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Preliminary Evaluation of Passive Thermal Control for the Soil Moisture Active and Passive (SMAP) Radiometer

A.J. Mastropietro, Eug Kwack, Rebecca Mikhaylov, Michael Spencer, Pamela Hoffman, Douglas Dawson

Jet Propulsion Laboratory/California Institute of Technology

Jeff Piepmeier, Derek Hudson, James Medeiros

NASA Goddard Space Flight Center

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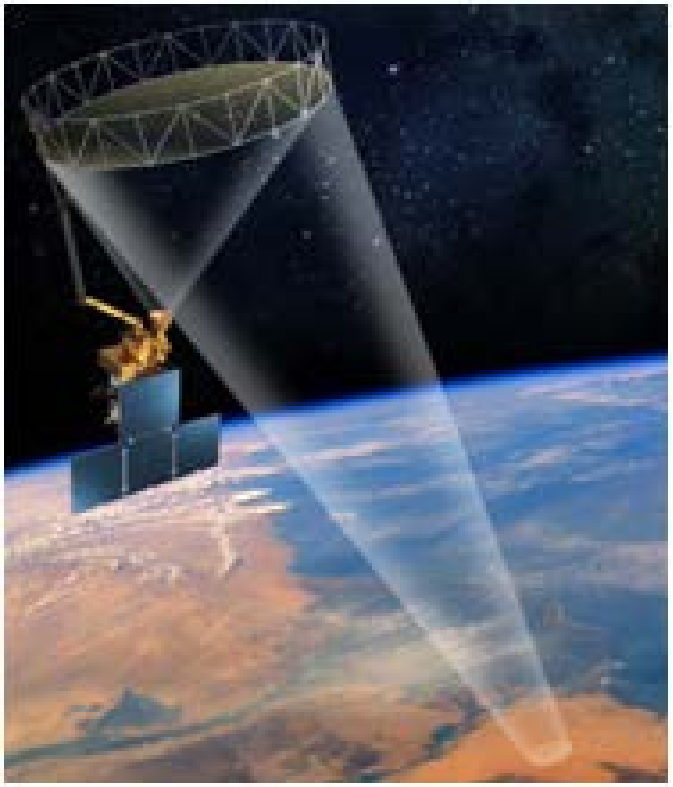
SMAP Mission Objectives



http://smap.jpl.nasa.gov/

- Direct observations of soil moisture and freeze/thaw states from space
- Improved estimates of water, energy and carbon transfers between land and atmosphere
- Enhanced weather and climate forecasts, improved flood prediction and drought monitoring

The SMAP mission has not been formally approved by NASA. The decision to proceed with the mission will not occur until the completion of the National Environmental Policy Act (NEPA) process. Material in this document related to SMAP is for information purposes only.

SMAP Team Members and Responsibilities

- Radiometer and ground science data processing (GSFC)
- Radar, instrument integration, test and prelaunch mission management (JPL)
- Reflector boom assembly (Northrop Grumman)
- Spin mechanism assembly (Boeing)

SMAP and Aquarius/SAC-D

Both fly a GSFC radiometer and JPL radar but:

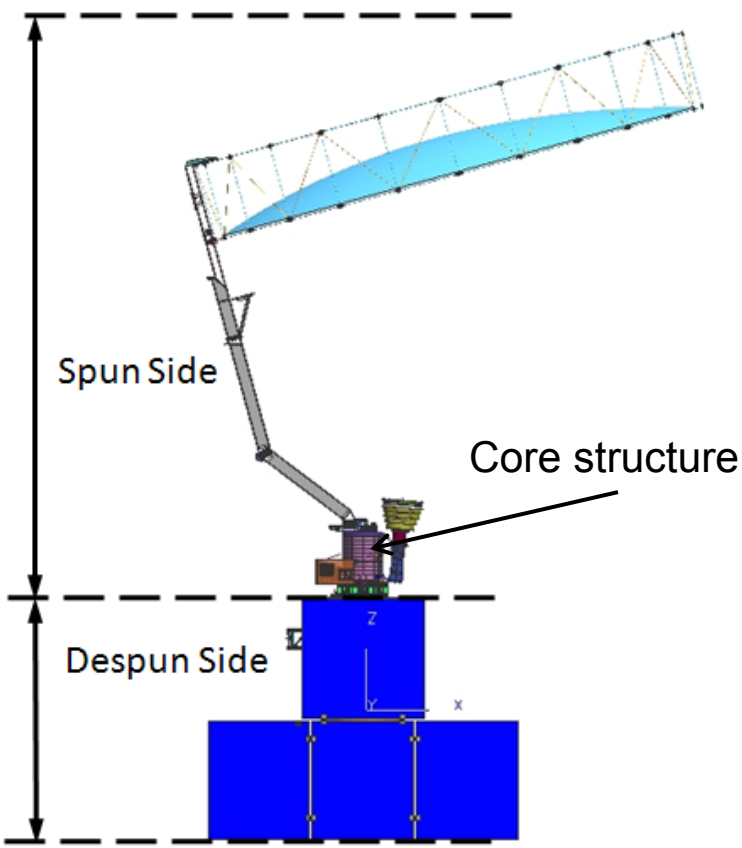
SMAP

- Measures soil moisture and freeze/thaw states
- Single feed horn exposed to the sun
- Spinning platform
- 6m deployable spinning antenna
- 0.6^{o}C/orbit thermal stability requirement

Aquarius/SAC-D

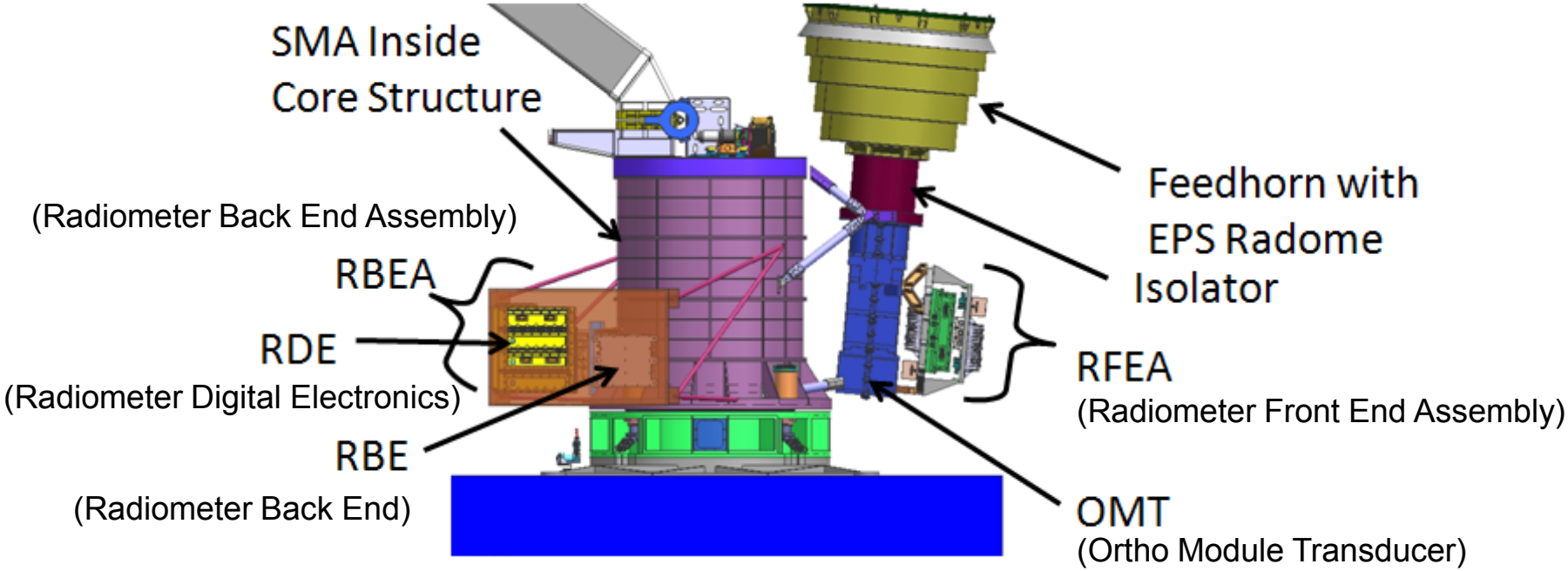
- Measures sea surface salinity
- 3 feed horns permanently shadowed
- Non-spinning platform
- 2.5m fixed antenna
- 0.1^{o}C/week thermal stability requirement

