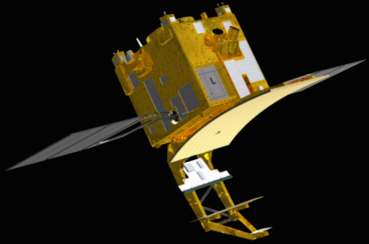
NORTHROP GRUMMAN



Technology Development for a Wide-swath Shared-aperture Cloud Radar (WiSCR)

Earth Science Technology Forum

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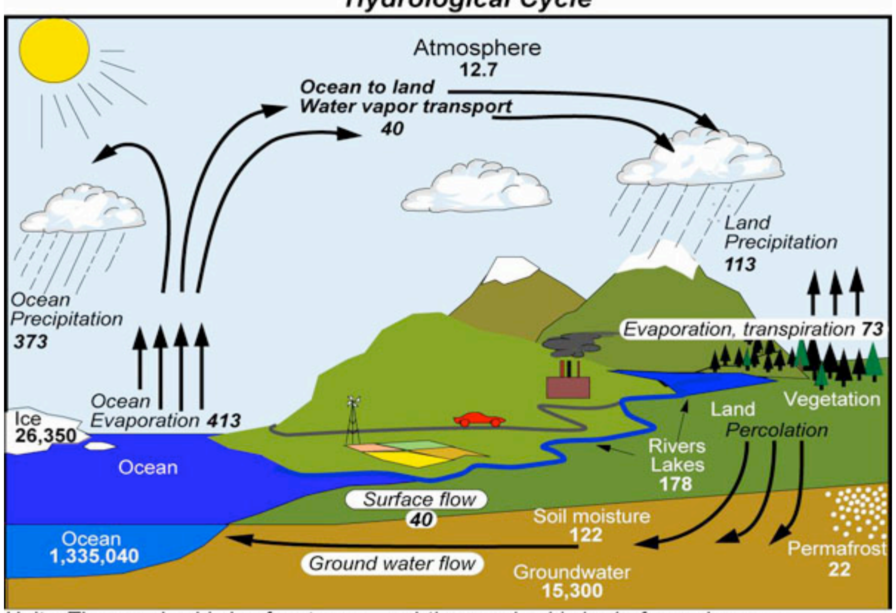
Outline

- Why Multi-band Wide-swath Imaging Radar?
- Tri-band Imaging Radar Concept
- Ka-band AESA T/R Module Development
  - ➢ Module design
  - ➢ MMIC development
  - ➢ Integrated Circulator
  - ➢ ASIC
- Advanced Radar Backend Electronic Technologies
  - ➢ Frequency diversity pulse pair Doppler measurement technique
  - ➢ Multi-channel waveform generation and frequency conversion modules
- Summary and Path Forward

Why Multi-band and Wide-swath Imaging Radar?

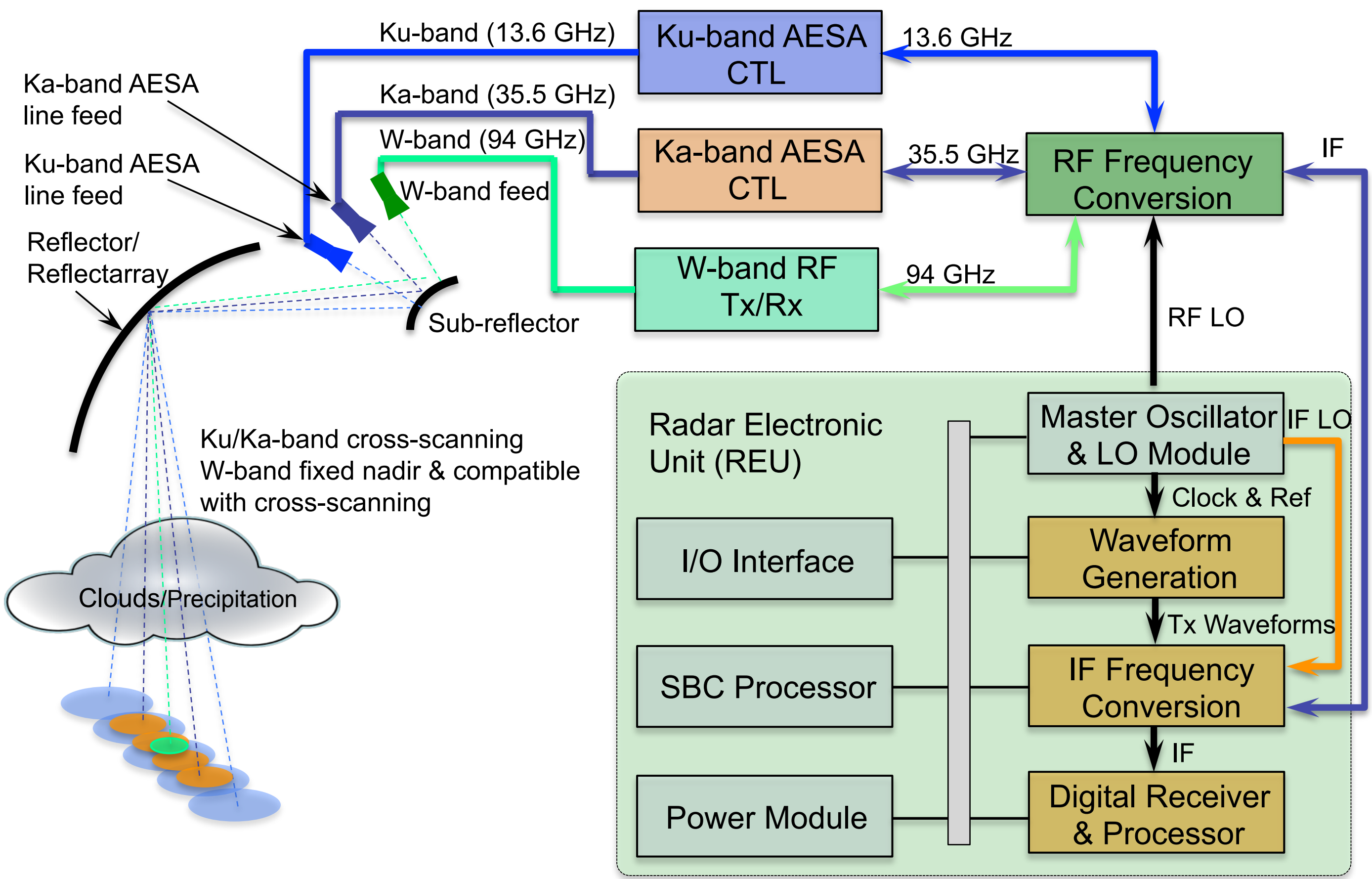
- Clouds and precipitation are among the greatest sources of uncertainty in climate change prediction. Global-scale measurements are critically needed.
- Multi-band radar with Doppler and imaging capability is crucial for improved understanding of the characteristics of clouds, precipitation, and their interaction.
  - *Provide quantitative estimates of Ice Water Path (IWP), Liquid Water Path (LWP), particle size, and particle phase with much higher accuracy than single frequency radar measurements.*
  - *Doppler velocity provides information on vertical air motion, convective up- and down-draft, particle size and classification, and latent heat transportation et al.*

- Decadal Survey 2007 Aerosol Cloud Ecosystem (**ACE**) - Ka/W-band radar.
- A tri-band imaging Doppler radar concept, Cloud and Precipitation Process Mission (**CaPPM**), as CloudSat and GPM follow-on mission
- Decadal Survey 2017 white paper inputs.



Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges

Dual- or Tri-band Radar Concept for ACE and CaPPM

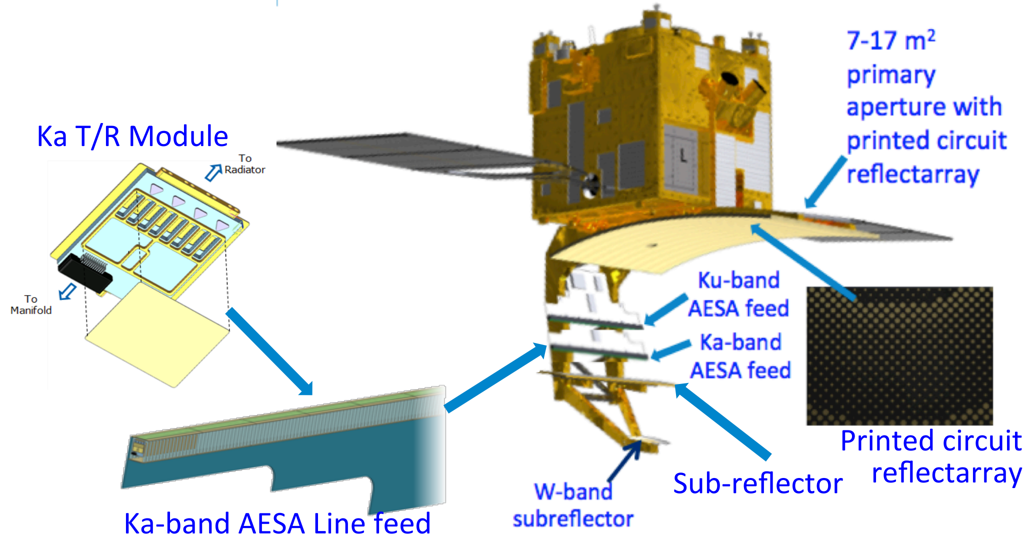


- IIP 2010 Achievements
  - Demonstrated an efficient dual-band (Ka/W), shared aperture antenna architecture
    - Reflector/reflectarray technologies
    - Sub-scale antenna
  - Developed Scalable Antenna Designs (7-17 sqm)
    - Dual-band (Ka/W) antenna
    - Ka-band AESA feed
    - Ka-band T/R module
- ACE Technology Maturation Study (2013)
  - Performed TRL assessment for Ka/W-band radar
  - Identified key areas to be advanced
  - Defined a pathway to space

Tri-band (Ku/Ka/W-band) Radar for Imaging Clouds and Precipitation

Discriminating Features

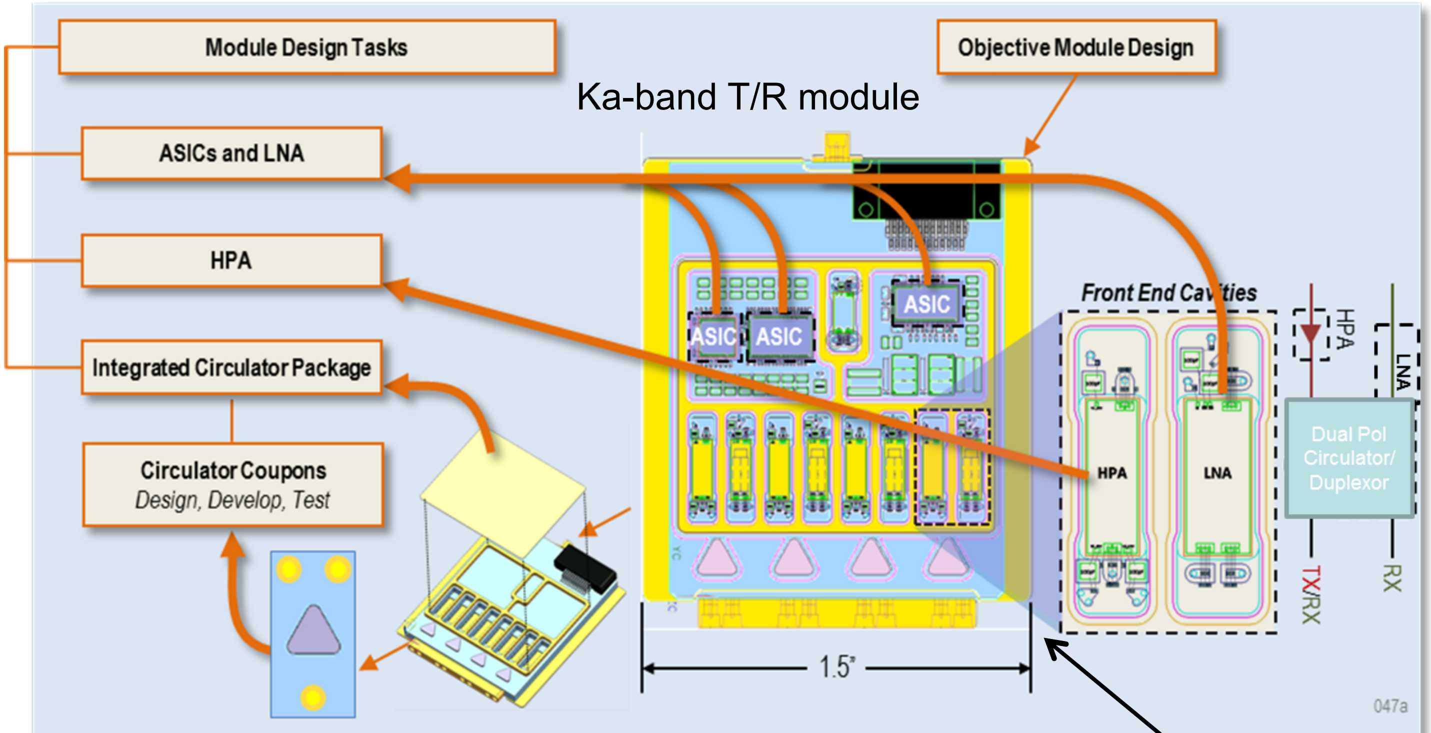
- Shared tri-band primary aperture
- Wide swath imaging at Ka-band (>120 km) and Ku-band (>250 km)
- Reflectarray enables co-located beams for tri-frequency with optional scanning W-band beam
- Programmable scanning mode
- Leverage high space readiness radar electronics from GSFC and NGMS
- Technology Maturation Plan to achieve TRL 6 within 2 years of funding initiative (after current IIP)

