
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

28 October 2014



**GODDARD
SPACE FLIGHT CENTER**



Outline



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

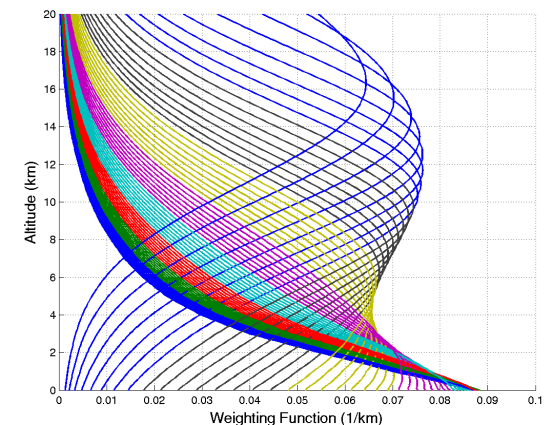
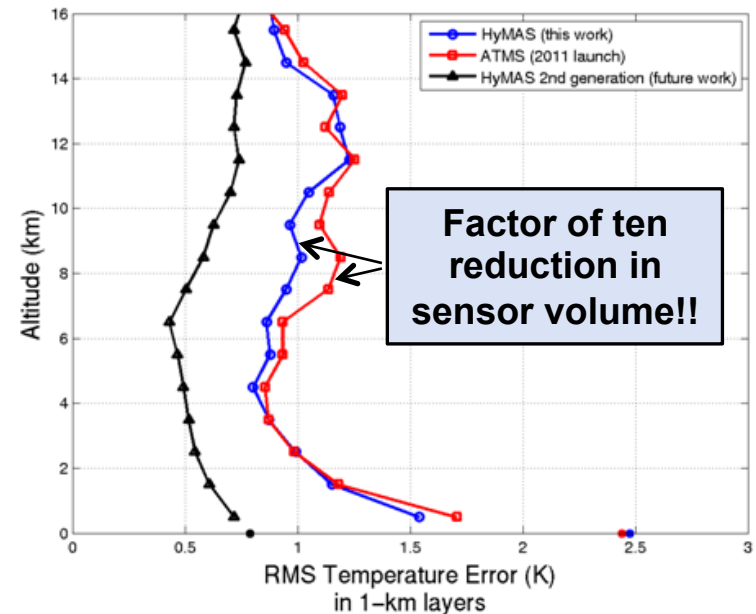


Project Summary and Key Objectives



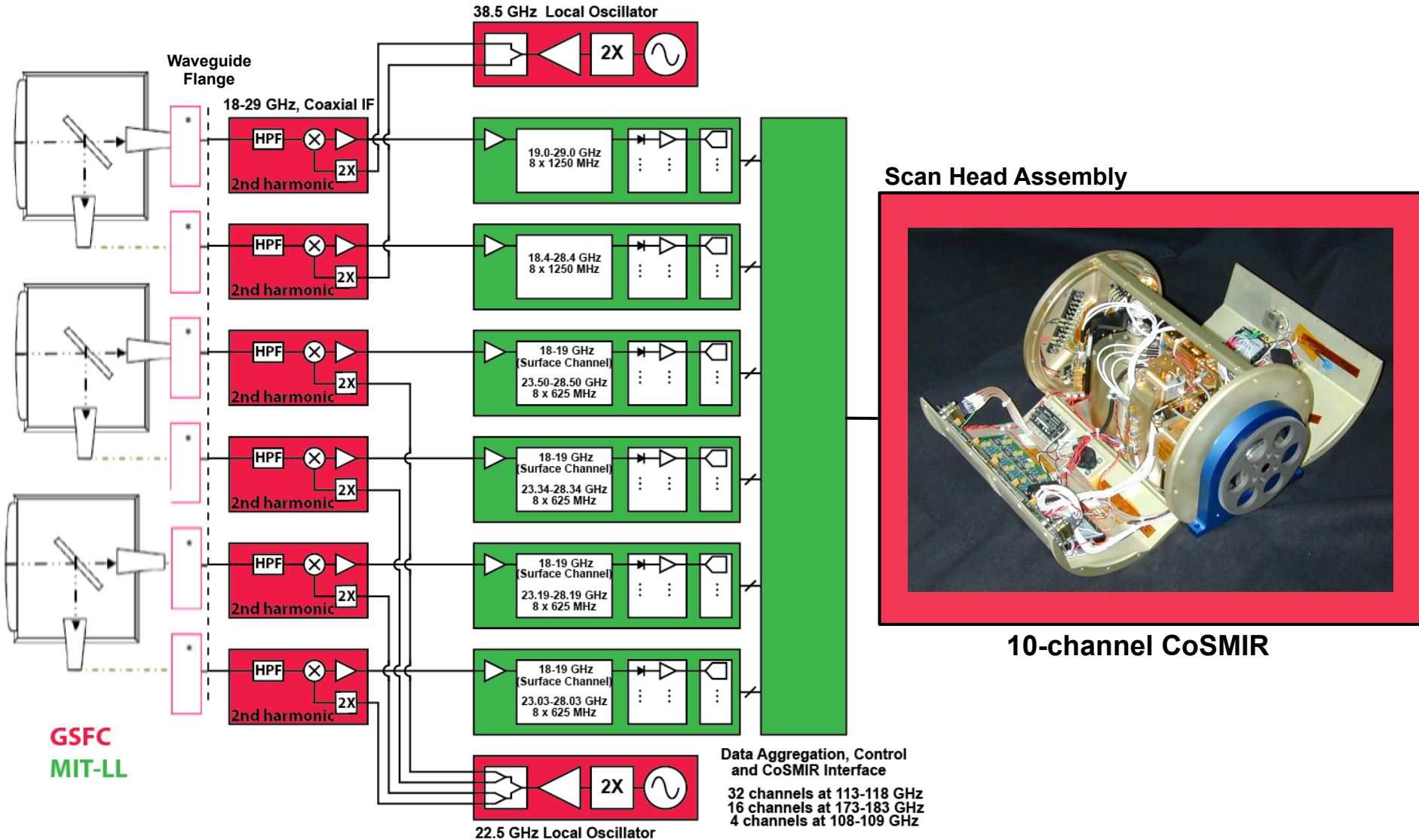
- Hyperspectral microwave (HM) sounding has been proposed to achieve unprecedented performance
- HM operation is achieved using multiple banks of RF spectrometers with large aggregate bandwidth
- A principal challenge is Size/Weight/Power scaling
- Objectives of this work:
 - Demonstrate ultra-compact (100 cm³) 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



GSFC
MIT-LL



HyMAS Technology Infusion Examples



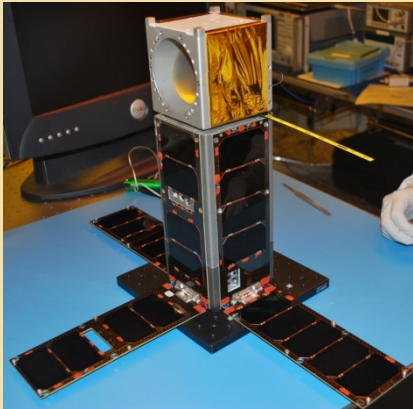
IFP enables ultracompact, high-performance radiometry

