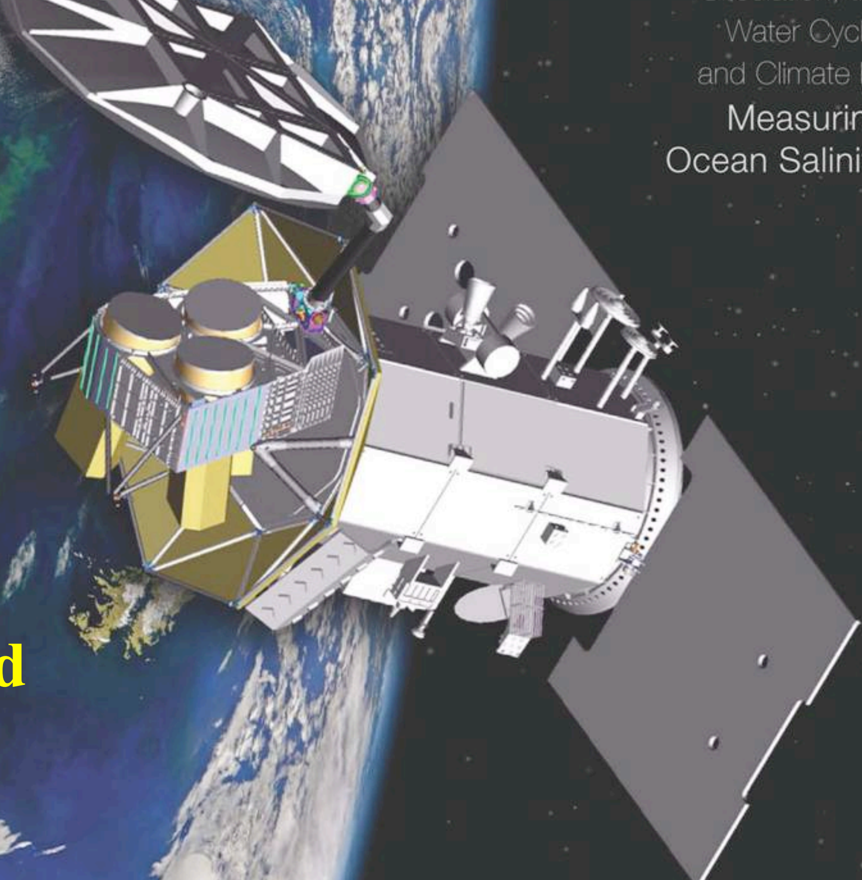
National Aeronautics and Space Administration

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

The Aquarius Mission Calibration/Validation Overview

Adam Freedman
Dalia McWatters
Aquarius Instrument Team



Understanding the Interaction Between Ocean Circulation, the Water Cycle, and Climate by Measuring Ocean Salinity

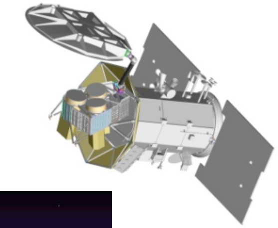
Aquarius/SAC-D

CEOS SAR Calibration and Validation Workshop 2009
17 - 19 November, 2009
Pasadena, California

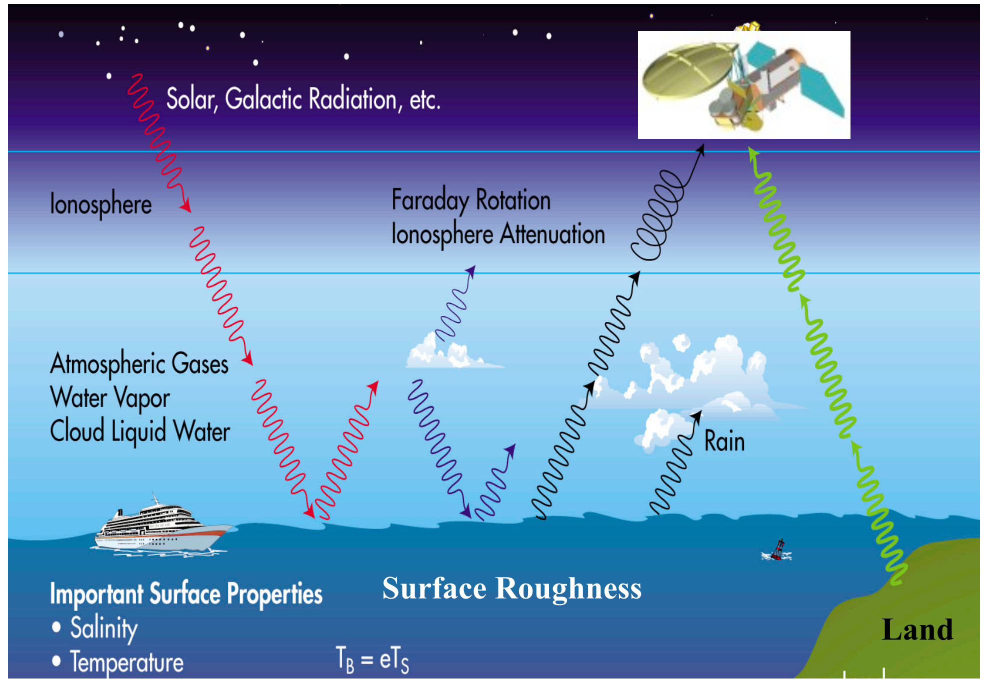
 © 2009 California Institute of Technology. Government sponsorship acknowledged.

CONAE • GSFC • JPL

Mission Introduction



- Aquarius retrieves sea-surface salinity (SSS) by measuring sea surface brightness temperature by using a very stable radiometer in L-band.
- The biggest error to this measurement is due to the sea surface roughness.
- A co-pointing scatterometer is used to accurately measure the sea surface roughness (to be removed by ground processing)
- The spacecraft (Service Platform, S/P) is built by CONAE (Argentina)
- Aquarius is the prime instrument on SAC-D, a joint NASA/CONAE mission
- The radiometer is built by GSFC
- Remainder of instrument is built/managed by JPL
- Launch planned for End of 2010



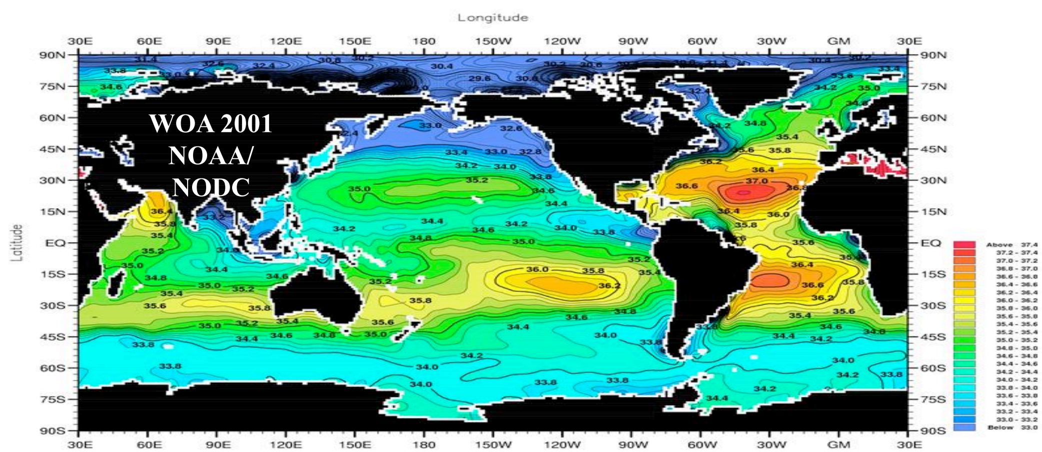
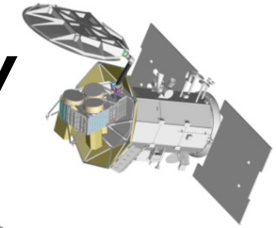
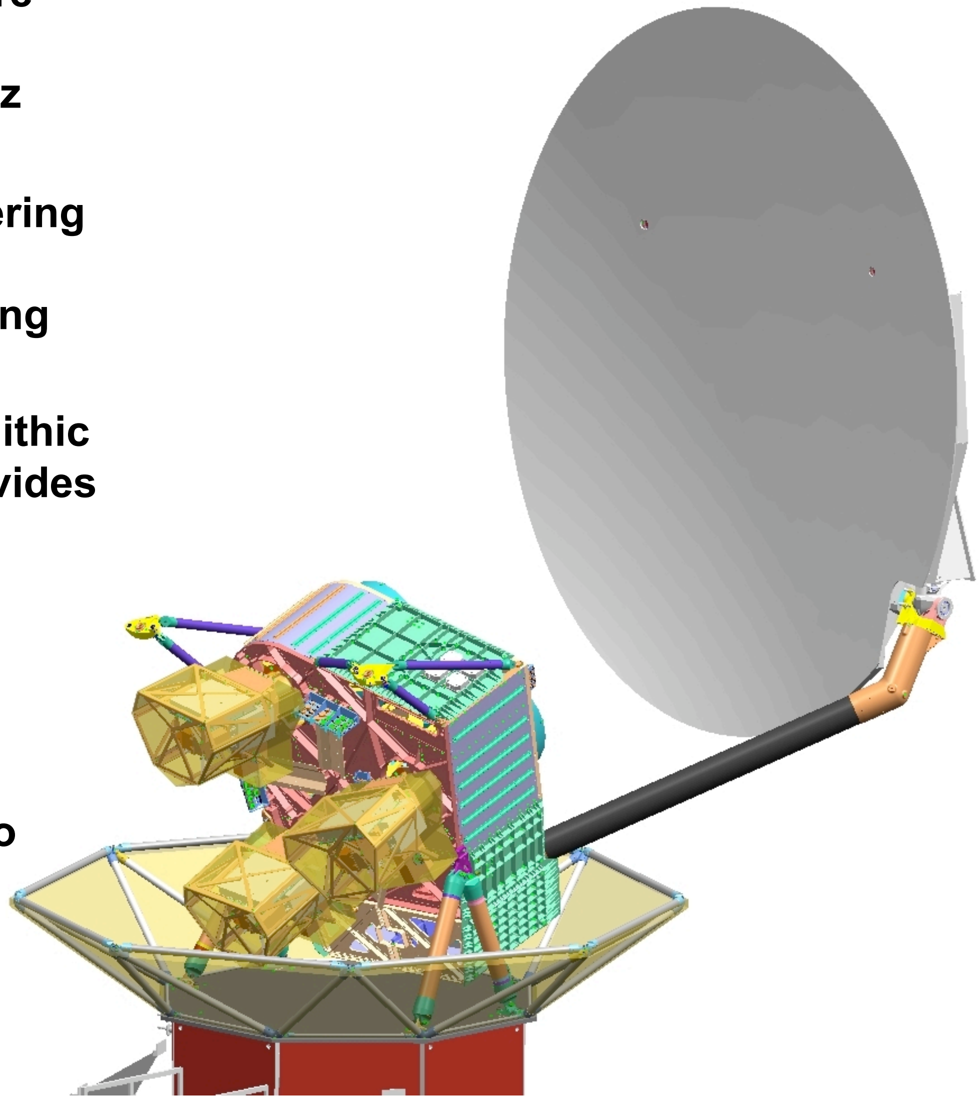


