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Concept Design of a Multi-Band Shared Aperture Reflectarray/Reflector Antenna

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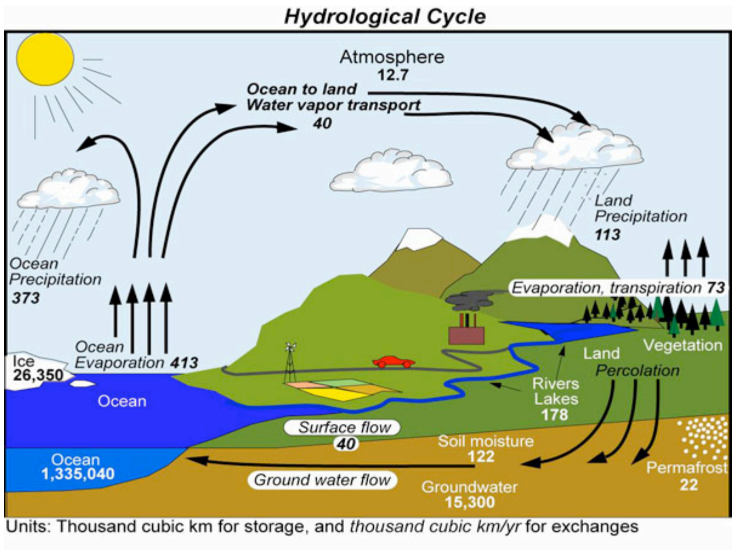
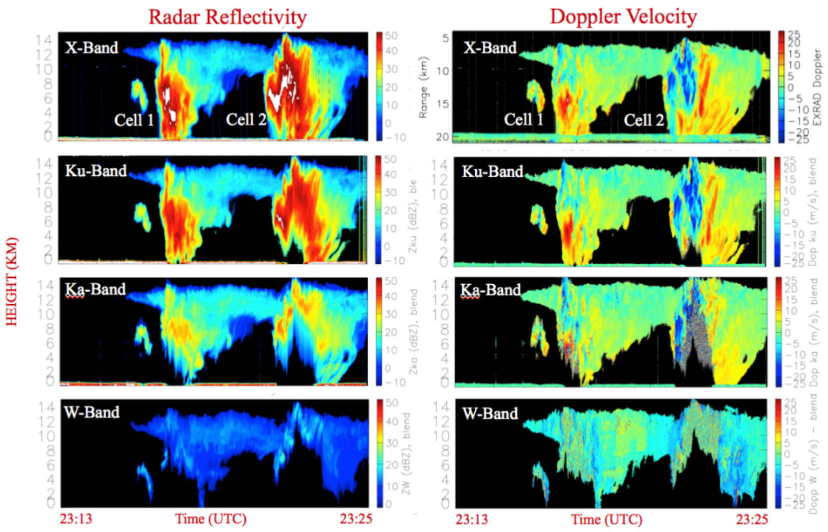
Agenda

- Mission Objectives
- Radar Concept
- Subscale Antenna Verification
- Shared-Aperture Antenna Design Trades
- AESA Line Feeds & T/R Modules
- Summary

