Technology Development for a Hyperspectral Microwave Atmospheric Sounder (HyMAS)

W. Blackwell, C. Galbraith, L. Hilliard (NASA GSFC), P. Racette (NASA GSFC), and E. Thompson

ESTF

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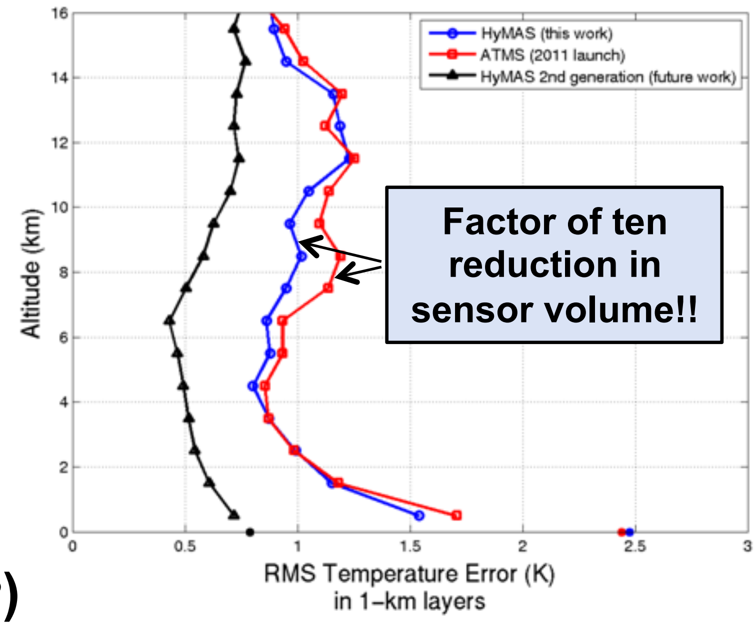
Outline

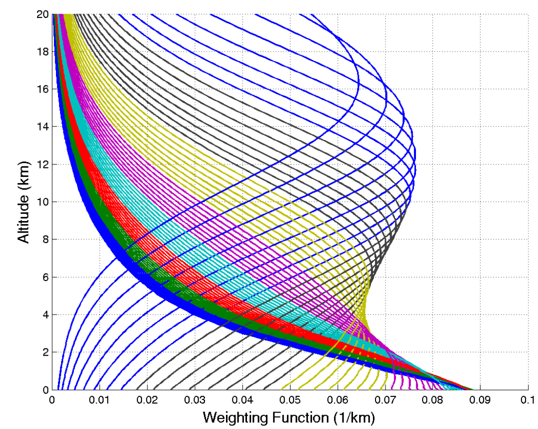
- HyMAS: Motivation and Overview
- Intermediate Frequency Processor (IFP)
- Receiver Front-End Electronics
- Airborne Instrument Accommodations
- Current and Future Work

Project Summary and Key Objectives

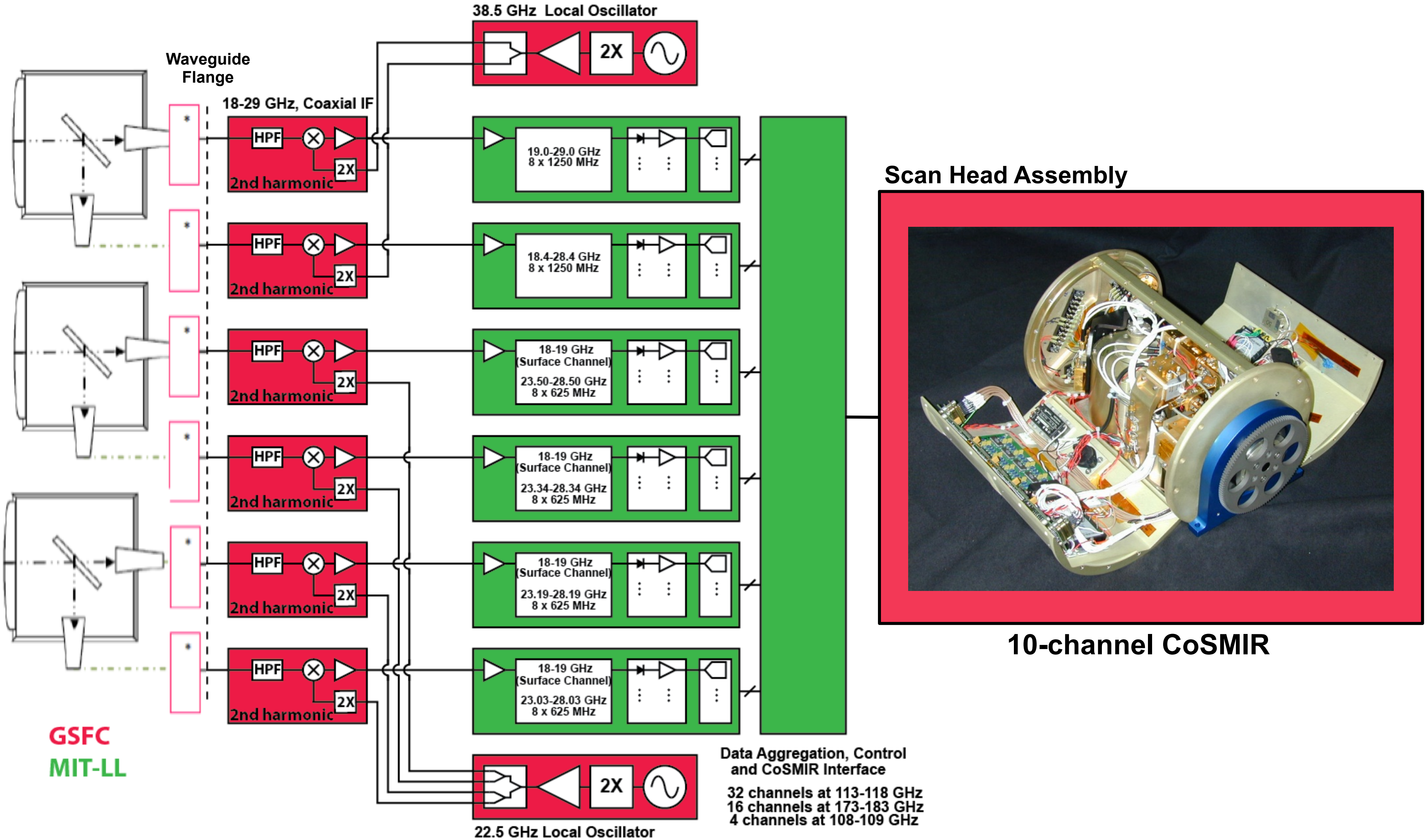
- **Hyperspectral microwave (HM) sounding has been proposed to achieve unprecedented performance**
- **HM operation is achieved using multiple banks of RF spectrometers with large aggregate bandwidth**
- **A principal challenge is Size/Weight/ Power scaling**
- **Objectives of this work:**
  - **Demonstrate 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



HyMAS Technology Infusion Examples

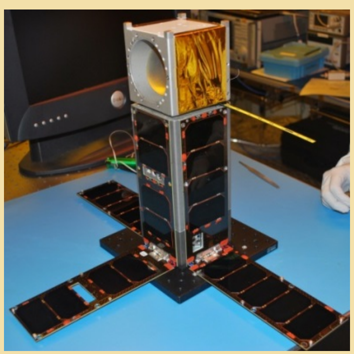
IFP enables ultracompact, high-performance radiometry

MicroMAS-2

3U cubesat scanning radiometer with channels near 90, 118, 183, and 206 GHz

12 channels for moisture and temperature profiling and precipitation imaging

Two launches in 2016

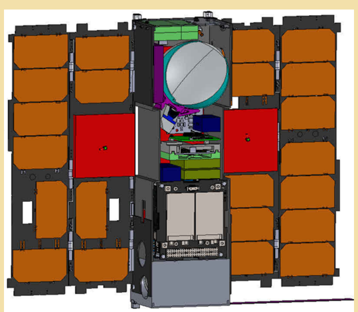


MiRaTA

3U cubesat with 60, 183, and 206 GHz radiometers and GPS radio occultation

10 channels for temperature, moisture, and cloud ice measurements

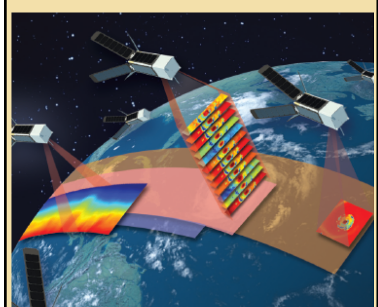
2016 launch expected



TROPICS

Constellation of high-performance cubesats for high-revisit observations of severe storms

Provides most of PATH objectives for a small fraction of the cost

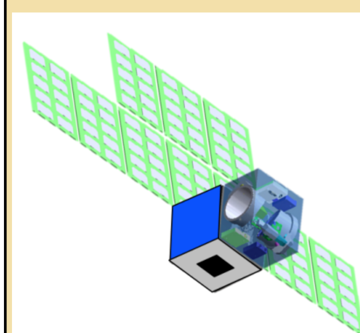


EON

12U cubesat scanning radiometer with channels near 23, 31, 60, 90, 165, & 183 GHz