Fig. A2-1. Annual mean salinity (PSS) at the surface.

Aquarius Instrument Overview

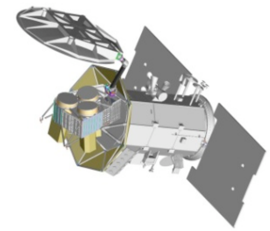


- **Sea surface brightness temperature measured by stable polarimetric radiometers operating at 1.413 GHz (first three Stokes parameters).**
- **Coincident sea surface backscattering cross-section measured by stable polarimetric scatterometer operating at 1.26 GHz (HH, VV, HV, VH).**
- **Deployable offset parabolic monolithic reflector with three feedhorns provides three beams in a push-broom configuration.**
- **Technical resource allocations:**
  - Mass: 375 kg
  - Power: 375 W
- **Aquarius science requirement is to provide a systematic global Sea Surface Salinity map**
  - 150 km Spatial Resolution
  - 0.2 psu Monthly Accuracy
  - Three Year Baseline Mission

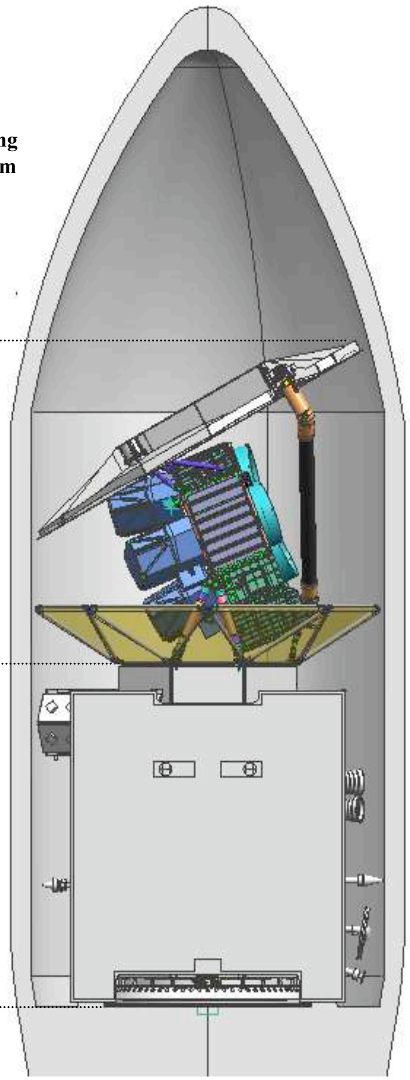


AQUARIUS/SAC-D

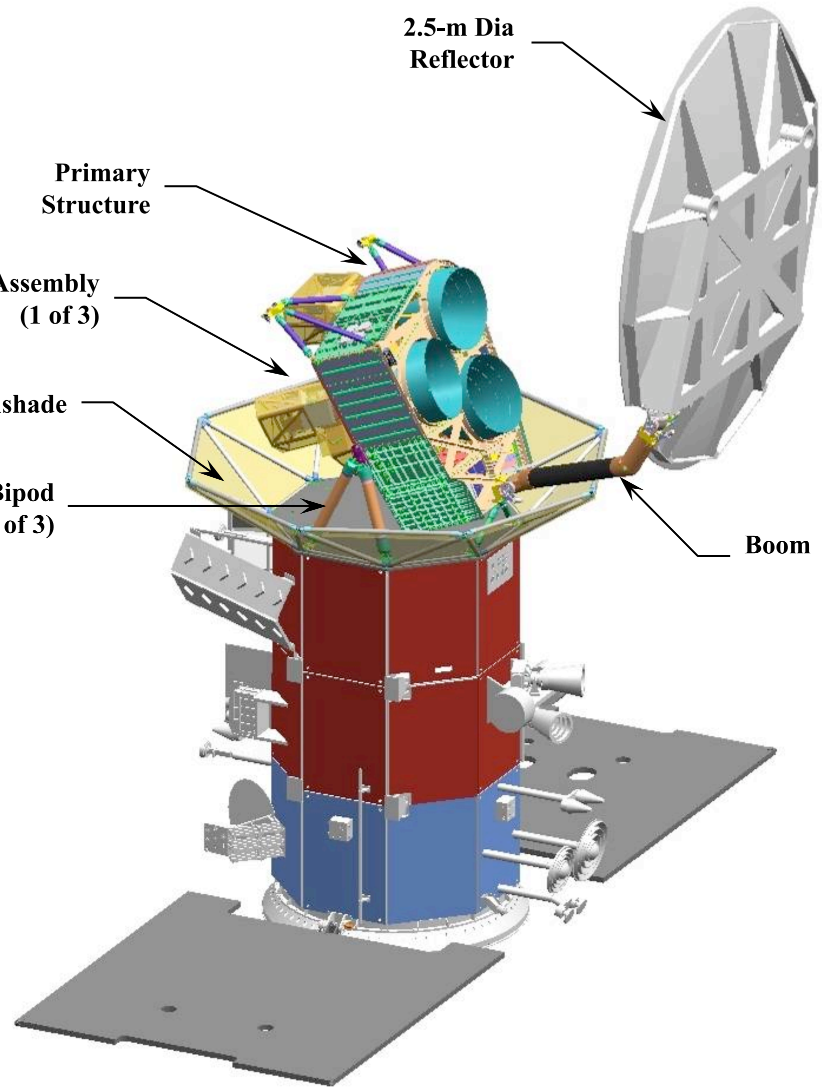
Observatory Configuration



Stowed Configuration

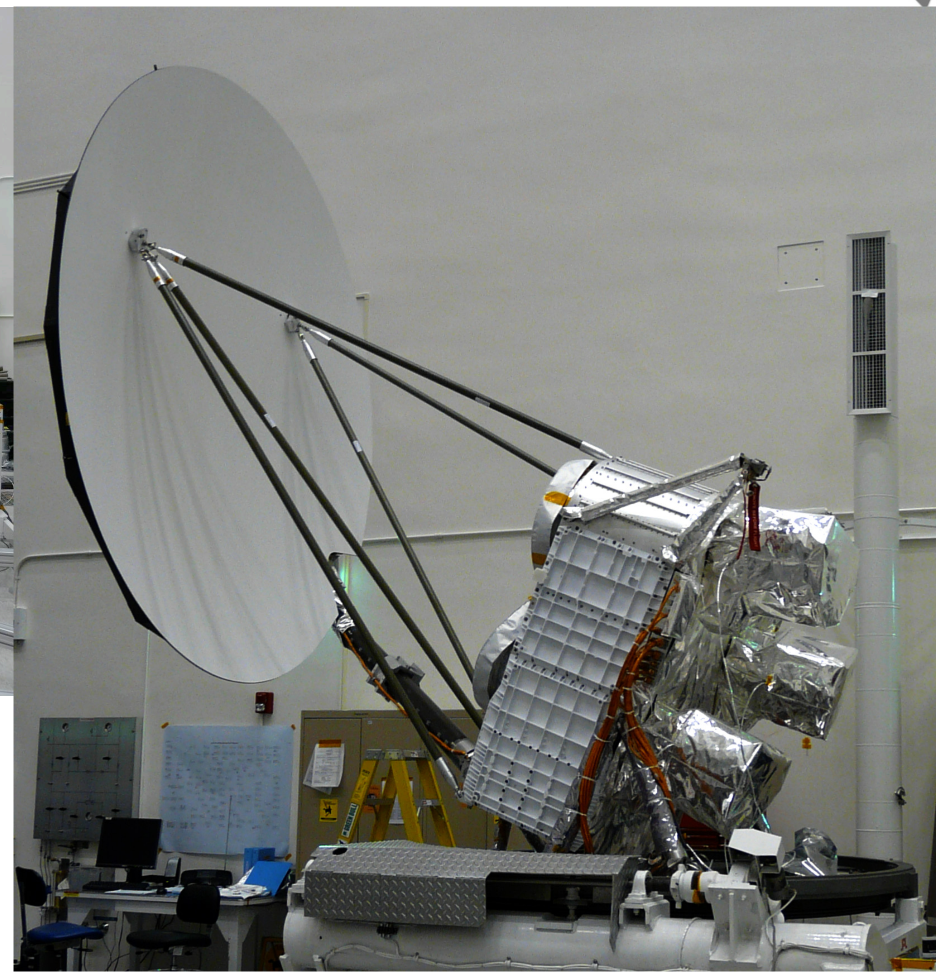


Deployed Configuration



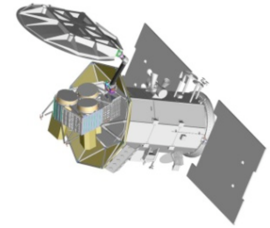
The Aquarius Instrument

Aquarius instrument in deployed state at JPL. Reflector suspended by Gravity Off-Load Fixture (GOLF)



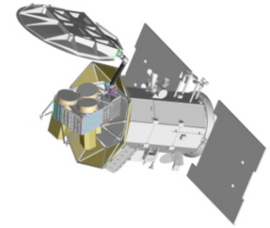
Aquarius instrument in deployed state at JPL. Fiber glass support struts hold the reflector when deployed in gravity environment.

