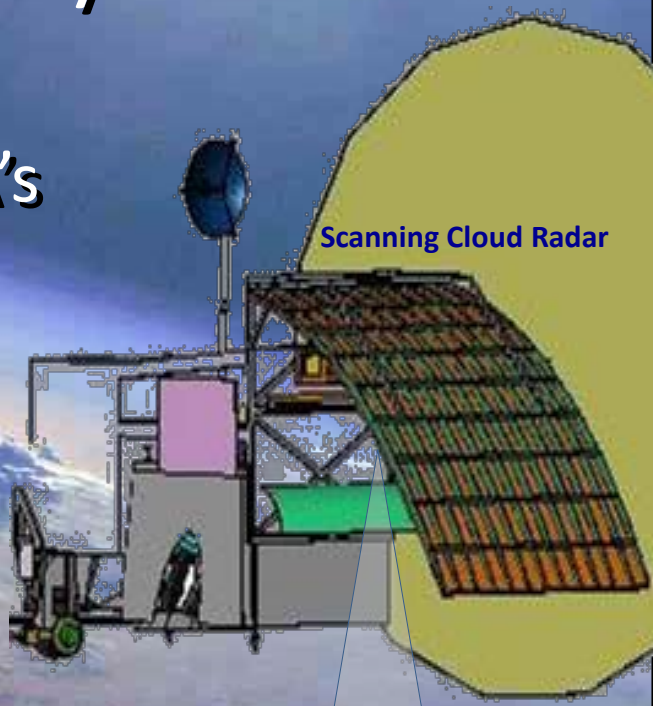
A Novel Reflector/Reflectarray Antenna

An Enabling Technology for NASA's Dual-Frequency ACE Radar



Paul E. Racette, Gerald Heymsfield, Lihua Li

NASA Goddard Space Flight Center (GSFC)

Michael E. Cooley, Richard Park, Peter Stenger

Northrop Grumman Electronic Systems (NGES)

Overview

- NGES – Goddard Partnership
- ACE Mission
- Radar Architectures
- Proposed Architecture
- Ka-band AESA
- Dual-freq Reflectarray
- Concluding Remarks

Our approach leverages over 15 years of reflectarray antenna technology development

GSFC - NGES Partnership

Three Focus Areas

- Technology Implementation
  - Antennas
  - Electronics
  - On-Board Processing
  - Science Data Processing
- Sensor Definition
  - Defining architectures to address science needs
- Sensor Demonstration
  - Collect data and validate performance

Dr. Laurie Leshin (former GSFC Director Science & Technology) and Joe Ensor (former VP/GM Space & ISR), Feb. 21st 2008 Signing Space Act Agreement

Aerosol-Cloud-Ecosystems Mission

ACE is a multi/interdisciplinary mission, bringing together 4+ scientific communities:

- *Aerosol (radiation/energy budget, geochemistry, air quality)*
- *Clouds (radiation/energy budget, precipitation)*
- *Ocean Ecosystems (biological productivity, carbon cycle)*
- *Aerosol-Ocean Interactions (eolian nutrient deposition, aerosol/precursor production)*

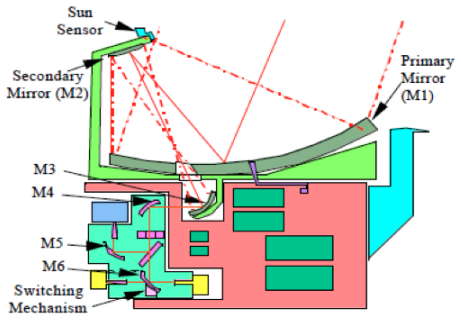
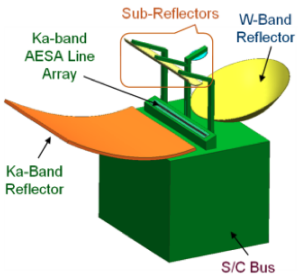
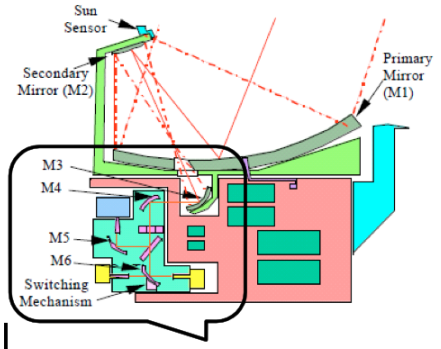
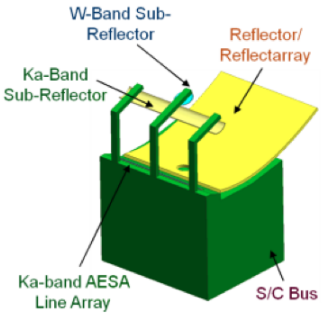
ACE Instruments

