Status of the High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

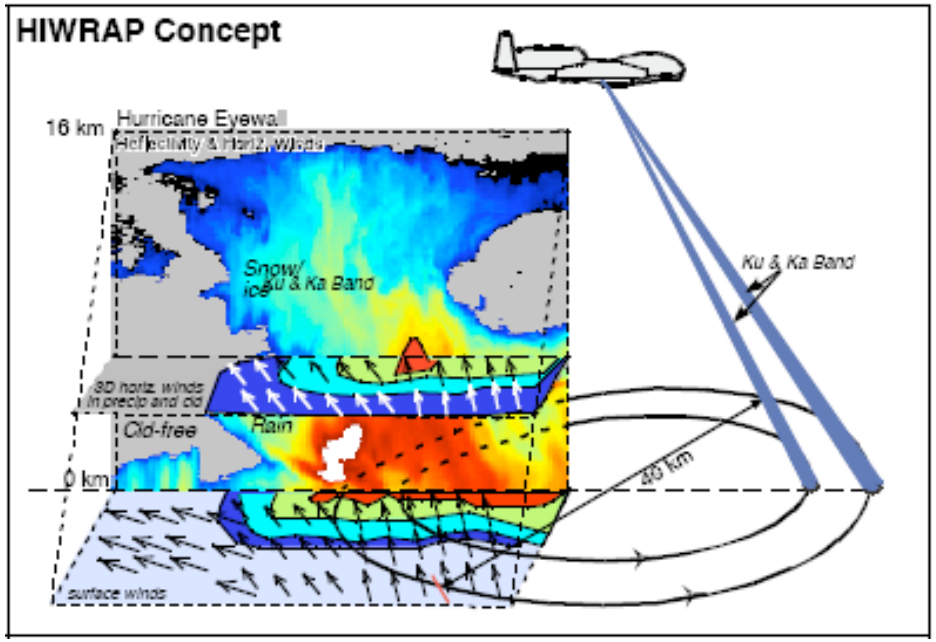
Gerald Heymsfield[1], James Carswell[2], Lihua Li[3], Dan Schaubert[4], Justin Creticos[4], Manuel Vega[1], Wayne Welch[5]

[1]Goddard Space Flight Center, Greenbelt, MD 20771
[2]Remote Sensing Solutions, Barnstable, MA
[3]University of Maryland Baltimore, MD
[4]University of Mass., Amherst, MA
[5]Welch Mechanical Designs, Havre de Grace, MD

HIWRAP CONCEPT

MEASUREMENTS GOAL: Provide horizontal winds in precipitation regions and ocean surface winds in clear to light rain regions

MEASUREMENT TARGET: Hurricanes and severe weather events.



NASA Global Hawk:

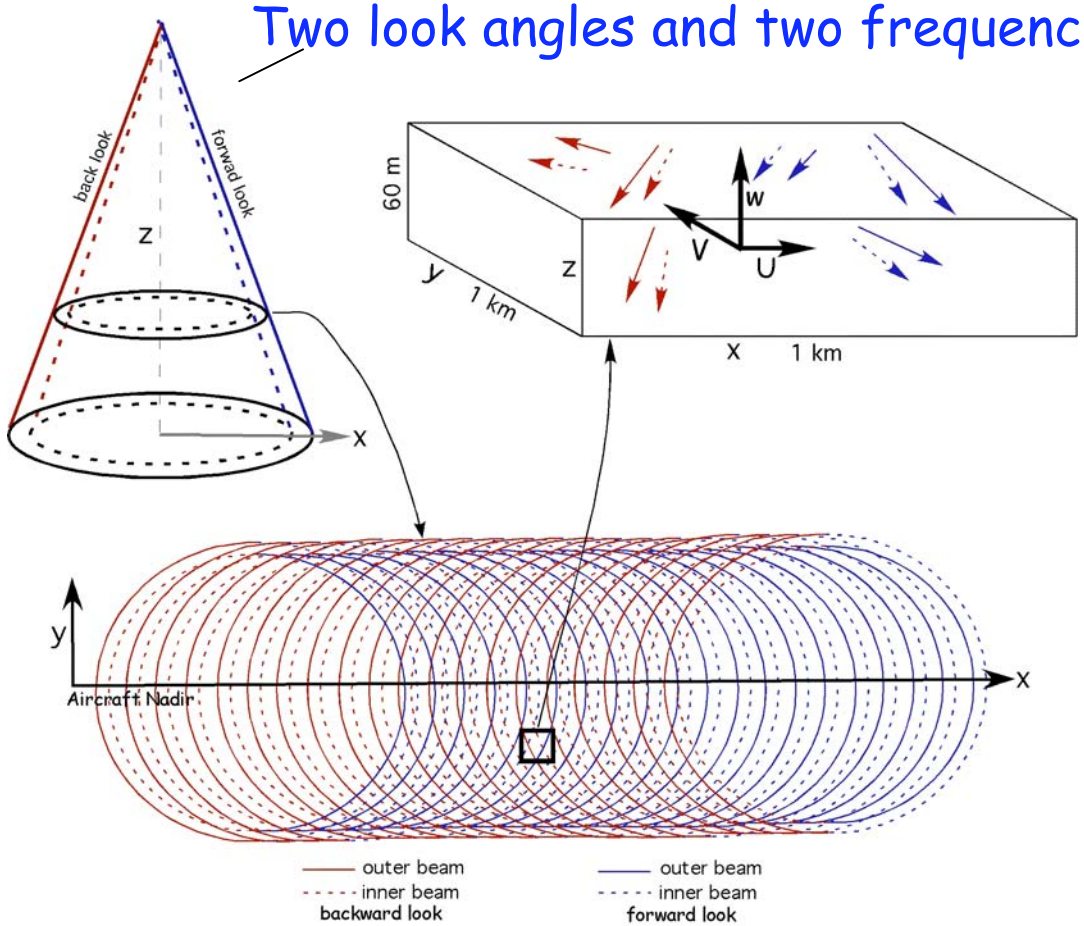
- 18 km altitude.
- > 24 hour missions.

HIWRAP Characteristics:

- Conically scanning.
- Simultaneous Ku/Ka-band & two beams @30 and 40 deg
- Precipitation & clouds as tracers.
- Ocean scatterometry.

HIWRAP Retrieval Method

Two look angles and two frequencies

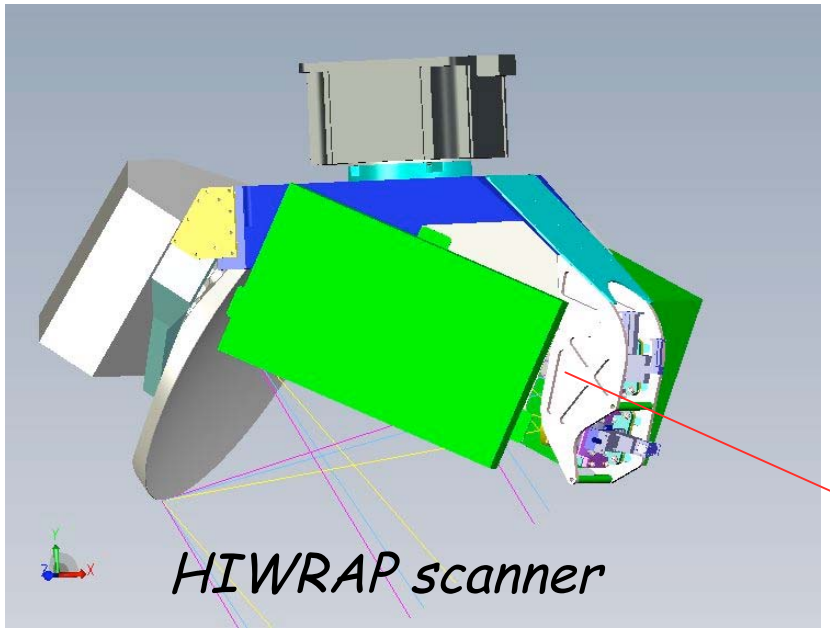


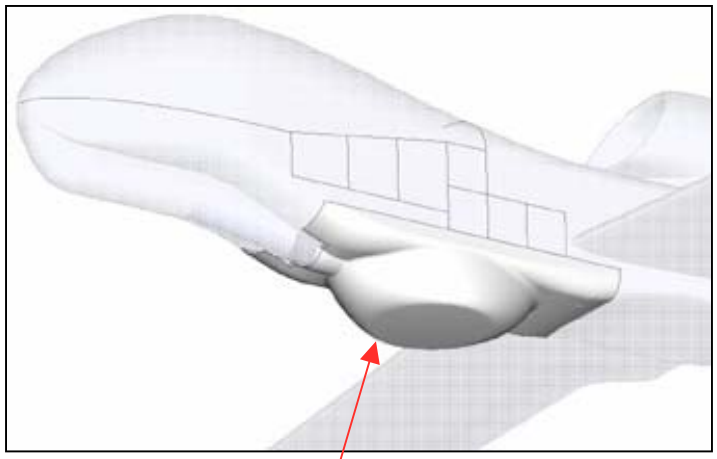
- Provides independent radial wind measurements at multiple azimuth angles and two incidence angles within grid volume. From which the wind vector can be calculated.
- Tradeoff study determined Ku and Ka-band and 30 and 40 deg are the best choice to maximize number of "good" retrievals.

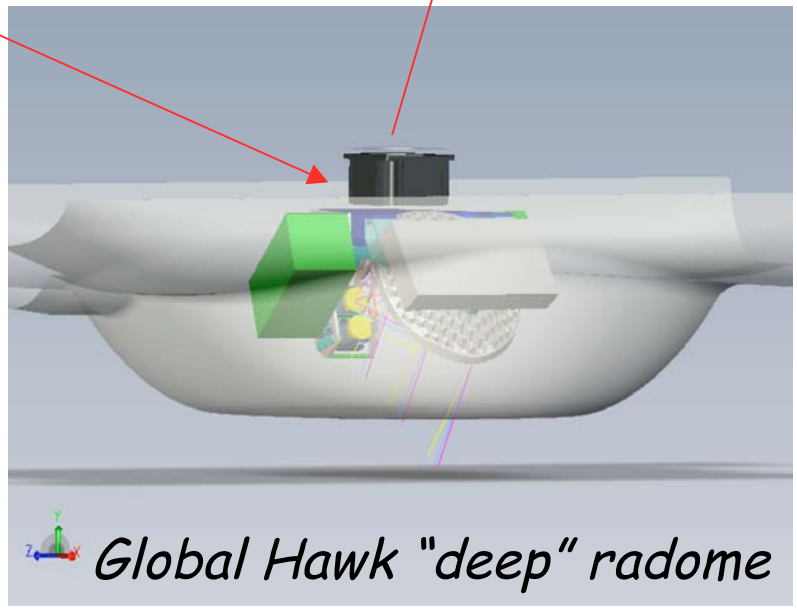
System Specifications

Parameters	Specifications	
	Ku-band	Ka-band
RF Frequency (GHz)	Inner Beam: 13.910 Outer Beam: 13.350	Inner Beam: 35.560 Outer Beam: 33.720
Peak Transmit Power (W)	30	10
3dB Beam Width (^{o})	2.9	1.2
Polarization	Vertical (inner beam), Horizontal (outer beam)	
Min. Detect. Reflectivity (dBZ_e, 60 m res. 10 km)	0.0	-5.0
Dynamic Range (dB)	> 65	
Doppler Velocity (ms^{-1})	0-150 (Uncertainty < 2 ms^{-1} for SNR>10)	
Scanning	Conical Scan, 10 rpm	

Design Goal: Global Hawk







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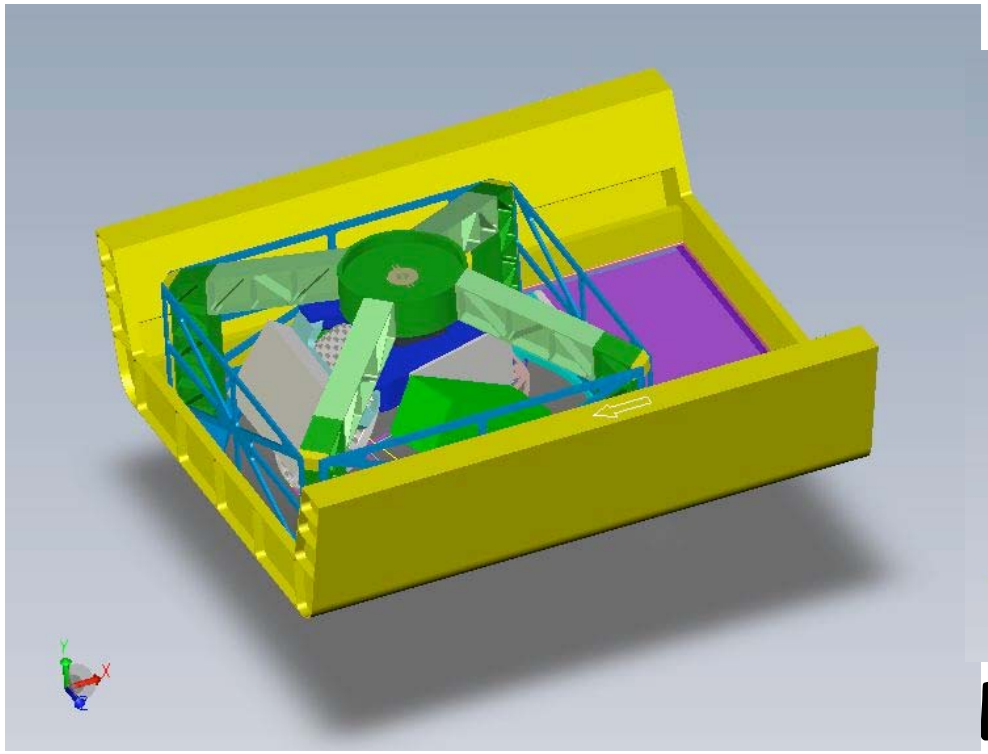
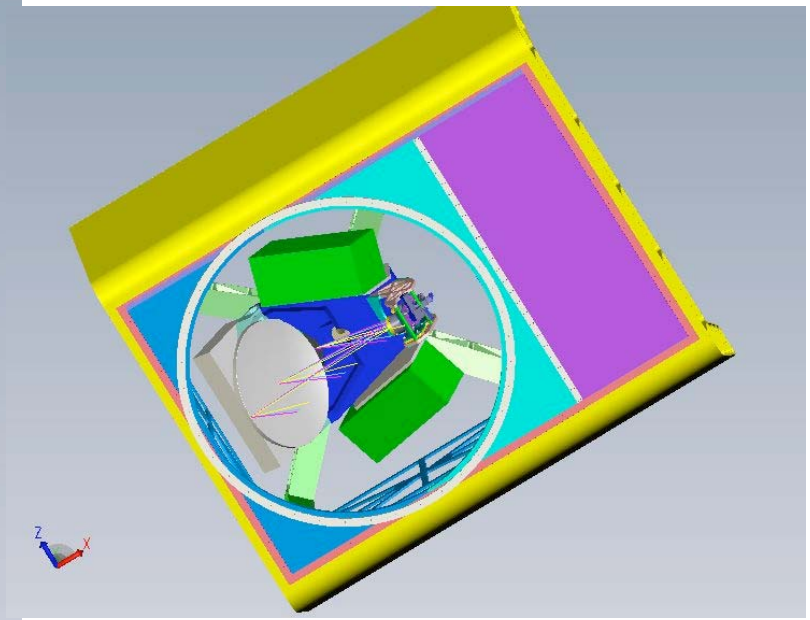
Current Effort: WB57 Aircraft



Side view of pallet & instrument



Bottom view of pallet & radome

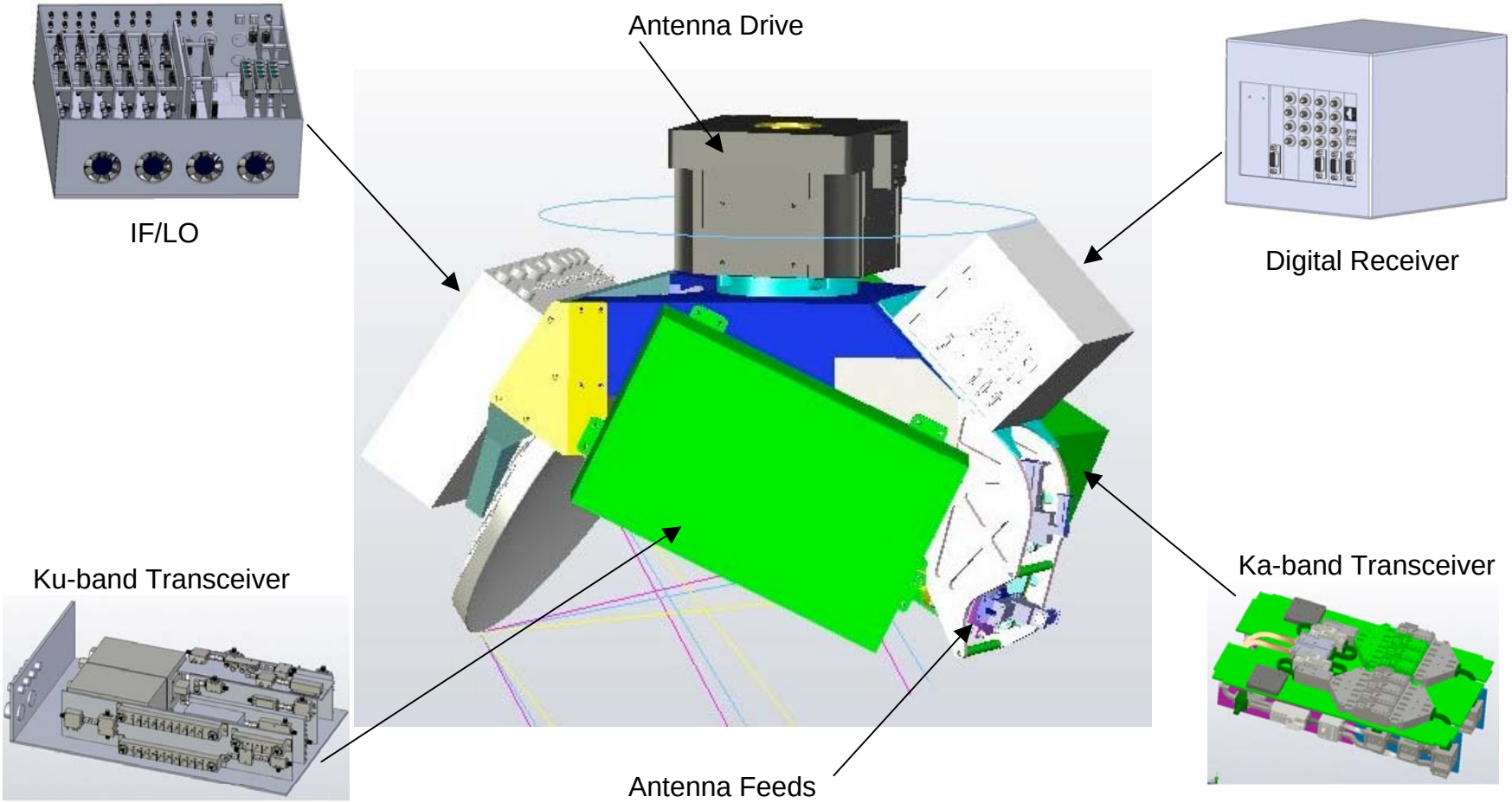
HIWRAP Development Challenges

- High Altitude UAS (Global Hawk) Platform
  - High altitude, unpressurized environment.
  - Limited space, weight and power.
  - Autonomous operations with limited communications.
- Antenna
  - Size and weight constraints require single aperture
  - Dual frequency, dual beam
- Transceiver
  - High sensitivity, solid-state design.
  - Support simultaneous, multiple beam transmit and receive.
  - Single aperture, no blind regions.
- Digital Receiver & Processor
  - Very high input data rate (> 1 Gb/s)
  - Pulse compression implementation.
  - Real-time Doppler processing for data reduction.
  - Network-based communications.