Instrument Configuration



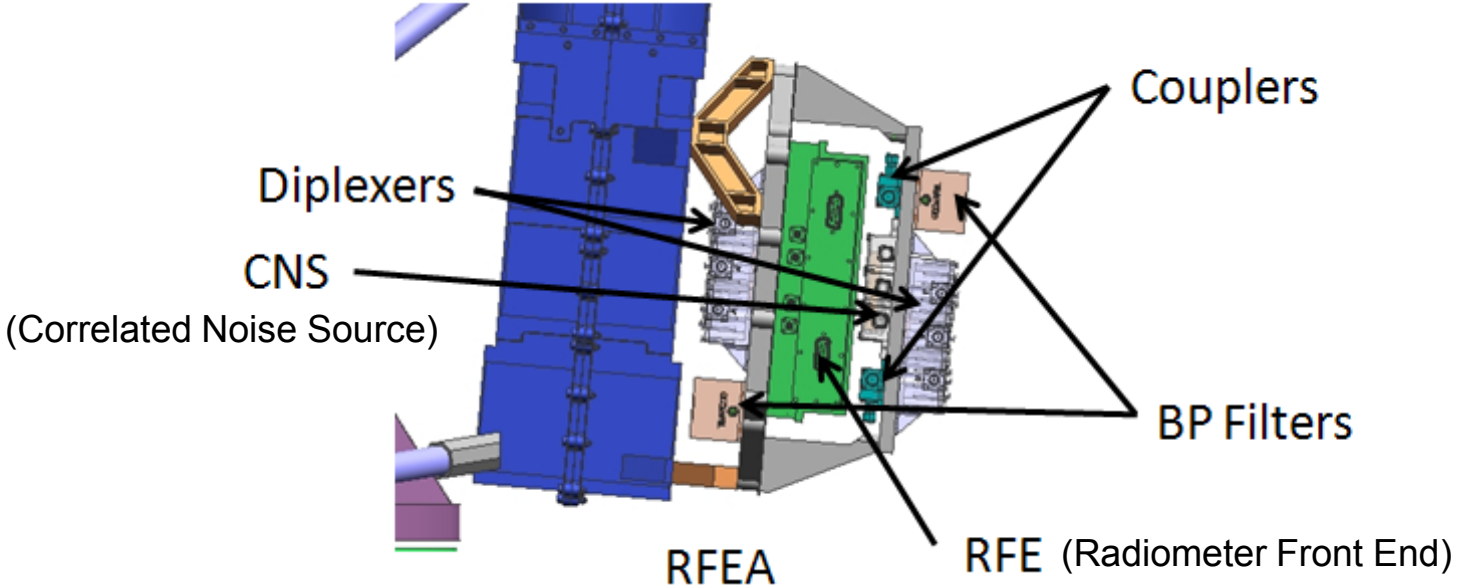
- The L-band radar components are on the despun side of SMAP
- The instrument resides on the spun side of the observatory
  - Cylindrical core structure houses Spin Mechanism Assembly (SMA)
  - 3 major assemblies
    - Reflector Boom Assembly (RBA)
    - Integrated Feed Assembly (IFA)
    - Radiometer Back End Assembly (RBEA)

Radiometer Configuration



- IFA and RBEA are the primary assemblies that make up the L-band radiometer
  - RFEA contains the most thermally sensitive components

RFEA Configuration

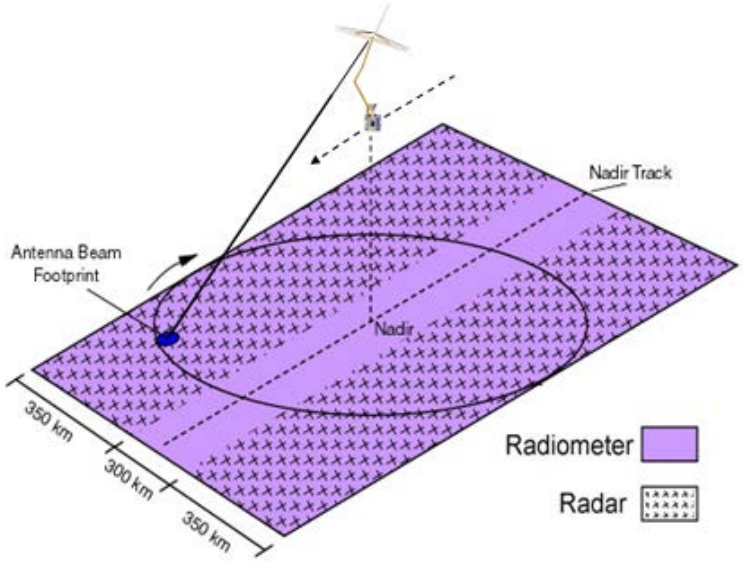


- RFE is the component with the tightest thermal stability requirement
- MLI cocoon is implemented around the RFEA
  - Isolates components from the environment

Derivation of Thermal Stability Requirements

Soil moisture error budget → **Antenna temperature calibration** → **Feed to Electronics input and RF loss and emission** → **Brightness temperature**

- An acceptable error was allocated to four time periods
  - Instantaneous per minute rate
  - Change per orbit, month and mission life



Radar and Radiometer shared components

- Shared signal chain

antenna→ feed horn→ OMT→ coupler→ diplexer

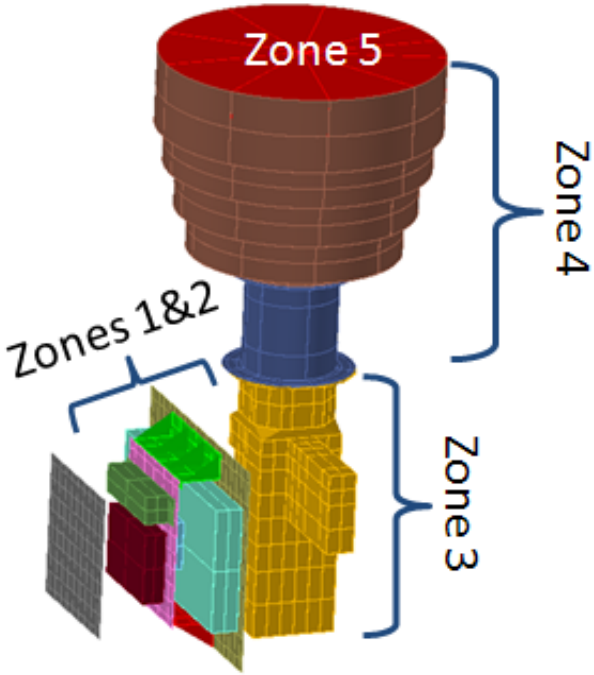
Radar: diplexer→ rotary joint→ radar electronics located on bus