Meets most ATMS Level 1B requirements

Includes MicroMAS & MiRaTA innovations with larger aperture



NAST-M

Radiometer upgrade funded by NOAA to include IFP back end

Substantial performance improvement at > 10X SWaP reduction

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IFP – Overview

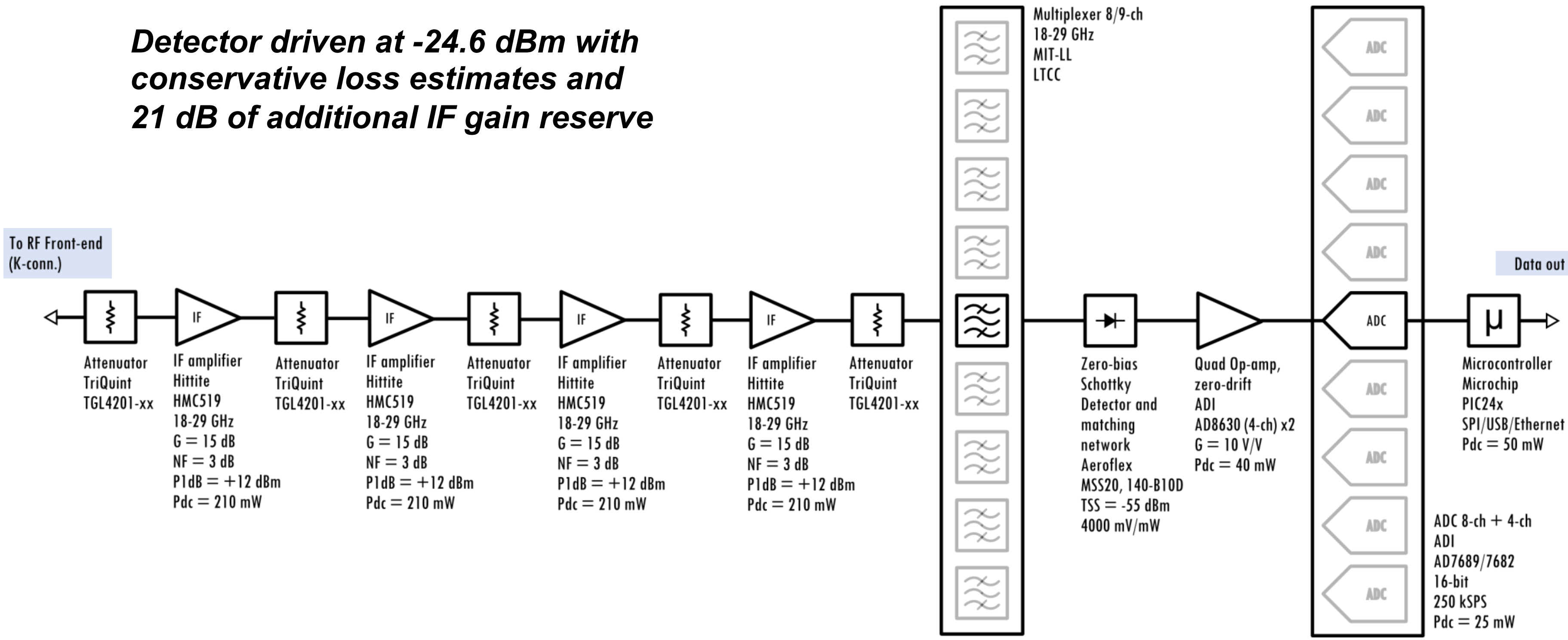
- IF processor functions
  - Amplify, channelize and detect 18-29 GHz IF bands (52 channels)
  - Post-detection filtering, A/D conversion, data processing
- Scalable in number of channels, processing capability
- LTCC microwave filters for high performance, small size
  - Assess state of technology for 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 cm^3) 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

	Antenna	Feed	W/G	Filter	LNA	Mixer	IF amp 1	Coax	Att 1	IF amp 2	Att 2	IF amp 3	Att 3	IF amp 4	Att 4	IF amp 5	Att 5	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	1.10E+10	1.10E+10	1.25E+09
Tb (K)	300																	
G (dB)		-0.2	-0.5	-1	15	-6	30	-2	0	15	0	15	-6	15	0	0	0	-16
P (W)	1.24E-10	1.19E-10	1.06E-10	3.08E-11	9.74E-10	2.45E-10	2.45E-07	1.54E-07	1.54E-07	4.88E-06	4.88E-06	1.54E-04	3.88E-05	1.23E-03	1.23E-03	1.23E-03	1.23E-03	3.50E-06
P (dBm)	-69.1	-69.3	-69.8	-75.1	-60.1	-66.1	-36.1	-38.1	-38.1	-23.1	-23.1	-8.1	-14.1	0.9	0.9	0.9	0.9	-24.6
Te (K)	3.00E+02	2.86E+02	2.55E+02	2.03E+02	6.41E+03	1.61E+03	1.61E+06	1.02E+06	1.02E+06	3.21E+07	3.21E+07	1.02E+09	2.55E+08	8.07E+09	8.07E+09	8.07E+09	8.07E+09	2.03E+08

Detector driven at -24.6 dBm with conservative loss estimates and 21 dB of additional IF gain reserve



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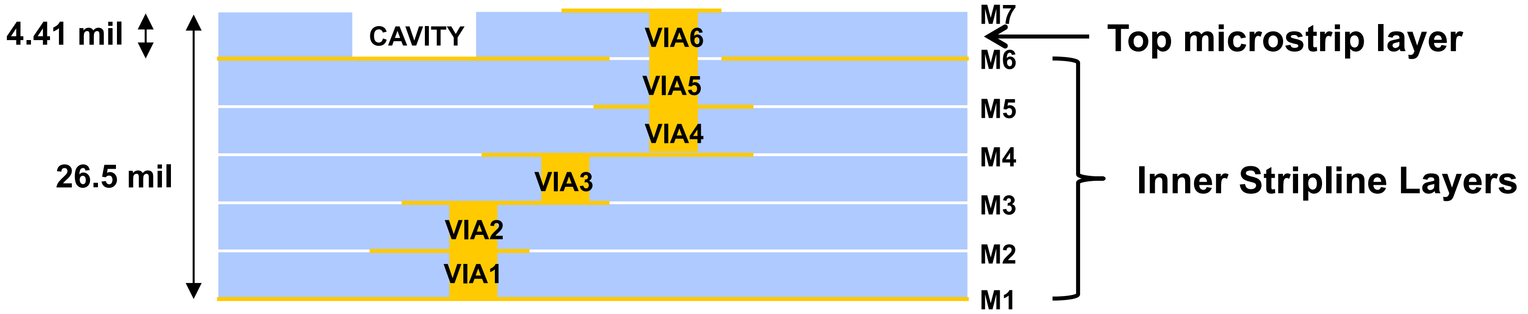
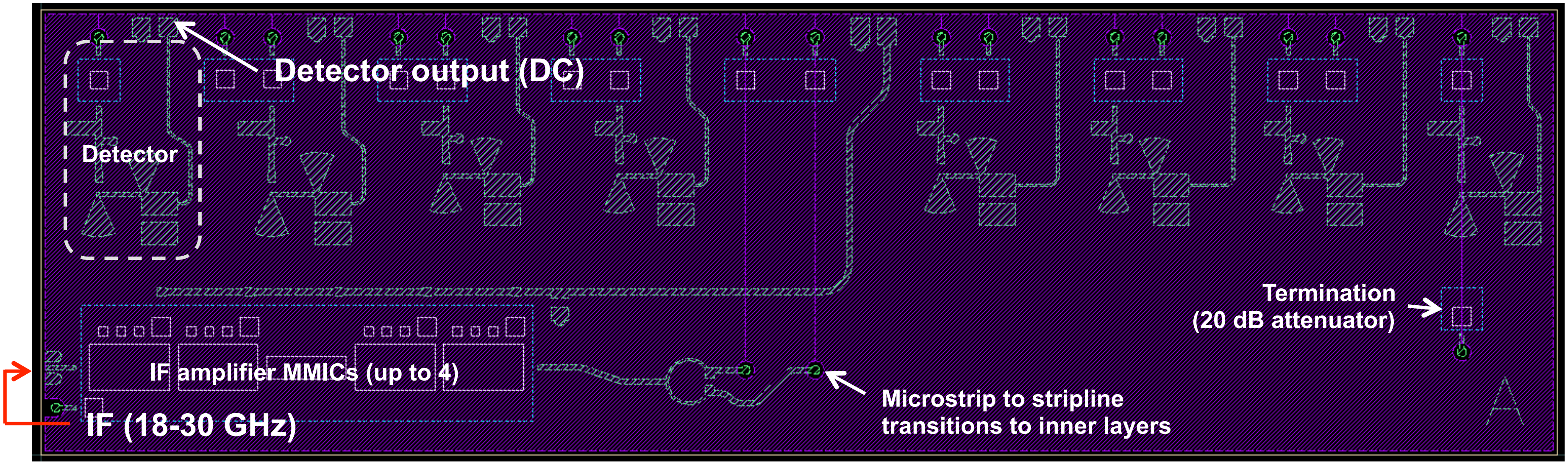
IFP Status

- **IFP Rev A successfully integrated and tested by NASA GSFC**
  - Partial RF functionality: subset of 52 channels usable in radiometer testing and evaluation of signal levels
  - Full digital functionality for development and testing of control and data flow
  - ICDs and software documents updated
- **IFP Rev B redesign complete**
- **IFP Rev B in fabrication**
  - LTCC currently in fabrication, expected in June 2015
  - PCB (carrier board) in fabrication, also expected June 2015
  - Simulations on following slides

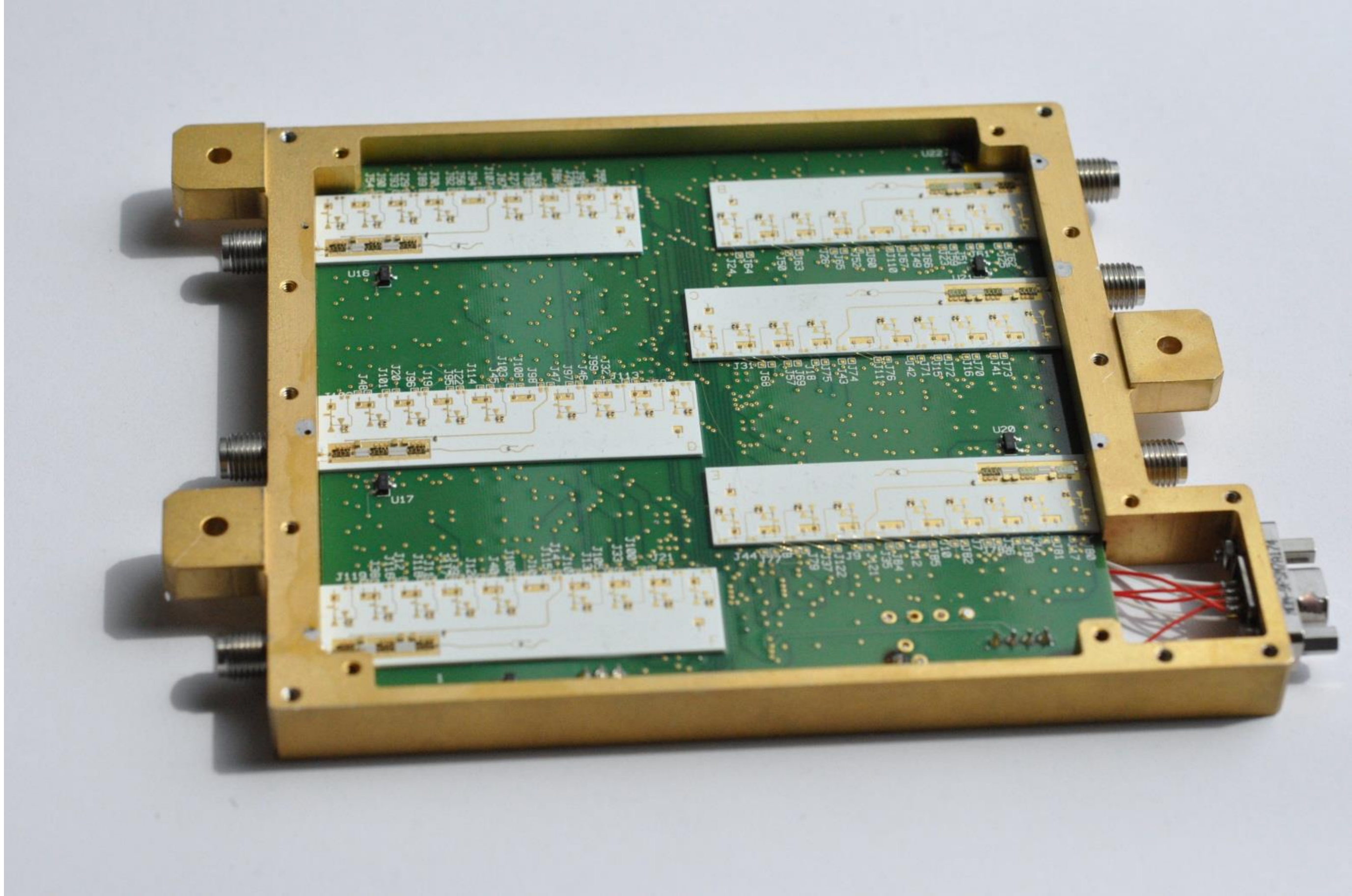
8/9-Channel LTCC IF Module Layout (top)