Aquarius Radar is Not a SAR



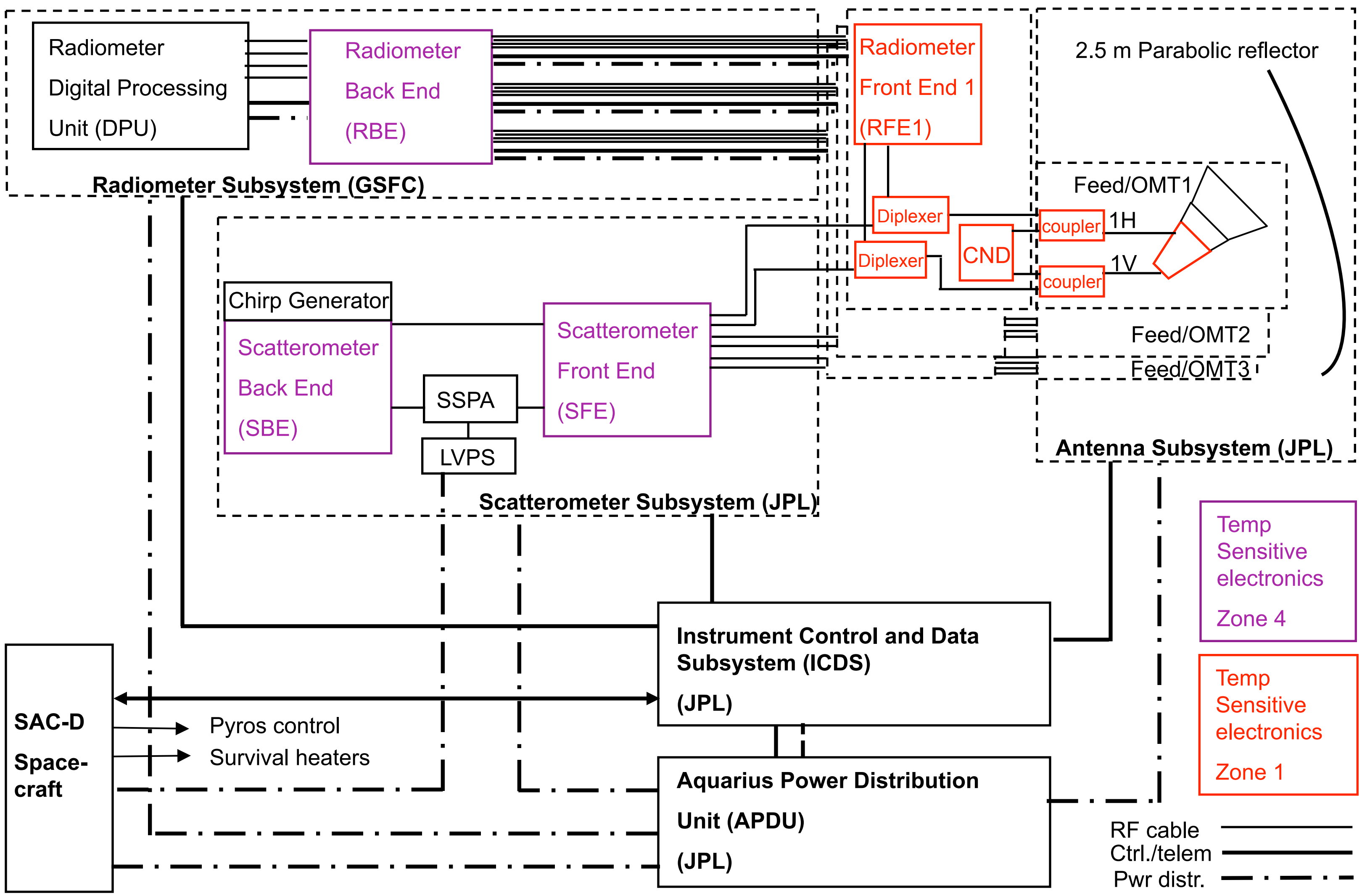
- **Aquarius scatterometer radar is not a SAR!**
- **Aquarius scatterometer is a simple, "bit-bucket", receiver**
- **No ranging or phase requirements, just precise measurement of received power**
  - No range compression, caltone, Doppler processing
- **Only real aperture needed (low spatial resolution for ocean)**
- **No adaptive gain, time-dependent range, or adjustable PRF**
  - Two calibrated attenuation settings for echo, two for loopback, 4 dB offset, changed by ground command
  - Receive window delays and widths adjustable by ground command
- **Low PRF of 100 Hz, Long Tx pulse of 1 millisecond (due to radiometer measurement requirements), 4 MHz Tx chirp**
  - No range or azimuth ambiguities
- **Both radar and radiometer: primary calibration is for relative stability in the measured polarimetric power**
  - Tight EMI requirements, high RFI sensitivity

Key Design Challenges

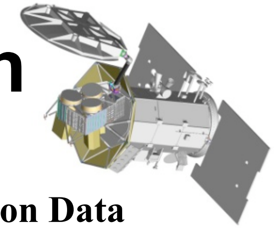


- **Very challenging science stability requirements:**
  - Radiometer stability requirement: 0.13 kelvin over 7 days, orbits
  - Scatterometer stability requirement: 0.1 dB over 7 days, orbits
- **Resulting in very challenging thermal stability requirements:**
  - 0.1 deg.C rms for front end RF electronics
  - 0.4 deg.C rms for back end RF electronics
  - Additional thermal requirements over seasonal periods
- **Driving the design into the following features:**
  - Need for Active Thermal Control in sensitive components zones
  - High thermal isolation between sensitive components and zones
  - Internal calibration sources for the Radiometer
  - Loop-back calibration for the Scatterometer
  - Many thermal sensors are distributed inside the sensitive electronics and on the structure in order to enable loss vs temp. corrections.
  - Built in scatterometer test mode for stability requirement verification
- **Ground calibration challenges**
  - Resolve absolute biases, and drifts over 7 days, seasonal fluctuations

Instrument Block Diagram



Pre-Launch Calibration Approach



Subsystem Level Calibration

Component ←→ Higher Assembly

Radiometer Subsystem

- CND Phase Balance
- T/V Calibration Test:
  - Loss vs. temp
  - Cal source output vs. temp
  - Linearity coefficients
- 2-port S-parameters

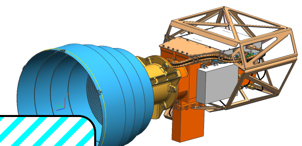
Antenna Subsystem

- Coupler:
  - Loss vs. temp
  - S-parameters
- Feed/OMT Loss and Loss vs. Temp Analysis
- OMT with coupler test:
  - Loss vs. temp (verif)
  - Phase stability vs. temp
  - Cross-pol stability
- Feed/OMT S-Parameters
- Reflector Coupon Loss vs. temp
- Antenna Scale model test
- Antenna range verification test

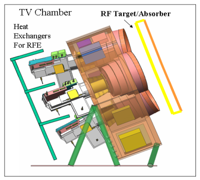
Scatterometer Subsystem

- Scatterometer component level test (loss vs. temp)
- Scatterometer TVAC FODLstability test

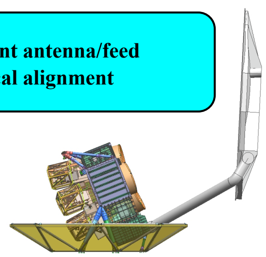
System Level Calibration



- R3 Ambient "Through he feed" Measurement.
- R5 T/V system level radiometric calibration verification