Radiometer: diplexer→ RFE→ RBE→ RDE

- RF dissipation is ~10W and must be accounted for in the RFEA and OMT

Thermal Requirements

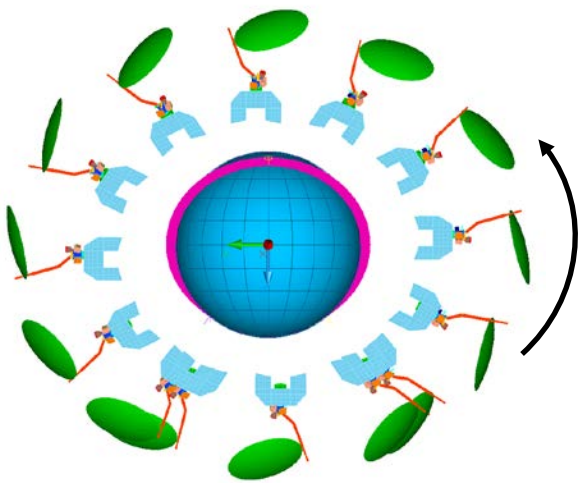
Radiometer Component	Zone	Short Term		Long Term	
		dT/dt (°C/min)	dT/orbit (°C/orbit)	Monthly (°C/month)	3 Year Mission Life (°C)
RFE	1	0.05	0.6	6.8	15
Diplexers, CNS, BP Filters, Couplers	2	N/A	1.2	6.9	15
OMT	3	N/A	2.4	7	19
Isolator & Feedhorn	4	N/A	8	8	30
Radome	5	N/A	120	60	100
RBE	N/A	0.1	N/A	N/A	N/A
RDE	N/A	0.5	N/A	N/A	N/A



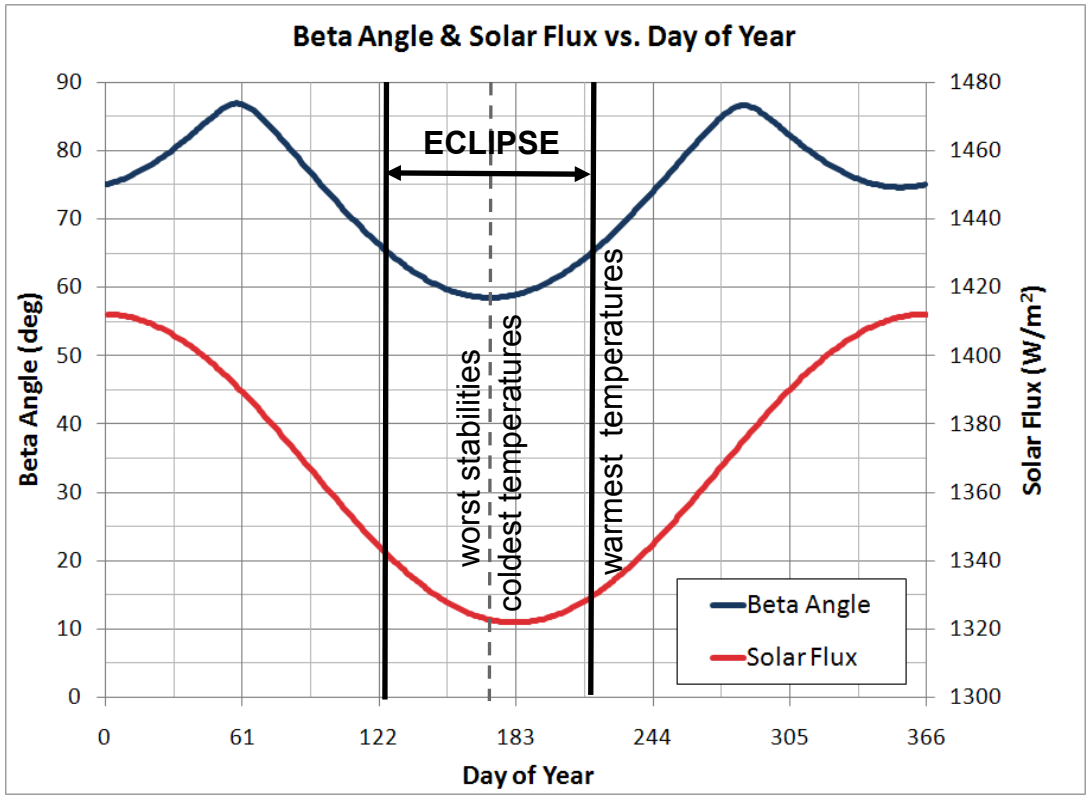
- RFE 0.6°C/orbit requirement is particularly challenging

Thermal Environments

- SMAP orbital parameters
  - sun-synchronous 6PM AN orbit
  - 685 km altitude
  - orbital period is 98.5 minutes
  - beta angles range from 58° to 88°
  - eclipse when 58° ≤β≤ 65°
  - max. eclipse time = 18.9 minutes
  - no eclipse when 65° ≤β≤ 88°
  - eclipse event lasts approximately 83 days from May 11 to August 2



Beta 58.5° (View From Sun)



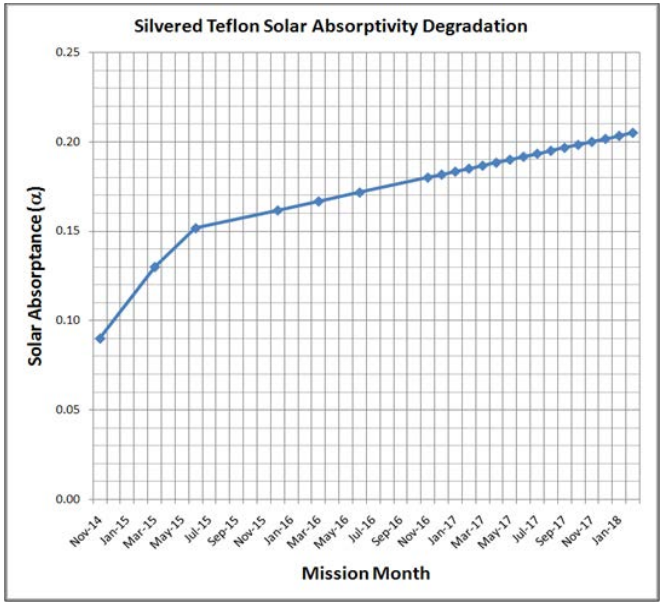
Environmental Parameter	Hot Case	Cold Case
Solar Constant	1420W/m²	1290W/m²
Earth IR	250W/m²	190W/m²*
Albedo Factor	0.35	0.25

* Recommended by Aquarius Thermal Team

Thermo-optical Properties

- SMAP Thermal team and GSFC Coatings Committee agreed to values
  - Includes an addition of 0.05 to Silver Teflon α due to contamination within first 6 months