HIWRAP Subsystems

- Ka-Band Transceiver
- Ku-Band Transceiver
- LO/IF
- Digital Receiver/Processor
- Antenna Drive
- Data System
- IMU (navigation)

HIWRAP Scanner Assembly



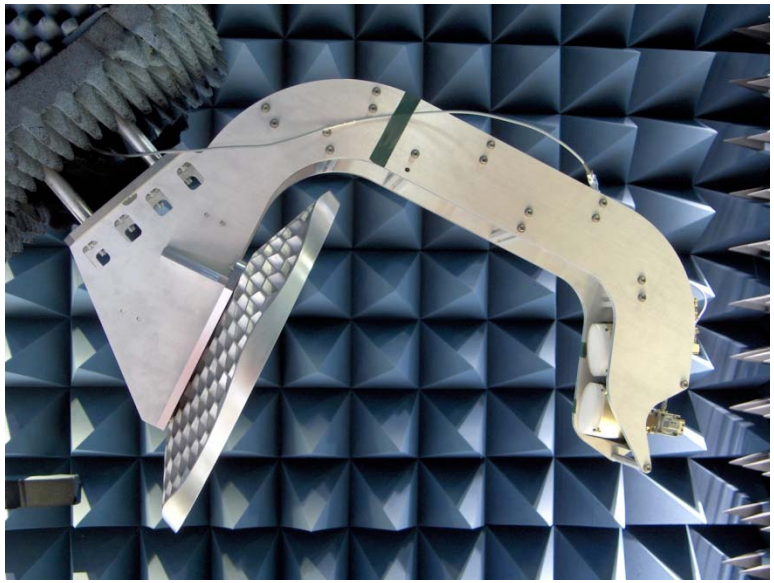
Antenna Development

- Single aperture
- Simultaneous operation at Ku and Ka-band & two beams.
- Limited available height.

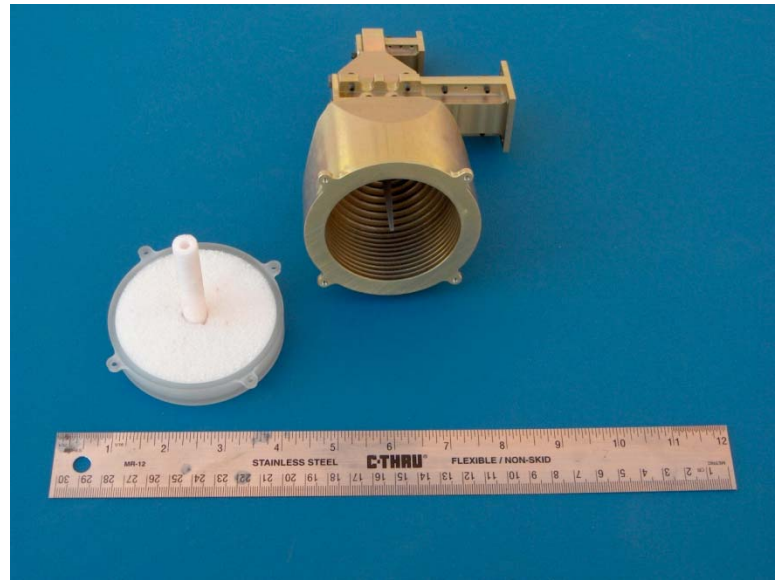
Antenna Performance Goals	
Frequencies (GHz)	13.35, 13.91, 33.72, 35.56
Number of beams at each band	2
3 dB Beamwidth	< 3.25° (Ku) < 1.35° (Ka)
Relative Sidelobe level	<-22 dB
Incidence angle separation	10°
Incidence angles	30° and 40°
Beam/Polarization	Inner/Horizontal Outer/Vertical
Minimum Return Loss	18 dB
Minnimum bandwidth at each frequency	100 MHz

Antenna design and feed development by UMass/CASCA

Antenna Status



HIWRAP antenna mounted in Goddard compact range.



Single HIWRAP Ku/Ka-band feed.

Reflector

- **20” diameter AL reflector**
- **Weighs ~17 lbs**
- **Surface finish < 5 mils**

Antenna Status

- HIWRAP feeds and reflector fabricated and tested
- Measured and simulated performance agrees well
- Antenna ready for final integration into aircraft flight frame.
- Future: radome testing, final support structure tests

Radome ~50" diam.

Dual feeds

Antenna Performance

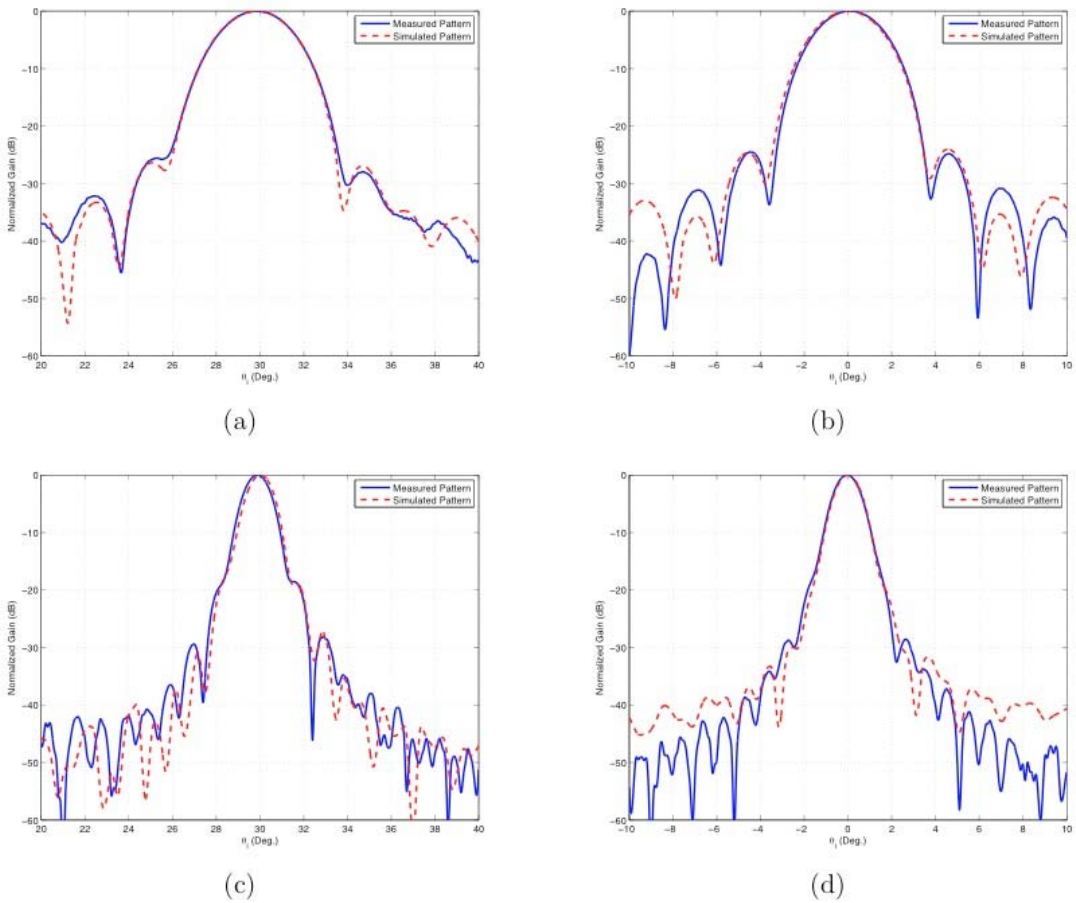
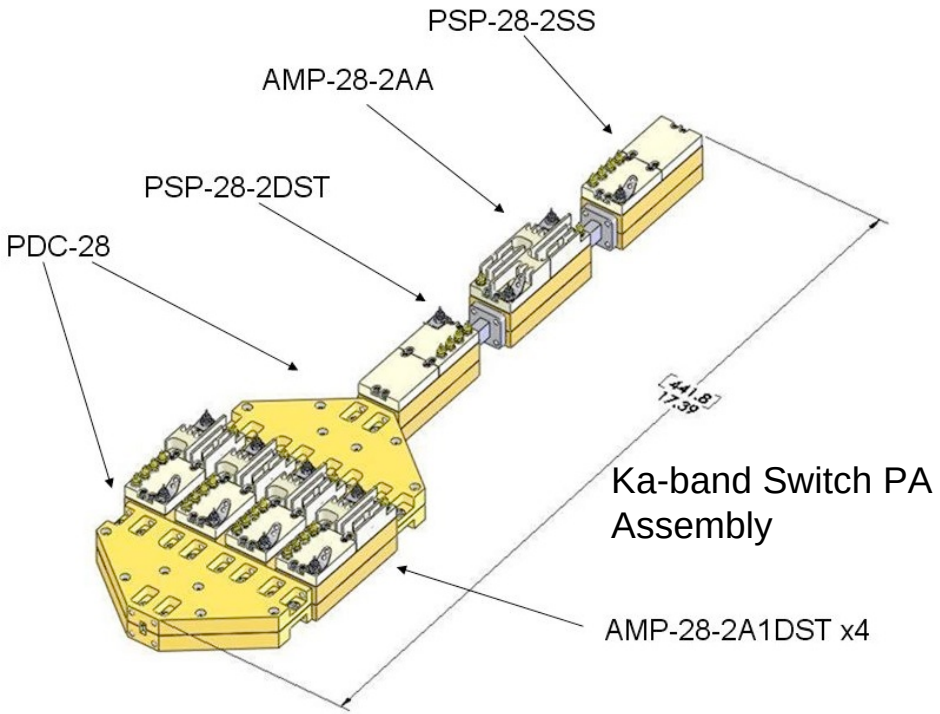


Figure 14: Inner beam feed (a) Ku band, elevation plane, (b) Ku band, azimuthal plane, (c) Ka band, elevation plane, and (d) Ka band, azimuthal plane patterns compared with simulated results for the higher gain tuning position.

Justin Creticos PhD Dissertation
University of Massachusetts

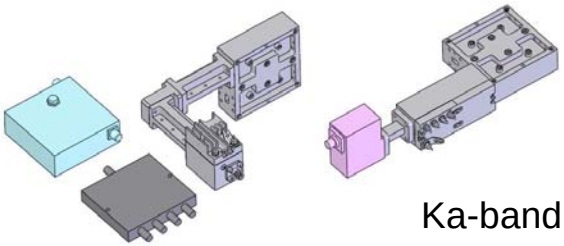
Ka-band Transceiver



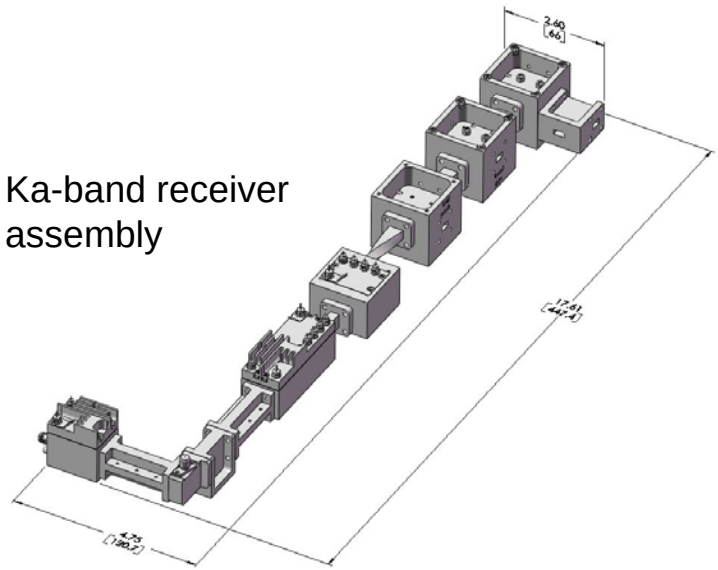
Ka-band Switch PA Assembly

Ka-band Power AMP

- 33.0-36.0 GHz
- 10 watts RF average power
- Internal RF switching (10 nsec)
- Noise output -174 dB/Hz when Tx signal not present
- Operates up to 65 kft
- 28 VDC power supply

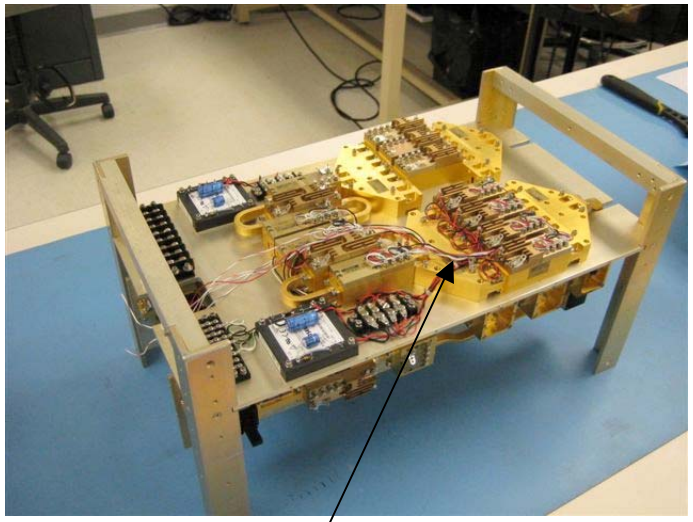


Ka-band Lo block

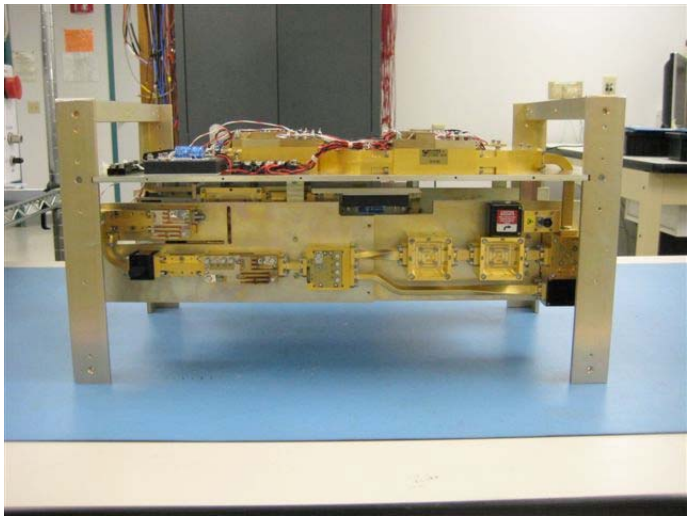


Ka-band receiver assembly

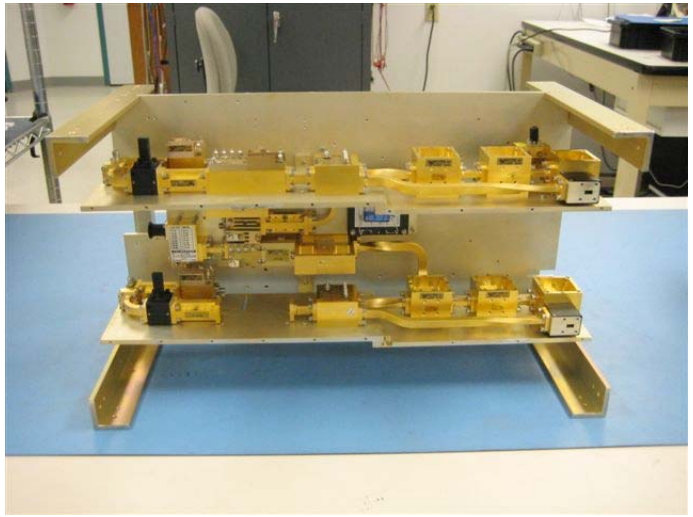
Ka-Band Test Assembly



Power Amplifiers



Side View

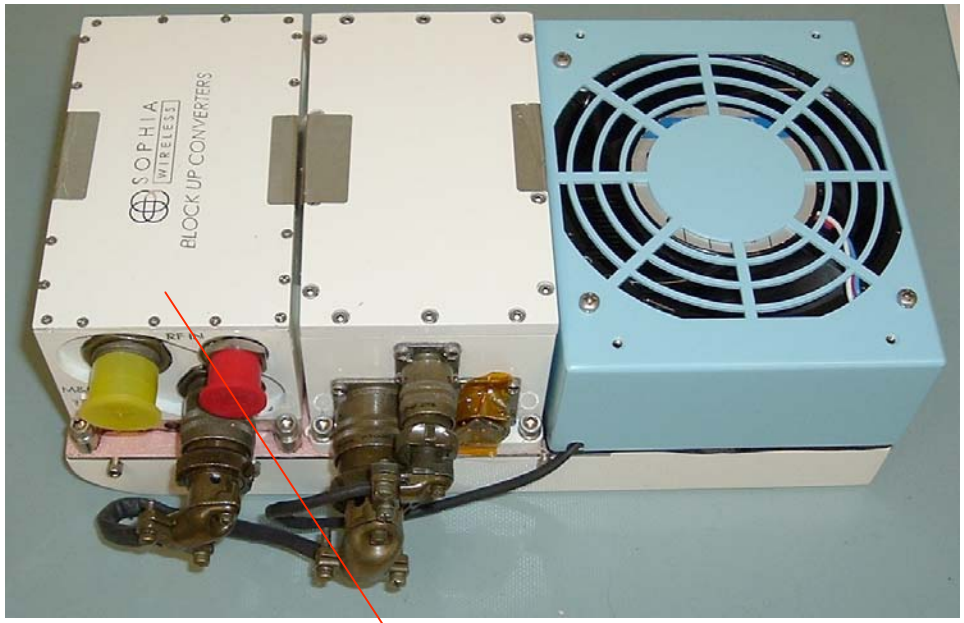


Bottom View

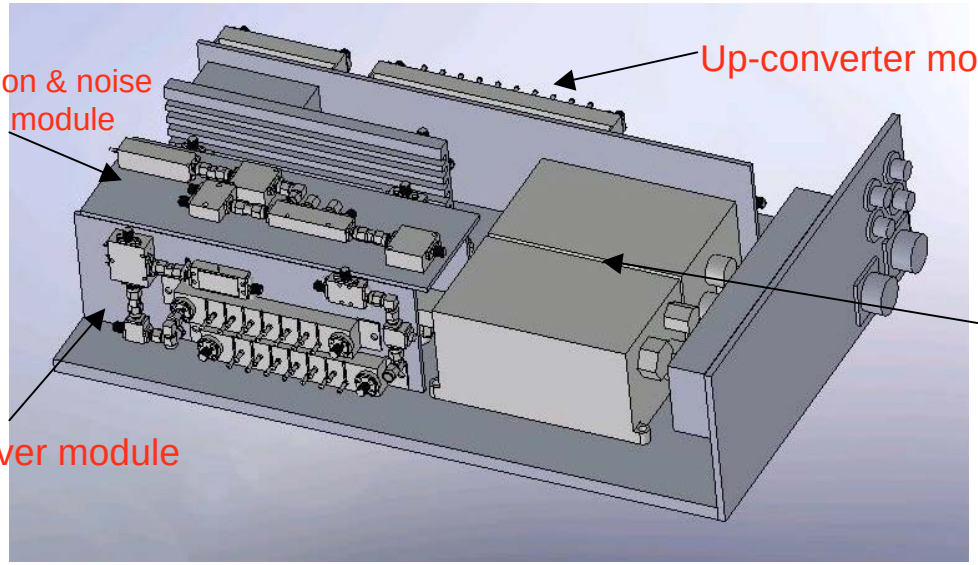
Ku-Band Transceiver

Ku-band PA

- 13.0-14.0 GHz
- 25 watts RF average power.
- Ultra efficiency
- Operates up to 65 kft
- 28 VDC power supply

