Three-frequency Cloud and Precipitation Radar (3CPR)

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Why not W-band scanning in 2008?

*The Earth Science Decadal Survey (NRC, 2007, p91) states that the ACE mission should include "**a cross-track scanning cloud radar with channels at 94 GHz** and possibly 34 GHz for measurement of cloud droplet size, glaciation height, and cloud height"*

So why have previous ACE radar concepts NOT included W-band scanning?

W-band scanning presents many technological challenges:

- **Array spacing density requires element pitch on the order of 2mm**
  - This is not achievable without very high levels of miniaturization
  - GaAs chips don't have the power density
  - LTCC substrates are too lossy – also difficult to predict performance due to dielectric variation
  - Digital control of typical phase shifter requires thousands of connections
- **Difficult to achieve required performance due to losses and inefficiency**
  - Lack of transmit efficiency and overcoming interconnect and component losses lead to unreasonably high transmitter power requirements.
  - Low loss technology such as waveguides and ferrite switches are too large to meet array spacing requirements
- **Lack of suitable high-power amplifier MMICs**
  - Without MMICs of approximately 1W power it's not possible to produce enough power in a 1D array
  - Building 2D arrays makes meeting the array spacing requirements even more difficult and multiplies cost

So what's changed?

A confluence of enabling technologies:

- Micromachined all-metal (no dielectric) coax, interconnects and radiators
  - Nuvotronics PolyStrata process ***provides high-density 3D RF signal routing, very low loss, excellent thermal conductivity and excellent design performance predictability***.
- Gallium Nitride (GaN) power amplifiers and low noise amplifiers (LNA)
  - Provide ***>1W transmit power in a chip only 1 mm wide***!
  - High input power tolerance LNAs – reduces isolation requirements
- Silicon Germanium (SiGe) phase shifters with integrated serial digital control
  - Integration of RF and serial digital control in SiGe MMICs ***eliminates thousands of interconnects*** in W-band array.
- Innovative interlaced array architecture ***eliminates need for front-end switching, greatly reducing losses***
  - Made possible by high element-to-element isolation and high leakage tolerance of LNAs

Evolution of an Instrument Concept

1999

Second Generation Precipitation Radar (PR-2)

- Ku/Ka-band Precipitation Radar
- First spaceborne precipitation radar concept using cylindrical parabolic reflector, active linear array feed

2009

Cloud Cross-track scanning Dual-frequency Doppler radar (C2D2)

- Ka/W-band
- Similar antenna configuration to PR-2
- First concept proposing W-band scanning

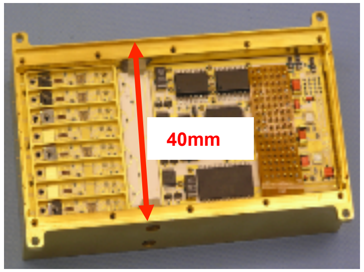
2013

Three-band Cloud and Precipitation Radar (3CPR)

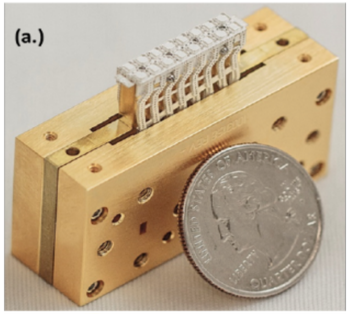
- Ku/Ka/W-band
- Similar antenna configuration PR-2/C2D2
- Combines three active linear array feeds
- Scanning at all three bands
- Capable of simultaneous cloud / precipitation measurements

Deployable Reflector Demo

8 TX / 16 RX Channel Ka-band TR Module



2x8 Element W-band Phased Array



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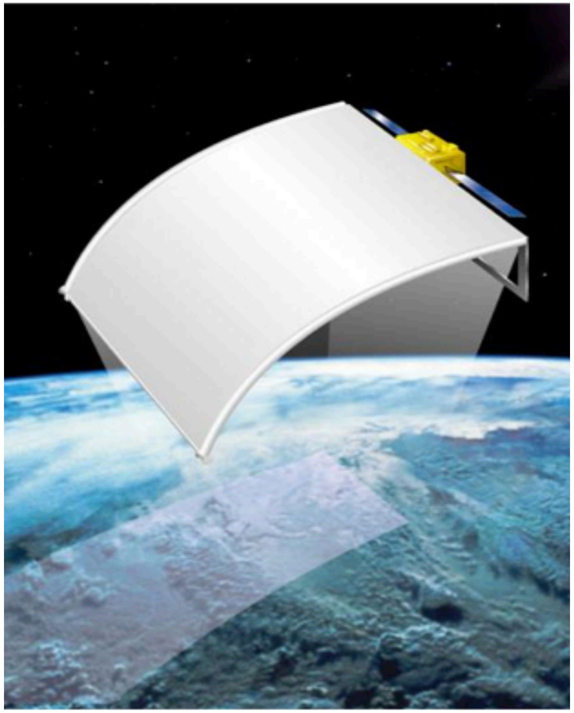
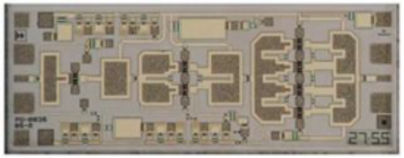
Array-fed Cylindrical Parabolic Reflector common to all three concepts



