National Aeronautics and Space Administration

NORTHROP GRUMMAN

ANTENNA TECHNOLOGY FOR 3-D WIDE SWATH IMAGING SUPPORTING ACE

Earth Science Technology Forum

October 28, 2014

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Outline

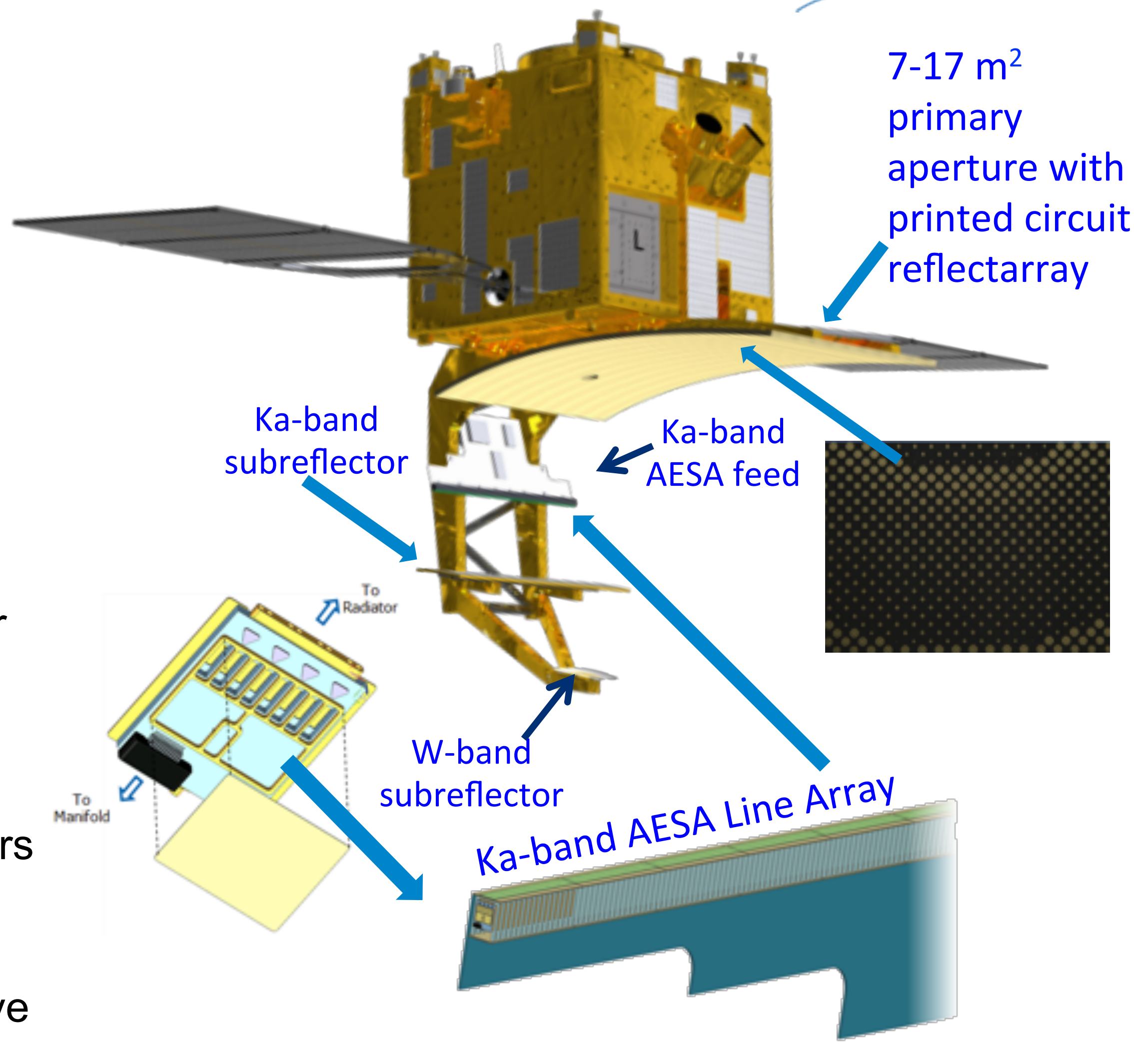
- ACE Radar Introduction
- Overview of 2010 IIP objectives
- Reflectarray Development
- Subscale Antenna Airborne Demonstration
- ACE Radar Design Study
- TRL Assessment
- E/PO Supplemental Award
- A look ahead: 2013 IIP Summary

Introduction to ACE Radar & 2010 IIP Objectives

Introduction to Dual Band ACE Radar

Discriminating Features

- Shared Dual-Band Primary Aperture
- Wide swath imaging (≥120km) at Ka-band enabled by Azimuth Electronic Scanning (AESA Feed)
- Fixed Beam at W-Band (Compatible with CloudSat / EarthCare Beam Waveguide and Transceiver)
- Reflectarray enables tri-band and/or scanning W-band options
- Significant Payload Size and Weight Savings (Compared with two-reflector solution)
- Leverages TRL 6+ W-band Space Radar
- Leverages HIWRAP/CRS Transceivers and Advanced Signal Processing Algorithms
- Technology Maturation Plan to achieve TRL 6 by 2017