- Dual frequency, Doppler cloud radar for profiles of cloud properties and precipitation
- HSRL Lidar for aerosol/ cloud heights and aerosol properties
- Multi-angle, multi-spectral imaging polarimeter for aerosol and clouds
- Ocean color multi-channel spectrometer for ocean ecosystems

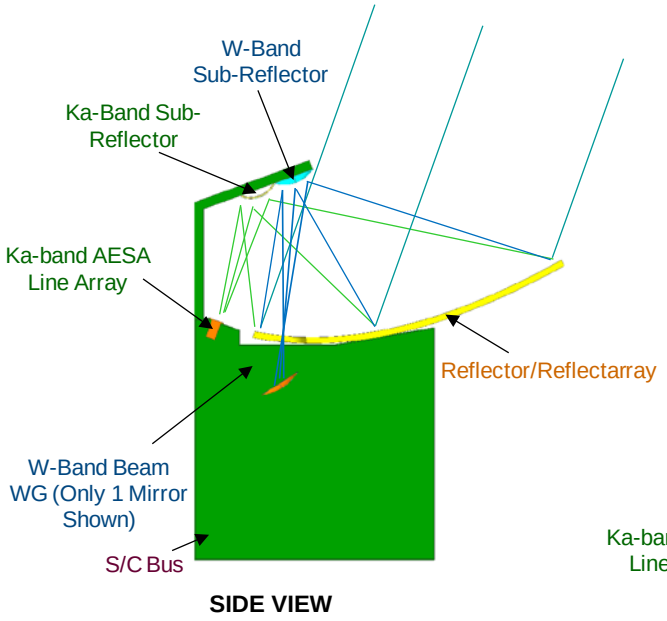
ACE Radar Requirements, Goals and Priorities

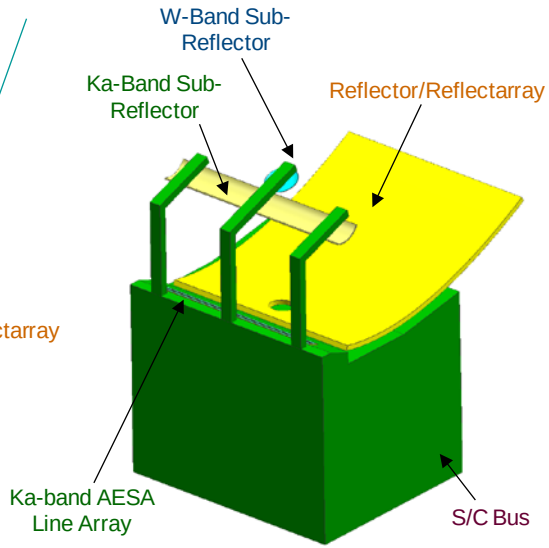
Measurement	Radar Priority	Requirement	Goal
Minimum detectable sensitivity (MDS)	W: #3 Ka: #2	-35 dBZ at W-band -10 dBZ at Ka-band	-40 dBZ at W-band -20 dBZ at Ka-band
Science window	W: #1 Ka: #4	No surface clutter above MDS from 500 m above surface	250 m above surface
Range resolution	W: #1	250 m	100 m
Horizontal resolution	W: TBD Ka: TBD	1 km at W-band 2 km at Ka-band	1 km at Ka-band Match cross track resolution of two bands
Swath	W: #4 Ka: #1	W-band nadir Ka-band nadir	W-band > 1 km Ka-band >25 km
Doppler	W: #2 Ka: #3	W-band 0.4 m/s Ka-band 1 m/s (nadir)	W-band 0.2 m/s Ka-band 0.5 m/s nadir, 1 m/s off nadir
Polarimetry	W: #5 Ka: #5	None	Depolarization (LDR or CDR) at W- and Ka-band