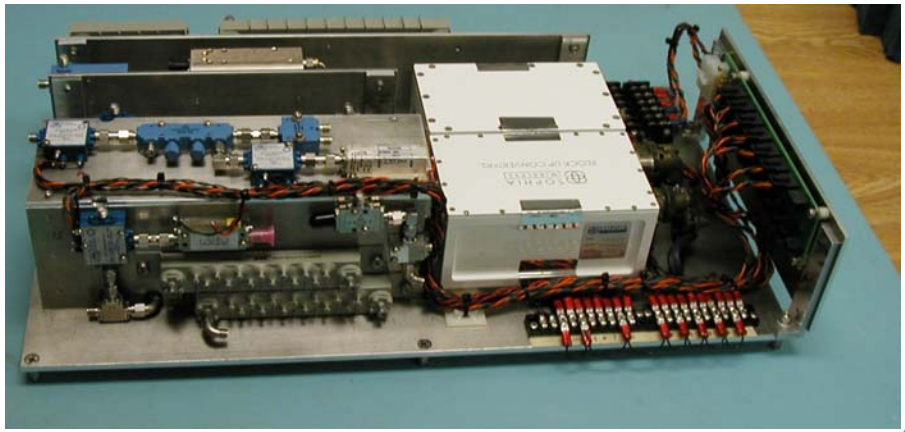


Ku-Band Transceiver



HIWRAP Ku-band transceiver assembly CAD layout

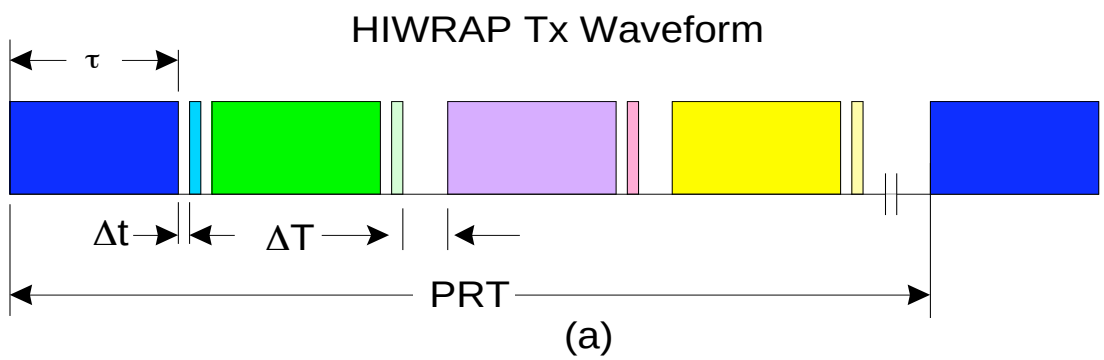
HIWRAP Ku-band transceiver test assembly



Direct Digital Synthesizer (DDS) andTiming Control

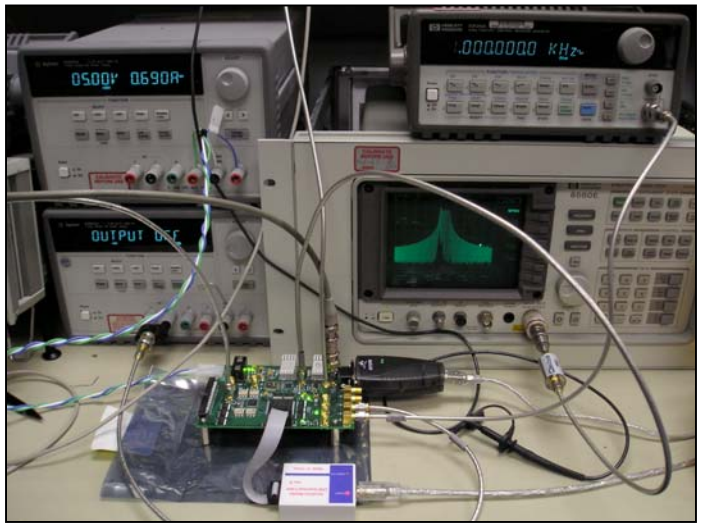
- Versatile transmission waveform generation: dual PRF, linear FM chirp pulse and frequency diversity, pulse amplitude tapering for range sidelobe reduction

- Software controlled timing source for the digital receiver, transmitter and RF switches



Direct Digital Synthesizer (DDS) and Timing Control

- Compact, custom board built to achieve high speed programming of DDS plus software controlled timing
- Consists of AD9959 DDS and Cyclone II FPGA with an RS232 interface

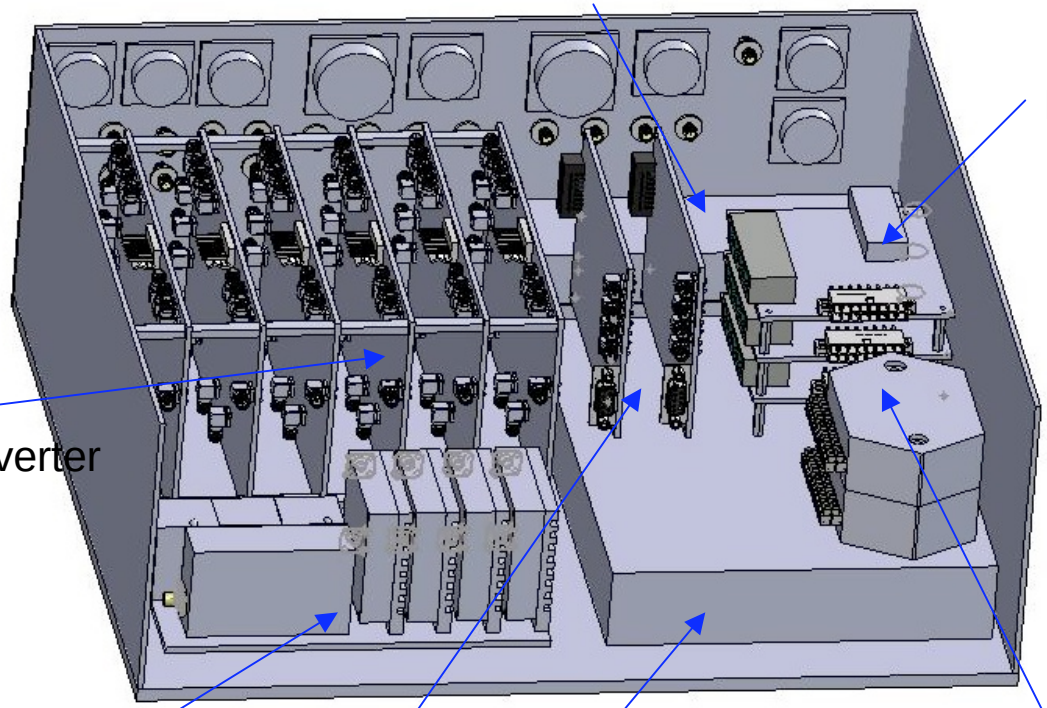


Direct Digital Synthesizer (DDS) and Timing Control

- Status
  - Board design and fabrication is complete
  - Electrical testing and debugging is 90% complete
  - Dual PRF, linear FM and frequency diversity waveform generation is 75% complete
  - Amplitude control algorithm is currently under development

HIWRAP IF/LO Enclosure

- IF boards in evaluation
- Enclosure in design



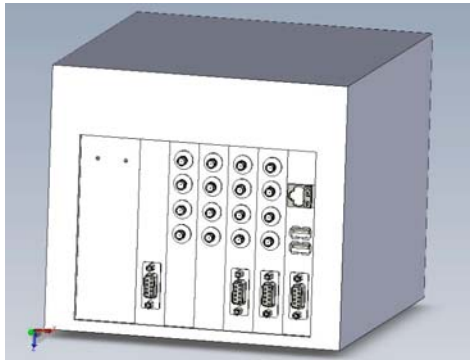
Digital Receiver & Processor
- Challenges

- **High Altitude Operations**
  - Environment (temperature & pressure).
  - Autonomous operation (little to no operator interaction).
  - Redundancy / high availability.
  - Embedded, standalone system.
- **Real-time Processing**
  - High input data rate – 8,960 Megabits/sec
  - Implement pulse compression (up to 30 dB & 16 independent sub channels).
  - Real-time Doppler processing for data reduction.
  - Network-based communications

Digital Receiver & Processor

Subsystems:

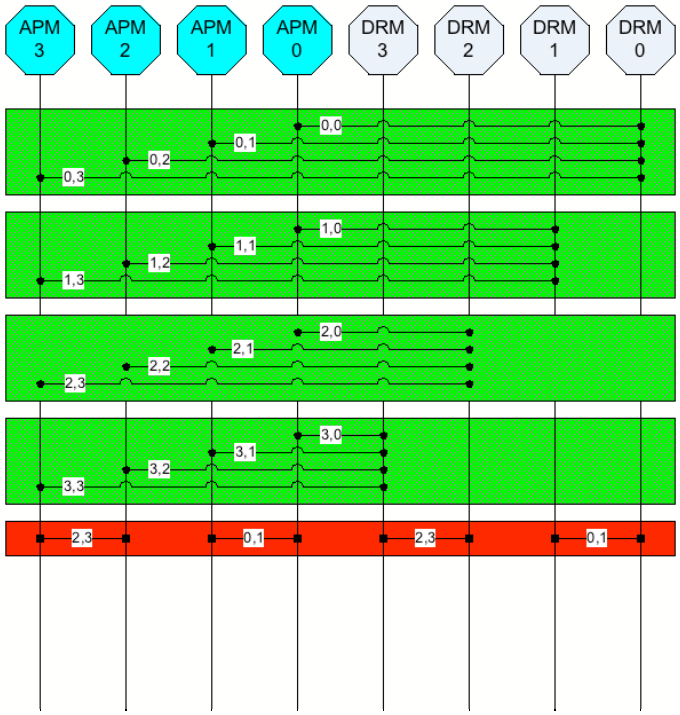
- **Digital Receiver Module (DRM)**
  - Based on Virtex-5 SX95T FPGA.
  - Implements Digital Receivers and Match Filters.
  - Same board can be reconfigured as an APM.
- **Algorithm Processing Module (APM)**
  - Based on Virtex-5 SX95T FPGA.
  - Implements Pulse-Pair processing.
- **Network Processing Module (NPM)**
  - Based on PowerQUICC II Processor
  - Serves as controller and communications processor.
- **Switch Fabric Board**
  - Provides communication between NPM and APMs / DRMs.



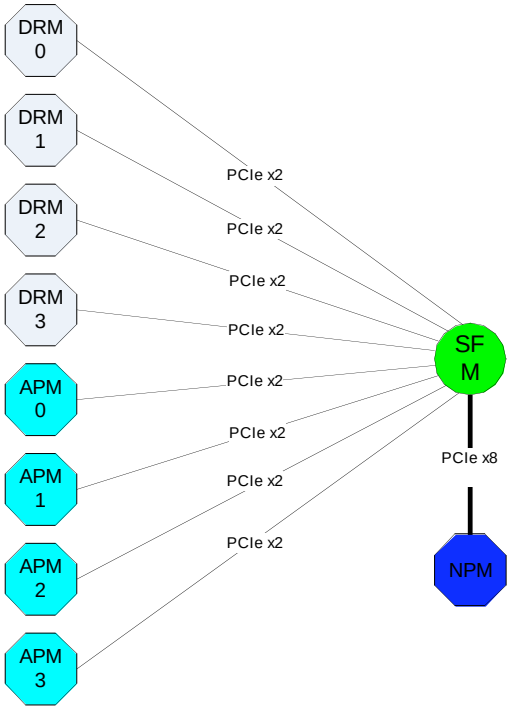
Card cage conforms to 3U CompactPCI form factor.

Processing & Communication Bus (i.e. custom backplane)

High Speed Dedicated Processing Bus



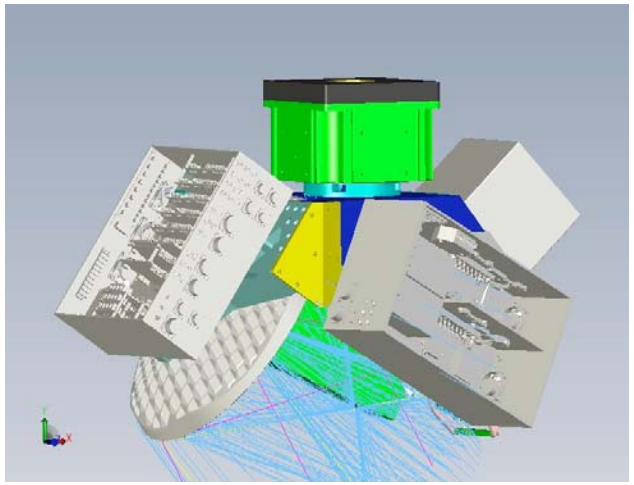
Communication Serial I/O (PCIe) Bus

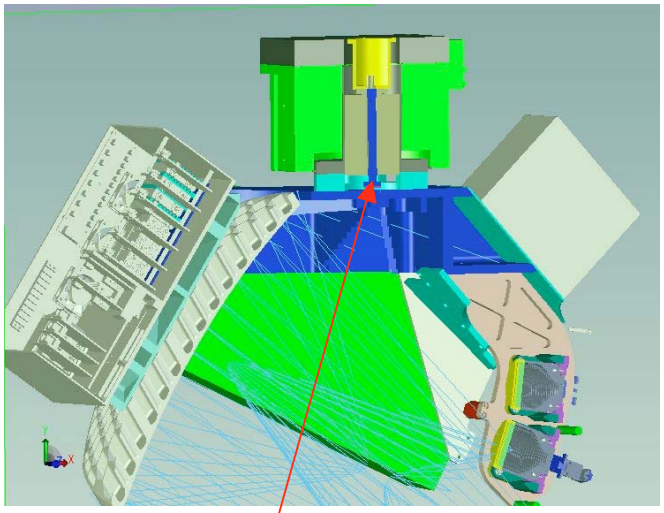


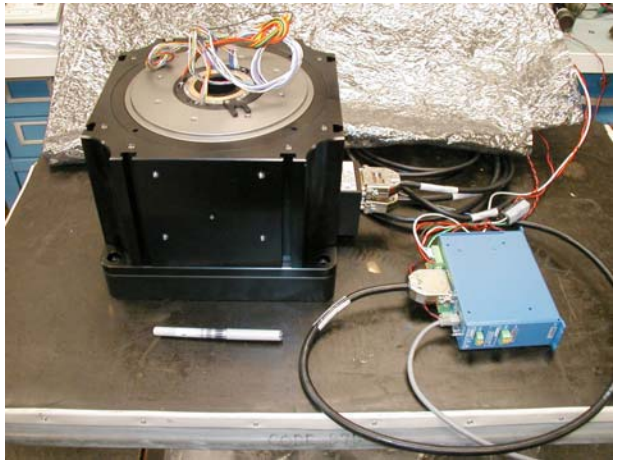
Digital Subsystem Status

- Adhoc system that can support a single IF channel is operating now.
- Signal integrity analysis and layout of backplane underway.
- Targeted completion of baseline digital/IF subsystem August 2008.
- Flight board completion October 2008

Scanner Assembly







Fiberoptic rotary joint, slip ring, scanner, assembly

Summary

- Test flights are planned for HIWRAP in January 2009 after instrument completion.
- Many technical challenges will have been met that are related to solid state transmitter/pulse compression approach, operating conditions, and size/weight constraints.
- New capability provided by HIWRAP will enhance hurricane research and routine hurricane monitoring.
- Future challenges: real time data processing and downlink of products.

BACKUP SLIDES

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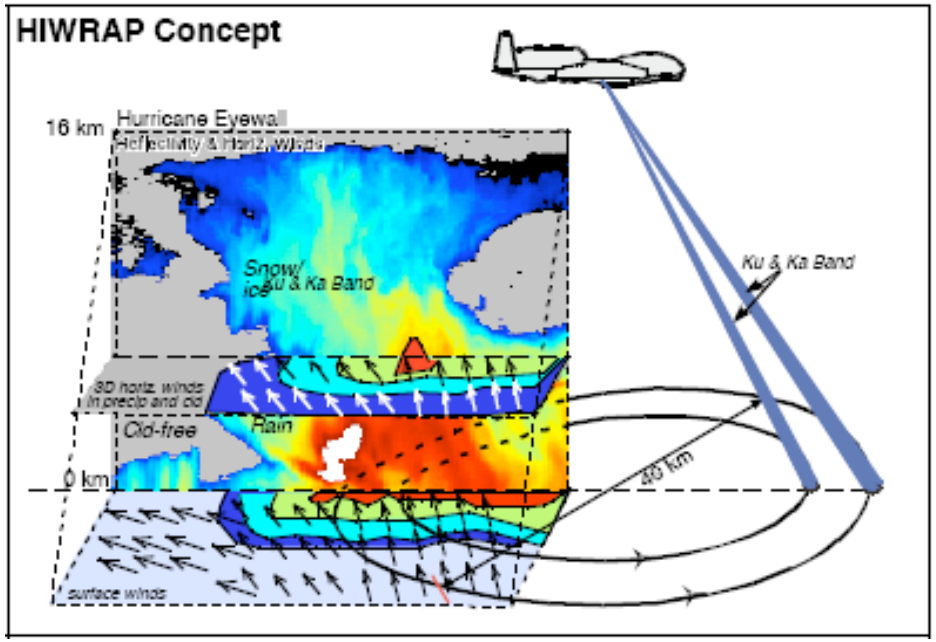

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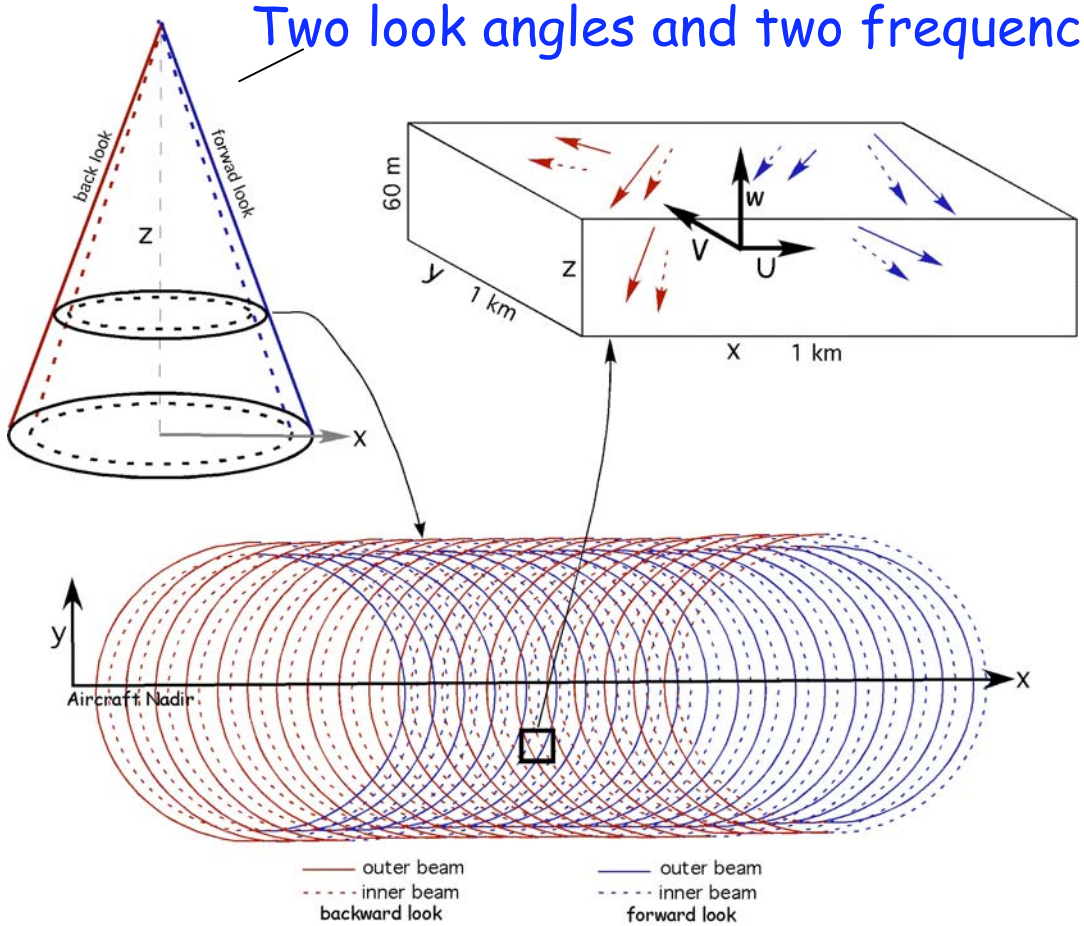