MicroMAS

3U cubesat with scanning 118-GHz radiometer

9 channels for temperature profiling and precipitation imaging

July 13, 2014 launch

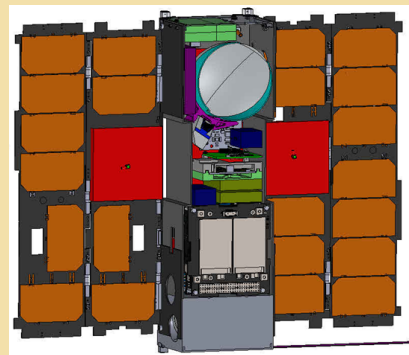


MiRaTA

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





Outline



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



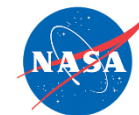
IFP – Overview



- **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 ($10 \times 10 \times 1 \text{ cm}^3$) and low DC power requirement ($<100 \text{ mW/ch}$) drives the architecture and design**
 - Leverage high performance miniature microwave filters, COTS MMICs, electronics packaging



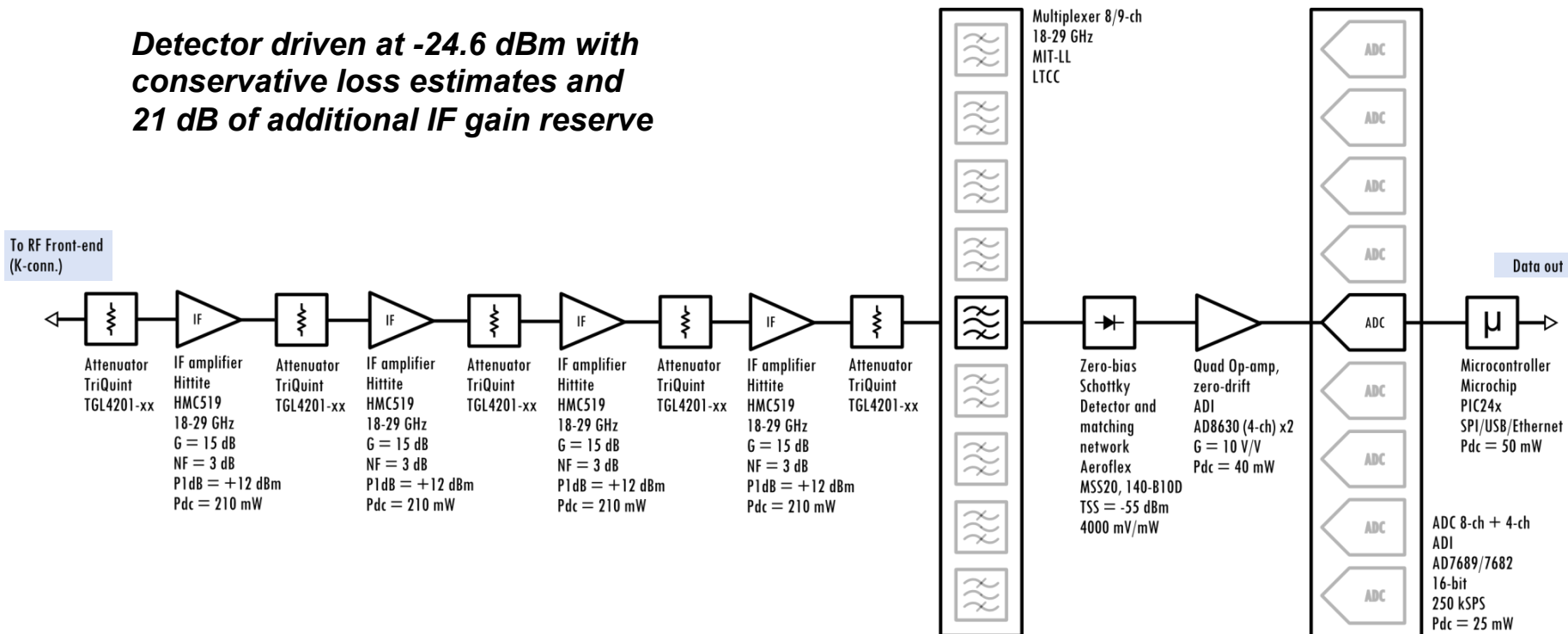
Single IF Channel Architecture



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	1.10E+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	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	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	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	8.07E+09	2.03E+08

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





IFP 9-Channel Prototype Summary



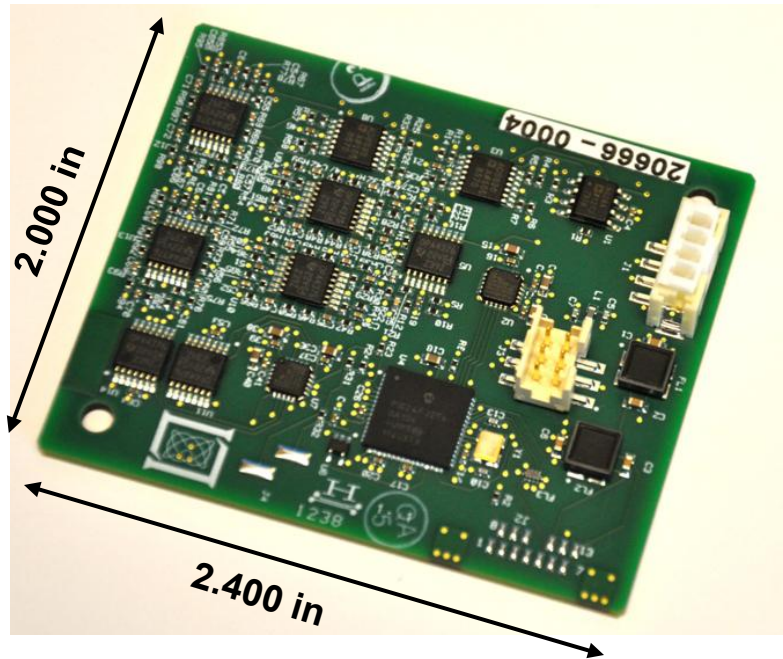
- **Demonstrated 9-channel IF processor**
 - **Scalable to larger numbers of channels**
 - **RF MMIC amplifiers and detectors**
 - **Post-detector analog processing and noise characterization**
 - **Data conversion and processing and software**
- **High frequency LTCC technology characterized for microwave filters**
 - **Tolerances within expectations confirming viability of representative circuits up to ~ 30 GHz**
 - **Very good measured SIW filter results**



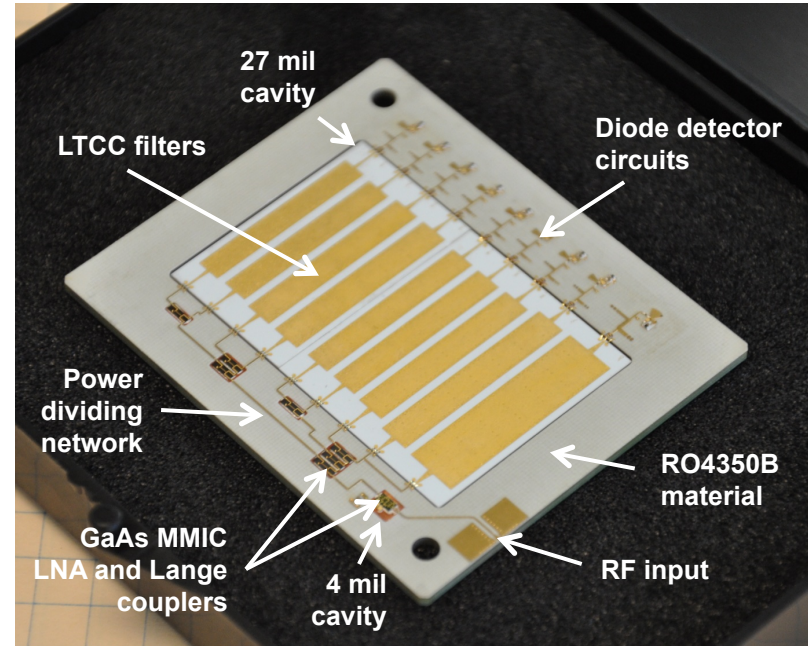
9-ch IFP Prototype PCB



Top (FR4)