Comparison of Architectures

	CloudSat Single Reflector, W-Band	**Two Reflectors** One at W-Band One at Ka-Band	**"Dual-Band Reflector"** Add Ka-Band to Quasi-Optic Feed	**NGES/GSFC** Reflector/ Reflectarray
Antenna Design Approach			 Possible Re-Design: Dual-Band (Ka/W) Quasi-Optical Beam Waveguide Feed	
Dual-Band Capability	None	Good	Good	Good
Ka-Band Wide FOV	None	Good	Poor	Good
Size and Weight	Good	Poor	Good	Good
TRL	9	3-4	3-4	3-4

Dual-Frequency Architecture

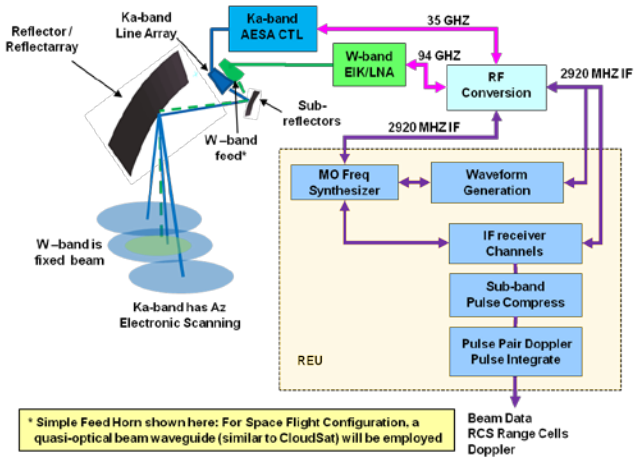




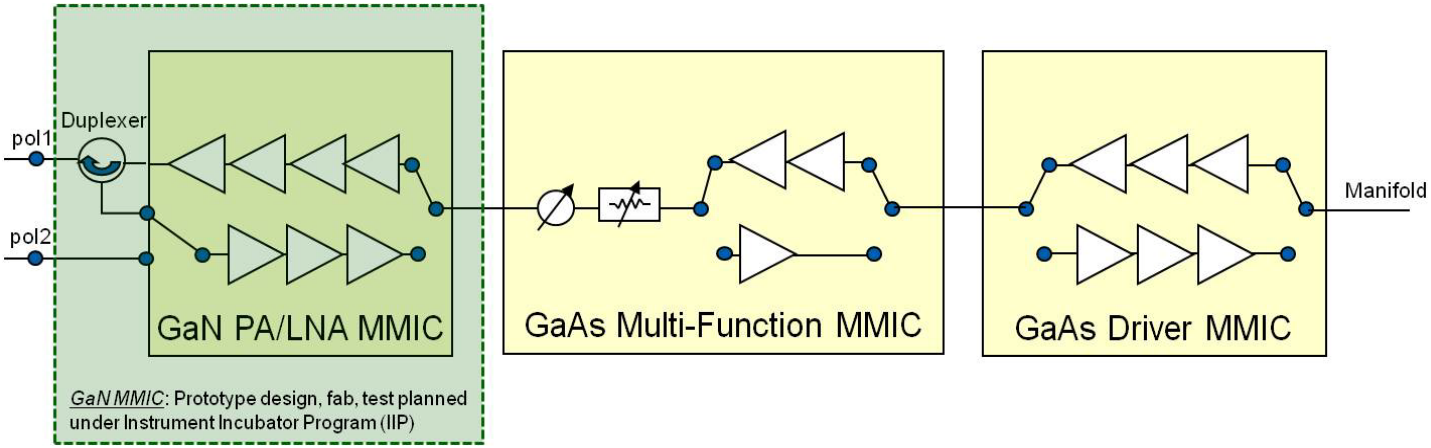
Reflector/Reflectarray
- Fixed W-band, High-TRL
- W-band Focusing
- Ka-band transparent

