National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

GeoSTAR Results

Not quite final yet…

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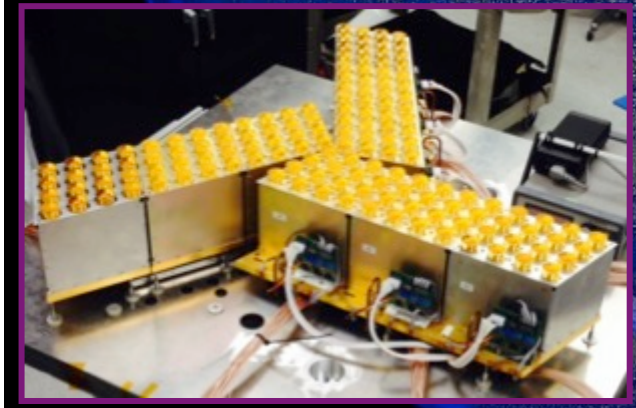
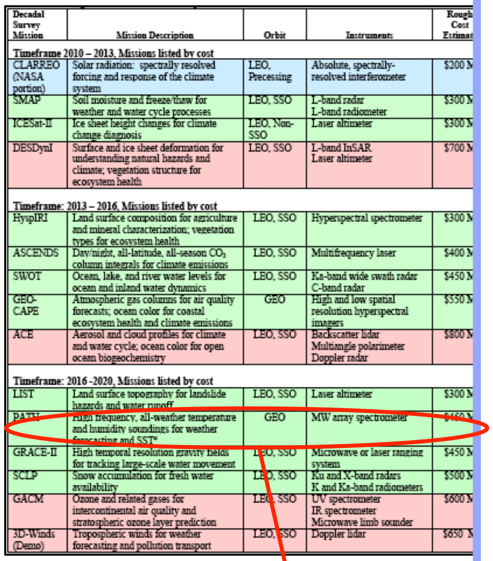


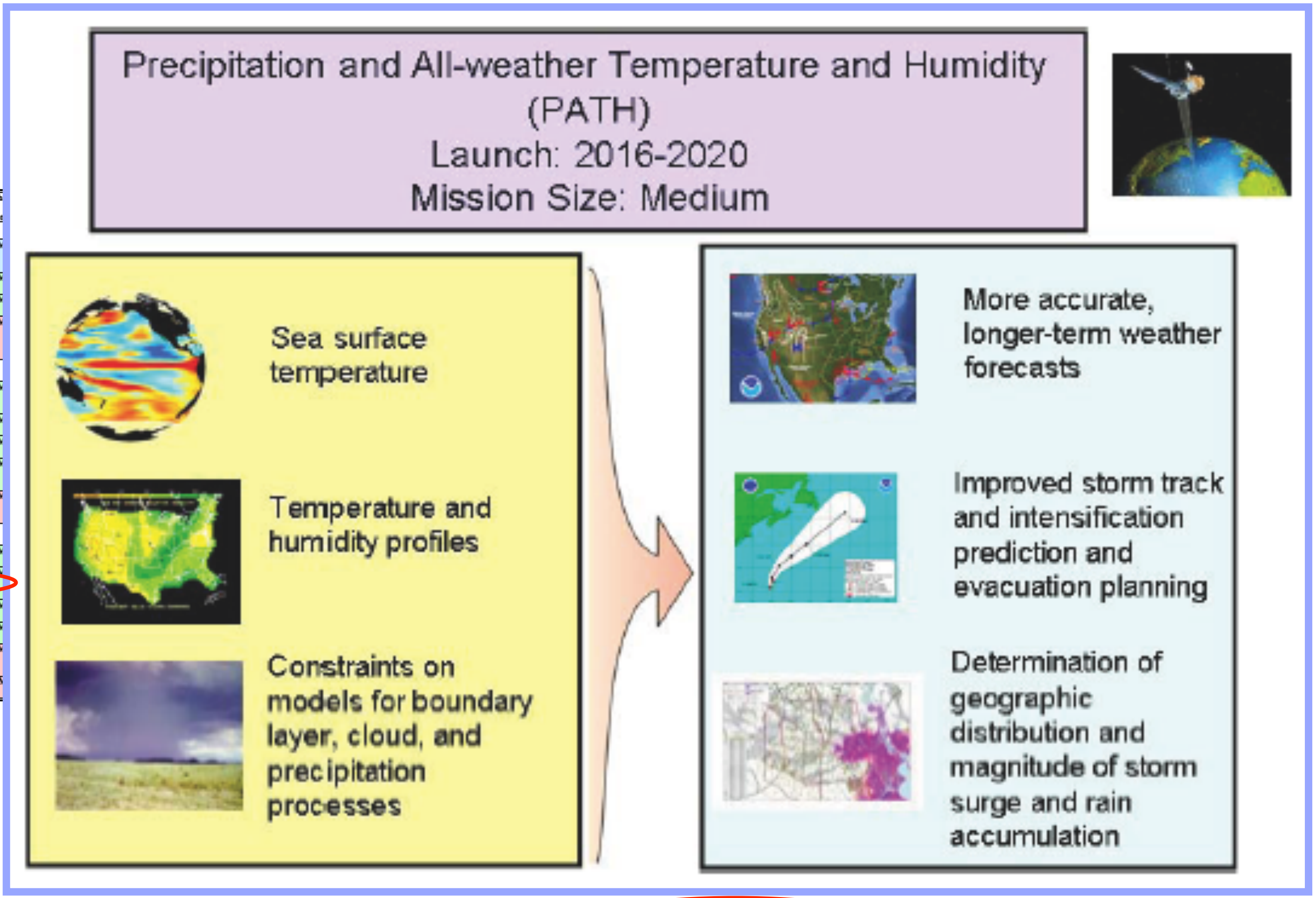
Earth Science Technology Forum
Pasadena; June 23-25, 2015

GeoSTAR Development History

Decadal survey: PATH mission



Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimat
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M



Precipitation and All-weather Temperature and Humidity (PATH)
Launch: 2016-2020
Mission Size: Medium

Sea surface temperature

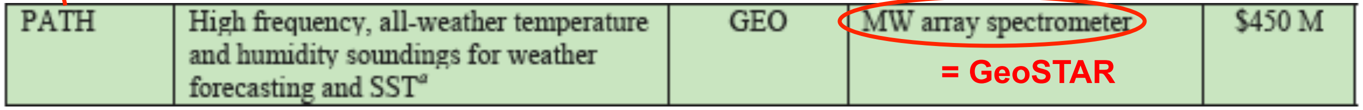
Temperature and humidity profiles

Constraints on models for boundary layer, cloud, and precipitation processes

More accurate, longer-term weather forecasts

Improved storm track and intensification prediction and evacuation planning

Determination of geographic distribution and magnitude of storm surge and rain accumulation



PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer	$450 M

= GeoSTAR

GeoSTAR timeline

- Concept development
  - NMP/EO-3 proposal (1998-1999)
  - NRC white paper (2005)
  - NRC Decadal Survey (2007)
- ESTO technology development
  1. IIP-03 (2003-2006): Proof-of-concept prototype
  2. ACT-05 (2006-2008): MIMRAM receivers
  3. IIP-07 (2008-2011): Key technology
  4. IIP-10 (2011-2015): Risk reduction
- Space implementation
  - *Venture mission (2020?)*
  - *PATH mission (~202X?)*

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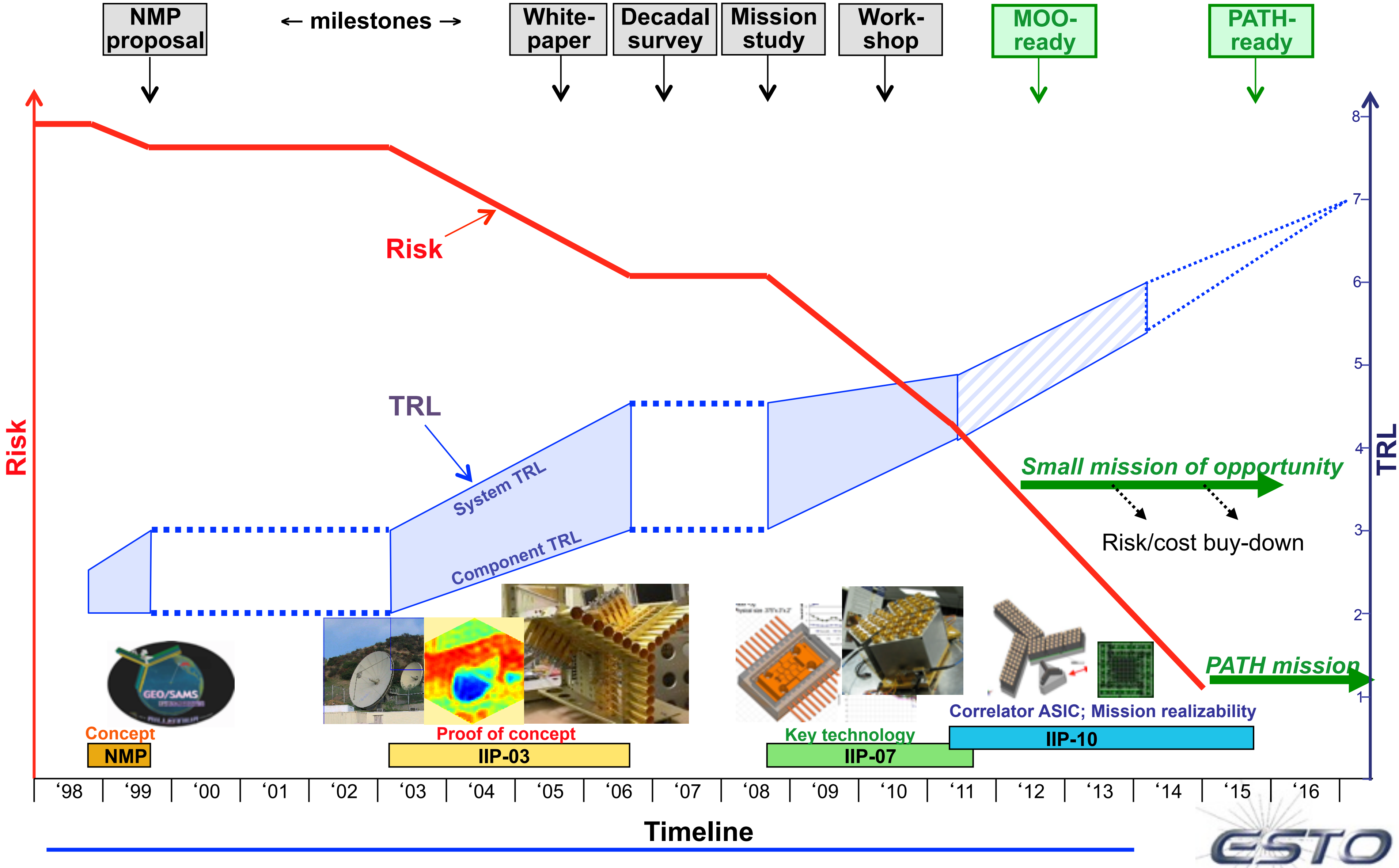
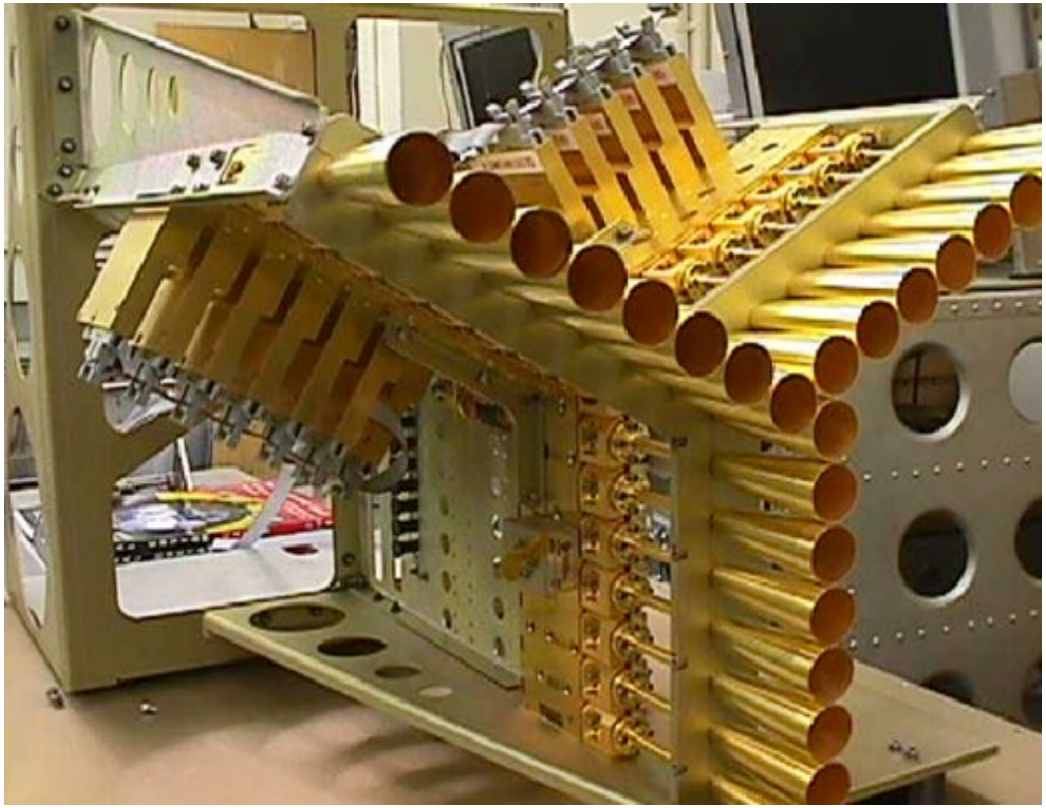
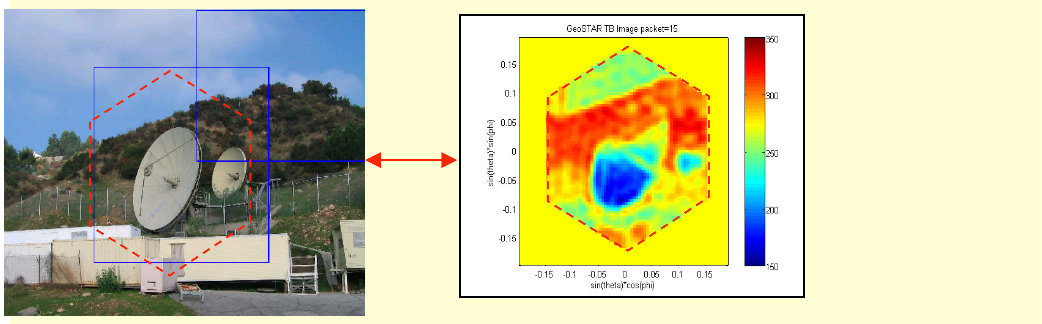
GeoSTAR timeline