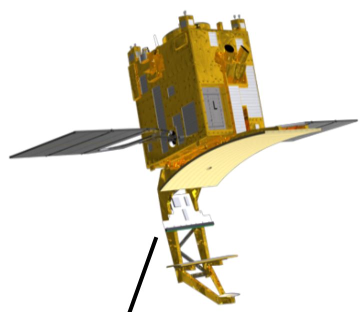


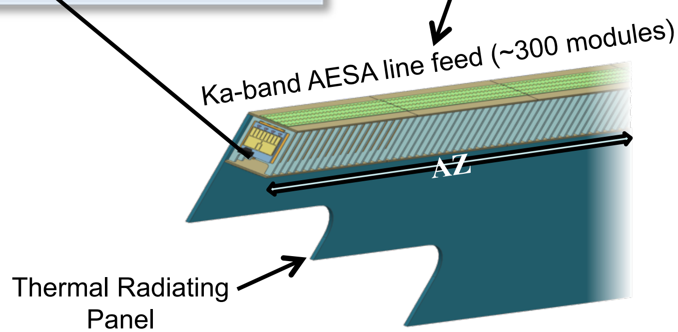
Parameters	CaPPM		
Frequency (GHz)	13.48	35.56	94.05
Orbit Altitude (km)	395-420		
Transmitter	SSPA	SSPA	EIK or SSPA
Tx Peak Power (W)	2000	2000	1800
Antenna Size (m)	3.0x2.3	3.0x2.3	3.0x2.3
PRF (Hz)	4700	4700	4700
Vertical Res.(m)	250	250	250
Horizontal Res.(m)	5.0x4.0	2.0x1.5	0.75x1.0
Cross-track Swath (km)	250	120	0.75
Nadir MDZ (dBZ)	1.0	-13.2	-33.6
Swath MDZ (dBZ)	4.0	-10.2	N/A
Doppler Vel. Accruacy (m/s)	1.0	0.5	0.2
Polarization Option	Yes	Yes	Yes

Objective Ka-Band T/R Module Design
Development Path Overview

Integrated circulator, MMIC and ASIC development currently under development…



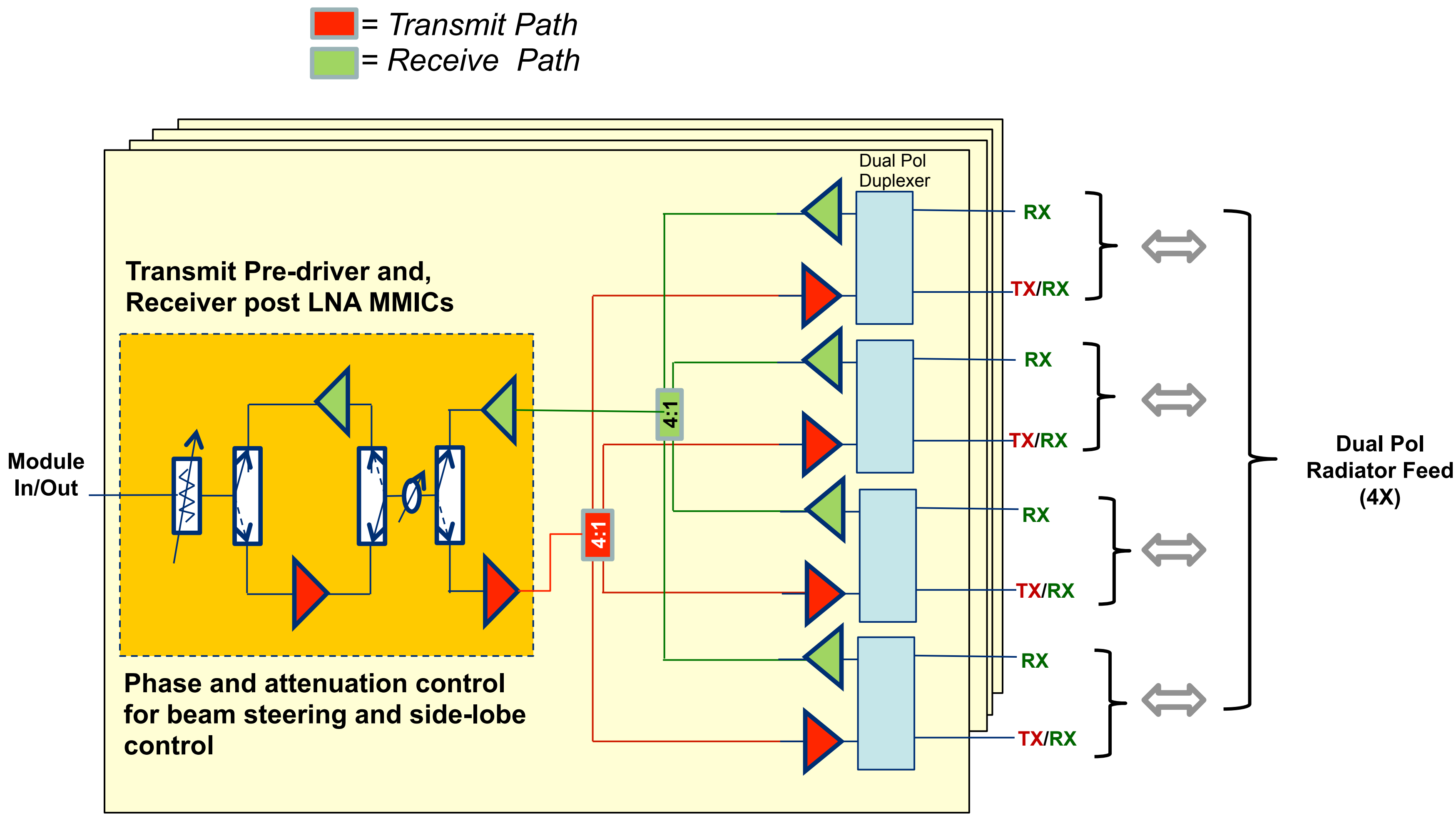




- First pass success demonstrated on all MMIC designs
- 3 Design Options For Circulator
- ASIC design and fab complete, testing underway

T/R Module RF Architecture

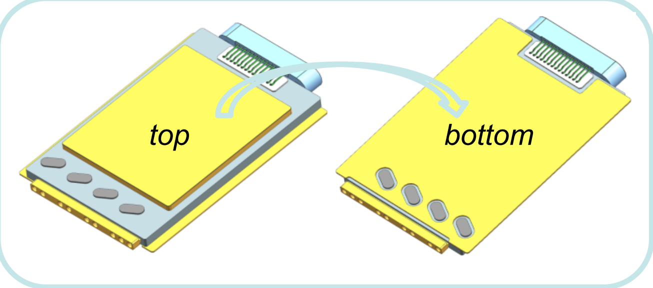
Supports Efficient T/R Functionality and Polarization Diversity