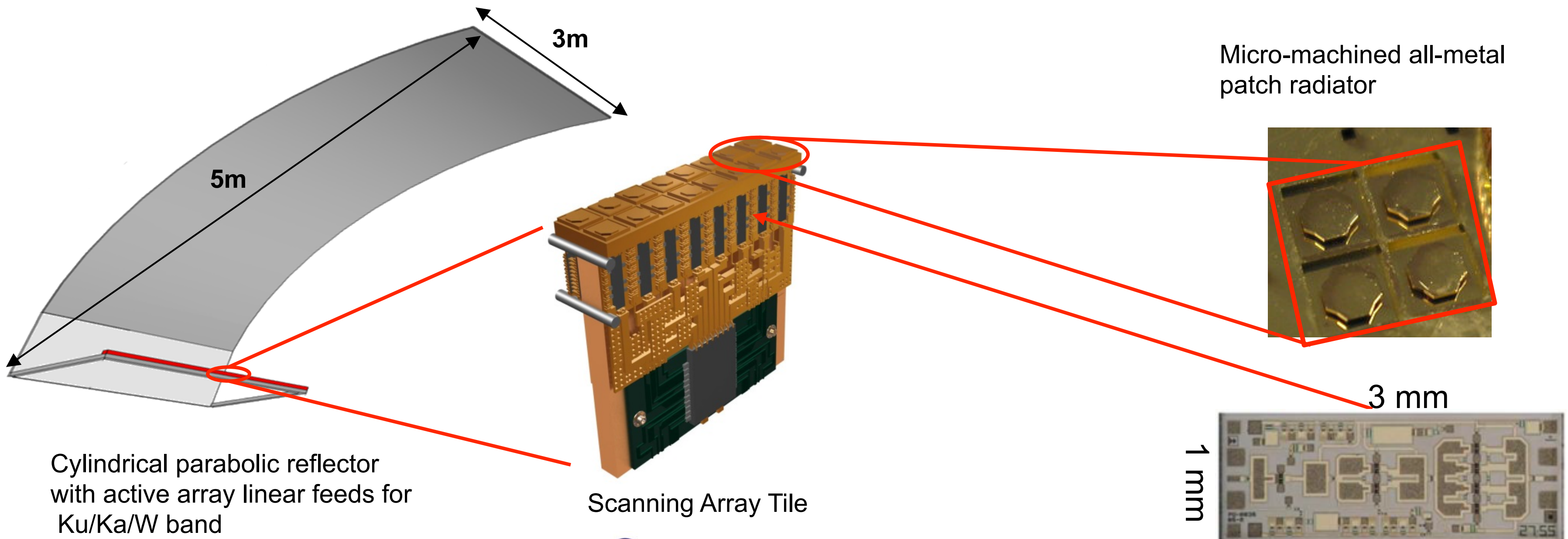
High-power W-band GaN MMIC



Raytheon

3-band Cloud and Precipitation Radar (3CPR)
ESTO IIP2103

- Cylindrical parabolic antenna provides high gain and cross-track scanning capability at Ku-band (13.4 GHz), Ka-band (35.6 GHz) and W-band (94 GHz)
- No need for heavy, lossy slotted waveguide arrays (as used in GPM)
- Some issues to be addressed including:
  - Reflector illumination over scan
  - Pattern / pointing distortion due to feed point offsets
- Feed technology exist for Ku and Ka bands
  - Ka-band TR 8-pack demo at JPL
  - More recent Ka-band developments from GSFC / NGES (*Racette, et al*)
- Focus on new technology required to enable W-band scanning
- IIP2013 task will demonstrate scaled reflector w/ scanning W-band Feed



Cylindrical parabolic reflector with active array linear feeds for Ku/Ka/W band

Only W-band shown

Scanning Array Tile

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GaN TR MMICs

Raytheon

3CPR System Design

- Support either:
  - ACE decadal survey mission concept(Ka- / W-band)
  - Cloud and Precipitation Processes Mission (CaPPM) concept. (Ku-, Ka-, W-band)
- Most precious resources:
  - Sampling time
  - Transmitted power
- Pulse-to-pulse beam agility and optimized timing enable optimization of performance WRT certain science requirements
- One point design was chosen for 3CPR system study
  - High-sensitivity nadir measurements
  - Significant swath at all three bands
- Hardware is highly adaptable to changes in measurement priorities or resource limitations.
- Supports adaptive scan strategies and pulsed compression if required by application

3CPR Key Parameters

Parameter	Value (Ku/Ka/W)
Reflector Size	5 m x 3 m
Feed Array Length	2.5 / 2.87 / 2.87 m
Feed elements (each for TX / RX)	160 / 480 / 1152
Transmit Power (peak)	3200 / 1600 / 1267 W
Pulse length	1.5 μs
Scan angle (+/-)	4.5 / 12 / 3.5 degrees

3CPR Predicted Performance

		NADIR			SWATH		
		Ku	Ka	W	Ku	Ka	W
EFOV (along x cross)	km	4 x 4	2 x 1.5	1 x 0.6	4 x 4	2 x 2	1 x 1
Clutter Free MDS	dBZ	-5	-20	-35	+2	-10	-22
Clutter Free hgt	M	300	300	300	500	850	500
Near Surface MDS	dBZ	+12	-5	-20	+12	0	-10
Near Surface hgt	M	250	250	250	400	500	300
Doppler 0 SNR	dBZ	+12	-5	-18	+12	N/A	*-13*
Doppler Prec.	m/s	0.3	0.2	0.1	0.5	N/A	*0.5*
Swath	km				60	195	50
Max Scan Angle	deg				4.5	12	3.5
# Beams		1	1	1	18	96	48
Polarization		FULL	LDR	LDR	FULL	LDR	LDR