- Instrument antenna/feed mechanical alignment



- TVAC FODL Scatterometer stability test

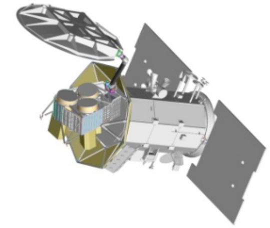
Calibration Data Package

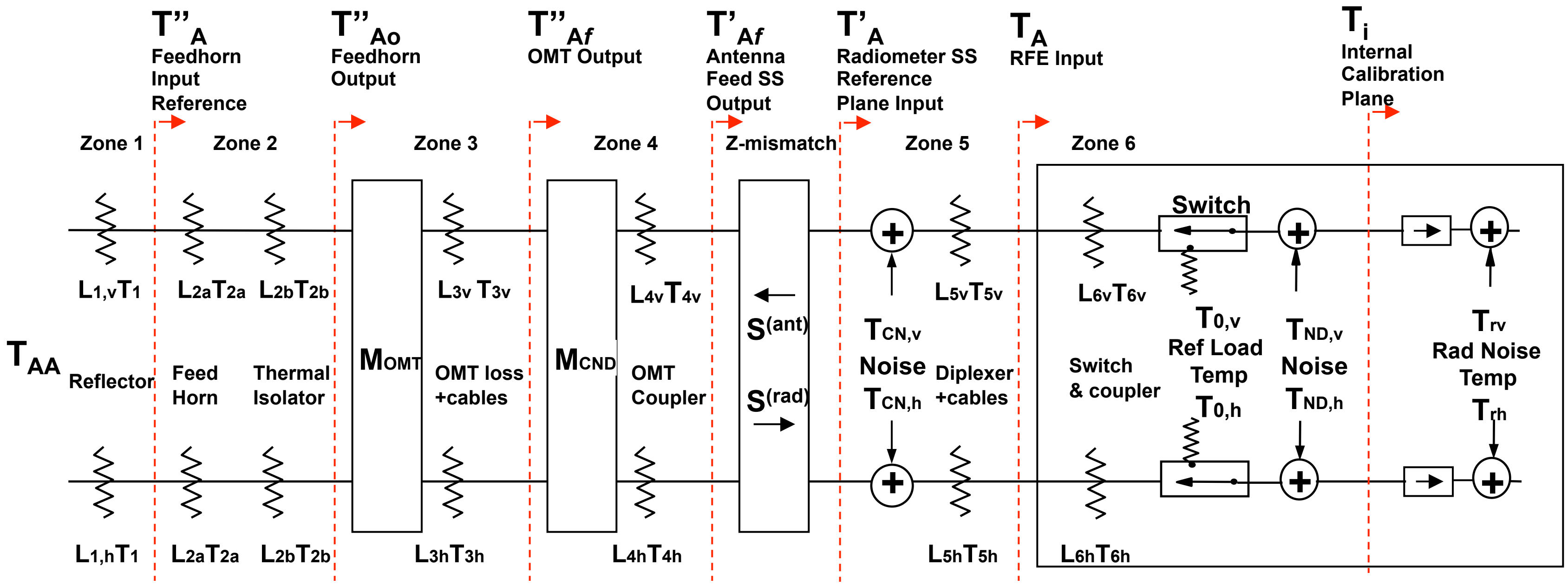
- Antenna temperature calibration model and coefficients
- Polarimetric calibration model and coefficients
- Mechanical alignment angles
- Antenna Pattern calibration
- Scatterometer calibration values and coeffcients

(Solid box = calibration test. Striped box = Calibration validation test.)

AQUARIUS/SAC-D

Radiometer calibration model

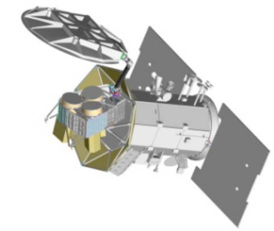




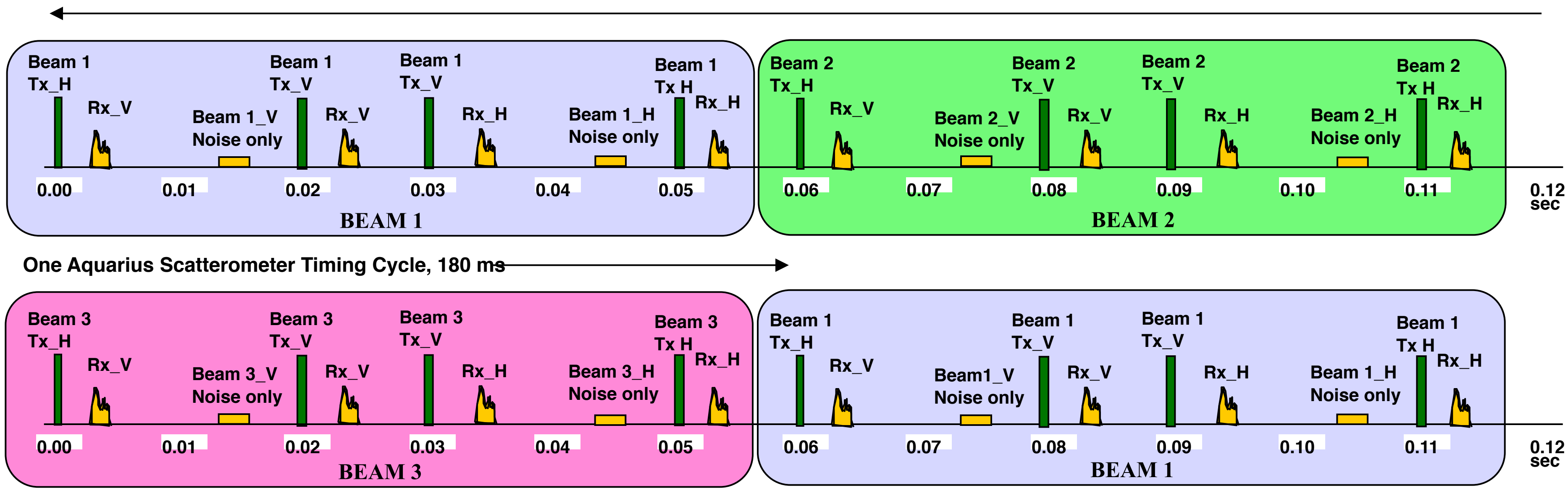
$L_{\#,v,h}$	Losses for zone # and polarization v or h Loss for each thermal zone. Temperature dependent.
$T_{\#}$	Physical temperature for zone # Match available housekeeping telemetry
T_x	Radiometric antenna temperature Stokes vector
M	Mueller matrix
S	Two-port S-Parameter matrix

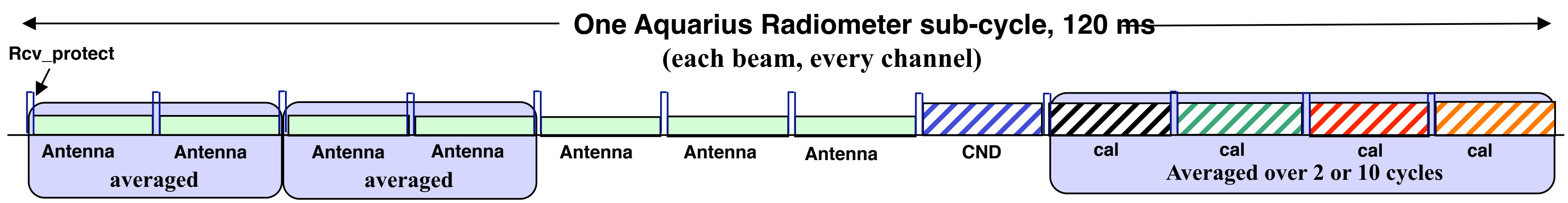
AQUARIUS/SAC-D

Instrument Timing



Aquarius Instrument Master Timing





cal = Dicke load and/or internal noise diode, or zero-offset

One Aquarius science data block is 1.44 sec long and contains:

8 scatterometer cycles

12 radiometer sub-cycles

When scat is in single beam mode, the sequence is preserved; the same beam is used in all 18 PRIs.

The CND noise diode is synchronous with a V-pol noise-only scat measurement, cycling through each beam.

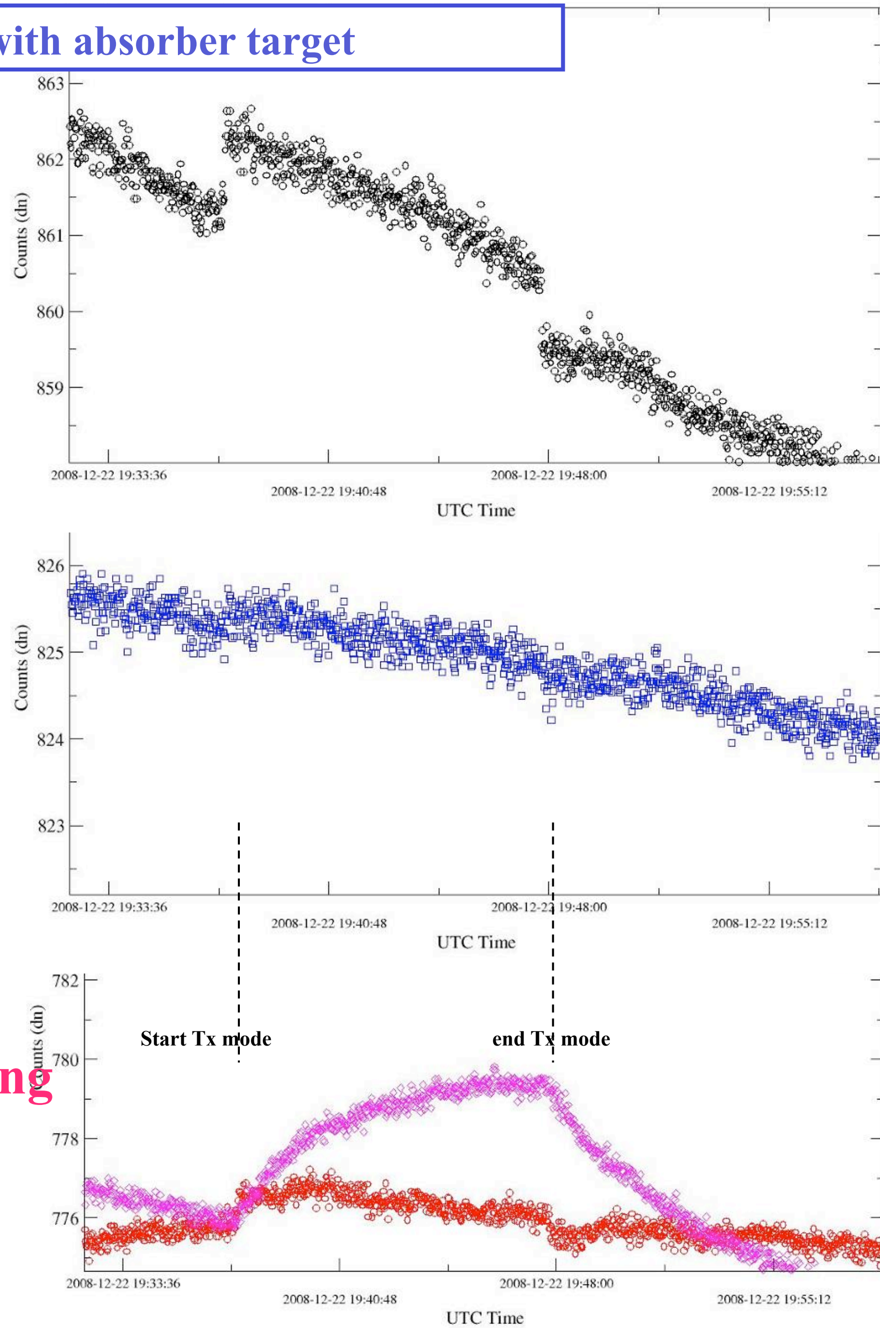
Radiometer offset when scat Tx with absorber target