IIP Project Activities

- **Modeling & Simulation**
  - Modeling Tools, Simulations, and Models developed and designs simulated
  - Verified and validated by coupon range test and analysis
  - Tools validated with confidence for, subscale, space payload full scale and alternate configurations
- **Coupon Development & Test**
  - Completed Development and Model Validation
  - Range Test confirmed; Low loss materials further characterized
- **Sub-Scale Antenna Development**
  - Design, Development, Concepts and Trades Completed
  - ATK reflector, Millitech hardware, Materials received; assembly complete
  - Ka-manifold fabricated
  - Range test validated design
  - Airborne demonstration
- **Full-Scale Antenna Design**
  - Validated design tools/Requirements analysis
  - Advanced Designs & Advanced concepts
  - PDR Completed
- **Ka Module & Feed Design – Full Scale**
  - MMICs defined/module requirements established
  - Design and PDR Completed
- **GaN HPA MMIC Development**
  - Trades and requirements completed
  - PDR completed
  - CDR
  - Foundry Fab & Test
- **E/PO Supplemental Grant**
  - Expand Earthzine's Earth sensing technology coverage

Reflectarray Technology Development & Airborne Demonstration

Reflectarray Antenna Design – Requisite Toolbox

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Reflectarray Analysis and Tools:

- MATLAB Reflectarray Architecture Analysis
- MATGO Aperture Synthesis/ Design
- Auxiliary Analyses; FEKO, GRASP, etc.

Mechanical Design:

- Antenna mechanical design
- RF and mechanical parts list
- Develop CAD mapping tool for reflectarray layout

Element/Surface Design:

- Element Design (HFSS)
- Element Trades/Grid & Substrate Optimization
- Anomalous mode analysis (e.g. surface wave) and mitigation
- Sensitivity assessment

Assembly and Test:

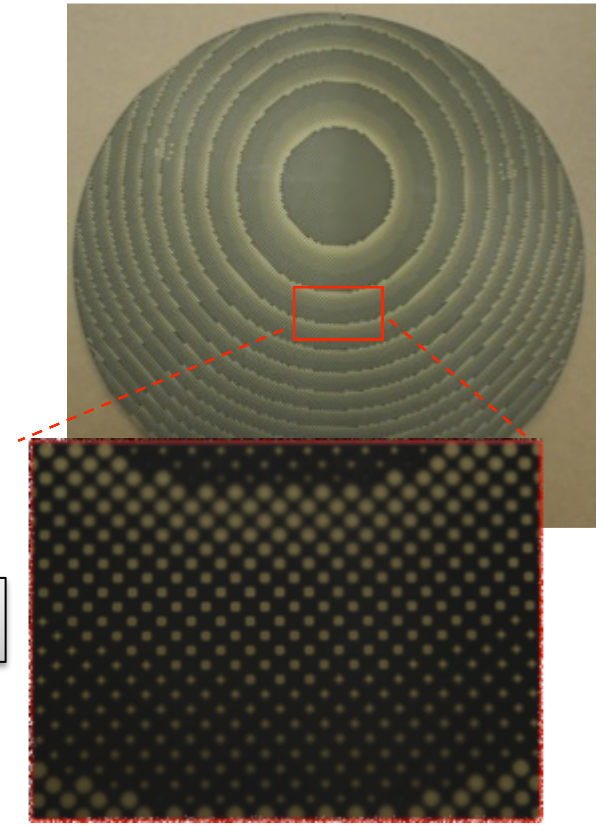
- Reflectarray assembly and alignment plan
- Range integration and test plan
- Range test plan

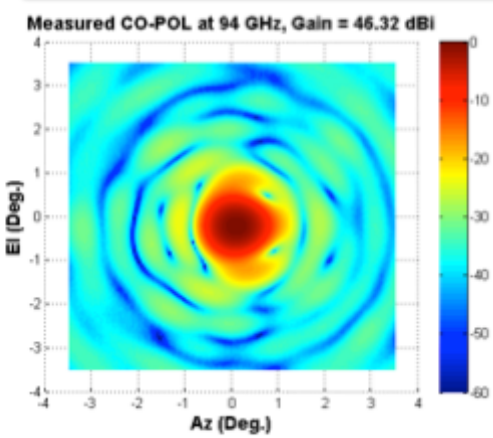
Reflectarray Design

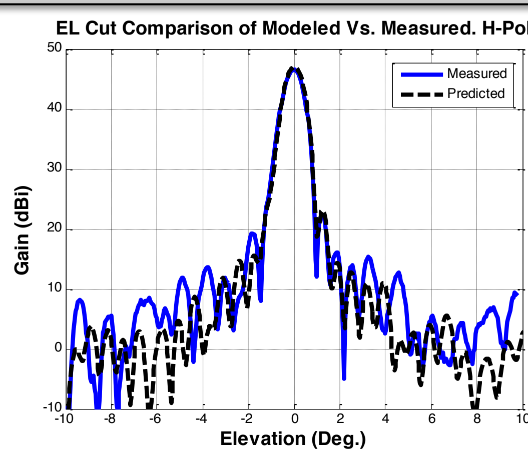
Planar Reflectarray Coupon Demonstration