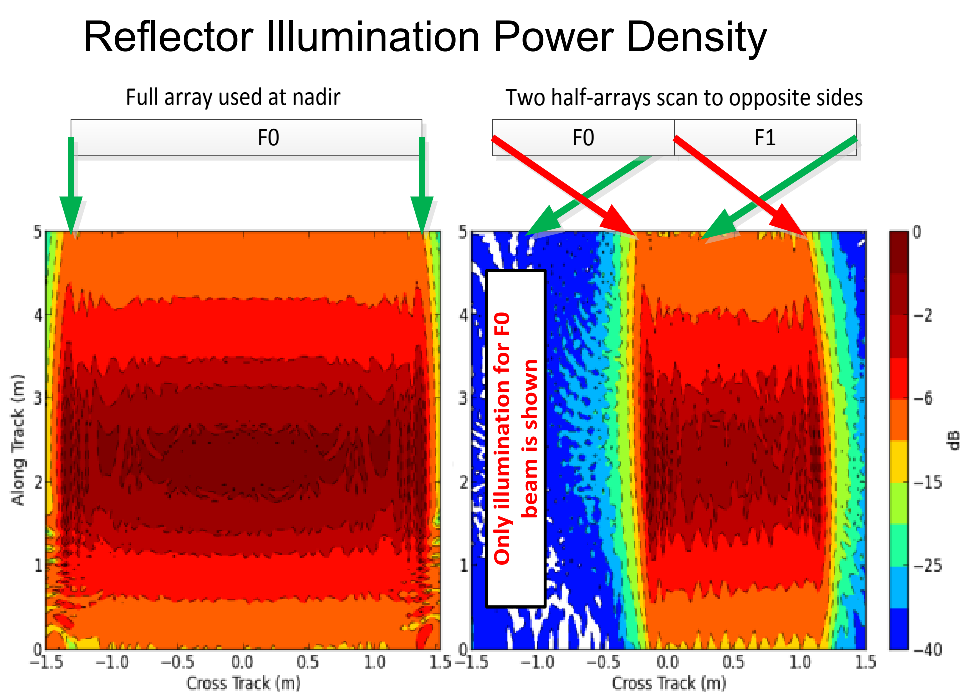
Legend	ACE	Req Met	Goal Met	IWSSM	Req Met	GPCM (Tent.)	Req. Met

Advantages of C2D2/3CPR Concepts

- **Uses mature technologies for most of system with key new technologies to enable W-band Scanning**
  - Prior work at JPL includes extensive system design and prototyping for PR-2 concept (Ku/Ka-band) including:
    - Airborne instrument (APR-2)
    - Cylindrical-parabolic reflector demonstration
    - Digital real-time pulse compression demonstration
    - Adaptive scanning demonstration
    - Ka-band TR module demonstration
  - Composite reflector technology similar to CloudSat
  - All technologies outside of antenna system are mature/flight proven (TRL 6+)
- **Solid-state array-fed reflector combines high-gain aperture with solid-state array**
  - 1D array much simpler w/ order of magnitude less elements than 2D array
  - No high voltage power supply
  - Inherent redundancy provide graceful degradation if failures occur
  - Operational flexibility to optimize measurement strategies
- **Advanced manufacturing techniques**
  - Micro-machined radiator, chip carriers and routing networks provide high packing density, high manufacturing yield, excellent RF and thermal properties
  - Automated manufacturing, assembly and test of array tiles and design for known yield dramatically reduce per element costs for array