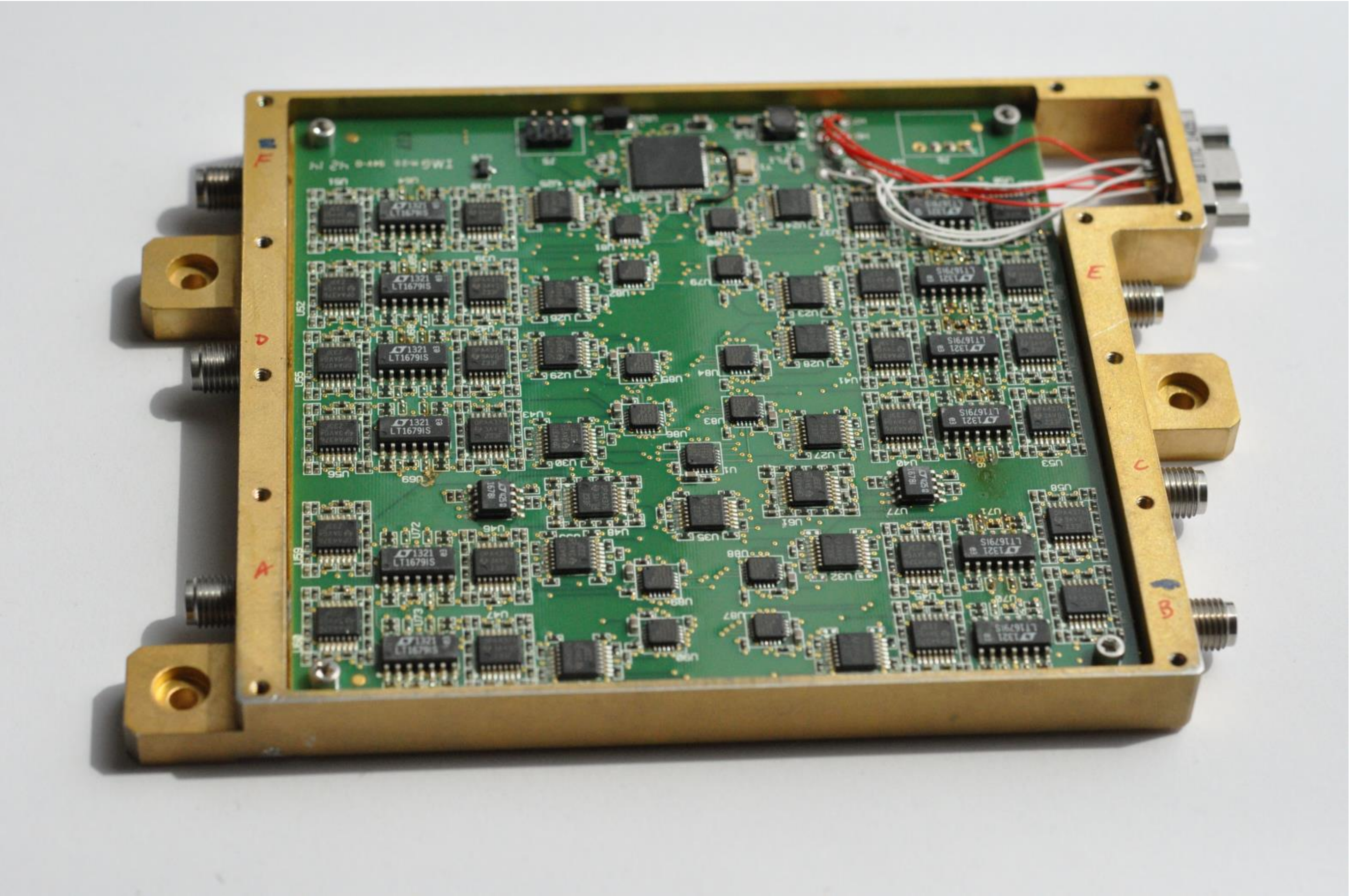


- **Modules (10 mm x 43 mm or 48 mm) contains all amplification, multiplexer filtering, and detection circuits for 8 or 9 channels**
- **Single 18-30 GHz input, (8) detector (DC) outputs**