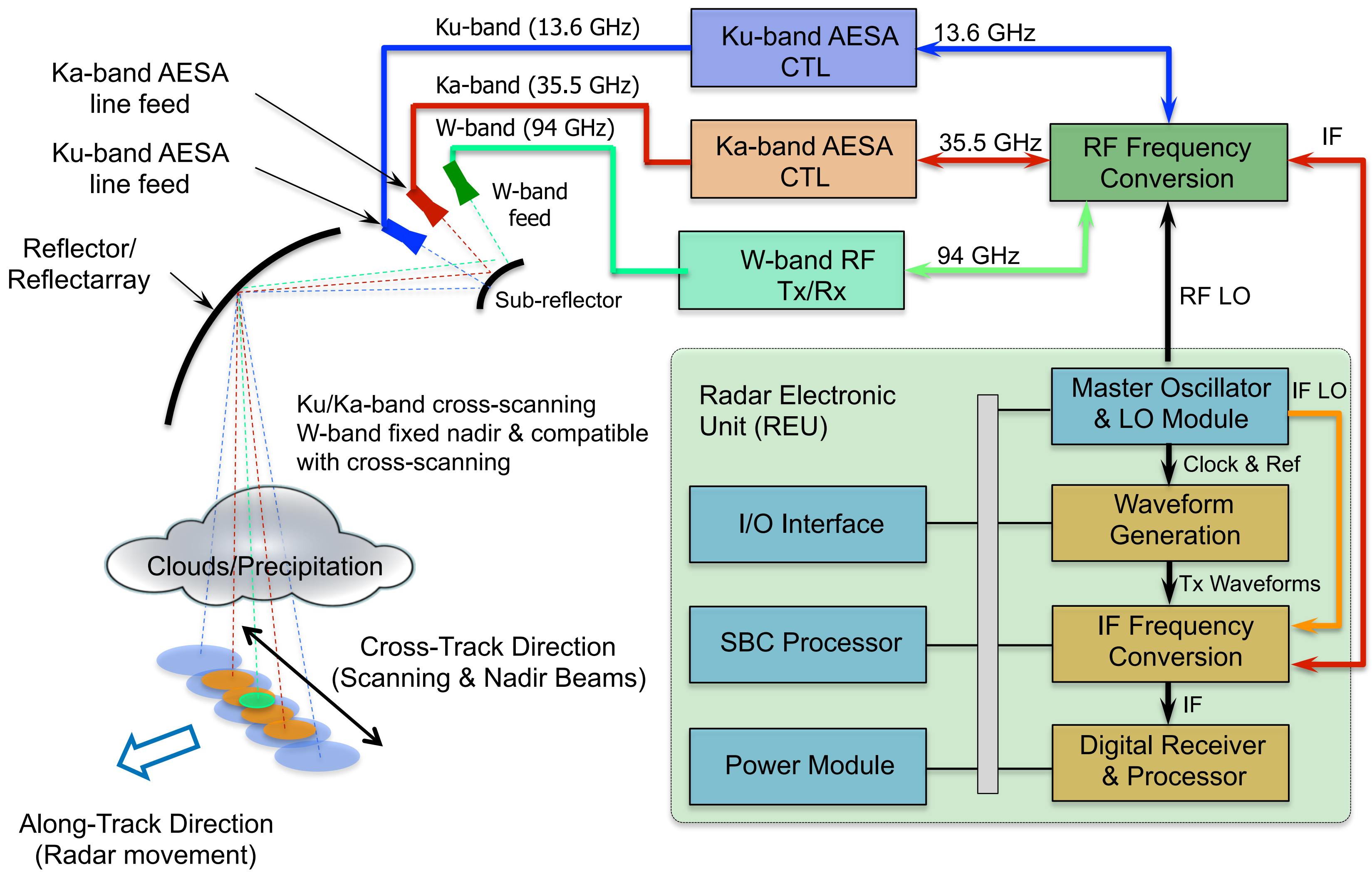
Science Motivations

- Clouds & precipitation are among the greatest sources of uncertainty in climate change prediction
- Multi-frequency imaging Doppler radar is critical for improved climate understanding
- Mission Motivation:
  - **ACE**: 2007 Decadal Survey Aerosol Cloud Ecosystem calls for a dual-frequency radar (Ka/ W band)
  - **CaPPM**: Cloud and Precipitation Process Mission concept requires a tri-frequency radar (Ku/Ka/W)





Tri-Band Radar Concept for ACE & CaPPM



Science Objectives Are Closely Tied to the Antenna Design and Associated Trades

Various antenna parameters must be balanced to meet mission objectives…

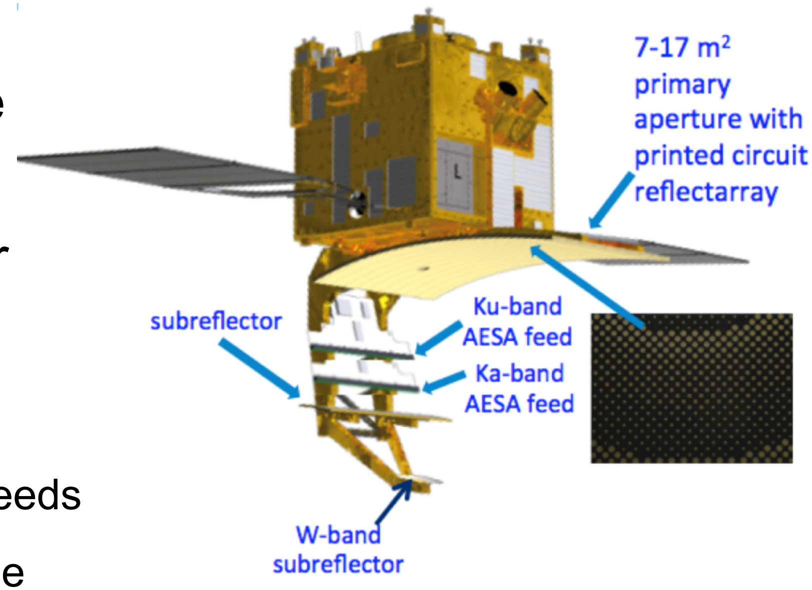
Radar Parameter	Antenna Parameter/Feature
Spatial Resolution	Aperture Size
Vertical Resolution	Tx Pulse Width
Field of Regard	Beam Steering
Polarimetry	Dual-Polarization
Sensitivity	Size, Radiated Power, Efficiency, Noise Figure
Data Diversity	Multi-Band Antenna
Doppler Vel. Accuracy	Aperture Size