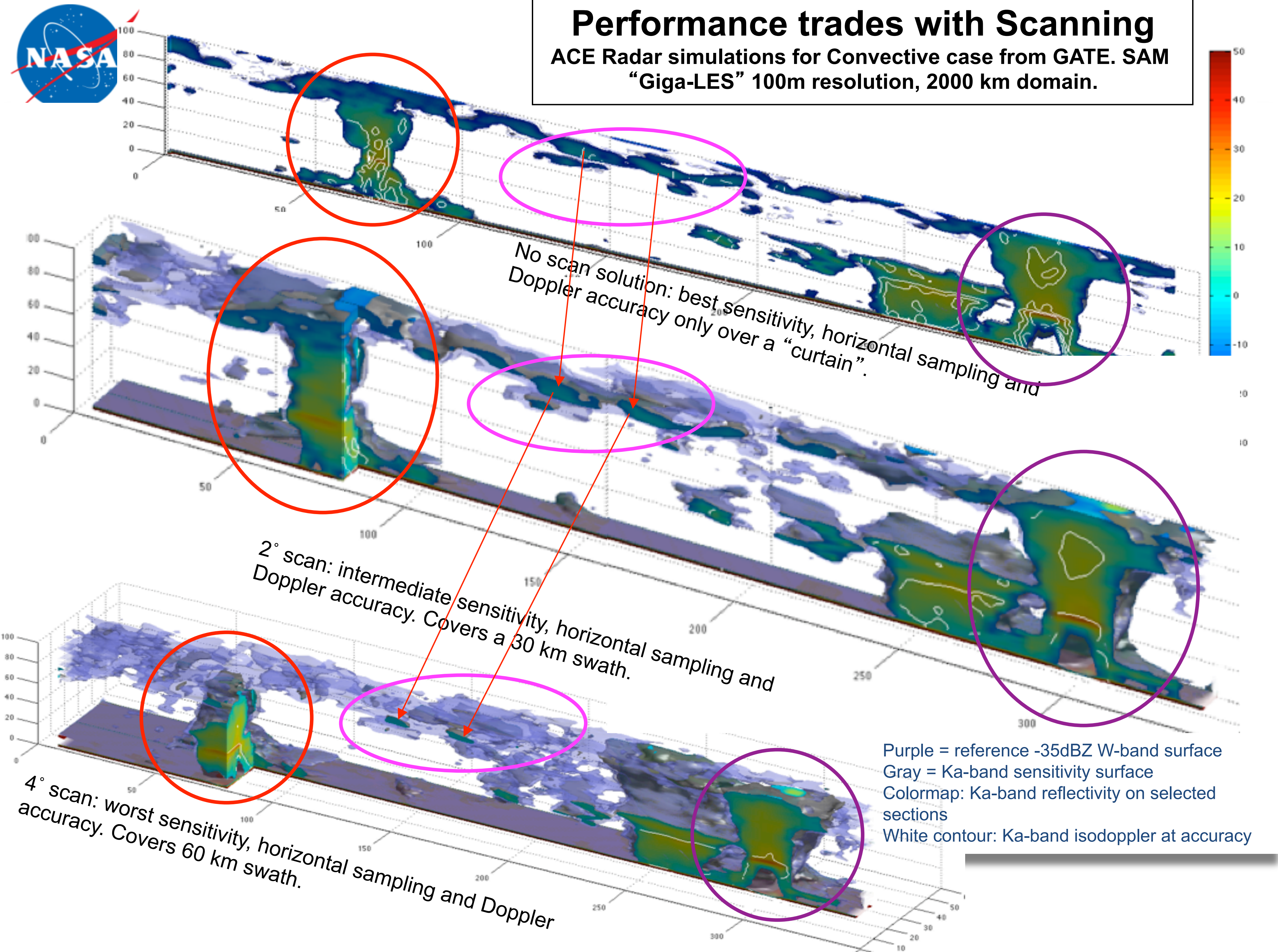
Flexible Scan Strategies

- Flexible scan strategies enable best allocation of scarce resources (TX power, sampling time) to optimize any particular measurements
- Trades include pulse length, signal bandwidth, pulses per beam, effective beam width
- For example: Two simultaneous W-band beams can be collected each using half arrays
  - This trades sensitivity for faster sampling
- Many other trades possible
- Adaptive scan strategies can be used to collect higher-fidelity data in areas of particular interest



Performance trades with Scanning

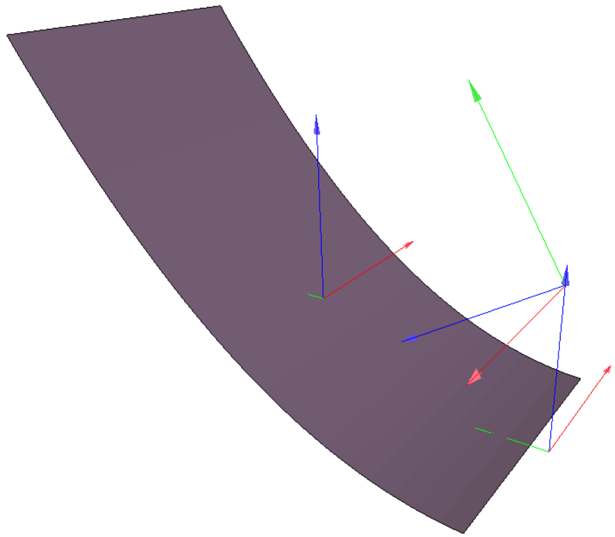
ACE Radar simulations for Convective case from GATE. SAM "Giga-LES" 100m resolution, 2000 km domain.

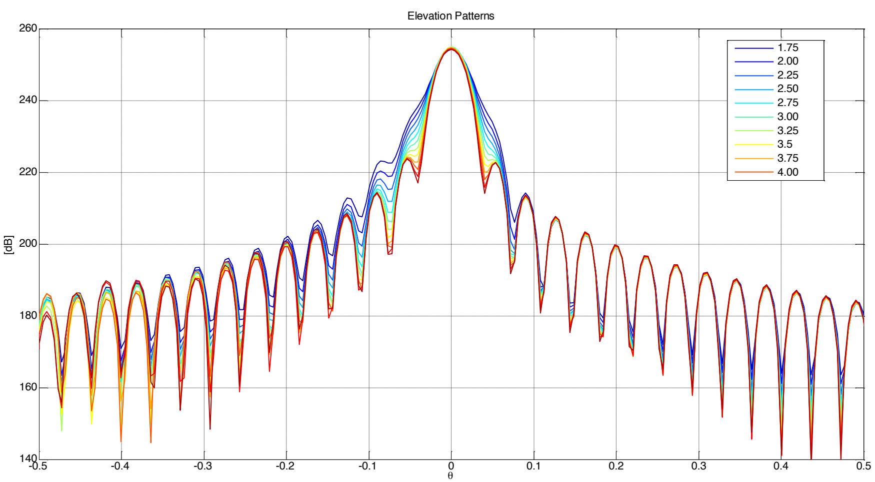


Antenna System Modeling

- Hybrid modelling approach simulates full feed / reflector system
- Combines Physical Optics / Physical Theory of Diffraction with Full Wave modelling