- Flat Coupons validated reflectarray RF models
  - Reflectarray analysis/synthesis model (MATGO) and Element models
- Demonstrate manufacturability of reflectarray PCBs on candidate materials
- Demonstrate basic reflector/reflectarray functionality
  - Reflectarray focusing at W-band
  - FSS transparency at Ka-band

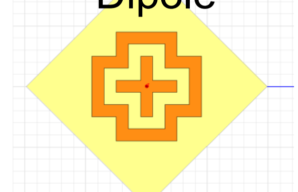
Measurements validate predicted performance



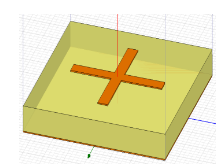




Loop/Crossed Dipole



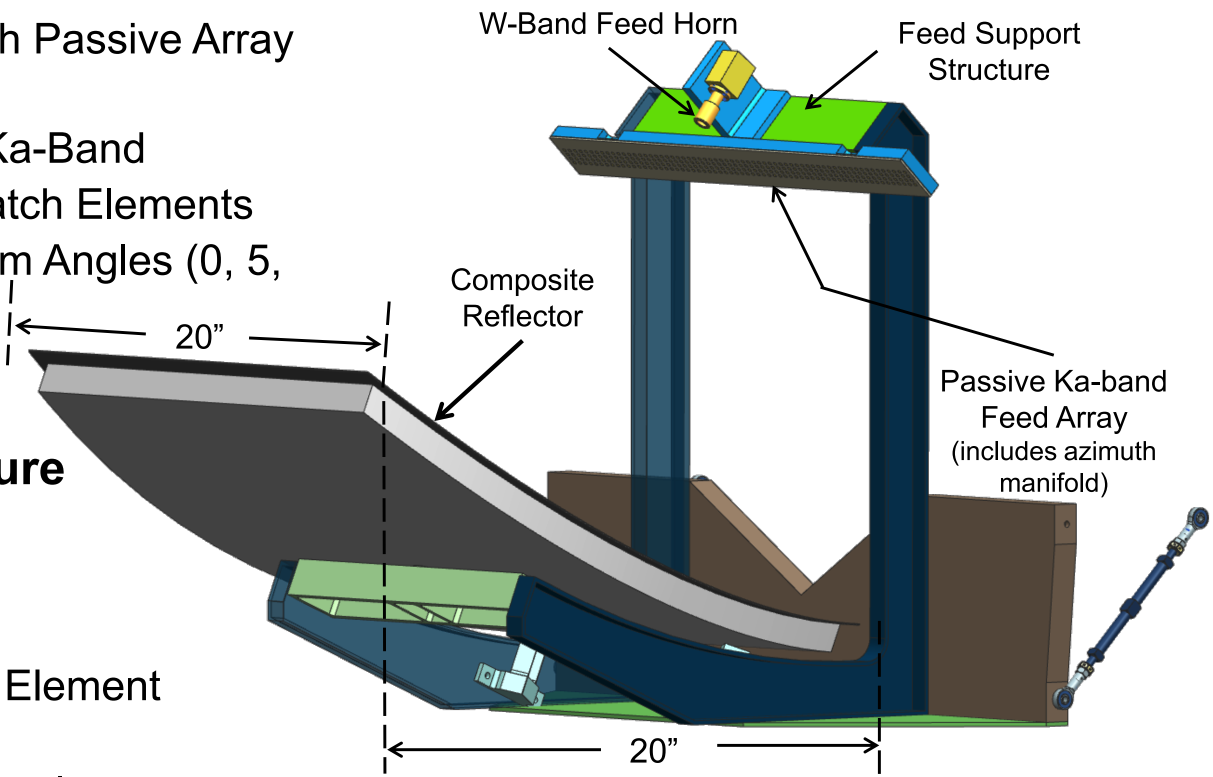
Crossed Dipole



Sub-Scale Demo Design/Architecture

Ka-Band Antenna Architecture

- 35.5 GHz Operating Frequency
- Parabolic Cylinder Reflector with Passive Array Feed
- W-Band Reflectarray - FSS at Ka-Band
- Array Feed - Dual Pol 4 x 64 Patch Elements
- 3 Manifold Designs - Fixed Beam Angles (0, 5, 10 degs)