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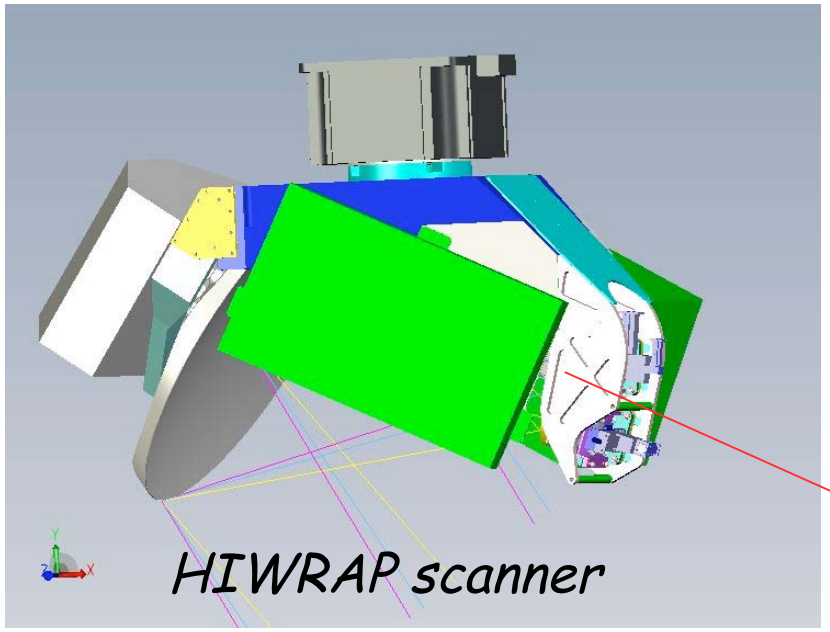

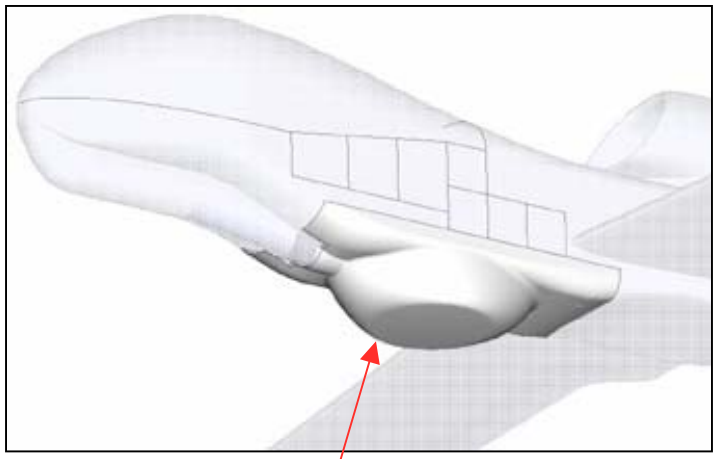

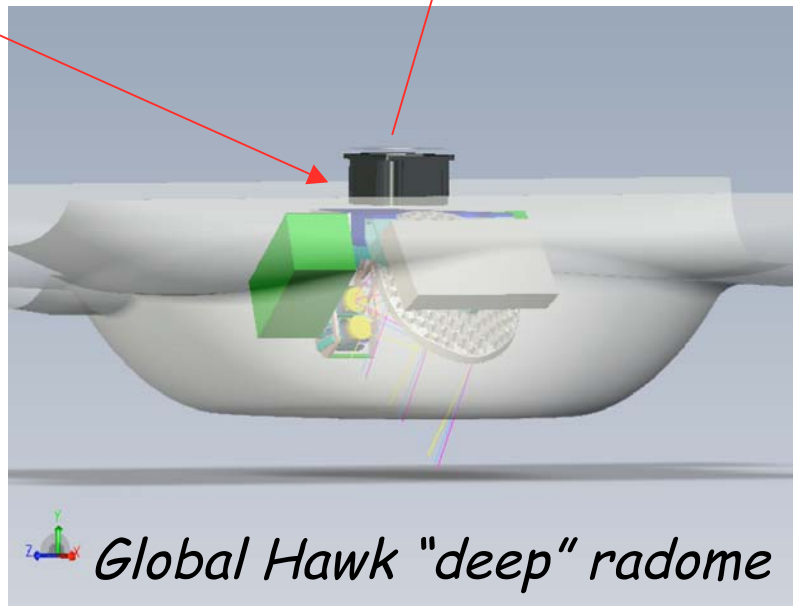

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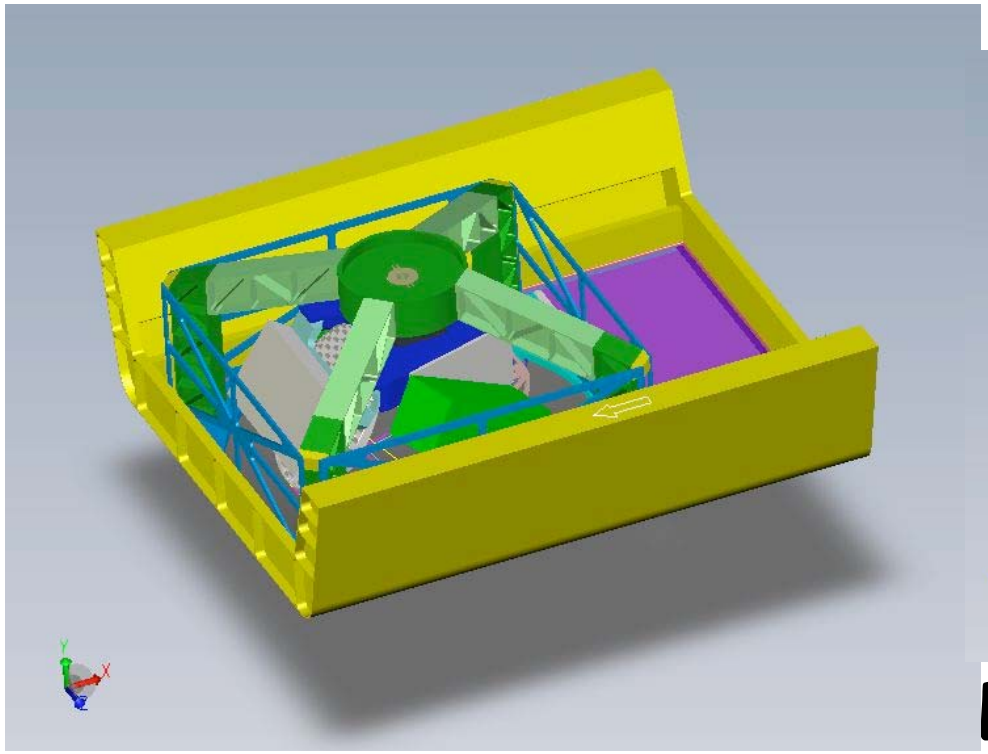

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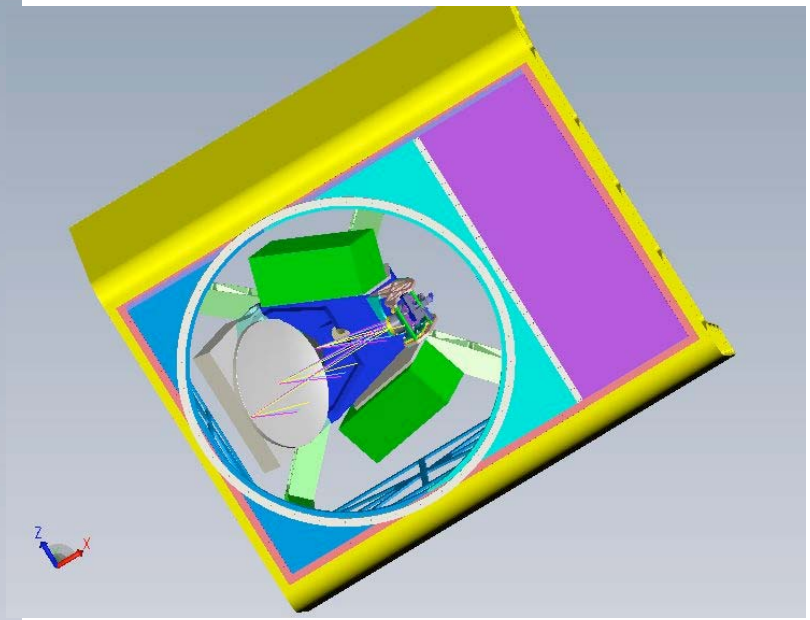

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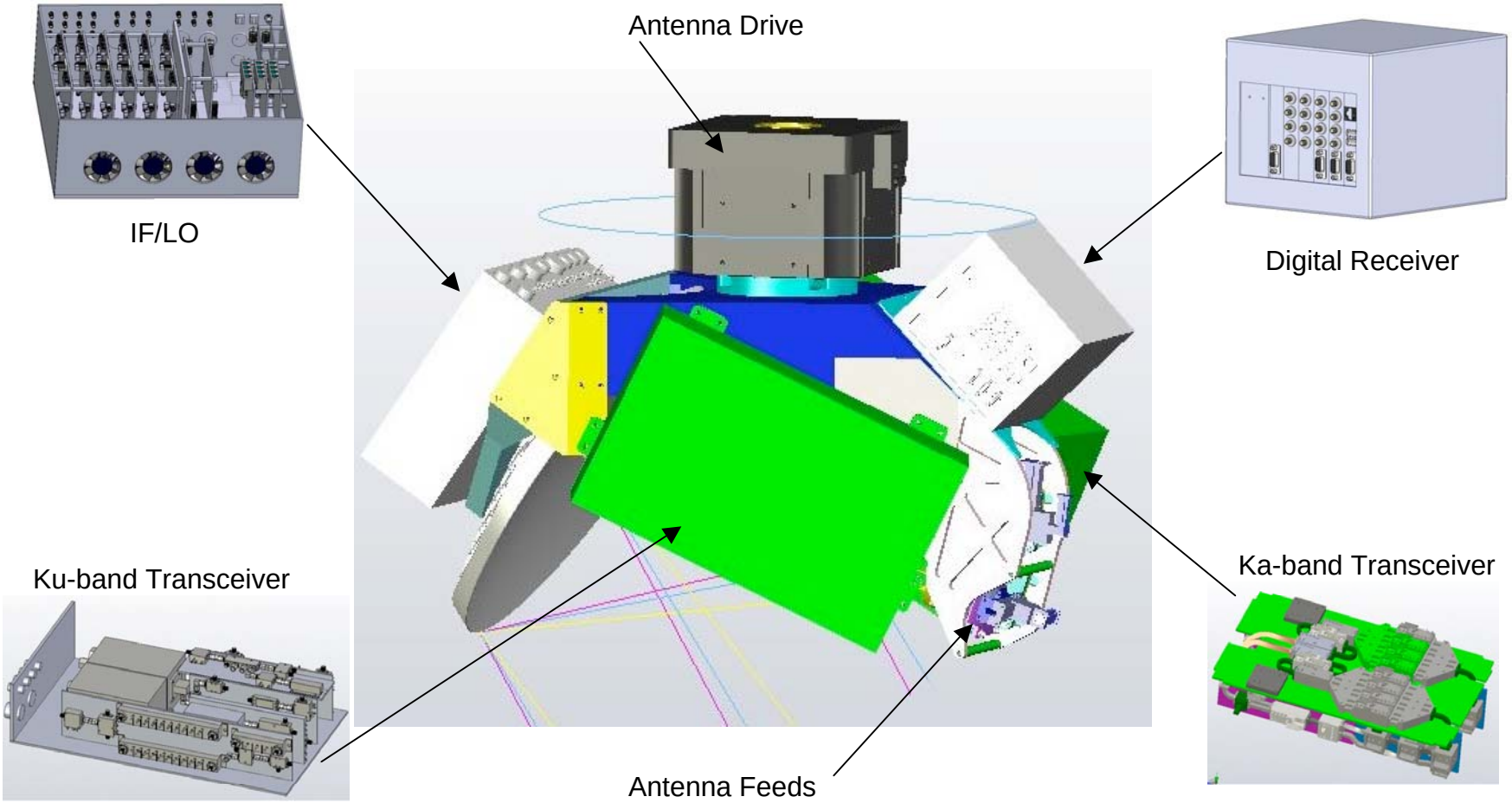

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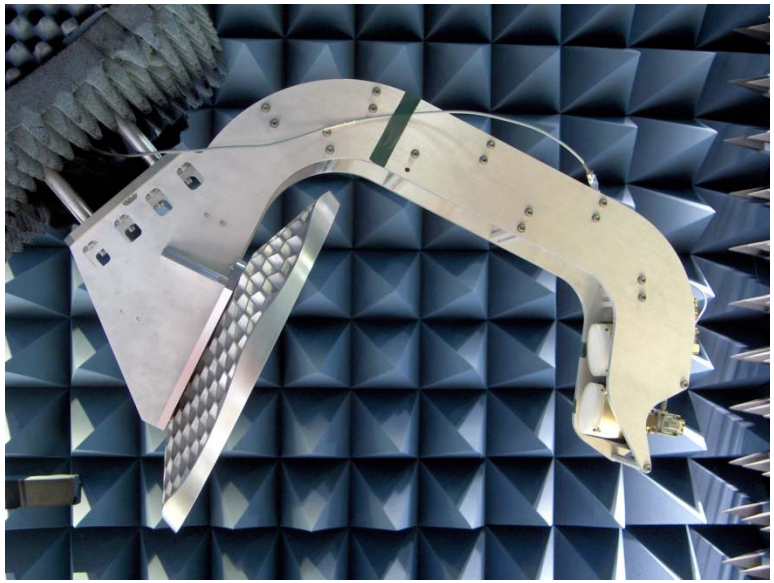

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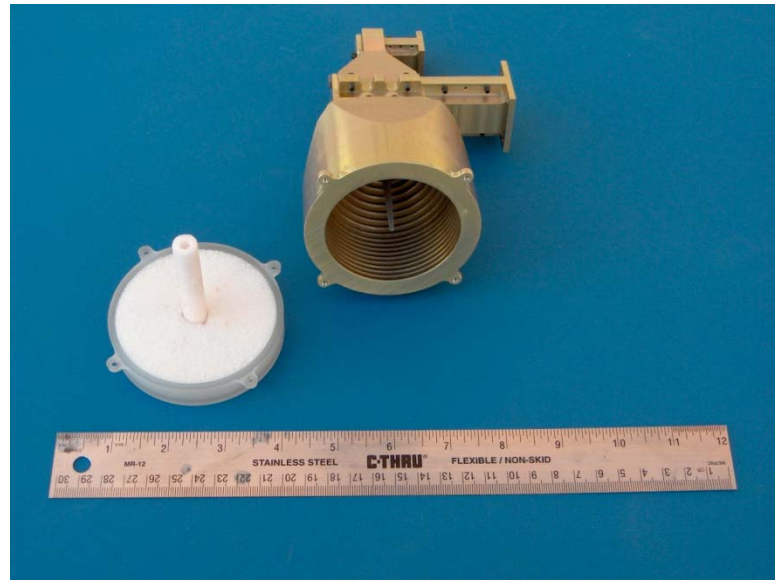


Single HIWRAP Ku/Ka-band feed.

Reflector

- **20” diameter AL reflector**
- **Weighs ~17 lbs**
- **Surface finish < 5 mils**

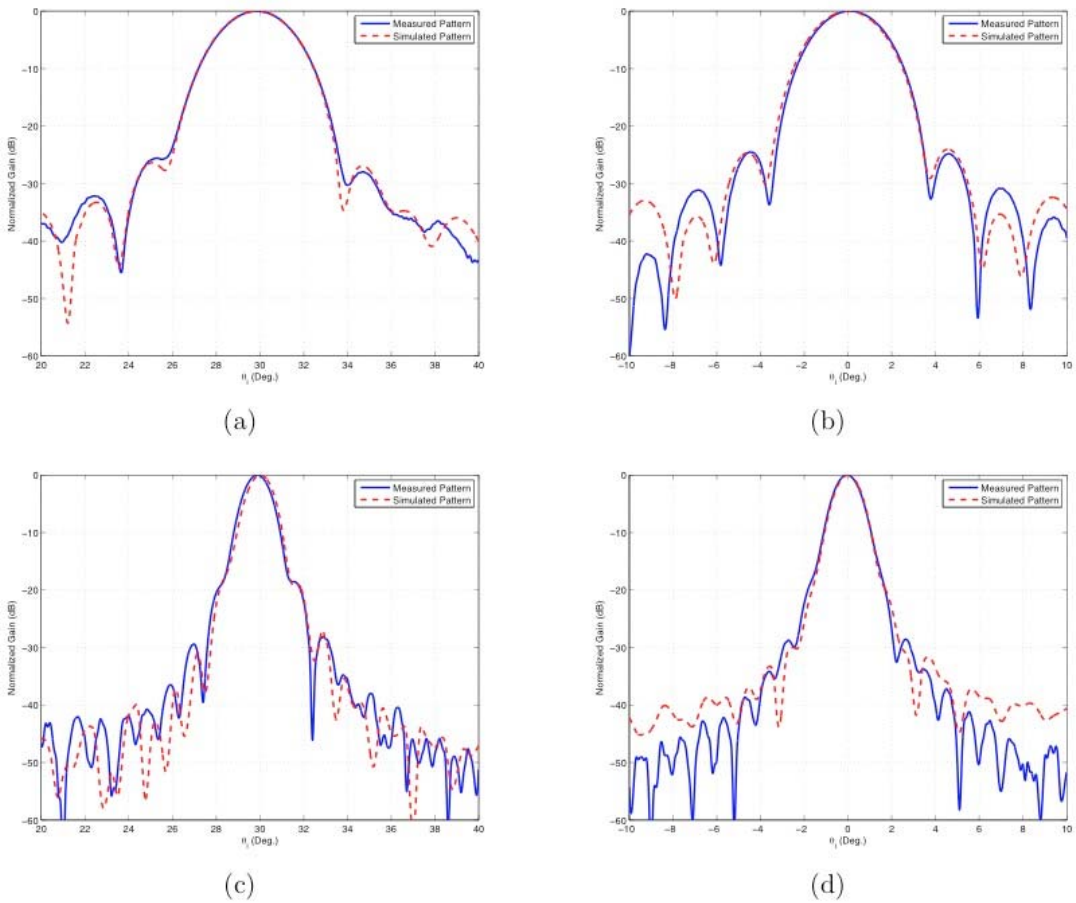
Antenna Status

- HIWRAP feeds and reflector fabricated and tested
- Measured and simulated performance agrees well
- Antenna ready for final integration into aircraft flight frame.
- Future: radome testing, final support structure tests

Radome ~50" diam.