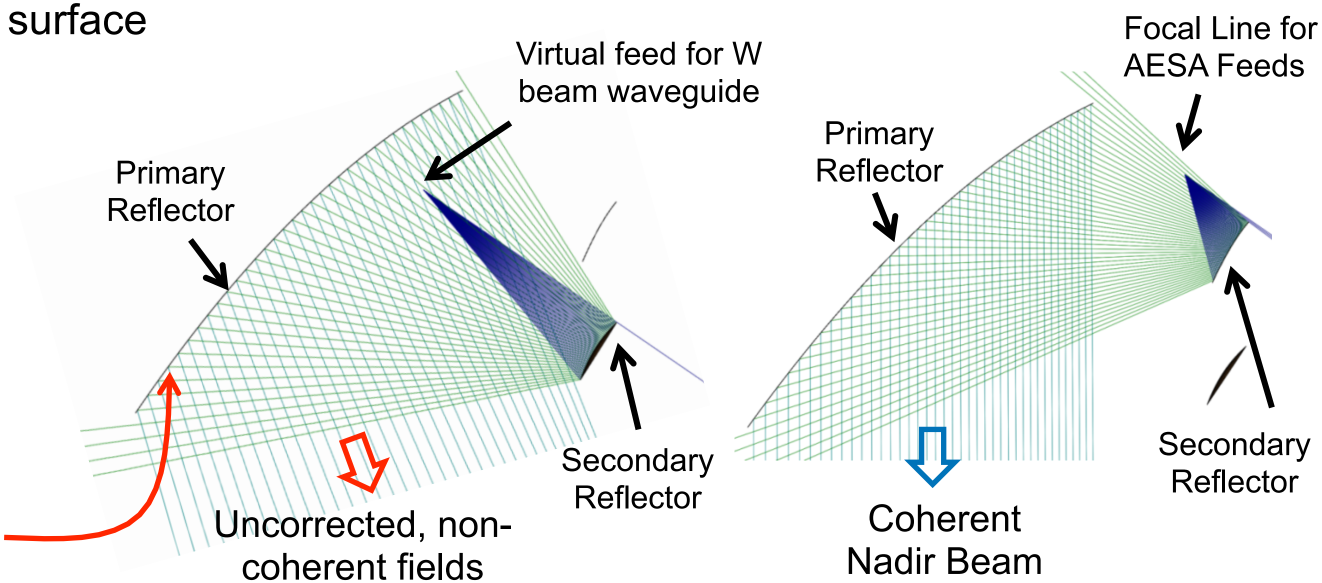
CaPPM Radar System Requirements

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. Accuracy (m/s)	1.0	0.5	0.2
Polarization Option	Yes	Yes	Yes

Efficient Shared-Aperture Antenna Design

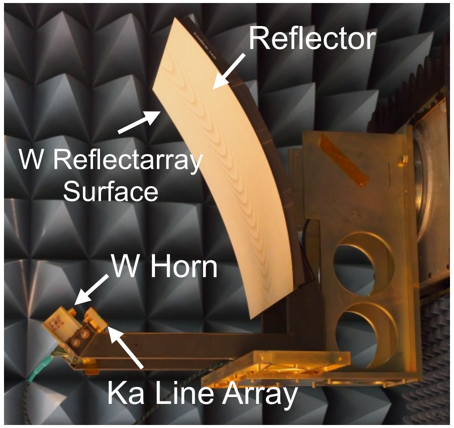
- Sharing the same primary reflector is the only practical tri-band solution
- Cassegrain optics with parabolic cylinder main reflector
- Beams:
  - Cross-track scanning enabled by AESA line feeds
  - Fixed nadir beam enabled by beam waveguide feed & reflectarray surface



