National Aeronautics and Space Administration

SCIENCE & MISSION SYSTEMS

MAPIR: An Airborne Polarimetric Imaging Radiometer in Support of Hydrologic Satellite Observations

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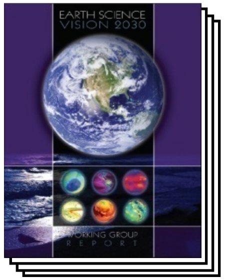
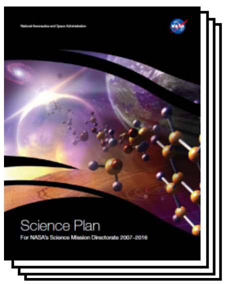
[3]Integrated Concepts & Research Corporation, Huntsville, Alabama

Science Motivation



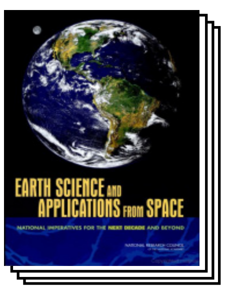
Earth Science Vision 2030

March 2004



NASA Science Plan

2007



National Research Council Earth Science and Applications from Space

January 2007

NASA Earth Science Technology Office

GPM

Global Precipitation Mission

2013-

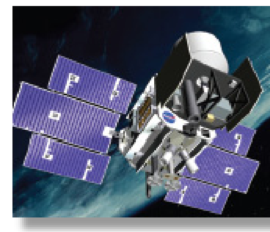
SMAP

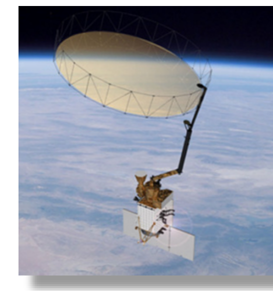
Soil Moisture Active Passive

2014-

ICESat-2

2015-

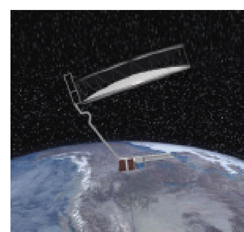


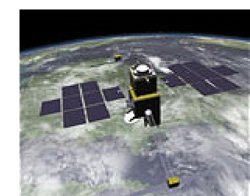


DESDynI

Deformation, Ecosystem Structure, Dynamics of Ice

2017-





SWOT

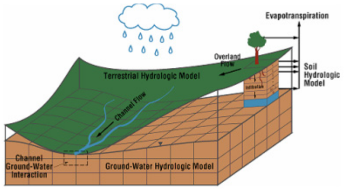
Surface Water Ocean Topography

2020-

Reports contain common theme of need for measurements of precipitation, soil moisture, and sea ice and provide measurement goals.

Shortage of available airborne simulators and instruments to produce data for algorithm development, validation, and for applied science activities.

Science Applications



Hydrologic Modeling

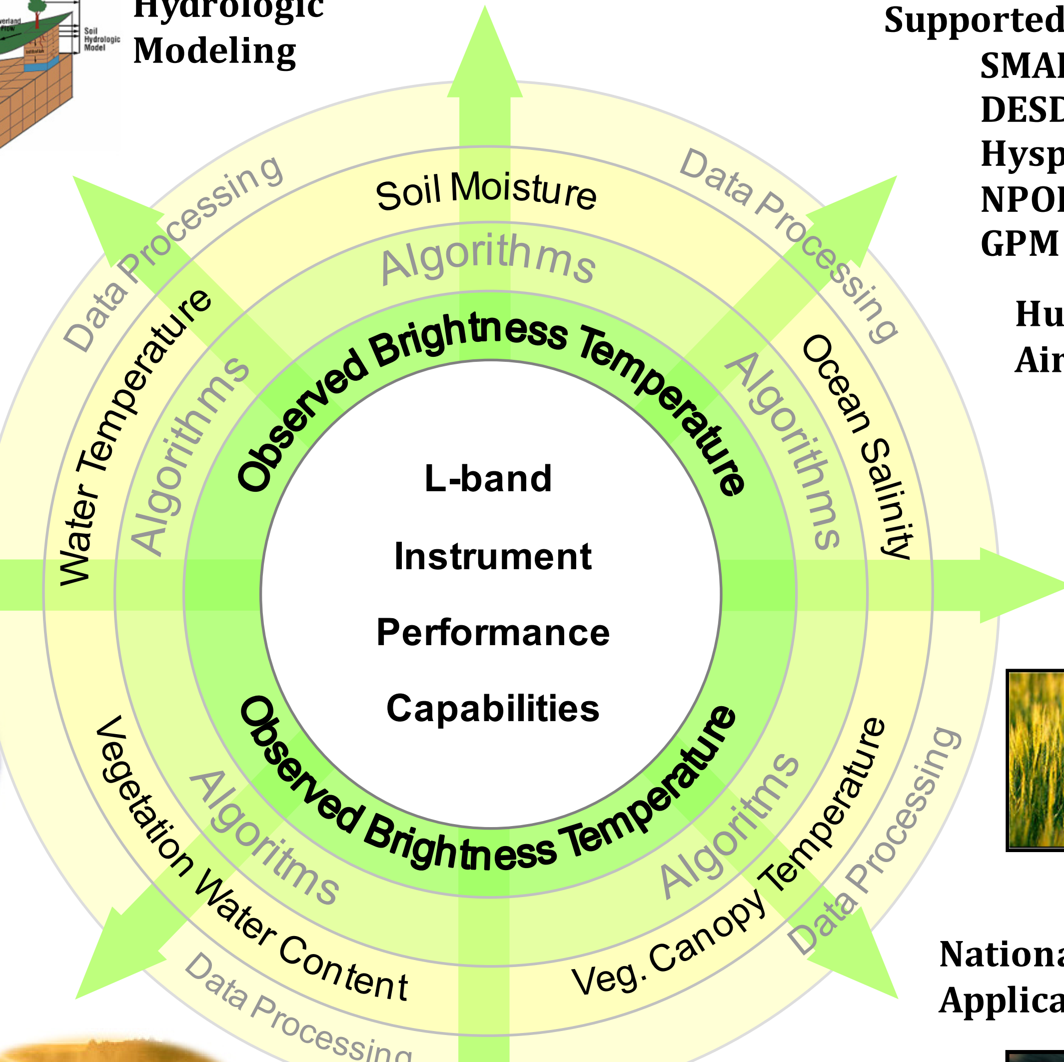
Weather Forecasting

Flood Water Monitoring

Precipitation Validation

Drought Detection

Irrigation Scheduling Agricultural Productivity

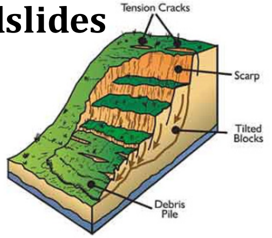


Supported NASA Missions:

SMAP
DESDynI
HyspIRI
NPOESS
GPM

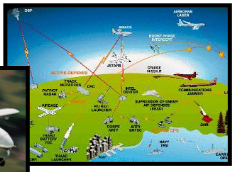
Human Health & Air Quality

Landslides



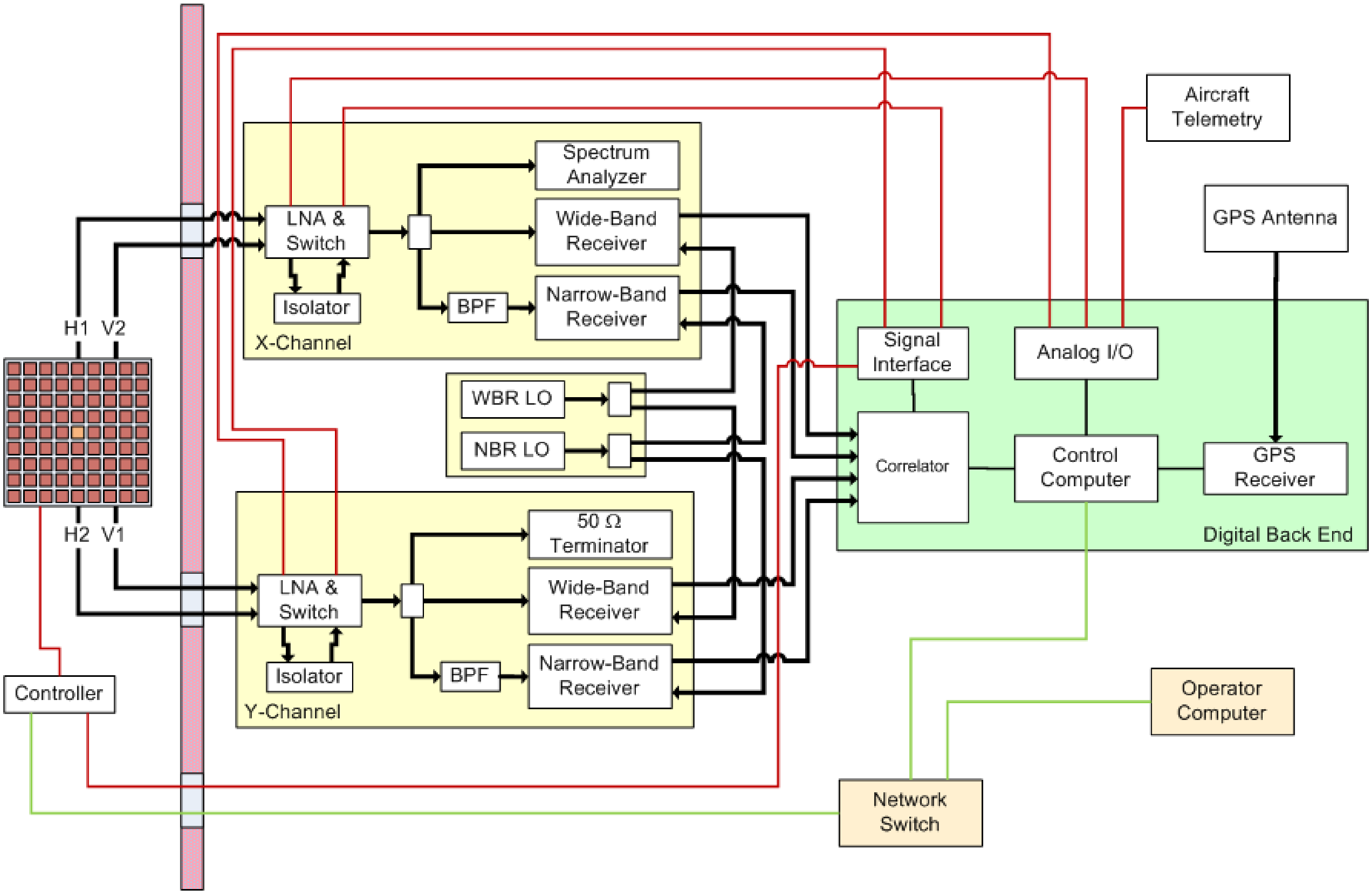
Biomass & Ecosystem Health

National Defense Applications



L-band RFI Surveillance

System Architecture

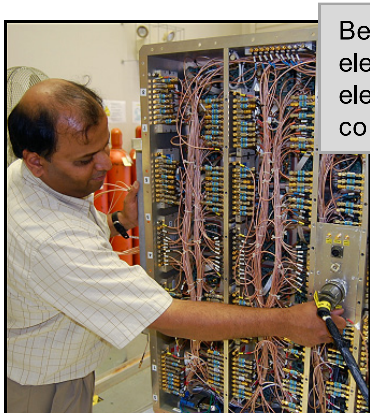


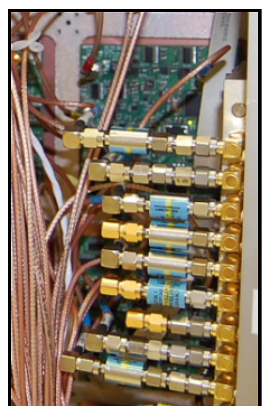
Phased Array Antenna

Frequency	L- band (2 passbands)
Antenna Type	Real aperture planar phased array
Array	81 element (9x9) electronic beam steering
Dimensions	102 x 102 x 18 cm
Weight	57 kg
Beamwidth	15 deg (3dB at nadir)
Polarizations	Horizontal, Vertical
Beams	2 simultaneous acquisition
Scan Type	Push-broom, Conical, Staring at any angle
Control	In-flight reprogrammable scan mode
Electronics	Programmable Integrated circuit (PIC)
Calibration	Emitted Gaussian noise source, 50 ohm termination

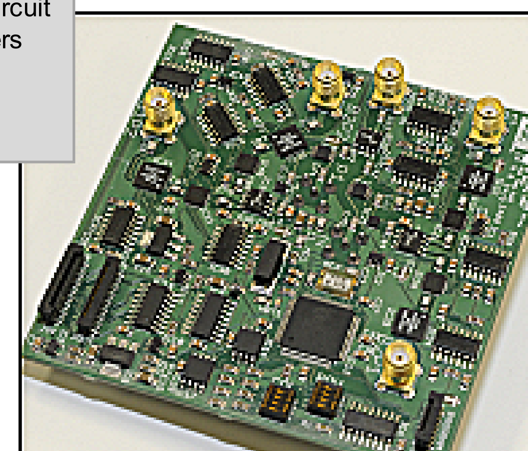
The front side comprises passive antenna elements.

Behind the antenna elements are the electronic control components.





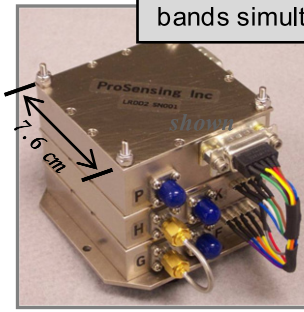
Each antenna element has a circuit board that steers the beam and switches RF polarization.



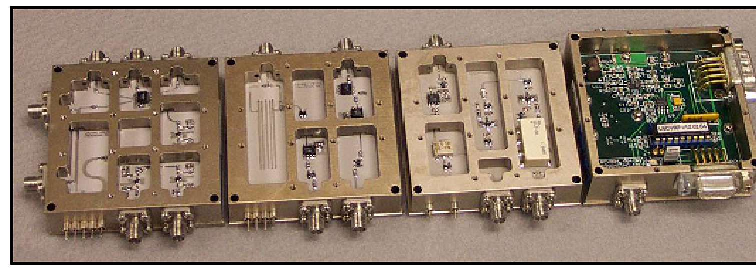
Receivers

Type	Hach
No. Channels	4
Array	81 element (9x9) electronic beam steering

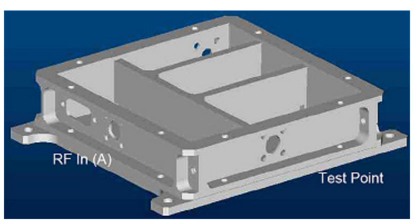
	Narrow	Wide
No. Receivers	2	2
Antenna Inputs	2 ea.	2 ea.
Passbands	1401-1425 MHz	1350-1450 MHz
Integration Time	10 ms (min.)	10 ms (min.)
Dimensions	7.6 x 7.6 x 7.6 cm	8.9 x 8.9 x 5 cm
Internal Cal. Loads	Warm: 300 K Cold: 210 K	Warm: 300 K Cold: 210 K
Down Convert Freq.	8-32 MHz	10-110 MHz

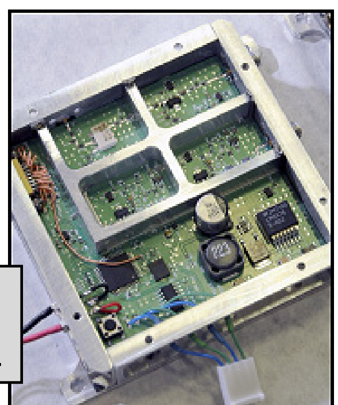


Four receivers acquire data at two narrow bands and two wide bands simultaneously.