Dual feeds

Antenna Performance



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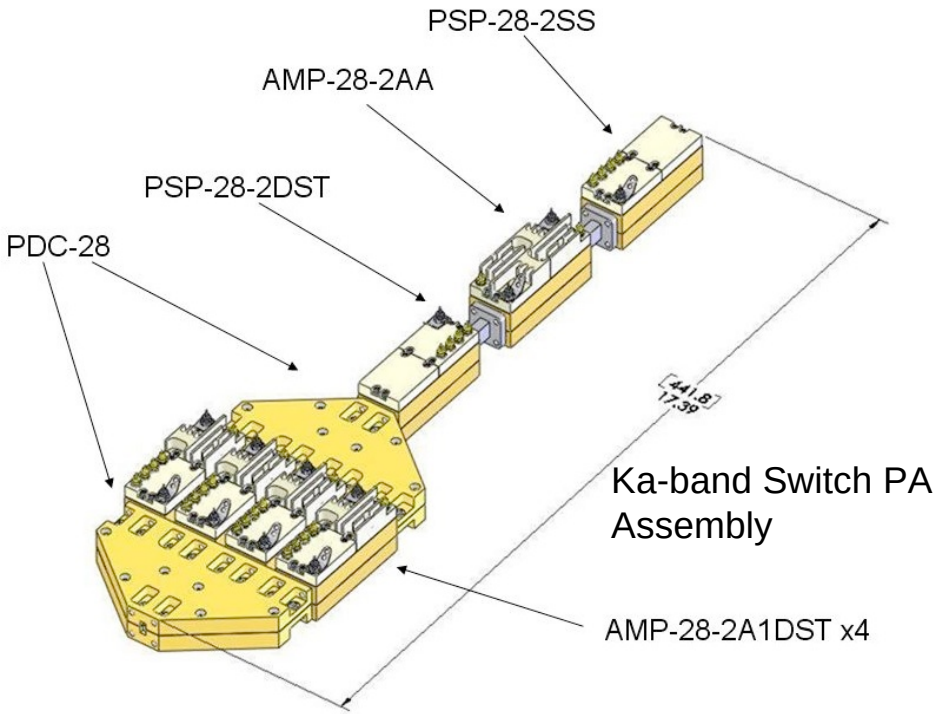
Justin Creticos PhD Dissertation
University of Massachusetts

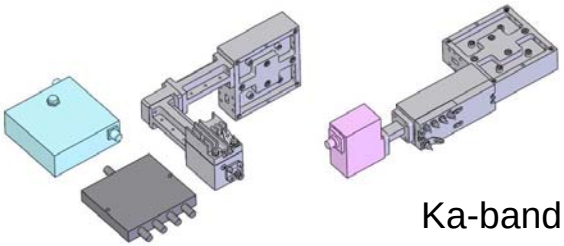
Ka-band Transceiver



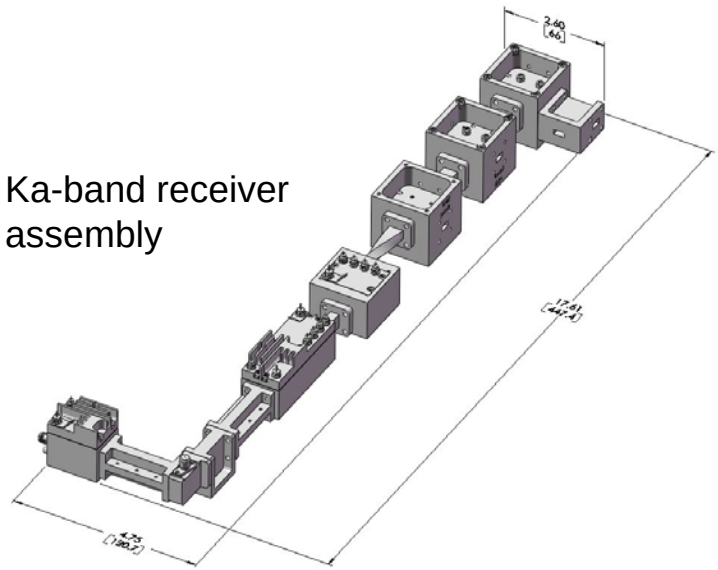
Ka-band Switch PA Assembly

Ka-band Power AMP

- 33.0-36.0 GHz
- 10 watts RF average power
- Internal RF switching (10 nsec)
- Noise output -174 dB/Hz when Tx signal not present
- Operates up to 65 kft
- 28 VDC power supply

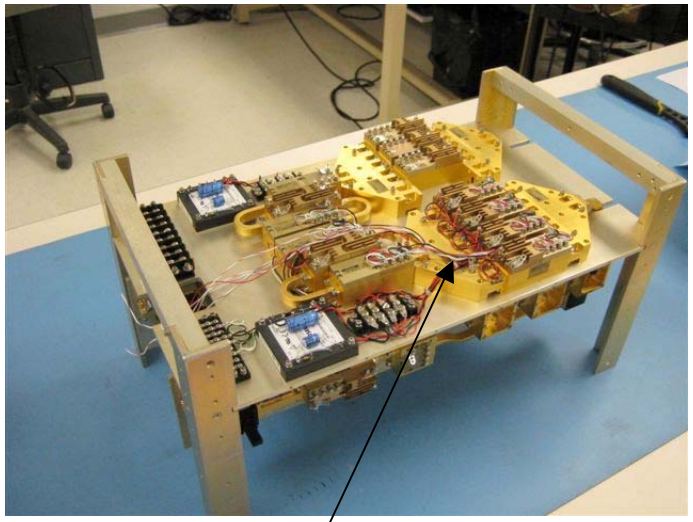


Ka-band Lo block

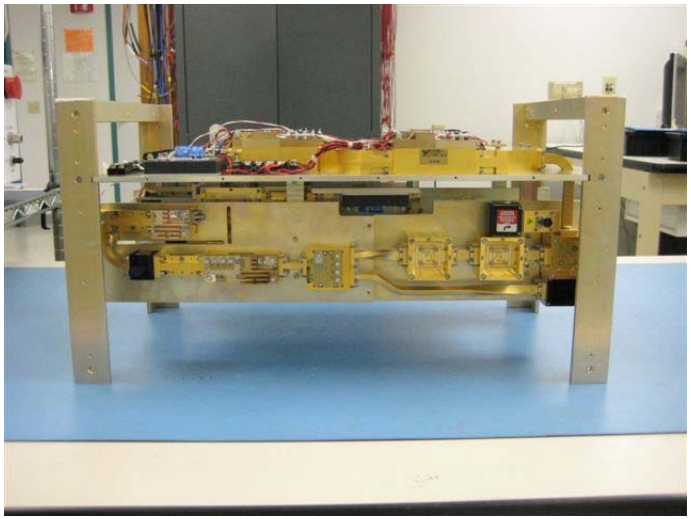


Ka-band receiver assembly

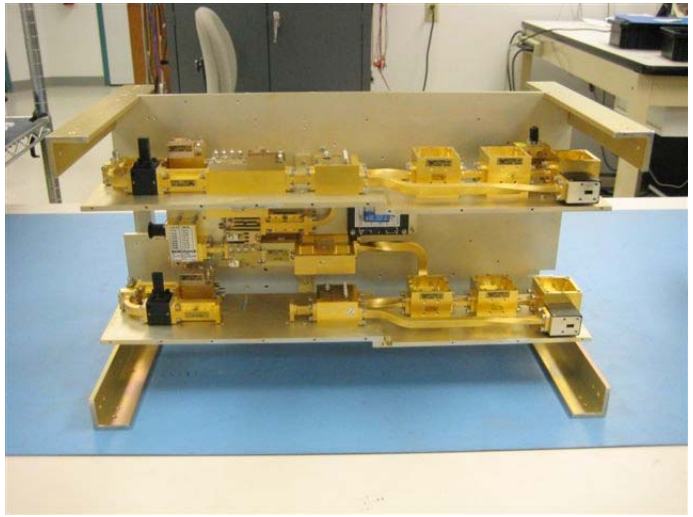
Ka-Band Test Assembly



Power Amplifiers



Side View



Bottom View

Ku-Band Transceiver

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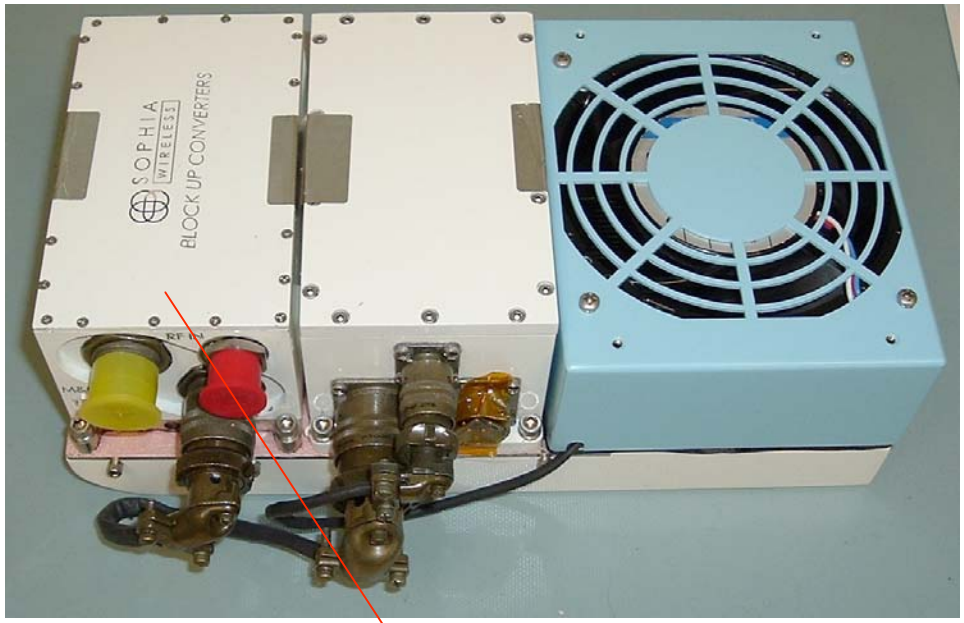

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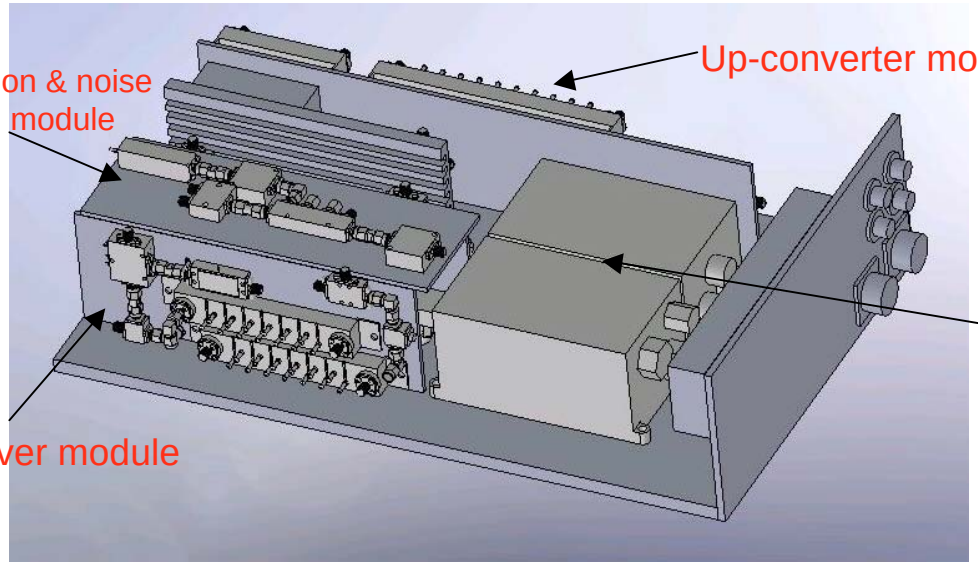
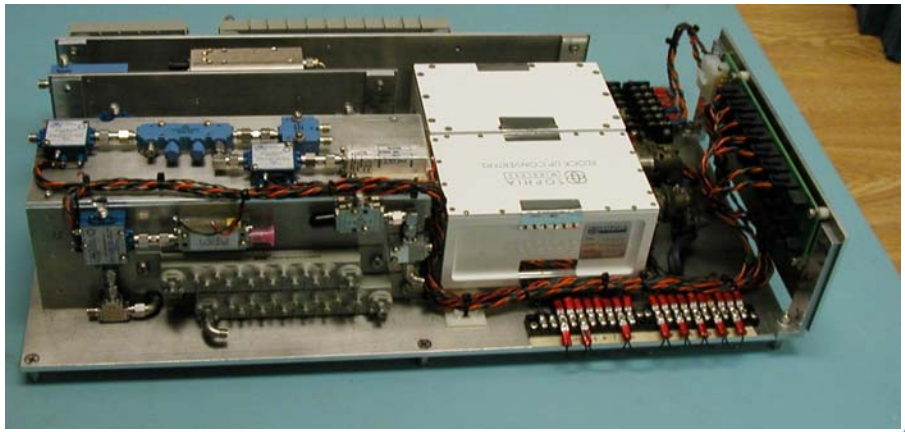


HIWRAP Ku-band transceiver assembly CAD layout

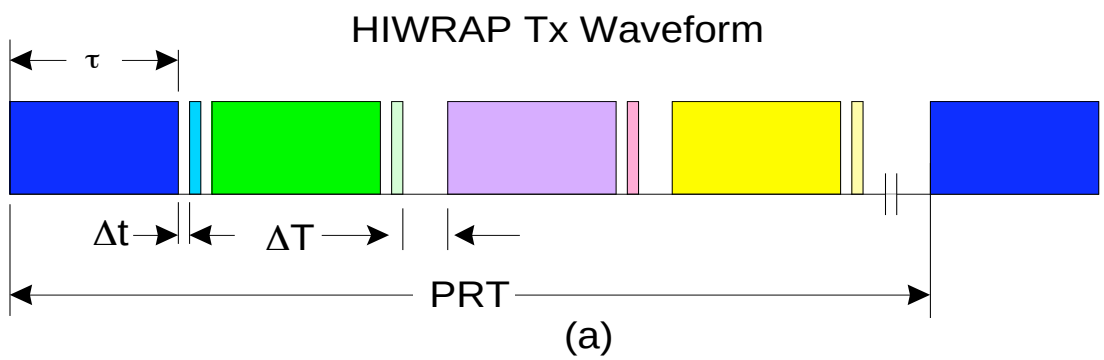
HIWRAP Ku-band transceiver test assembly



Direct Digital Synthesizer (DDS) andTiming Control

- Versatile transmission waveform generation: dual PRF, linear FM chirp pulse and frequency diversity, pulse amplitude tapering for range sidelobe reduction

- Software controlled timing source for the digital receiver, transmitter and RF switches



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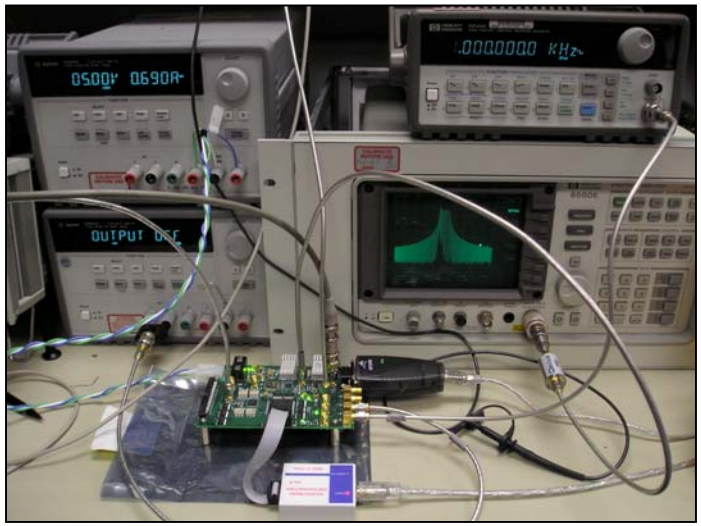
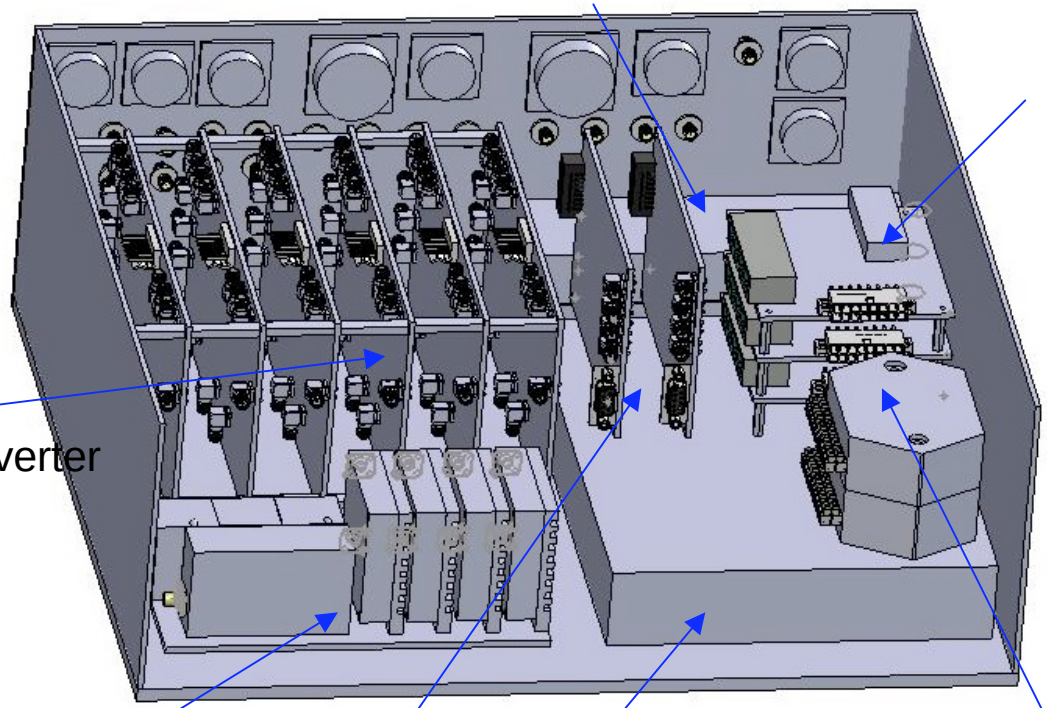


Direct Digital Synthesizer (DDS) and Timing Control

- Status
  - Board design and fabrication is complete
  - Electrical testing and debugging is 90% complete
  - Dual PRF, linear FM and frequency diversity waveform generation is 75% complete
  - Amplitude control algorithm is currently under development

HIWRAP IF/LO Enclosure

- IF boards in evaluation
- Enclosure in design



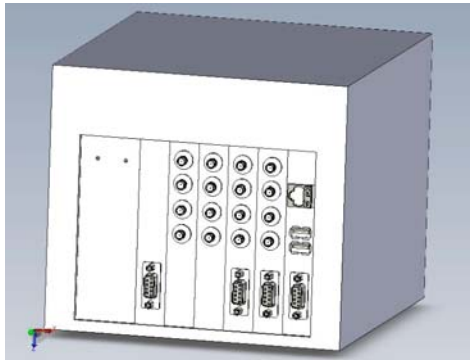
Digital Receiver & Processor
- Challenges

- **High Altitude Operations**
  - Environment (temperature & pressure).
  - Autonomous operation (little to no operator interaction).
  - Redundancy / high availability.
  - Embedded, standalone system.
- **Real-time Processing**
  - High input data rate – 8,960 Megabits/sec
  - Implement pulse compression (up to 30 dB & 16 independent sub channels).
  - Real-time Doppler processing for data reduction.
  - Network-based communications

Digital Receiver & Processor

Subsystems:

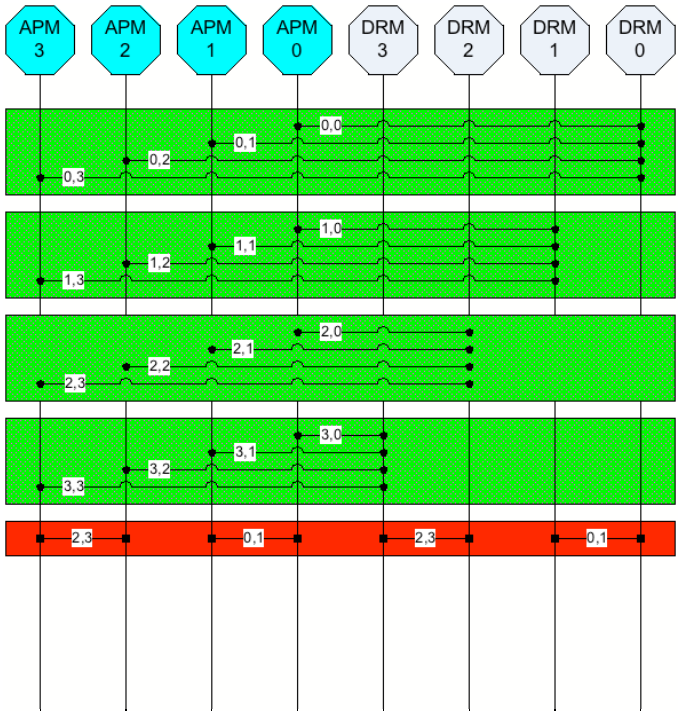
- **Digital Receiver Module (DRM)**
  - Based on Virtex-5 SX95T FPGA.
  - Implements Digital Receivers and Match Filters.
  - Same board can be reconfigured as an APM.
- **Algorithm Processing Module (APM)**
  - Based on Virtex-5 SX95T FPGA.
  - Implements Pulse-Pair processing.
- **Network Processing Module (NPM)**
  - Based on PowerQUICC II Processor
  - Serves as controller and communications processor.
- **Switch Fabric Board**
  - Provides communication between NPM and APMs / DRMs.