Ka-band Active Electronically Scanned Antenna
- Provides >100 km swath
- Leverages NGES AESA technologies

System backend
- Leverages SpaceRadar Designs



Ka-band AESA Module

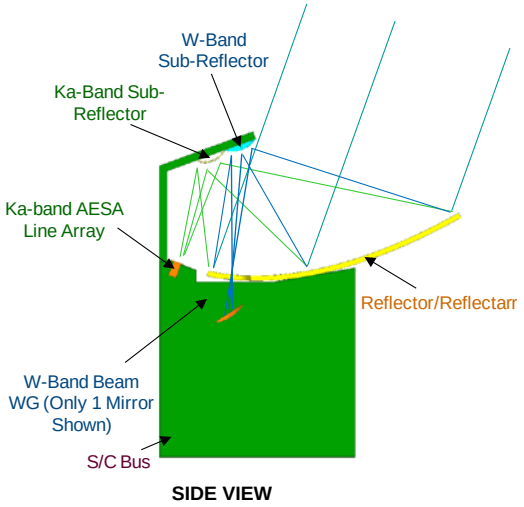


- Ka-band T/R module is the AESA line feed "building block"
  - Leverages similar Northrop-Grumman designs from other Programs
  - Provides azimuth electronic scanning for wide radar FOV
  - Enables low azimuth sidelobes for high fidelity radar imaging
- Novel GaN T/R model technologies
  - High performance; low sidelobes, amplitude taper control, calibration, ...
  - High efficiency, high reliability
  - Supports tech growth path (multiple beams, wider scanning, etc.)
- Highly integrated multi-site T/R package reduces complexity, cost

Ka-band AESA

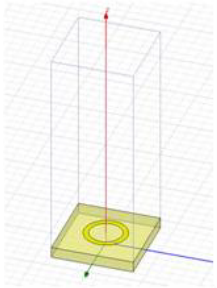
Advantage/Benefit	Description
Wide Az FOV Enables Imaging	* AESA feed provides Az electronic scanning
Enhanced Reliability	* Distributed nature of AESA feed provides graceful degradation * Robust design meets effective isotropic radiated power (EIRP) spec with 10% T/R module failure rate
Ultra-Low Az Sidelobes/ Image Fidelity	* AESA feed has amp/phase control * High tolerance reflector surface accuracy * Highly accurate reflectarray surface phasing
Sensor Flexibility, Beamwidth Control	* Beam can be broadened in Az via phase spoiling * Provides FOV/coverage flexibility if needed
Calibration/Correction	* AESA feed has amp/phase control * Enables calibration/correction for thermal distortion and/or alignment errors
Growth Path –Multiple Az (Rx) Beams	* AESA technology enables multiple Az beams * Supports sensor capability spiral growth path for ACE follow-on missions