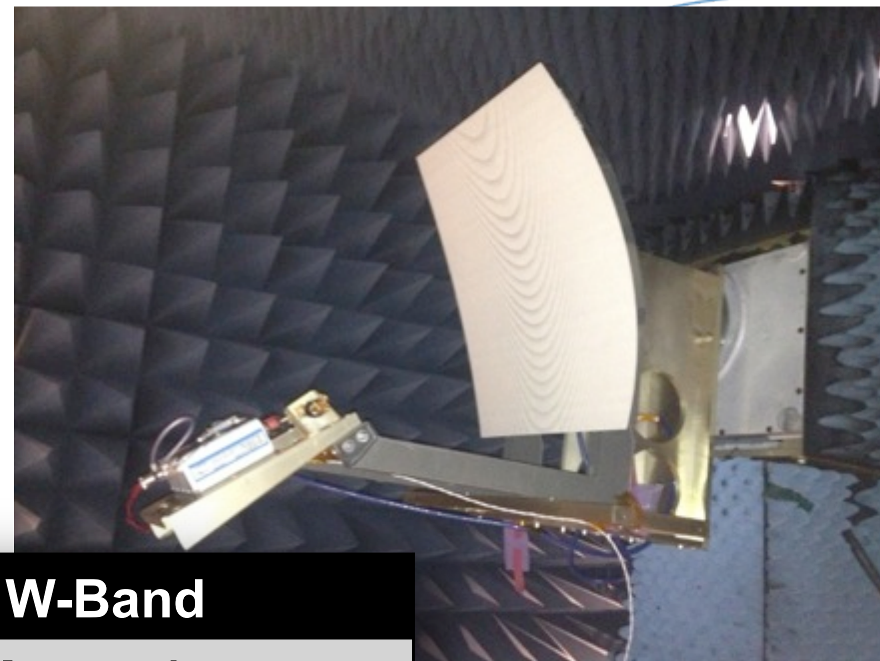
W-Band Antenna Architecture

- 94 GHz Operating Frequency
- Parabolic Cylinder Surface w/ Reflectarray to Focus Beam
- Reflectarray Uses Hybrid Loop Element on Rogers 6002
- Scalar Horn Feed with OMT (Dual Linear Pol)

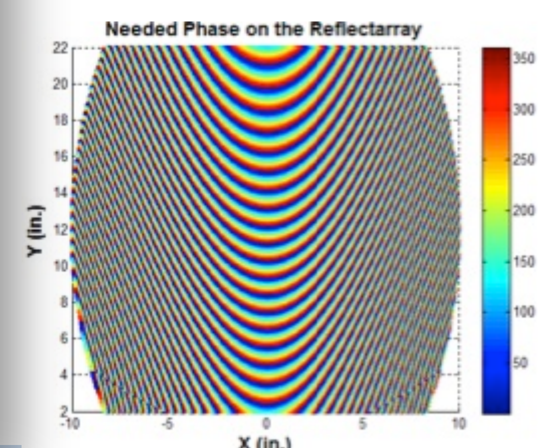
Sub-Scale antenna has been successfully tested on ER-2 with CRS during IPHEX/RADEX mission

Sub-Scale Laboratory Measurements

Loss Budget for W-Band Antenna	
Aperture Directivity:	54.4 dBi
Taper Loss:	1.5 dB
Spillover:	0.4 dB
Phase Error Loss:	0.3 dB
Absorptive Loss:	0.6 dB
Gain:	51.7 dBi

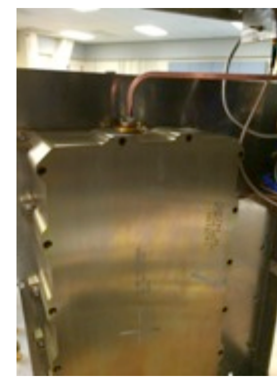


Performance Summary for W-Band	
	Measured:
VPOL (Co) Realized Gain:	51.1 dBi (94.05 GHz)
HPOL (Co) Realized Gain:	50.9 dBi (94.05 GHz)
Az Beam Width:	0.45° (V) / 0.47° (H)
El Beam Width:	0.47° (V) / 0.48° (H)
Cross-Pol (dB):	-33.2 (V) / -28.6 (H)
Peak Az Side Lobe (dB):	-28.8 (V) / -26.9 (H)
Peak El Side Lobe (dB):	-27.2 (V) / -29.5 (H)



Subscale Demonstration Flights using CRS

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



SSPA installed in CRS

IPHEX/RADEX
May – June, 2014

GSFC Microwave Instruments

ER-2 Instruments

HIWRAP (Radar)	13.91/13.47 GHz, 35.56/33.72 GHz
EXRAD (Radar)	9.626 GHz (nadir); 9.596 GHz (scanning)
CRS (Radar)	94.15 GHz (dual-polarized)
CoSMIR (Radiometer)	53 (x3), 89, 165.5, 183.3+/-1, 183.3+/-3, 183.3+/-8 GHz