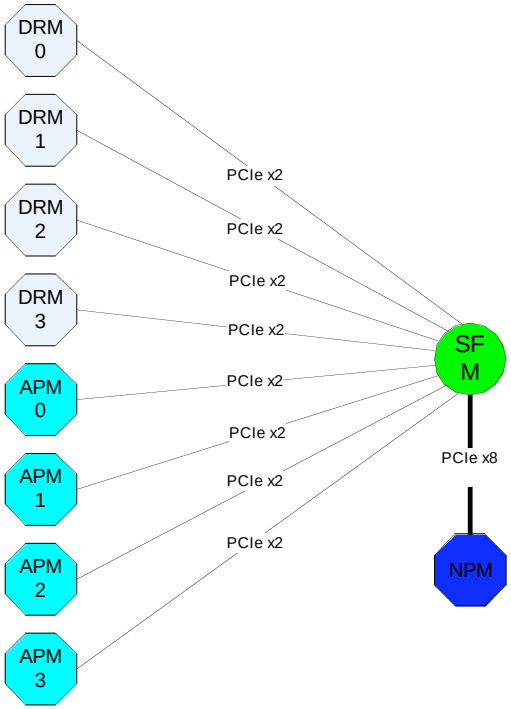
Card cage conforms to 3U CompactPCI form factor.

Processing & Communication Bus (i.e. custom backplane)

High Speed Dedicated Processing Bus



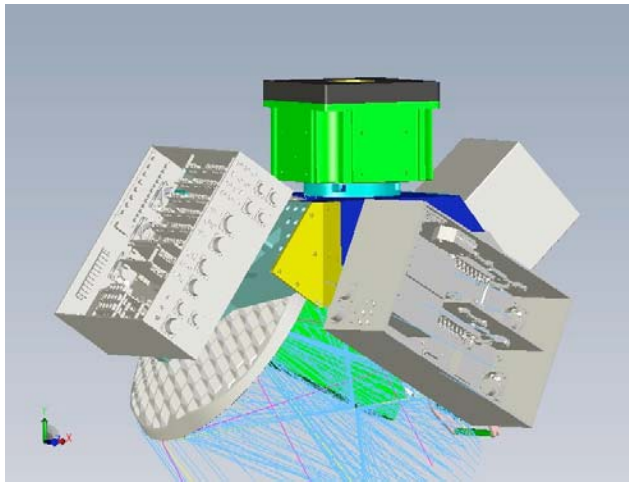
Communication Serial I/O (PCIe) Bus

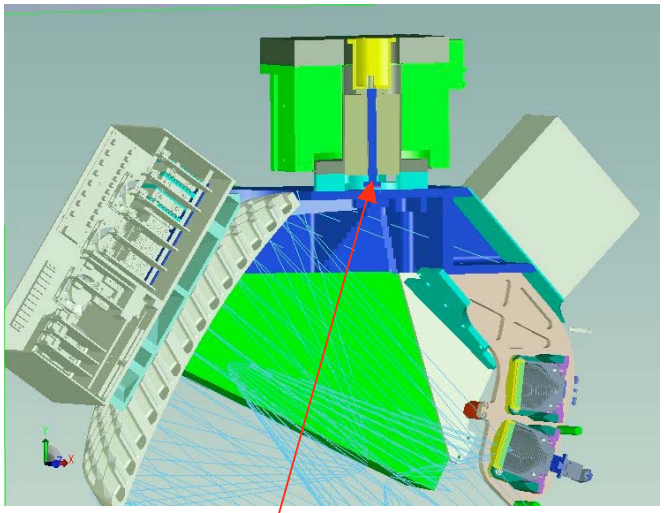


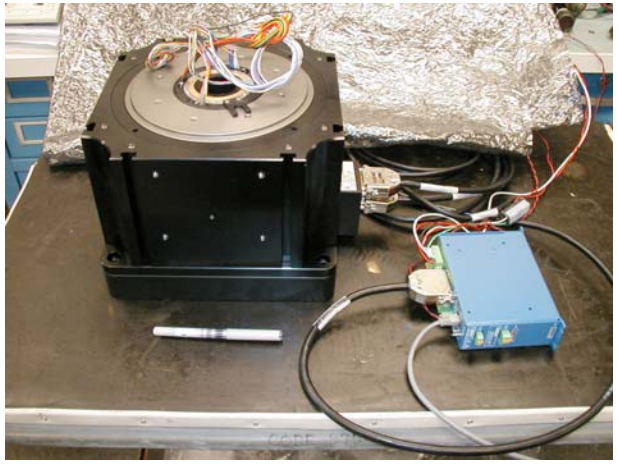
Digital Subsystem Status

- Adhoc system that can support a single IF channel is operating now.
- Signal integrity analysis and layout of backplane underway.
- Targeted completion of baseline digital/IF subsystem August 2008.
- Flight board completion October 2008

Scanner Assembly







Fiberoptic rotary joint, slip ring, scanner, assembly

Summary

- Test flights are planned for HIWRAP in January 2009 after instrument completion.
- Many technical challenges will have been met that are related to solid state transmitter/pulse compression approach, operating conditions, and size/weight constraints.
- New capability provided by HIWRAP will enhance hurricane research and routine hurricane monitoring.
- Future challenges: real time data processing and downlink of products.

BACKUP SLIDES

Status of the High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

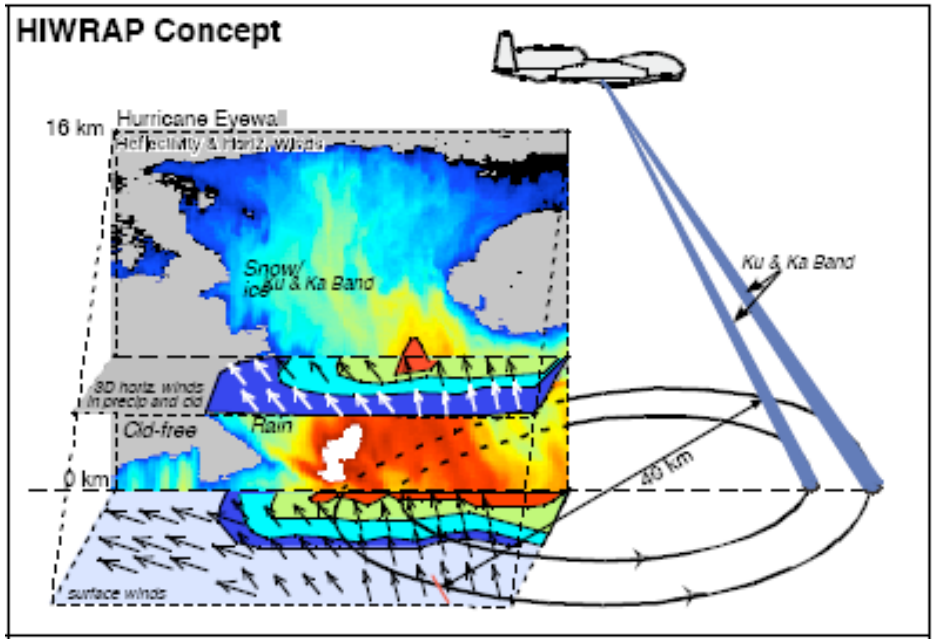
Gerald Heymsfield[1], James Carswell[2], Lihua Li[3], Dan Schaubert[4], Justin Creticos[4], Manuel Vega[1], Wayne Welch[5]

[1]Goddard Space Flight Center, Greenbelt, MD 20771
[2]Remote Sensing Solutions, Barnstable, MA
[3]University of Maryland Baltimore, MD
[4]University of Mass., Amherst, MA
[5]Welch Mechanical Designs, Havre de Grace, MD

HIWRAP CONCEPT

MEASUREMENTS GOAL: Provide horizontal winds in precipitation regions and ocean surface winds in clear to light rain regions

MEASUREMENT TARGET: Hurricanes and severe weather events.



NASA Global Hawk:

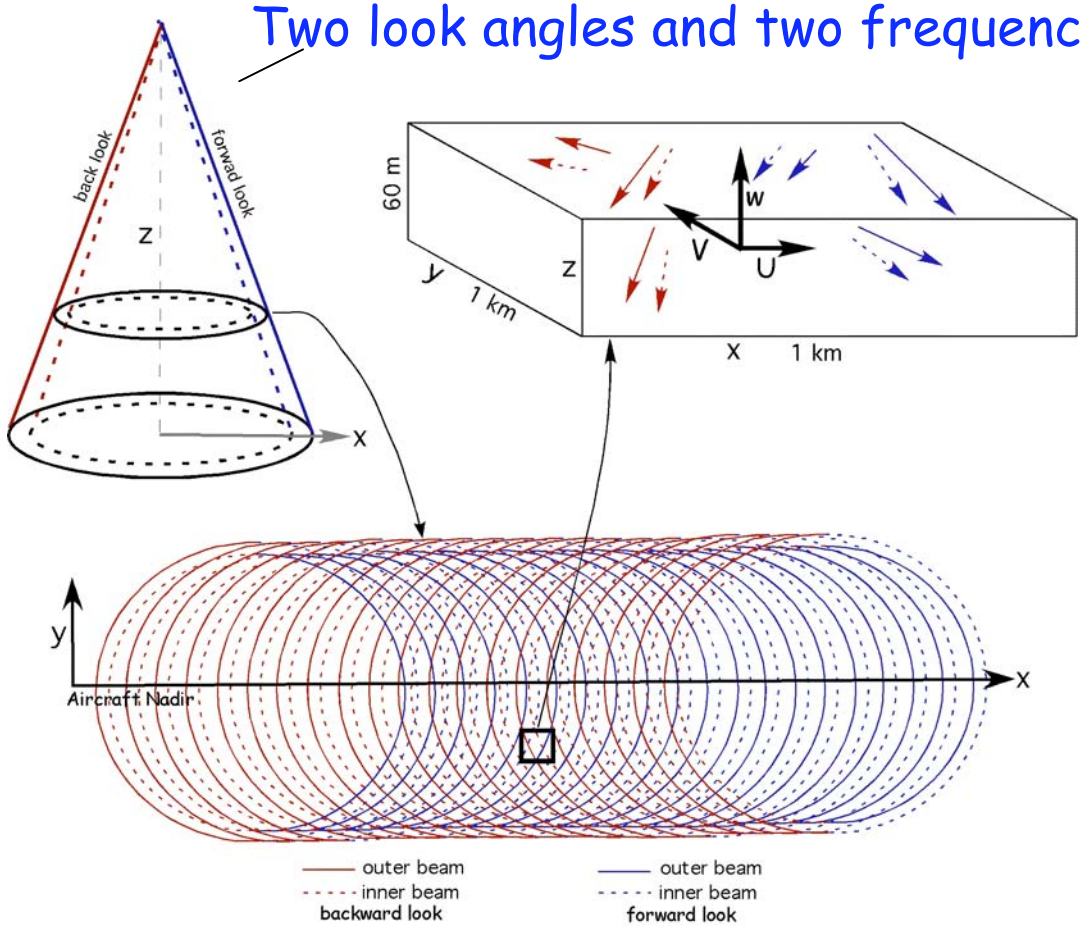
- 18 km altitude.
- > 24 hour missions.

HIWRAP Characteristics:

- Conically scanning.
- Simultaneous Ku/Ka-band & two beams @30 and 40 deg
- Precipitation & clouds as tracers.
- Ocean scatterometry.

HIWRAP Retrieval Method

Two look angles and two frequencies

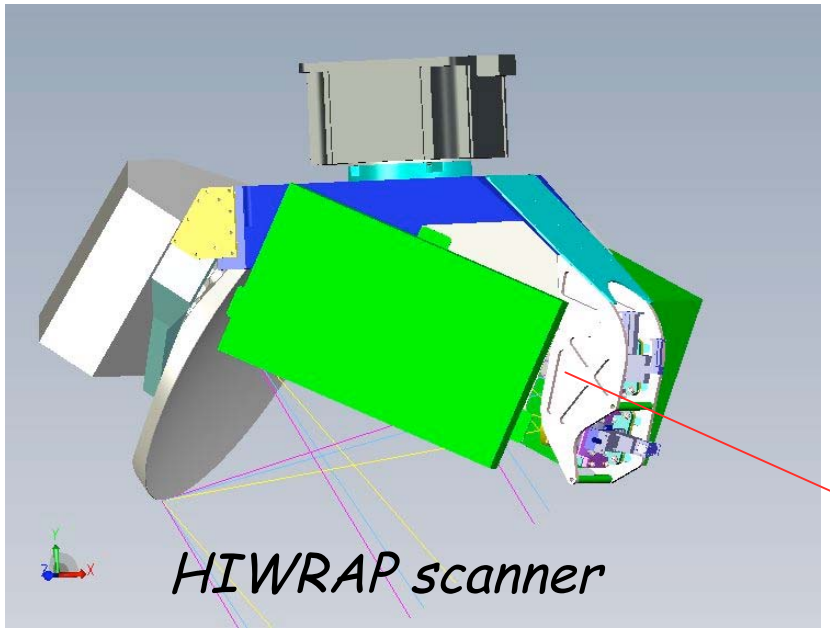


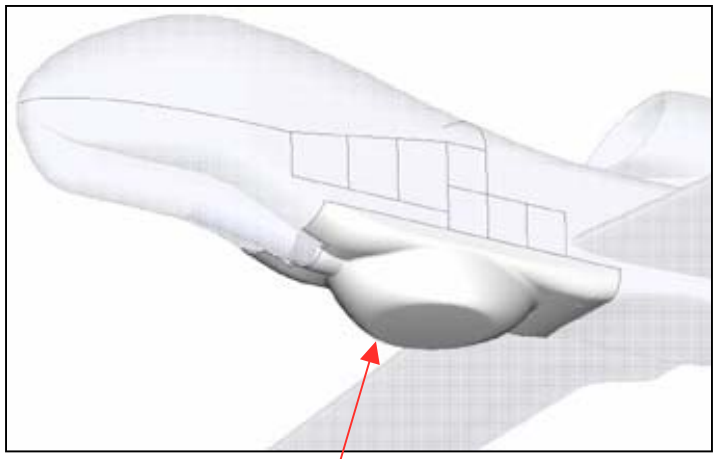
- Provides independent radial wind measurements at multiple azimuth angles and two incidence angles within grid volume. From which the wind vector can be calculated.
- Tradeoff study determined Ku and Ka-band and 30 and 40 deg are the best choice to maximize number of "good" retrievals.

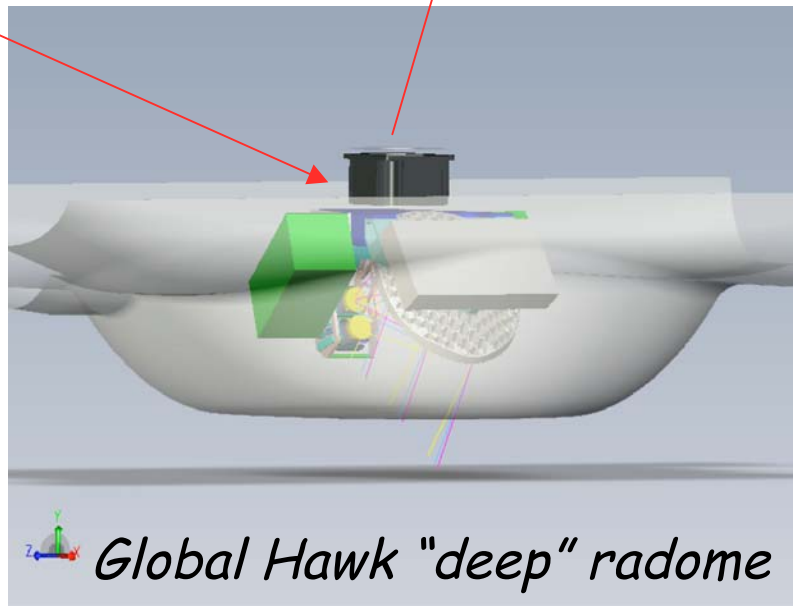
System Specifications

Parameters	Specifications	
	Ku-band	Ka-band
RF Frequency (GHz)	Inner Beam: 13.910 Outer Beam: 13.350	Inner Beam: 35.560 Outer Beam: 33.720
Peak Transmit Power (W)	30	10
3dB Beam Width (^{o})	2.9	1.2
Polarization	Vertical (inner beam), Horizontal (outer beam)	
Min. Detect. Reflectivity (dBZ_e, 60 m res. 10 km)	0.0	-5.0
Dynamic Range (dB)	> 65	
Doppler Velocity (ms^{-1})	0-150 (Uncertainty < 2 ms^{-1} for SNR>10)	
Scanning	Conical Scan, 10 rpm	

Design Goal: Global Hawk

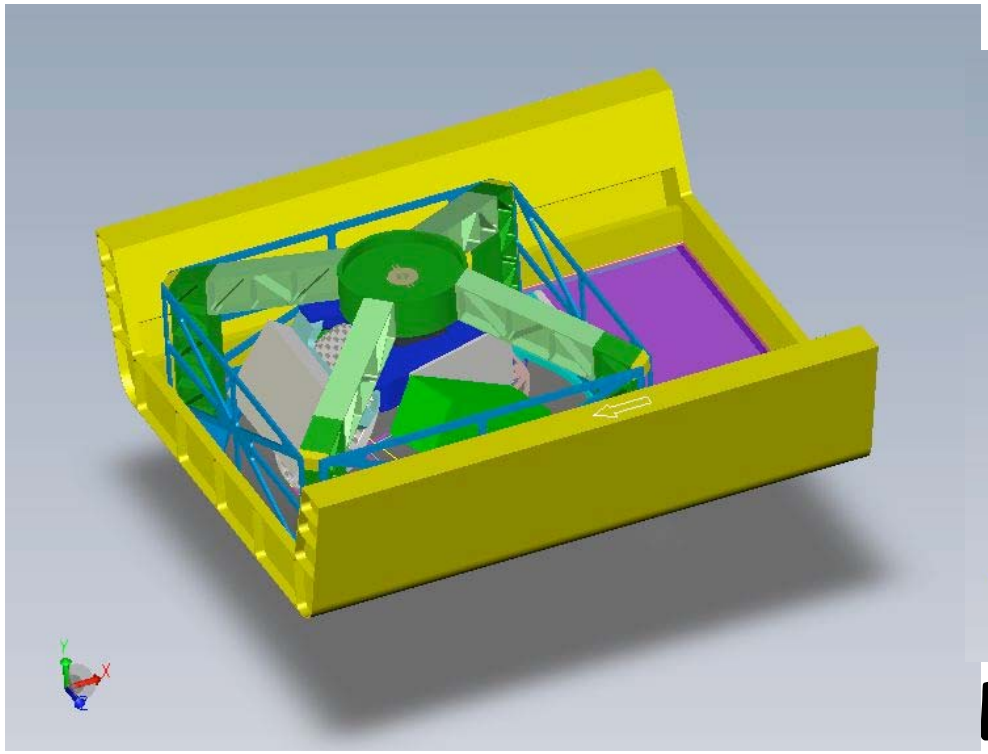




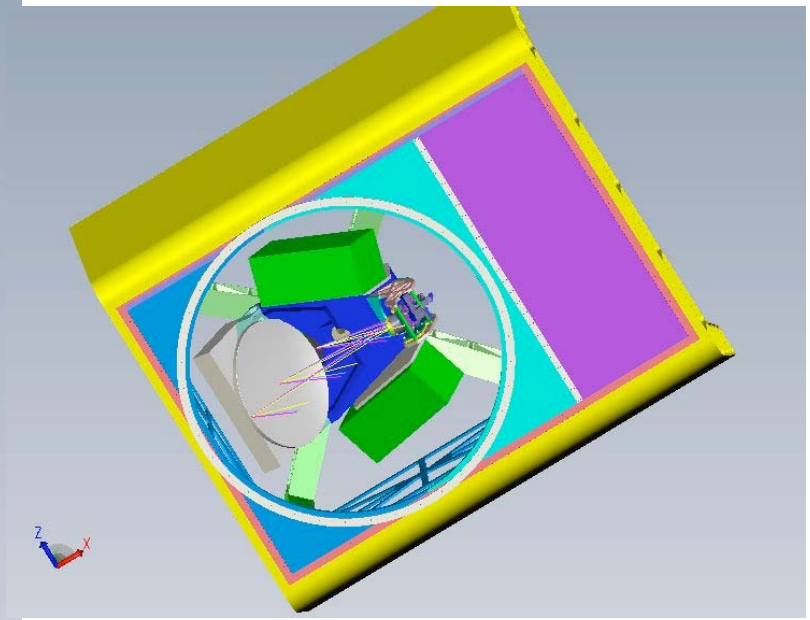


Global Hawk is being considered by NASA for hurricane science missions and by NOAA for routine monitoring.