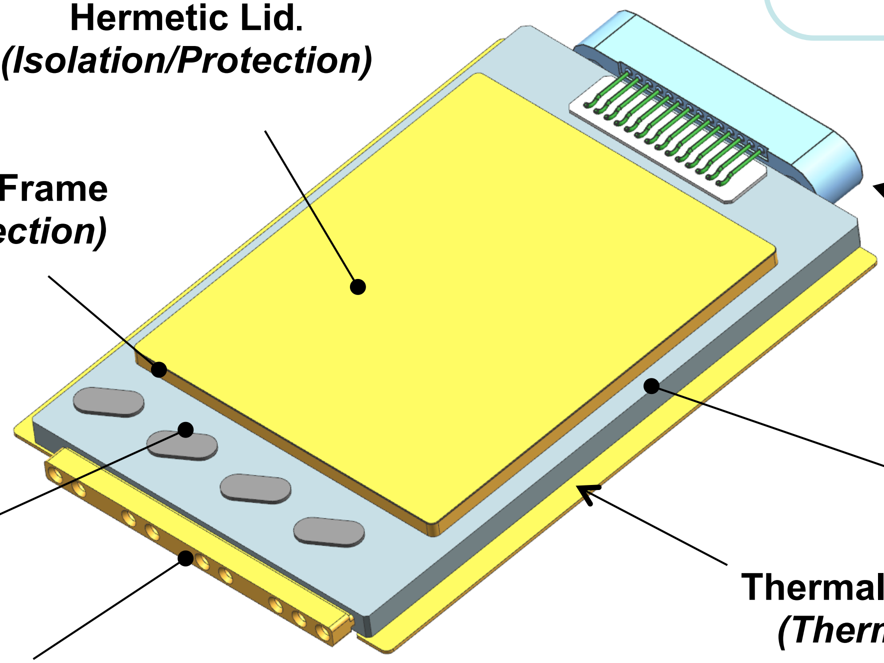


~ 300 modules in azimuth, each with 4 TR channels in elevation direction, form phase array line feed to reflector

Ka TR Module Mechanical Layout

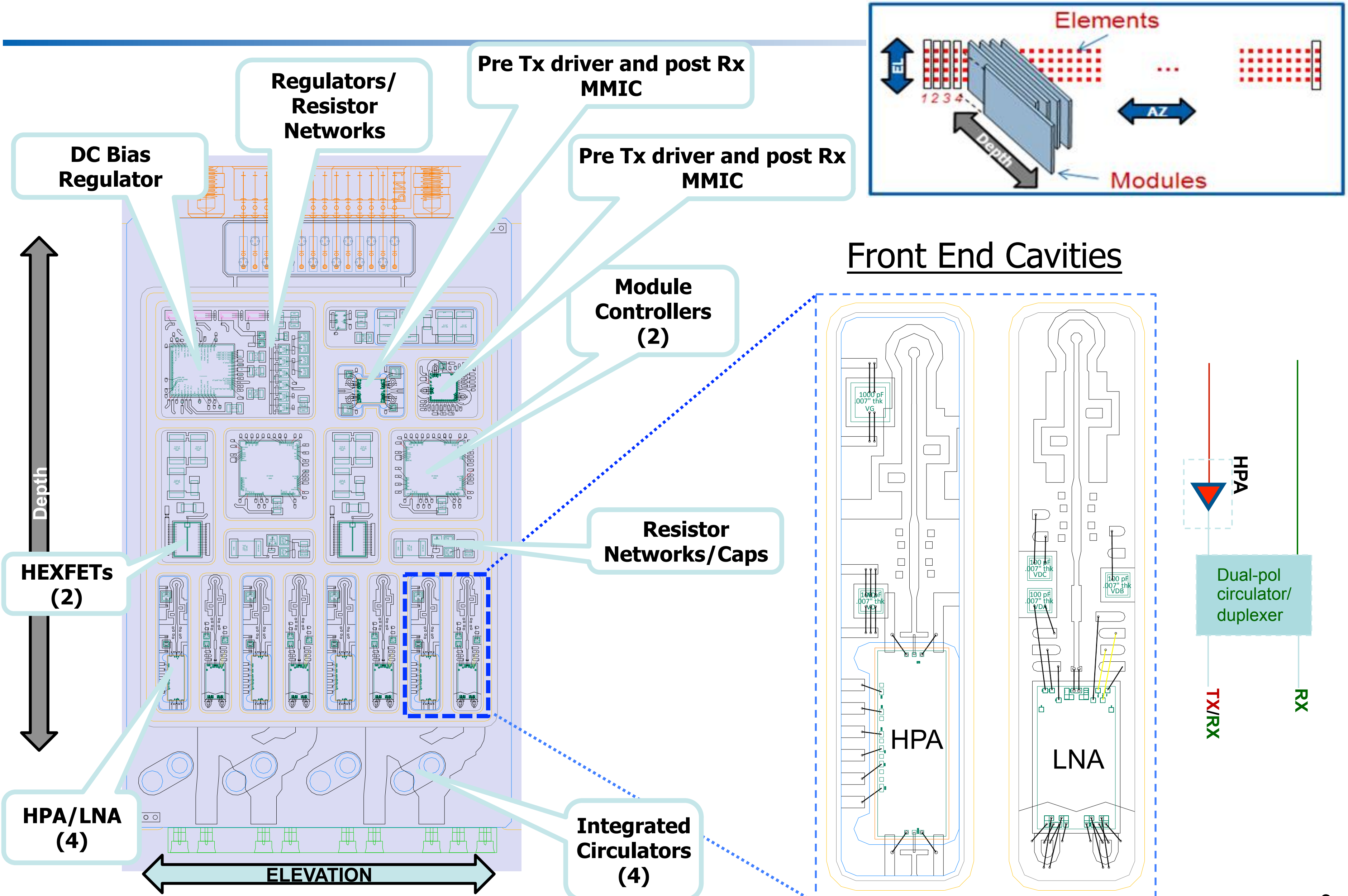
- Hermetic Design
- Low Temperature Co-fired Ceramic (LTCC)





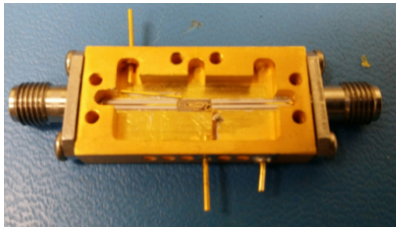
Overall Size: 1.9" x 2.6" x 0.19" (without connectors)