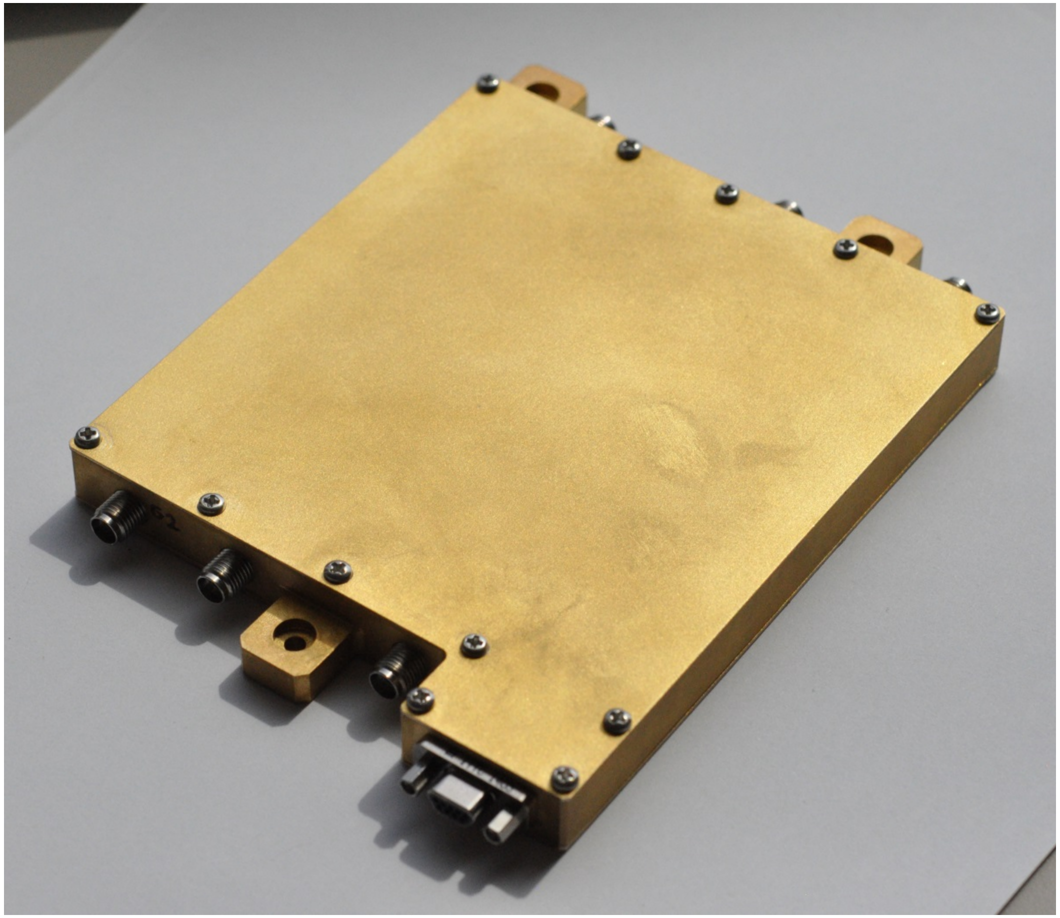
HyMAS IFP Rev A – RF LTCC/PCB



HyMAS IFP Rev A – Mixed Signal/PCB

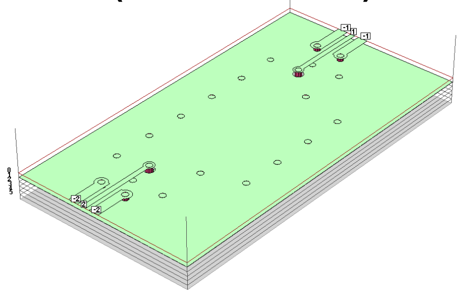


HyMAS IFP Rev A Assembly

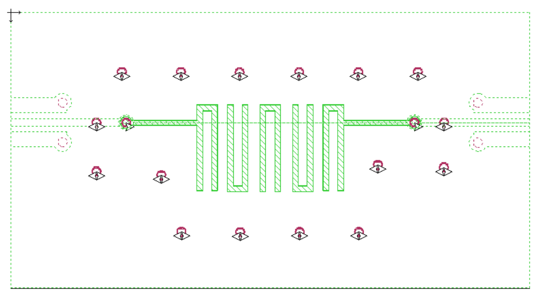


LTCC Design Optimization

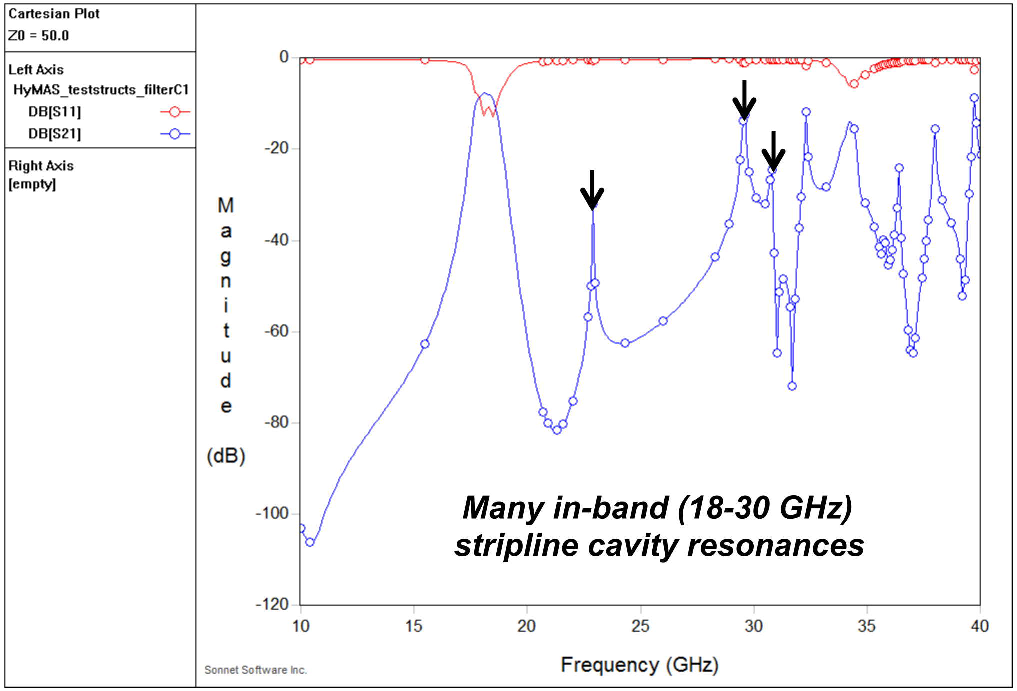
Filter Test Structure Sonnet Model (External view)



Interior Stripline Layer



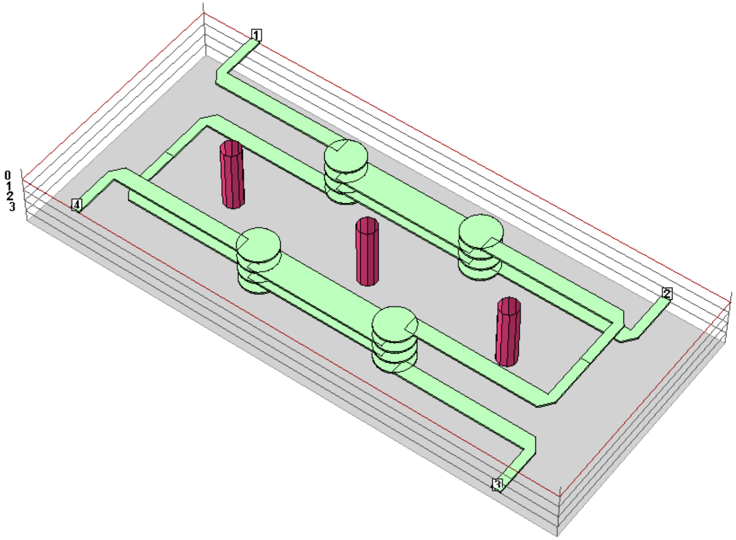
Simulated Filter Test Structure S-Parameters



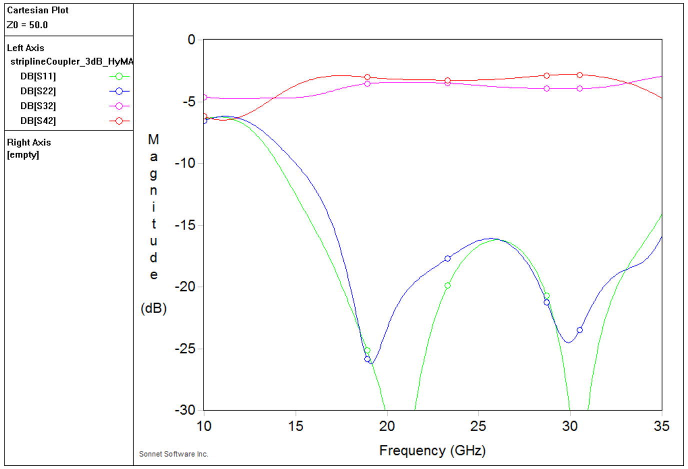
- Resonances seen in filter test structures measurements
  - Test structures were cut/pasted from multiplexer layouts
- Resonances were recreated in simulations, confirming hypothesis
  - Original simulations did not include vertical microstrip-stripline launch

RevA Coupler Design

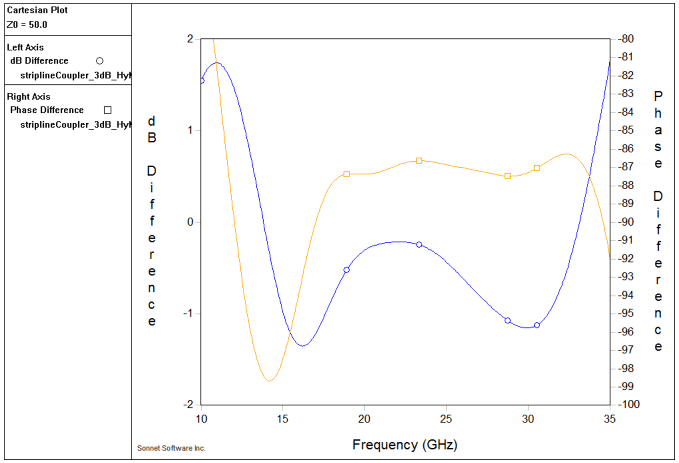
Coupler Sonnet Model



Coupler Simulated S-Parameters



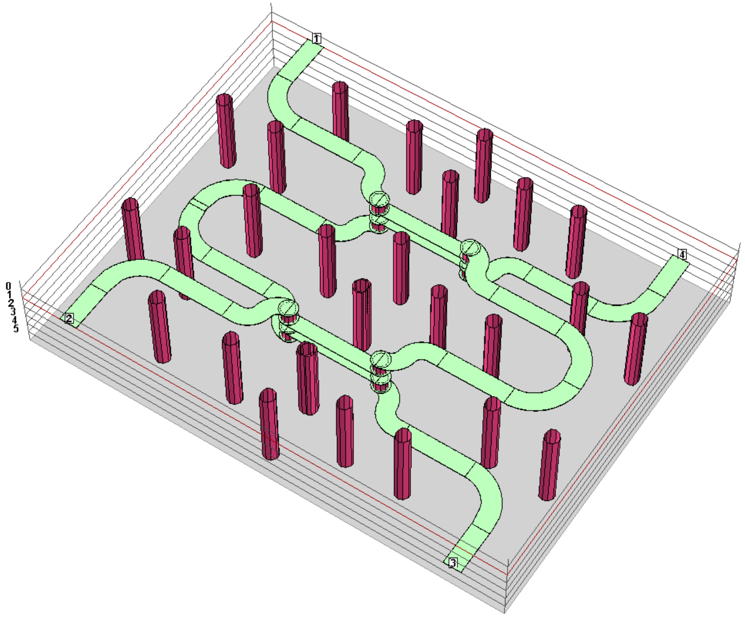
Coupler Simulated Amplitude/Phase Balance



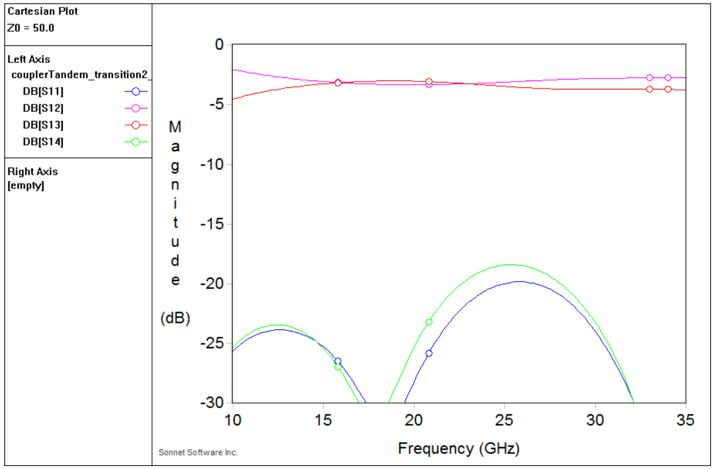
- **Old design had borderline acceptable response over 18-30 GHz bandwidth due to minimum via size (5.5 mil) limit**
  - **Some tuning required to compensate for transitions between layers**
  - **Very sensitive to fabrication tolerances**

RevB Coupler Design

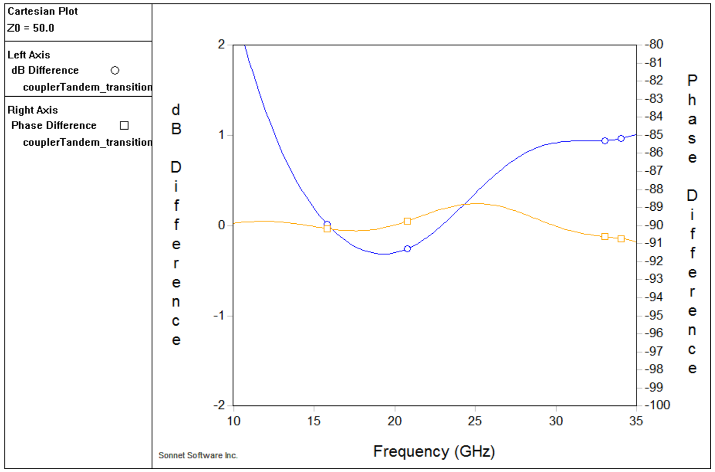
Coupler Sonnet Model



Coupler Simulated S-Parameters



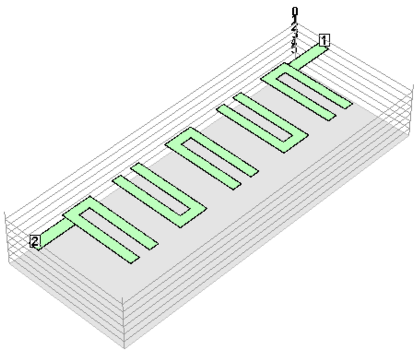
Coupler Simulated Amplitude/Phase Balance