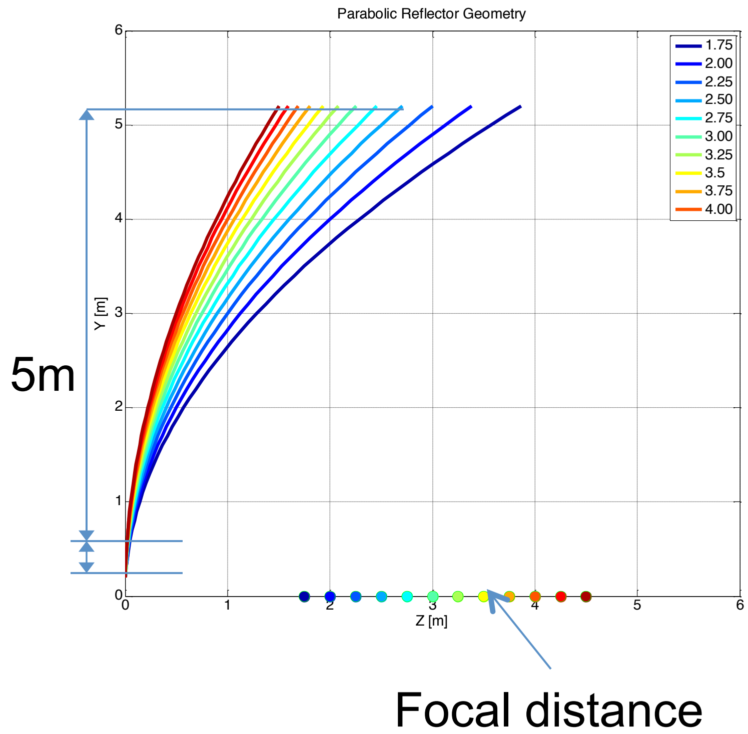
- Some important issues to investigate:
  - Optimal focal length
  - Optimal illumination pattern for feed
  - Array sidelobes / grating lobes
  - Feed spillover
  - Pointing errors / sidelobes due to feed displacement

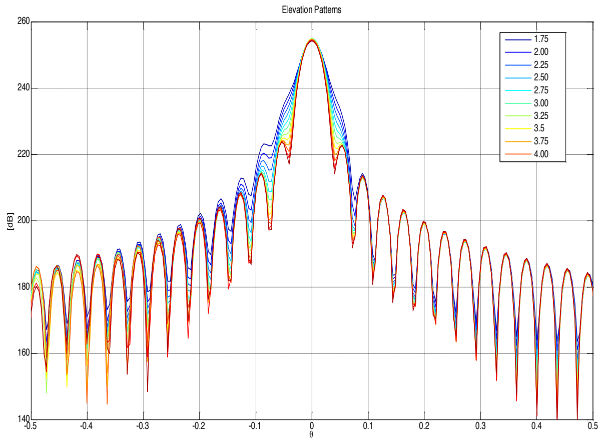


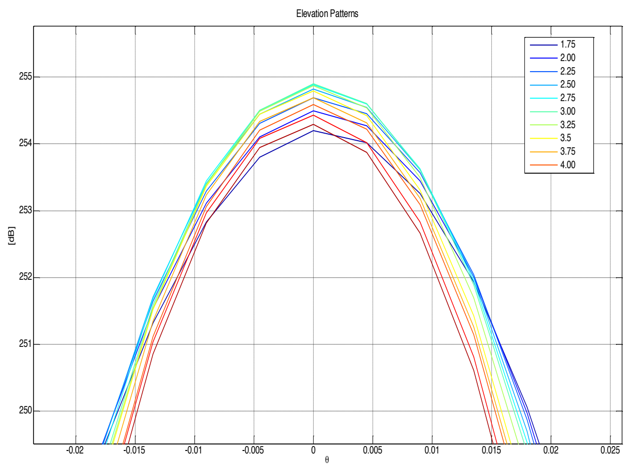


Focal Length Variation

- Focal length variation affects
  - Overall system size
  - Gain, beam shape
  - Required feed illumination pattern
    - Very short F/D degrades performance and requires very wide beam feed