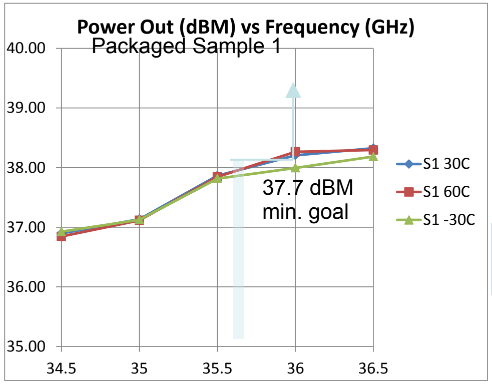
Ka TR Module Component Layout

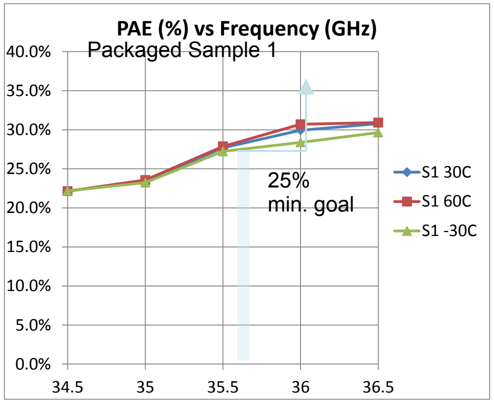


MMIC Device Development Test Articles

GaN HPA Device Verification Test



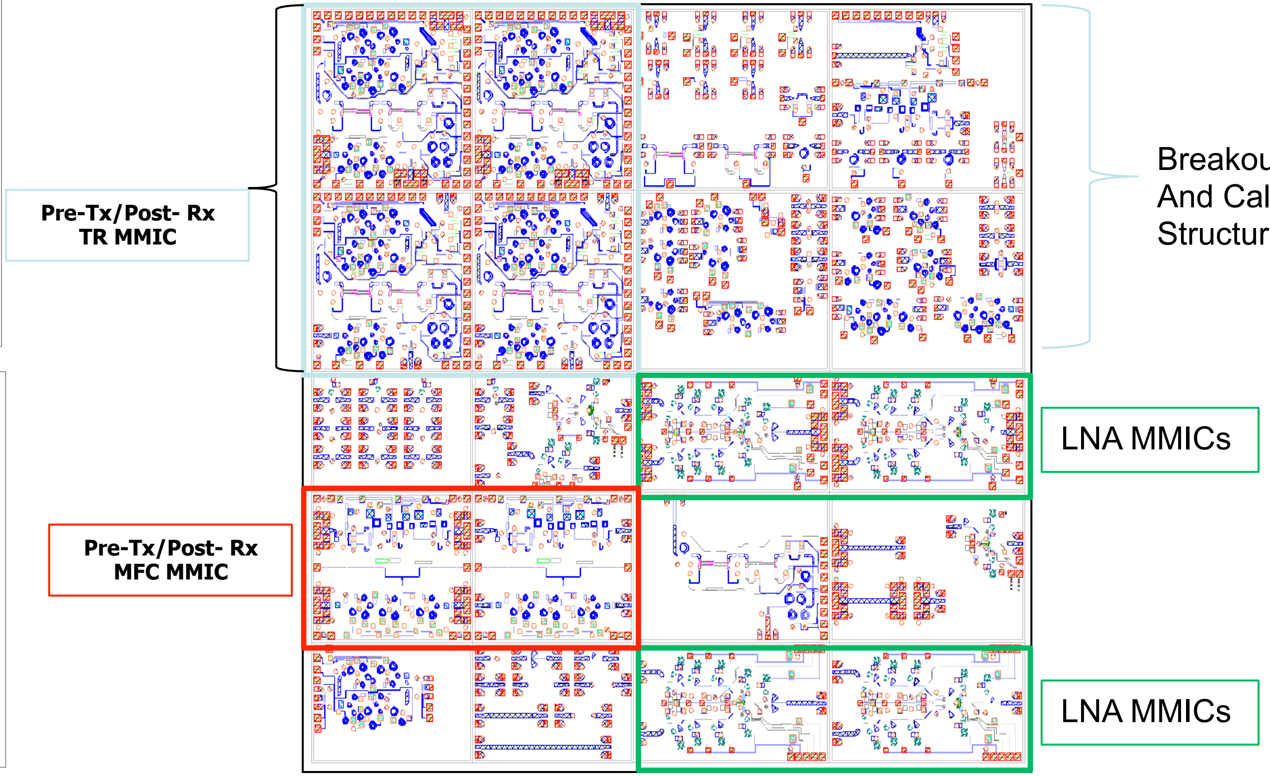




GaAs MMIC wafer and test

- GaAs MMICs including MFC, TR, LNA/switch MMIC wafer built
- Test results agree with design well

GaAs MMICs – Reticle shown

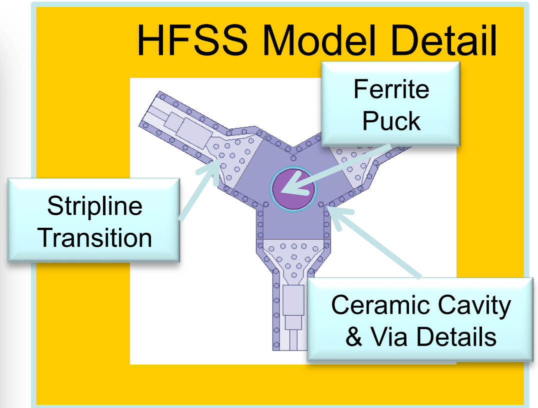


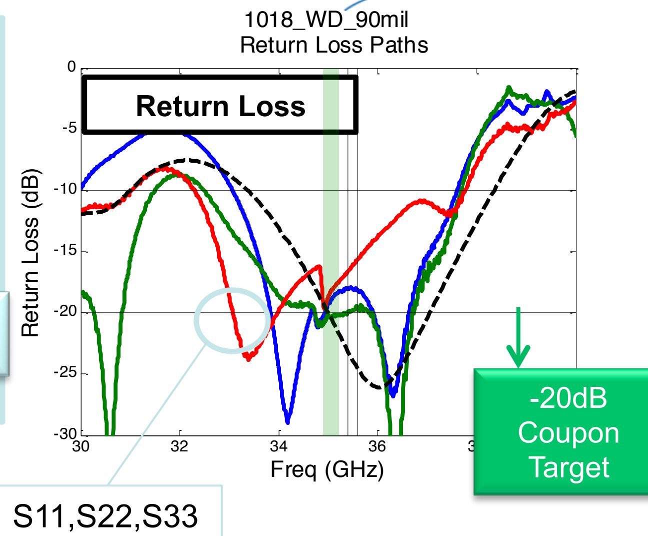
Summary of Measured MMIC Data @ 25C

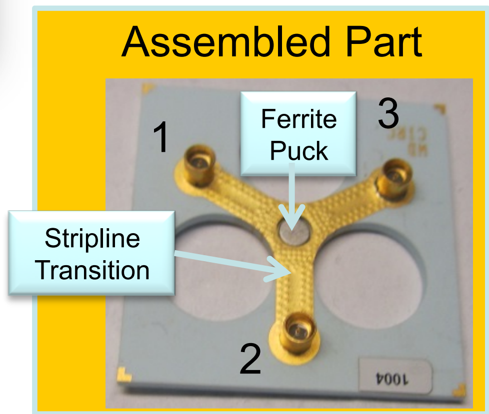
	Measured Parameter	GOAL	Measured	Comments
GaN HPA MMIC	HPA Tier 1 Pout	37.8 dBM	38.5 dBM	DVT Complete on 3 units
	HPA Efficiency	25 %	31%	DVT Complete on 3 units
GaAs LNA MMIC	LNA Gain	28.6 dB,	27.3 dB	
	DC Current @ 1.5v	18 mA	18 mA	
	LNA Noise Figure	2.5 dB	2.9 dB	Recover system SNR with Tx power margin
GaAs TR MMIC	Tx Driver Pout	26.5 min pulsed	27.0 dBM CW,	CW, should increase pulsed
	DC Current @ 6v	307 mA @ P1dB	366 mA@ P1dB	
	Receive Gain	21.7 dB	21.2 dB	Gain margin in entire chain exists to mitigate
	Rx Pout and DC Current	-3.5 dBM min 15 mA	0.5 dBM 12 mA	
GaAs MFC MMIC	Tx Pre Driver Pout and DC Current	11.6 dBM 61.2 mA	12.7 dBM 60 mA	
	Rx Gain	-4 dB @ 9mA	-4 dB @ 12 mA, -6 dB @ 9 mA	Gain margin in entire chain exists to mitigate
	Rx Pout and DC Current	-7.8 dBM 9 mA	-1 dBm 9 mA	
	RMS Attenuator Error	0.5 dB	0.5 dB	Calibrated
	RMS Phase Shifter Phase Error	1.7 deg	1.7 deg	Linearized