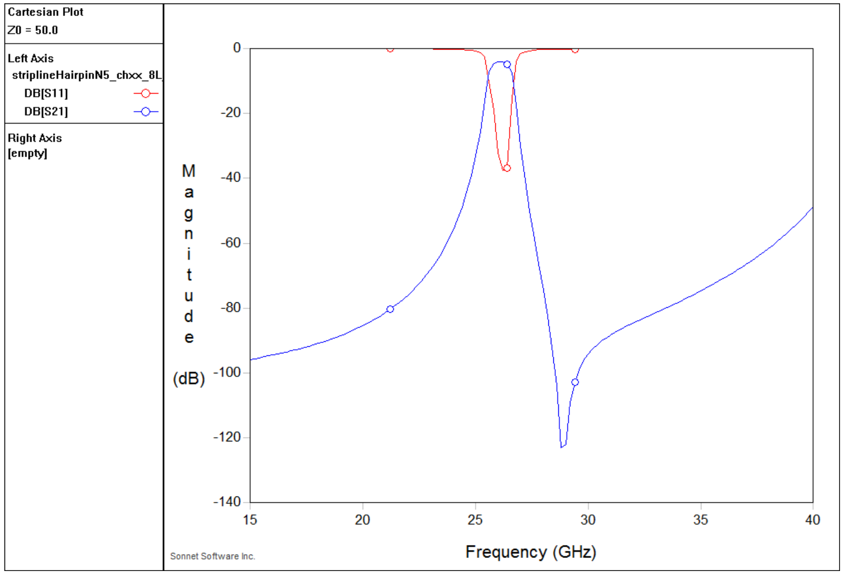


- **New minimum via size (4.5 mil) allows better stripline layer transitions, new design has much better response**
  - **Smooth response from 13 GHz to roughly 40 GHz**
  - **Less tolerance sensitive**

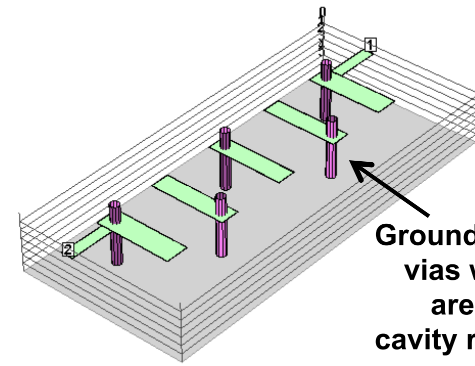
Hairpin vs. Interdigital Filters

RevA: Hairpin

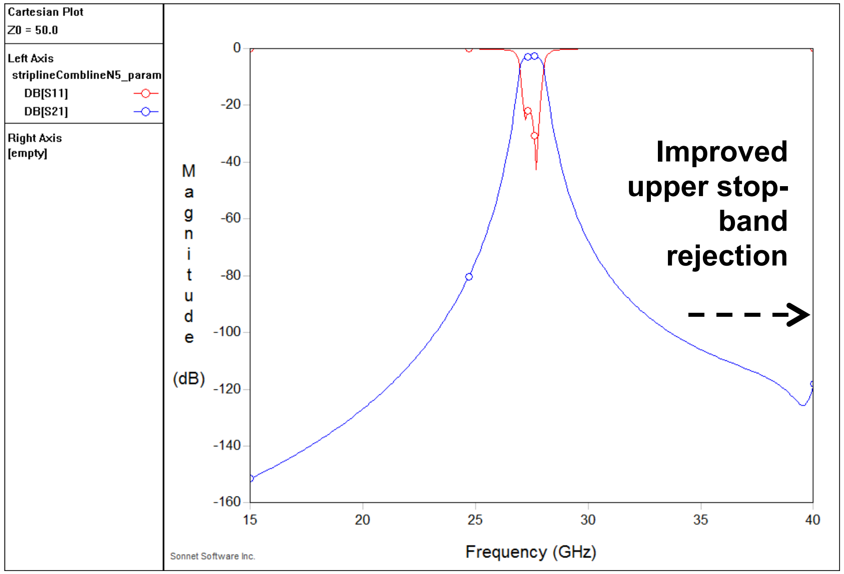




RevB: Inter-digital

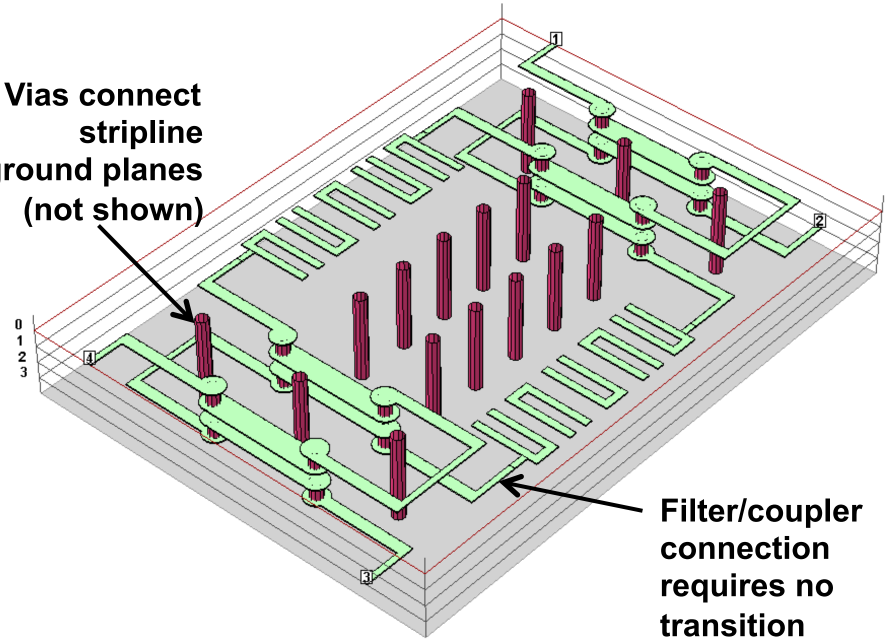


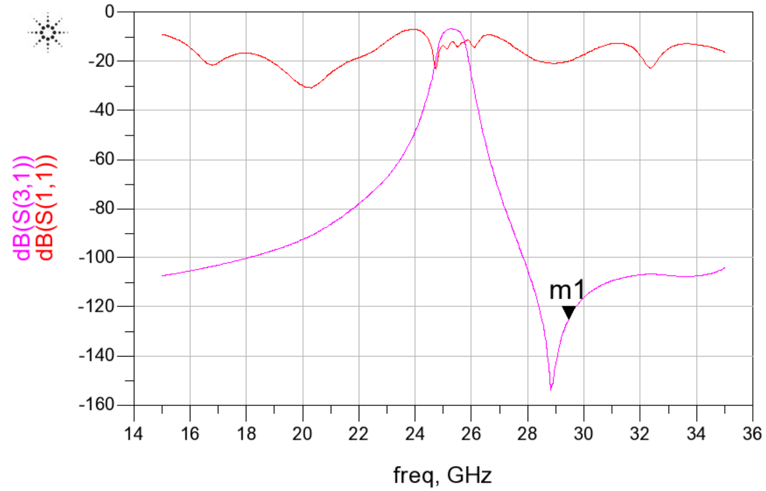
Ground-to-ground vias within filter area suppress cavity resonances



RevA Design Unit Cell

Coupler and Filter Sonnet Model and Simulated Response

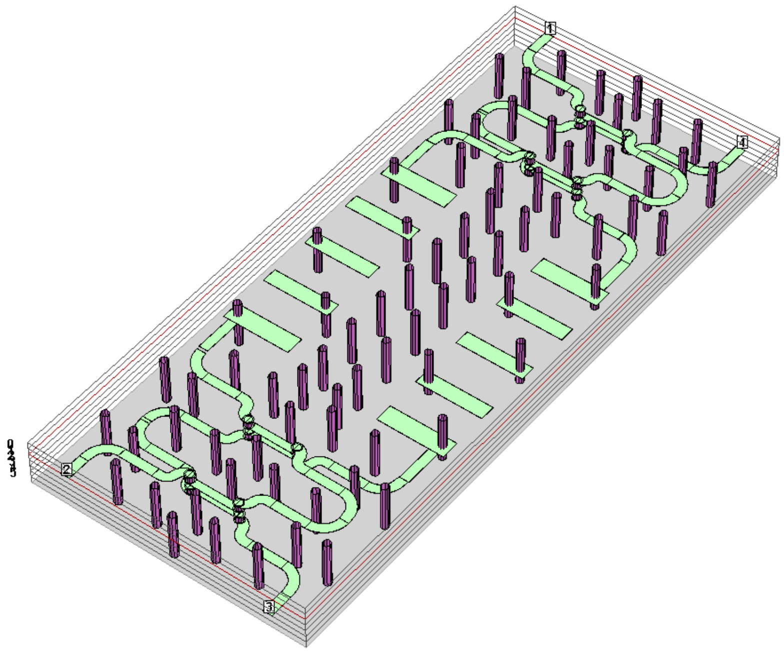


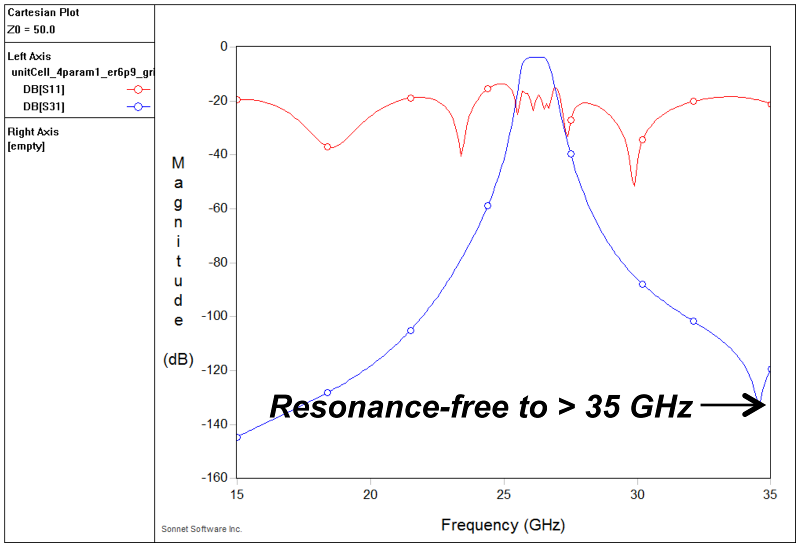


- Multiplexer is composed of a cascade of coupler-filter-coupler unit cells
- Return loss is limited by the coupler response