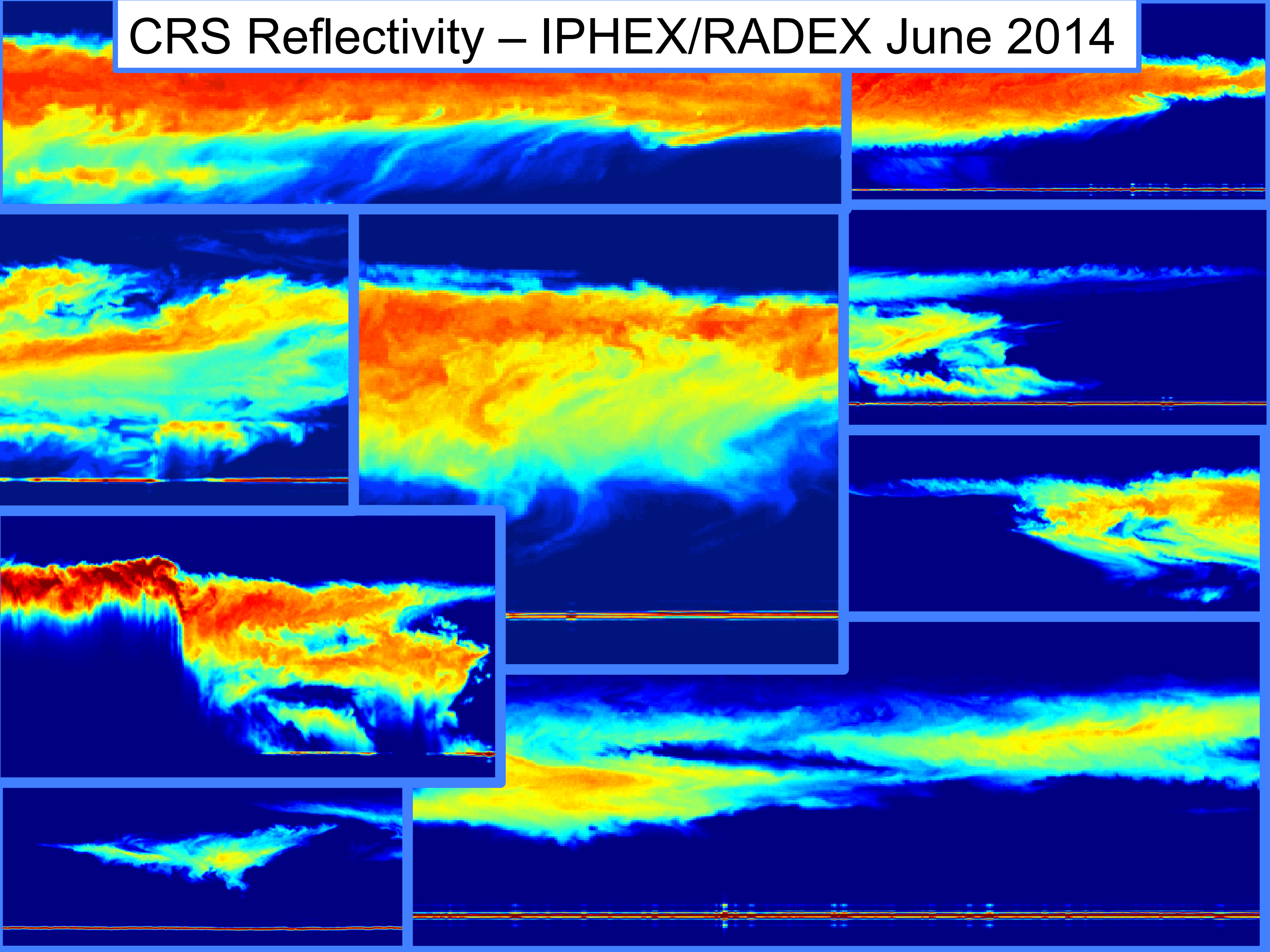
Ground-based Instruments

N-POL (Radar)	2.8 GHz
D3R (Radar)	13.91 GHz, 35.56 GHz
ACHIEVE (Radar)	10, 24, 94 GHz
DoER (Radiometer)	22 (x5), 37, 89 GHz

The GPM Integrated Precipitation and Hydrology Experiment

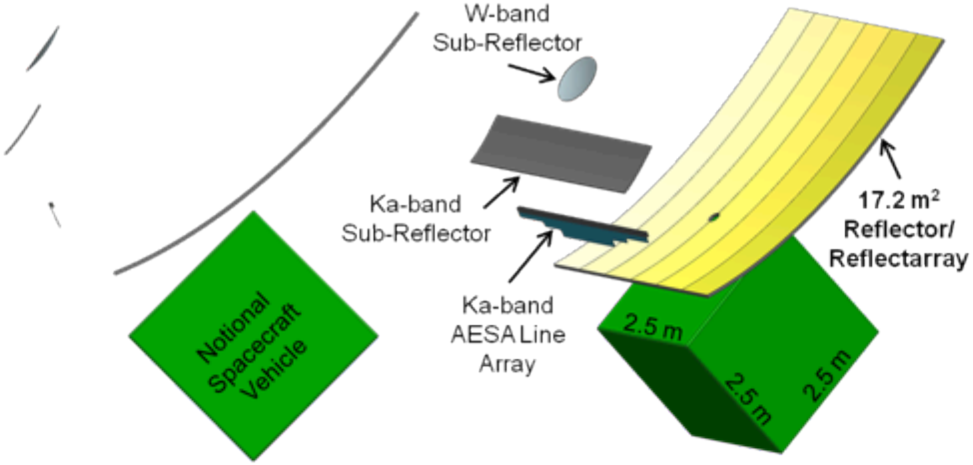
CRS flights funded through IIP and RADEX