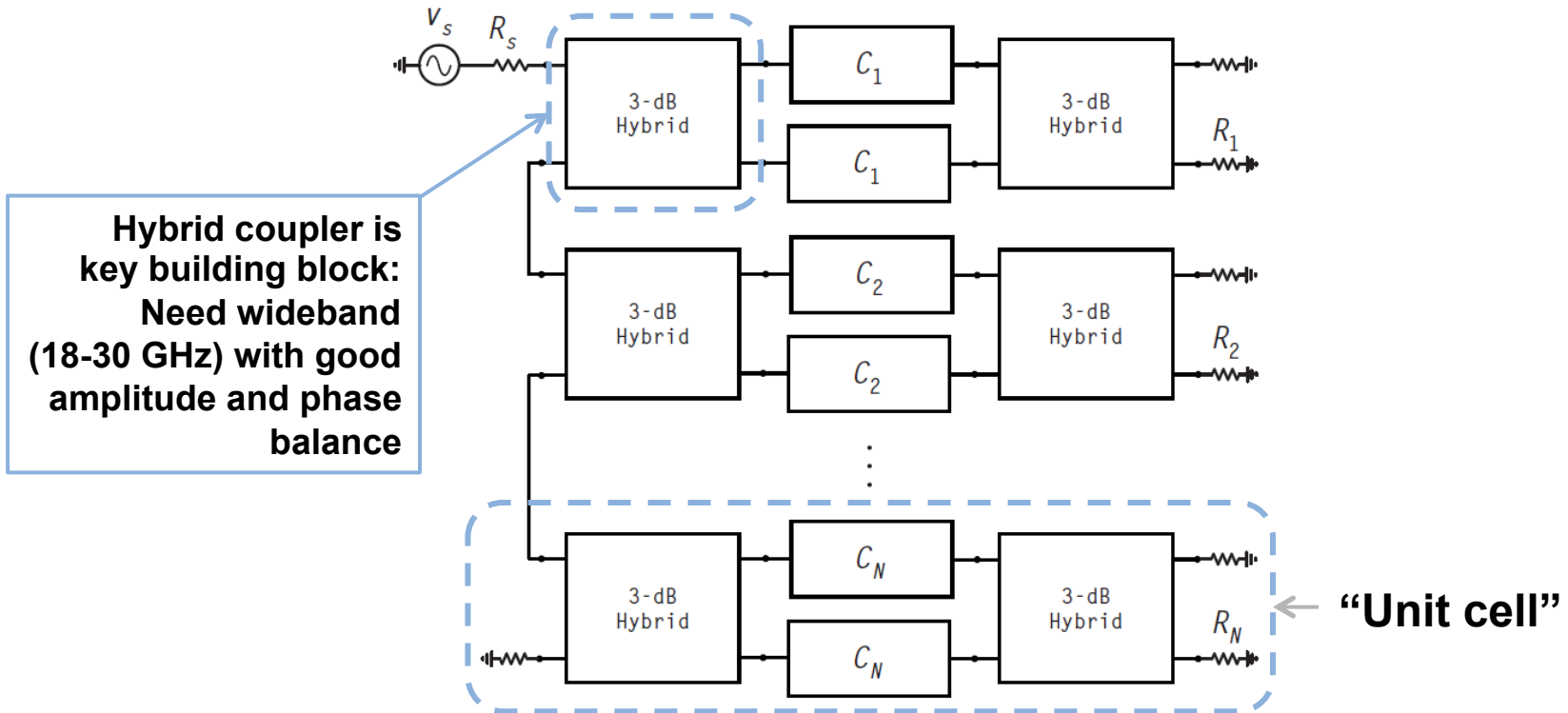
Bottom (RO4350B)



- 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



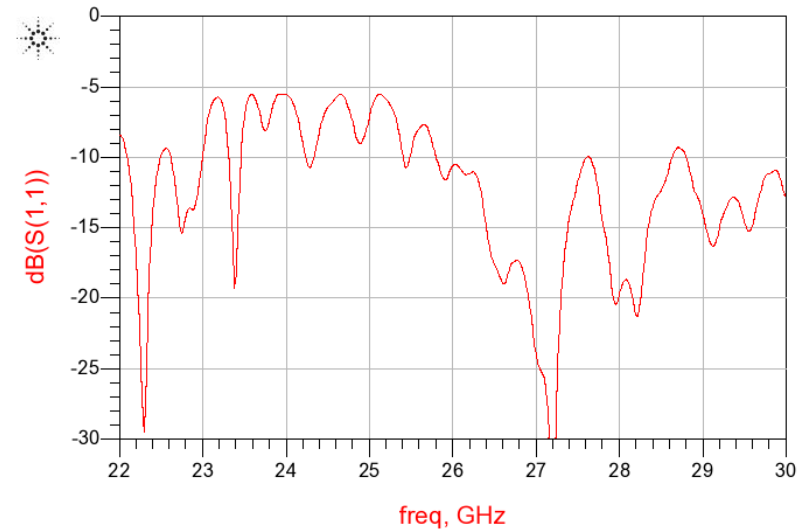
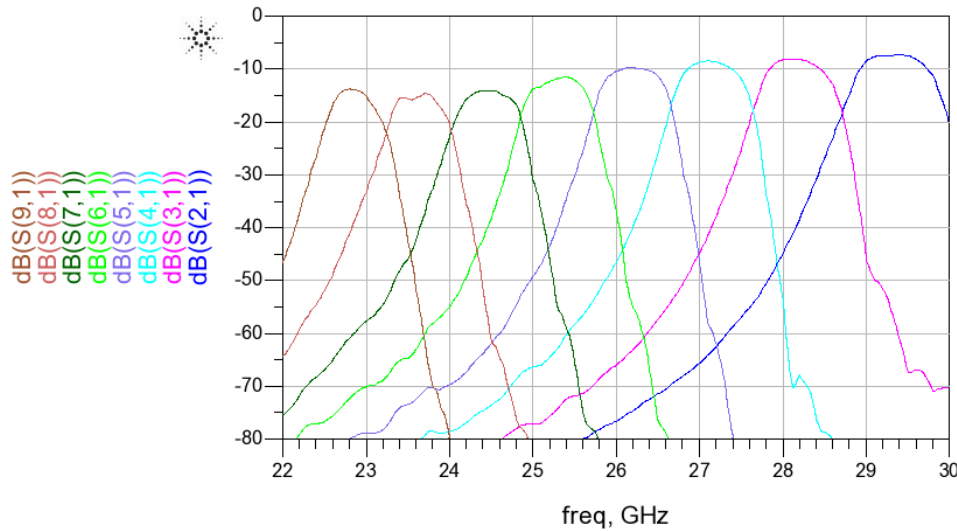
- Requires pairs of identical filters
- Accommodates arbitrary number of channels, any channel characteristics, bandwidth determined by coupler response