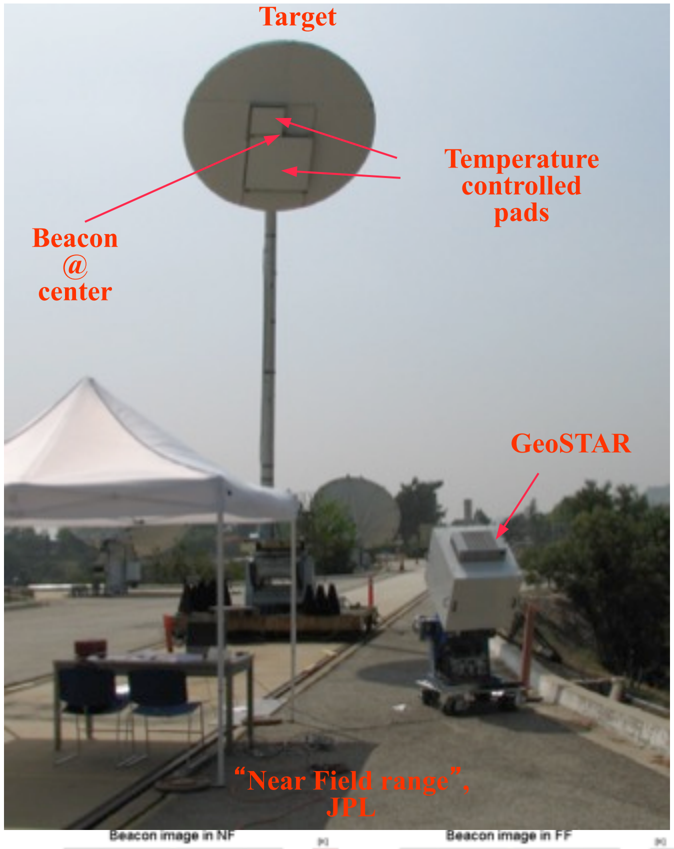


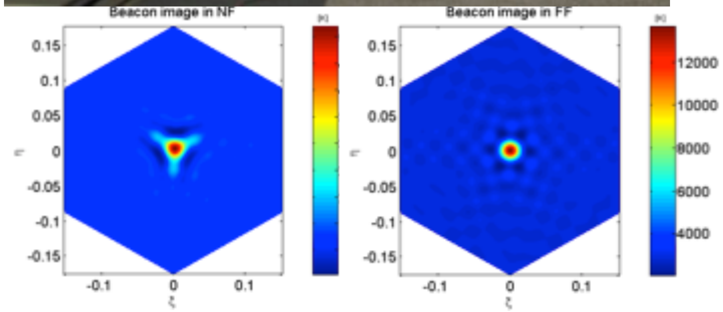
IIP-03: Proof of concept

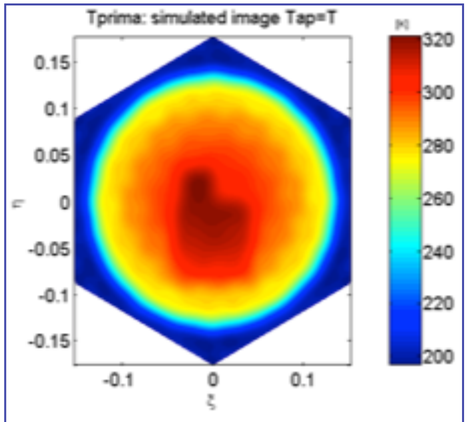




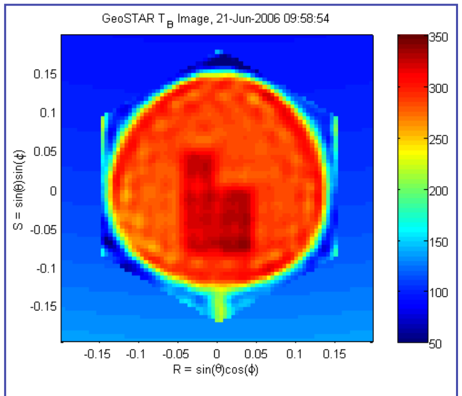
JPL R&TD: Calibration





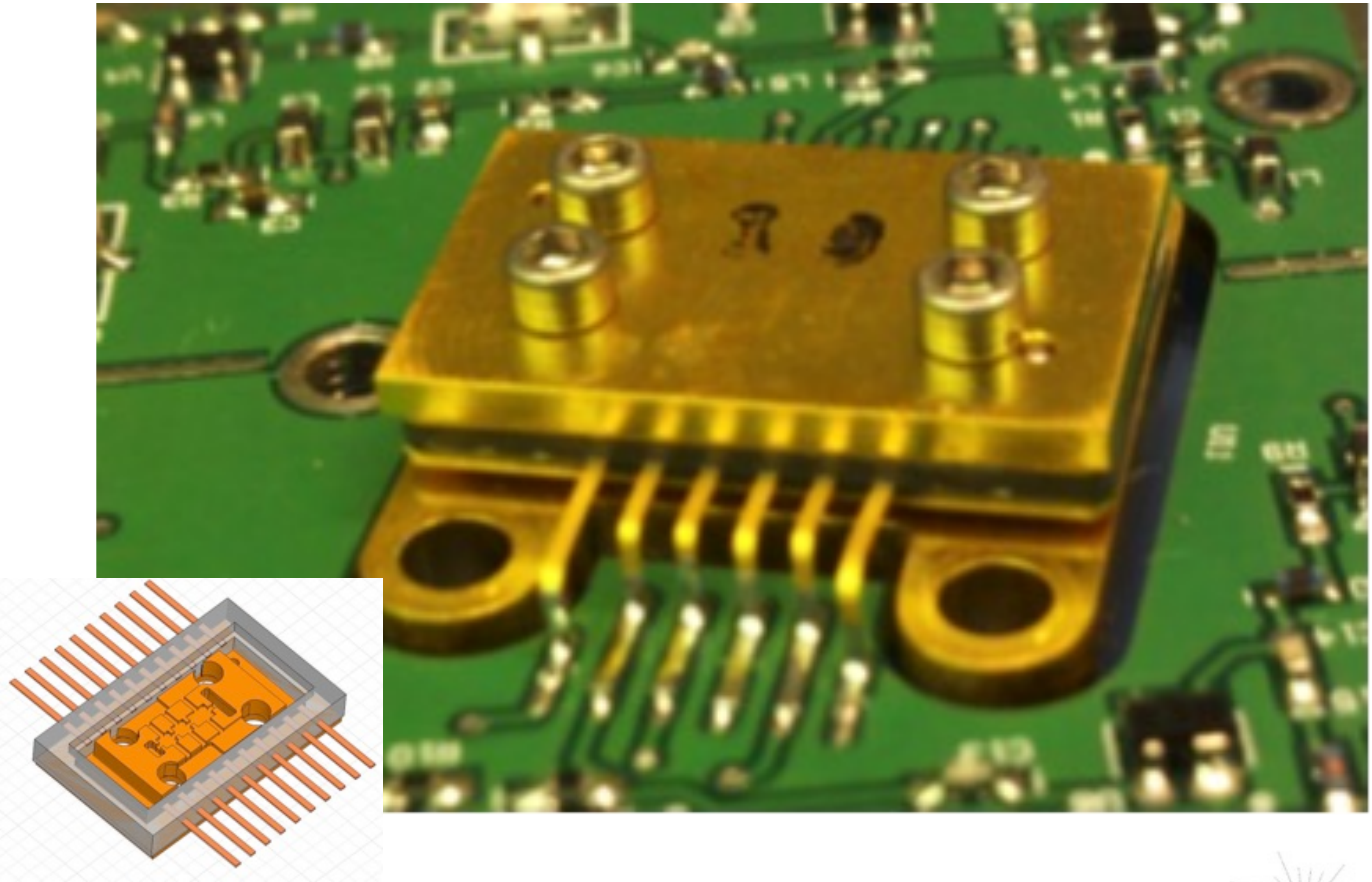


Raw synthesized image

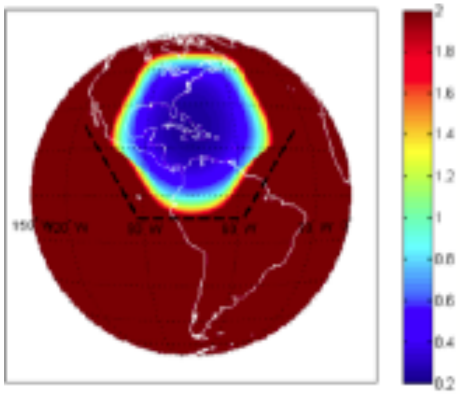


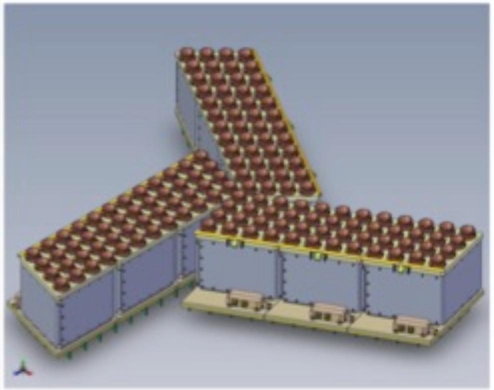
Processed image

ACT-05: MIMRAM

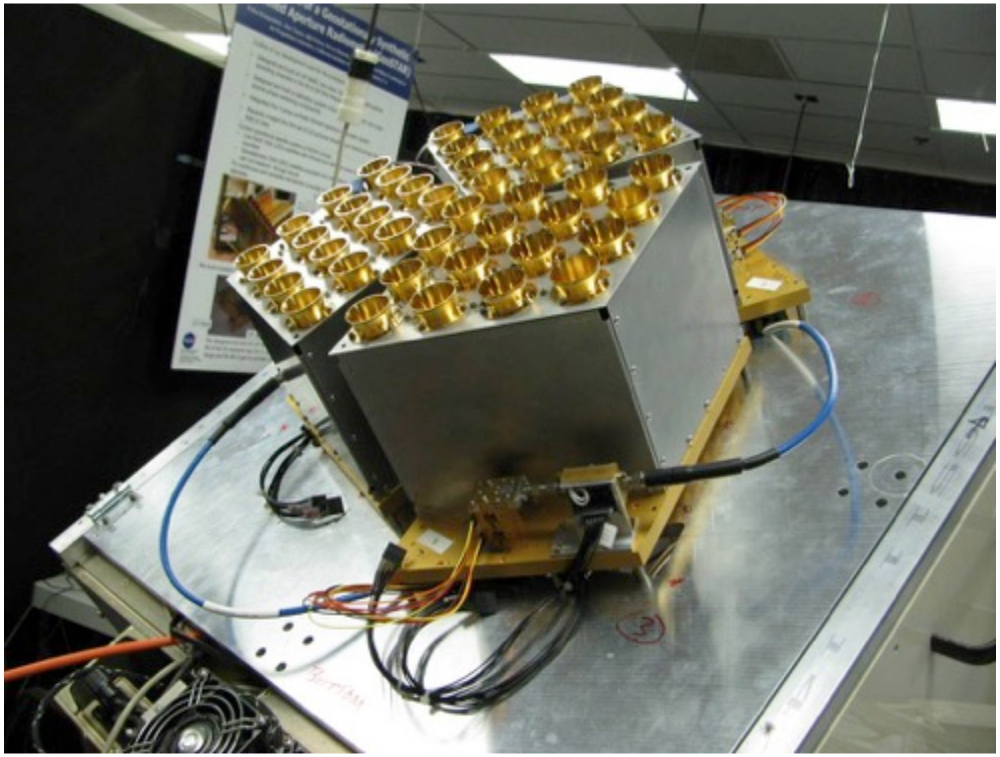


IIP-07: Architecture & technology





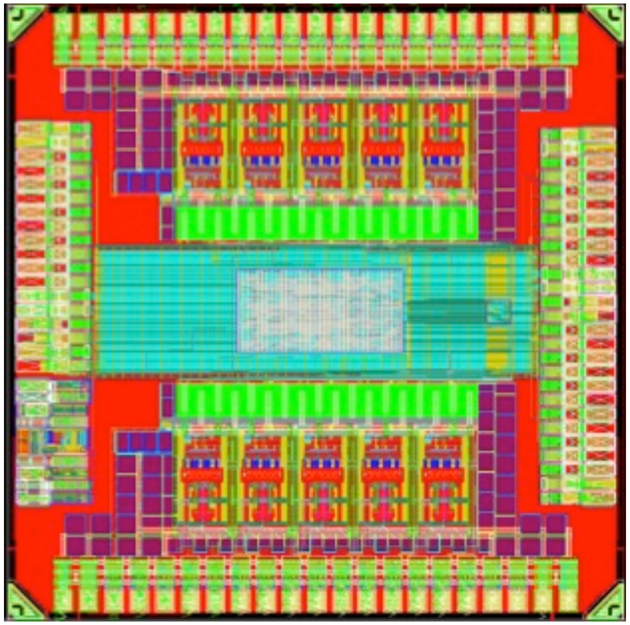
- Develop 50 low-noise 183-GHz receivers
- Develop 3 2x8-element receiver sub-array modules
- Develop low-power Application-Specific Integrated Circuit (ASIC) correlator chips
- Develop low-mass/power signal distribution system
- Develop functional 183-GHz 2D STAR prototype



IIP-10: Correlator – 5x5 test chip