RevB Design Unit Cell Design

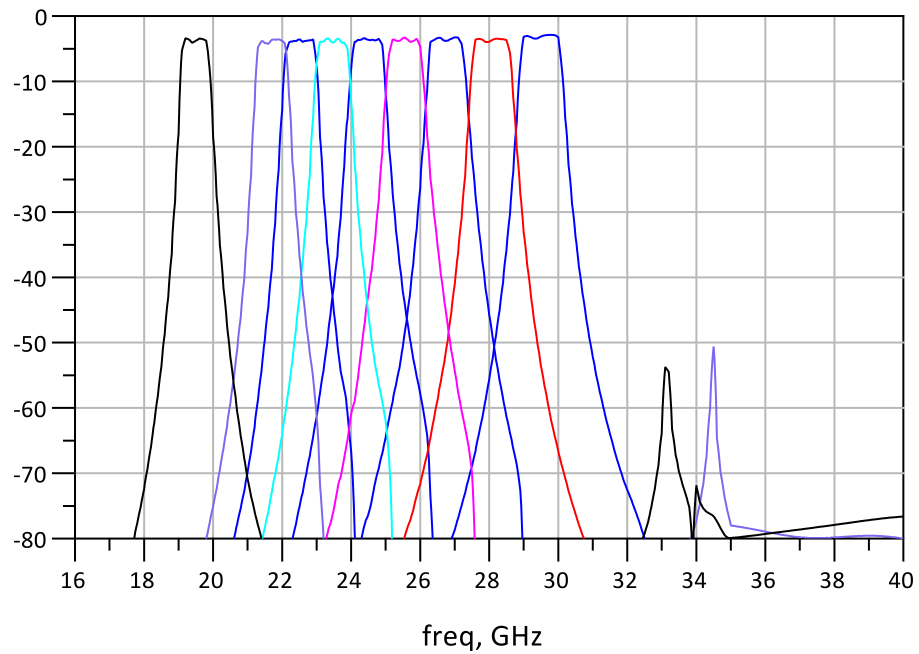
Coupler and Filter Sonnet Model and Simulated Response





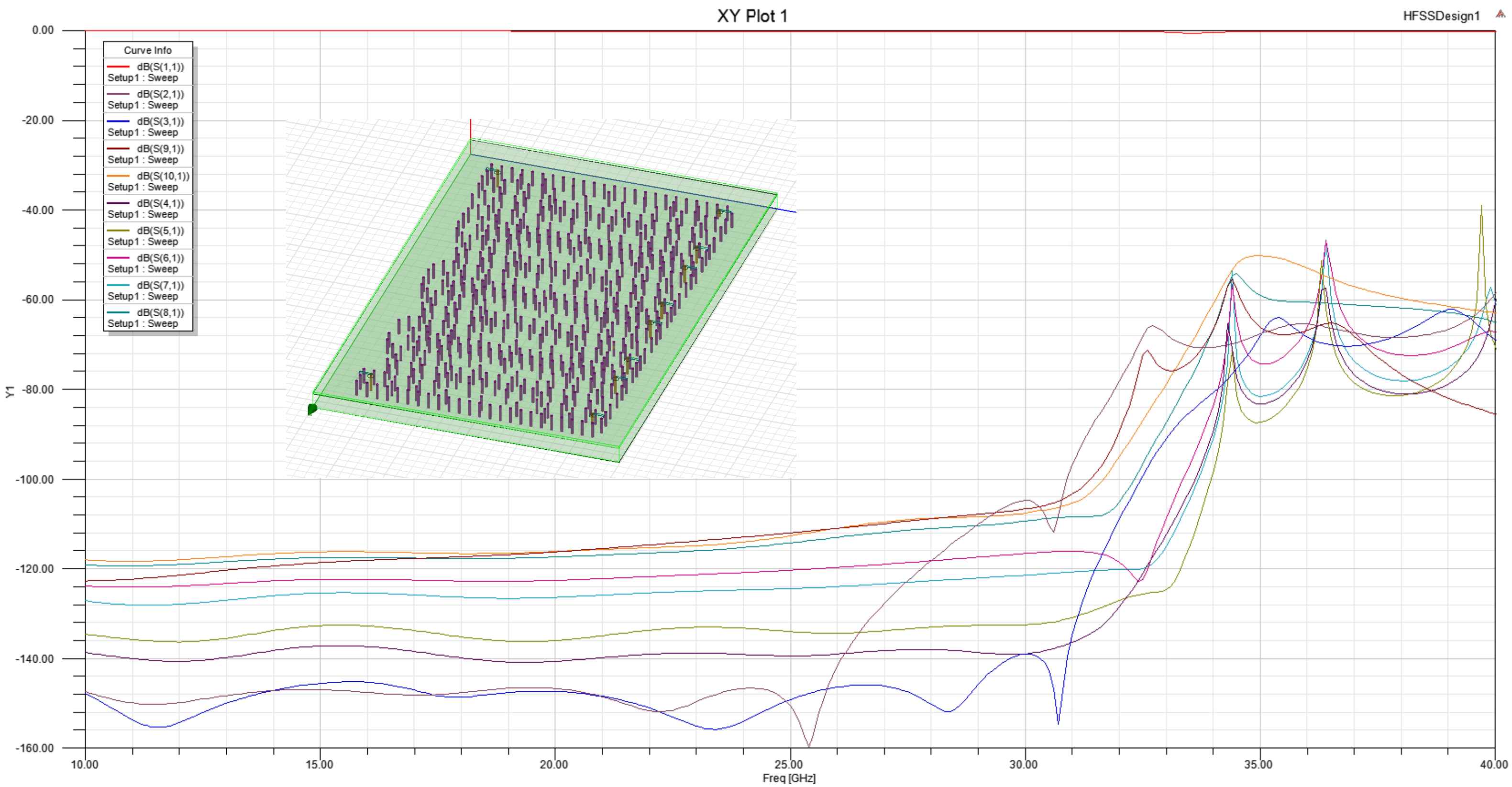
- **New coupler design and new filter design implemented in single channel unit cell**
  - **Coupler performance gives better return loss over wide bandwidth**
  - **New filter and coupler allows denser arrangement of ground stitching vias to kill cavity resonances**

RevB 9-Channel RF MUX Simulation



- **Simulation includes cascade of 9 channel (coupler-filters-coupler "unit cells") in S-parameter simulation (ADS)**
- **Each unit cell is a Sonnet (2.5-D EM) simulation**
  - **No loss included to speed up simulation (~ 1 hour per channel)**
- **Response is excellent and insensitive to inter-channel line spacing due to improved coupler response**

Stripline Cavity Modes – 4-channel Multiplexer



- **3-D HFSS model of stripline via structure with microstrip-to-stripline transitions**
- **Confirms no in-band (18-30 GHz) resonances due to stripline via structure**

IFP Summary

- Rev A fabricated, tested, and delivered to NASA GSFC
  - Integration and testing in progress
  - Results of system testing will be ported to IFP Rev B design changes (e.g. channel gains, software, data formatting)
- Rev A problems identified and corrective actions designed and now in fabrication (Rev B)
  - Root causes determined through measurements, test structure analysis, and post-fabrication simulations
- Redesign of RF (LTCC) hardware, PCB, and enclosure complete; fabrication underway to correct problems

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HyMAS System Overview

sensitivity and dynamic range for the amplifier and filtering functions in the IF electronics.

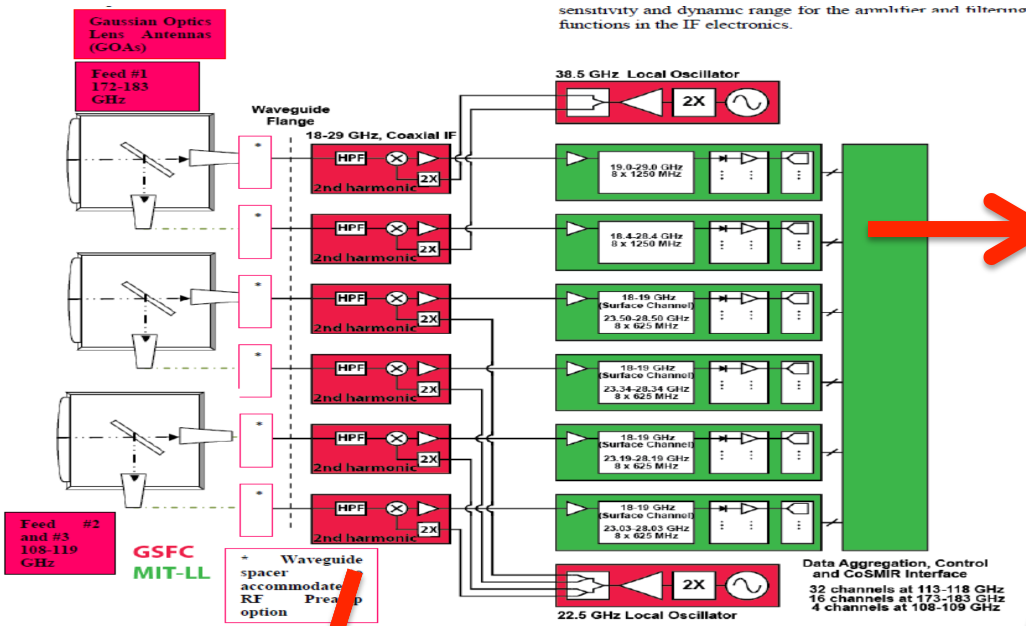
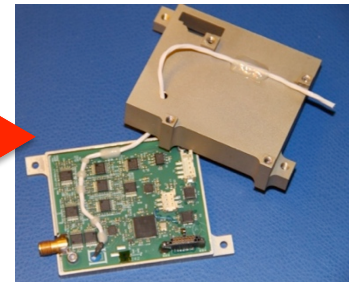
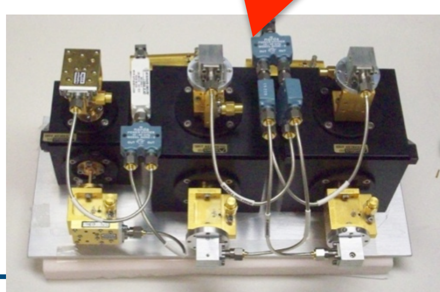
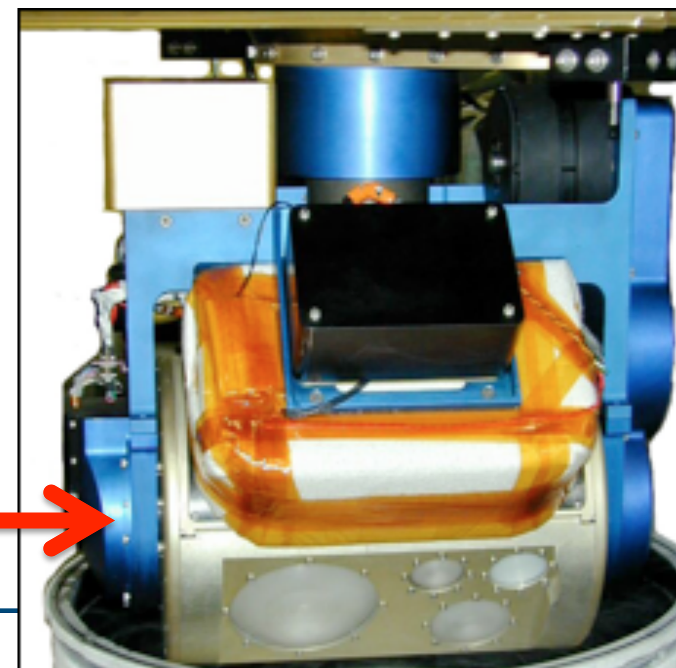