Novel Dual-Frequency Reflectarray

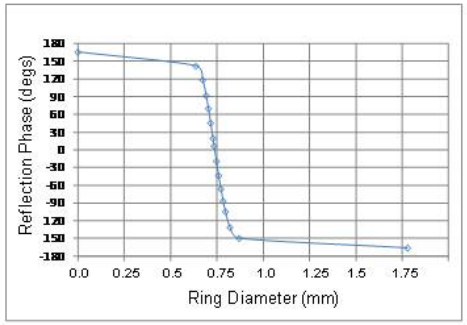


SIDE VIEW

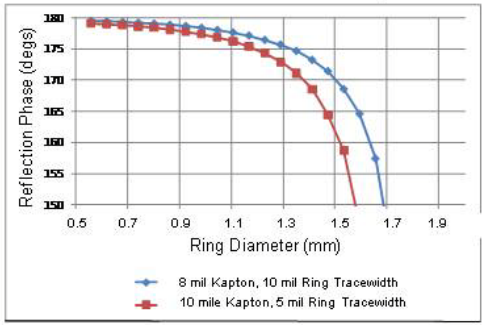
Ring Element

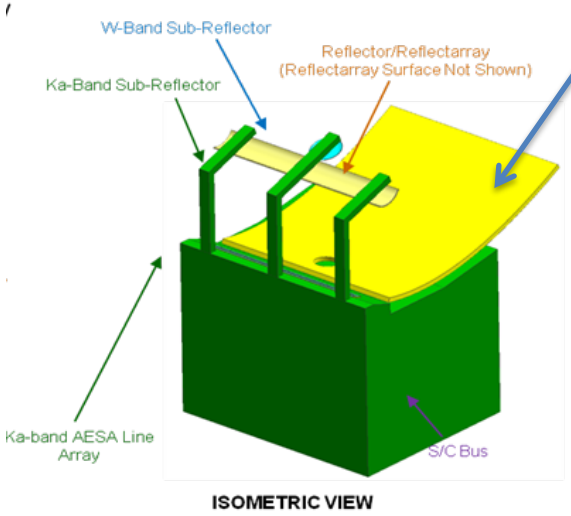


W-Band Phase Shift Response



Ka-Band Phase Error Response





ISOMETRIC VIEW

GSFC pioneered W-band reflectarrays in the 90's

Scale Model Reflectarray

- Design and Fabricate scale model of reflectarray
- Electrical characterization at W- and Ka-bands
- Environmental testing
- Test fly with CRS on ER-2 or WB-57

Scale model of reflectarray will fly with CRS

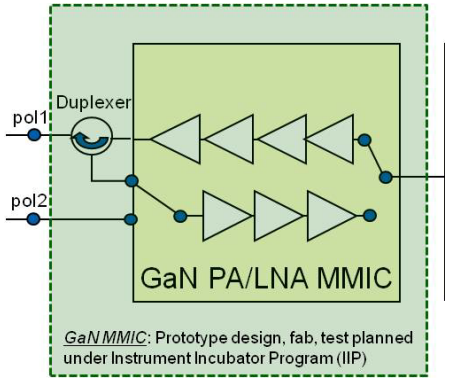
Cloud Radar System (CRS) is being upgraded with new transceiver and data system

Reflectarray Performance

Parameter	Ka Gain (dB)	W Gain (dB)	Comments
Maximum directivity (dBi)	64.1	72.7	3m x 5 m aperture
Spillover efficiency (dB)	-0.3	-0.3	Estimate
Taper Efficiency (dB)	-1.2	-2	Estimate
Dielectric and Conductor Loss (dB)	-0.1	-0.7	W-band includes element losses
Phase error losses (dB)	-0.3	-0.7	Estimate
Feed losses (dB)	-0.5	-0.5	VSWR and line losses
Realized Gain (dBi)	61.7	68.5	

IIP Objectives

- Ka-band AESA
  - Feed/Module PDR-level Design
  - Fab/Demo GaN switch, PA & LNA
- Reflectarray
  - Design/Demo Surface characteristics
  - Full Scale design concept
  - Scale model Design & Fab
  - Aircraft Demo
- System Studies
  - Mission Radar System requirements and impact of the technology development
  - Development of Concepts and detailed requirements; implications to radar system



Conclusion

- NGES/GSFC has developed novel dual-frequency shared aperture concept for ACE radar
- Dual-frequency reflectarray surface
  - focusing at W-band
    - high-TRL W-band transceiver
  - transparent at Ka-band
    - Ka-band AESA
- Three-year IIP to develop/demonstrate key technologies
  - PDR level AESA Design
  - Airborne Demonstration of Reflectarray