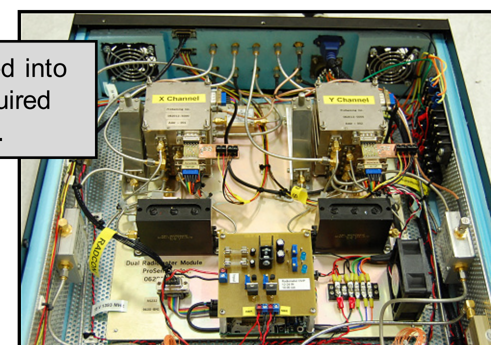
PROSENSING





The wide band receivers developed in-house observe a wider spectrum for possible RFI that may effect observations.

All four receivers are integrated into a common enclosure with required splitters, filters and amplifiers.

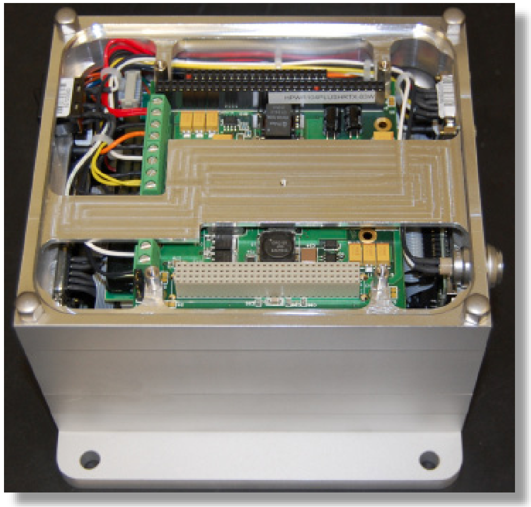


Theses radiometers are a byproduct of a Phase I and Phase II SBIR

Correlator & Digital Back End

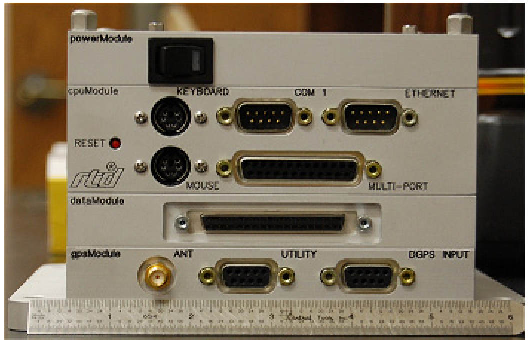
Dimensions	48 cm x 69 cm x 22 cm
Filters	16 subbands for each channel
Subchannel Bandwidth	1.625 MHz (narrowband receiver) 7.8125 MHz (wideband receiver)
Clock	125 MHz oscillator
Digitizer	12 bit ADC; internal processing to 7 bit
Correlator	Nallatech BenADC-V4 with Xilinx FPGA
RFI Processing	ADD method: Computes I & Q moments
Control	RTD PC/104-*Plus* stack
Storage	11 Mb packets

Subband	Center Freq. (MHz)	
Number	Narrow	Wide
1	1401.7	1338.9
2	1403.2	1346.7
3	1404.7	1354.5
4	1406.3	1362.3
5	1407.8	1370.2
6	1409.4	1378.0
7	1411.0	1385.8
8	1412.5	1393.6
9	1414.1	1401.4
10	1415.7	1409.2
11	1417.2	1417.0
12	1418.8	1424.8
13	1420.3	1432.7
14	1421.9	1440.5
15	1423.5	1448.3
16	1424.6	1456.1



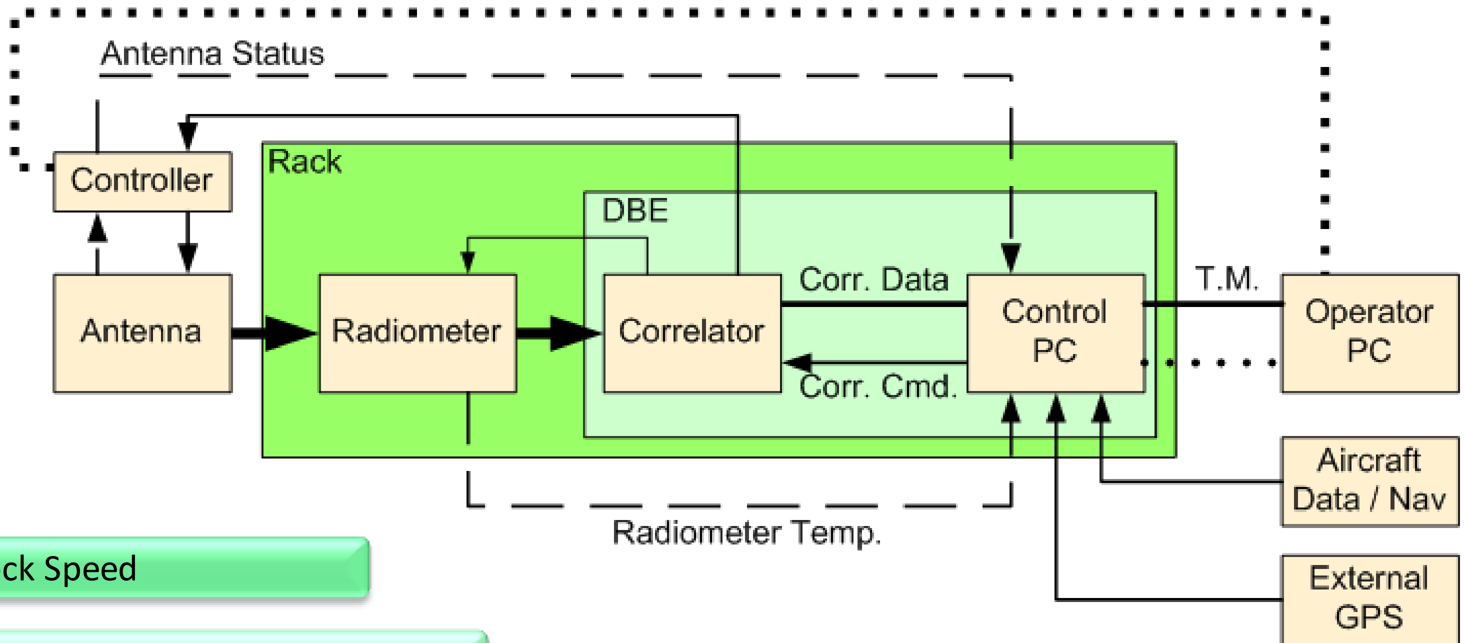
Correlator Module:
Nallatech BenADC-V4 firmware with Xilinx Spartan FPGA

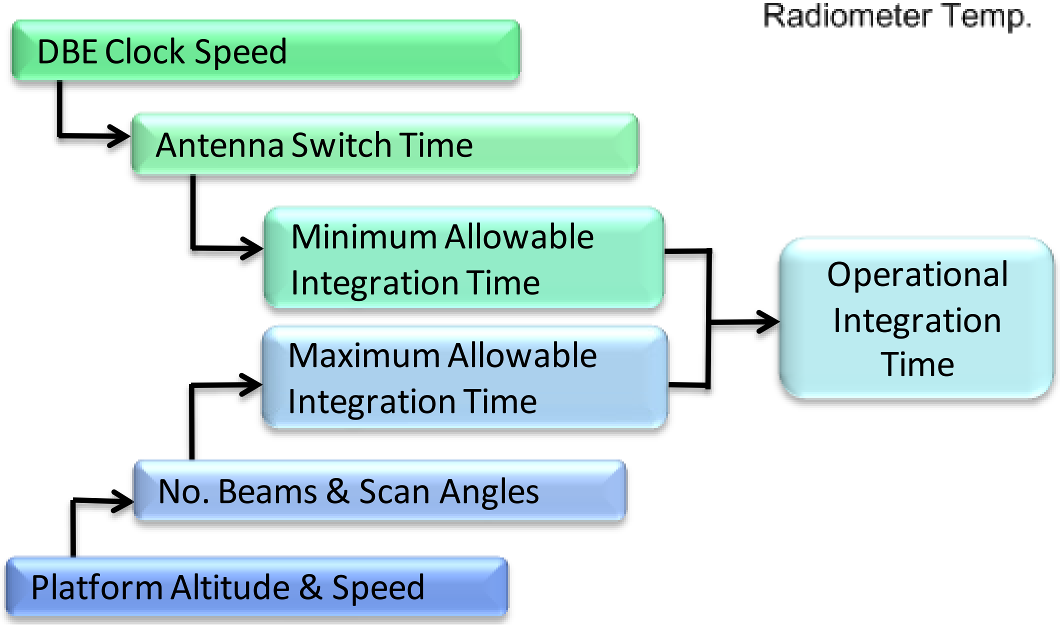
Control Computer:
RTD PC/104-*Plus* Stack