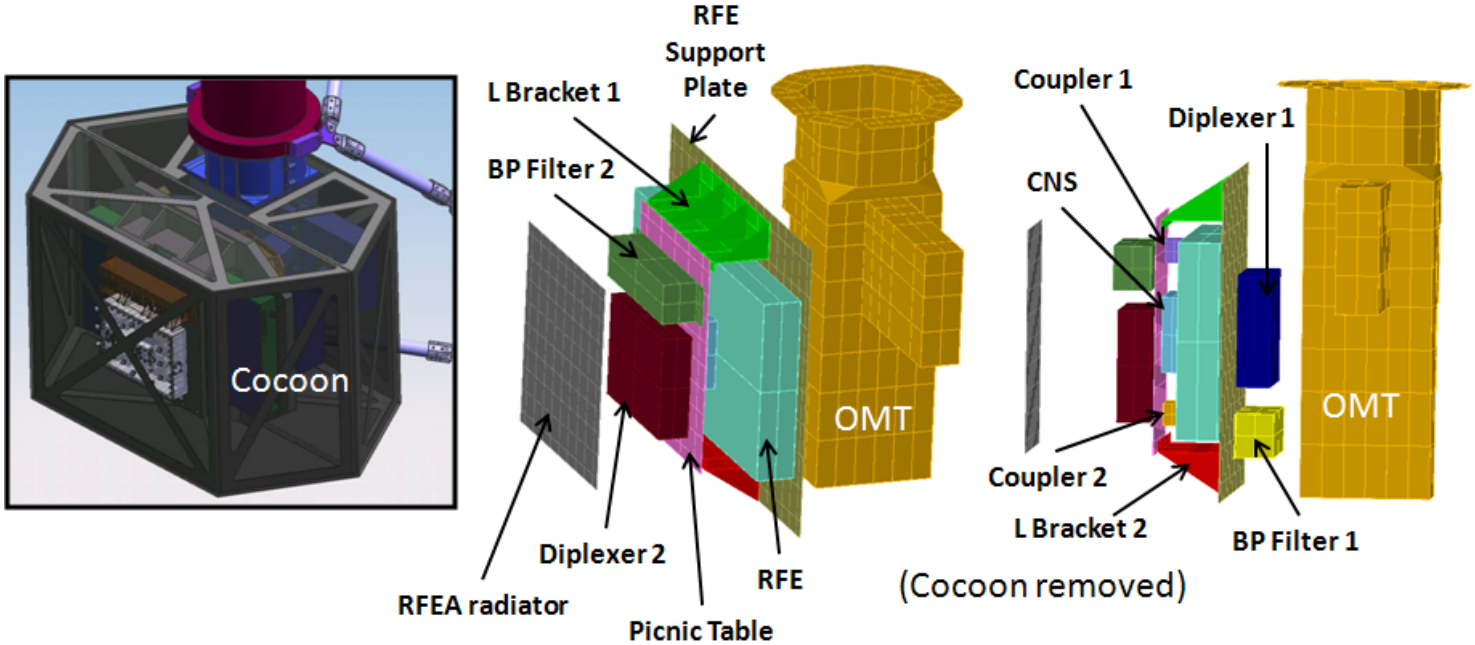
Coating/Material	Solar Absorptivity, α	IR Emissivity, ε
	BOL/EOL	BOL/EOL
Silvered Teflon (10mil)	0.09/0.2	0.85/0.82
Silvered Teflon (5mil)	0.08/0.2	0.81/0.76
Interior MLI	N/A (never sees sun)	0.1/0.08
Bare Aluminum	N/A (never sees sun)	0.1/0.03
Bare Titanium	N/A (never sees sun)	0.18/0.08
Radome (ESP)	0. 20/0.33	0.90/0.7
Alodine (Chem Film)	N/A (never sees sun)	0.19/0.03
Clear Anodize (RBE/RDE)	N/A (never sees sun)	0.89/0.66



Thermal Analysis Assumptions

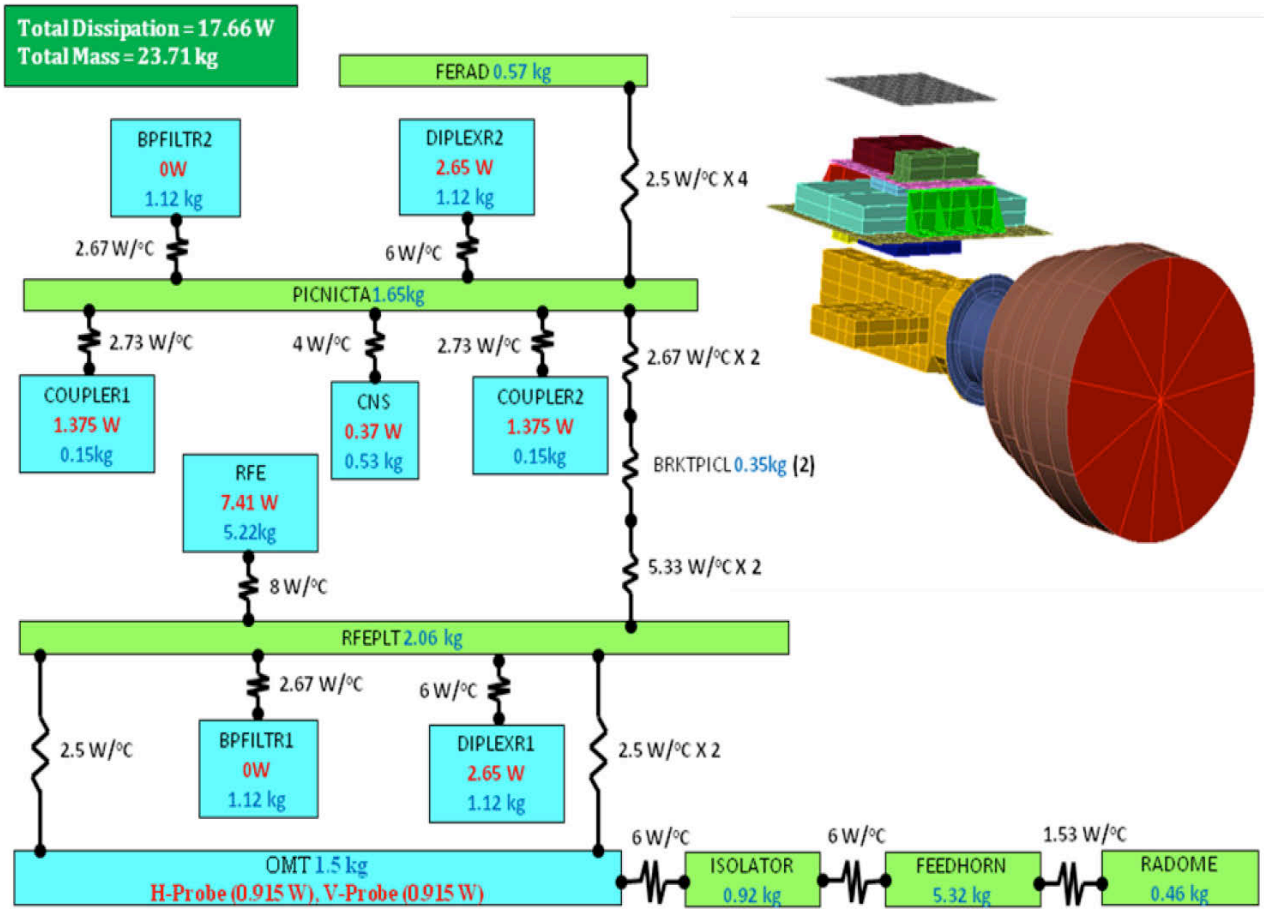
Steady State Results	Transient Results	Monthly Results
To Size Radiators: **Worst Case Hot for Science**	**To Assess Short Term Thermal Stabilities:** **Worst Stabilities for Science**	**To assess Mission Life and Monthly Stabilities:** **3 Year Mission Life and Month to Month Thermal Analysis**
• Highest Solar Flux • Highest Earth IR • Highest Albedo Factor • β=89° (No Eclipse) • Nominal ε^* = 0.02 • CBE + Uncertainty for Dissipations • CBE Mass • EOL Optical Properties • S/C Despun Interface Modeled as +40°C Boundary	• Highest Solar Flux • Highest Earth IR • Highest Albedo Factor • β=58° (Maximum Eclipse Duration) • Nominal ε^* = 0.02 • CBE + Uncertainty for Dissipations • CBE Mass • EOL Optical Properties • S/C Despun Interface modeled as +40°C Boundary	• Solar Flux interpolated from Fig. 8 • Earth IR Flux Interpolated (between 250 W/m^2 and 190 W/m^2) Proportionally to Solar Flux Variation from Fig. 8 • Nominal Albedo • β interpolated from Fig. 8 • Nominal ε^* = 0.02 • CBE + Uncertainty for Dissipations • CBE Mass • Optical properties linearly degraded over time to EOL values (includes initial 0.05 increase to ST α value due to contamination) • S/C Despun Interface Modeled as Time Varying Temperature Boundary