Multiplexer Simulation – EM Models



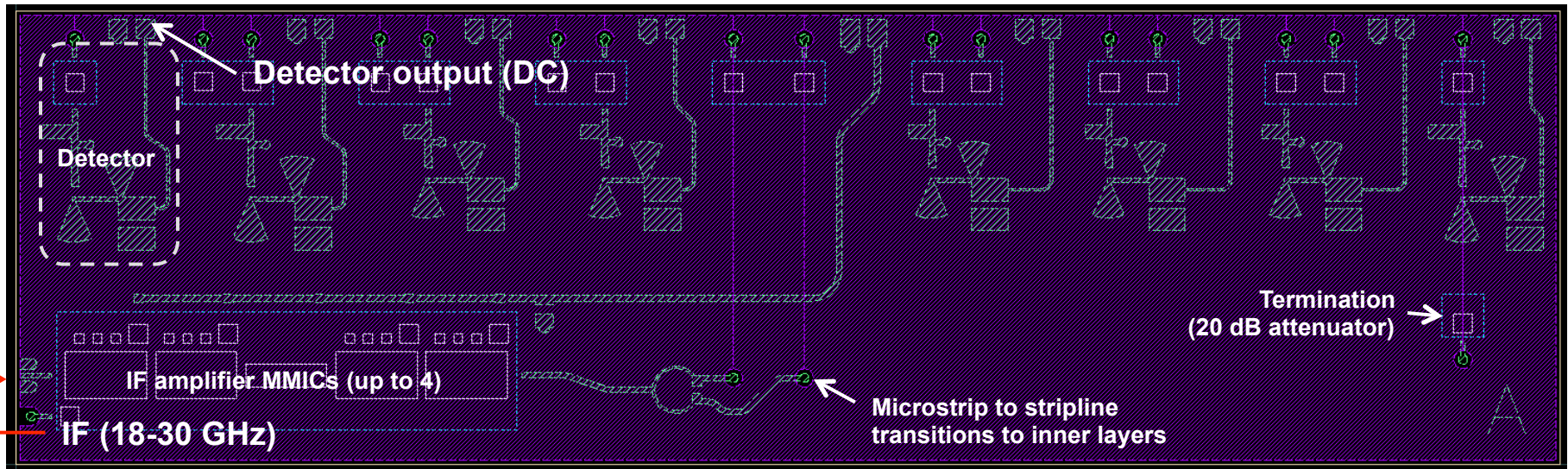
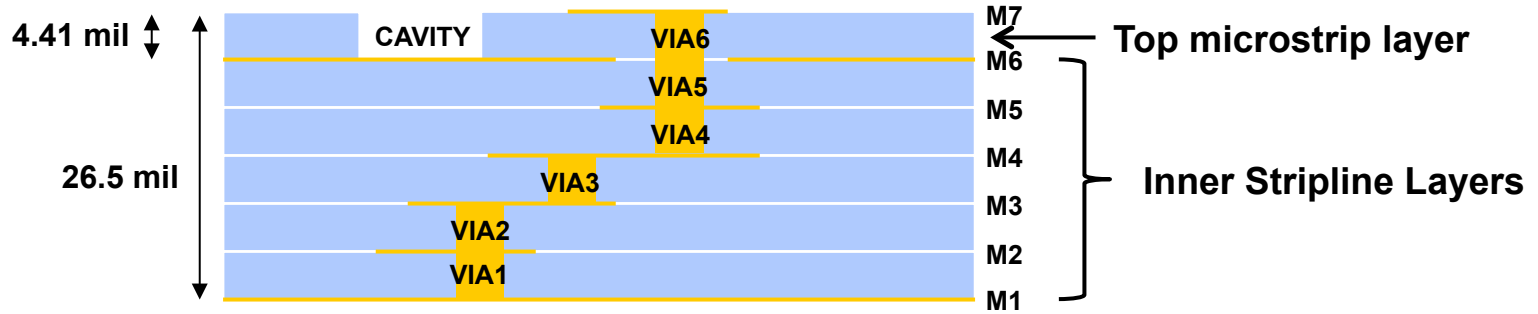
Simulated Multiplexer Response



- **Optimized line lengths**
- **Coupler amplitude and phase mismatch causes reflections**



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



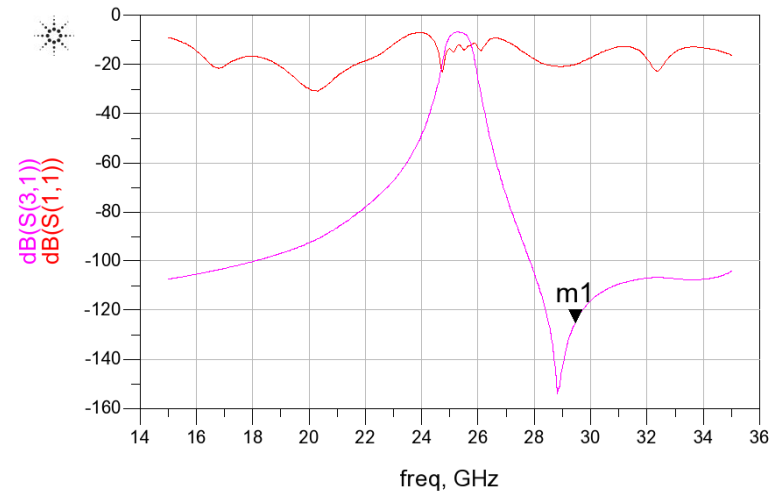
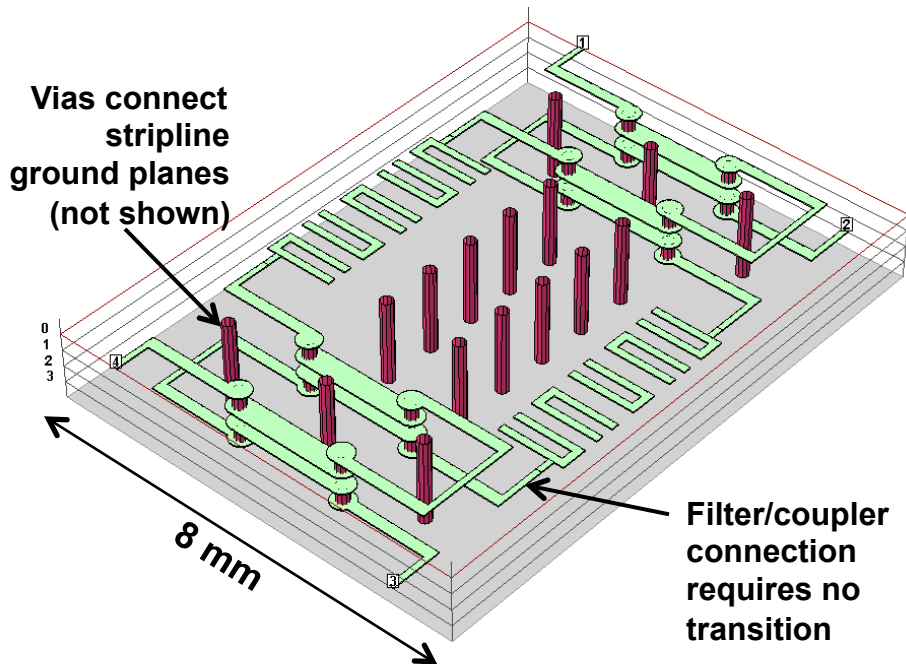
- Modules (10 mm x 43 mm or 48 mm) contains all amplification, multiplexer filtering, and detection circuits for 8 or 9 channels
- Single 18-30 GHz input, (8) detector (DC) outputs



Hybrid Multiplexer Unit Cell



Coupler and Filter Model and Simulated Response



- Multiplexer is composed of a cascade of coupler-filter-coupler unit cells
- Full-wave simulation confirms response as expected

