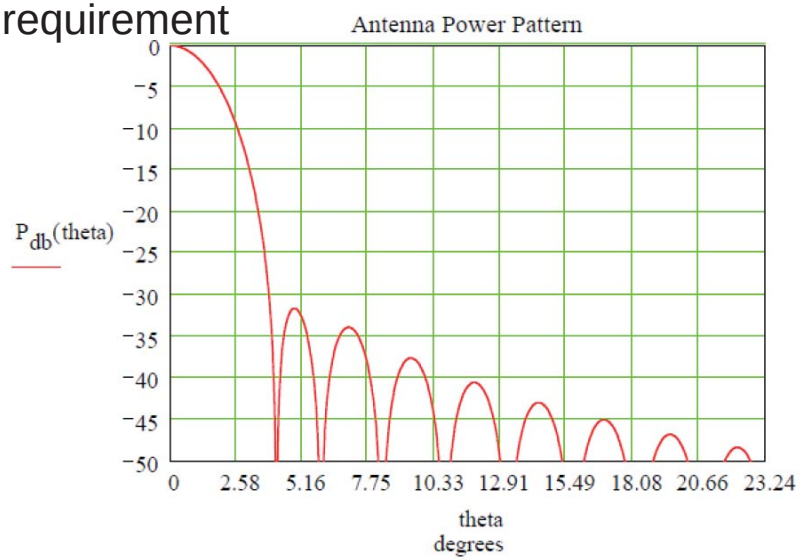
Photo/Information courtesy of Millitech Inc.

Gaussian optic antenna with wire grid to separate polarizations



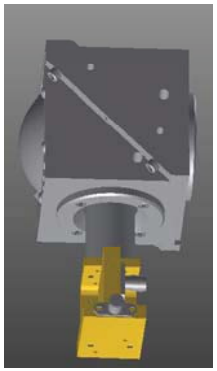


Antenna pattern analysis using 16 dB aperture taper achieves sidelobe requirement

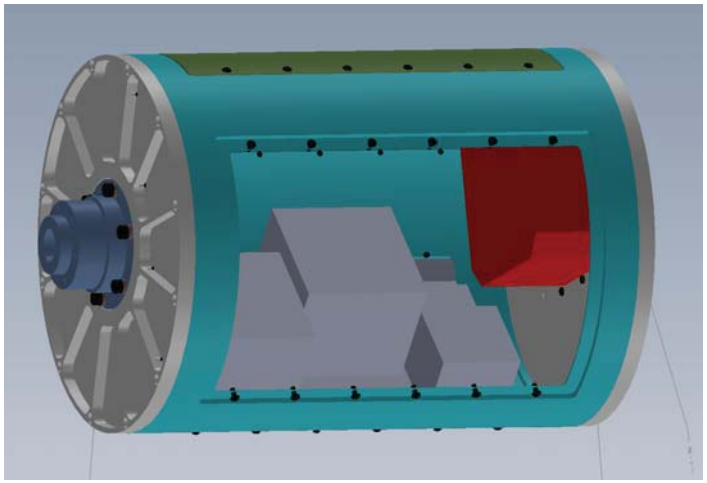


HyMAS Antenna Patterns must be well matched and co-aligned

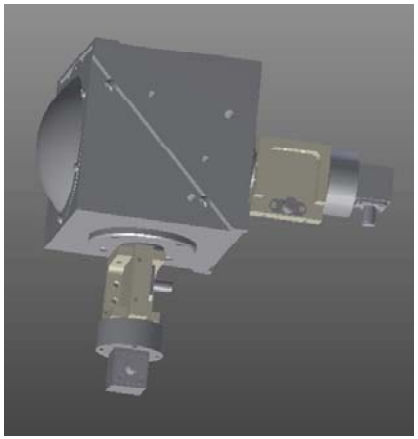
183 GHz GOA antenna and receiver (1 shown but dual linear Polarization are planned)



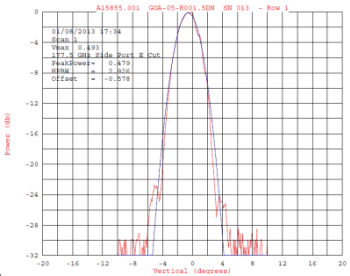
HyMAS drum and placement of GOAs in wall



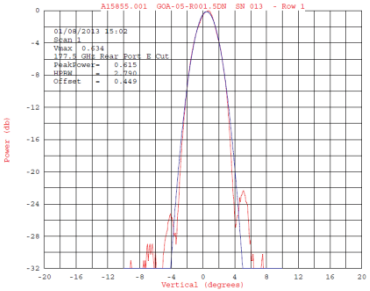
118 GHz GOA (2) & receivers(4)

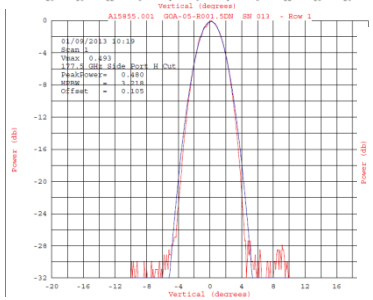


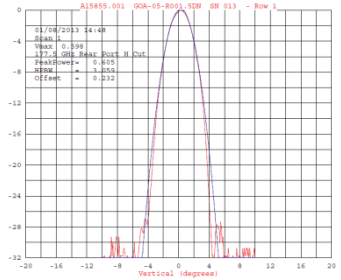
side



rear



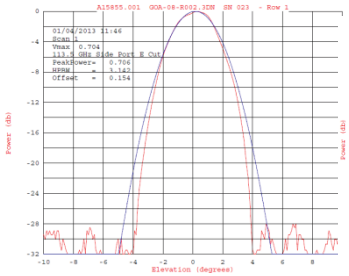




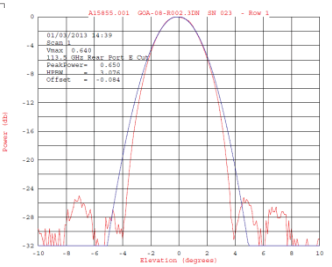
E-plane cuts

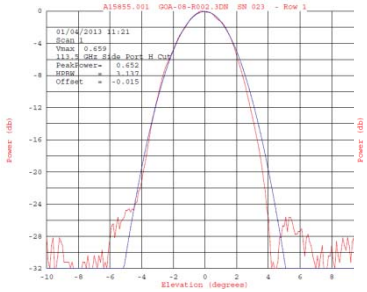
H-plane cuts

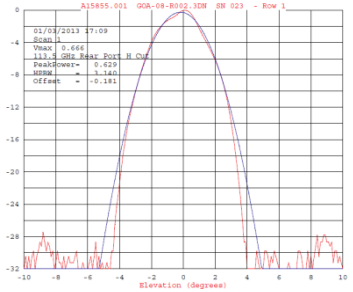
side



rear







Photo/Information courtesy of Millitech Inc.

HyMAS Receiver Gain/Loss Budget

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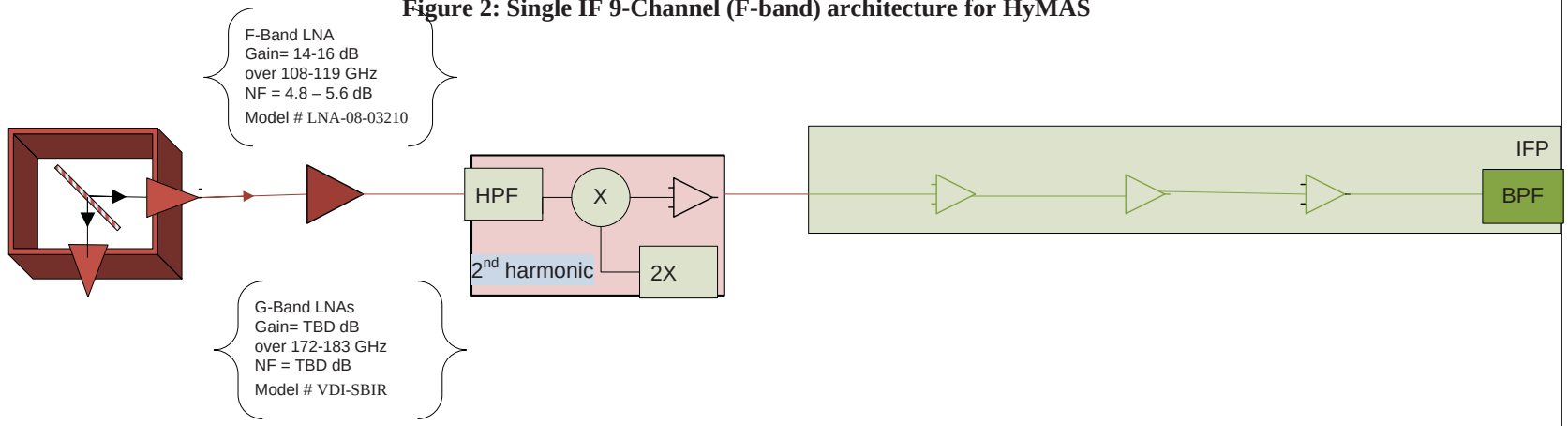
Figure 2: Single IF 9-Channel (F-band) architecture for HyMAS