CRS Reflectivity – IPHEX/RADEX June 2014



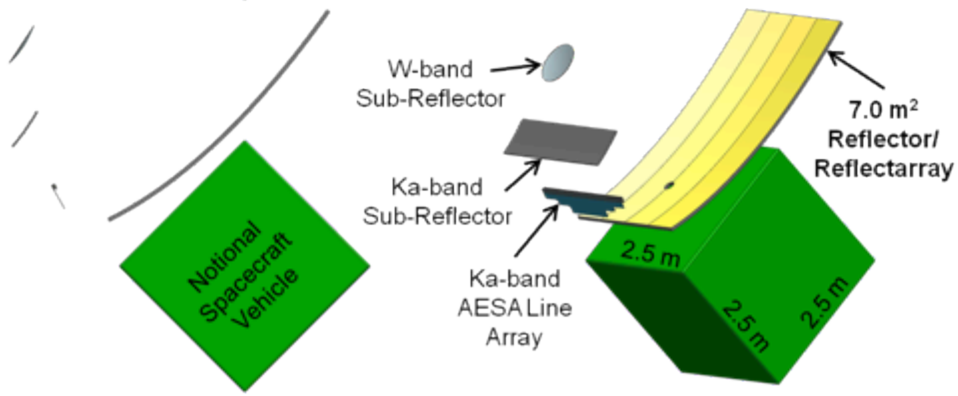
ACE Radar Design Study

Full-Scale Antenna Trades
Shown Relative to Notional Space Vehicle



<u>4.15 x 4.15 m^2 Projected Aperture:</u>

Reflector/Reflectarray:
Cassegrain Folded Optics



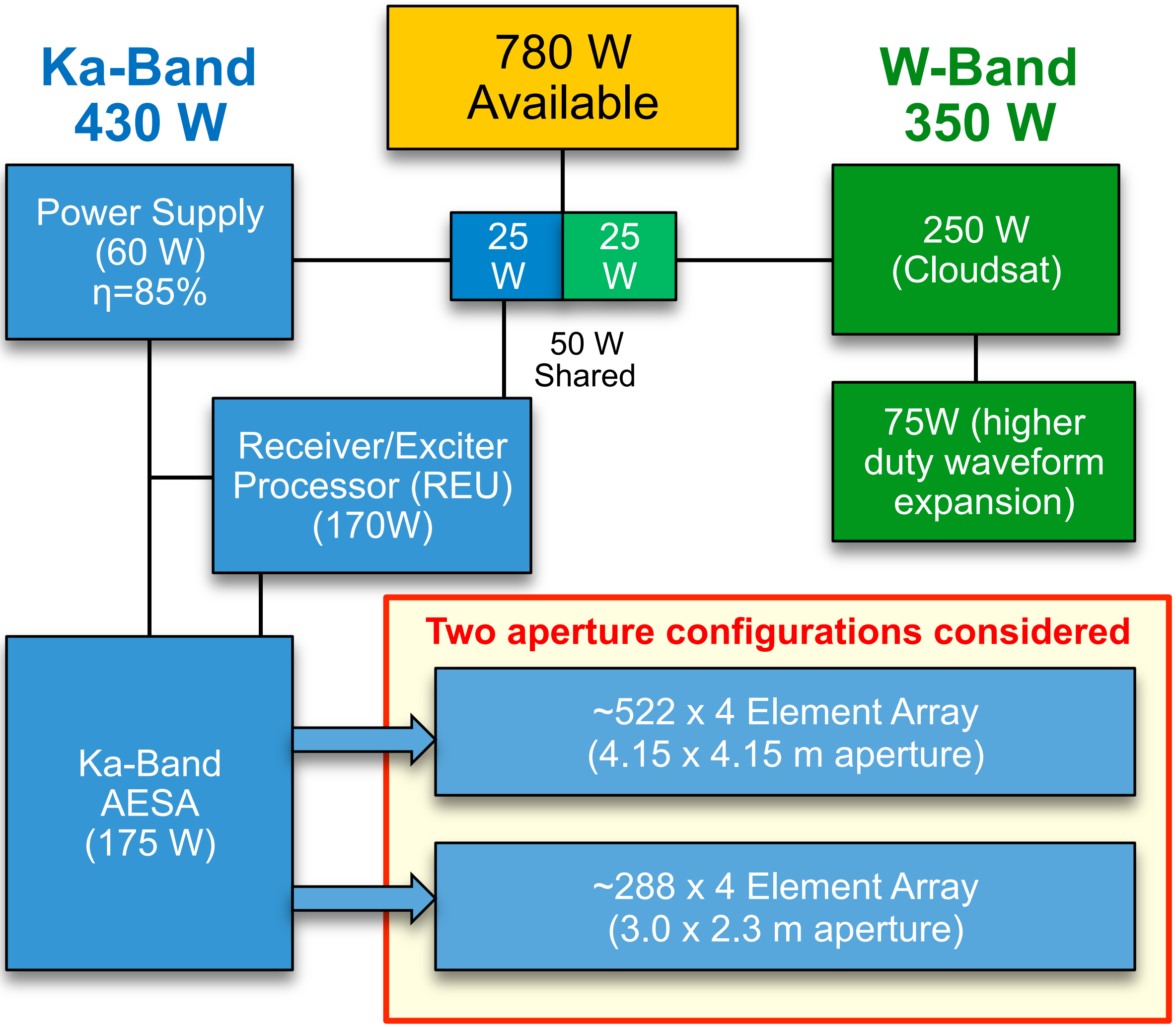
<u>2.33x 3 m^2 Projected Aperture:</u>

Reflector/Reflectarray:
Cassegrain Folded Optics

Full-Scale Design is Modular and Scalable… It Leverages RF Design, Mechanical Design and Manufacturing Processes Developed for Coupon and Sub-Scale Designs

Assumed Power Allocation for Radar Design and trade studies

- Power availability on spacecraft affects the achievable performance and influences the radar design, especially the AESA
- Selected 780W to be consistent with GPM/DPR