Radiometer 1V →

Radiometer 2H →

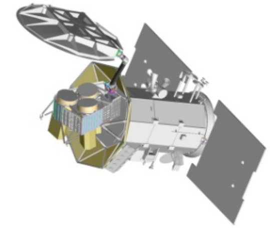
Radiometer 3V showing target heating (only beam3 is transmitting) →

Radiometer 1H (shows offset) →

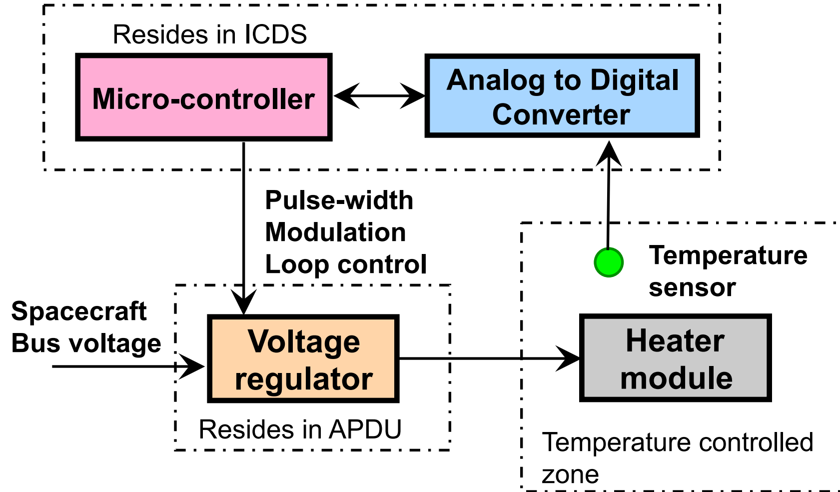


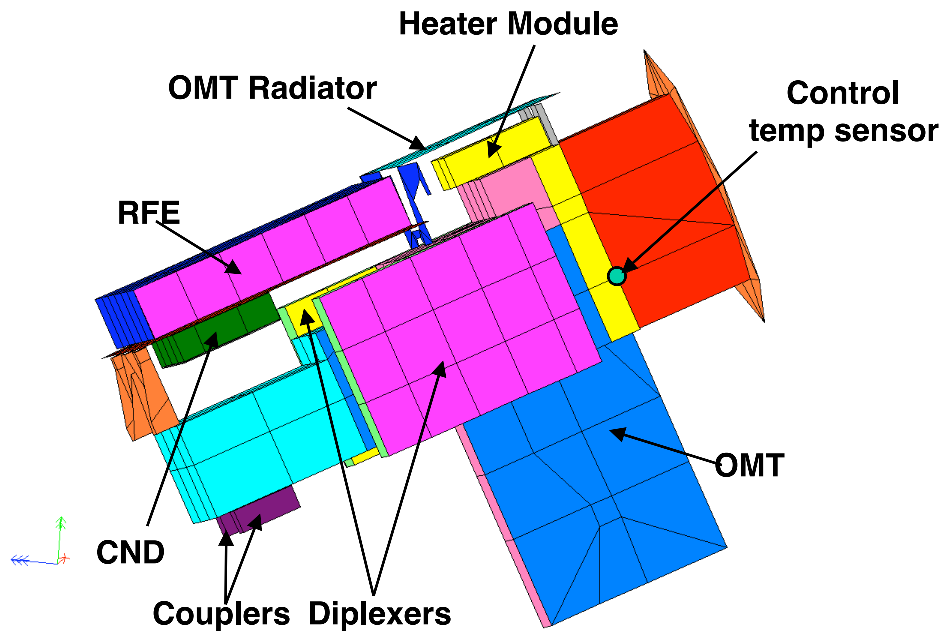
(12/22/08) offset (R4 target) with no absorber filling the gaps

Active Thermal Control

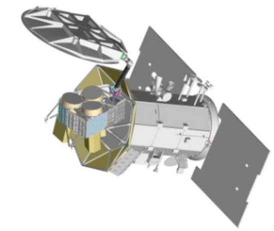


- **Thermal stability is key to instrument stability**
- **Active thermal control architecture is distributed in order to optimize instrument mass and power resources:**
  - Proportional Integral micro-controller housed with digital electronics. Closes a software algorithm loop to match sensor temperature to commanded setpoint.
  - Analog voltage regulator control loop compensates for bus voltage variations, to increase power efficiency
  - Analog heater modules located near the sensitive electronics
  - Each of the 4 thermal control zones circuits are independent and have redundant ADCs and control sensors.