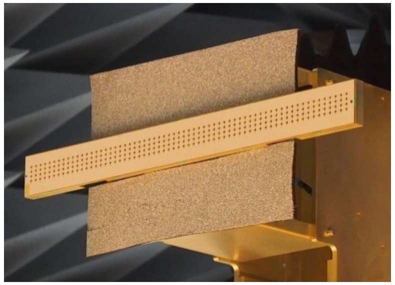


A Subscale Antenna Validated the Efficient, Dual-Band Shared Aperture Concept

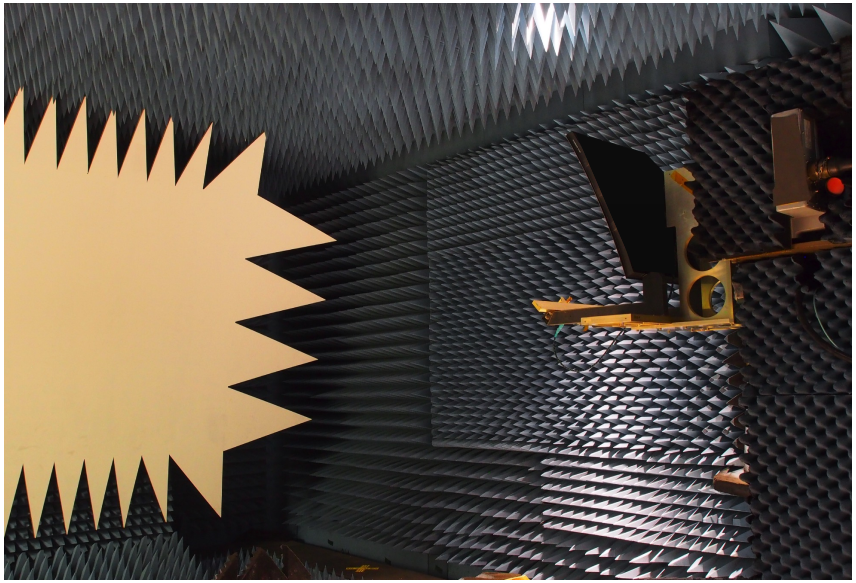
Subscale Antenna



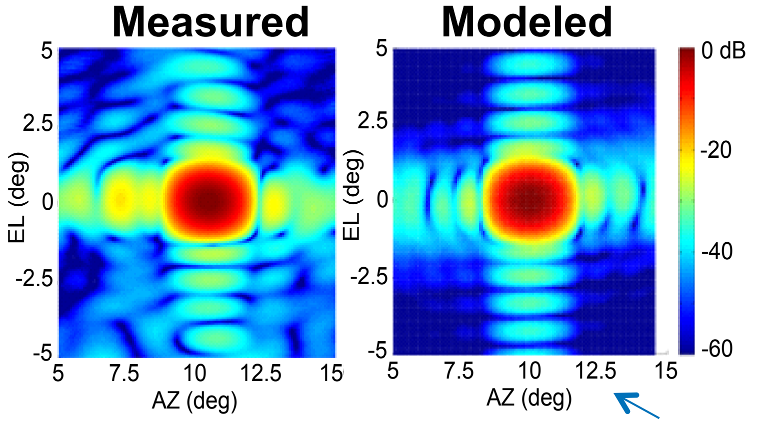
Ka Line Array



Beam steering replicated by swapping among scanned, fixed beam feeds

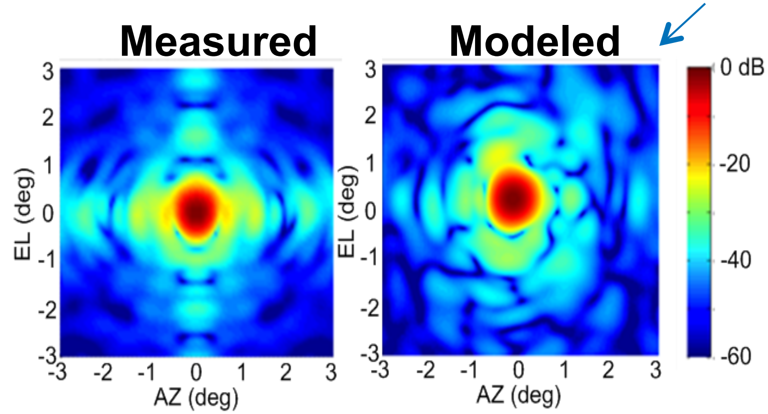


35.5 GHz Scanned Pattern



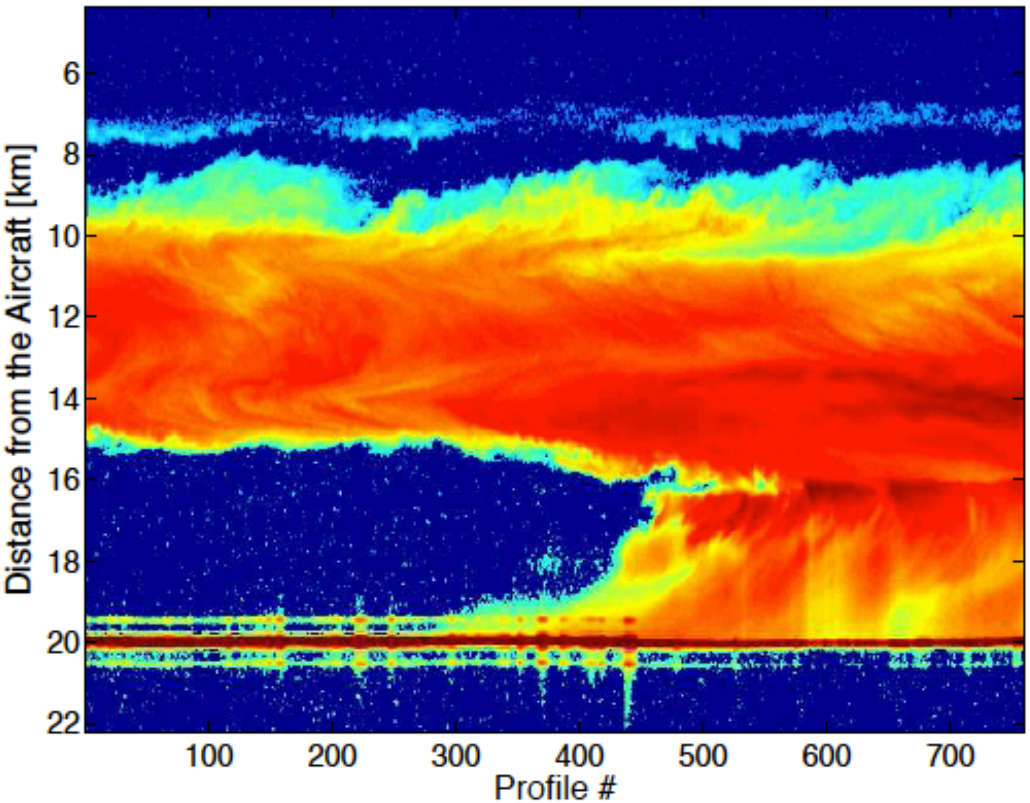
Pattern are shown in the vicinity of the main beam