Current Effort: WB57 Aircraft



Side view of pallet & instrument



Bottom view of pallet & radome

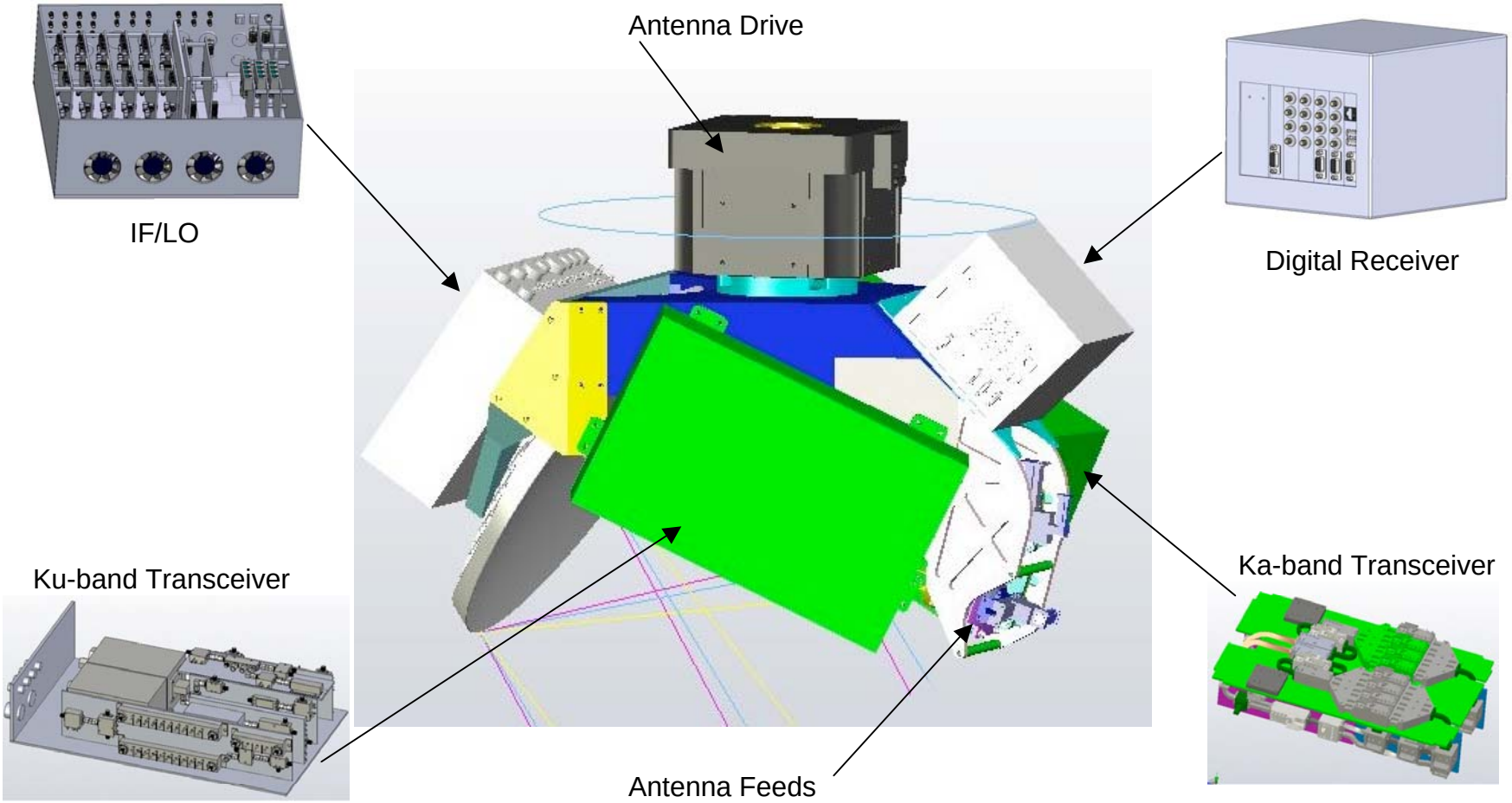
HIWRAP Development Challenges

- High Altitude UAS (Global Hawk) Platform
  - High altitude, unpressurized environment.
  - Limited space, weight and power.
  - Autonomous operations with limited communications.
- Antenna
  - Size and weight constraints require single aperture
  - Dual frequency, dual beam
- Transceiver
  - High sensitivity, solid-state design.
  - Support simultaneous, multiple beam transmit and receive.
  - Single aperture, no blind regions.
- Digital Receiver & Processor
  - Very high input data rate (> 1 Gb/s)
  - Pulse compression implementation.
  - Real-time Doppler processing for data reduction.
  - Network-based communications.

HIWRAP Subsystems

- Ka-Band Transceiver
- Ku-Band Transceiver
- LO/IF
- Digital Receiver/Processor
- Antenna Drive
- Data System
- IMU (navigation)

HIWRAP Scanner Assembly



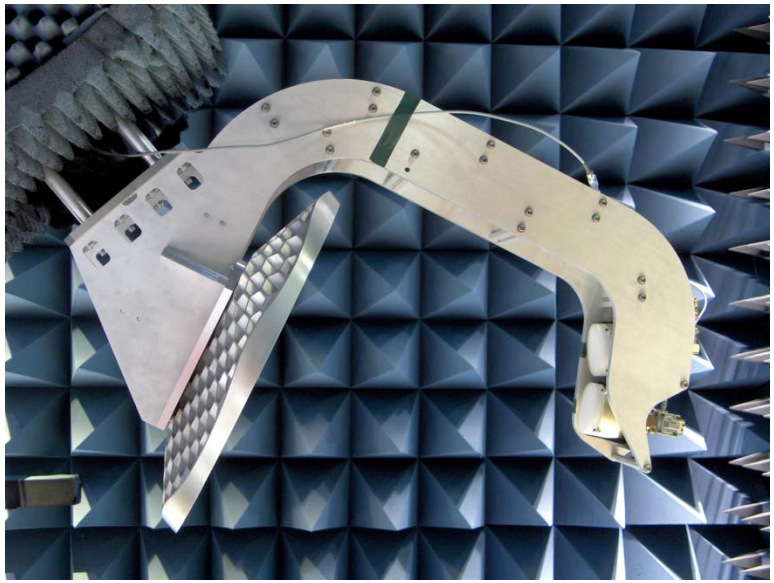
Antenna Development

- Single aperture
- Simultaneous operation at Ku and Ka-band & two beams.
- Limited available height.

Antenna Performance Goals	
Frequencies (GHz)	13.35, 13.91, 33.72, 35.56
Number of beams at each band	2
3 dB Beamwidth	< 3.25° (Ku) < 1.35° (Ka)
Relative Sidelobe level	<-22 dB
Incidence angle separation	10°
Incidence angles	30° and 40°
Beam/Polarization	Inner/Horizontal Outer/Vertical
Minimum Return Loss	18 dB
Minnimum bandwidth at each frequency	100 MHz

Antenna design and feed development by UMass/CASCA

Antenna Status



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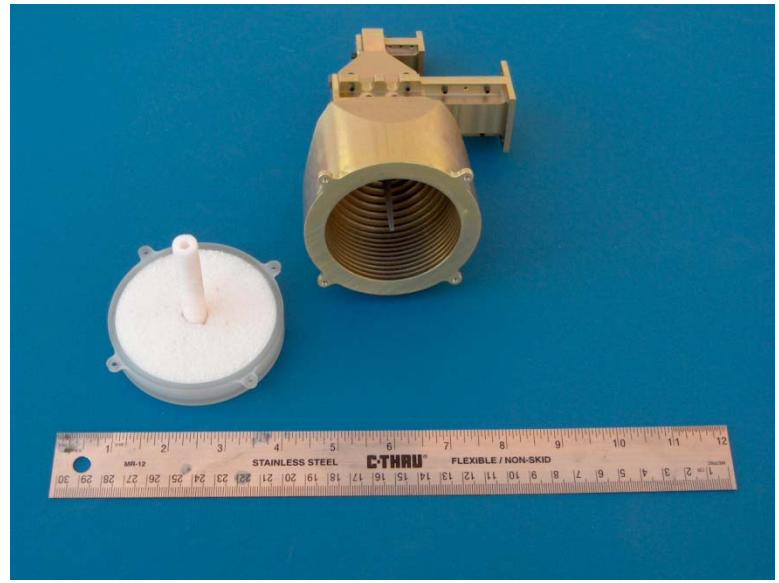

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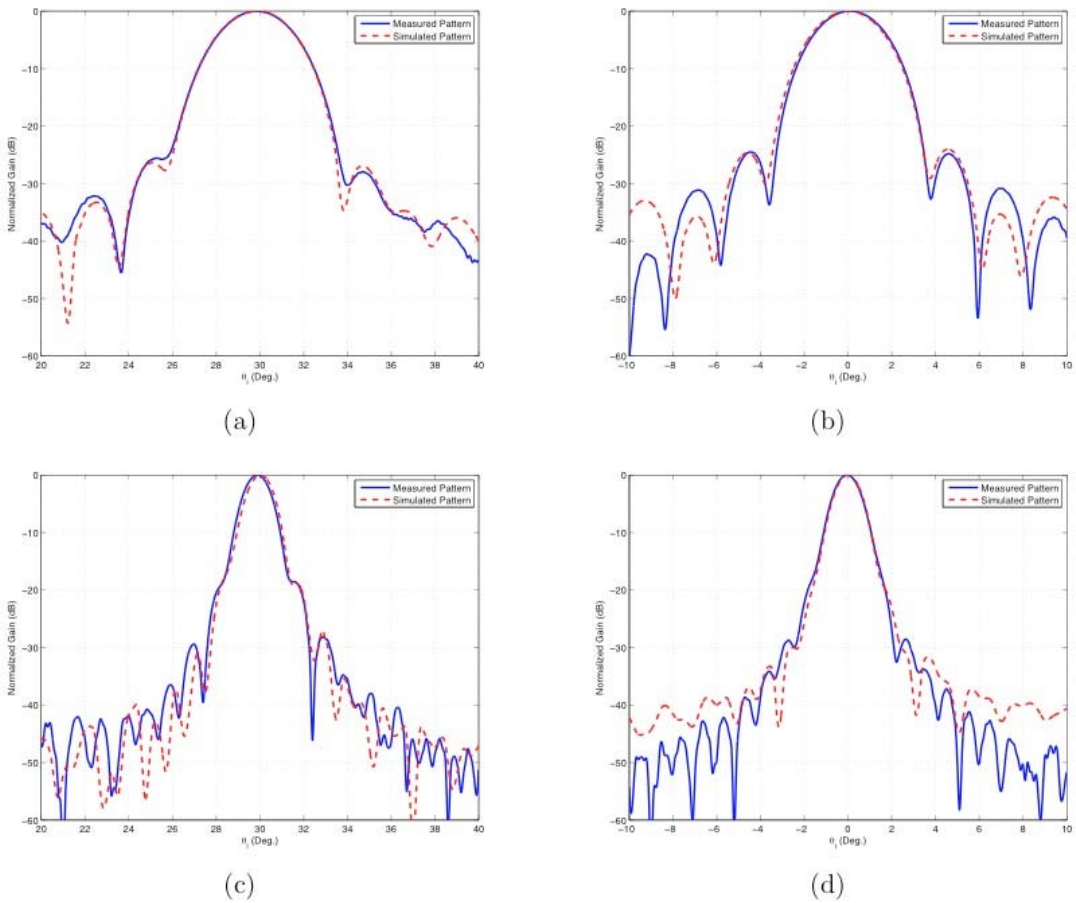

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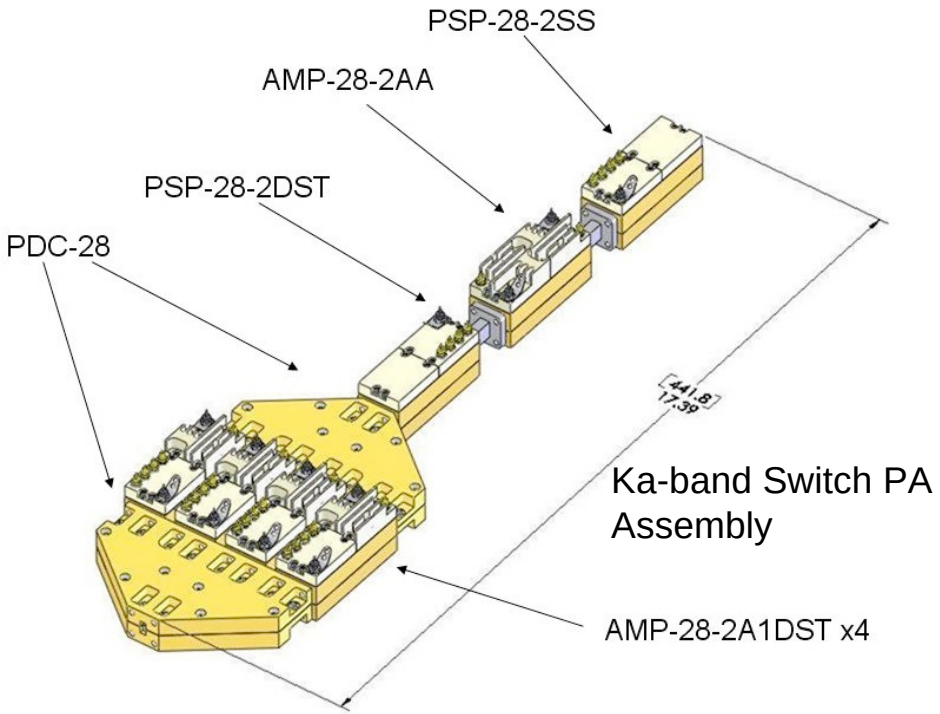

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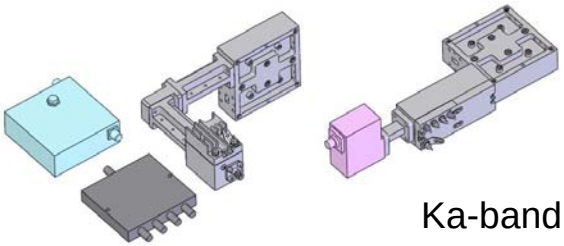

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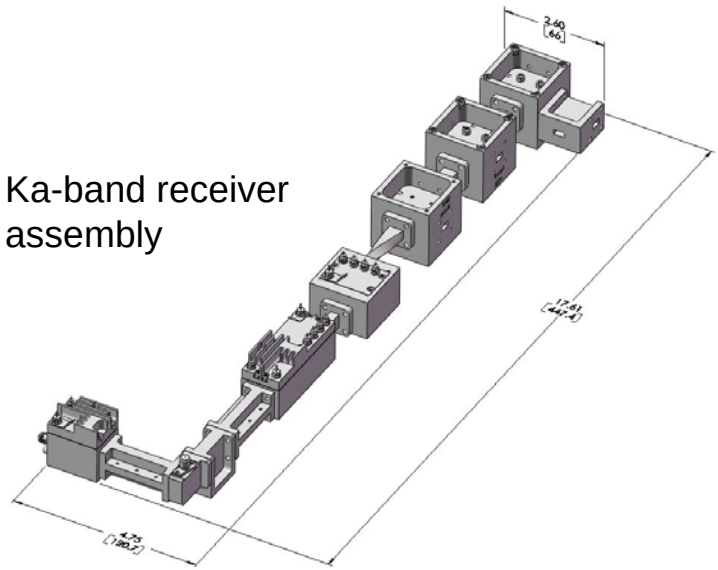
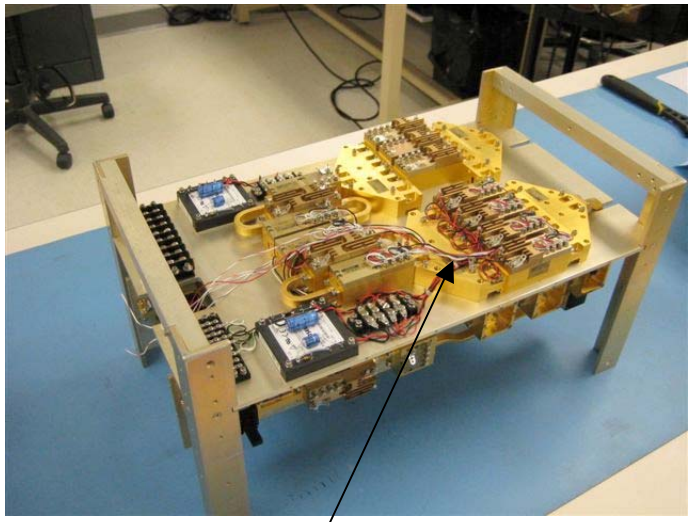


Ka-band receiver assembly

Ka-Band Test Assembly



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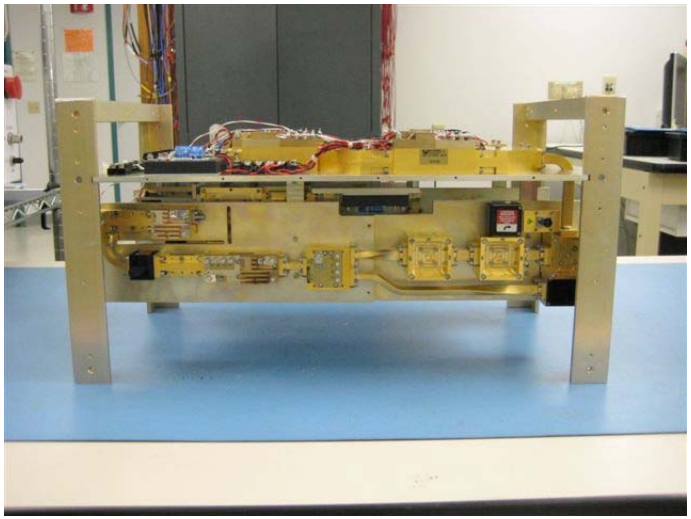