Development of Integrated Circulator

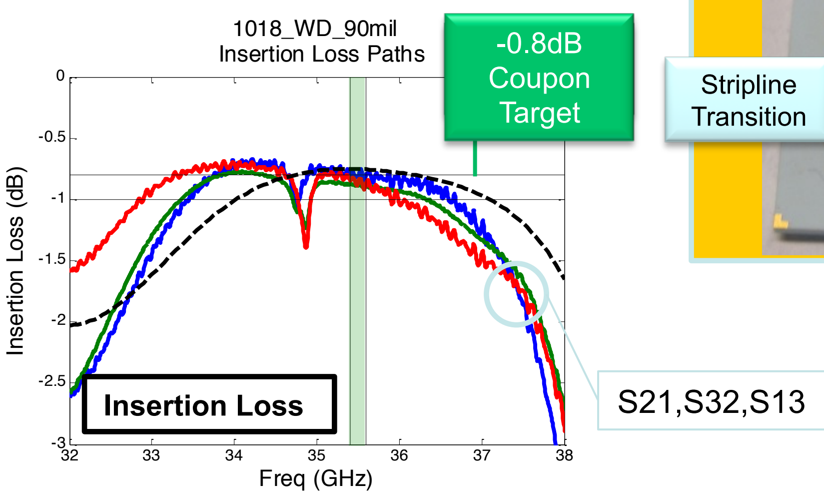
RF Performance of Junction at Reference Planes

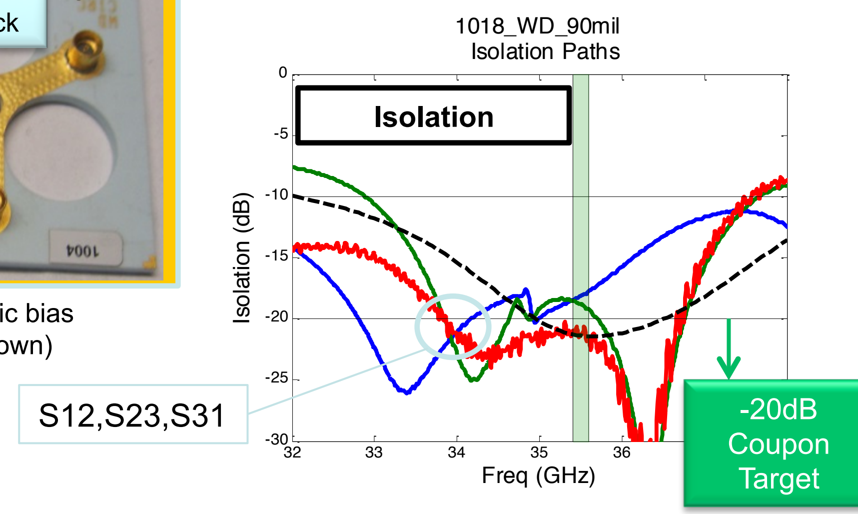






(Magnetic bias not shown)

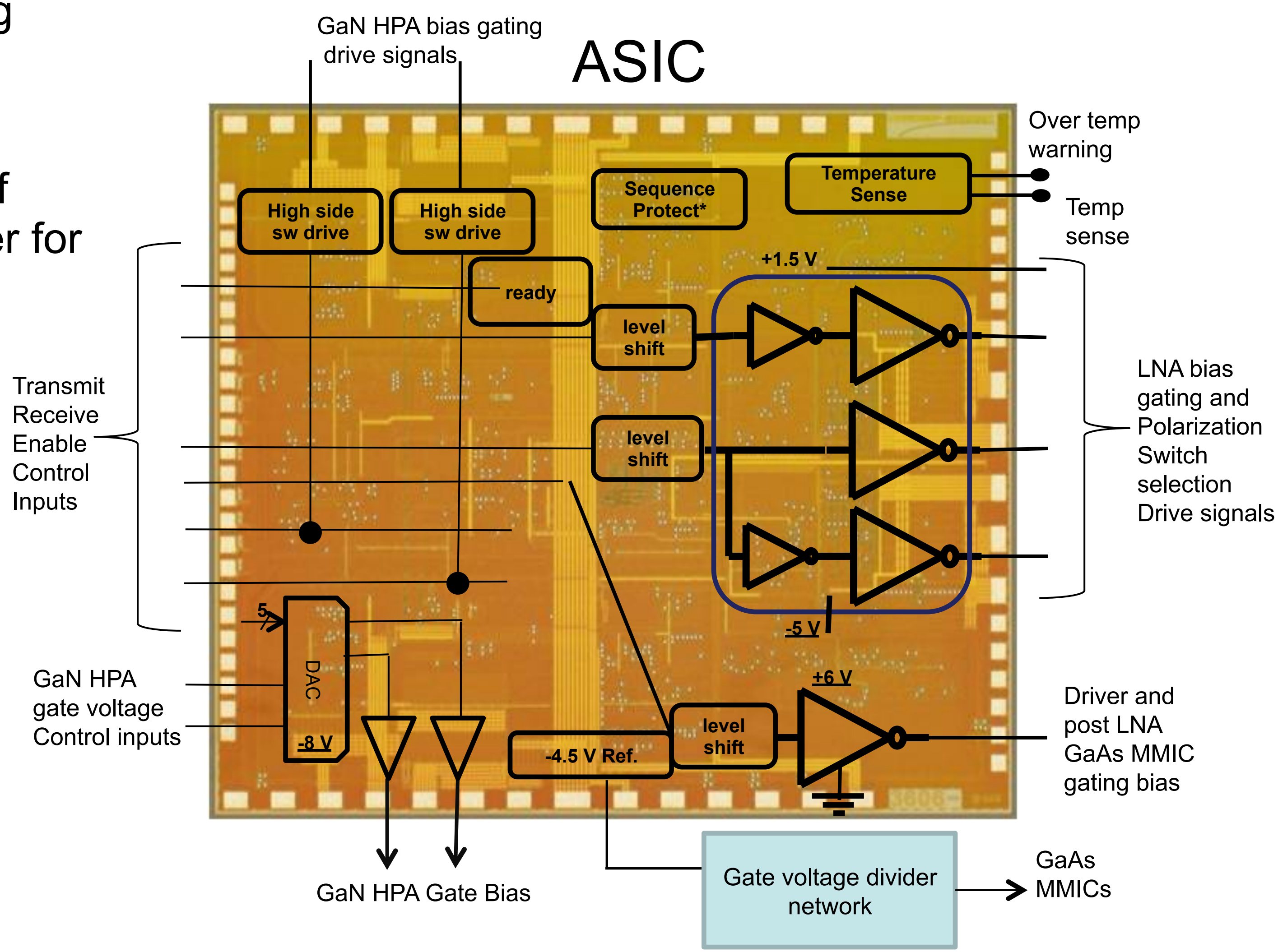




Model (Ref plane @ coax-SL transition) **Path 1 of 3** **Path 2 of 3** **Path 3 of 3**

Power Controller ASIC

- Key features
  - Bias Sequencing
  - Conditioned voltages
  - Timing control of pulsed DC power for radar modes
  - Temp sensor to monitor module temperature