94 GHz Pattern

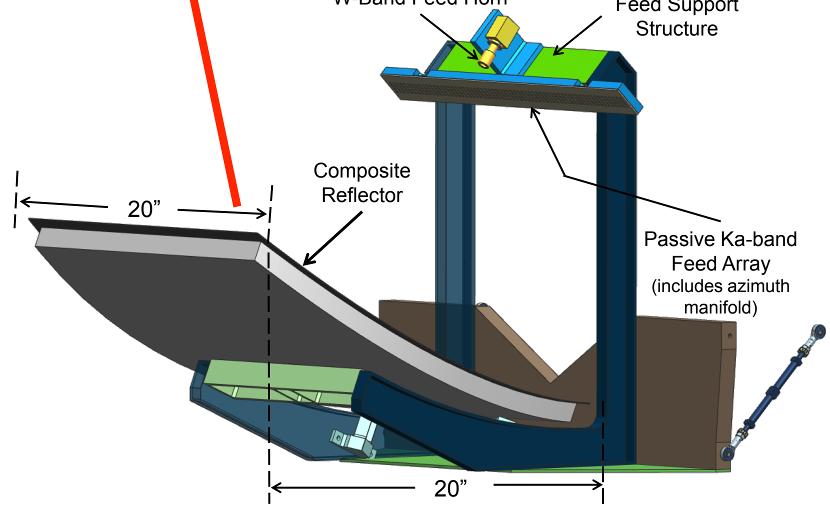


Demonstration of the Subscale Antenna During Flight Tests

94 GHz Radar Measurements



Sub-scale antenna in CRS canister in ER-2 tail cone



Tri-Frequency Antenna Trade Study

Rich Trade Space

Enables tailoring for particular frequency and/or requirements

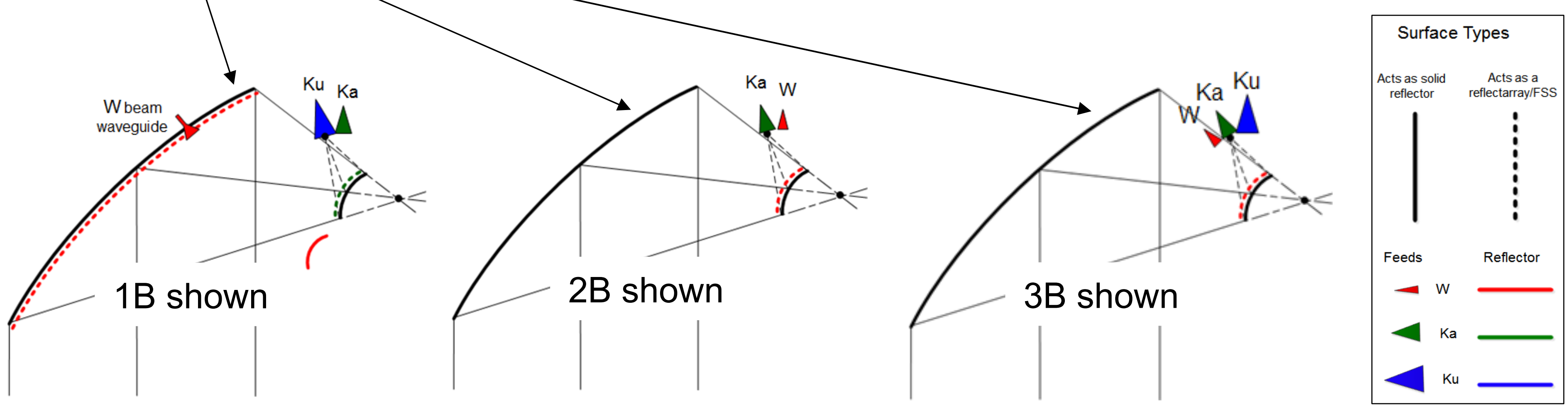
	1. Ku & Ka Scanning, W Fixed		2. Ka & W Scanning		3. Ku, Ka, W Scanning					
	1A	1B	2A	2B	3A	3B	3C	3D	3E	3F
	Defocused Ku. Focused Ka. W RA on main.	Focused Ku. Focused Ka via RA on sub. W RA on main.	Defocused Ka. Focused W.	Focused W via RA on sub. Focused Ka.	Defocused Ku & Ka. Focused W.	Defocused Ku. Focused Ka. Focused W via RA on sub.	Focused Ku. Focused Ka & W via RAs on sub & main.	Focused Ku. Focused Ka & W via dual-band RA on sub.	Focused interleave Ku/Ka. Focused W via RA on sub	Separate subs for Ku/Ka & W. RA on both subs.
Tri-Band Capability	Yes	Yes	Ka & W	Ka & W	Yes	Yes	Yes	Yes	Yes	Yes
W-Band Cross Track Scanning?	Fixed	Fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Aligned Along Track Beams?	Ka & W	All	None	All	None	Ka & W	All	All	All	All
Matched Cross-Track Beams Possible?	Ku/Ka Only	Ku/Ka Only	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

	1A			1B			2A			2B			3A			3B			3C			3D			3E			3F		
	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W	Ku	Ka	W
2-way Antenna Loss																				LPF response of RA does not support 3C			Requires low loss dual-band RA			Qualitative assessment			Qualitative assessment	
3-dB Beam Width																														
2-way SLL																														

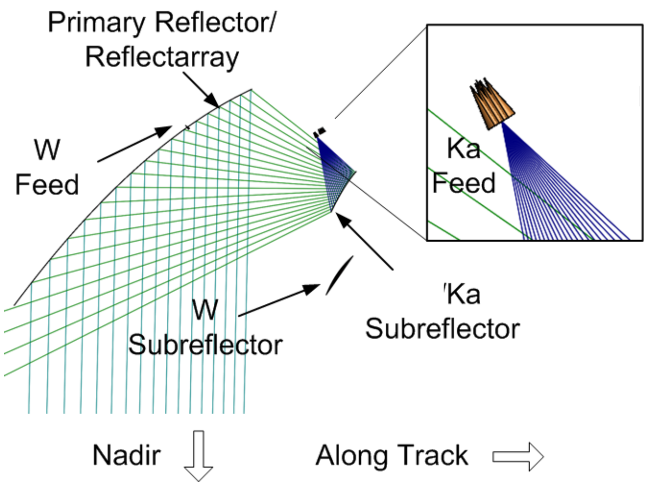
RA = reflectarray

Trade Study Summary

- Assessed 10 candidate architectures (3 classes)
- Down selected primary candidates
- Evaluated & traded various AESA and T/R module design approaches (Ku, Ka, & W-band)
- Explored usage of reflectarrays for aperture sharing
- Down selected to 1B, 2B, 3B shown below