Thermal Design



- Thermal Desktop used to model Instrument
- Signal chain power dissipations varied during design phase
  - Two different thermal designs proposed

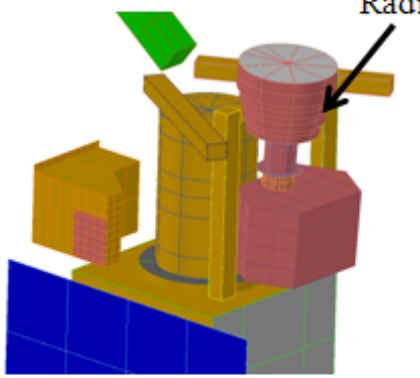
Thermal Block Diagram



* For design A: no FERAD, Al ISOLATOR, heavier OMT (2.39kg)

Thermal Design Options

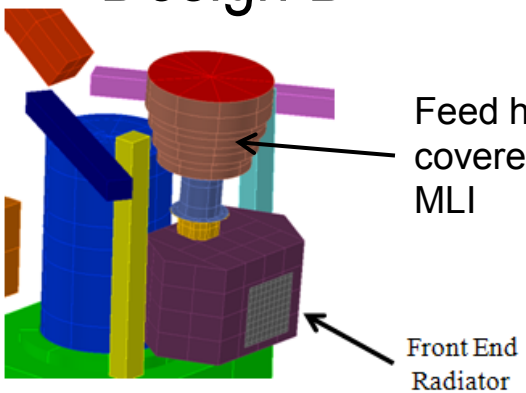
Design A



Design A

- 10mil Silver Teflon on circumference of feed horn as radiator
- ST MLI (IFA)
- Aluminum Isolator
- Thickened OMT

Design B



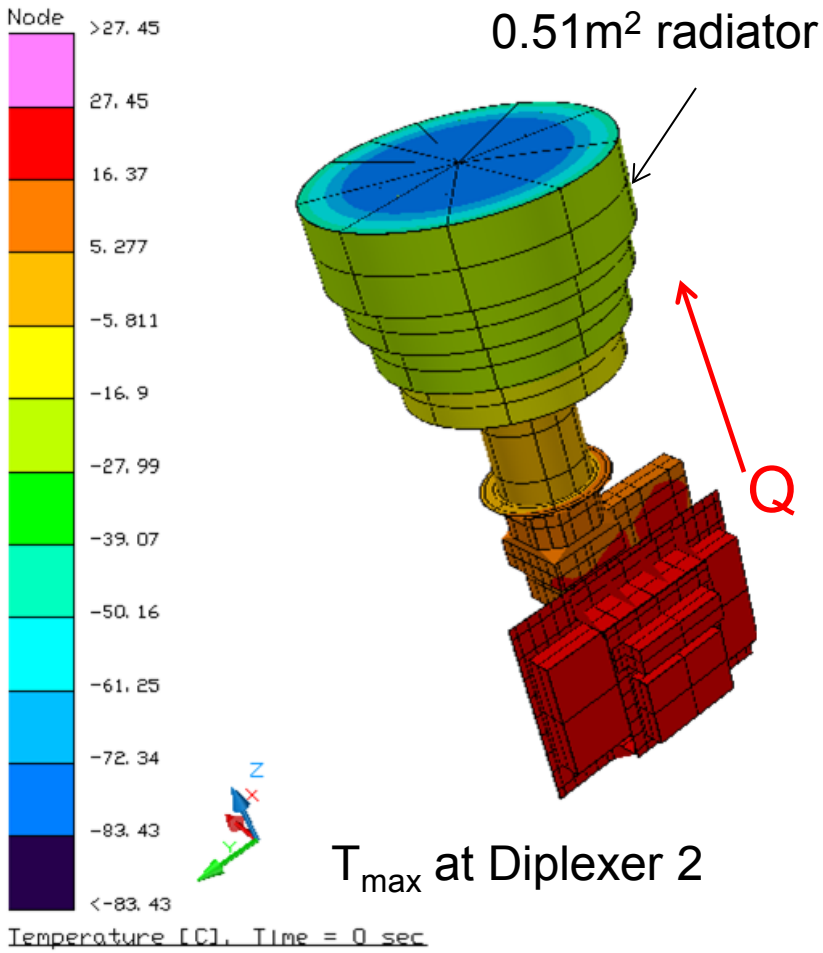
Design B

- Dedicated front end radiator (10 mil ST)
- Feed horn covered with ST or AK MLI
- Titanium Isolator
- 5mil Silver Teflon or Aluminized Kapton MLI (IFA)