Ka-band AESA T/R Module Recent Accomplishments

- Tested samples of LNA/Switch, MFC and TR GaAs MMICs
- Completed HPA Design Verification Testing (DVT)
- Completed module package design and now in fabrication
- Completed ASIC design, fab and preliminary functional test
- Completed circulator development
- All module components parts are on hand or on order
- Implementing module assembly tooling, test fixture and test equipment items
- Complete module functional test plans

Frequency Diversity Pulse Pair Airborne Demonstration

Challenges of Doppler Measurement from Space:

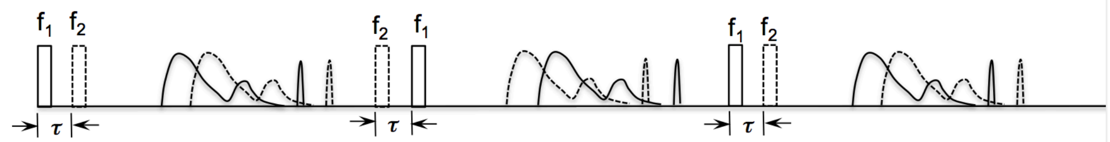
- Velocity folding and spectrum broaden due to spacecraft ground speed and up- and down draft
- $\sigma/2V_{max} < 0.3$ for good Doppler measurements
- Approaches:
  - large antenna: reduce σ
  - higher PRF, stagger PRF: increase V_{max}

FDPP Implementation on 94 GHz CRS

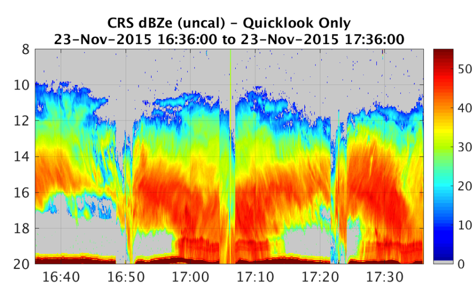
- Waveform implementation
- Digital receiver configuration

- Olympic Mountain Experiment (OLYMPEX)/Radar Definition Experiment (RADEX)
  - Objectives: GPM cal/val and ACE algorithm study
  - Time: Nov 2015-Feb. 2016, ER-2 flights Nov. 14 -Dec. 5, 2015.
  - Location: Olympic Peninsula of Washington State

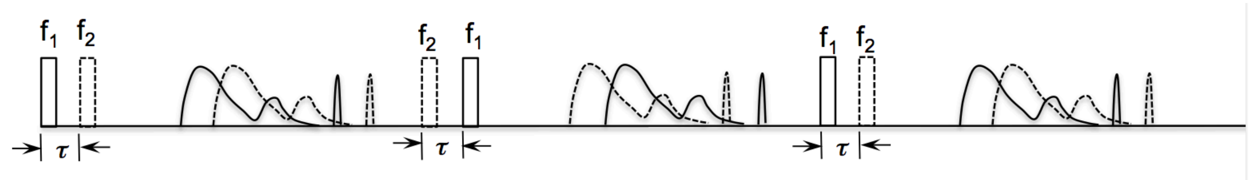
FDPP Algorithm



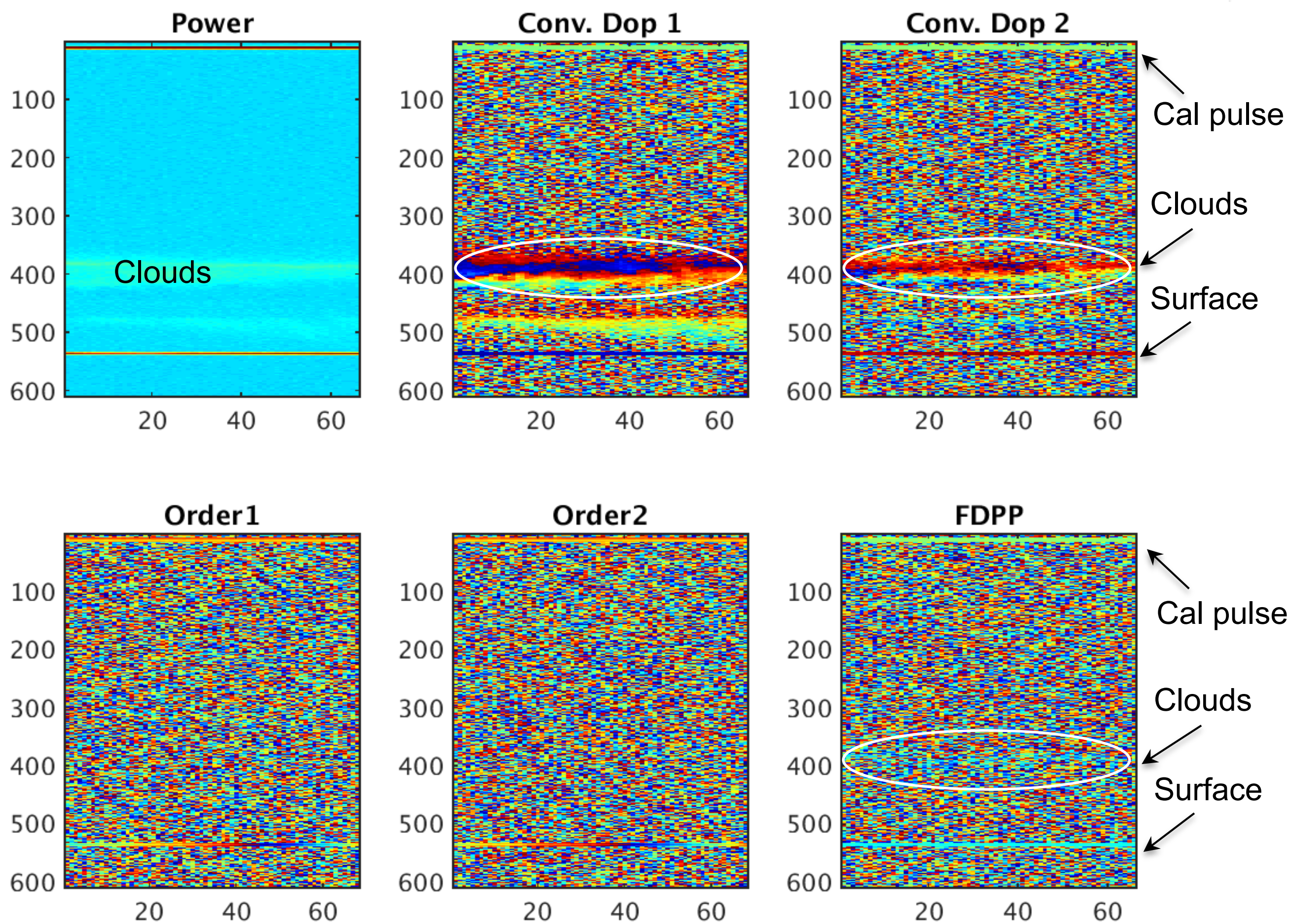
- Frequency Diversity Pulse Pair (FDPP) utilizes alternate pair of pulses with slightly different center frequencies.
- Programmable time interval between the pulses to extend the Doppler Nyquist range without causing range ambiguity.
- Integration of equal number of pair f_1/f_2 and pair of f_2/f_1 to cancel the range dependent phase