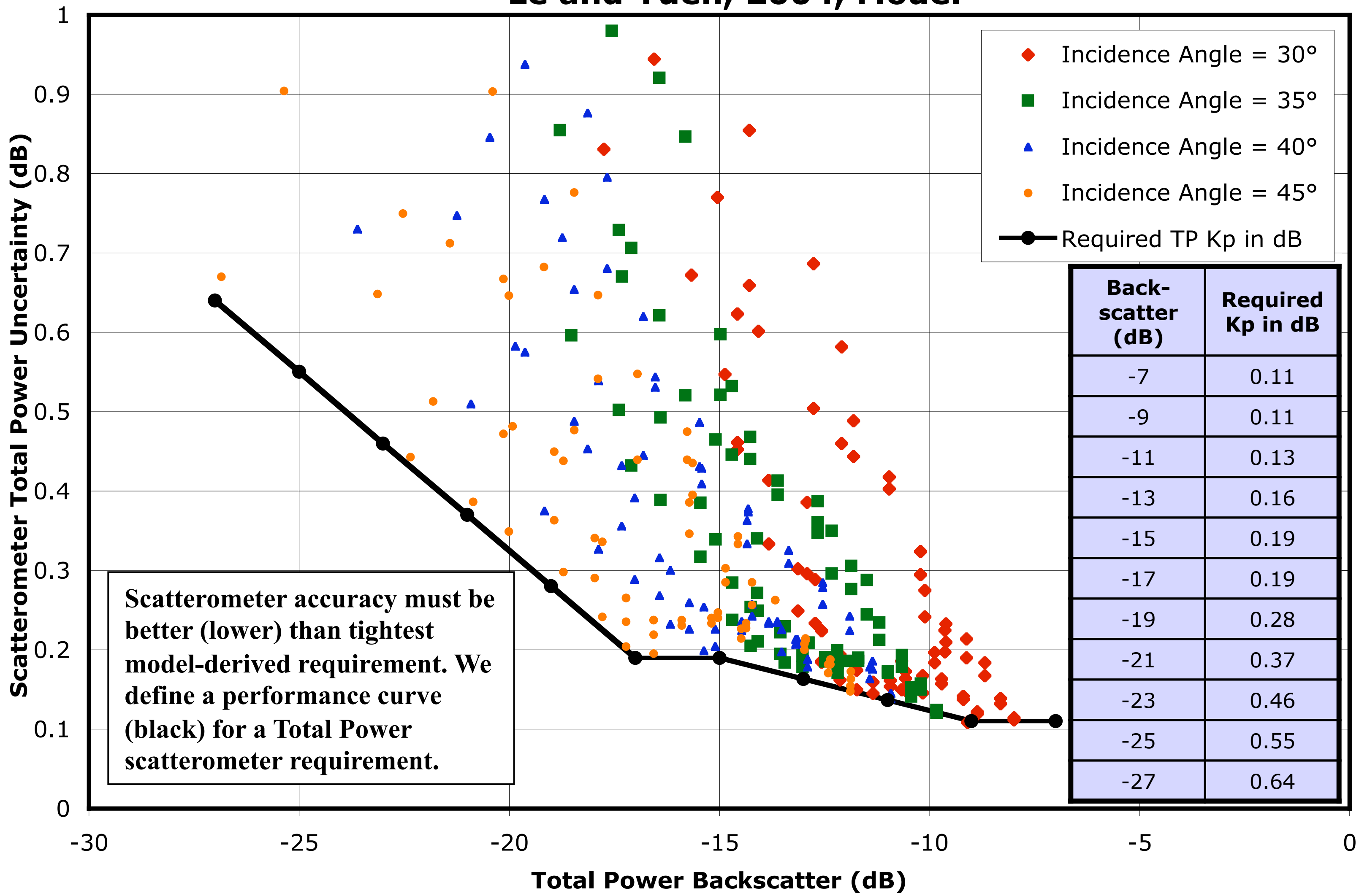


AQUARIUS/SAC-D



Required Total Power Performance

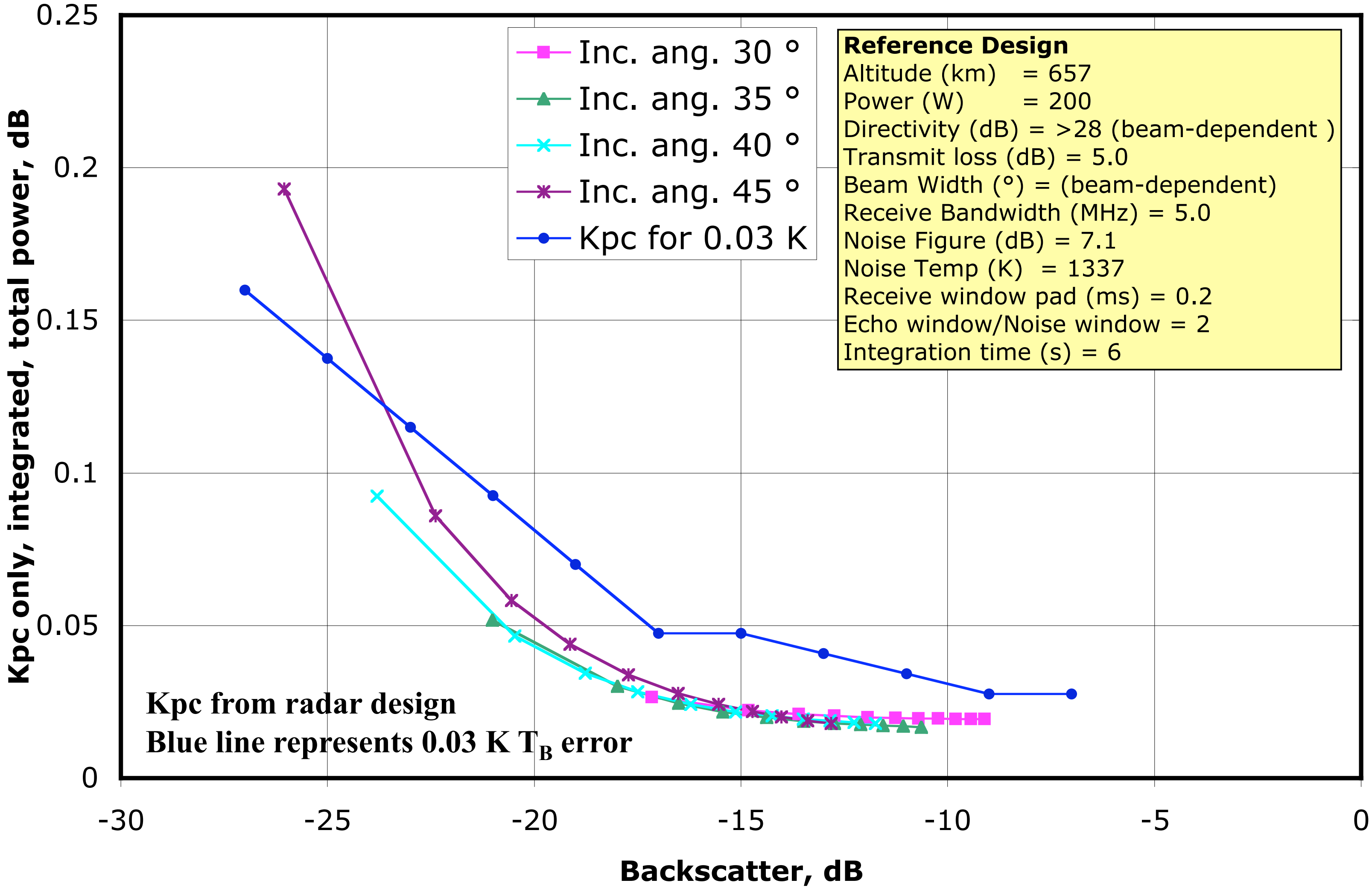
Scatterometer Accuracy Required For 0.12 K T_B Uncertainty
Le and Yueh, 2004, Model



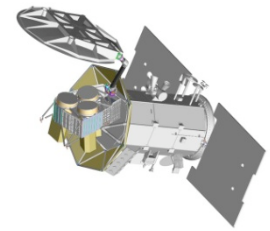
Back-scatter (dB)	Required Kp in dB
-7	0.11
-9	0.11
-11	0.13
-13	0.16
-15	0.19
-17	0.19
-19	0.28
-21	0.37
-23	0.46
-25	0.55
-27	0.64

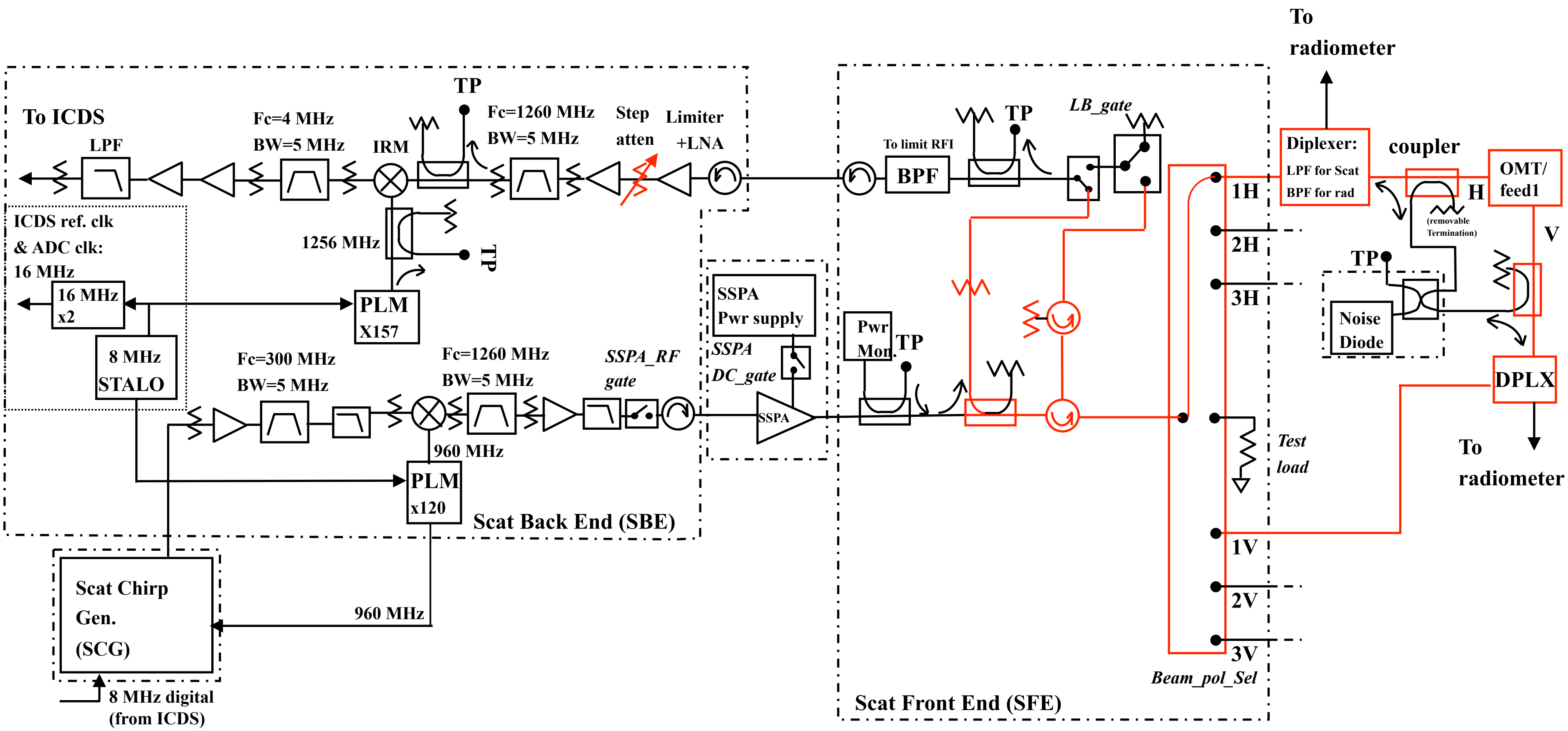
Expected Reference Model Performance for Kpc

Predicted Scatterometer Performance, Ref Model



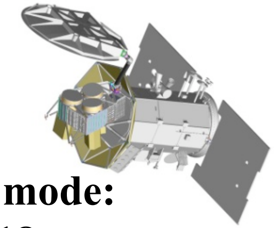
Aquarius Scatterometer Block Diagram
Key Calibration Components