Figure 1 – Block diagram showing both the HyMAS RF electronics and core technology in the IF filter bank

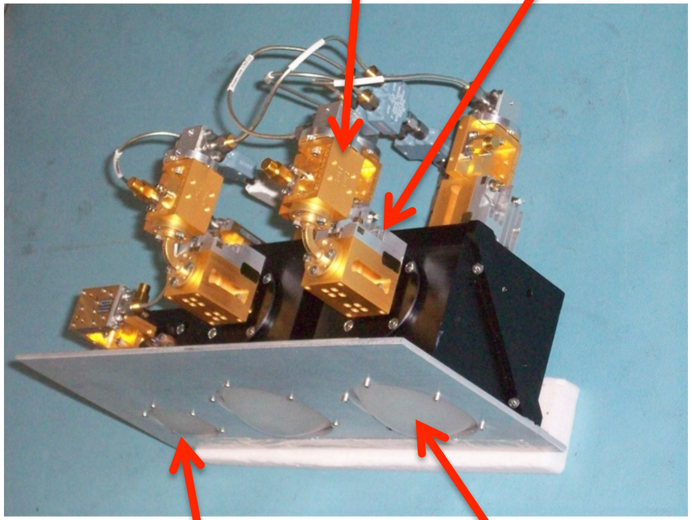






HyMAS Receivers

- Four F-band Receivers (108 – 119 GHz)
  - 9 IF Channels each
  - 22.6 GHz DRO
- Two G-band Receivers (172 – 183GHz)
  - 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.



HyMAS Antenna Subsystem

Three antennas

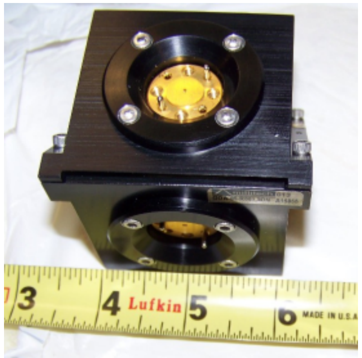
One at 183 GHz

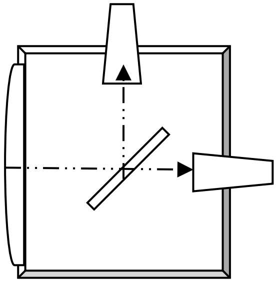
Bandwidth 172-183 GHz
Beamwidth: 3.1 – 3.3 degrees over the bandwidth
Sidelobes: ~30 dB below main lobe
VSWR: <1.5:1
Polarization: dual linear

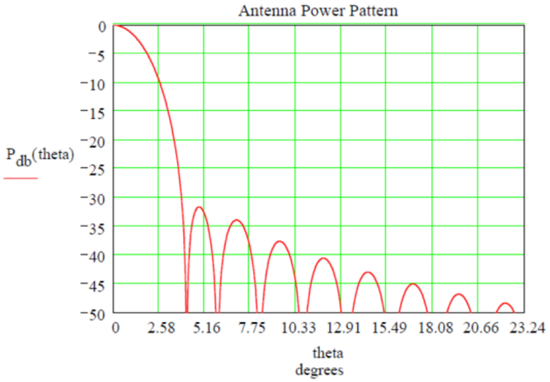
Two at 118 GHz

Bandwidth 108-119 GHz
Beam width: 3.1 – 3.3 degrees over the bandwidth
Side lobes: ~25 dB below main lobe
VSWR: <1.5:1
Polarization: dual linear

Gaussian optics lens antenna with wire grid to separate polarizations

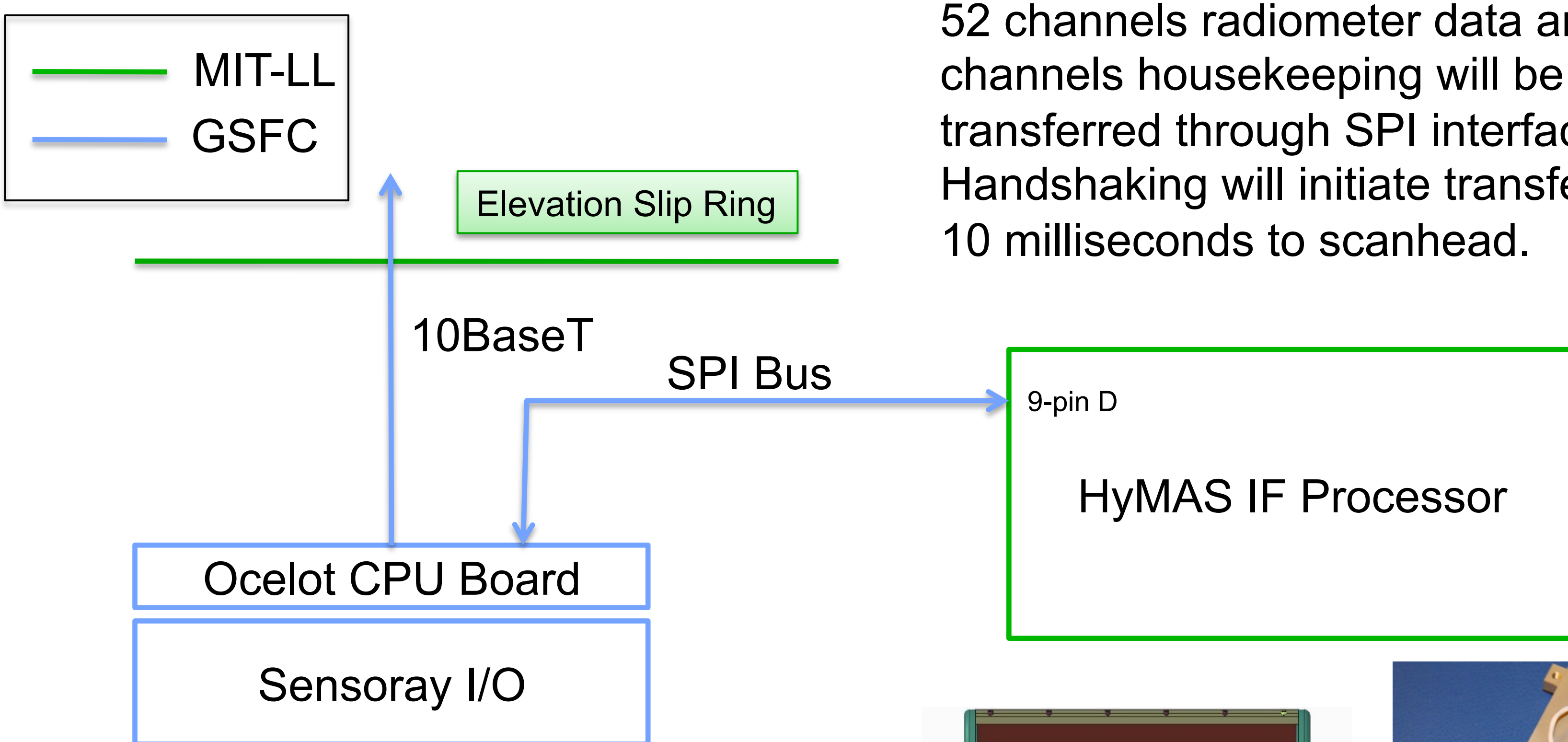




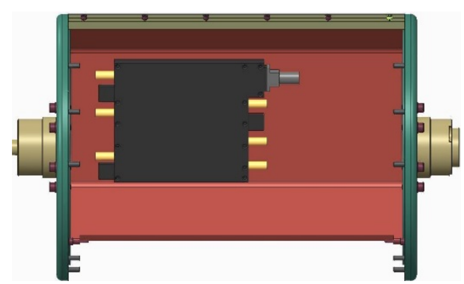


HyMAS Scanhead Computer Configuration

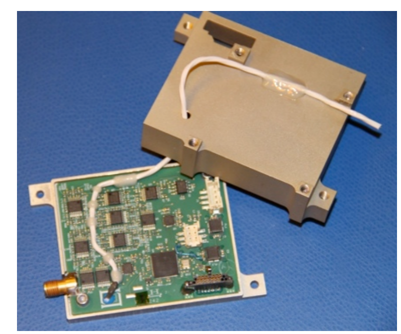
52 channels radiometer data and 12 channels housekeeping will be transferred through SPI interface. Handshaking will initiate transfer every 10 milliseconds to scanhead.