FDPP Data Analysis



- Conv. Dop 1: f1, f1 pair
- Conv. Dop 2: f2, f2 pair
- Order 1: f1, f2 pair
- Order 2: f2, f1 pair
- FDPP: sum of Order 1 and Order 2

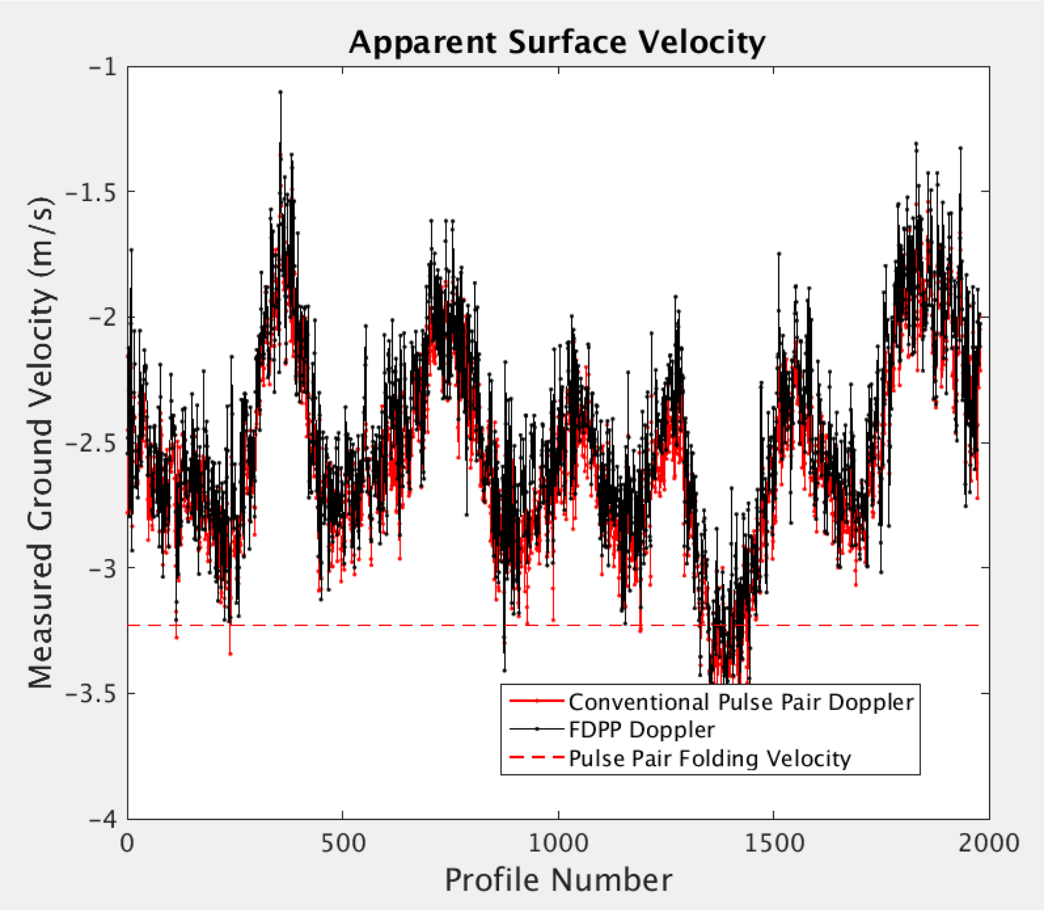


Preliminary analysis

- FDPP works well for ocean surface return
- Indicates coherent Doppler phase for cloud region with relative high SNR. Working progress on improving the results.

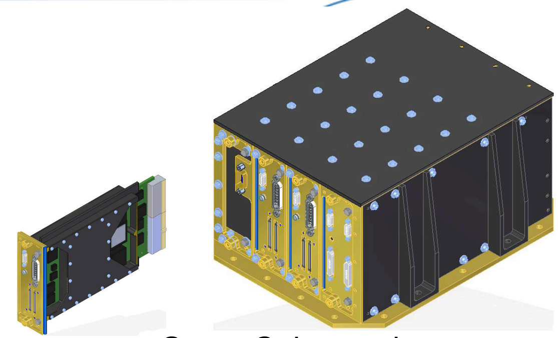
FDPP Data Analysis (cont'd)

- FDPP results were compared with traditional pulse-pair velocity estimates.
- Based on simulation predictions, a high SNR target (i.e. surface echo) was isolated for quantitative comparison.
- Preliminary analysis showed excellent fidelity for the FDPP estimates for surface return.

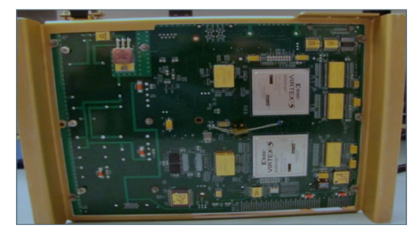


Multi-channel Waveform Generation and Frequency Conversion Modules

- FPGA Based Multi-channel Waveform Generator
  - Support multi-channel simultaneous versatile transmit waveform and timing signal generation
  - Based on GSFC high TRL SpaceCube processor card
  - Adding high-speed DACs for waveform generation and I/O interface
  - Completed schematic design and board layout
  - Prototype unit ready for fabrication

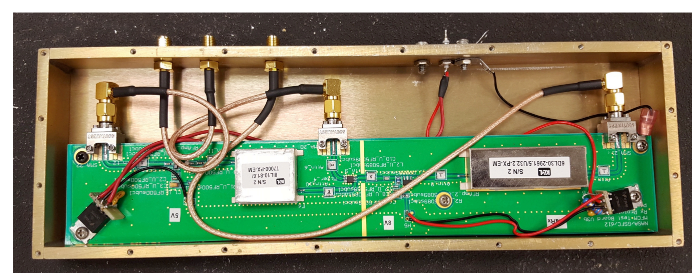


SpaceCube card cage



SpaceCube Virtex-5 FPGA processor card

- PCB Based Multi-channel Frequency Conversion Module
  - Support multi-band, multi-channel transmission and receive
  - Shared common circuits and parts to reduce SWaP
  - Prototype module built
  - Test on airborne radar underway



Prototype frequency conversion module

Summary and Path Forward

- Technologies for dual- or tri-band spaceborne cloud and precipitation radar under development at NASA GSFC and NGMS.
- Dual- or tri-band, shared-aperture antenna
  - Trade study and concept design
  - Identified primary candidates supporting all variant of final mission requirements
  - Addresses various band combinations with options for W-band fixed beam and scanning
  - Includes application of proven reflectarray technologies
- Ku-band AESA technology is mature
- Ka-band AESA T/R module development
  - Module RF and mechanical design
  - MMIC, circulator and ASCI design, fabrication and test
  - GaN HPA MMIC design and verification test
  - LTCC in fabrication
- W-band compatible with either fixed nadir beam or AESA scanning beam
  - Leverage high TRL CloudSat technologies
  - Compatible with AESA cross-track scanning design
- Continue to enhance the Technology Readiness Level (TRL) for space


NASA
NORTHROP GRUMMAN
ACE/CaPPM
EarthCare
GPM
CloudSat
TRMM
Thank You!
Developing technologies for the next generation spaceborne atmospheric radars