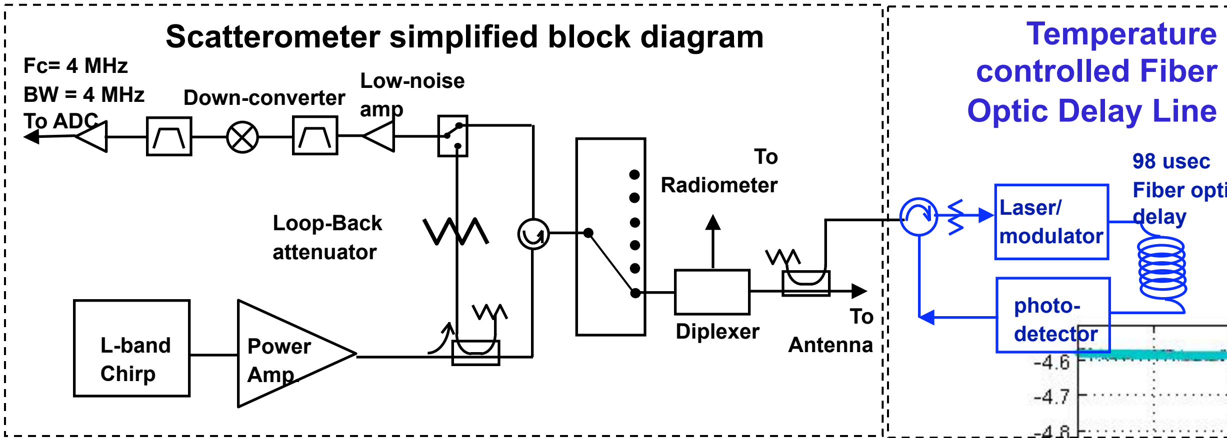




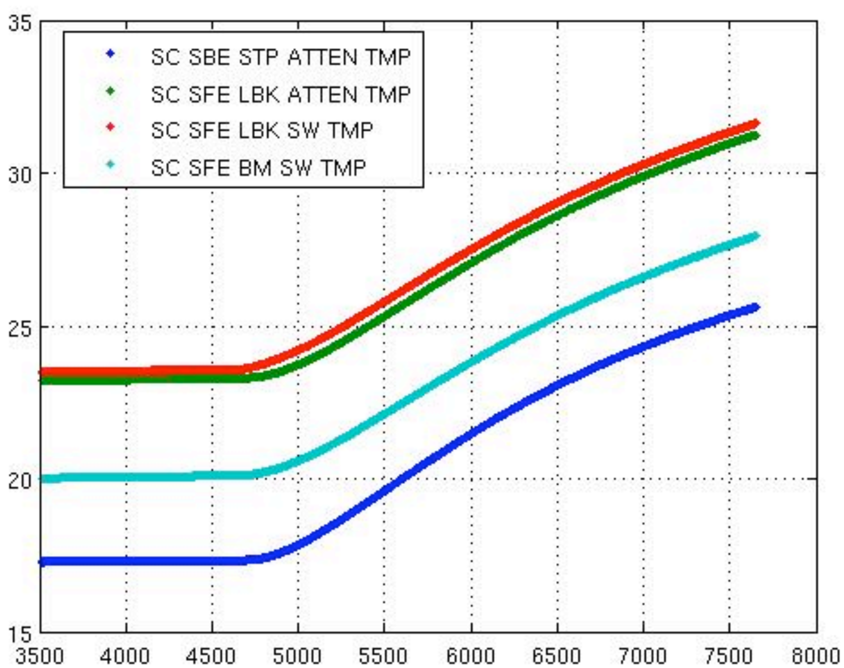
Key Calibration Components

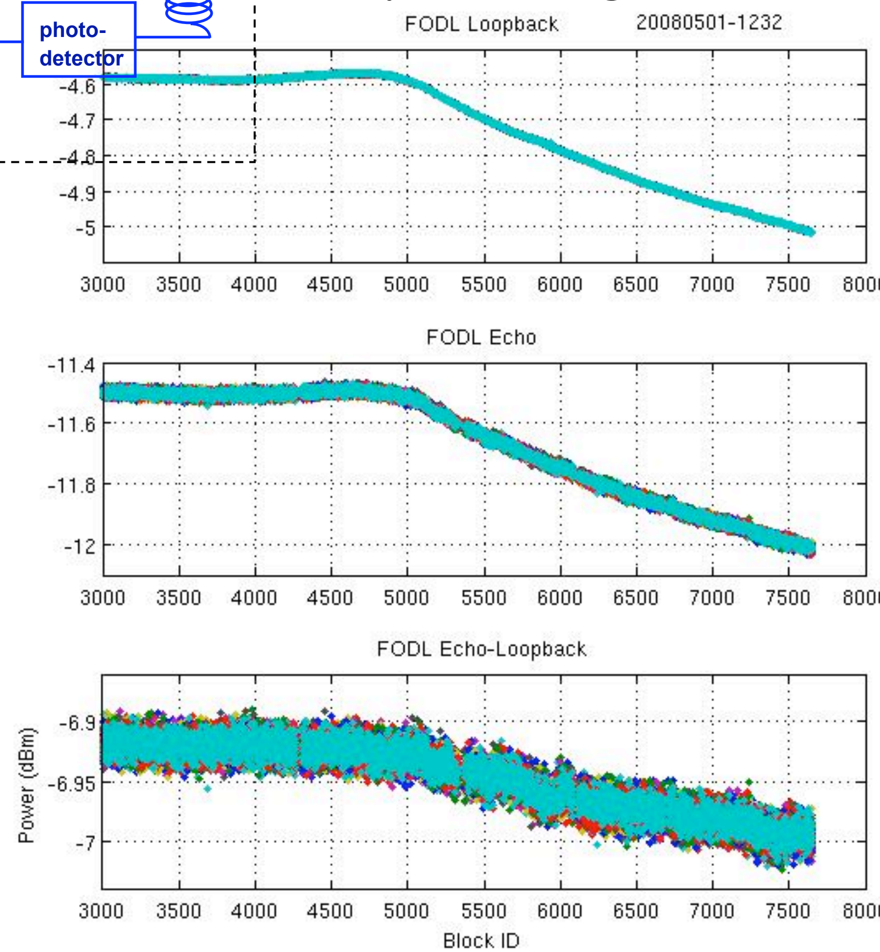
Scatterometer Stability Testing





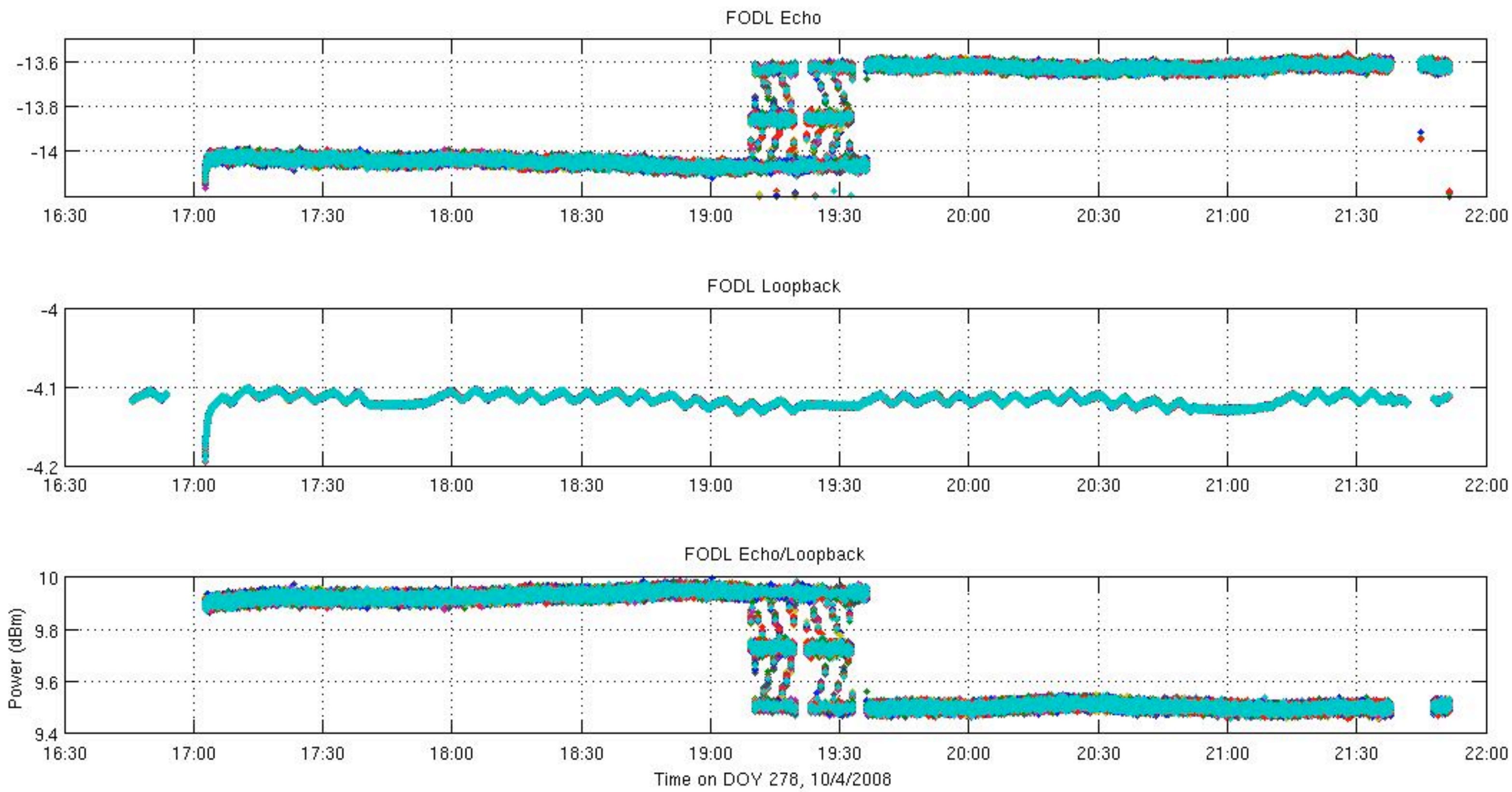
- Special FODL test mode: Timing accelerated 18x
- Residual thermal drift: ~0.1 dB / 7°C
- Subsystem testing



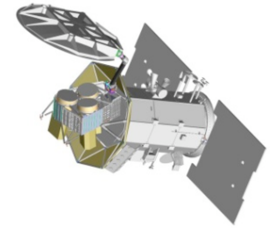


Scat Stability With Expected Thermal Perturbations

- **Drift less than 0.1 dB over several orbits**
- **Orbit period 98 minutes**
- **Amplifier heater cycling 7 minutes**
- **Instrument T/Vac testing**

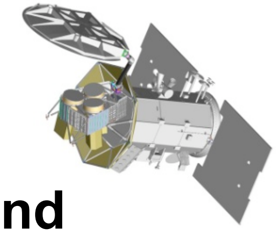


Science Calibration

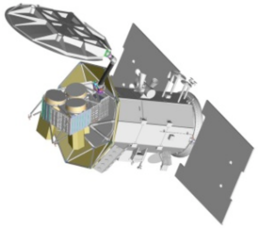


- **Science ground calibration is challenging**
  - No corner reflectors, transponders, point targets
  - RFI common at L band
  - High accuracy stability requirements (0.1 dB, 0.1 K)
- **Instrument intracomparisons**
  - Cross-over comparisons
  - Inter-beam comparisons
  - Polarization comparisons
- **Geophysical references**
  - Land/ocean interfaces
  - Vicarious ocean calibration
  - Antarctica: Dome C
  - Amazon rain forest
  - Quiet, stable ocean
  - Cold sky calibration (radiometer)
  - In situ salinity, ocean roughness

Summary



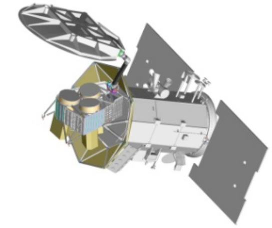
- **The Aquarius instrument completed the integration and test campaign in the Spring, was shipped to Argentina for integration with the spacecraft over the next 2-3 months, with planned launch at end of 2010.**
- **Elaborate thermal vacuum test, simulating worst case thermal environment variations in orbit (eclipse season), verified that the radiometer and scatterometer meet their stability requirements.**
- **Key design features contributing to this success:**
  - Active thermal control in combination with passive thermal design ensures <0.4° C stability.
  - High RF isolation and thermally stable RF components
  - Internal RF calibration paths
  - Scatterometer test mode enabling the use of a stable fiber optic delay line to route the transmitted chirp back into the receiver, for round-trip stability verification.