	Antenna	Feed	RF LNA	W/G	Filter	Mixer	IF Amp 1	Coax	Att 1	IF amp 2	Att 2	IF amp 3	Att 3	IF amp 4	Att 4	IF filter
B(Hz)	3.00E+10	3.00E+10	3.00E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.25E+09
Tb (K)	300															
G (dB)		-0.2	15	-0.5	-1	-6	30	-2	0	15	0	15	0	0	0	-16
P(mW)	1.23E-07	1.17E-07	3.72E-06	3.31E-06	2.63E-06	6.61E-07	6.61E-04	4.17E-04	0.00042	0.01318	0.01318	0.41687	0.41687	0.41687	0.41687	0.01047
P(dBm)	-69.1	-69.3	-54.3	-54.8	-55.8	-61.8	-31.8	-33.8	-33.8	-18.8	-18.8	-3.8	-3.8	-3.8	-3.8	-19.8
Te(K)	3.00E+02	283.58618	8967.783	21797.8	17314.6	4349.24	4349243	2744187	2744187	8.7E+07	8.7E+07	2.7E+09	2.7E+09	2.7E+09	2.7E+09	6.1E+08

LMH1

Mechanical Design

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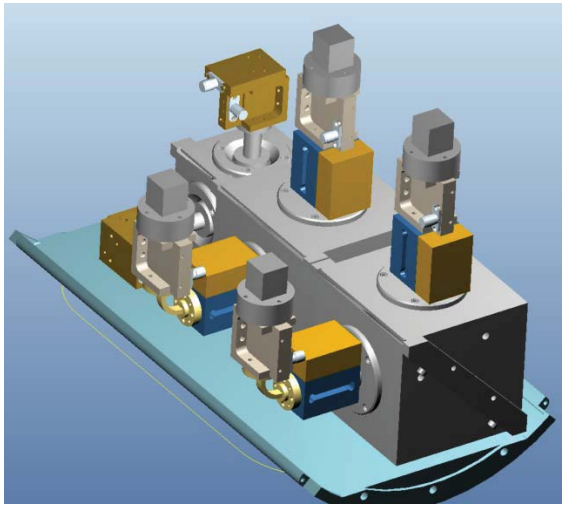
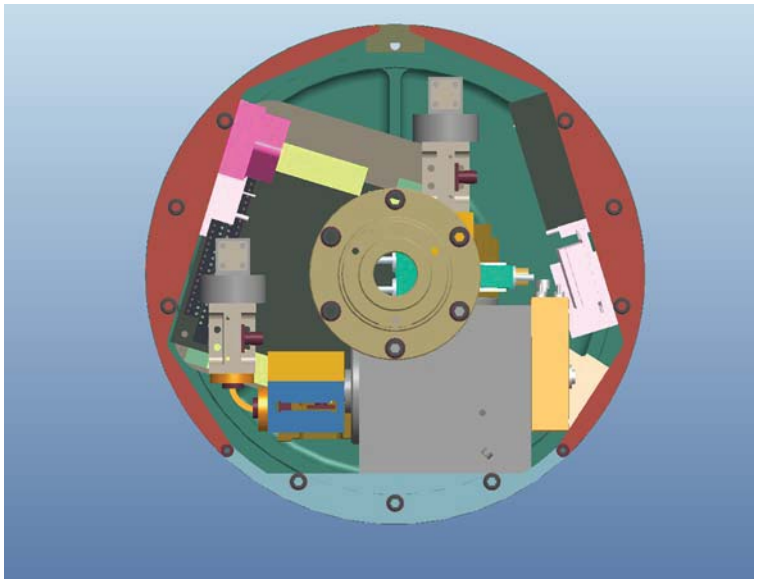
F-band low noise amplifiers are incorporated into the mechanical design

All hardware fits within drum envelop, substantially reducing the risk in I&T

Two dozen parts comprising the drum assembly are on order with expected delivery in mid-September



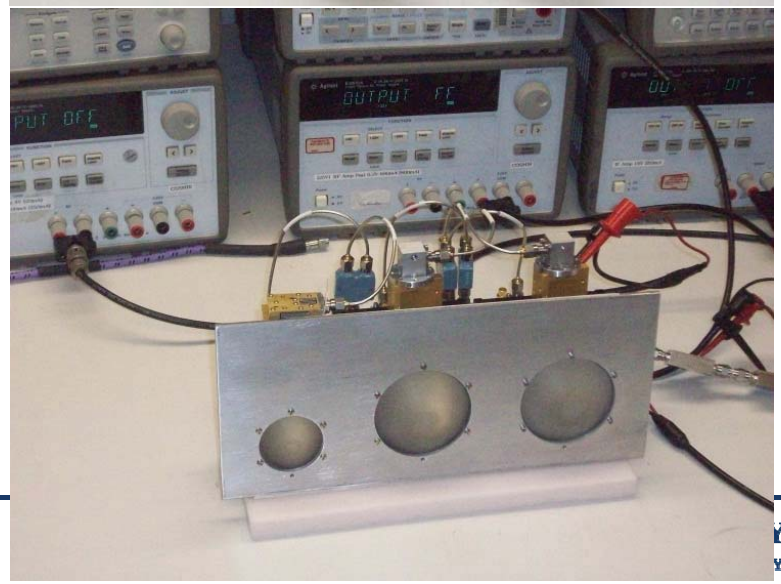


LMH1 G-Band LNAs not incorporated yet

Lawrence M Hilliard, 8/30/2013

HyMAS Receiver I & T

- HyMAS receivers and antennas have been assembled in laboratory for testing
- Initial results hampered by lack of test equipment at the high IF frequency
- IF amplifiers and detectors are procured
- NF measurement indicate 3-dB higher than expected. High NF attributed to
  - Broadband detection
    - Acquiring filter to test NF over narrow band
  - Loss in Millitech antennas
    - Pursuing specialized tests to characterize the loss



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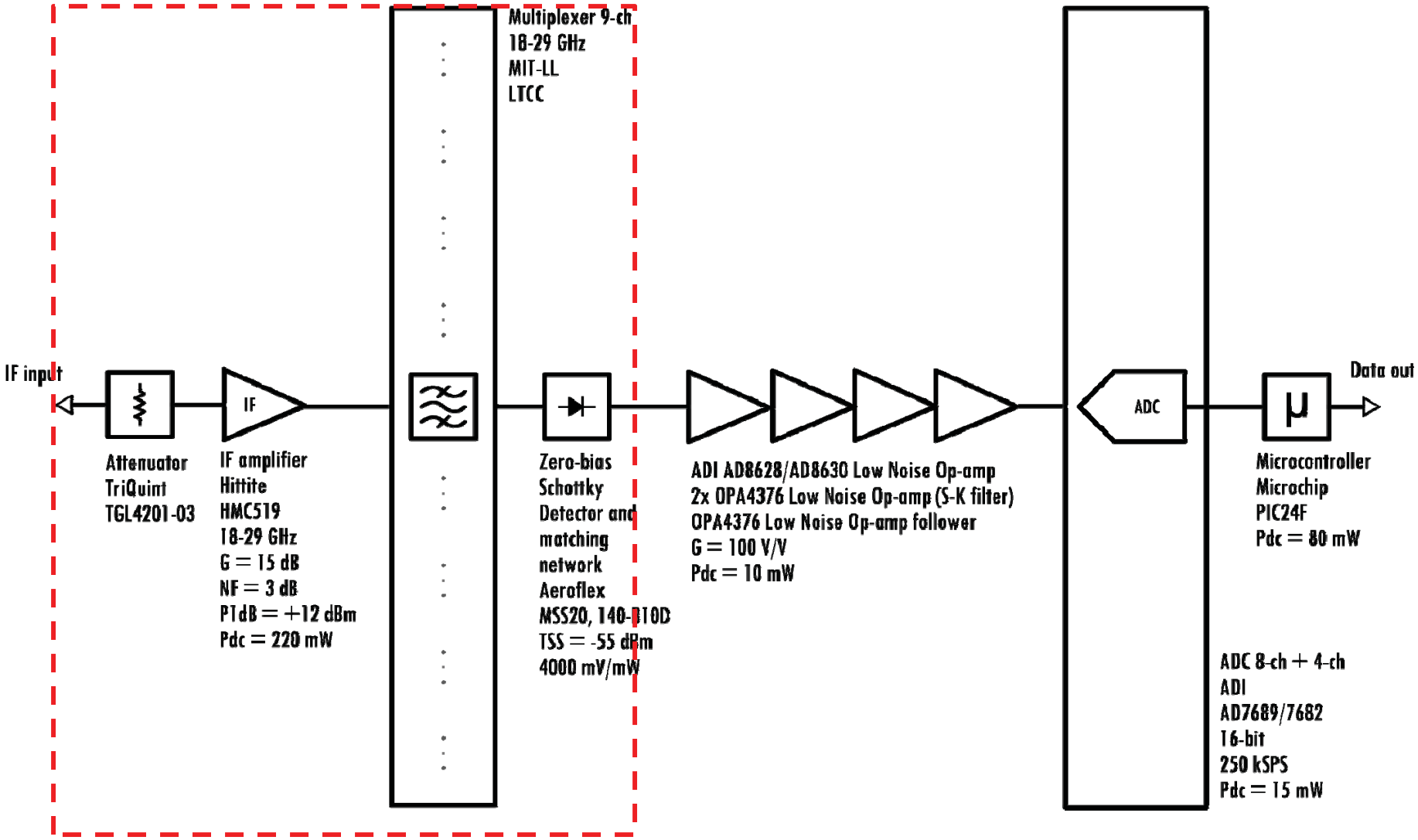
IF Processor Requirements