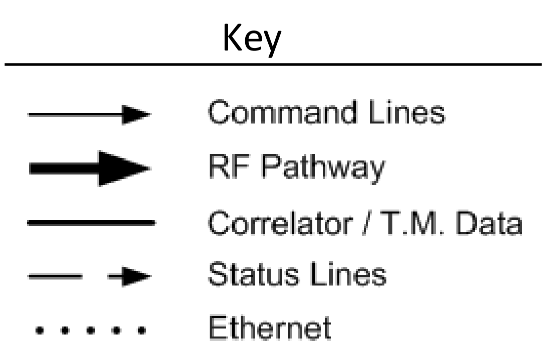


Developed by Univ. of Michigan, Space Physics Research Lab

Command and Control





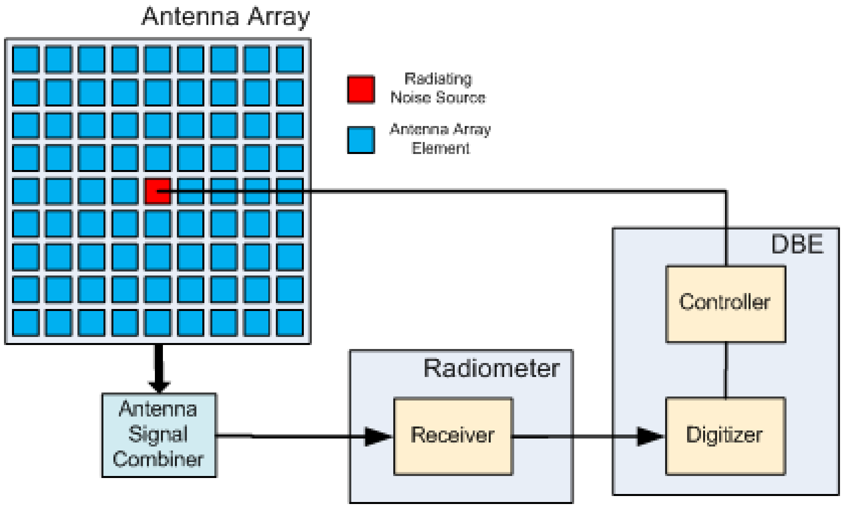


Calibration Method

Motivation: In-flight real-time continuous calibration

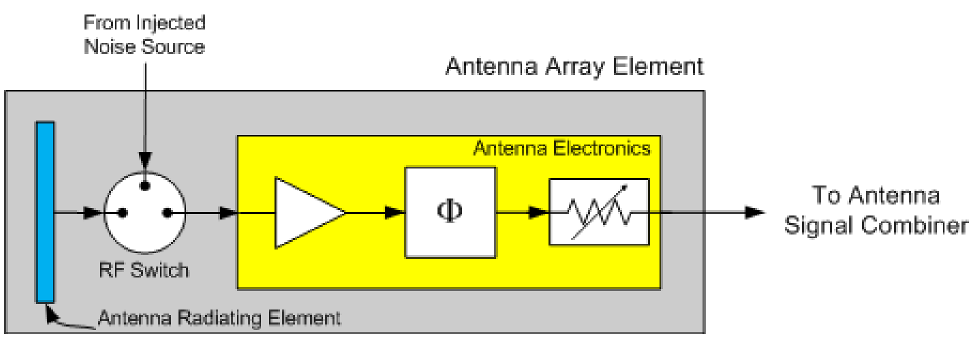
Features:

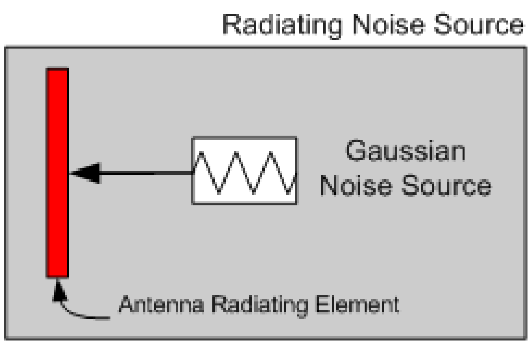
- Two diode calibration
- End-to-end calibration for a phased array system
- Calibrate every scan angle in real time
- Utilize mutual coupling between antenna elements as a calibration source



Implementation:

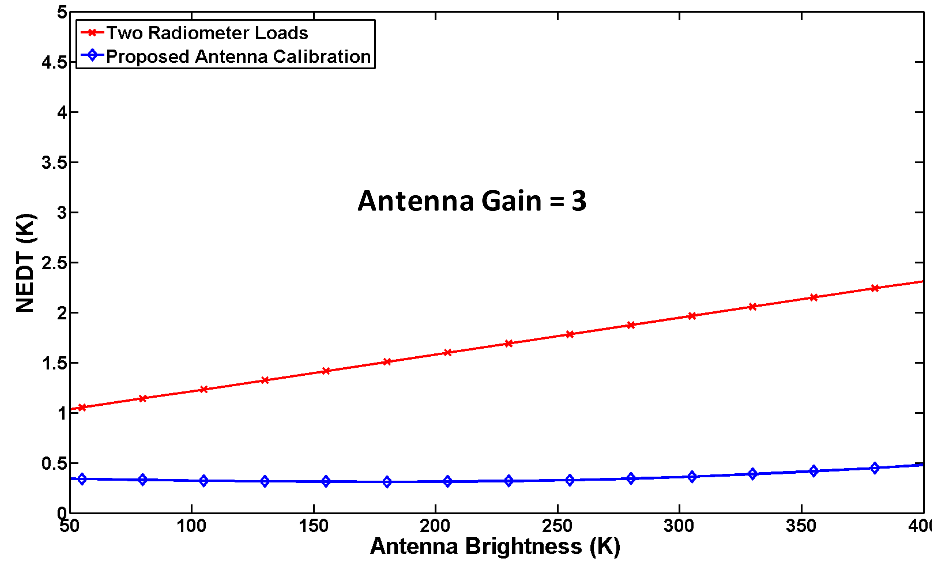
- Radiate a noise source from the center element of the array
- Radiated diode (ENR = 40 dB) and an injected noise source (~300 K)

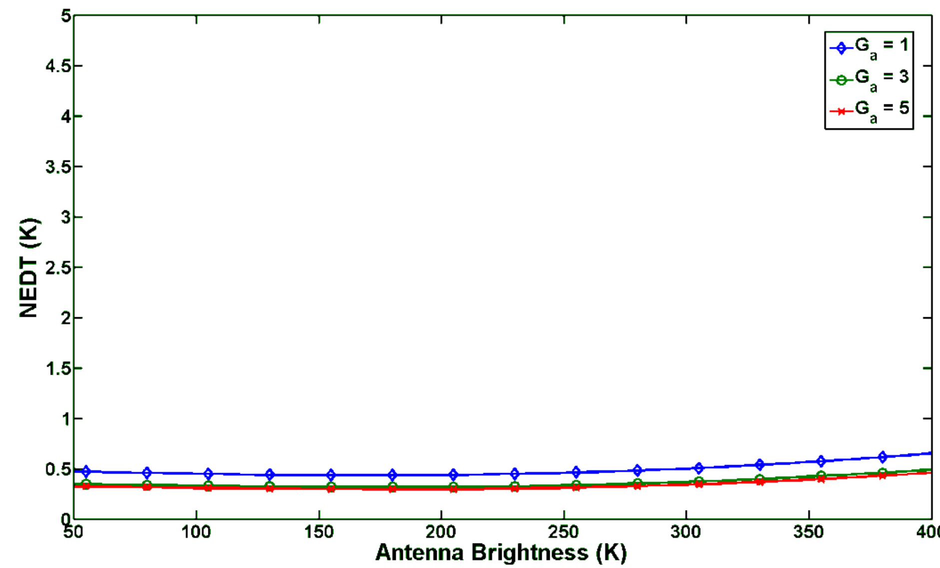




Calibration

Receiver Noise Temperature	400 K
Pre-detection Bandwidth	24 MHz
Antenna Noise Temperature	300 K
Total Dwell Time	1 sec
Radiometer Warm Load [1]	300K
Radiometer Cold Load [1]	210K
Antenna Injected Load [2]	300K
Antenna Radiated Diode [2]	300K