A 5x5 digitizer/correlator and evaluation board was built to provide risk reduction for the development of the larger A/D correlator ASIC.

- Test A/D and correlator cells together to uncover design or implementation flaws
- Determine crosstalk between channels



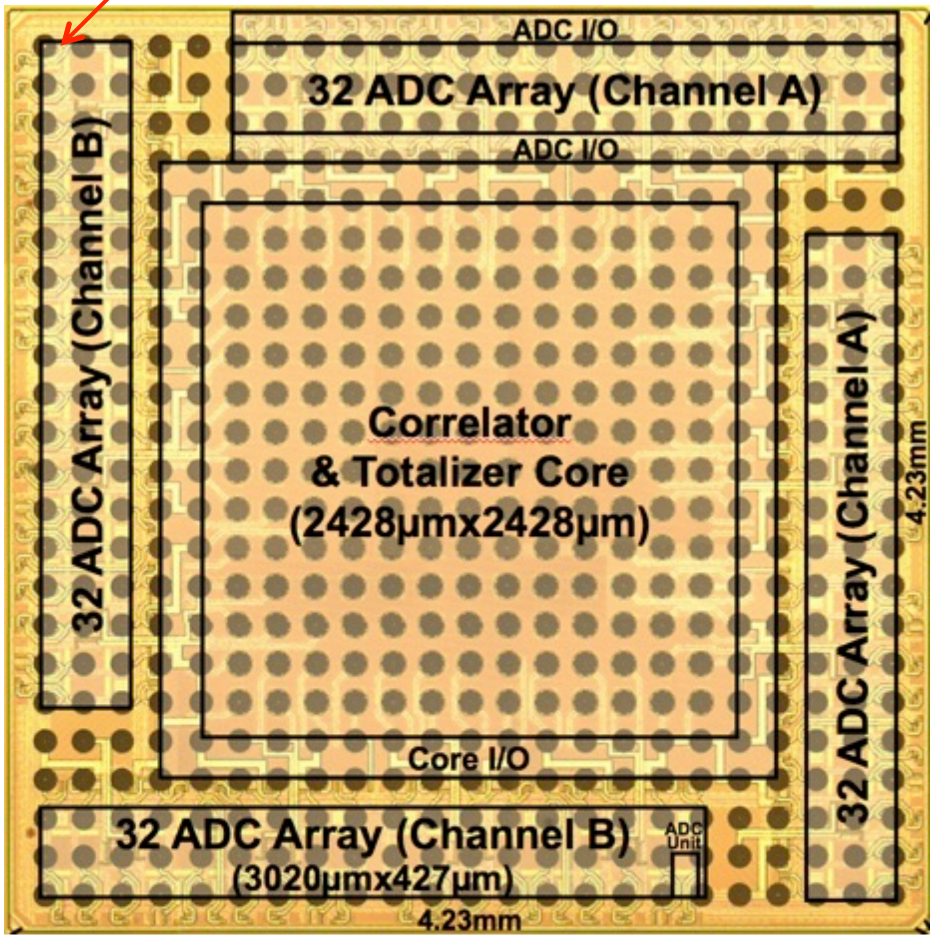
Initial tests indicated problems, but design was fixed, chip re-spun and tested

Tested for rad-hardness: OK

IIP-10: Correlator 64x64 chip

Chip orientation

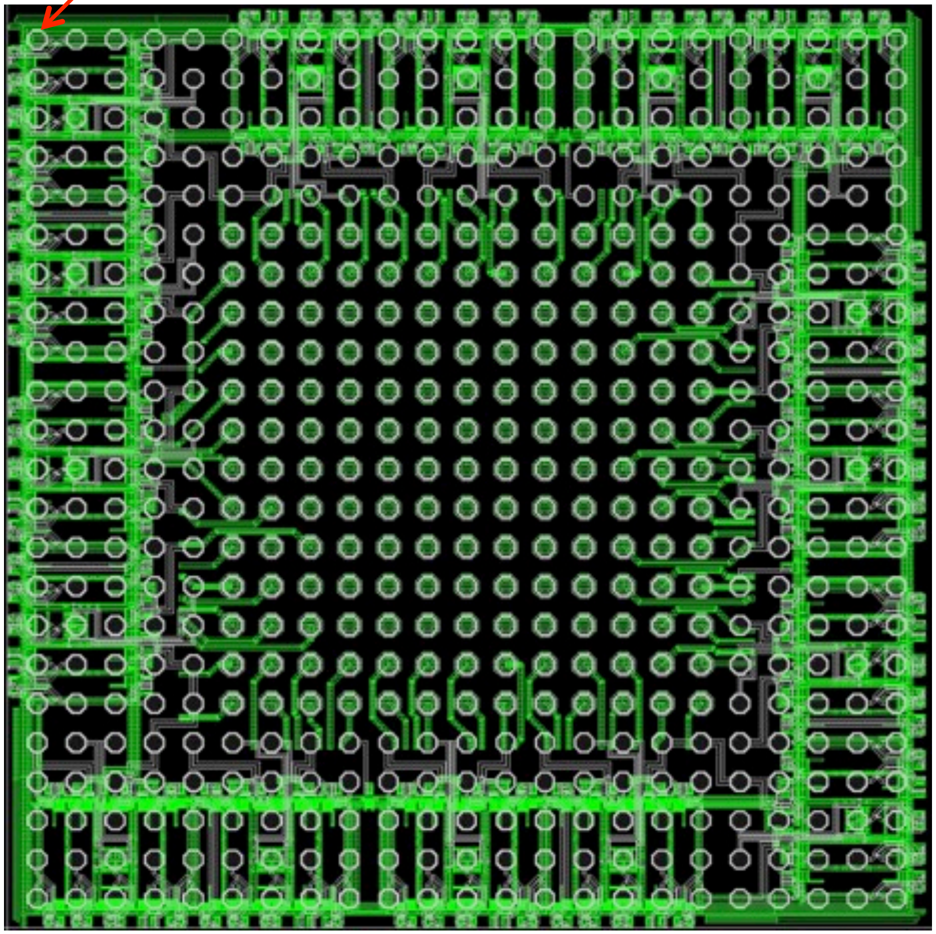
Pin A1



- Die Photo -

Pin A1

24x24 = 529 pins



- Layout (M9, AP) -

Correlator Test Board

Test system allowed only four independent inputs and on-board switches and dividers to excite all ASIC inputs

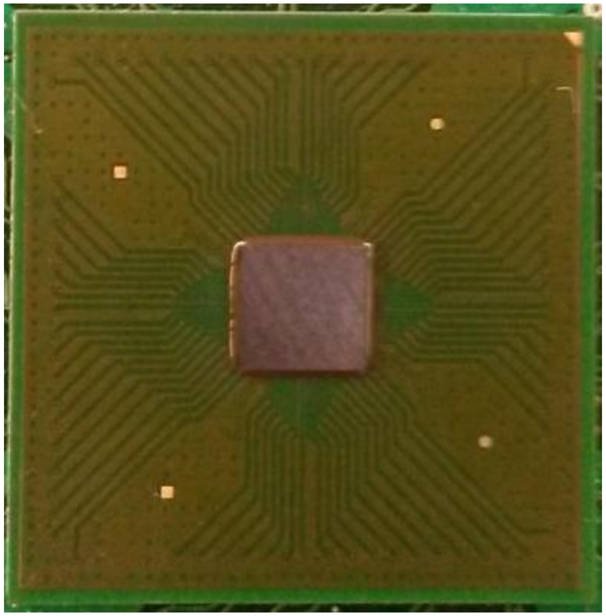


Figure S2: The correlator die is flip chip bonded to a custom-designed 576 pin 8-layer substrate.