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

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

9-ch IFP Prototype Block Diagram



The Hybrid Manifold Technique was a key breakthrough in the development of the IFP

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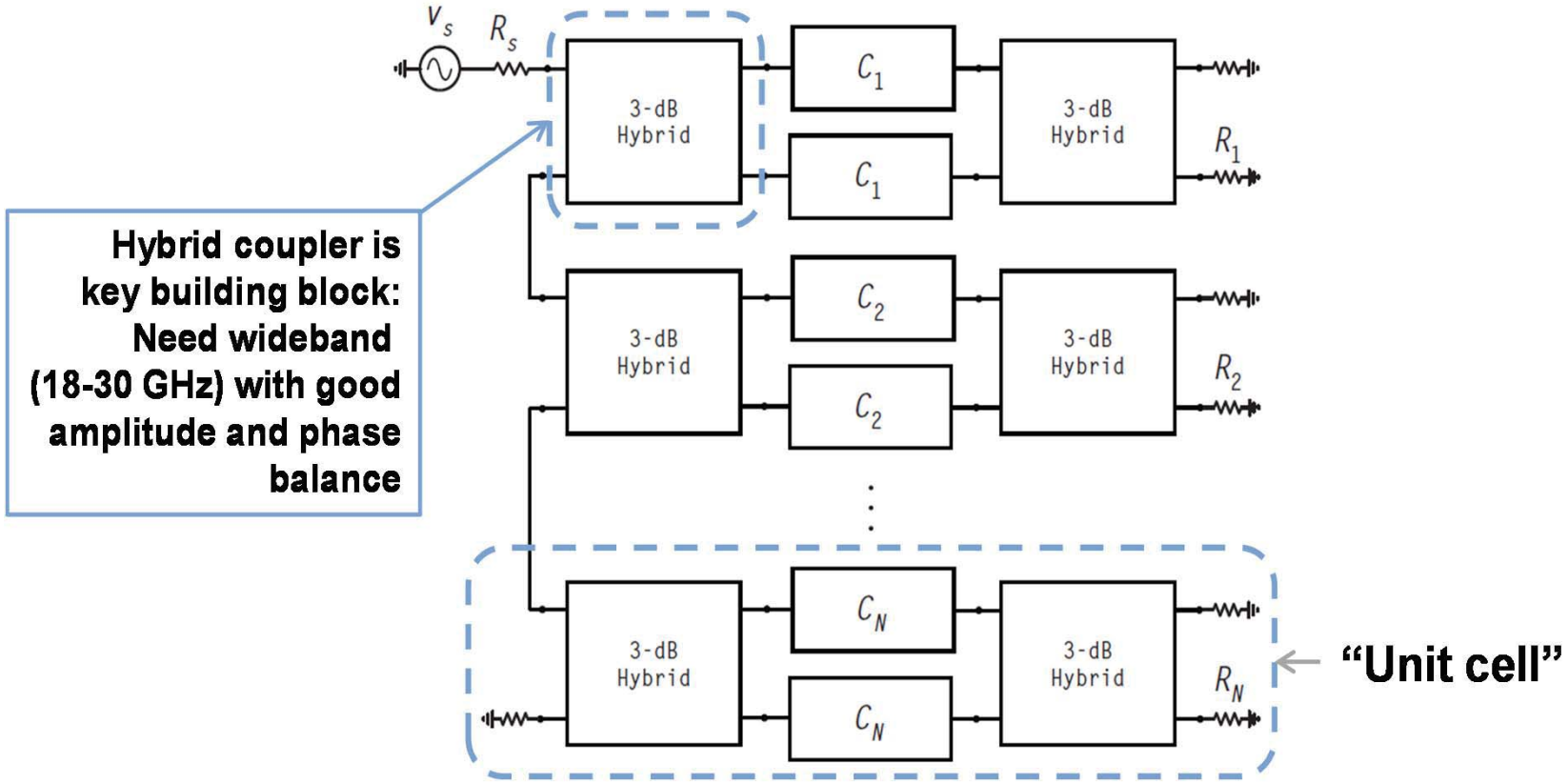

HyMAS IFP – Assembled "A" IF Module

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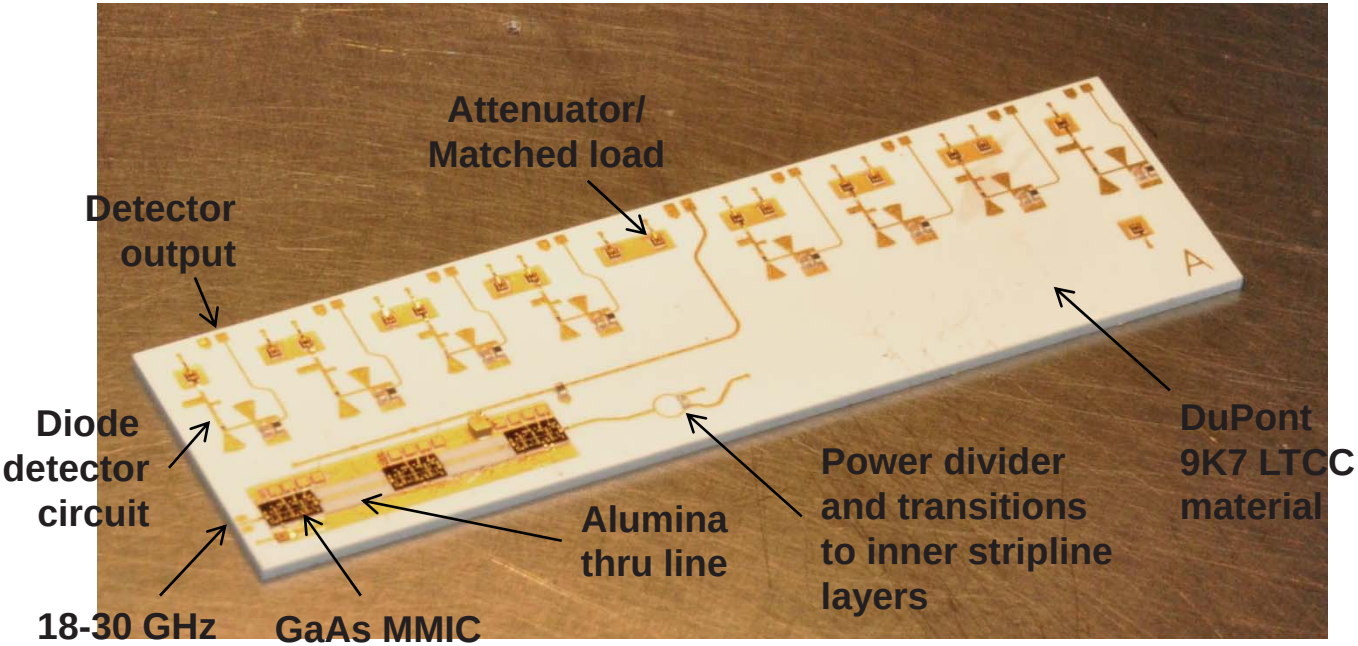
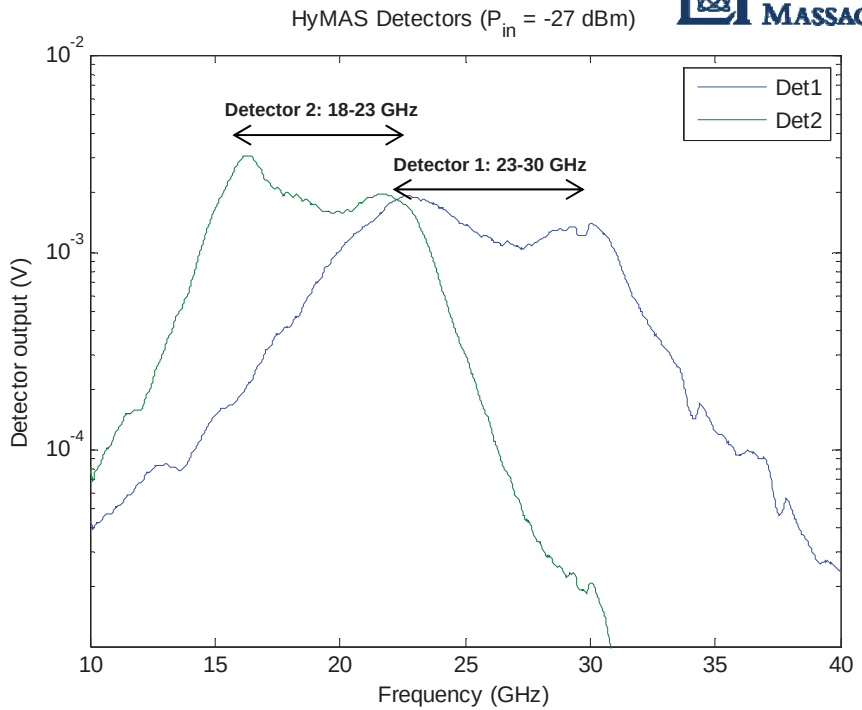


HyMAS Test Structure: Detectors Excellent Performance; No Tuning Required!!