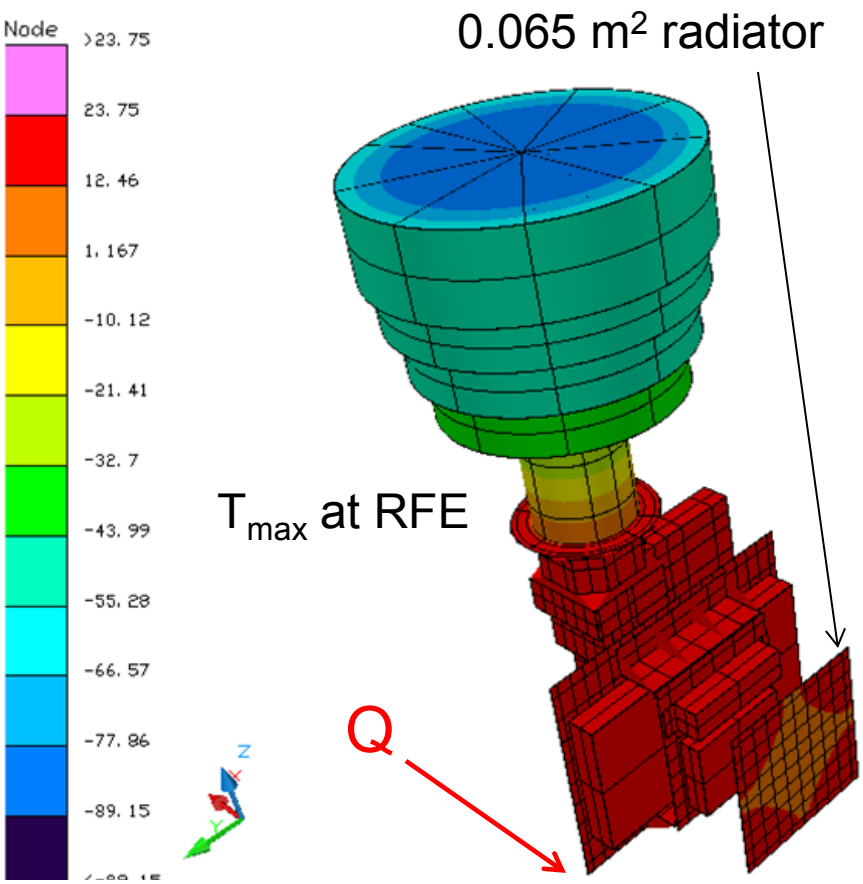
Steady State Results

β = 89° hot environment

Design A



Design B with ST MLI



AK MLI Results: RFEA temps increase ~2°C; Feed horn >30°C than ST MLI

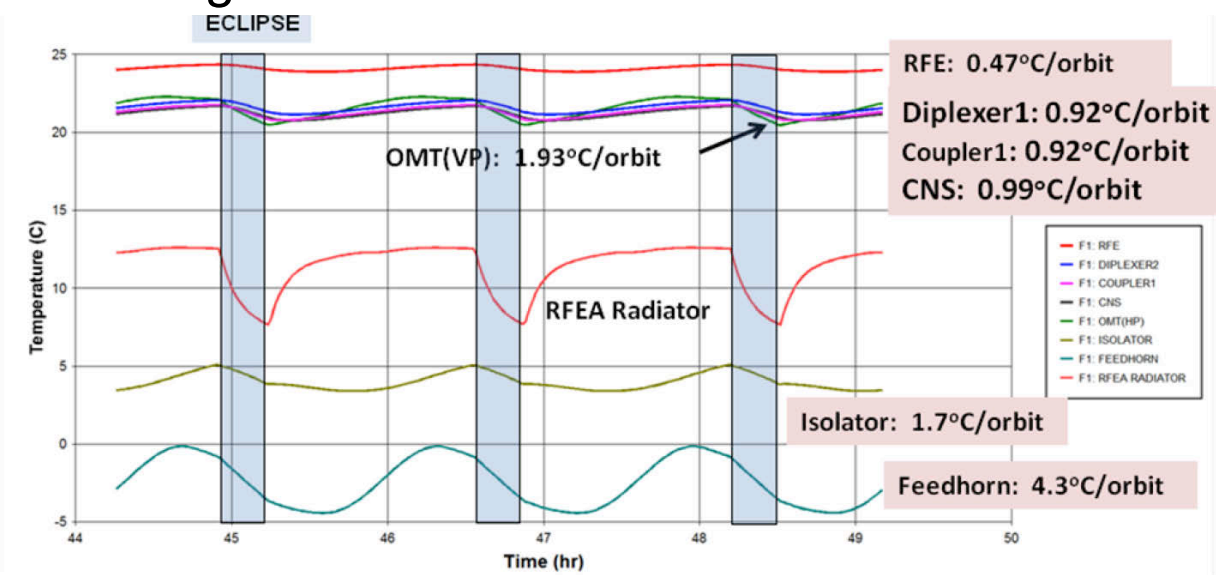
Orbital Transient Results

β = 58.5° hot environment

Zone	Component	Design A	Design B ST	Design B AK	Requirement
1	RFE	0.14	0.32	0.47	0.6
2	Diplexer (Picnic Table)	0.16	0.78	0.99	1.2
3	OMT	0.57	1.22	1.93	2.4
4	Isolator	4.75	1.42	1.71	8
	Feedhorn (middle)	18.4	3.91	4.28	
5	Radome (outside center)	101	104	99	120

Design B meets requirements

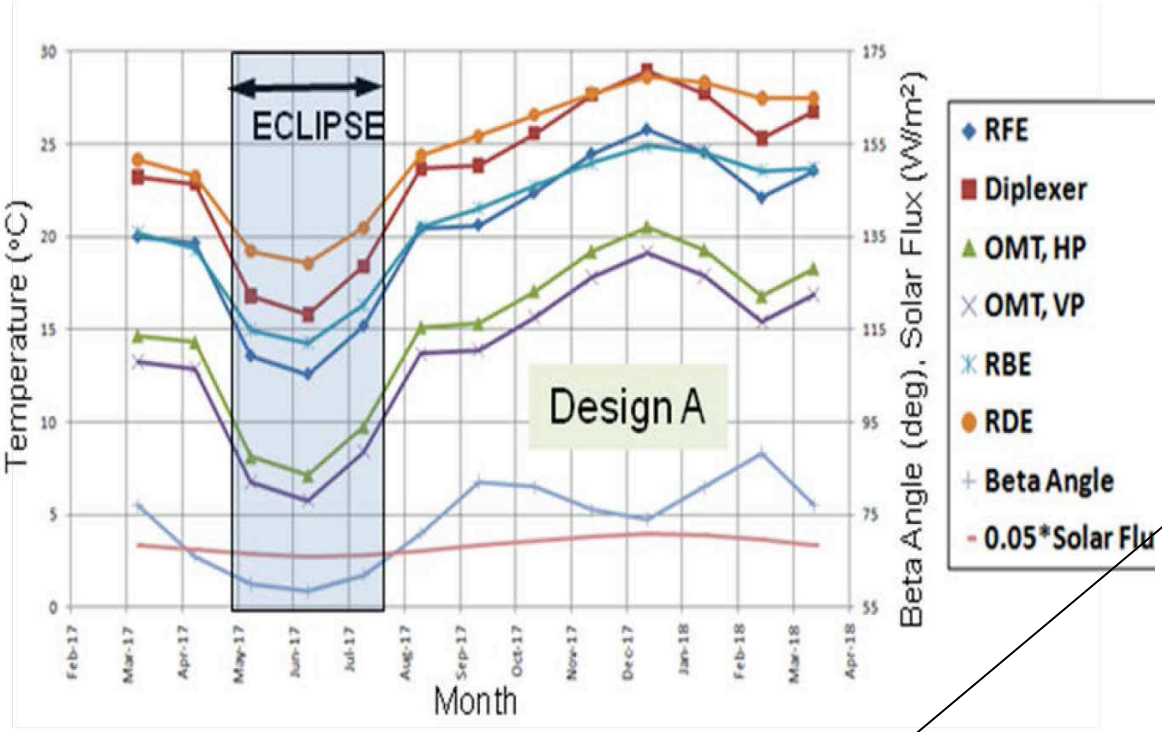
Design B AK Transient Results

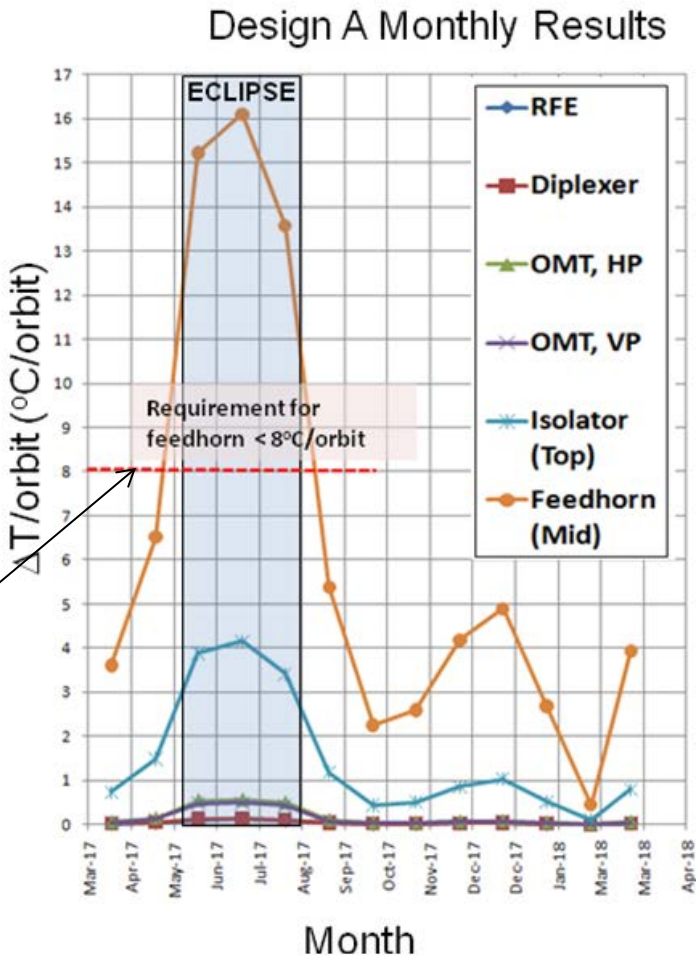


RFE short term reqt.
All three cases show large margin against 0.05°C/min requirement (0.008°C/min)