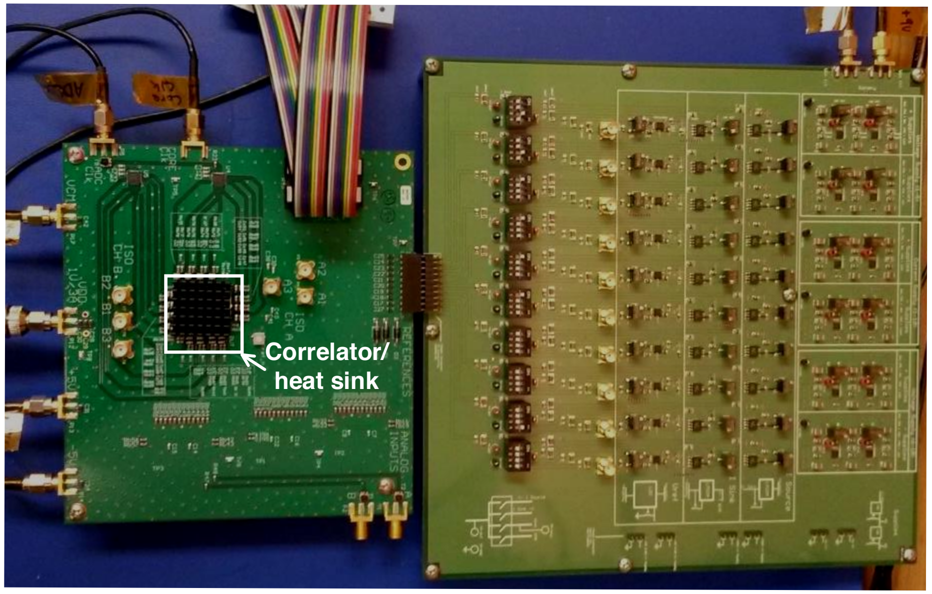
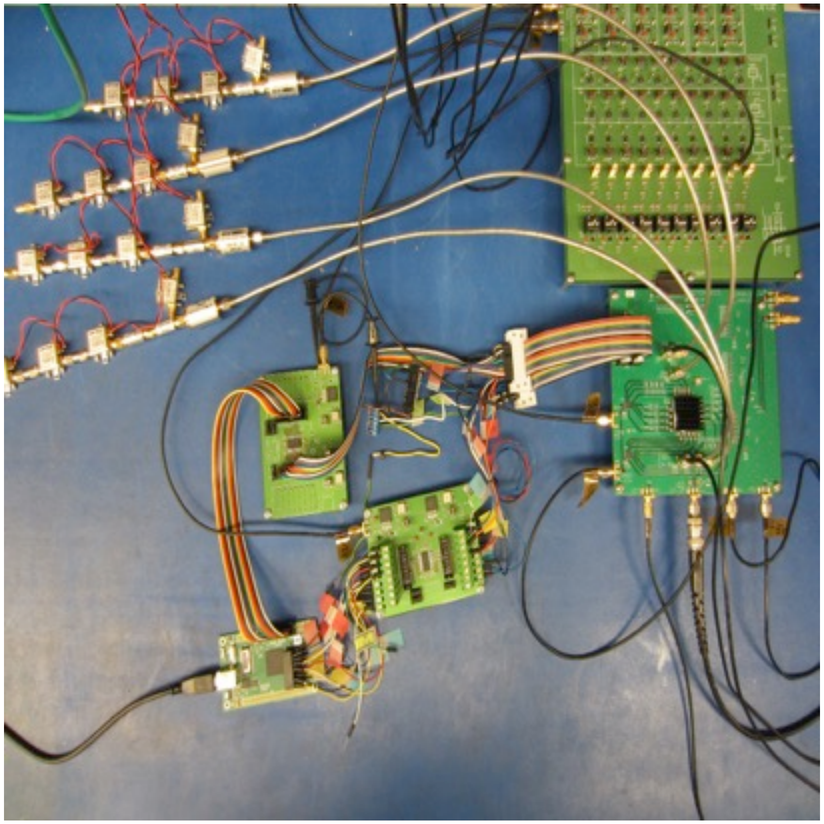


Figure S3: Test circuit board and test setup.

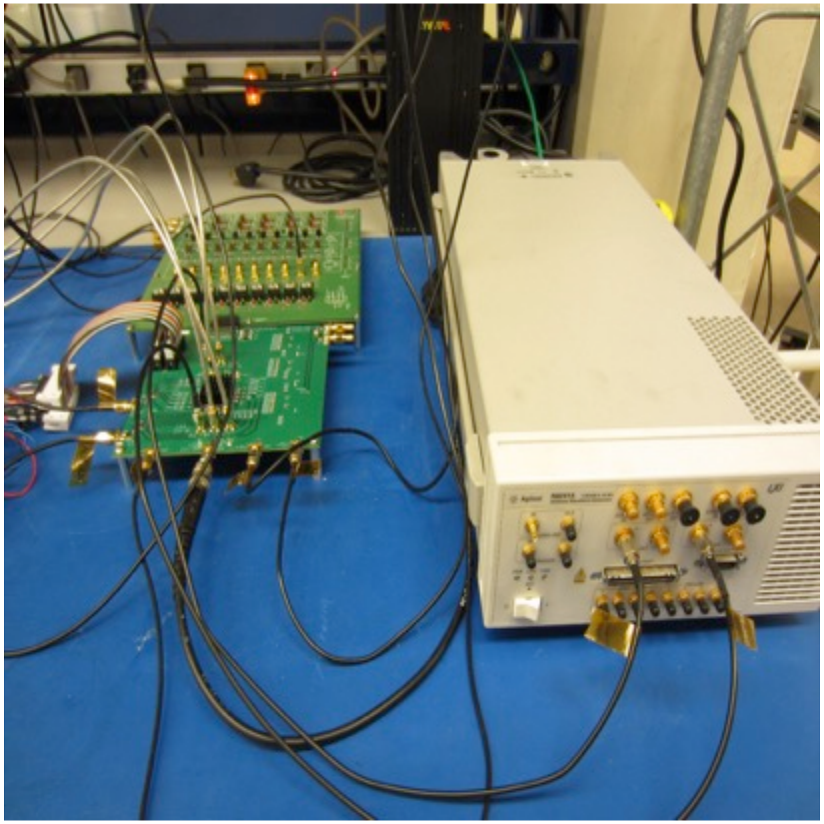
General Test Configuration

- Test board designed by EECS
  - Hard-wired input ports for a 3x3 subarray of adjacent channels
  - A13-A15, B13-B15
- Inputs
  - 2-channel AWG on one A-side, one B-side input, drives the correlator cell of interest
  - Adjacent inputs driven by independent amplified Johnson noise (uncorrelated white noise)
- Nominal clock: 1 GHz (sig gen max of 990 MHz)
- Nominal integration time: 10 ms



Correlation Efficiency

- 2-channel AWG sends 100% correlated or anti-correlated white noise signals to two ASIC input channels with input power of -25 dBm
- Resulting digital correlations are mapped to analog using totalizers
- Ratio between the analog correlation obtained and the analog correlation of input signal (here, unity) is the correlation efficiency.
  - Observed to be between 97% and 98% for the nine cells tested (averaged in 25 repeated samples)



IIP-10: ASIC preliminary test results

Chips assembled and tested on EECS test board

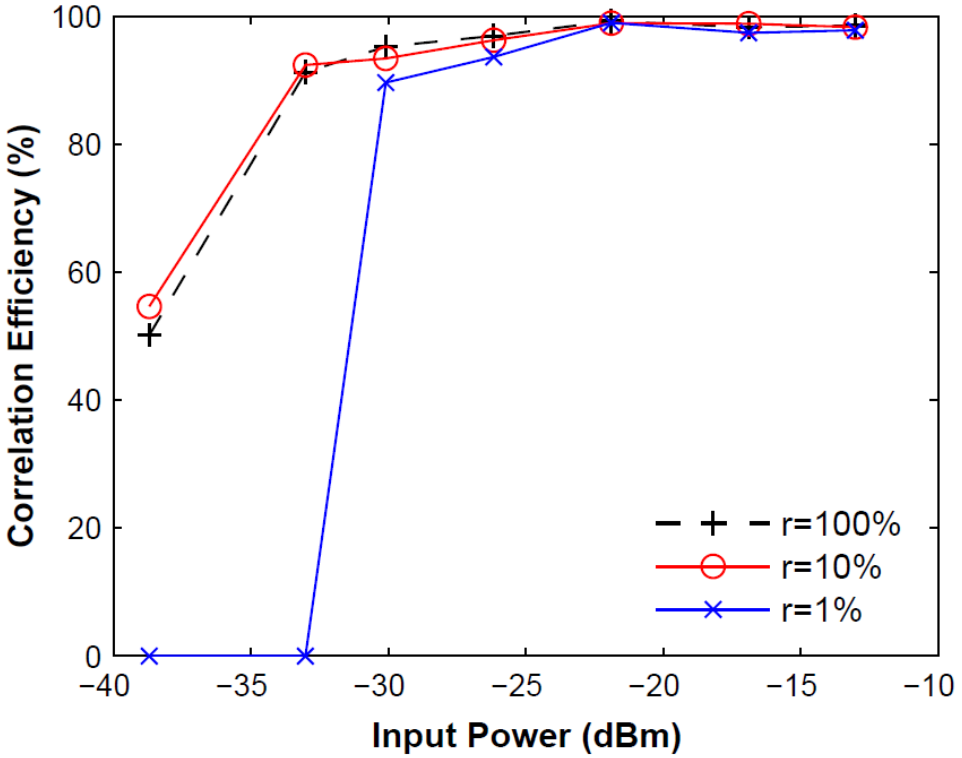
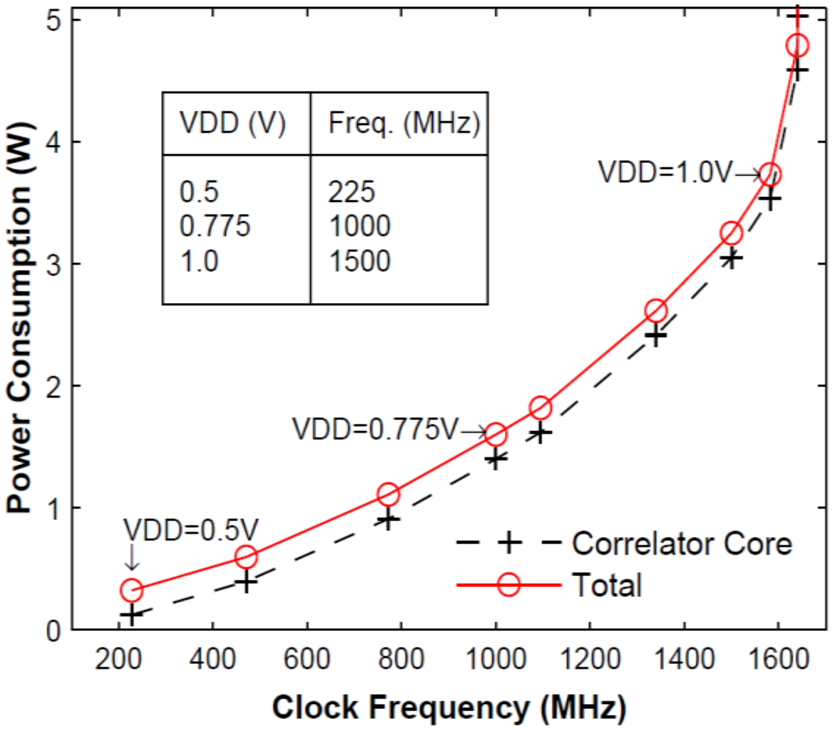