- **Detectors working as expected**
  - **Sensitivity ~ 2 mV/uW**
- **Final modules will be built with additional 3 dB attenuation before detector to improve input return loss**

(Pspice) Circuit Model of a Manifold System

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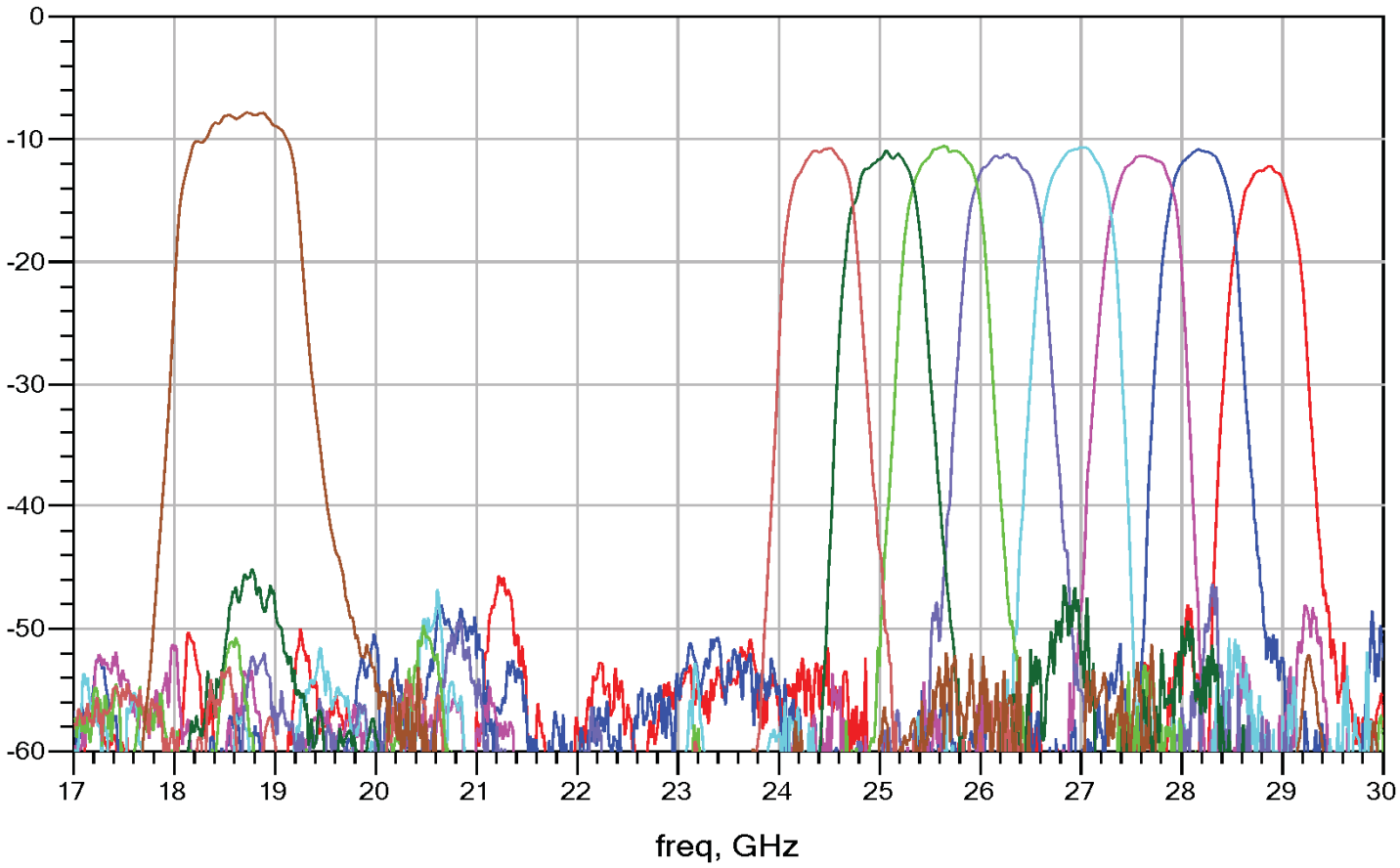

Electromagnetic Model (HFSS) of a 9 channel System

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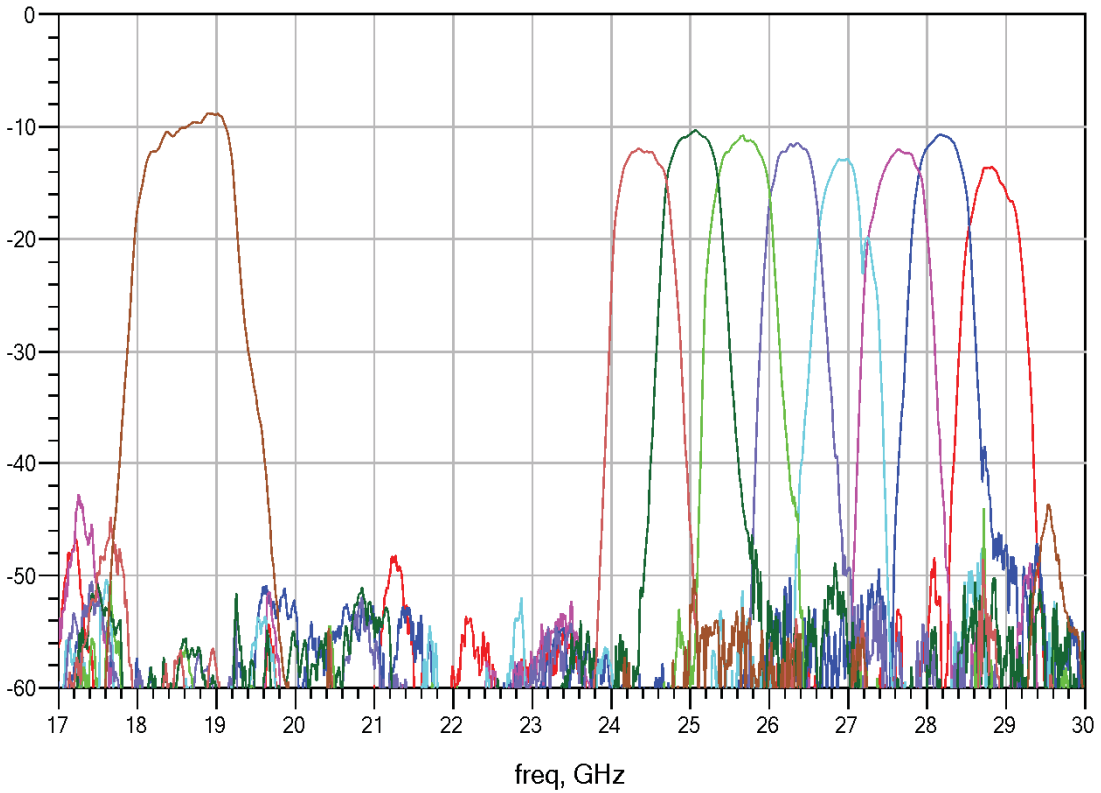

9-Ch IFP Prototype Measured Response

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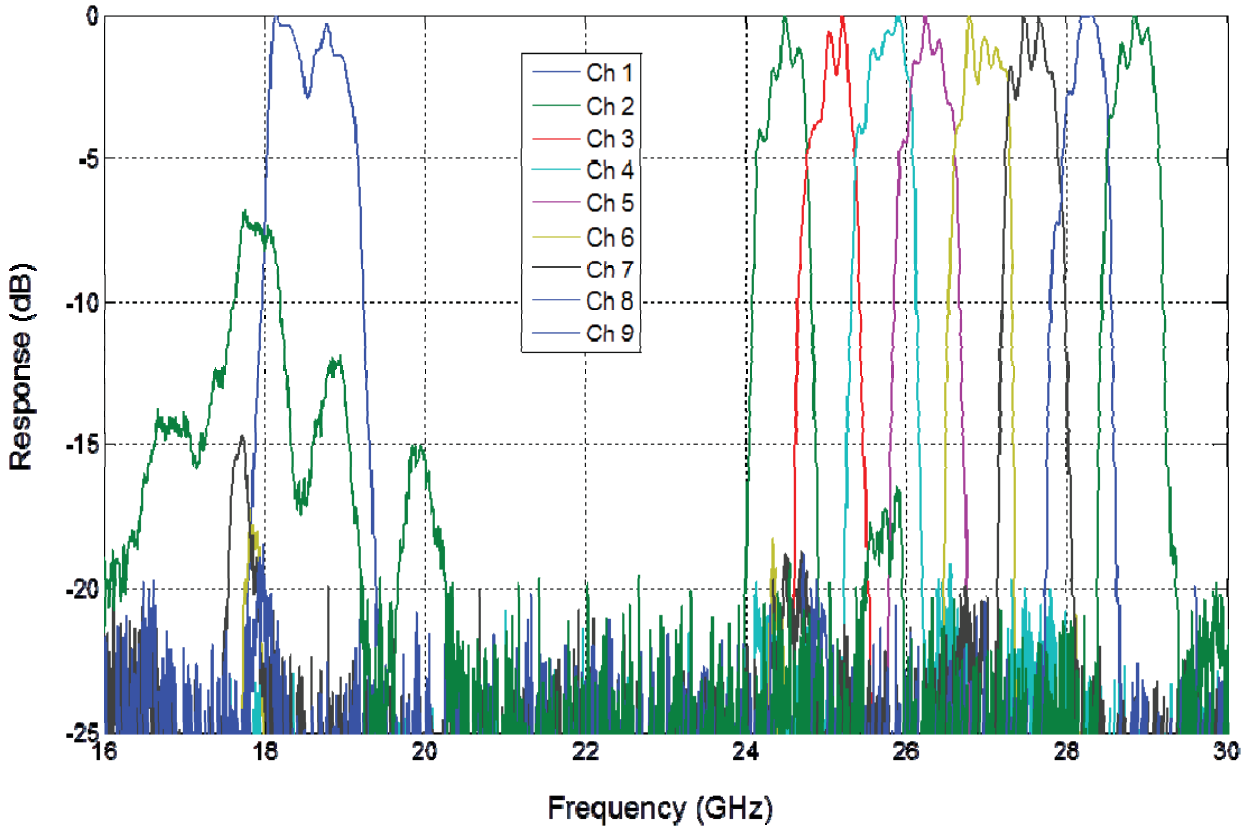