- Evaluated performance of two aperture sizes using the same available power
- Evaluated how design of the AESA was influenced by available prime power



Aperture Size – Performance and Cost Driver

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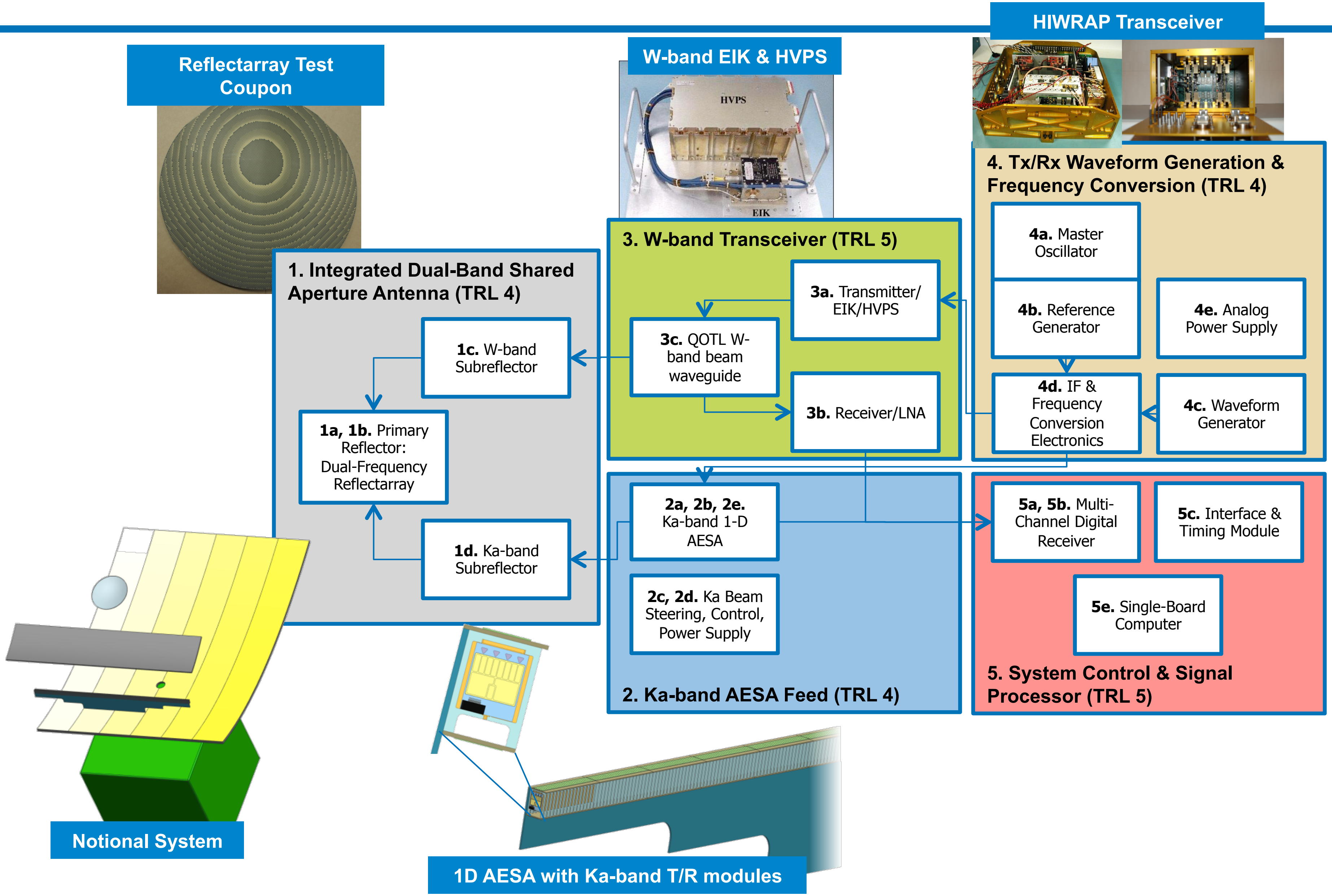
Performance Trades between Two Aperture Sizes		
	7 m^2 Aperture	17 m^2 Aperture
Ka-Band Resolution	Meets Requirement	Meets Goal
Ka-Band Sensitivity (off Nadir)	-10.2 dBZ (Meets Requirement)	-13.9 dBZ (Meets Requirement)
Ka-Band Doppler	1 m/s (Meets Requirement)	0.5 m/s (Meets Goal)
W-Band Resolution	Meets Goal	Meets Goal
W-Band Sensitivity	-33.6 dBZ (Marginal to Requirement)	-37.4 dBZ (Meets Requirement)
W-Band Doppler	0.4 m/s (Meets Requirement)	0.2 m/s (Meets Goal)
Mass (Kg)	325 - 375	500 - 600