Figure 5: Correlation efficiency of the test chip. (r = 100% represents when the two channels receive 100% correlated inputs; r = 10% represents the two channels receive 10% correlated inputs and so on.)

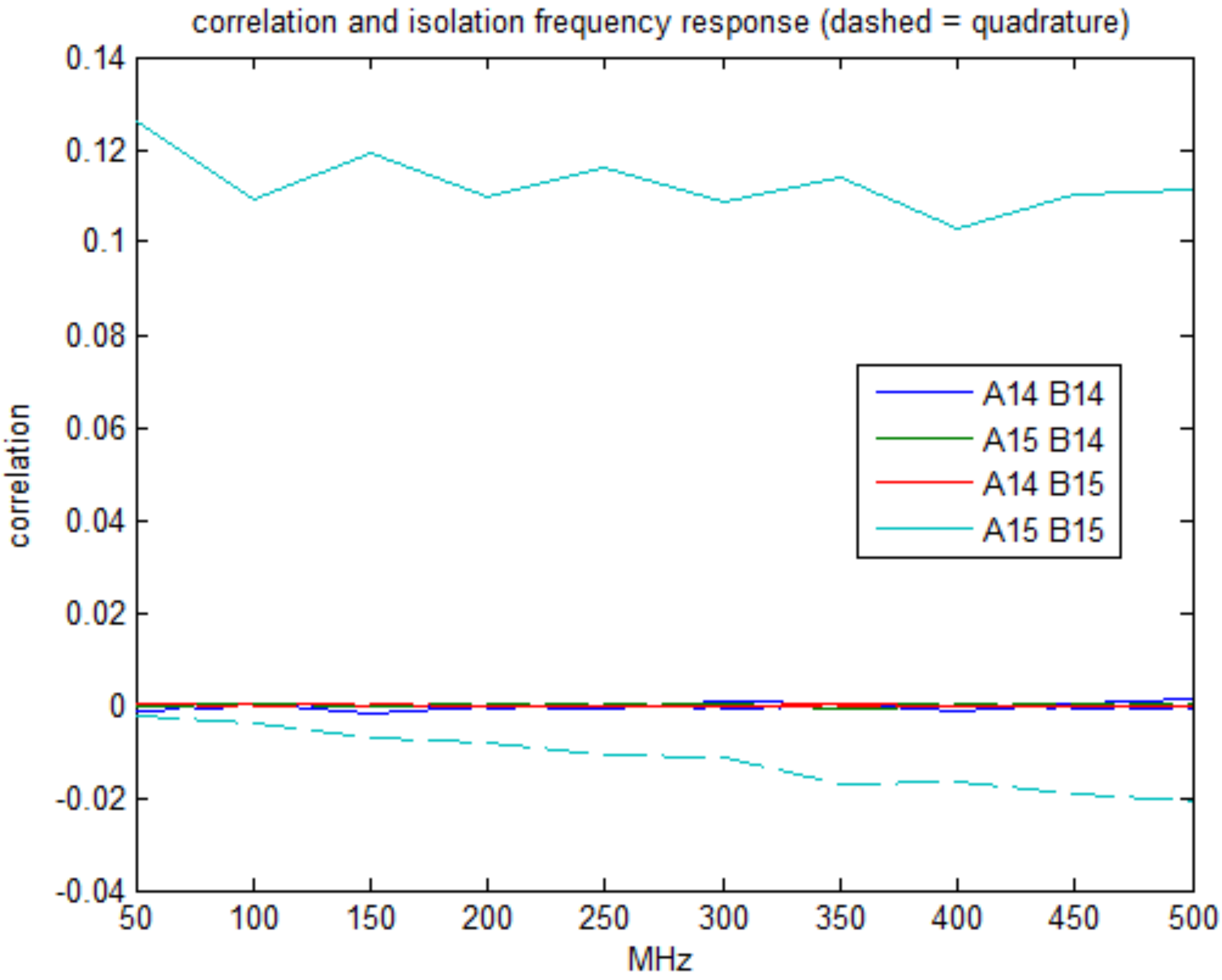
ASIC Correlator Measured Performance



	This work
# of Channels	128
# of Correlators	4096
Channel Bitwidth	2
On-Chip ADCs	yes, 128
Logic Family	static
Correlation Efficiency (%)	>90% @ >30dBm
Isolation (dB)	-42.4
Technology	65nm
Total Power (W)	1.44 @775mV, 1GHz 3.73@1V, 1.5GHz
Energy per Correlation (pJ/correlation/cycle)	0.35 @775mV, 1GHz 0.61 @1V, 1.5GHz (2b corr + ADC)
Core Area (mm^2) Chip Area (mm^2)	5.9 17.9
Max Performance (T correlation/s)	6.14 @1V, 1.5GHz