9-ch IFP Prototype Block Diagram

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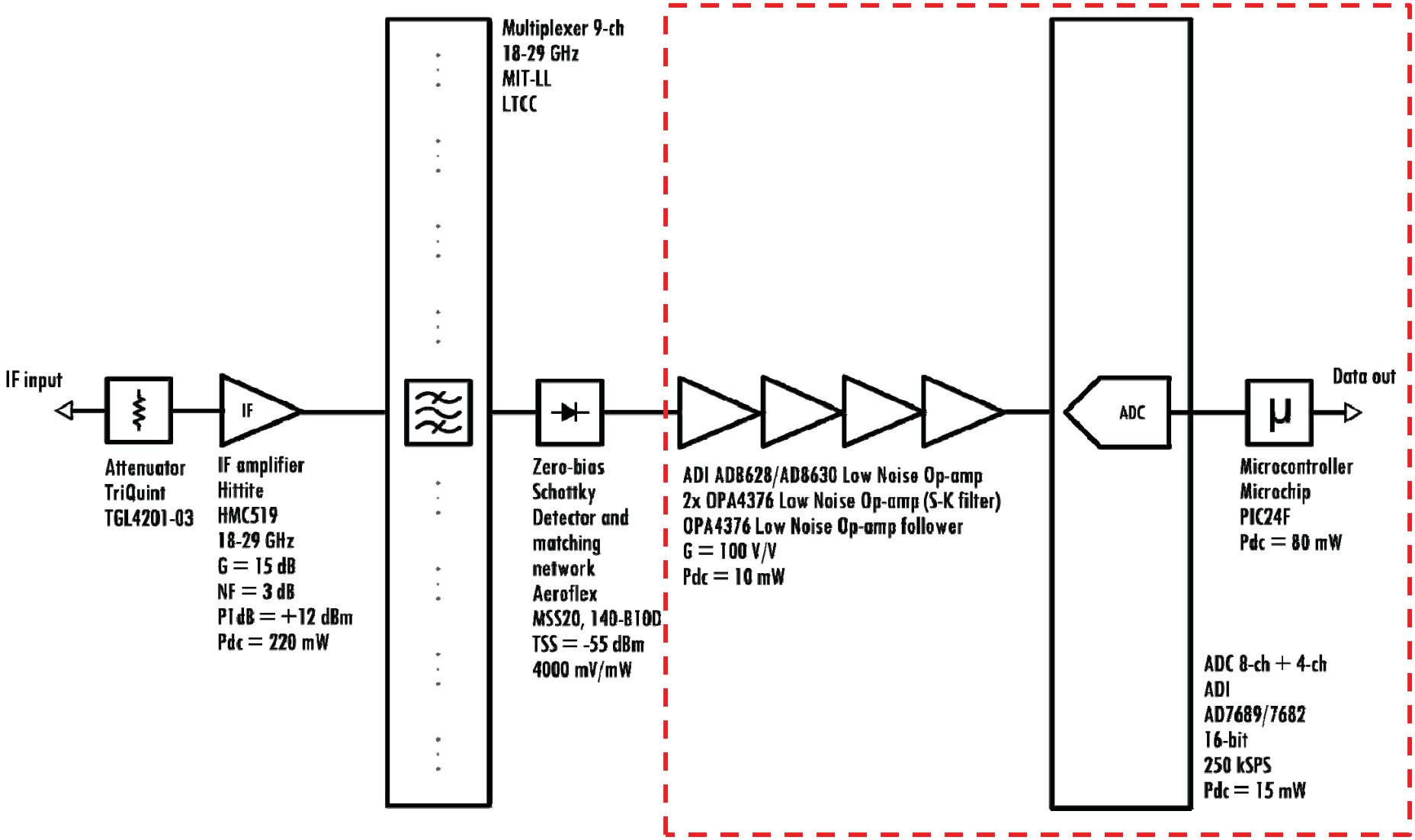

HyMAS IFP – Printed Circuit Board

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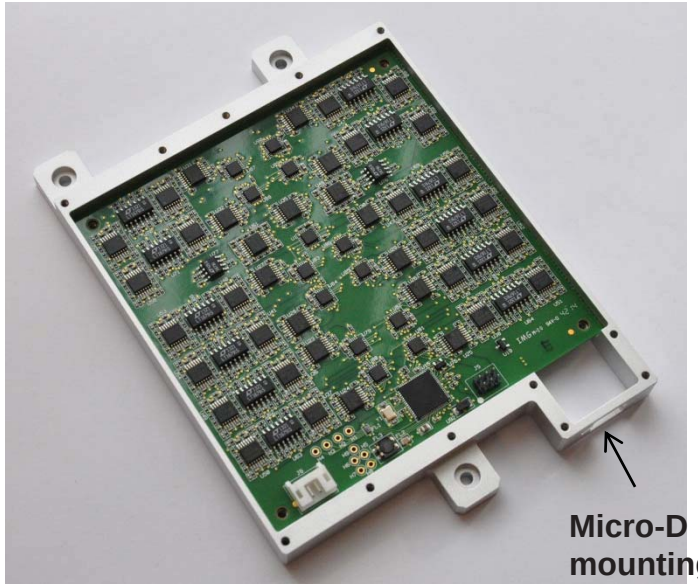
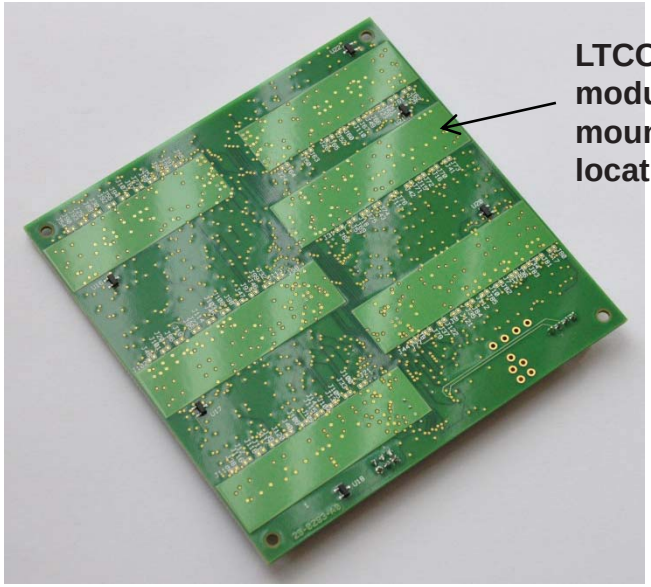
HyMAS IFP PCB in Enclosure (front)



HyMAS IFP PCB (back)



- **DC and basic functionality tests completed**
- **Requires a few “green wire” modifications to correct board layout connections, but no impact on performance**