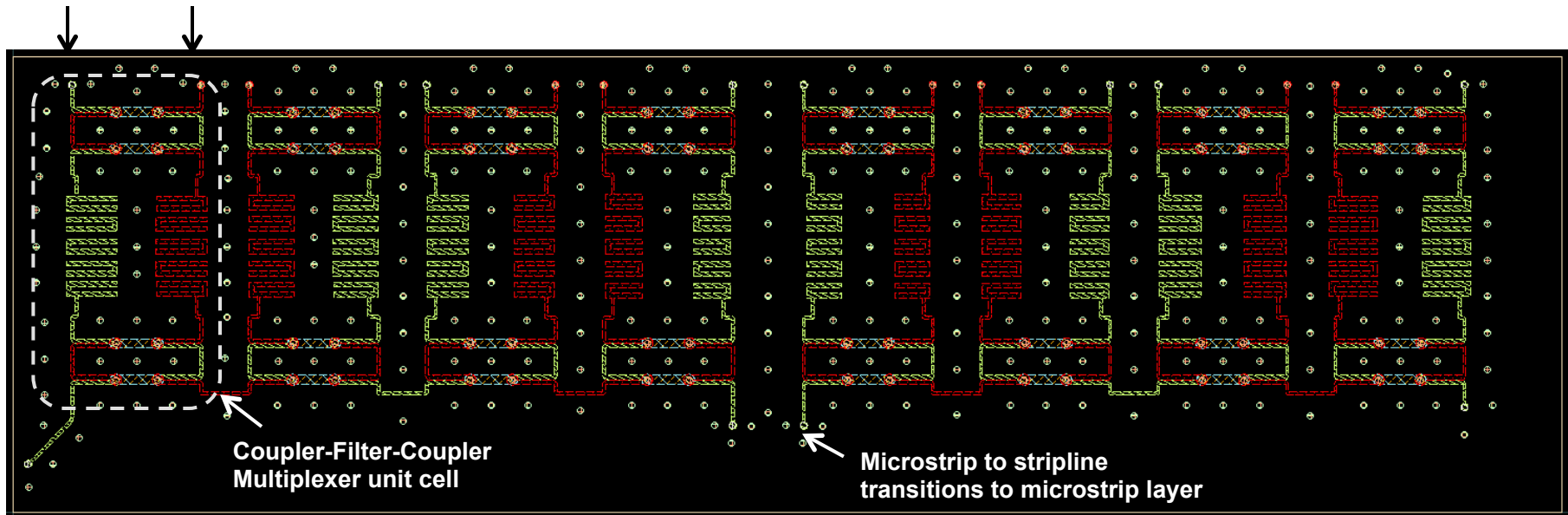


8/9-Channel LTCC IF Module Layout



Channel output to top layer
(detector input and termination)

Inner Layers



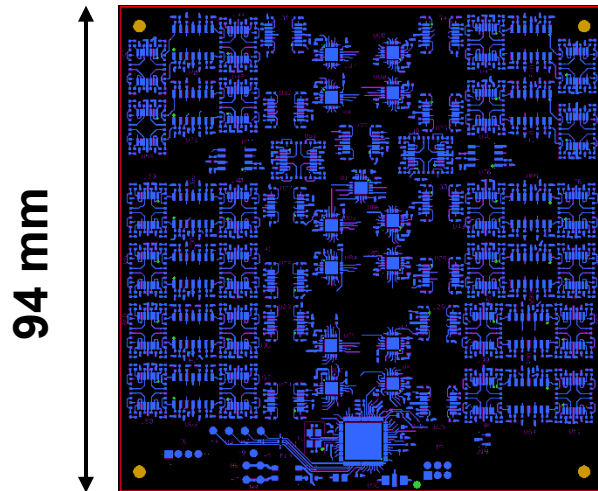
- Inner stripline couplers and filters built in 5 LTCC layers
- Multiplexer is divided into two “quadplexers” for additional channel isolation
- Via fences used for isolation and eliminating cavity modes



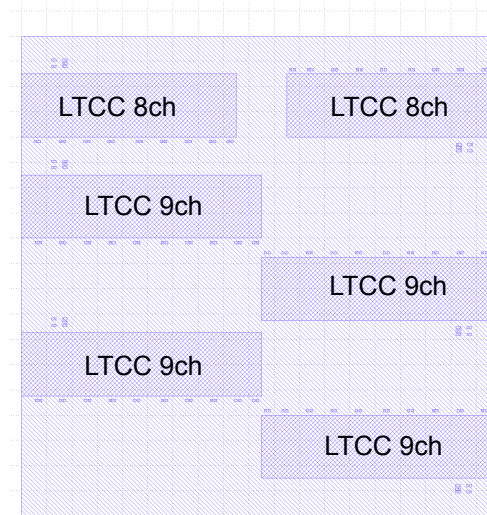
52-ch IFP Packaging – PCB



PCB top layer



PCB bottom layer



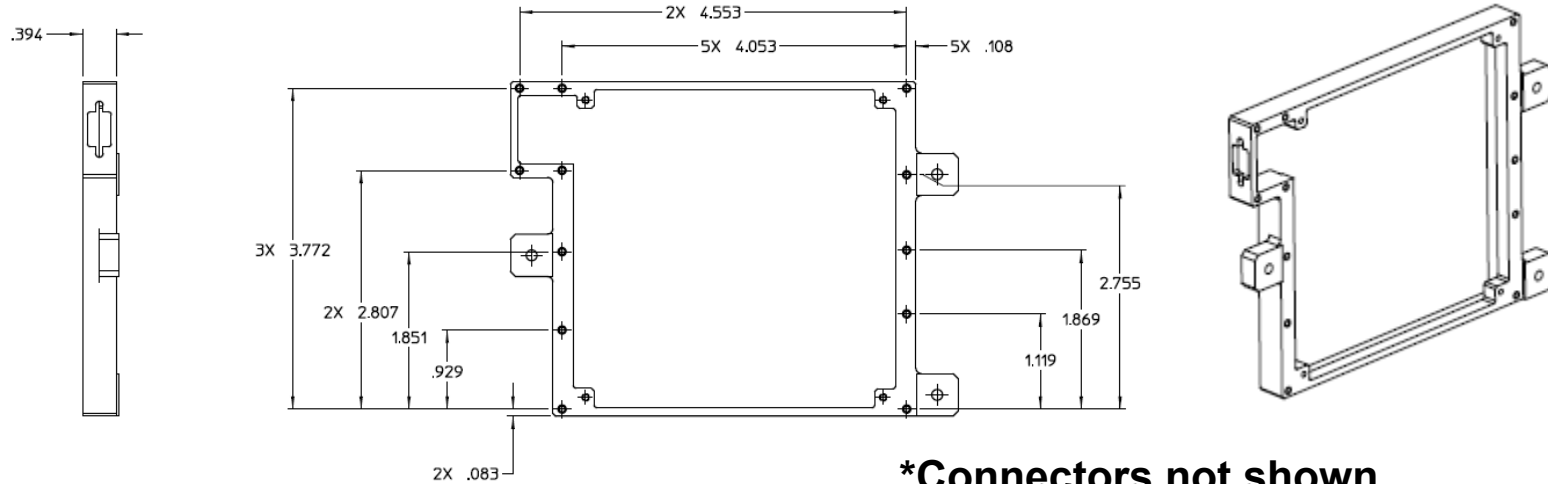
- Top of board contains digital, post-detector analog circuit, bottom is mounting platform for LTCC IF modules
- Low cost 6-layer FR4 PCB using ENEPIG finish for soldering/wire-bonding
 - All RF circuits confined to LTCC modules, eliminating need for HF materials, PCB cavities



52-ch IFP Packaging – Enclosure



IFP Enclosure CAD Model



- Overall size 114 mm x 96 mm x 10 mm (~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**