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



Final IFP footprint

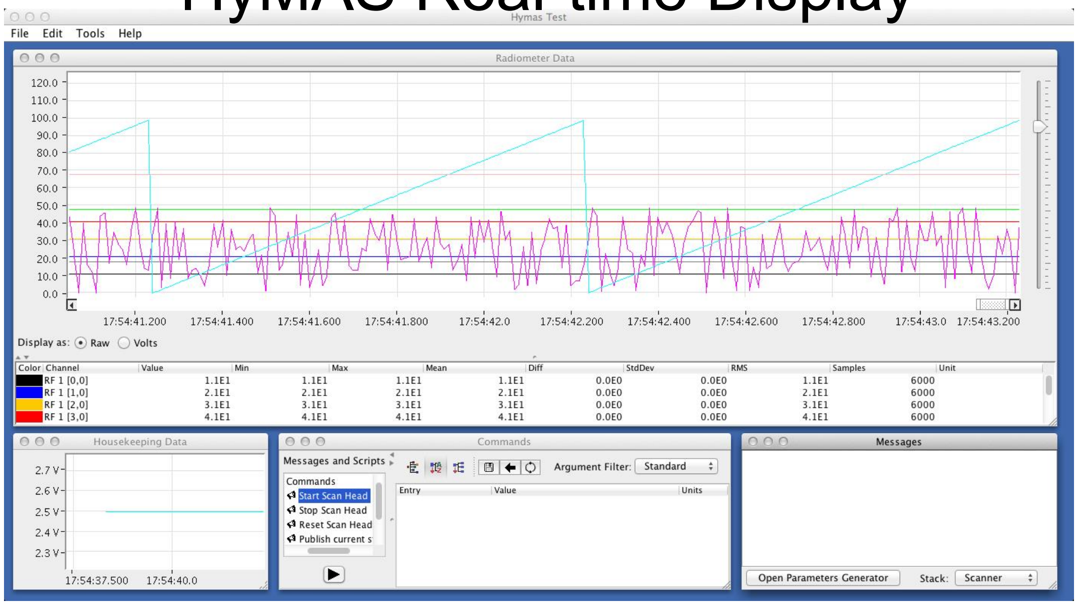


Surrogate IFP

HyMAS Data Acquisition

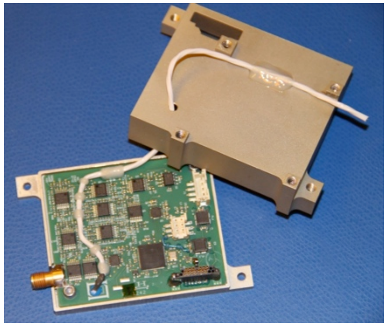
- "Surrogate IFP" used to develop communications and electrical interfaces with HyMAS electronics
- Maximum sampling rate from IFP is ~180 data frames per second
  - 52 Radiometer channels
  - 12 Housekeeping
- Time stamp of data using network time protocol (NTP) implemented on CoSMIR – applicable to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

HyMAS Real-time Display



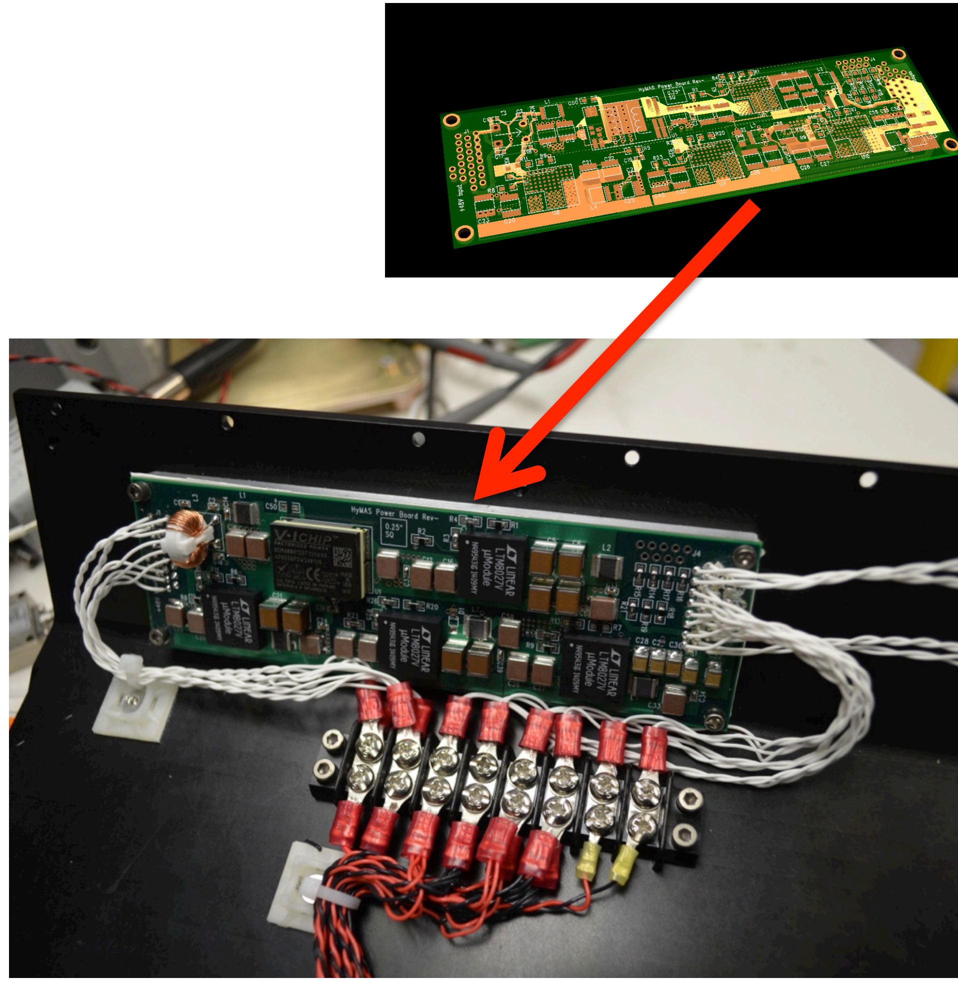
Plot and data display functions for testing HyMAS surrogate IFP using simulated data

Photo of surrogate IFP used to test electrical compatibility of HyMAS electronics



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

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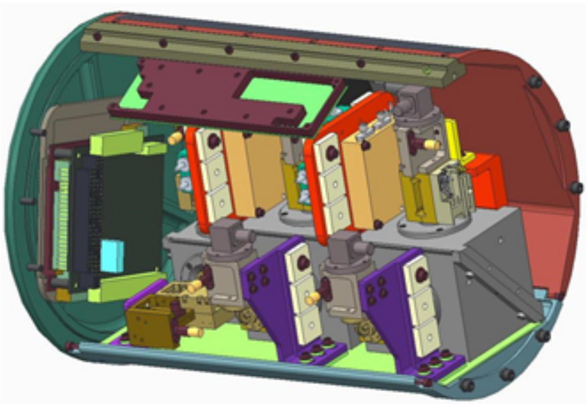
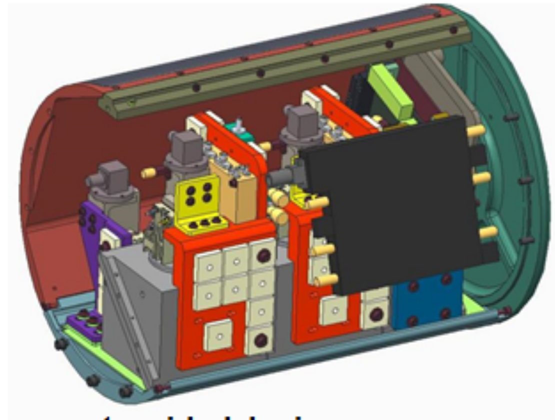
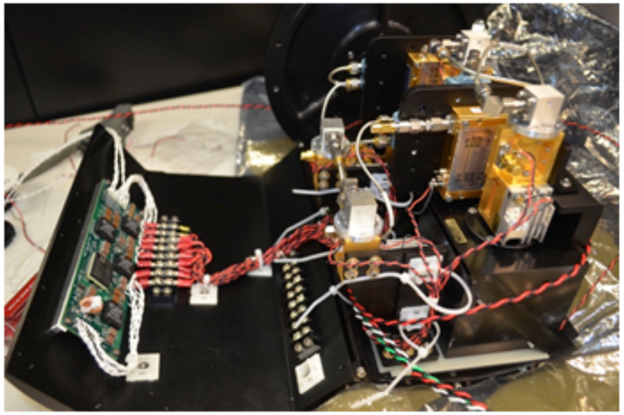
- Current and Future Work

HyMAS Scanhead Mechanical Integration

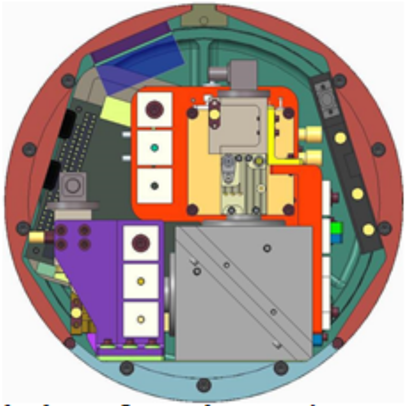




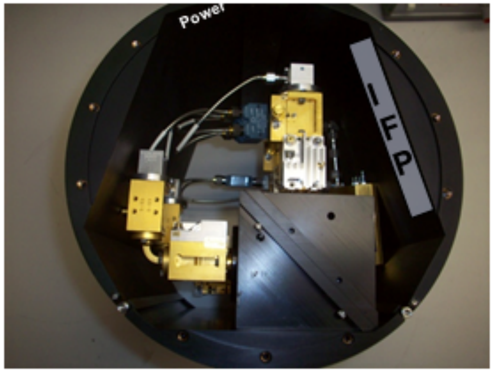
Layout facilitated by computer aided design



Partial assembly of HyMAS electronics



End-view of receivers w/ brackets to support waveguide



Antennas and receivers fit within drum envelope

HyMAS Scanhead Assembly

Summary and Conclusions

- The hyperspectral microwave receiver offers profound atmospheric sounding performance in a small package
- IFP technology offers two order of magnitude improvement in the size of the radiometer back end
  - Enables cubesat/smallsat implementation
  - Enables hyperspectral microwave operation with very large aggregate bandwidth (necessary for optimum performance)
- Program conclusion in August with complete airborne sensor ready for demonstration flights
- Technology infusion already started (MicroMAS-2, MiRaTA, NAST-M, and others)