HyMAS IFP – Enclosure and Lid Shipped to NASA GSFC for fit check

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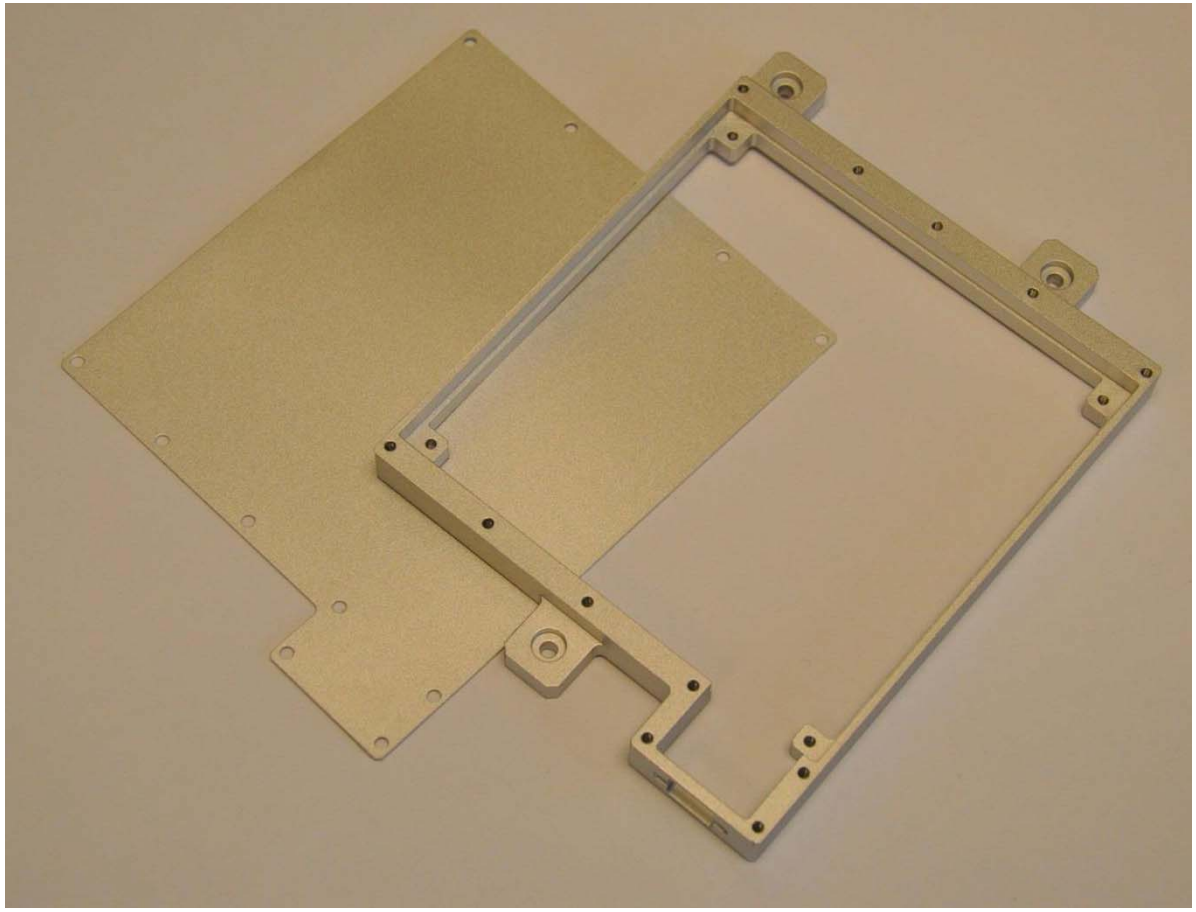

Mechanical Design

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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

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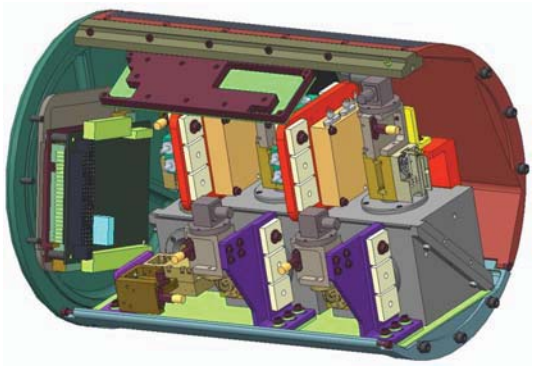
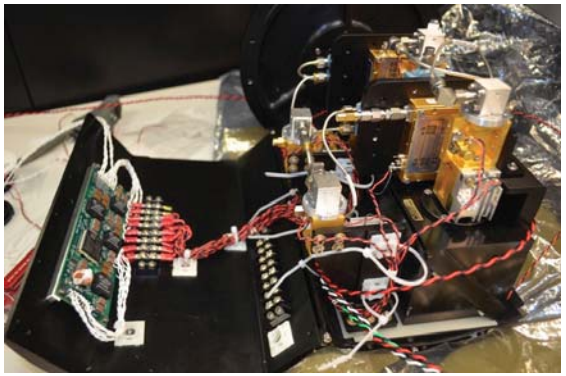
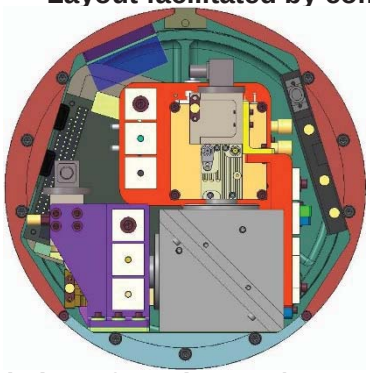
HyMAS Scanhead Mechanical Integration



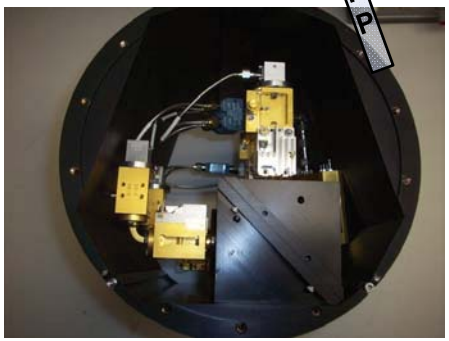
Layout facilitated by computer aided design



Partial assembly of HyMAS electronics



End-view of receivers w/ brackets to support waveguide

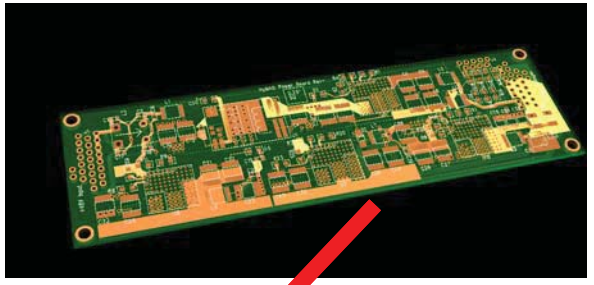


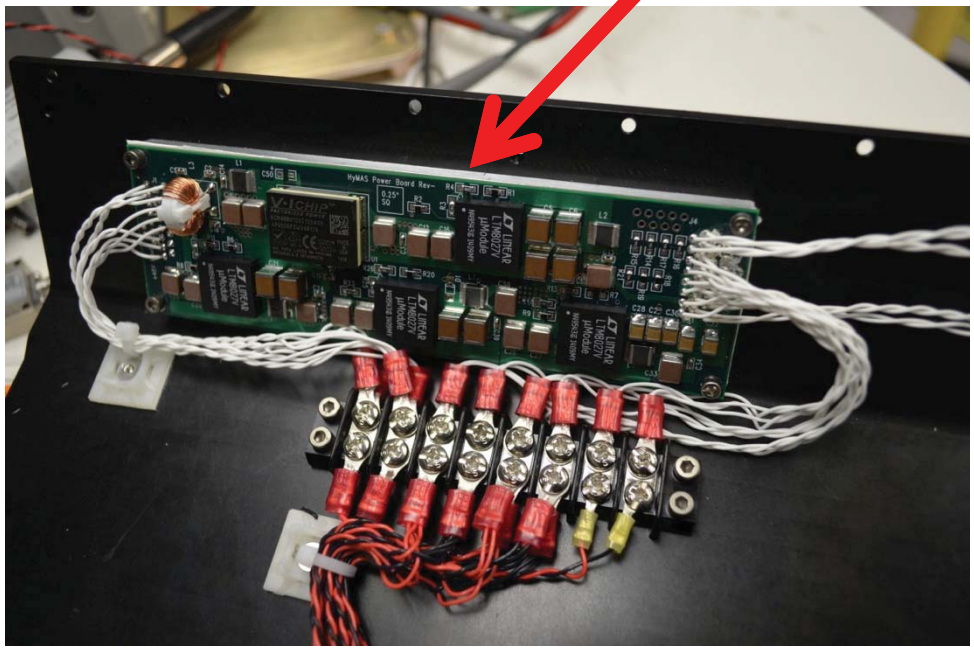
Antennas and receivers fit within drum envelope

HyMAS Scanhead Assembly

Power Board

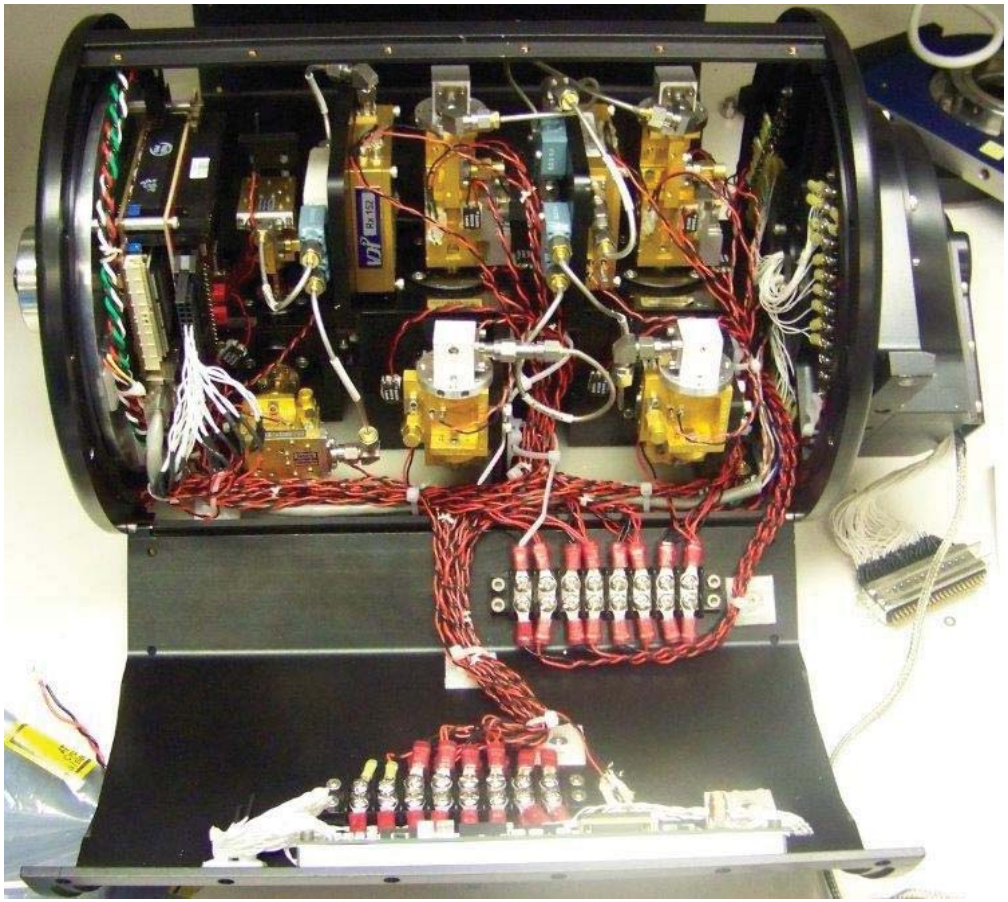
- Custom PCB Layout
- Input 48 VDC
- Output
  - +8 V @ 2.3A
  - +3 V @ 1.1A
  - 3.3 V @ 1.9A
  - +/- 12 V (future use)
- Computer power
  - 5 V @ 1.75 A
- Heater power
  - 48 V @ 8 A