Outline



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



HyMAS System Overview

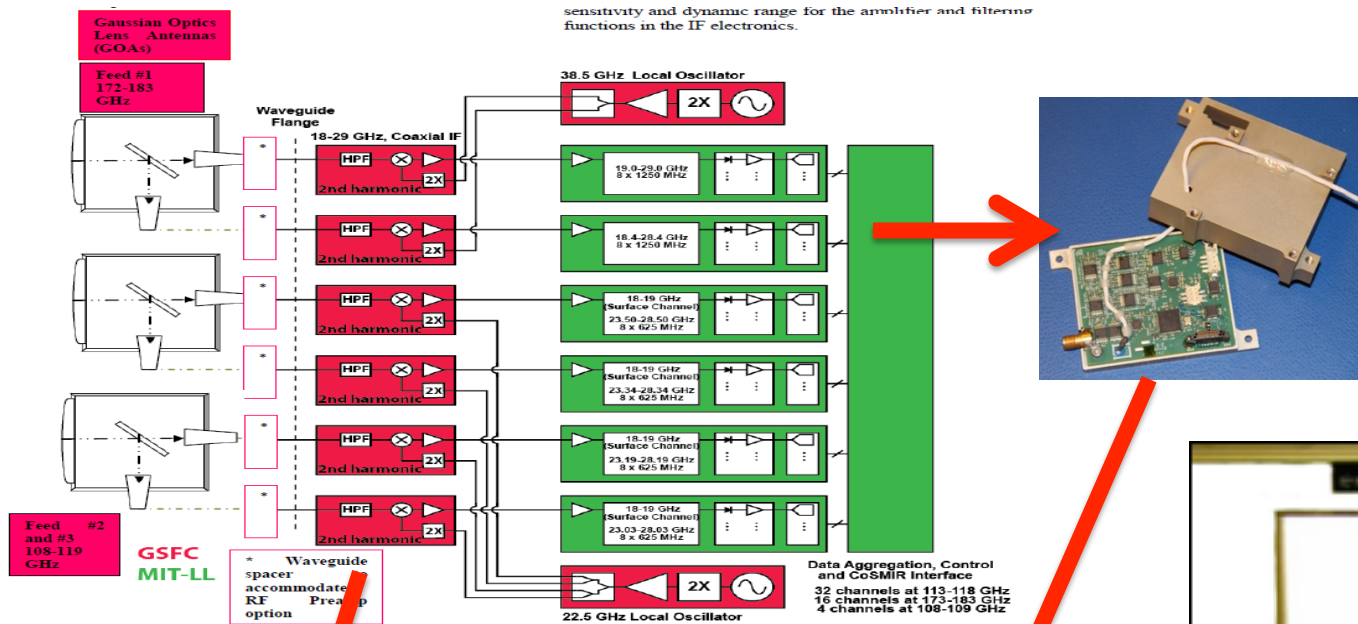
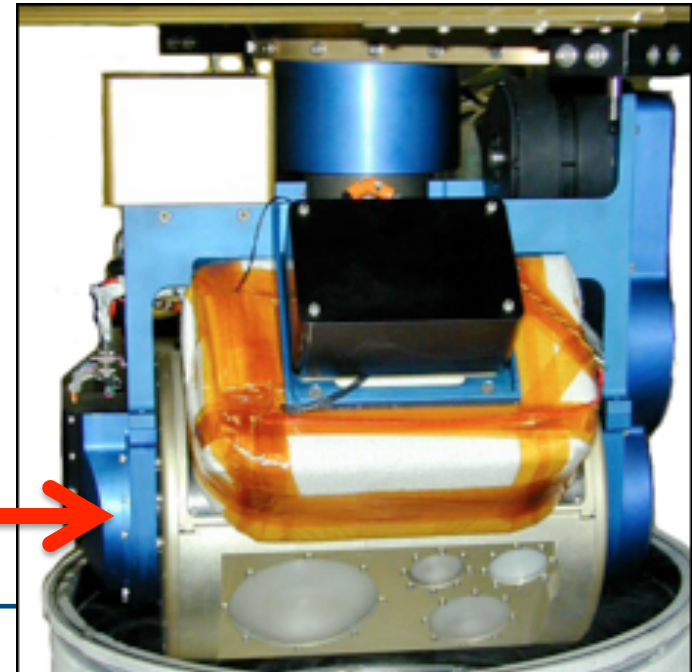
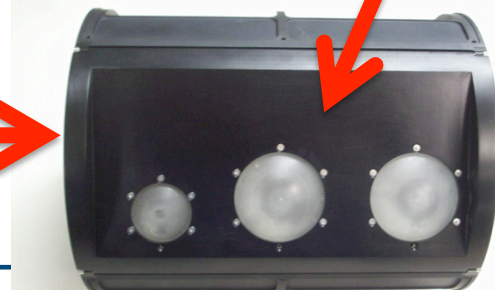
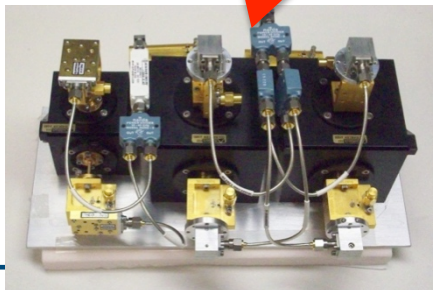


Figure 1 – Block diagram showing both the HyMAS RF electronics and core technology in the IF filter bank