Aperture size drives cost, performance, and spacecraft packaging

TRL Assessment

ACE Radar TRL Block Diagram



Education and Public Outreach Supplemental Award

Supplemental Education and Public Outreach

Earthzine is an on-line publication that supports the intergovernmental Group on Earth Observation (GEO) and its outreach for the Global Earth Observing System of Systems (GEOSS). Earthzine publishes original articles by professionals, researchers, educators, students and others about the benefits of using Earth information in our daily lives.

Supplemental Outcomes:

- Expanded Earthzine's coverage of Earth Science technology
  - Quarterly theme on Earth Science Informatics Challenges
- Published articles featuring ESTO-sponsored technology development
  - 2013 Earth Science Technology Showcase
- Engaged students in deliberating the role of technology in adapting to Earth's evolving climate
  - Student Essay Contest on 'Science Technology for Observing Earth's Climate'

2013 ACE Radar IIP

Wide-swath Shared Aperture Cloud Radar (WiSCR), 2013 IIP Award

GSFC: Lihua Li/555 (PI), Paul Racette/555, Gerry Heymsfield/612, Matt McLinden/555
NGES: Pete Stenger, Tom Spence, Mike Cooley, Richard Park

Advance Readiness of Scanning AESA Feed - Ka-Band T/R Module Tasks

- Develop design of Space-Qualifiable Ka-band AESA T/R Module Package with (new design) Integrated RF Circulator
- Design, fabricate and test Ka-band circulator coupon
- Design, fabricate and test Ka-band T/R Module GaAs LNA, Switch and Multifunction Phase/Atten MMICs, second iteration of GaN HPA, Si ASICs for power and amp/phase control.

Tri-band Antenna Concept (Ku/Ka/W)

- Evaluate performance of W-band fixed vs scanning feed
- Study trade between single Ku/Ka-band line feed vs. separate feeds
- Study trade, separate vs. shared subreflectors

Wide-swath Shared Aperture Cloud Radar (WiSCR), 2013 IIP Award Tasks (Cont'd)

GSFC: Lihua Li/555 (PI), Paul Racette/555, Gerry Heymsfield/612, Matt McLinden/555
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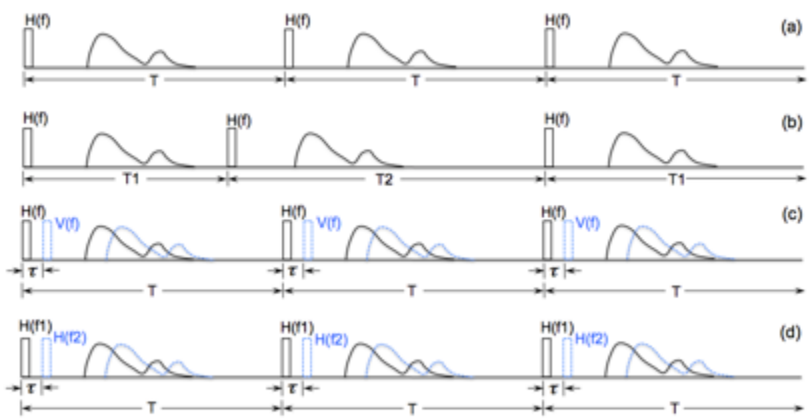
Frequency up/down converter

- Design and fabricate Multi-channel Frequency Conversion Module (MFCM)
- Design and fabricate Multi-channel Arbitrary Waveform Generator (MAWG)
- Develop FPGA firmware
- Airborne flight demonstration of MFCM and MAWG

Advanced Doppler Processing Algorithms

- Develop Frequency Diversity Pulse Pair (FDPP) processing
- Noise assisted I-Q data analysis
- Airborne demonstration of FDPP algorithm



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Thank You!