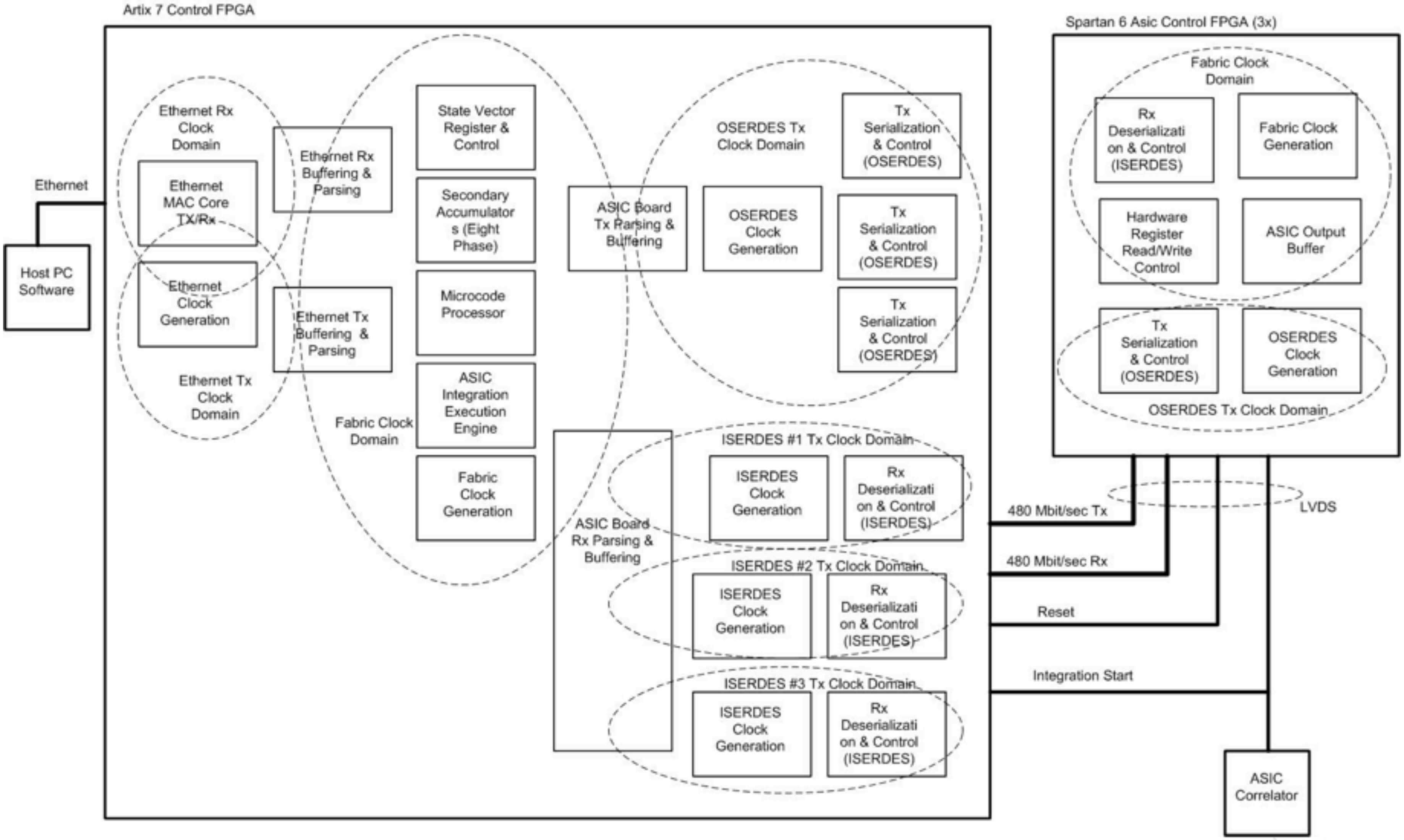
[a]: a 1-bit correlation is just XOR

Correlator ASIC Frequency Response

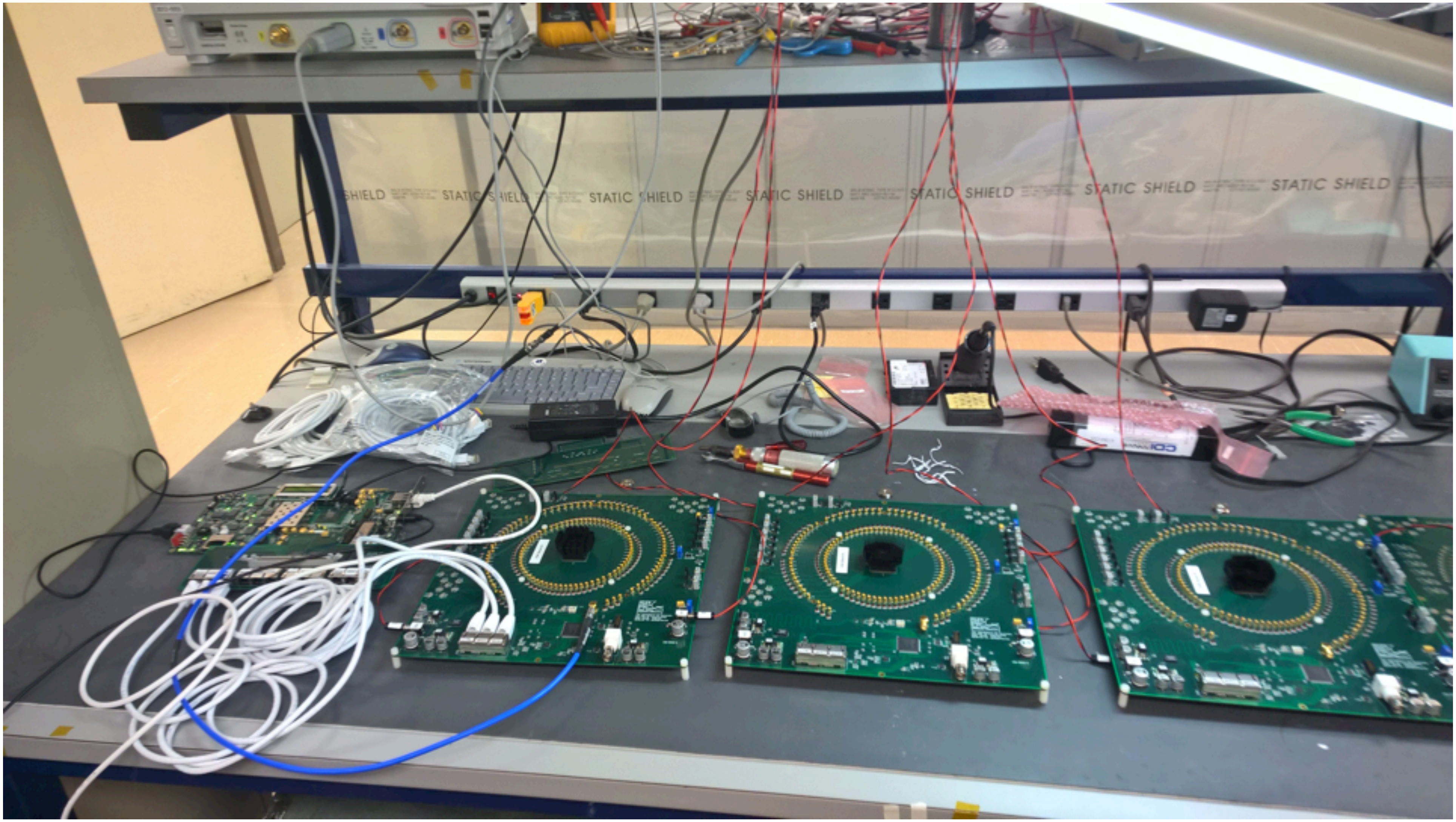


Note: quadrature channel should be 0, but has small leakage. That is in the test set .