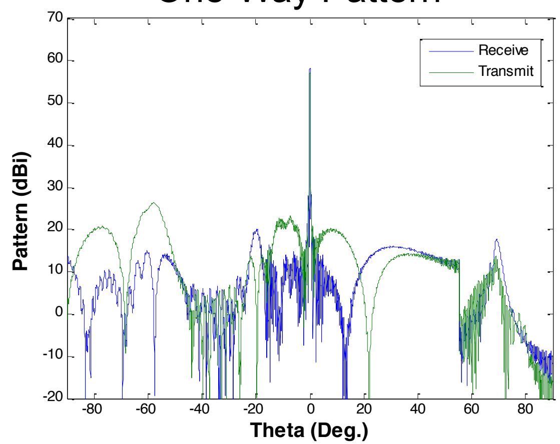


Performance Example of a 7 m^2 Ka/W Shared Aperture Design

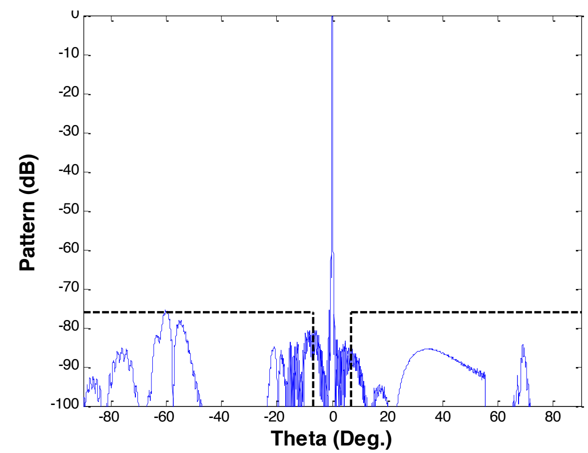


Ka-Band

One-Way Pattern

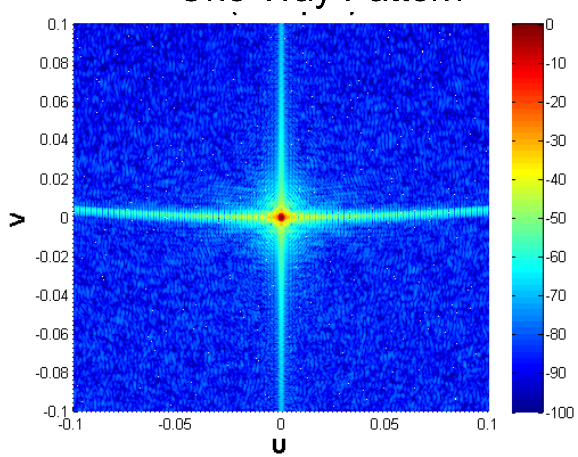


Two-Way Pattern Cut

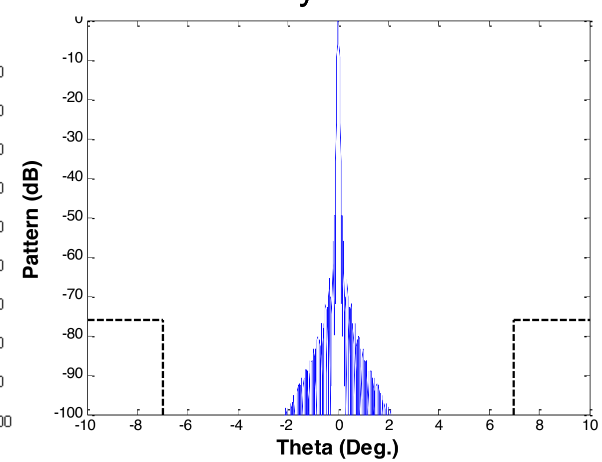


W-Band

One-Way Pattern

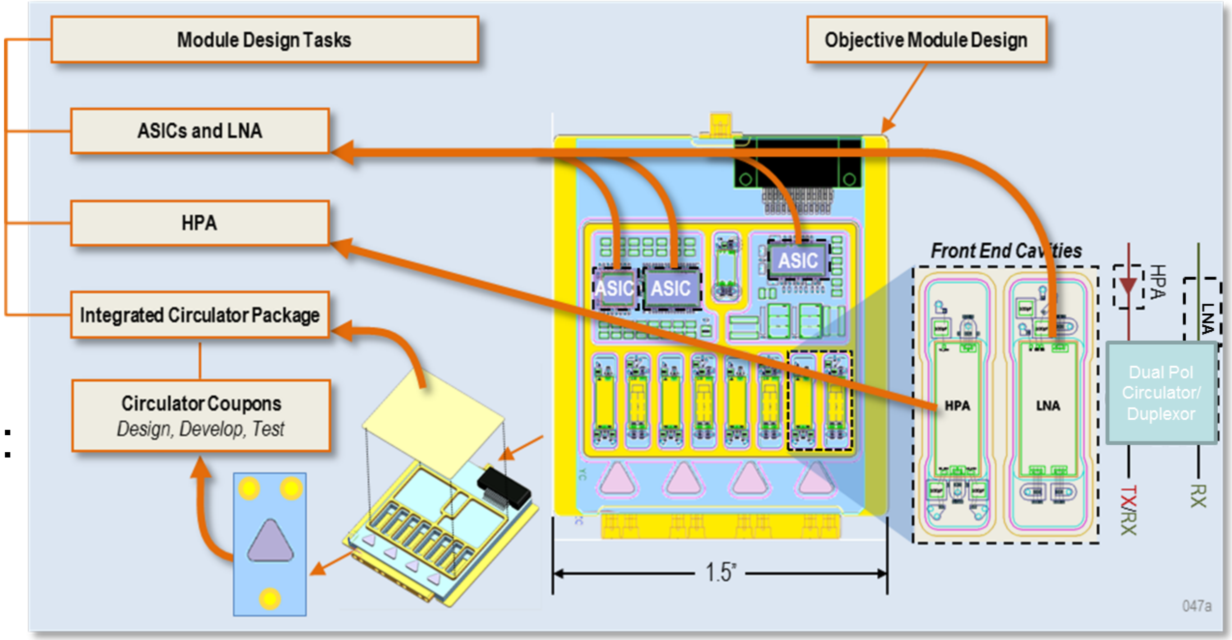


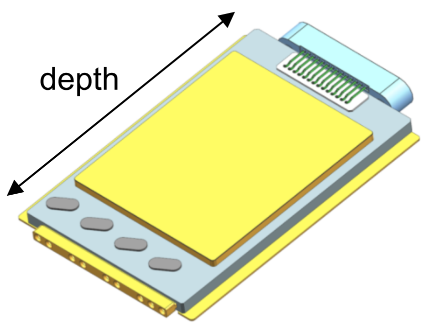
Two-Way Pattern Cut

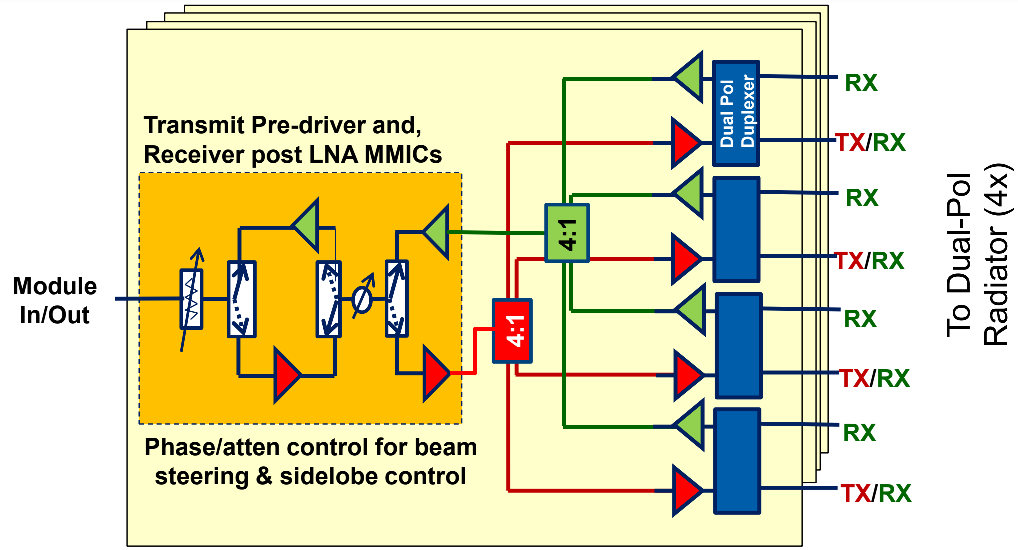


Ka Module Development & Component Testing Demonstrates Key Technology

- Optimized for:
  - High radar sensitivity
  - Very low DC power
  - Compact size
- Fab & Test Completed:
  - GaN HPA MMIC