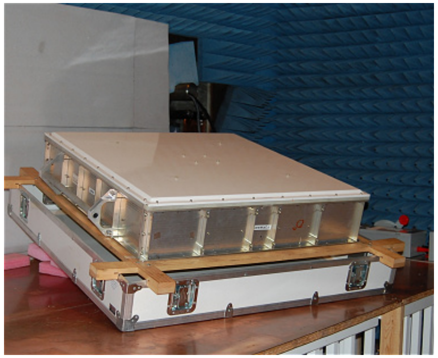




[1] Two radiometer loads – Goodberlet et al, 2006

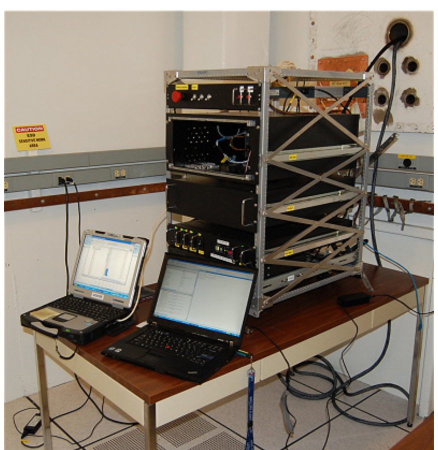
[2] Two Diode method

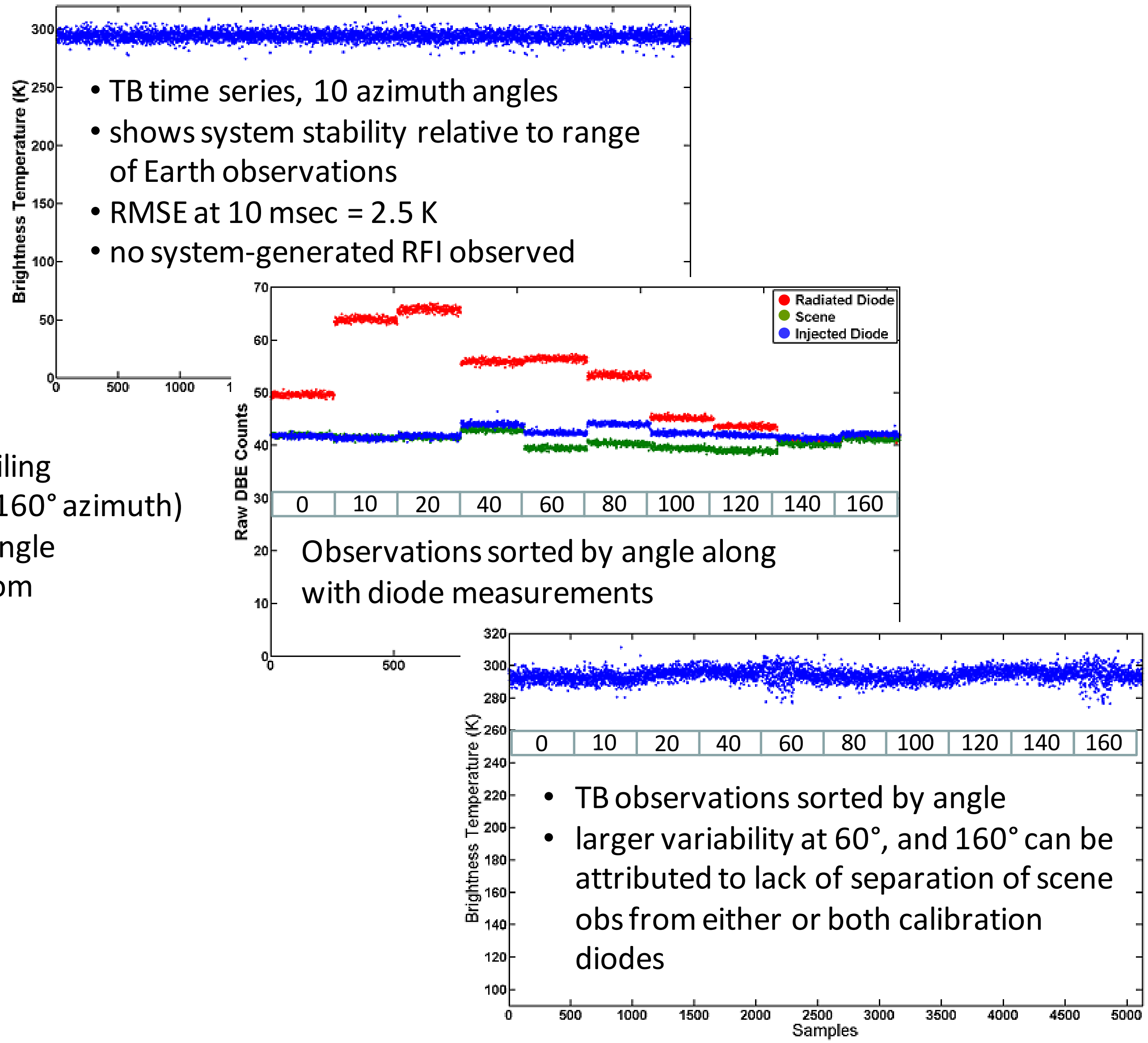
Performance Evaluation



Experimental Set-up

- NASA EMI chamber
- Antenna on table looking at ceiling
- Scanning forward half only (0-160° azimuth) in 20° increments at 40° look angle
- Control system in adjoining room





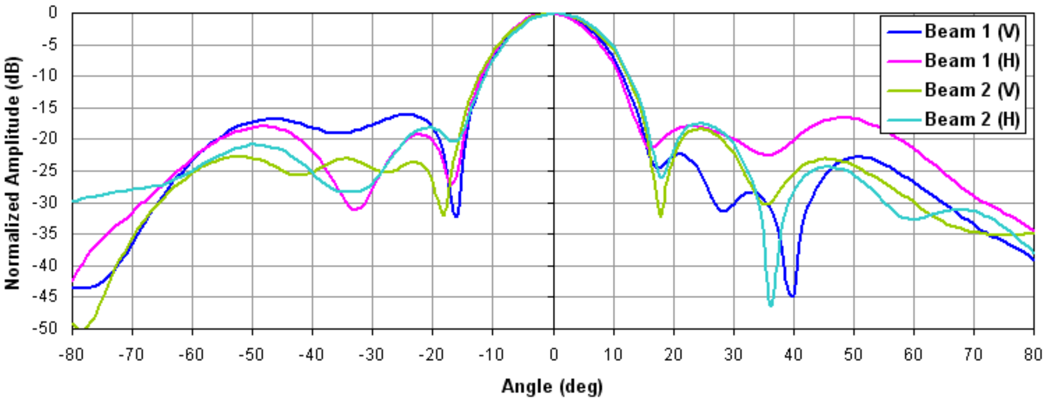
- TB time series, 10 azimuth angles
- shows system stability relative to range of Earth observations
- RMSE at 10 msec = 2.5 K
- no system-generated RFI observed