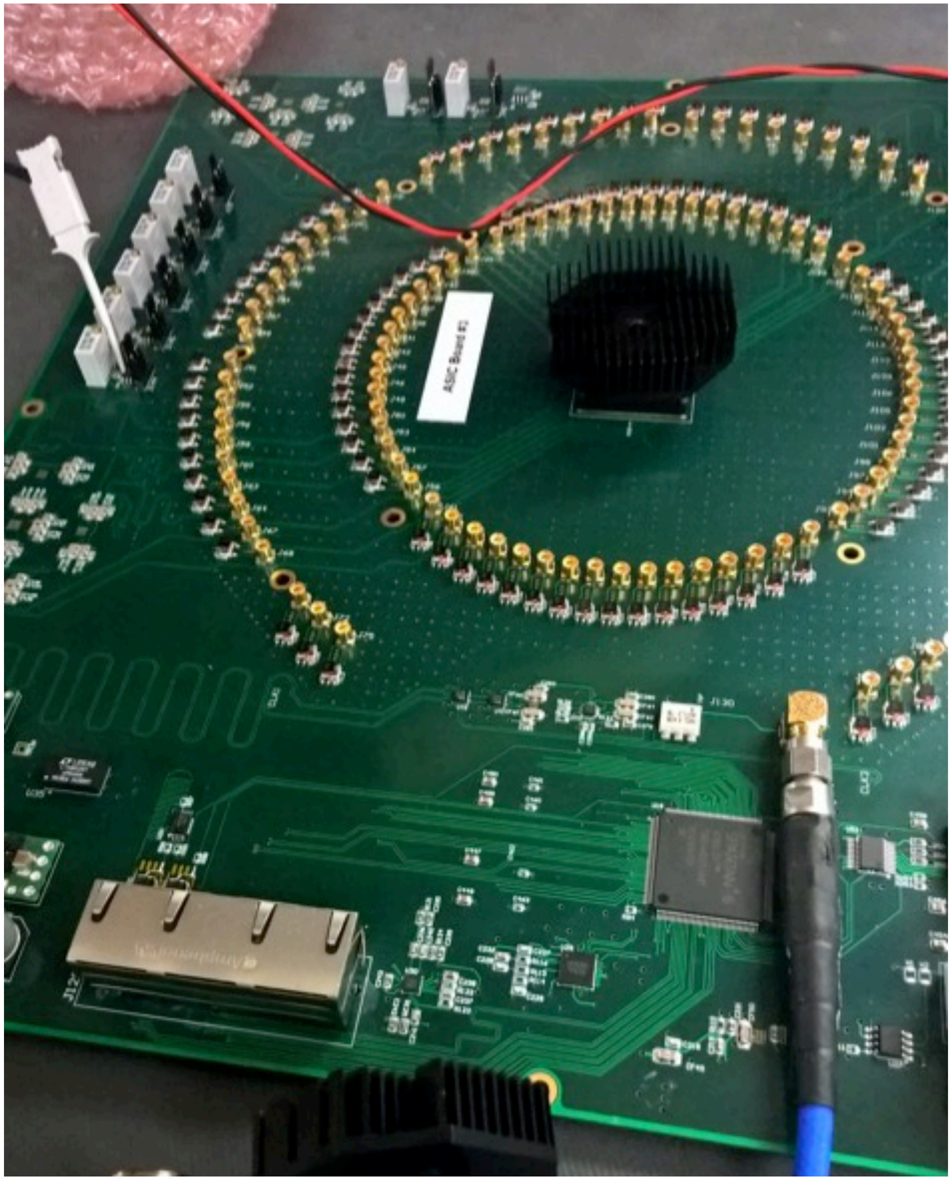
IIP-10: ASIC full system test boards



IIP-10: ASIC full system test boards



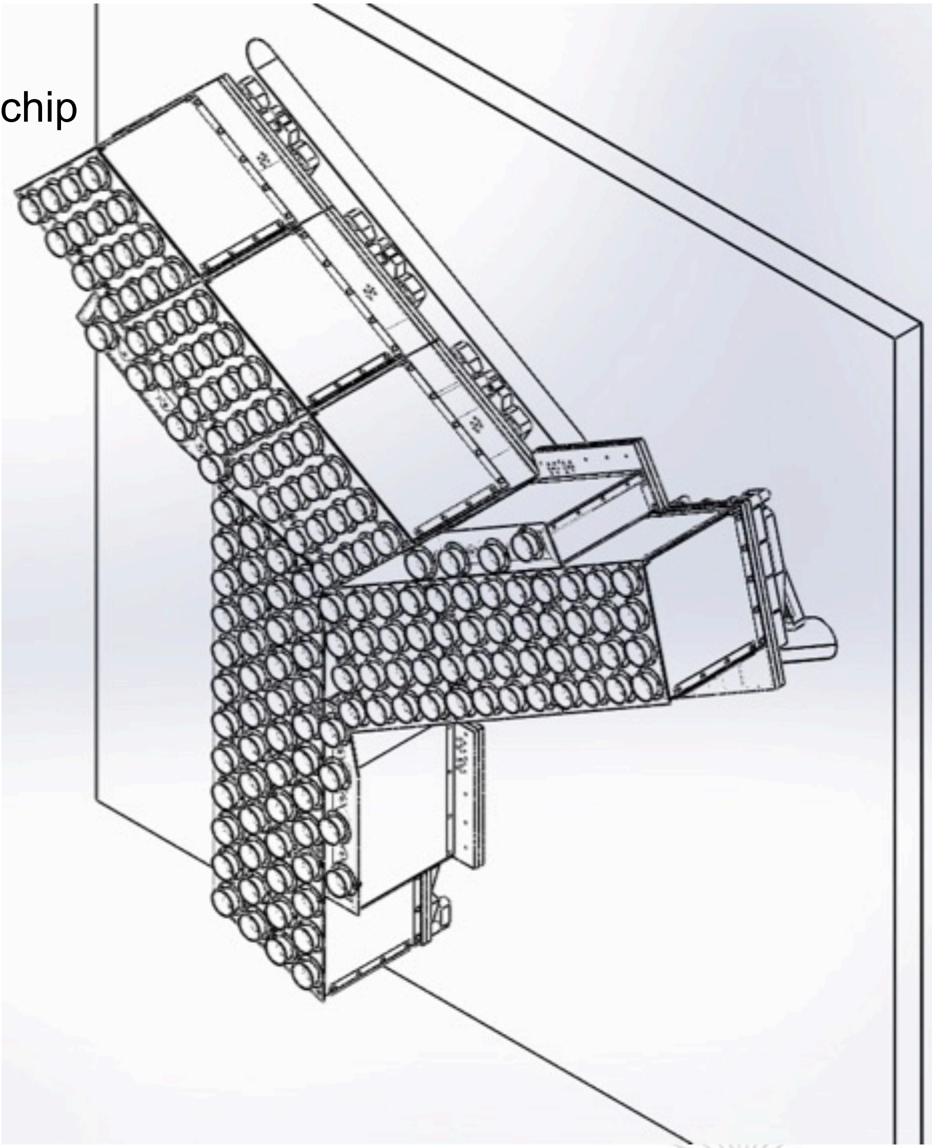
IIP-10: ASIC system test board

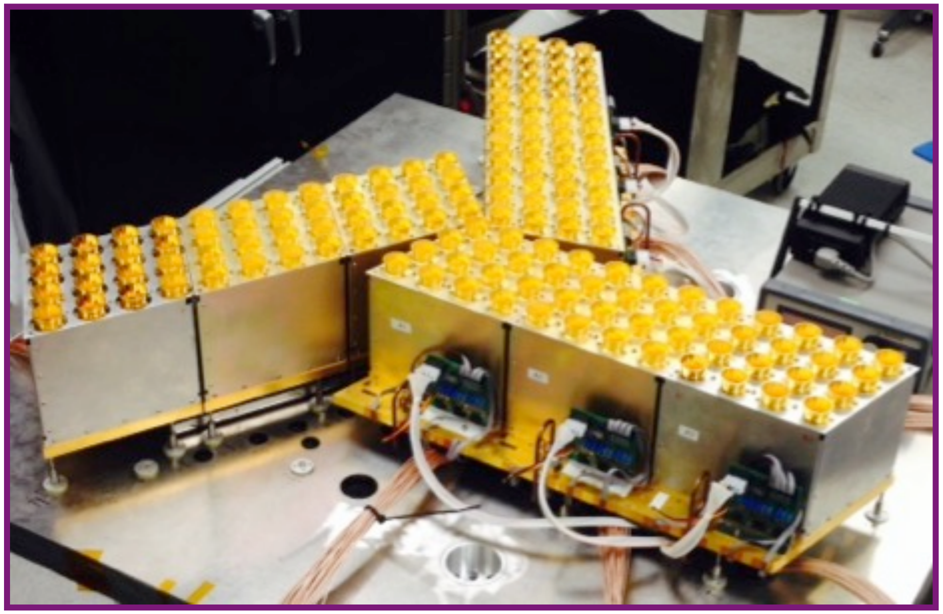


IIP-10: System testing

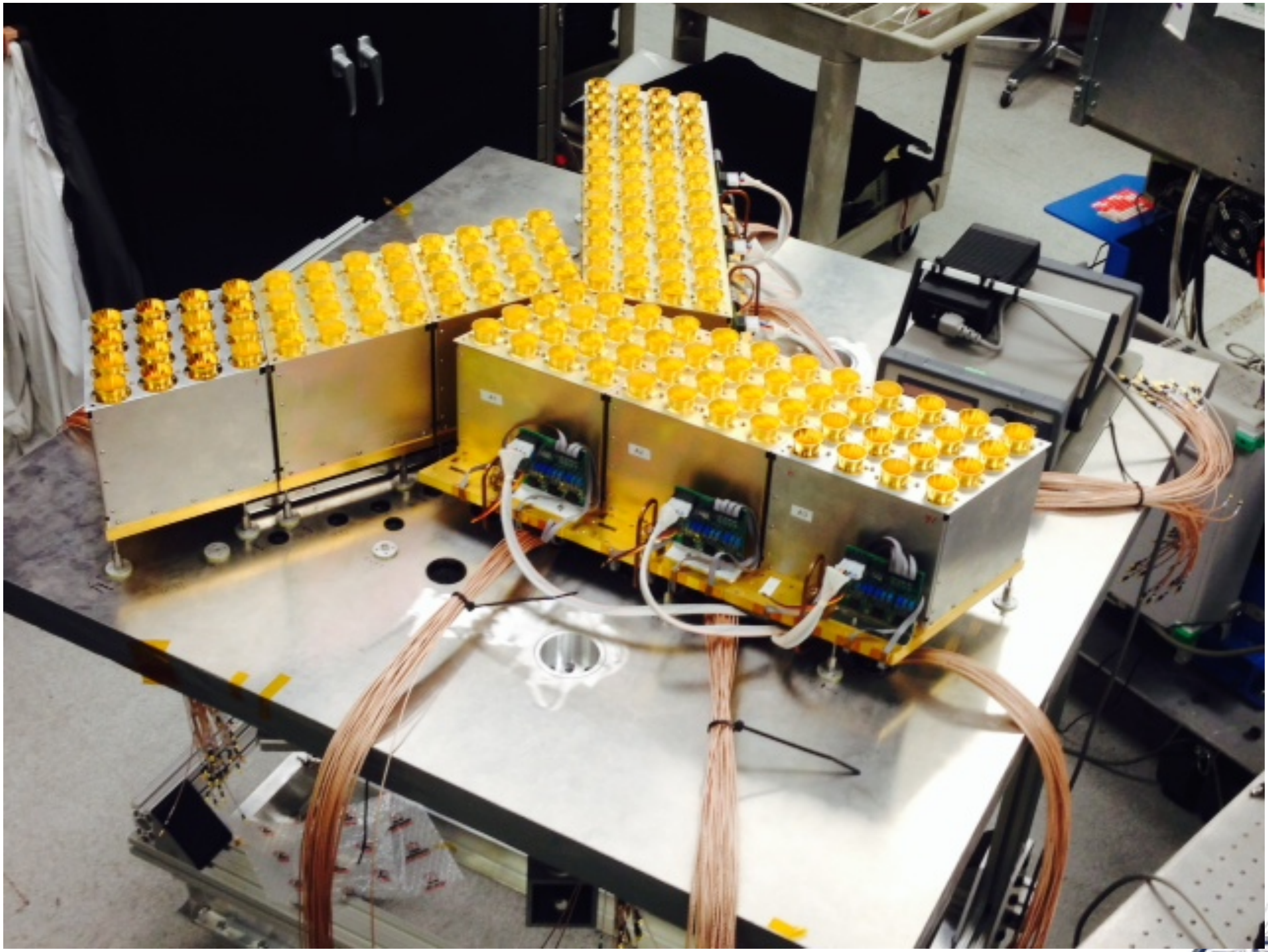
Awaiting completion of correlator test board

- Further testing of correlator ASIC
  - Complete full correlator board hosting new chip
  - Full functional testing of new chip
- System testing
  - Assemble small 183-GHz antenna array
    - Using miniature ultra-low-power MIMRAM receivers
  - Integrate full system with correlator
  - Characterize system performance
  - Imaging demonstration





System Integration

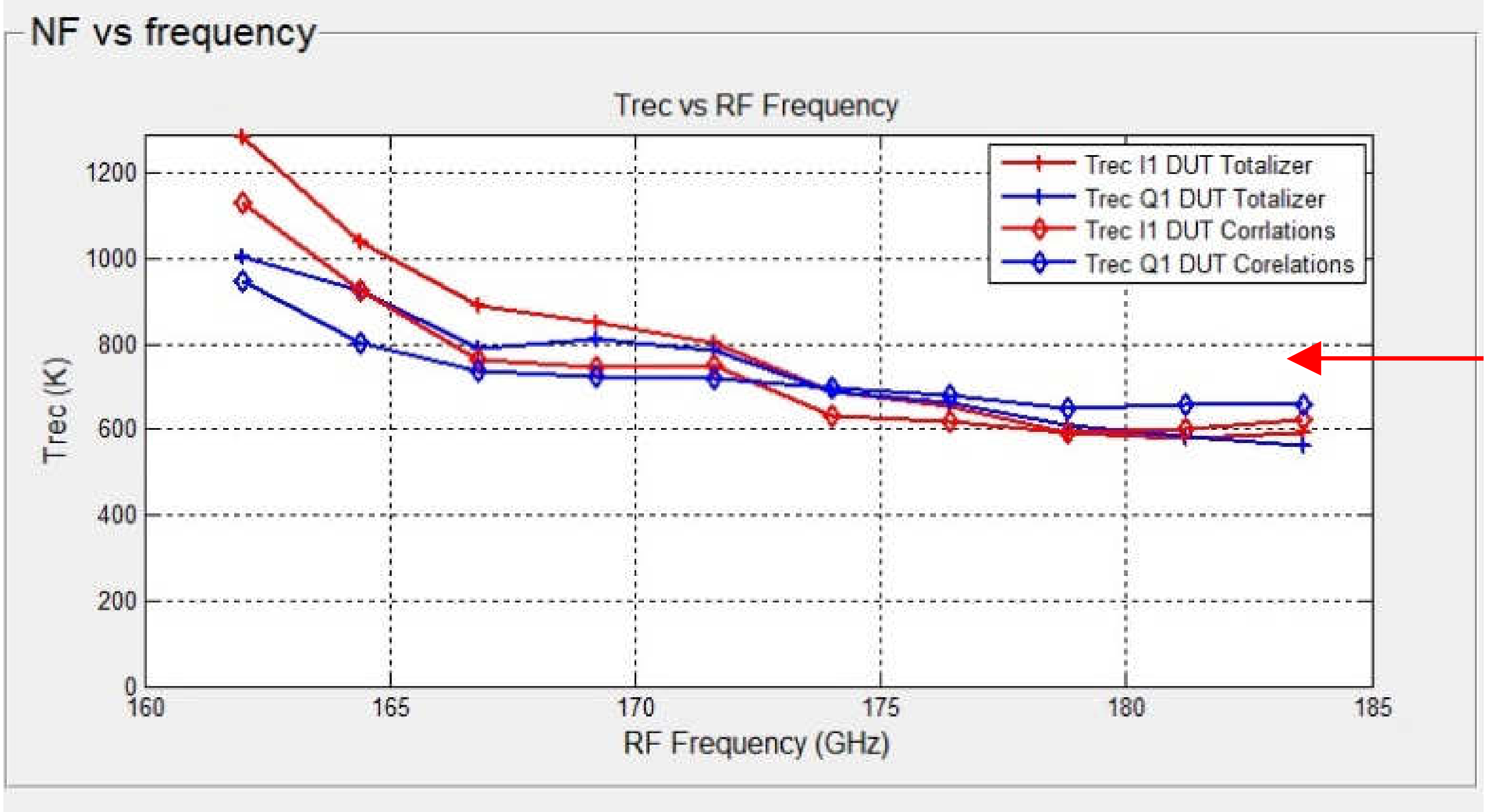


System Integration

Table assembled
Tiles assembled
Power supplies integrated
LO integrated
IF cables installed
Synthesizer Installed

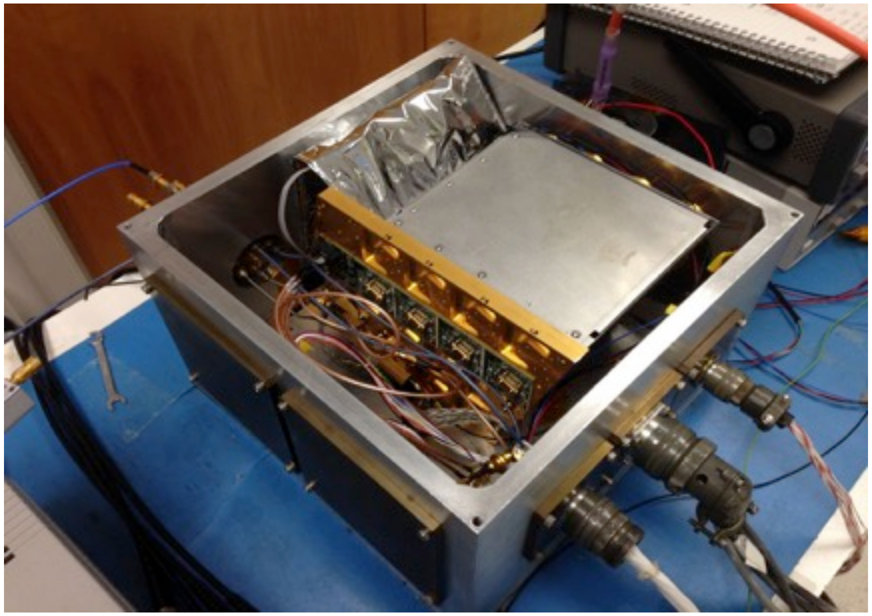
135 Receivers Populated

FPGA-based system level performance for a typical receiver.