  - LNA Switch MMIC
  - T/R MMIC
  - Integrated circulator
  - Gate/Control ASIC



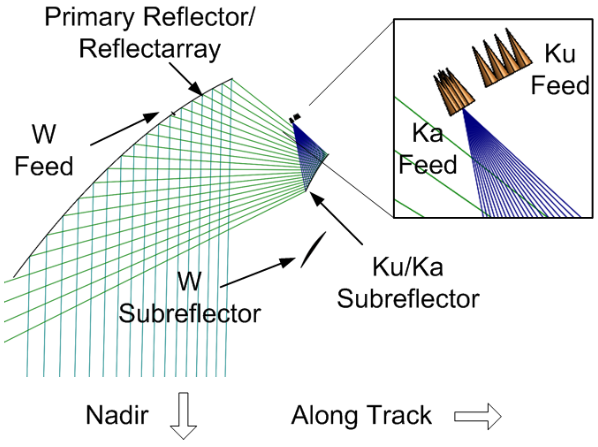


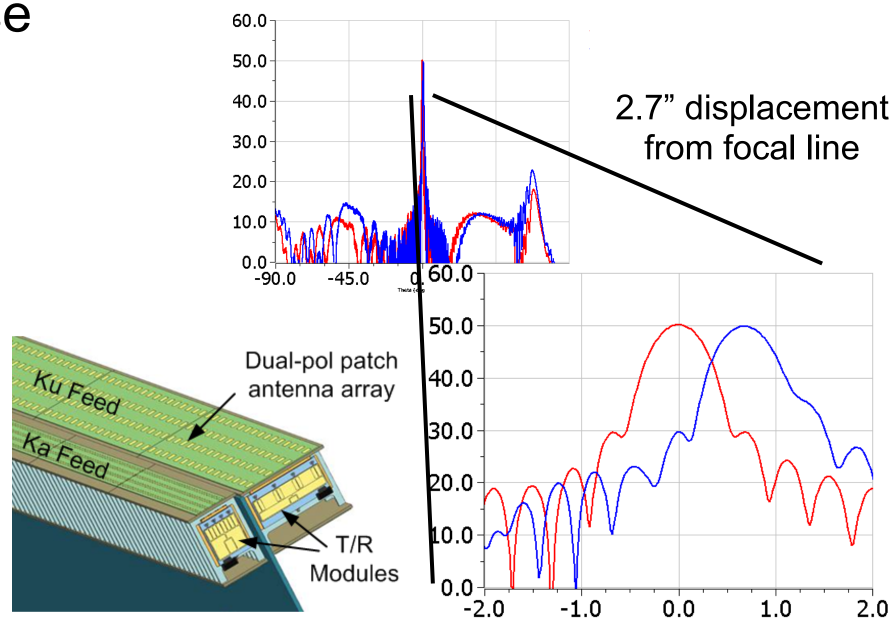


Design Space Explored for Dual/Tri-Band AESA Line Feeds

- There are multiple approaches:
  1. Individual line feeds (Ku, Ka, W)
  2. Wide-band line feed (e.g., Ku-Ka)
  3. Interleaved line feeds (e.g., Ku/Ka)
- Trades: Efficiency, complexity, cost, packaging, TRL
- Displaced feeds from focal line cause pattern aberrations
  - Effects: Gain, beam pointing, side lobes
- Reflectarray surface can be used to correct a defocused feed
  - Can achieve co-aligned beam pointing