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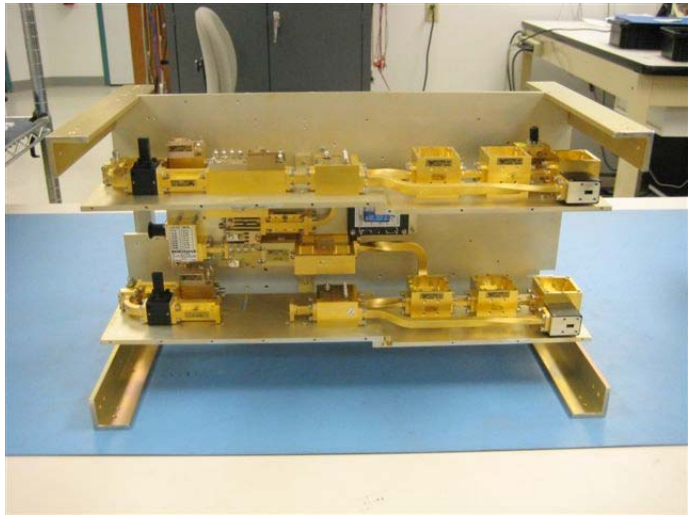

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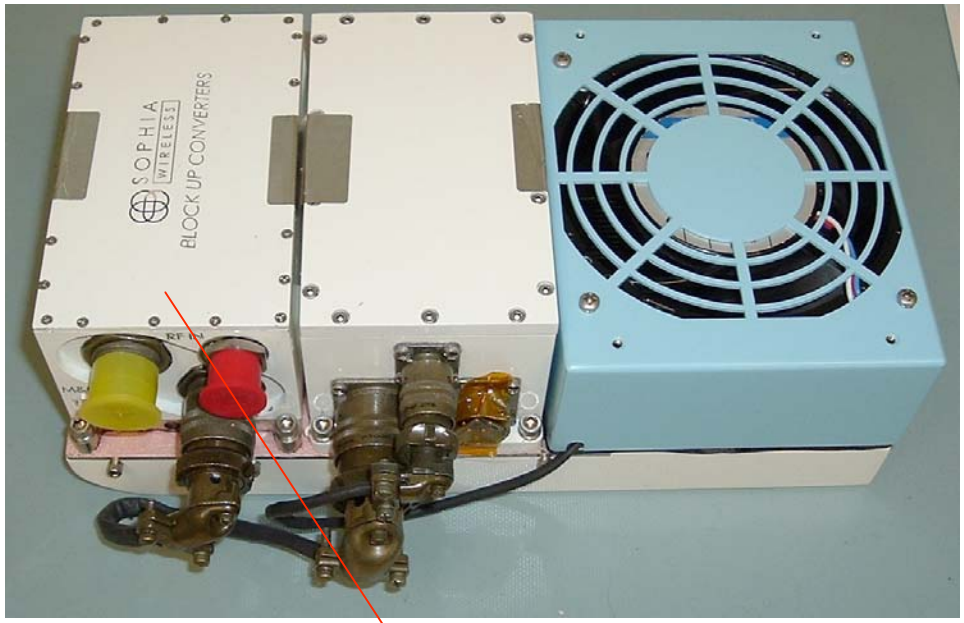

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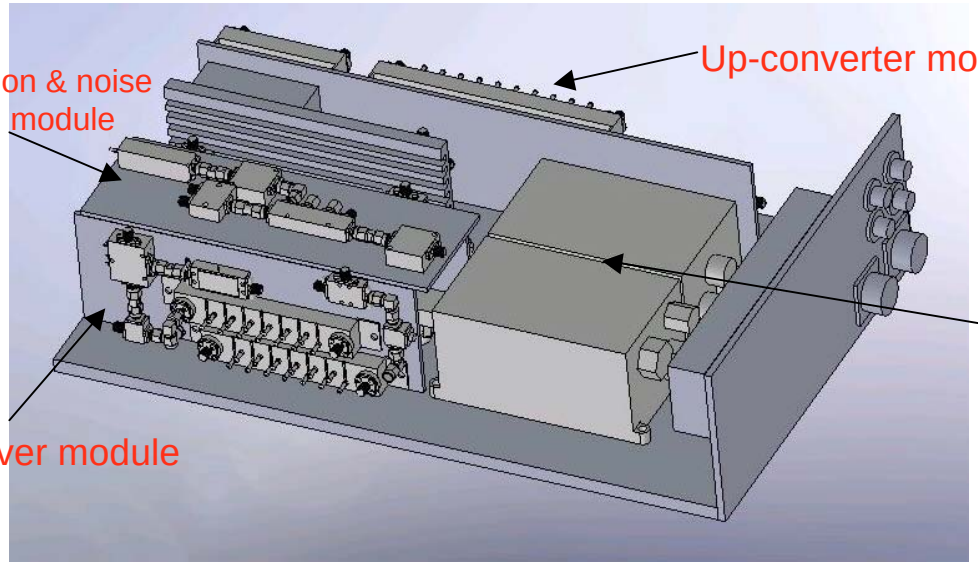
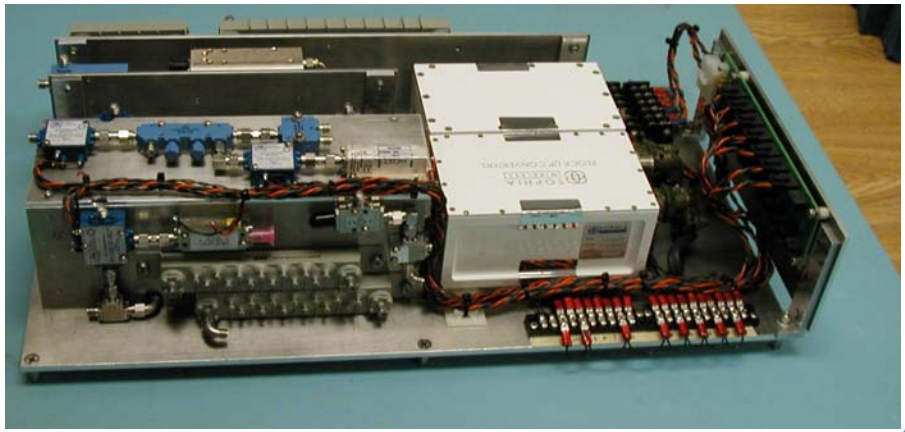


HIWRAP Ku-band transceiver assembly CAD layout

HIWRAP Ku-band transceiver test assembly



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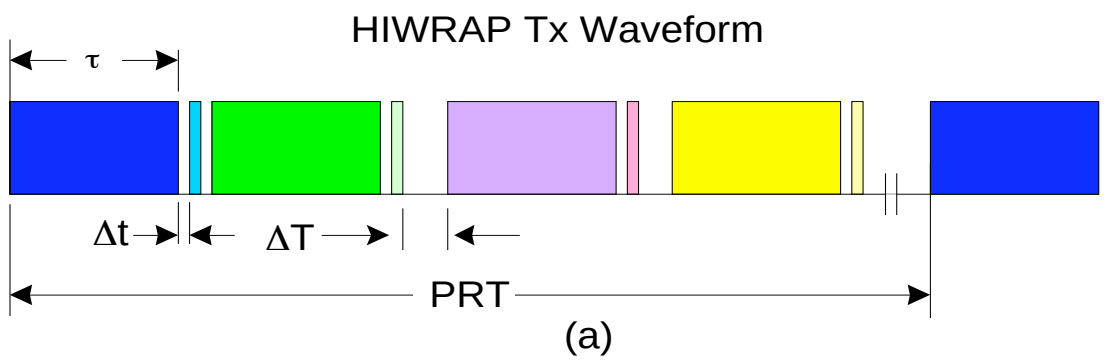

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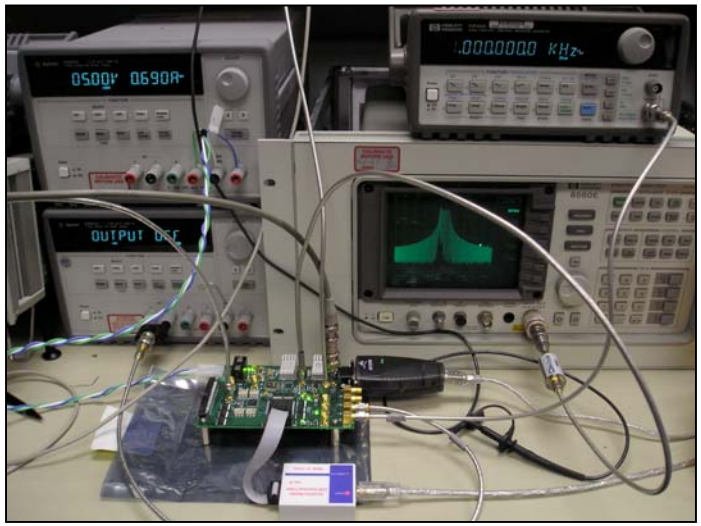
- Compact, custom board built to achieve high speed programming of DDS plus software controlled timing
- Consists of AD9959 DDS and Cyclone II FPGA with an RS232 interface

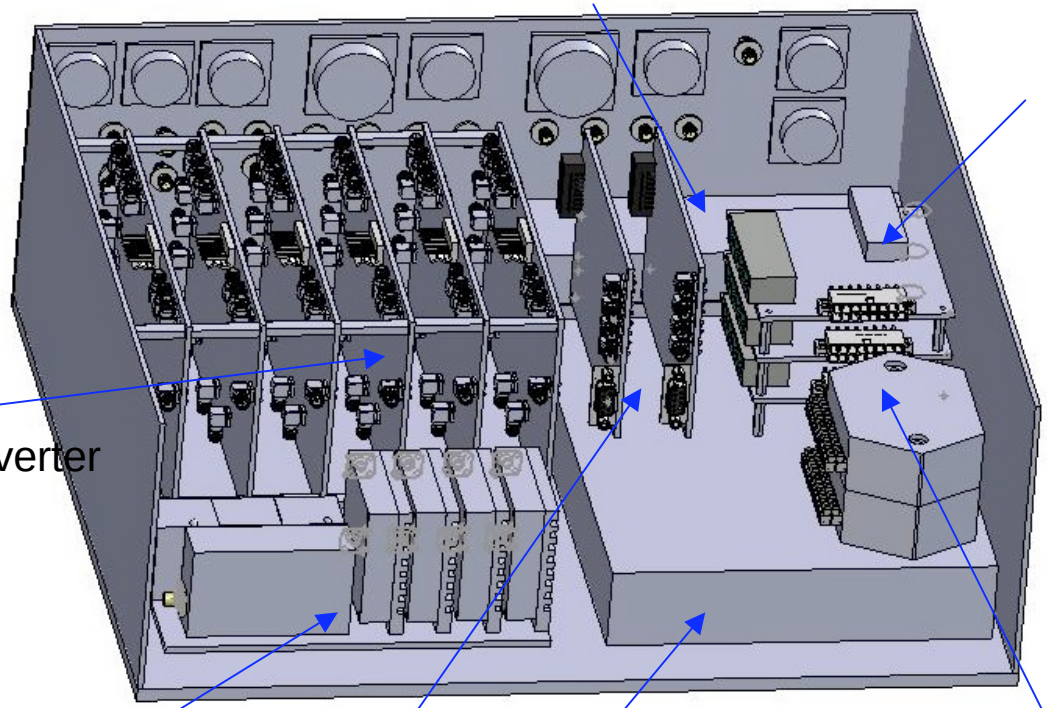


Direct Digital Synthesizer (DDS) and Timing Control

- Status
  - Board design and fabrication is complete
  - Electrical testing and debugging is 90% complete
  - Dual PRF, linear FM and frequency diversity waveform generation is 75% complete
  - Amplitude control algorithm is currently under development

HIWRAP IF/LO Enclosure

- IF boards in evaluation
- Enclosure in design



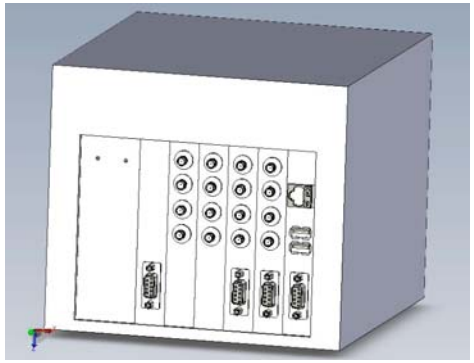
Digital Receiver & Processor
- Challenges

- **High Altitude Operations**
  - Environment (temperature & pressure).
  - Autonomous operation (little to no operator interaction).
  - Redundancy / high availability.
  - Embedded, standalone system.
- **Real-time Processing**
  - High input data rate – 8,960 Megabits/sec
  - Implement pulse compression (up to 30 dB & 16 independent sub channels).
  - Real-time Doppler processing for data reduction.
  - Network-based communications

Digital Receiver & Processor

Subsystems:

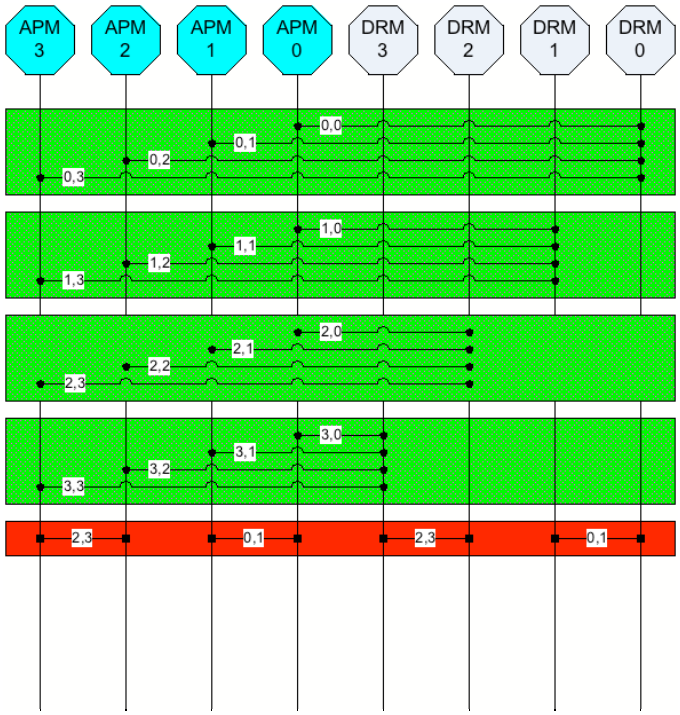
- **Digital Receiver Module (DRM)**
  - Based on Virtex-5 SX95T FPGA.
  - Implements Digital Receivers and Match Filters.
  - Same board can be reconfigured as an APM.
- **Algorithm Processing Module (APM)**
  - Based on Virtex-5 SX95T FPGA.
  - Implements Pulse-Pair processing.
- **Network Processing Module (NPM)**
  - Based on PowerQUICC II Processor
  - Serves as controller and communications processor.
- **Switch Fabric Board**
  - Provides communication between NPM and APMs / DRMs.



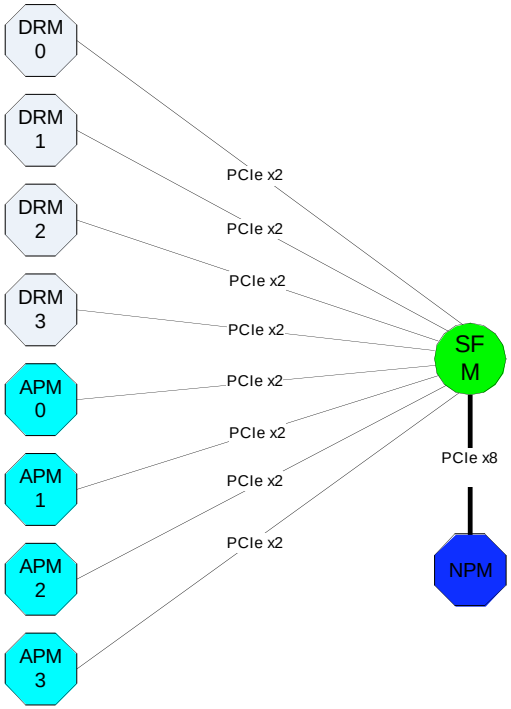
Card cage conforms to 3U CompactPCI form factor.

Processing & Communication Bus (i.e. custom backplane)

High Speed Dedicated Processing Bus



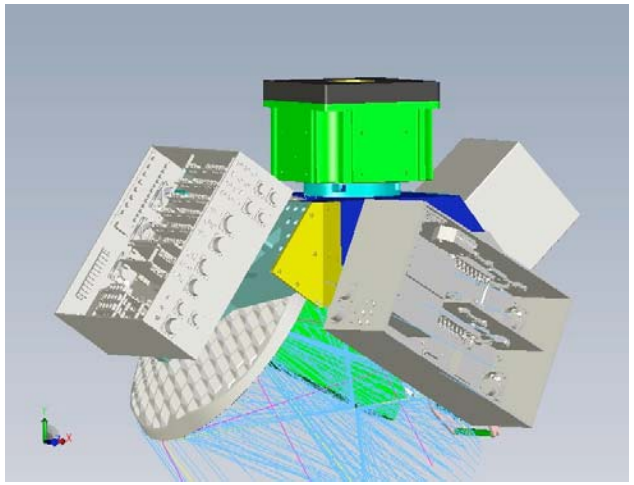
Communication Serial I/O (PCIe) Bus

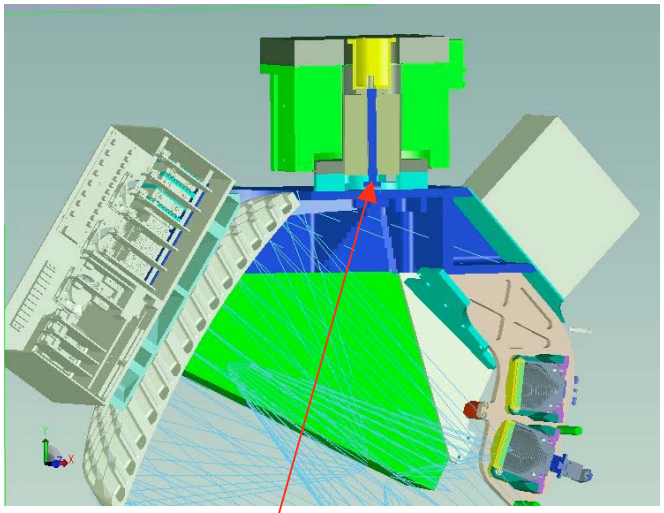


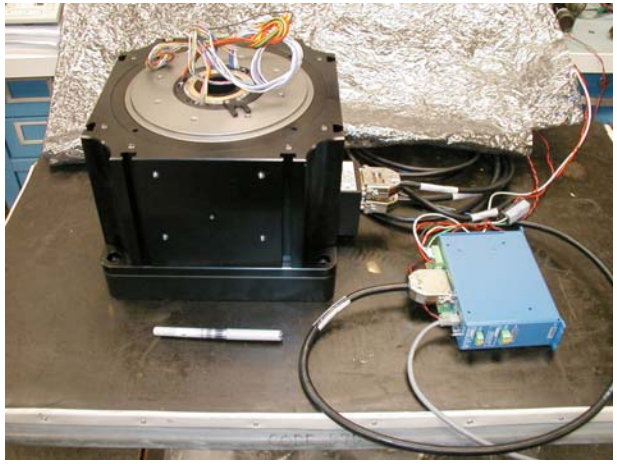
Digital Subsystem Status

- Adhoc system that can support a single IF channel is operating now.
- Signal integrity analysis and layout of backplane underway.
- Targeted completion of baseline digital/IF subsystem August 2008.
- Flight board completion October 2008

Scanner Assembly







Fiberoptic rotary joint, slip ring, scanner, assembly

Summary

- Test flights are planned for HIWRAP in January 2009 after instrument completion.
- Many technical challenges will have been met that are related to solid state transmitter/pulse compression approach, operating conditions, and size/weight constraints.
- New capability provided by HIWRAP will enhance hurricane research and routine hurricane monitoring.
- Future challenges: real time data processing and downlink of products.

BACKUP SLIDES