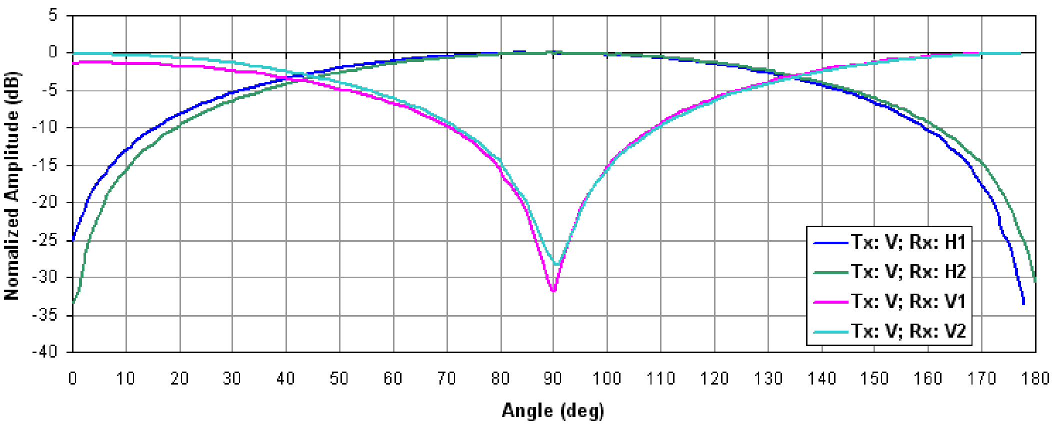
Observations sorted by angle along with diode measurements

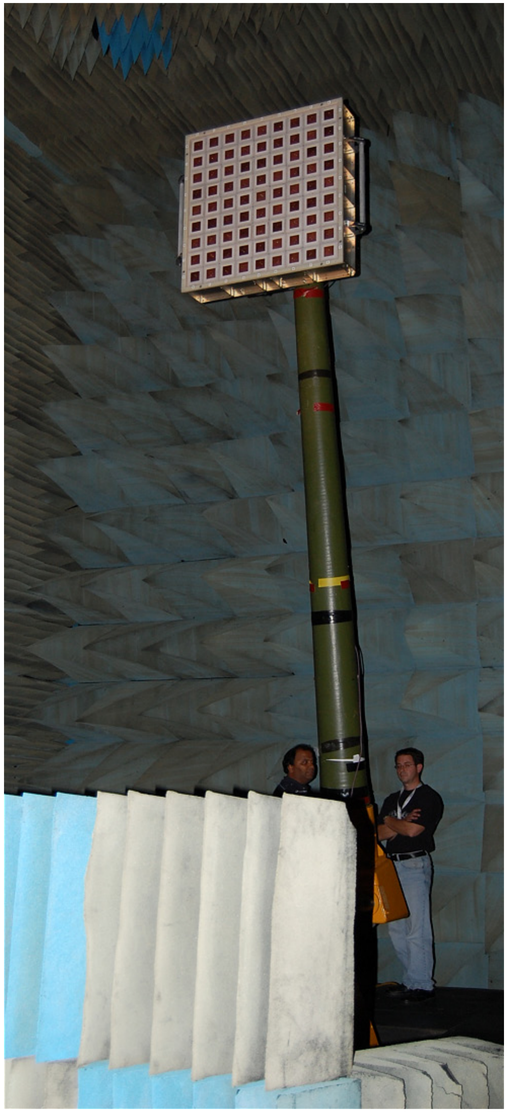
- TB observations sorted by angle
- larger variability at 60°, and 160° can be attributed to lack of separation of scene obs from either or both calibration diodes

Performance Evaluation

Evaluation:	Results:
Beam patterns	Symmetric
3 dB nadir beamwidth	15 degrees
Side lobe characterization	1st side lobe: -20 dB
Functionality of scan modes	Functionality of all modes confirmed
Cross polarization isolation	30 dB



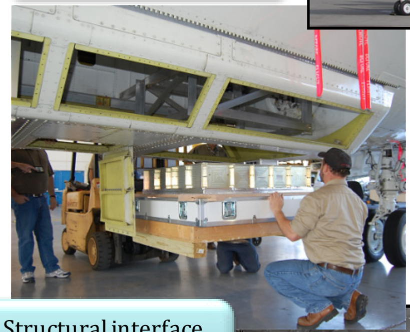




Aircraft Integration

NASA P3-B Orion

Forklift raises antenna into bomb bay

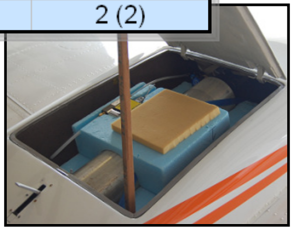


Structural interface for antenna inside bomb bay

UTSI Piper Navajo, PA-31

Adapter box provides interface between antenna and aircraft

Characteristics	P-3B Orion	Piper Navajo
Range (nm)	3,800	1,000
Payload (lbs.)	16,000	350
Cruise Speed (kts)	330	150
Max. Altitude (ft.)	30,000	10,000
Capacity (crew)	15 (4)	2 (2)



Single GN_2 tank installed in left wing locker

Belly pod fairings fabricated in-house at UTSI

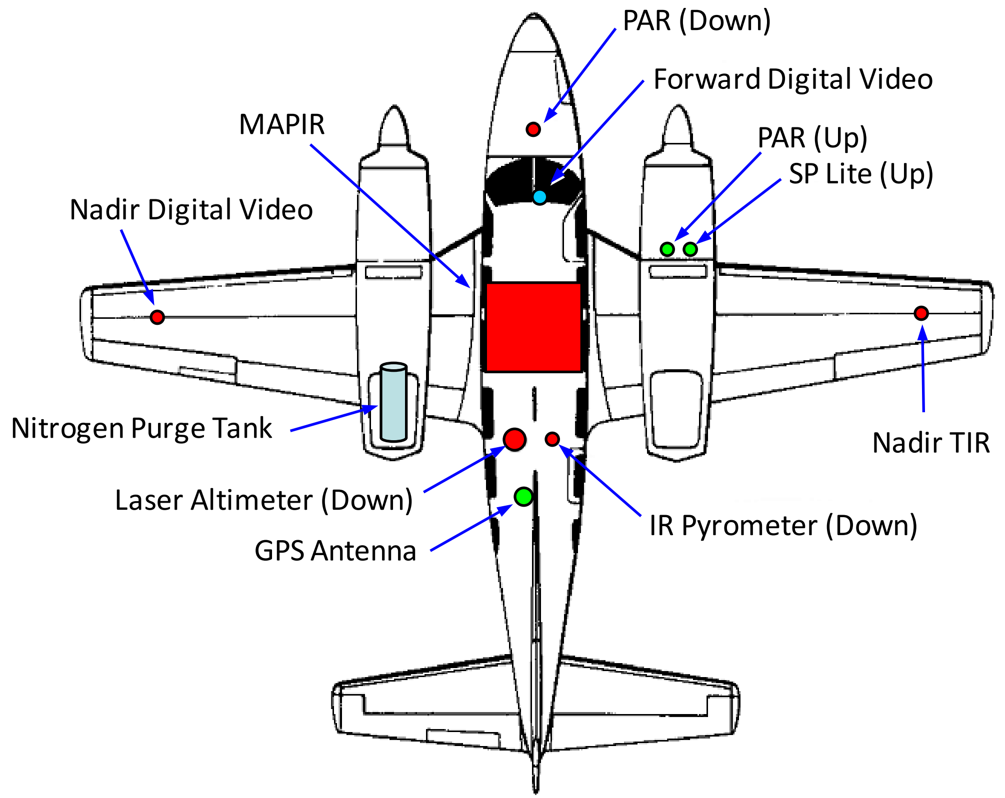
Airborne Platform Configuration

Piper Navajo PA-31 (N11UT)