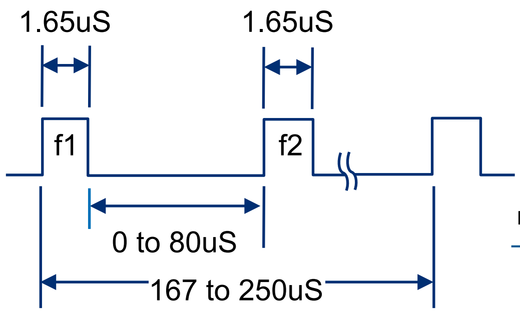
Example of Displaced Ku Feed

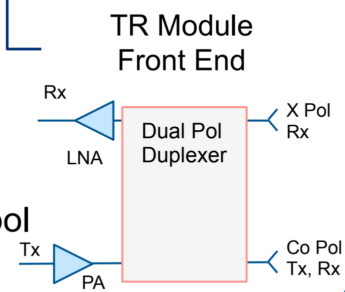




Overview of the Four Main Modes of Operation

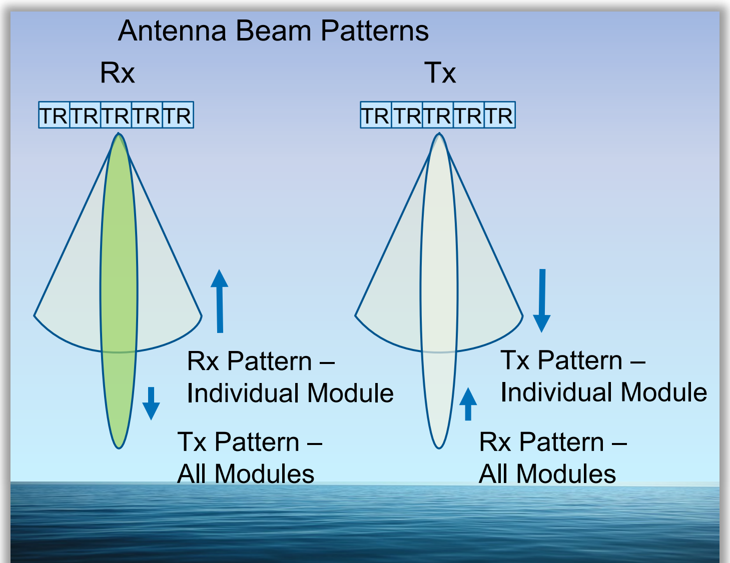
1. Module 1D Scanning Radar Puled Mode





- Switch Between Rx Co- & Cx-pol
- Duty Cycle held at 1.56%

2. Module Head Count Mode (Health Check)



3. Telemetry – Metadata Modes

- Temp, Current, Voltage
- Phase and Amplitude Control Read-back
  - Serial phase shift and attenuator commands are read back to beam steering control unit

4. Power Up/Down Modes

- Standby
  - TR Module powered up without TR pulsing
- All OFF Power Down
  - "Zero" DC current draw

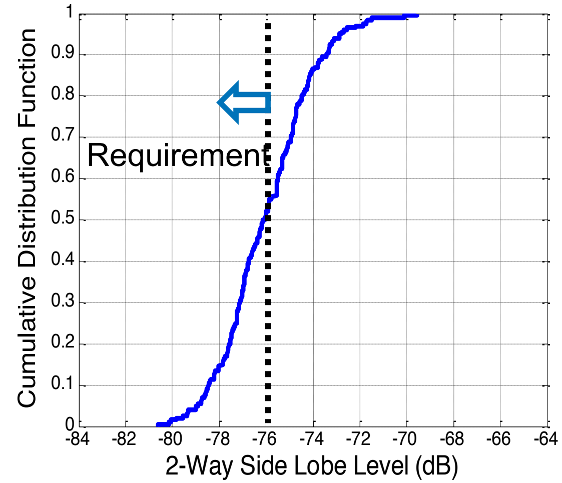
Other Modes Under Consideration

- Mutual Coupling Across Module Radiators
- Receive Noise Power Check at IF Receiver

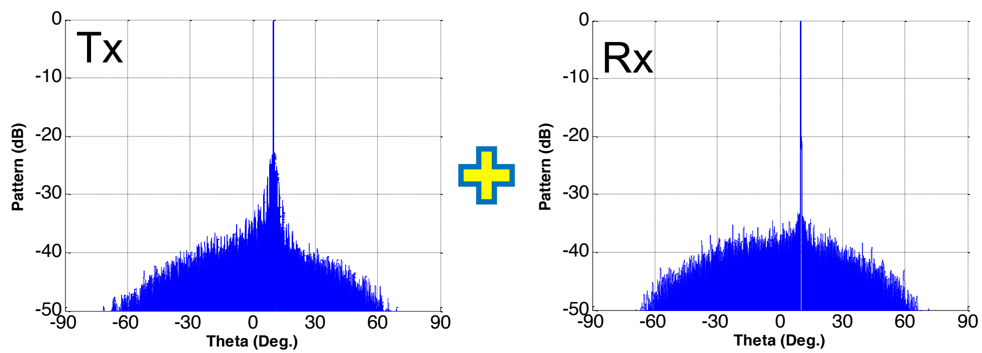
Management of Tolerances & Errors is Critical to Maintain Low Sidelobes

- Low 2-way side lobes are critical to minimize effects of an earth ground return
- Primary AESA error contributions:
  - Component variability
  - Device resolution
  - Failures
- Leveraging range tuning & in-the-field techniques to maintain low side lobes

2-way Side Lobe Cumulative Distribution Function



Ka AESA Feed Monte Carlo Simulations



Summary

- Dual- & tri-band radar concepts were developed in support of the CaPPM & ACE missions
- Careful aperture sharing permits efficient tri-band operations
  - Proven reflectarray surface allows for efficient, co-alignment of beams
- Highly leveraged development work on the Ka T/R module
- Down selected to leading candidates within each of the three radar capabilities categories
- Developed multiple point designs that meet mission objectives

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