Power board is integrated and tested with receivers

HyMAS Scanhead
Outside and Inside



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
- Custom Power regulation board
- PC104 stack including Ocelot CPU with Serial Peripheral Interface (SPI) to IFP and Sensoray 8-channel temperature sensor board
- Thermal control system (distributed)

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

The PIC24 processor puts 52 channels in a serial stream

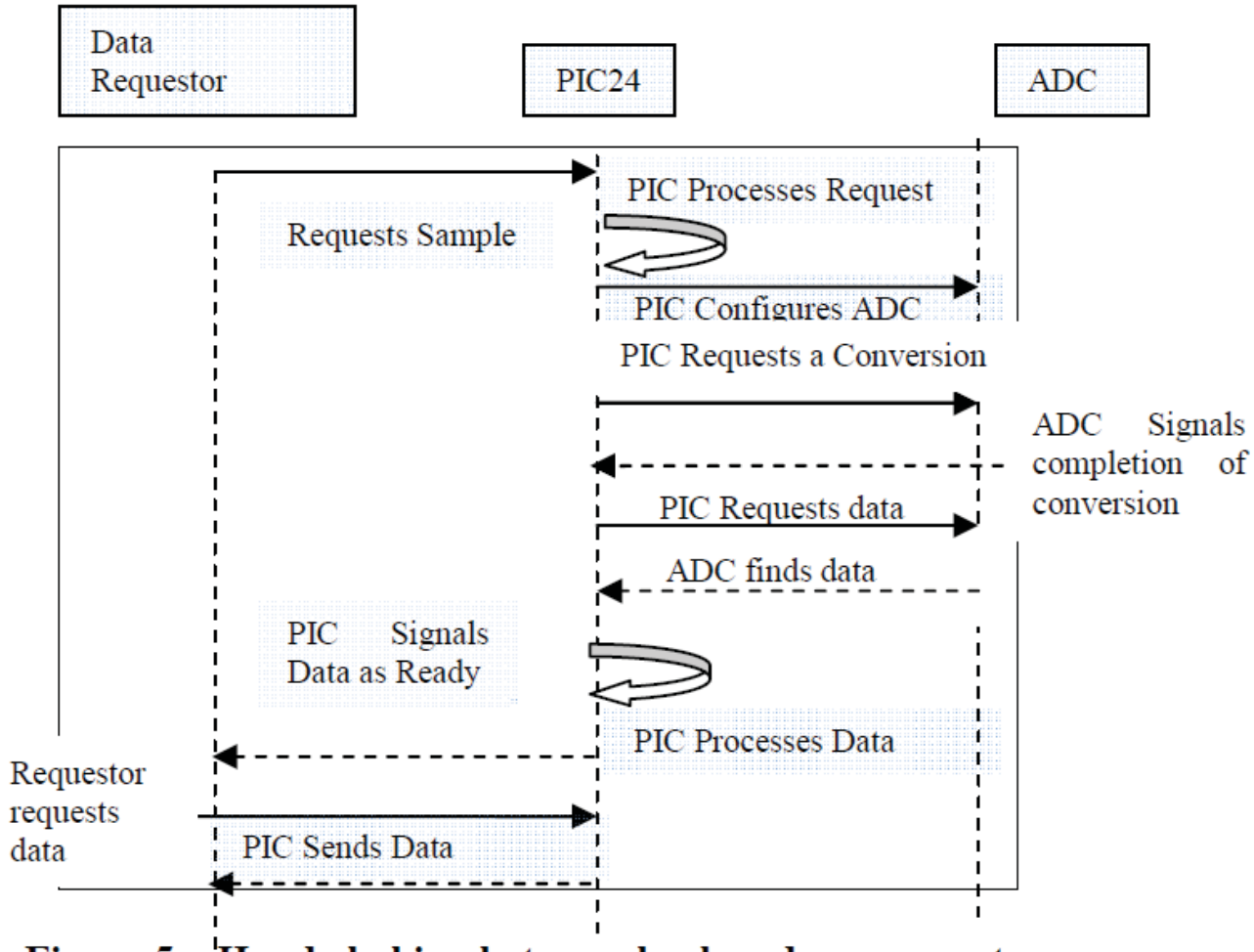
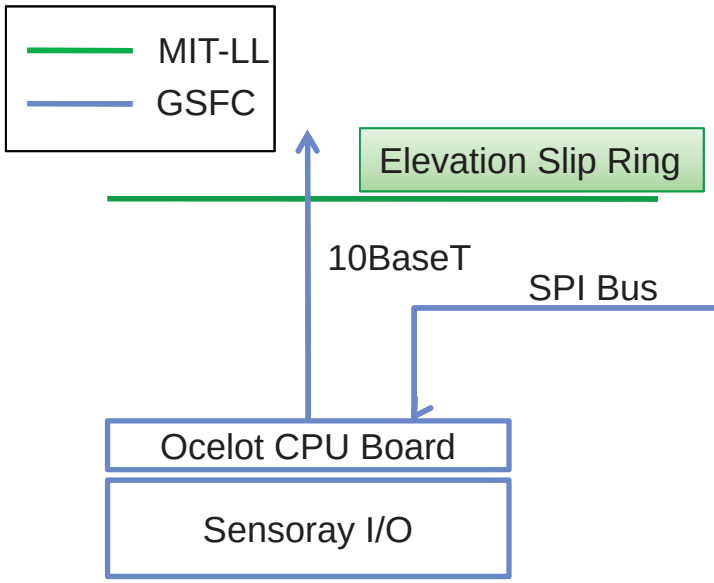


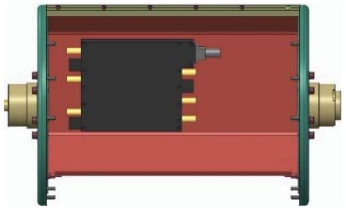
Figure 5c: Hand-shaking between back end components

HyMAS Scanhead Computer Configuration

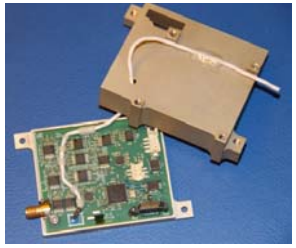


•52 channels radiometer data and 12 channels housekeeping will be transferred through SPI interface. Handshaking will initiate transfer every 10 milliseconds data to scanhead.

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



Final IFP footprint

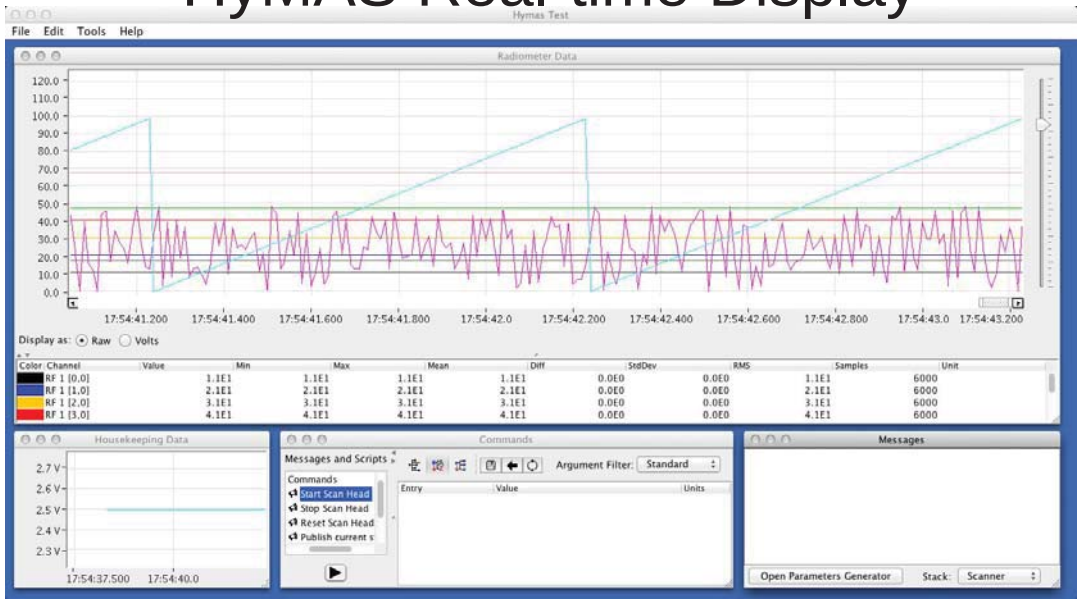


Surrogate IFP

HyMAS Data Acquisition

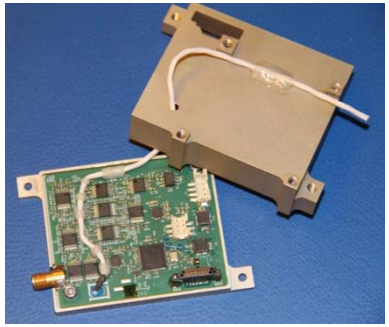
- "Surrogate IFP" used to develop communications and electrical interfaces with HyMAS electronics
- Maximum sampling rate from IFP is ~180 data frames per second
  - 52 Radiometer channels
  - 12 Housekeeping
- Time stamp of data using network time protocol (NTP) implemented on CoSMIR – applicable to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