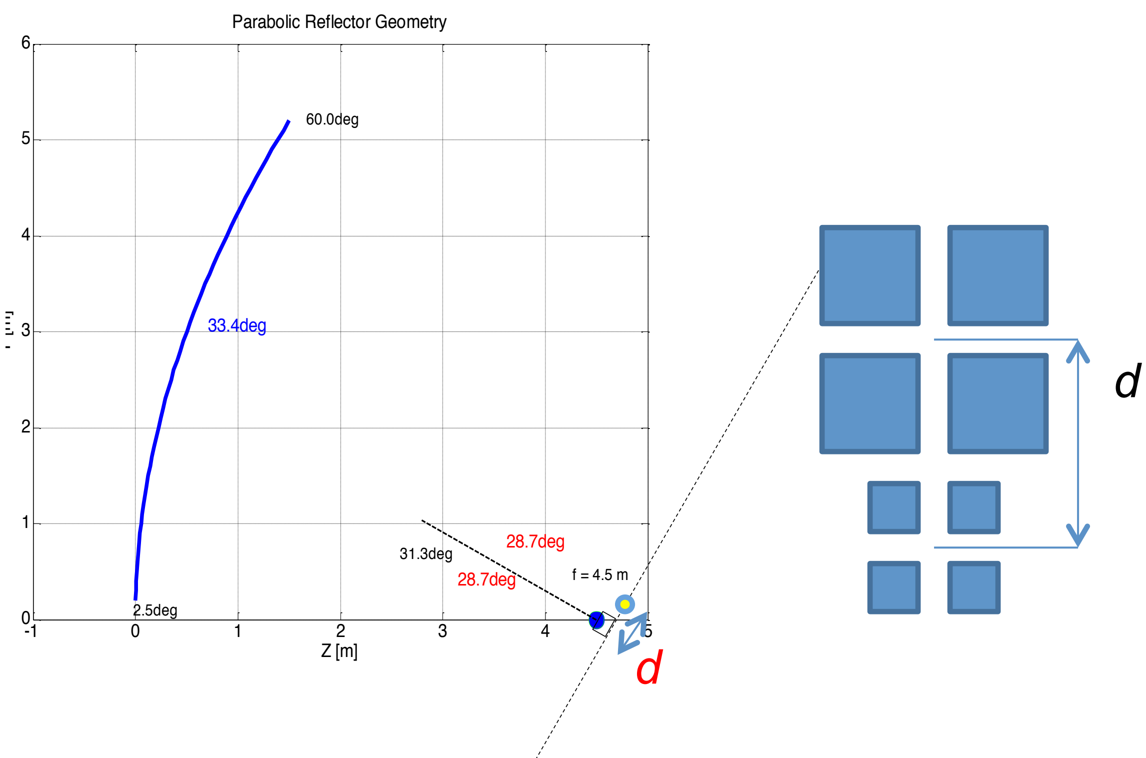


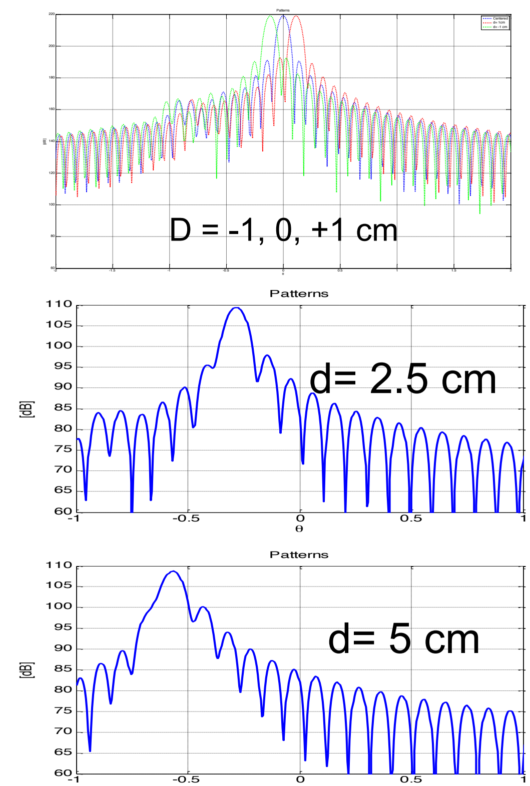




Displacement of Feed from Focus

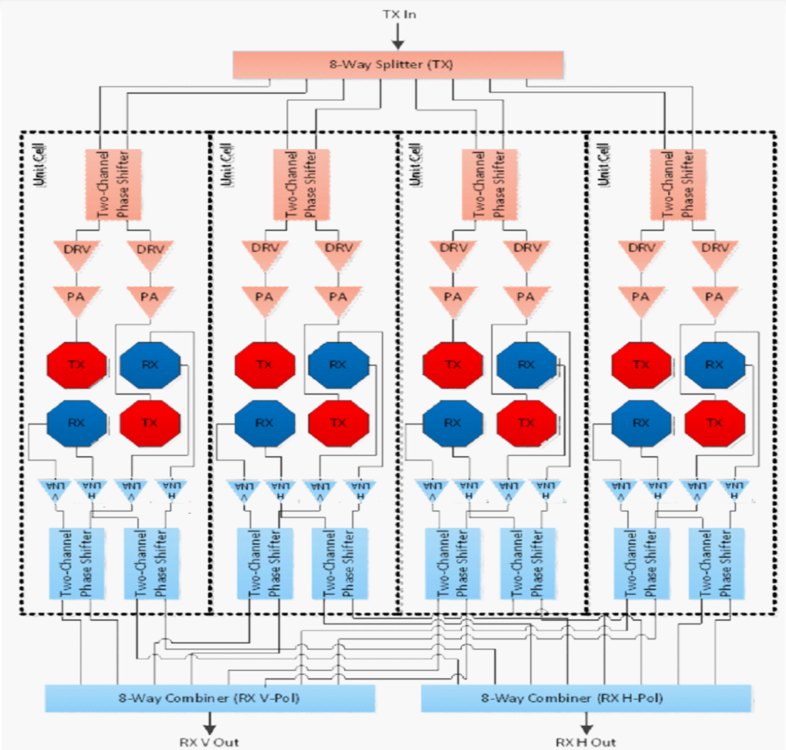
- Multiple feeds required displacement of one or more feeds from focus
  - In this example W-band is on focus, Ka-band is displaced.
- This results in “scallop” lobes and along-track pointing offset.
- Small along-track offsets are easily corrected by temporal re-alignment of the data.