UT Space Institute

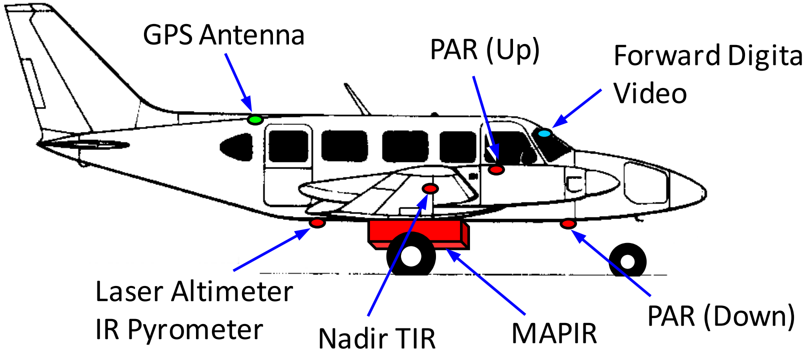
Instrumentation

- MAPIR
  L-band brightness temperature
- Infrared Pyrometer
  Surface temperature
- Laser Altimeter
  Precise platform altitude
  Vegetation canopy height
- PAR (Up, Down)
  Photosynthetically active radiation
- Total Solar Radiation Pyrometer
  Downwelling solar radiation



Supporting Equipment

- GPS Antenna
  Platform position and attitude
- Nitrogen Source Tank with Electronic Controller
  Humidity control inside MAPIR antenna enclosure
- Forward and Nadir Digital Video
- Data Acquisition System



Flight Mission Profile

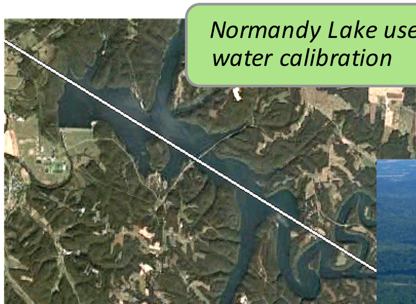
Study area in central Tennessee

Date	Destination
18-May	Normandy Lake, abort
19-May	CHESS, abort
20-May	CHESS, Crossville, Normandy L.
25-May	Crossville
26-May	Crossville, abort

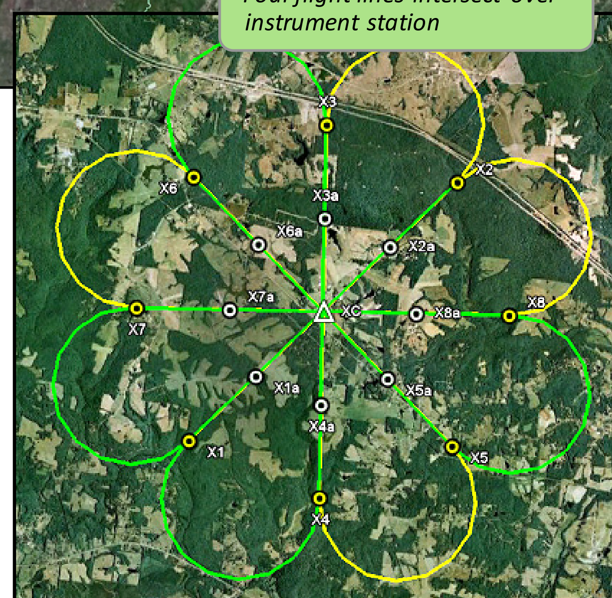
Typical Climate Reference Network station configuration

CHESS tower at Oak Ridge National Lab

Normandy Lake used for water calibration



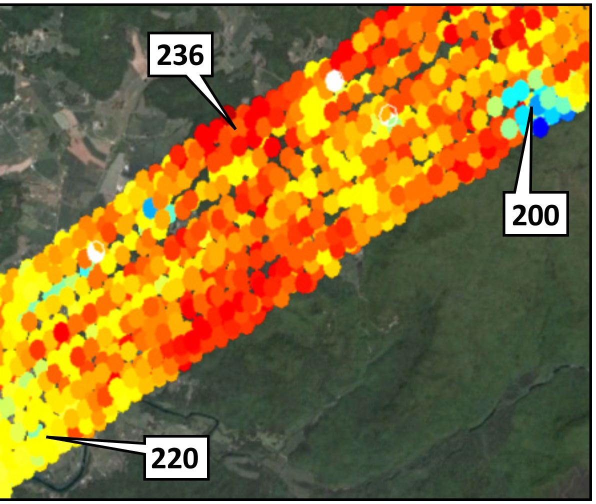
Four flight lines intersect over instrument station

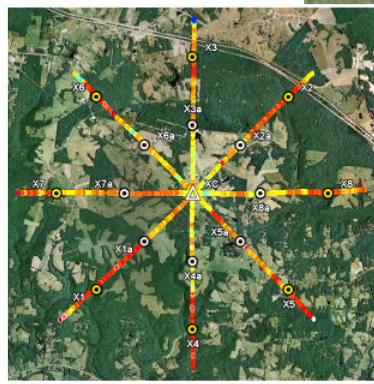


Scan Mode	Altitude (ft. MSL) Normandy	Crossville	CHESS
Conical, dual beam	6500	5600	8500
Conical, dual beam	4700	5500	4700
Nadir, single beam	3180	3840	3080
Nadir, single beam	2850	3540	2780
Nadir, single beam	2550	3240	2480
Nadir, single beam	2100	2940	2180

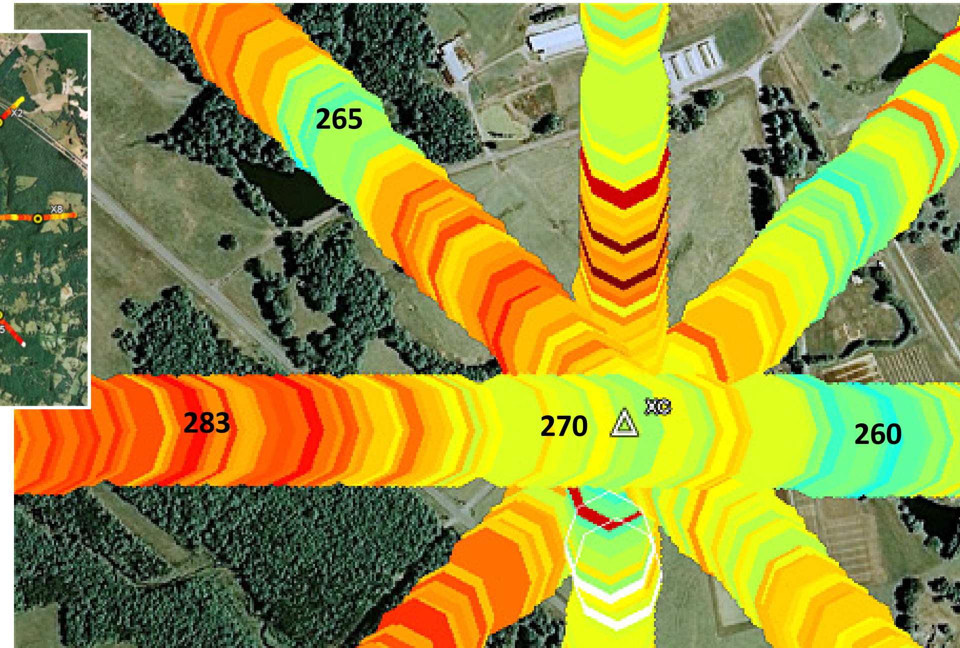
Demonstrated Performance

Vertical polarization; single beam conical scan at 40° look angle; 4600 ft.AGL; raw observed TB data, not gridded