Outline

- Overview
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- **Summary and Next Steps**

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

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Back up

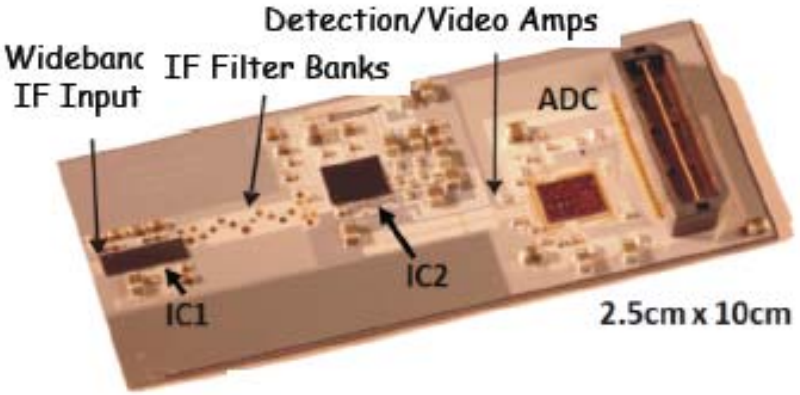
Charts

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

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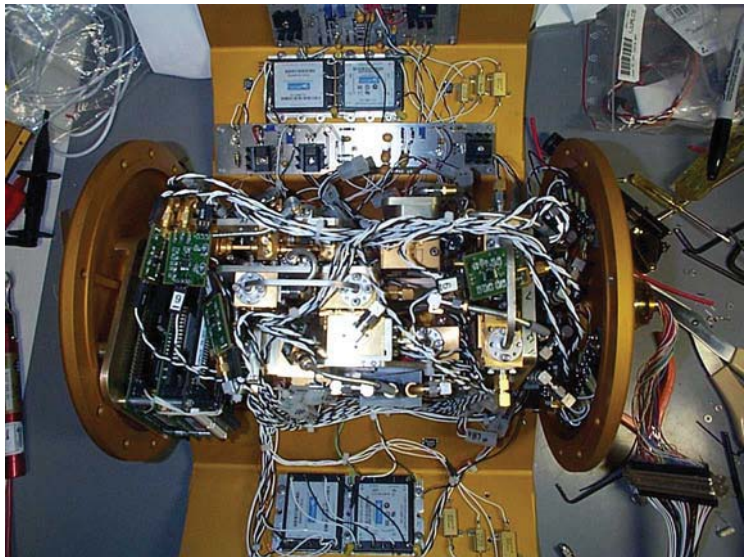
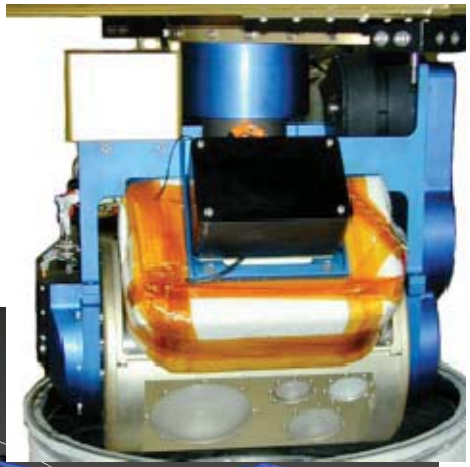
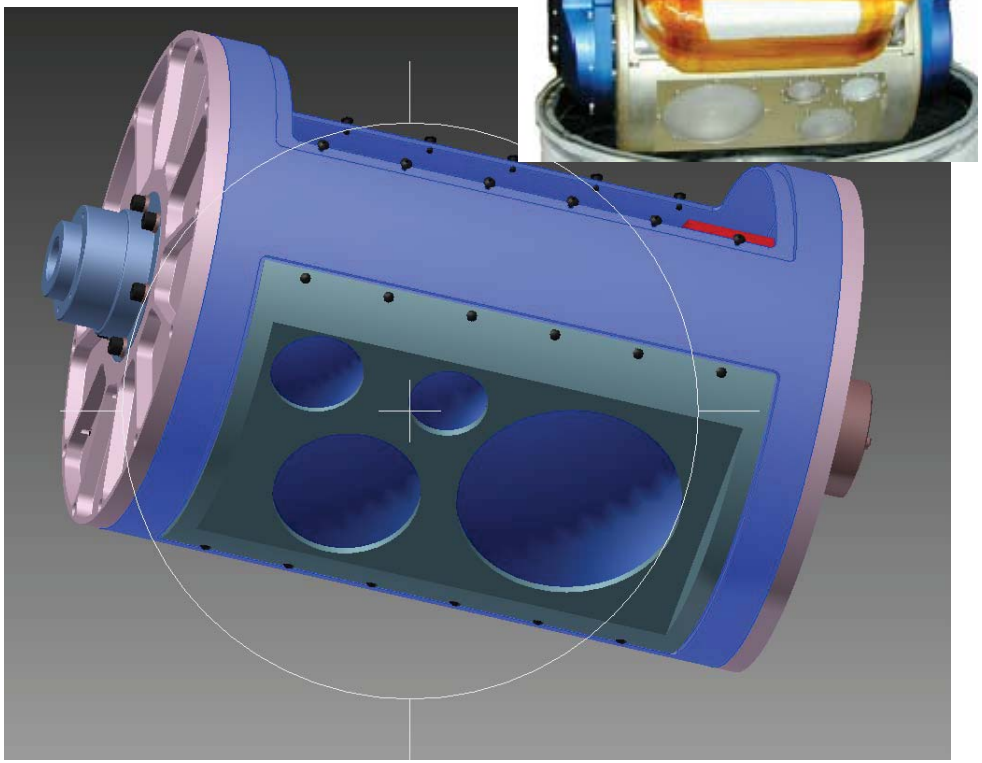


←- Integrate the inside



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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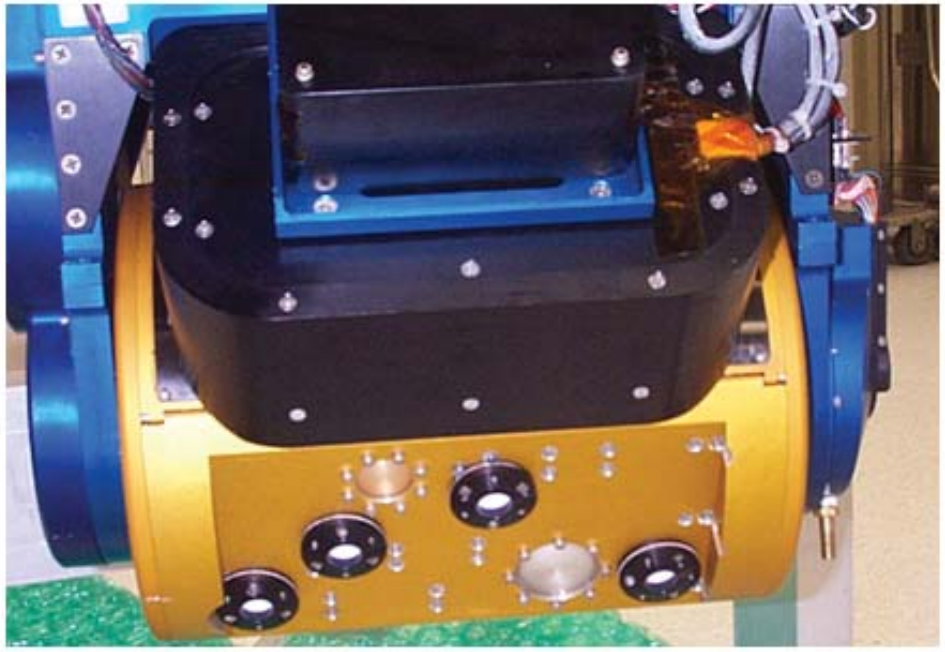

The scan head provides calibration and control infrastructure and rotates in azimuth and elevation. CoSSIR is shown in the photo at left.

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