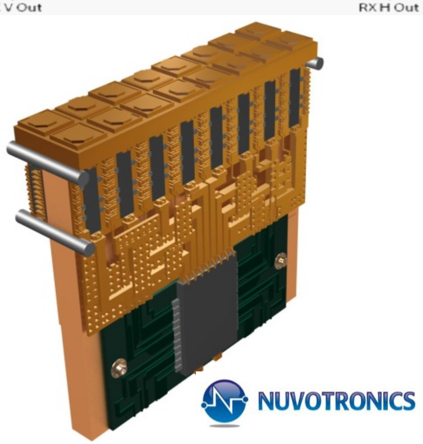




Scanning Array Tile (2x8)

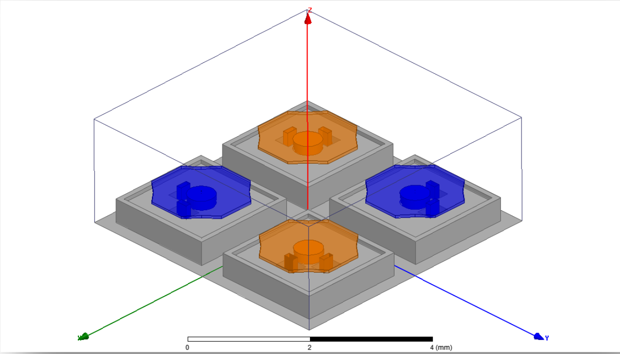
- 8 transmit / 8 dual-pol receive elements
- H-pol transmit, V- and H-pol receive
- RX / TX triangular interlaced grid
  - Eliminates transmit/receive switches or circulators
- GaN provides high-power, high-efficiency TX
  - 1W per channel transmit power
- PolyStrata™ carriers include
  - All-metal radiator array
  - PolyStrata™ rectacoax interconnects
  - PolyStrata lowers RF losses, good isolation, increased packaging density, provides high-stability and high yield
- SiGe phase shifter MMIC
  - SiGe provides miniaturized mixed signal circuits including phase shifter *and* digital control circuits.



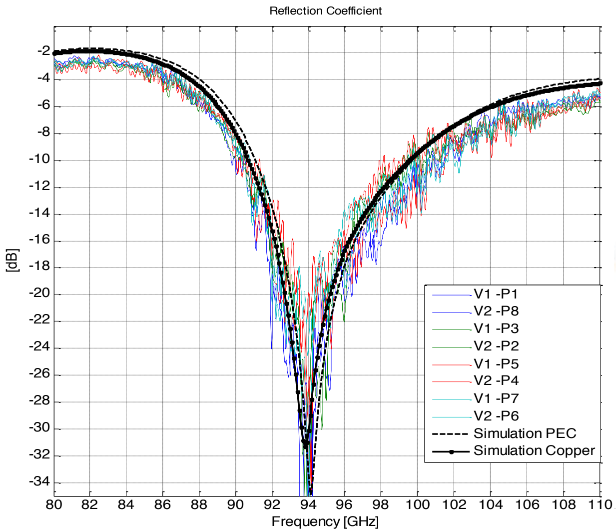


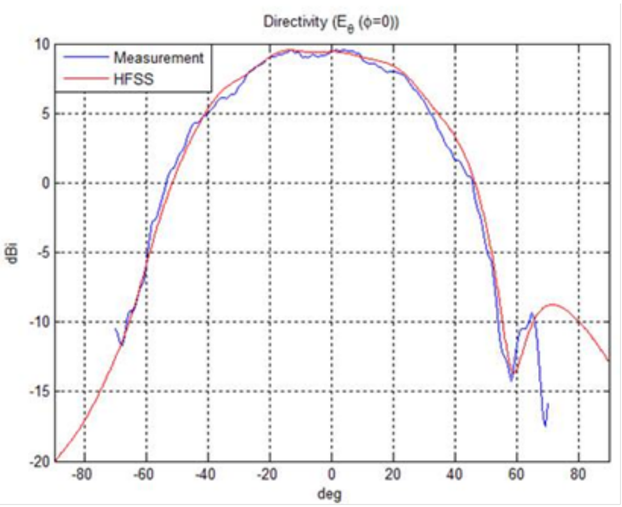
W-band Radiator Prototyping

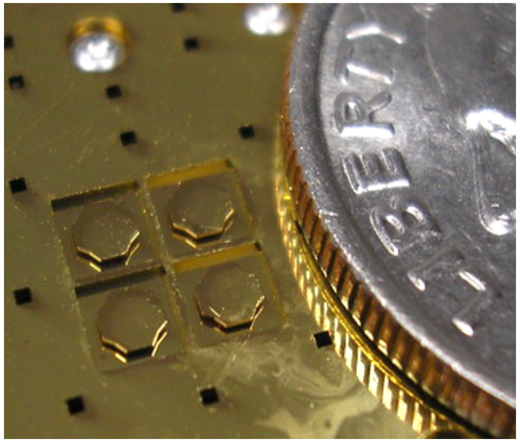
- Four element unit cell designed by JPL, fabricated by Nuvotronics
- Extensive feed modeling has been performed using 3D electromagnetics software HFSS
- Initial return loss measurements match models very well on first pass!