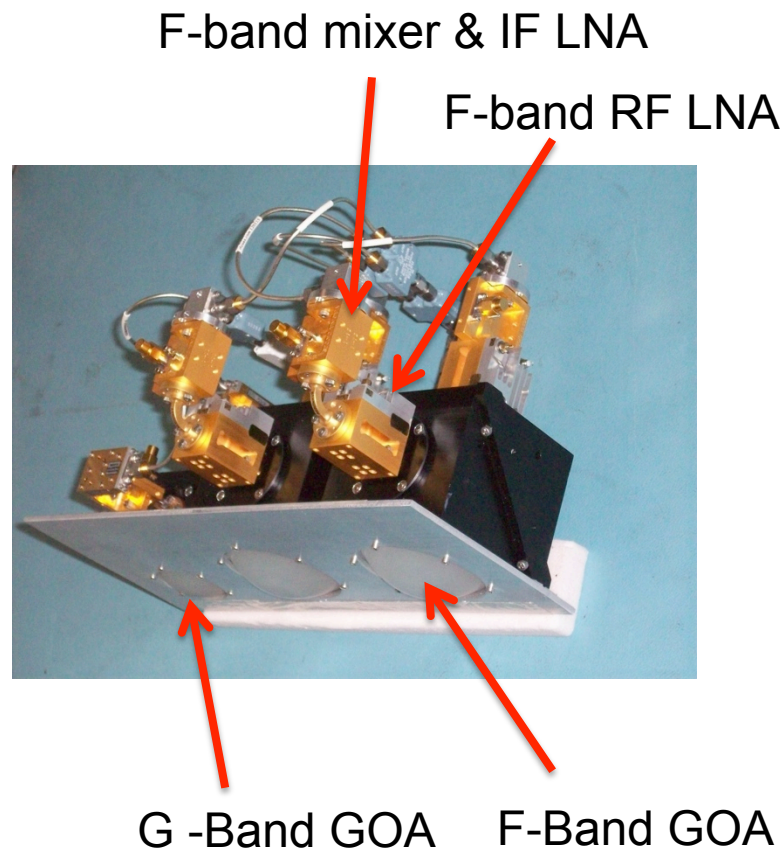




HyMAS Receivers



- 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

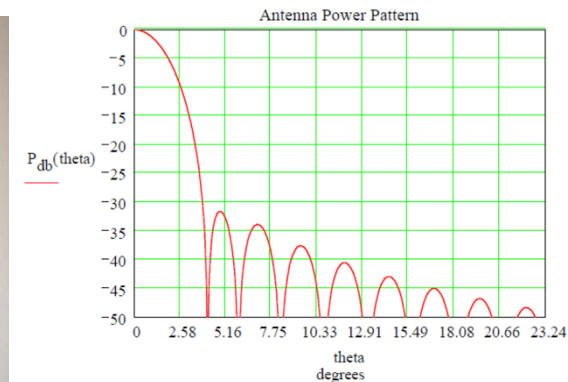
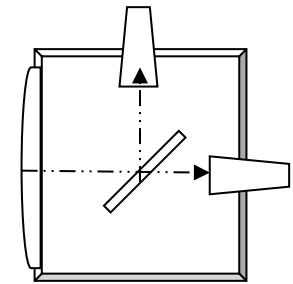
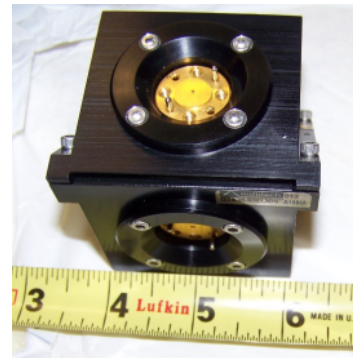
One at 183 GHz

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

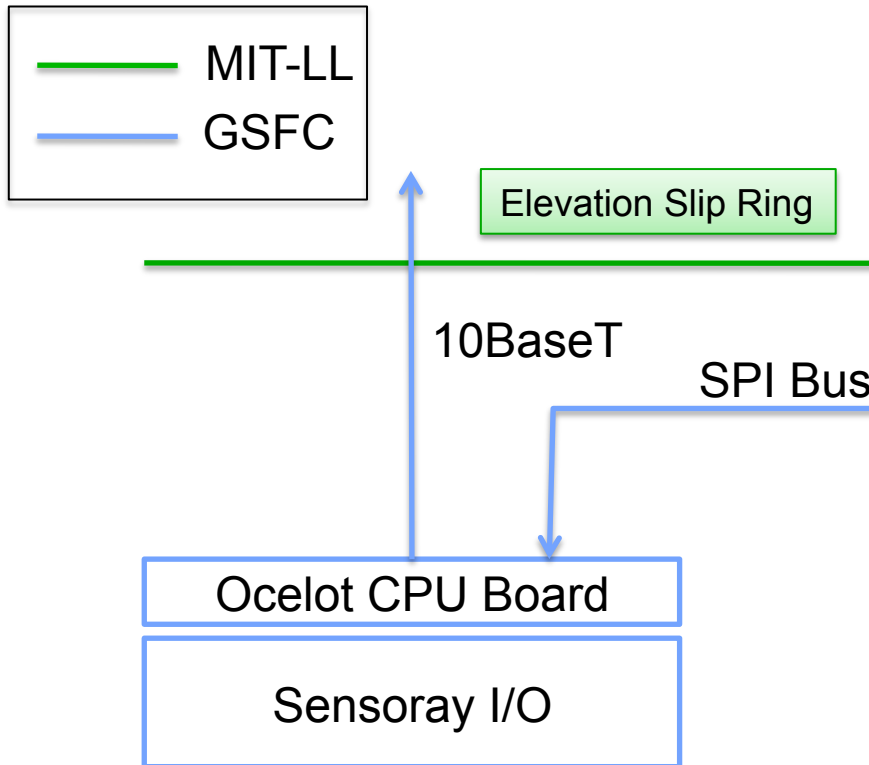
Bandwidth 108-119 GHz
Beam width: 3.1 – 3.3 degrees over the bandwidth
Side lobes: ~25 dB below main lobe
VSWR: <1.5:1
Polarization: dual linear

Gaussian optics lens antenna with wire grid to separate polarizations

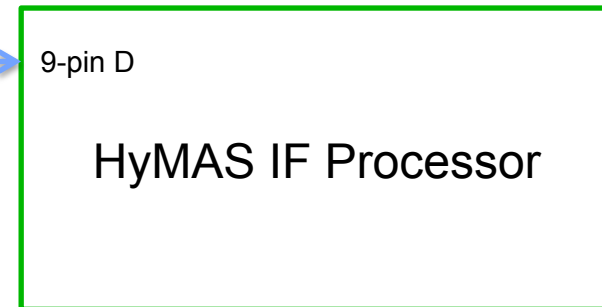




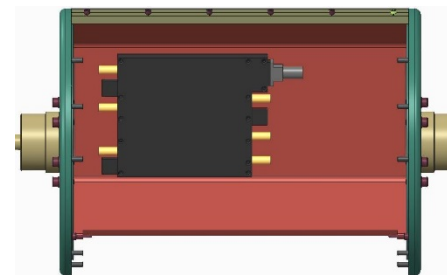
HyMAS Scanhead Computer Configuration



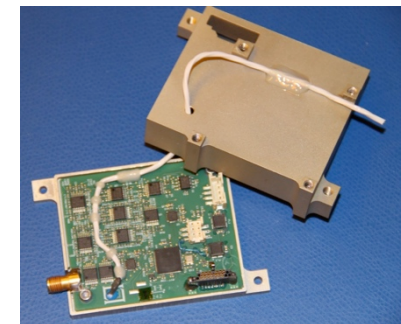
52 channels radiometer data and 12 channels housekeeping will be transferred through SPI interface. Handshaking will initiate transfer every 10 milliseconds to scanhead.



- 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

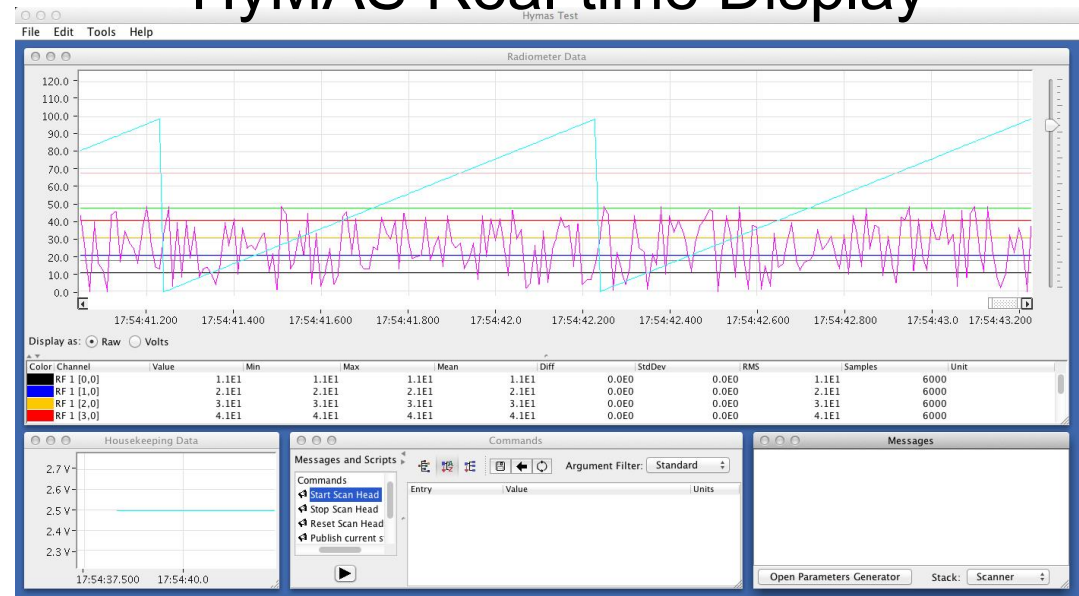


HyMAS Data Acquisition



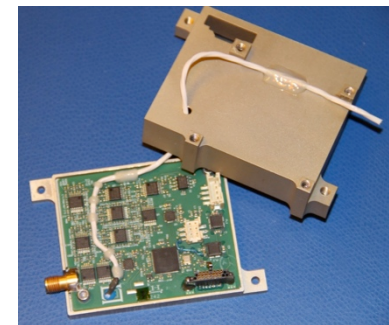
- “Surrogate IFP” used to develop communications and electrical interfaces with HyMAS electronics
- Maximum sampling rate from IFP is ~180 data frames per second
 - 52 Radiometer channels
 - 12 Housekeeping
- Time stamp of data using network time protocol (NTP) implemented on CoSMIR – applicable to HyMAS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