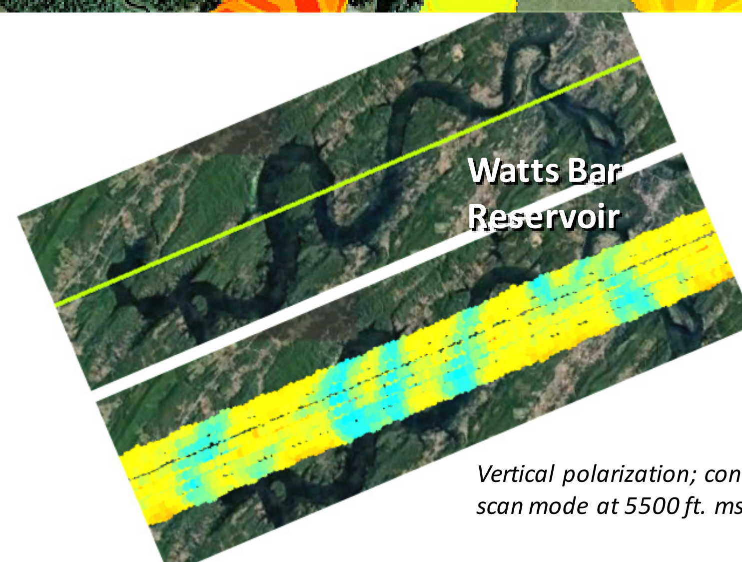




Vertical polarization; Nadir at 3540 ft. msl

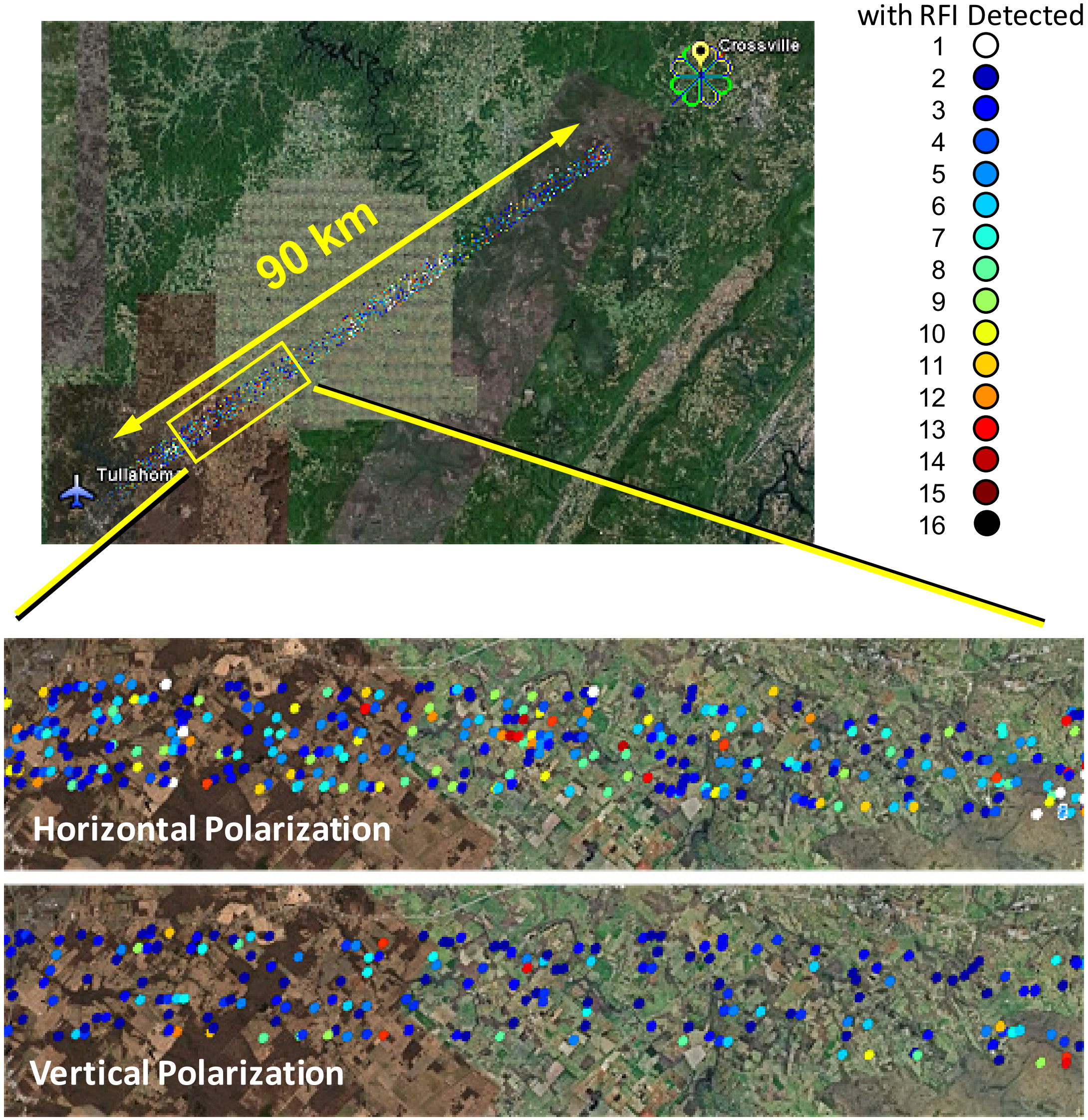


Landscape is gently rolling with a mix of woodland, pasture and cropland



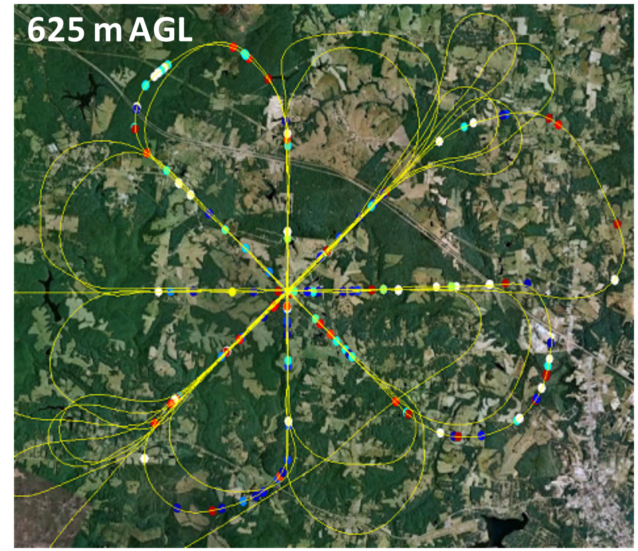
Vertical polarization; conical scan mode at 5500 ft. msl

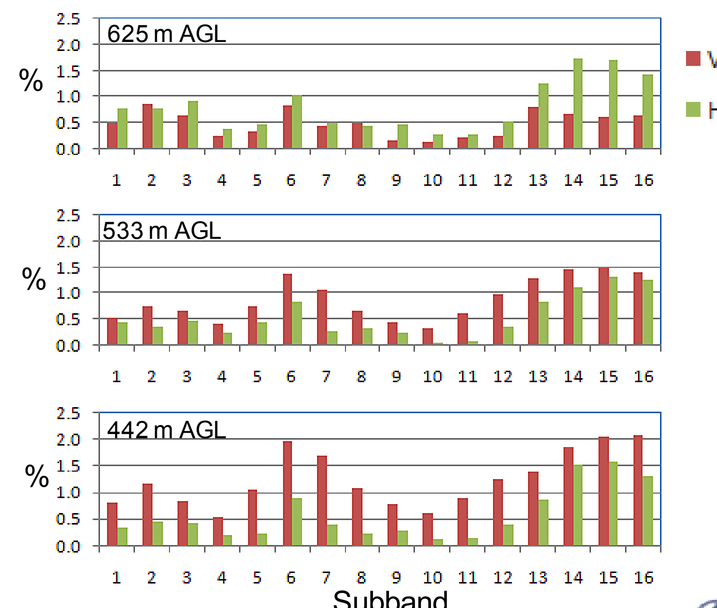
RF Interference Characterization



No. of Subband with RFI Detected

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16





Conclusions & Future Work

Conclusions

- Results indicate successful performance of beam forming radiometer
- Successful implementation of real-time calibration with emitted and injected Gaussian noise
- Opportunities for improvement

Future Work

- Improve calibration method
- Implement angle (phase) specific calibration
- Refine gridded product production
- Conduct additional performance tests
  - In situ observations
  - Mapping
  - Instrument intercomparisons
- Conduct more RFI analysis

FR2.L07.2 (10:45, Nautilus) *Phased array radiometer calibration using a radiated noise source*; Srinivasan, Limaye, Laymon, and Meyer