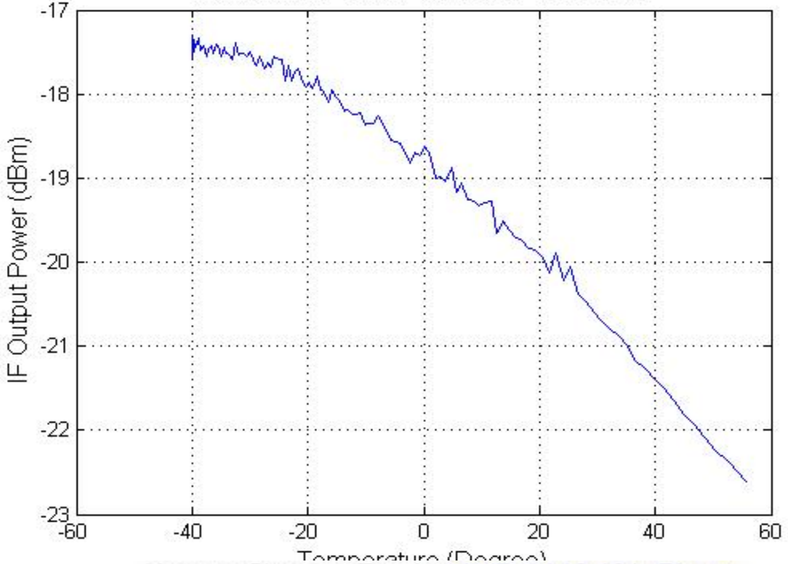


Tile TVAC Tests-Raising TRL

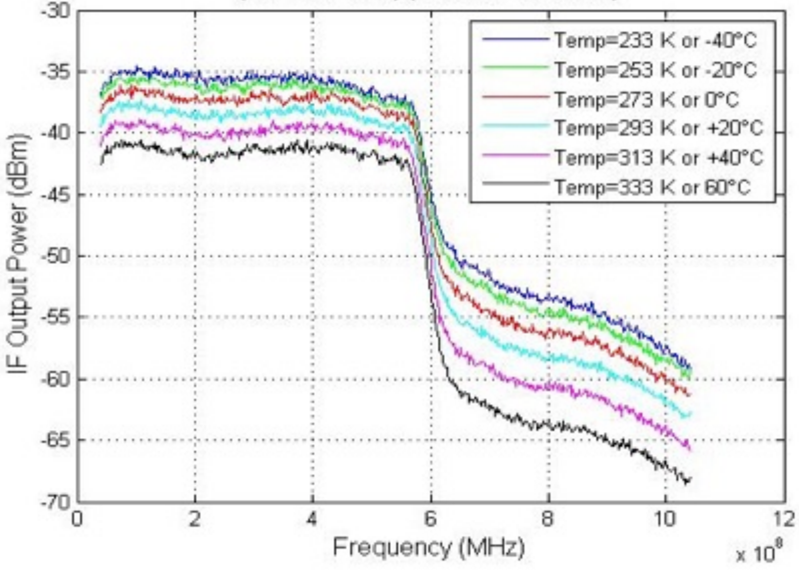
(beyond proposed scope)



IF Power vs Temperature
MIMRAM 16-04 In-Phase (LO=13.5 GHz)



Vacuum Chamber Test for MIMRAM 16-10 In-Phase
(LO 13.5 GHz) (Data 05-07-2015)



Tested in vacuum (<10^{-4} torr) over AFT± 10° C

4 IFs monitored, one continuously

Tile/Board/MIMRAM Random Vibe Tests

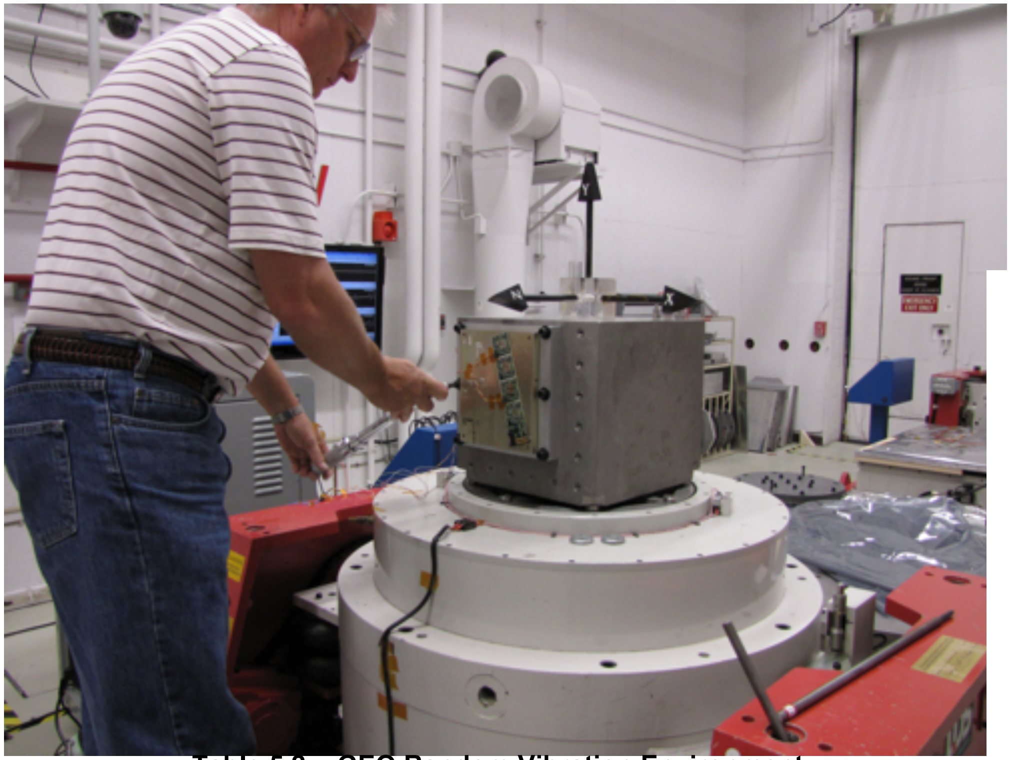
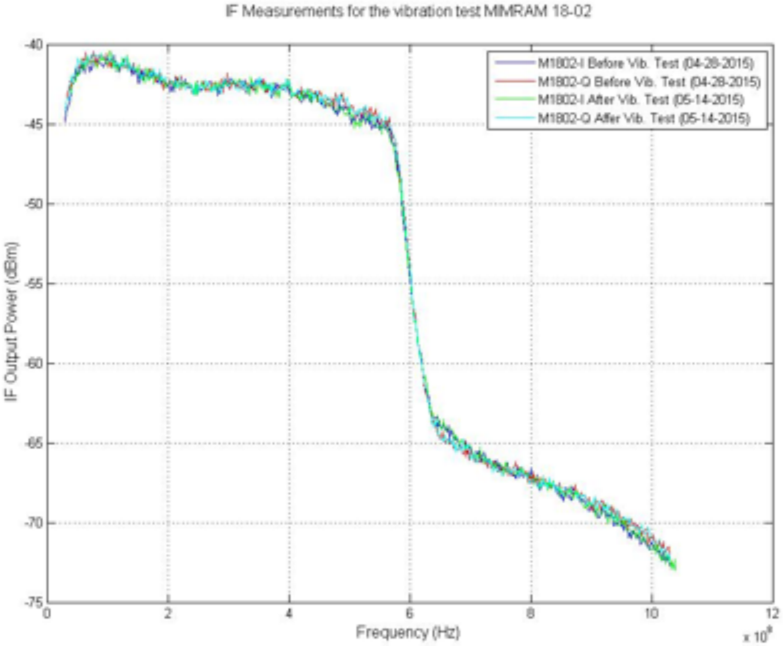


Table 5.2 - GEO Random Vibration Environment

Frequency (Hz)	**Level**
20	0.4 g^2/Hz
20 – 50	+3 dB /octave
50 – 500	1.0 g^2/Hz
500 – 2000	-4 dB /octave
2000	0.16 g^2/Hz
Overall G_{rms}	32.1

Test duration: 120 seconds

Pre- and post-vibration data



What can we do with GeoSTAR?

TIME TESTED MEASUREMENTS AND DATA PRODUCTS USING MATURE ALGORITHMS

GeoSTAR will make similar measurements from GEO as AMSU currently does from LEO, but every 15 minutes vs. 2 times per day

High-intensity events can be sampled in 5 minutes or less

GeoSTAR will uniquely provide measurement of
Temperature/moisture/clouds; Wind; Precipitation
simultaneously, continuously and in 3 dimensions

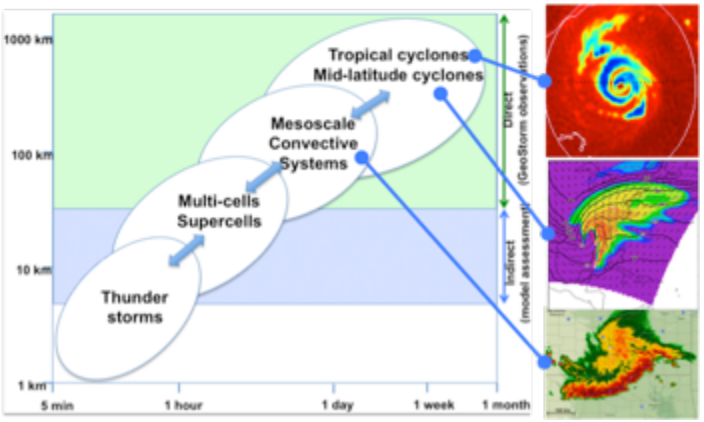
Parameter	Horizontal	Vertical	Temporal	Precision	Accuracy	Thermodyn.	Microphys.	Dynamics
Brightness temperatures	25 - 50 km	N/A	5-20 min.	0.5-1.5 K	0.5 K			
Temperature	25 - 50 km	2-3 km	10-20 min	1.5 K	0.5 K	√		
Water vapor				25%	10%	√		
Wind vector (u,v)				5 m/s	2 m/s			√
Reflectivity				4 dBZ	2 dBZ		√	
Rain rate		N/A		5 mm/hr	50%	√	√	
LWP				25%	10%	√		
IWP				25%	20%	√	√	

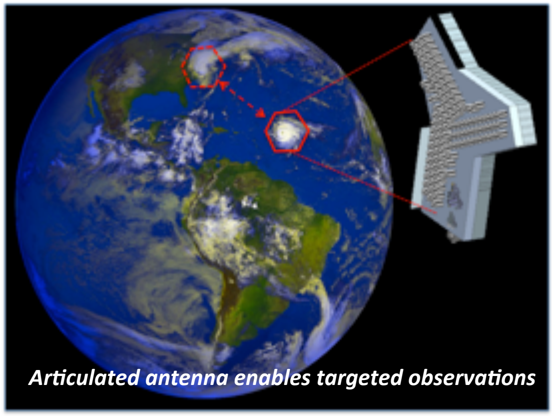
Precision & accuracy reflect performance of MIRS (except for reflectivity)

GeoStorm

Improve our understanding of sudden and unpredicted change in intensification and motion of destructive storms:

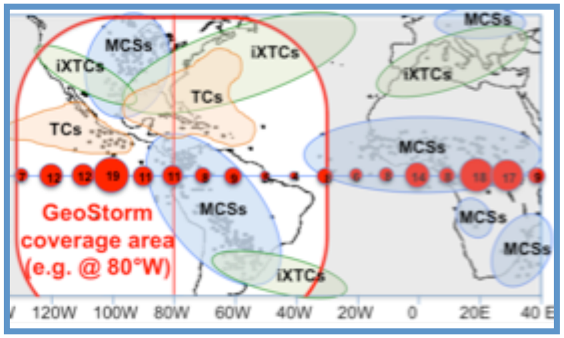
- ***hurricanes***
- ***severe thunderstorms and mesoscale convective systems***
- ***mid-latitude cyclones and winter storms***




Articulated antenna enables targeted observations

Low cost as a hosted payload

Many hosting opportunities in GEO:



There are more than 80 GEO comm-sats that provides a view of the Americas, being replaced at a rate of 5-6 per year

GeoStorm Highlights	
Targeted observations	Life cycle storm tracking
Time-continuous	Capture dynamic processes; diurnal cycle fully resolved
Multiple simultaneous key parameters	Temperature, humidity, precipitation, wind
All-weather	Cloud/rain-penetrating
3-D observations	1000 km dia x 15 km vert. (volume); 25 km dia x 3 km vert. (resolution)
Wide coverage	All storms visible from GEO

Summary

- STAR concept demonstrated in IIP-03
  - Developed a functional 50-GHz STAR demonstrator
- Key technologies developed in IIP-07
  - Developed miniature low-power 183-GHz MMIC receivers
  - Developed new alias-rejecting antenna array design
- Ready for PATH mission after IIP-10
  - Full-size 64x64 correlator ASIC is a success!
  - Can start development ~2015 → launch ~2020

- We have advanced the technology from Tier-3 level to Tier-1 level – a major achievement