Design A Monthly Results

Nominal environment

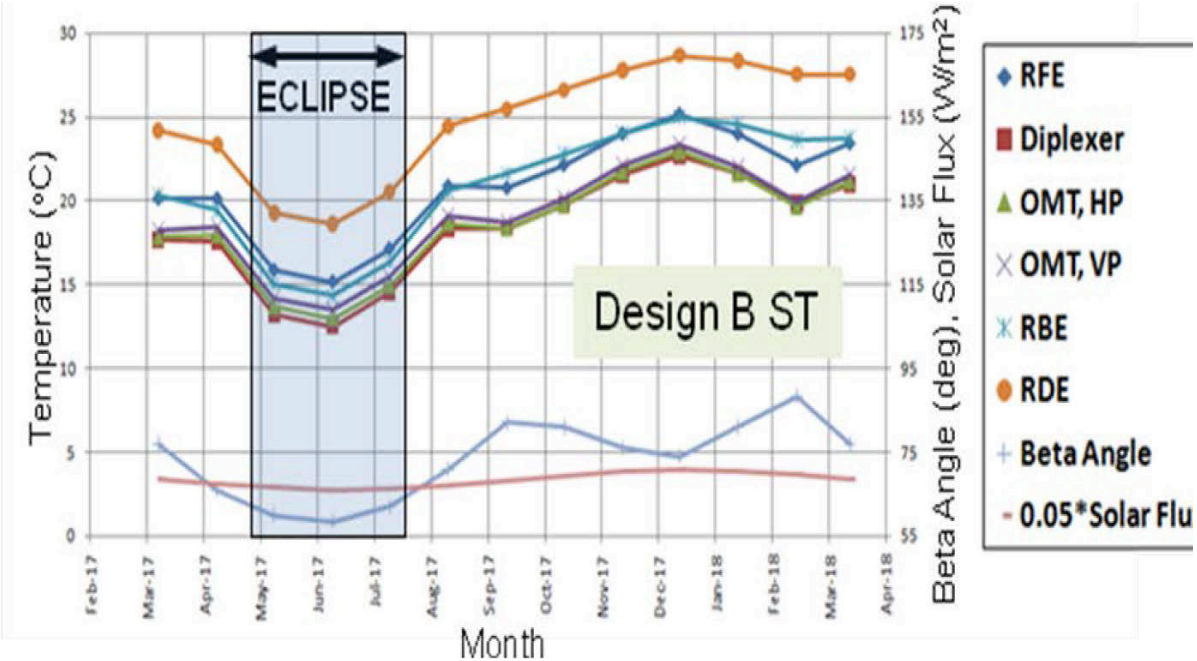


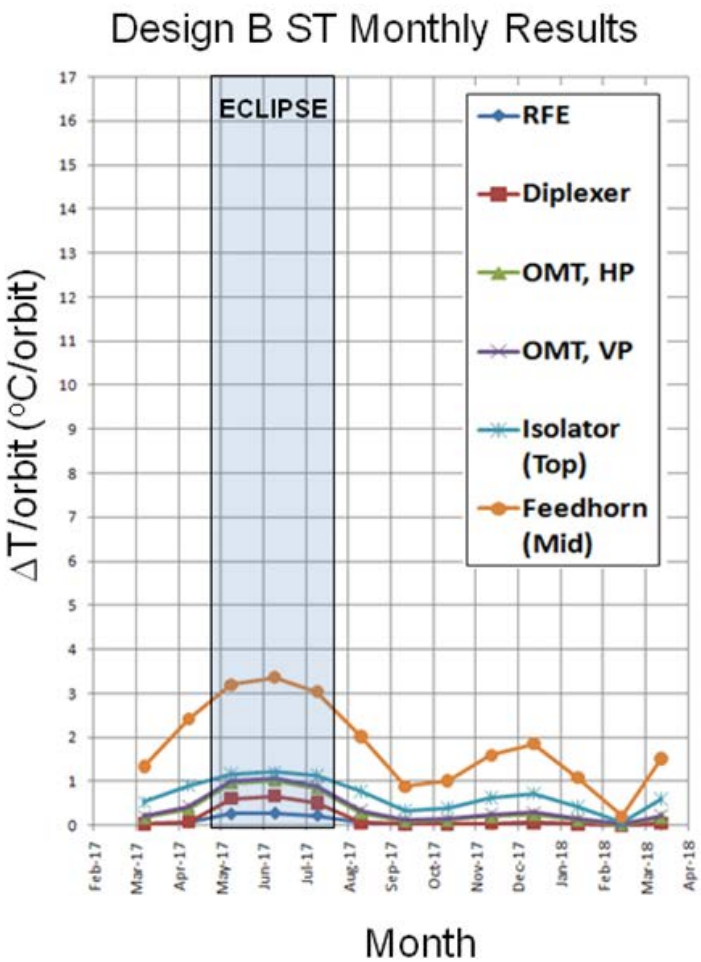


Exceeds feed horn short term requirement during eclipse season

Design B ST Monthly Results

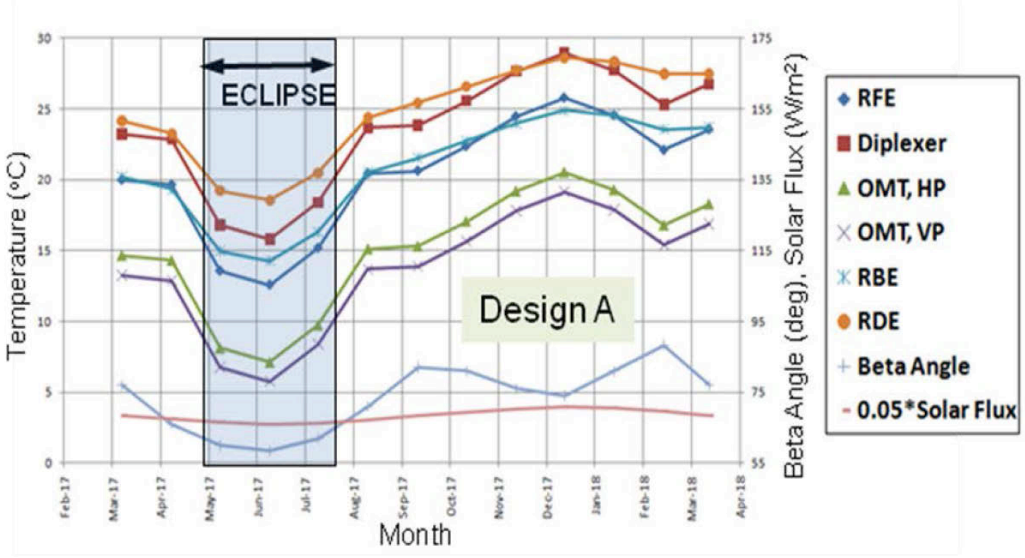
Nominal environment

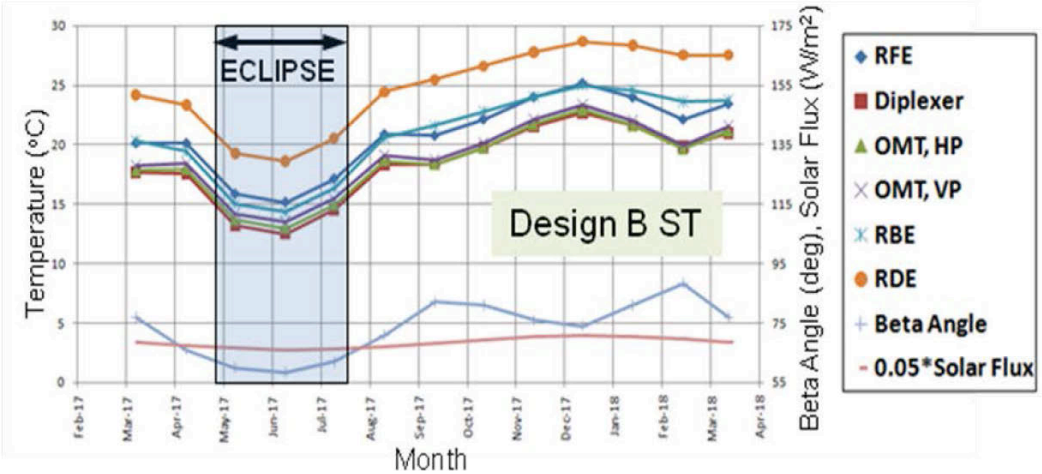




Meets all monthly requirements

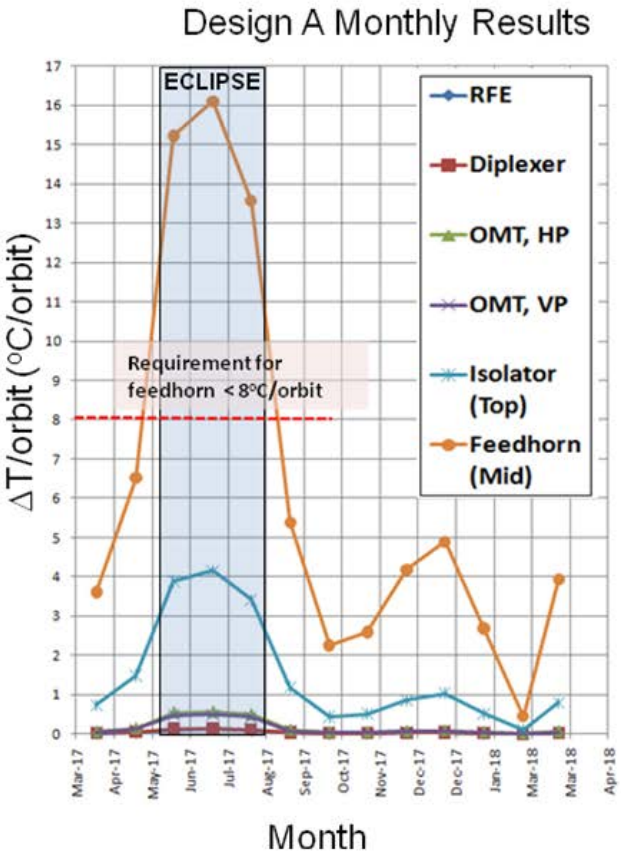
Monthly Temperatures: Last Year of Mission

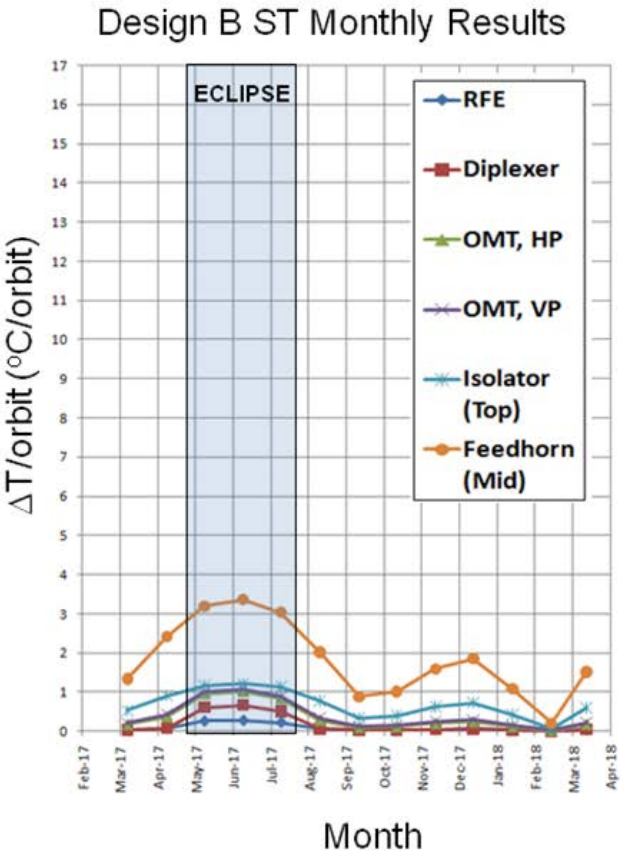




- During eclipse season, temperatures drop about 5°C