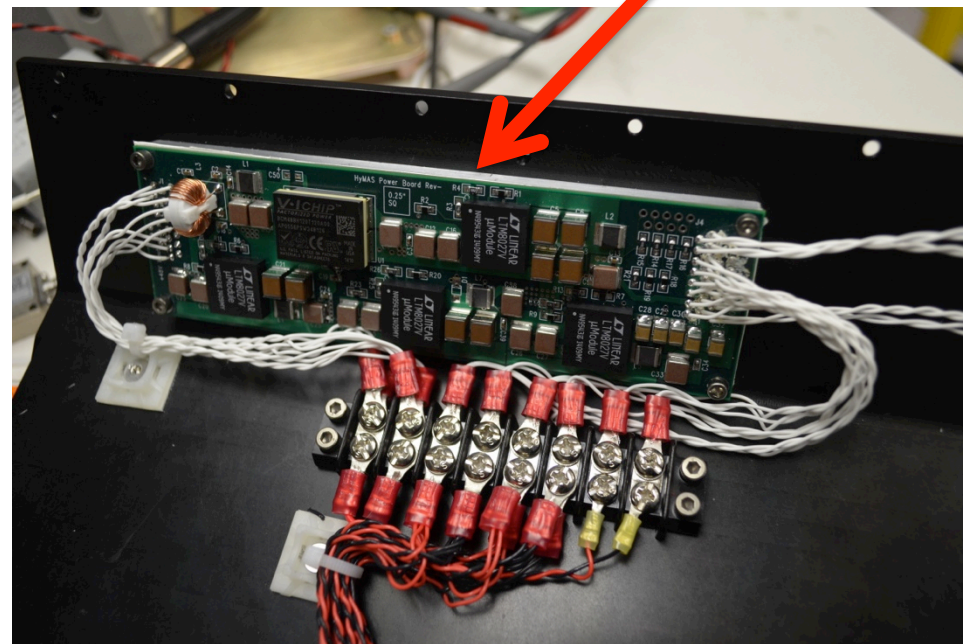
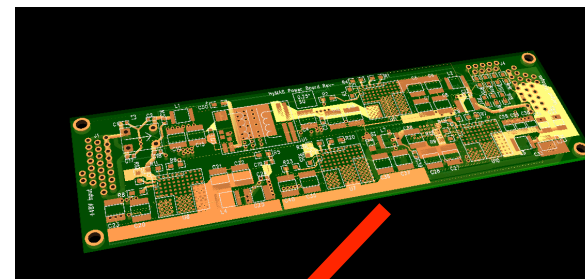




Power Board



- 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





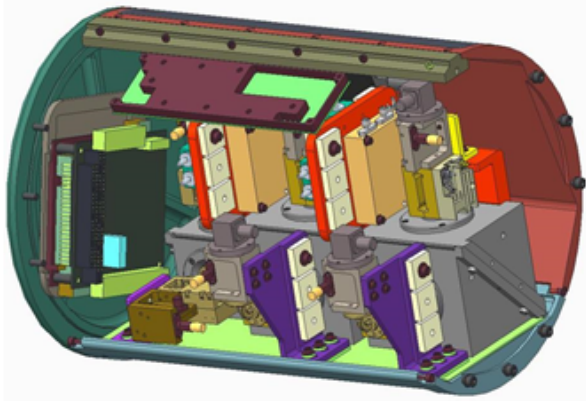
Outline



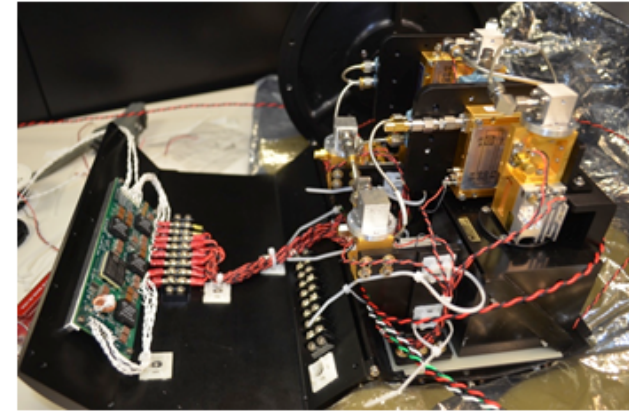
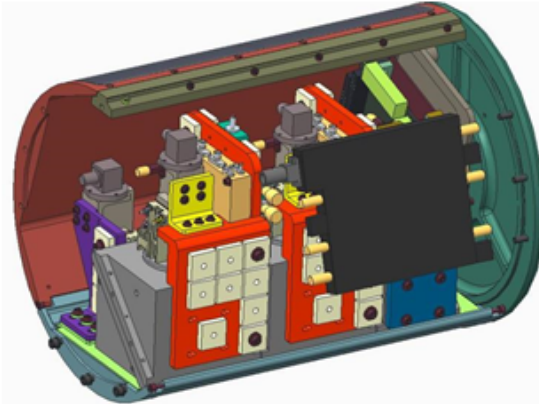
- **HyMAS: Motivation and Overview**
- **Intermediate Frequency Processor (IFP)**
- **Receiver Front-End Electronics**
- ➔ • **Airborne Instrument Accommodations**
- **Current and Future Work**



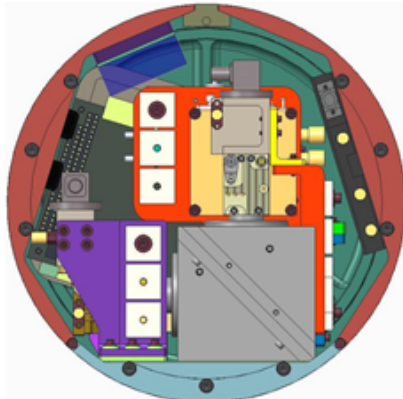
HyMAS Scanhead Mechanical Integration



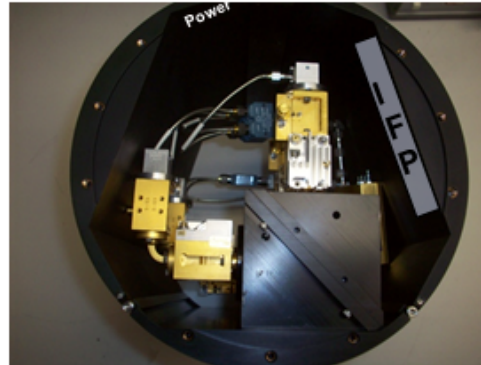
Layout facilitated by computer aided design



Partial assembly of HyMAS electronics



End-view of receivers w/
brackets to support waveguide



Antennas and receivers fit within
drum envelope



HyMAS Scanhead Assembly



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**



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)**
- **Complete airborne sensor ready for demonstration flights in early 2015**
- **Technology infusion already started (MicroMAS, MiRaTA, NAST-M, and others)**