HFSS model







Unit cell prototype

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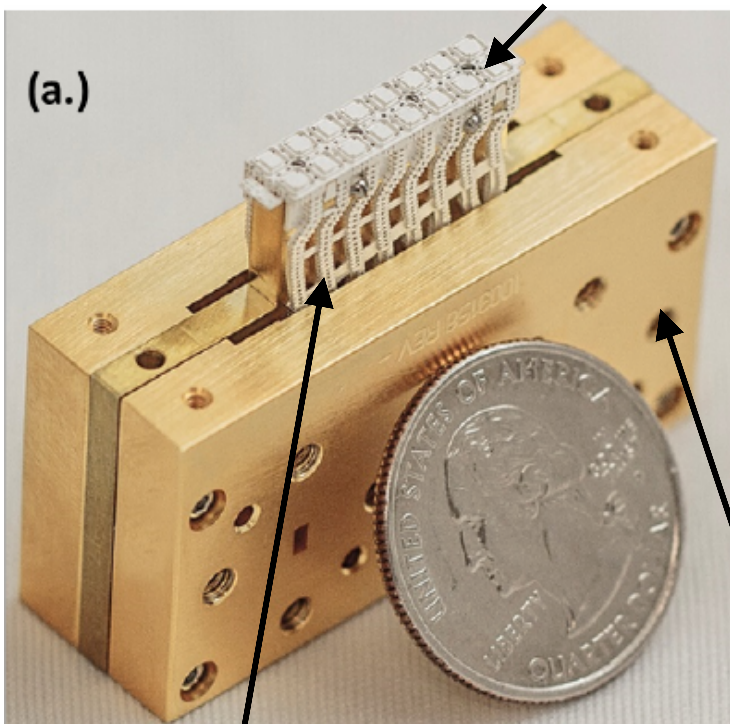
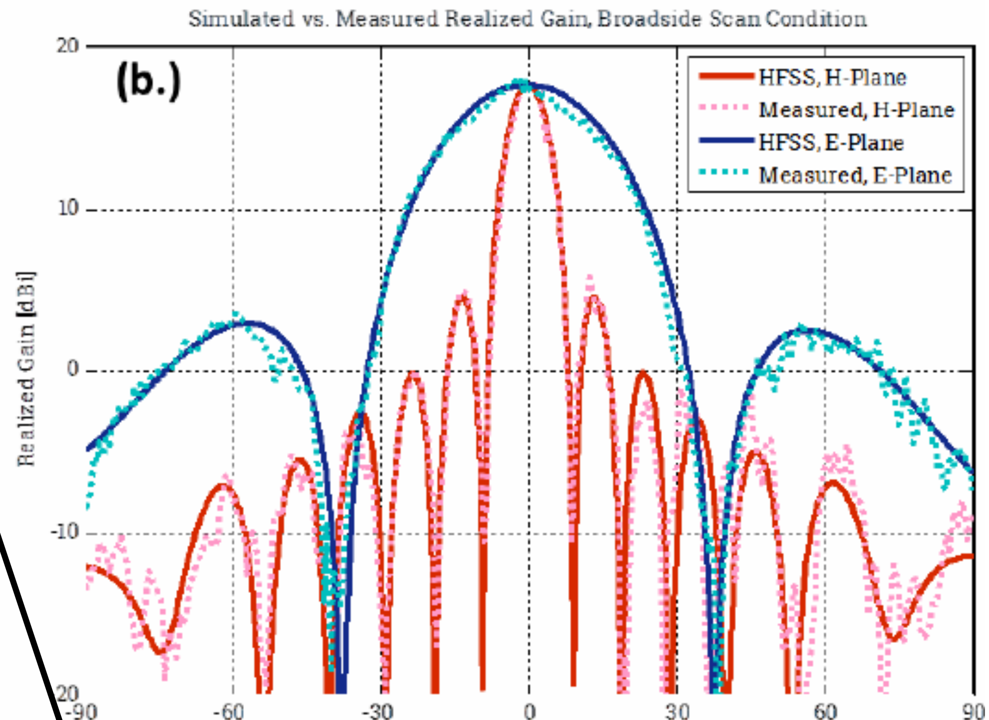
2x8 Array Demonstration

- 8 TX channels (H), 16 RX channels (V and H)
- Developed by Nuvotronics under SBIR contract
- Again, excellent agreement between prediction and measurement on 1st pass!

2x8 element radiator array





24 Rectacoax feed lines

Brass block is a test fixture to enable measurement

3x 8-way power combiners are not visible (they are inside brass block)

C2D2/3CPR Status Summary

- Two-frequency (Ka/W-band) version meets all ACE requirements and most goals (C2D2)
- Three-frequency (Ku/Ka/W-band) suitable for sensing of both clouds and precipitation, supporting CaPPM concept (3CPR)
- Broad trade space enables further design optimization to meet changing requirements
- Instrument Incubator Program 3CPR started April 2104
  - Complete system design study
  - Demonstration of 2x64 Element Dual-Pol W-band scanning array integrated with scaled reflector
- Antenna and system design optimization are in progress
- Passive-scanned W-band 2x8 scanning array tile (SAT) demonstrates
- GaN MMICs in currently fabrication
- Development of actively-scanned SAT beginning

The End

Thank you for your attention…questions?

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