BACKUP

AQUARIUS/SAC-D

Instrument Summary 1



KEY ORBIT PARAMETERS

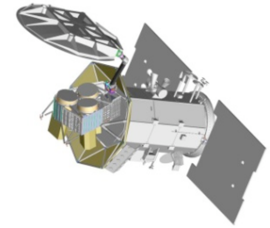
Parameter	*Value*
Observatory Orbit Altitude (km)	657 (655-685 km)
Orbit Inclination (deg)	98.0 (sun-synchronous)
Orbit Equatorial Crossing	6:00 PM ascending
Ground-track repeat interval	7 days, 103 orbits

KEY INSTRUMENT PARAMETERS

Parameter	*Radiometer*	*Scatterometer*
Frequency (MHz)	~1413	1260
Band Width (MHz)	≤ 26	4
Swath Width (km)	407	373
Polarization	Th, Tv, T+45, T-45	HH, HV, VV, VH
PRF (Hz)	100	100
No. Measurements Per Second	58.3	5.6
Transmitter Power (W)		200 - 250
Transmit Pulse Length (ms)		1
Pulse Integration Time (ms)	~9	~1.6
A/D (# bits)		12
Data Rate (kbits/sec)	11.0	2.1
Measurement Integration Time (s)	6	6
Dynamic Range (K, s_0)	<5 K to 1400 K	0 dB to -40 dB

Key Parameters
6/20/05

Instrument Summary 2



KEY ANTENNA PARAMETERS

Parameter	*Value*
Antenna	2.5 m diameter, offset parabola (2.5 x 2.9 linear dimension)
Feedhorns	3 feeds, 50 cm diam, equilateral triangle about focus

(off-nadir pointing angle of 33°)

	Radiometer			Scatterometer		
Parameter	*Inner beam*	*Middle beam*	*Outer beam*	*Inner beam*	*Middle beam*	*Outer beam*
Look Angle (deg)	25.8	33.8	40.3	25.9	33.9	40.3
Azimuth Angle (deg)	9.8	-15.3	6.5	9.7	-15.3	6.5
Average 3 dB Beam Width (deg)	6.1	6.3	6.6	6.5 / 4.7 *	6.7 / 4.8 *	7.1 / 5.1 *
Beam Efficiency (%)	94.0	92.4	90.4	89.9	87.6	85.4
Peak Gain (dBi)	29.1	28.8	28.5	28.5	28.1	27.7
Gain Stability (K, dB)	0.11	0.11	0.11	0.04	0.04	0.04
Peak Cross-Pole Gain (dBi)	6.5	8.6	10.3	6.3	8.4	10.1

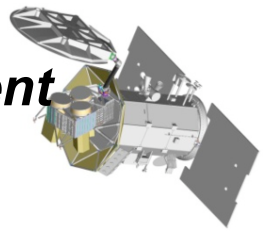
* one-way / two-way 3 dB beam widths

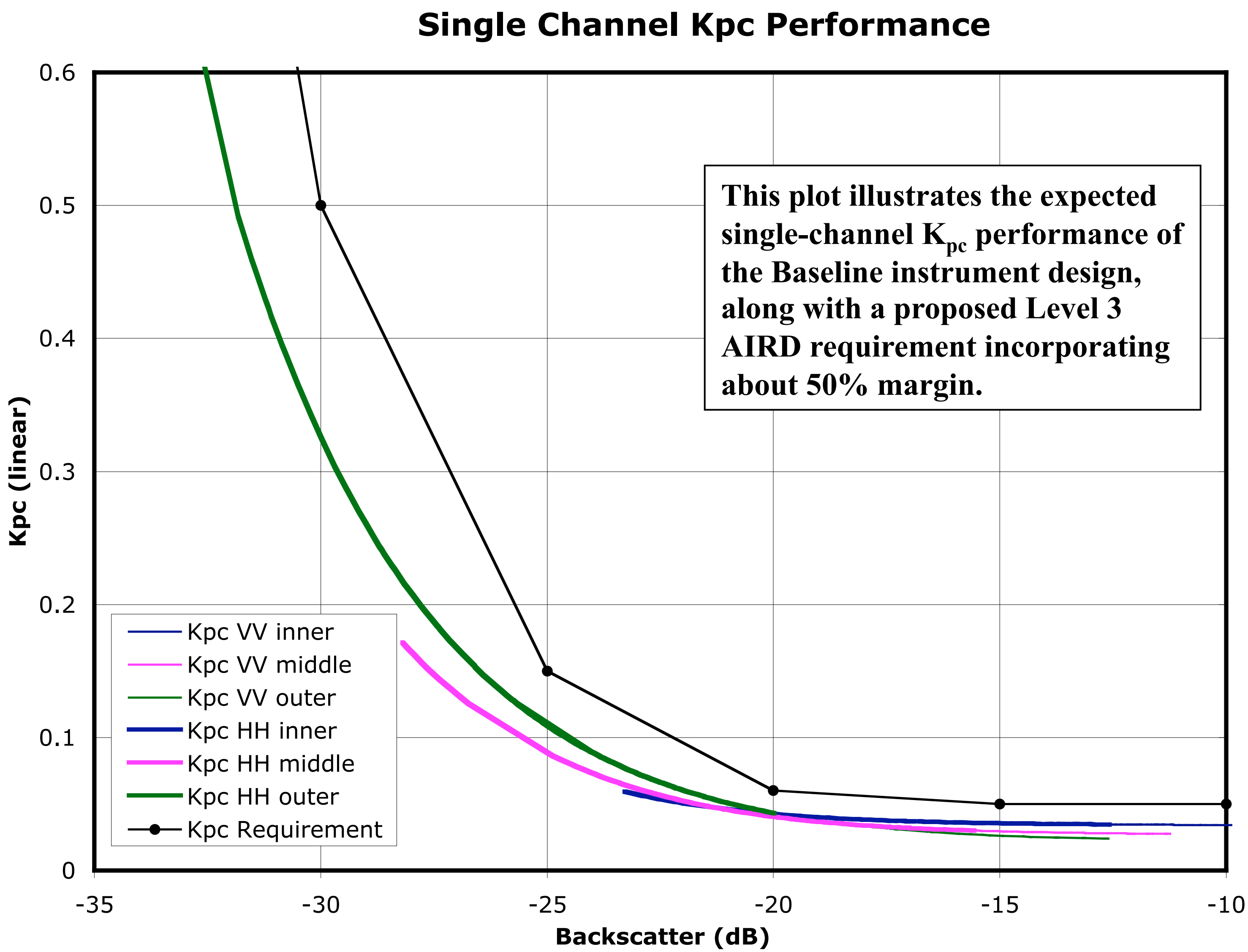
KEY MEASUREMENT PARAMETERS/REQUIREMENTS

	Radiometer			Scatterometer		
Parameter	*Inner beam*	*Middle beam*	*Outer beam*	*Inner beam*	*Middle beam*	*Outer beam*
Incidence Angle (deg)	28.7	37.8	45.6	28.8	37.9	45.5
Footprint Size (3 dB one-way, two-way)	94 x 76	120 x 84	156 x 97	71 x 58	91 x 65	122 x 74
Noise-Equivalent Sigma-0 (dB, pulse)				-29	-26	-24
Stability (K, dB)	0.12	0.12	0.12	0.13	0.13	0.13
Radar Sensitivity (dB)				0.04	0.06	0.1
Radiometer Sensitivity (NEDT, K)	0.06	0.06	0.06			
Power Sensitivity (after integration) (dBm)	-137	-137	-137	-119	-126	-127

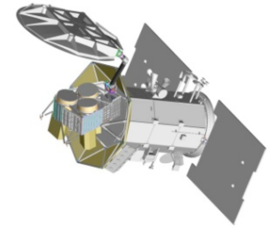
Note for reference: 0.1 K error for a 100 K T_B = 0.1 % => 0.004 dB error

Single-Channel Kpc Performance and Requirement





Level 1 ATBD (Radiometric Calibration)



$$\sigma_0 = \left(\frac{(4\pi)^3}{\lambda^2}\right)\left(\frac{L_{T_{bp}} L_{R_{bp}}}{P_t G_r G_{bp_{pk}}^2}\right)\left(\frac{1}{\iint_{area} \frac{g^2 dA}{R^4}}\right)(P_e - P_n)$$

Where

$L_{T_{bp}}$	Transmit path Loss between the start of the cal-loop and the antenna.
$L_{R_{bp}}$	Receive path Loss between the end of the cal-loop and the antenna.
P_t	Transmit Power.
G_r	Receiver Gain
$G_{bp_{pk}}$	Peak Antenna Gain.
g	Relative Antenna Gain Pattern
R	Distance from the radar antenna to the earth.
λ	Radar Wavelength
4π	Constant
P_e	The echo power measured by Aquarius
P_n	The noise power measured by Aquarius
σ_0	Normalized Radar Backscatter.