- Long torturous thermal path from diplexer to feed horn (Design A): ΔT from diplexer to OMT(VP) is 10°C
- ΔT from diplexer to OMT(VP) is only 3°C for Design B

Monthly Orbital Stabilities: Last Year of Mission



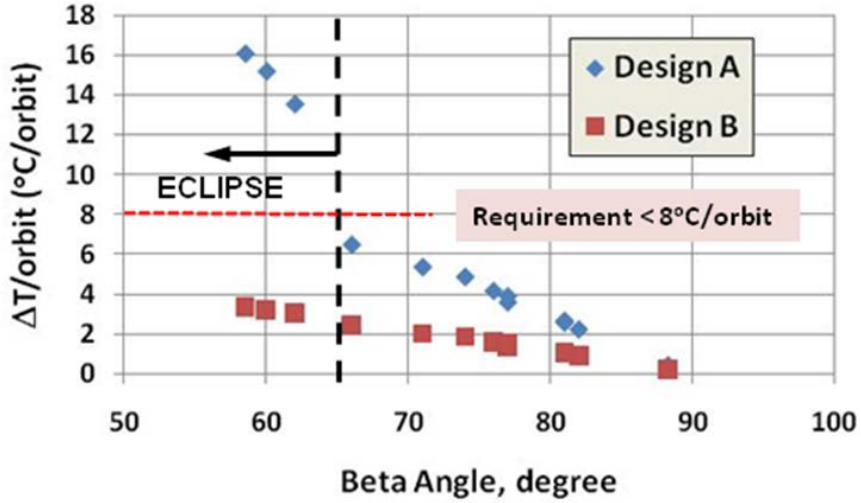


- The short term stabilities of components inside cocoon for design A are better than those of design B
- However, the isolator and feed horn short term stabilities for design A are much worse than those of design B since the feed horn is used as radiator for design A

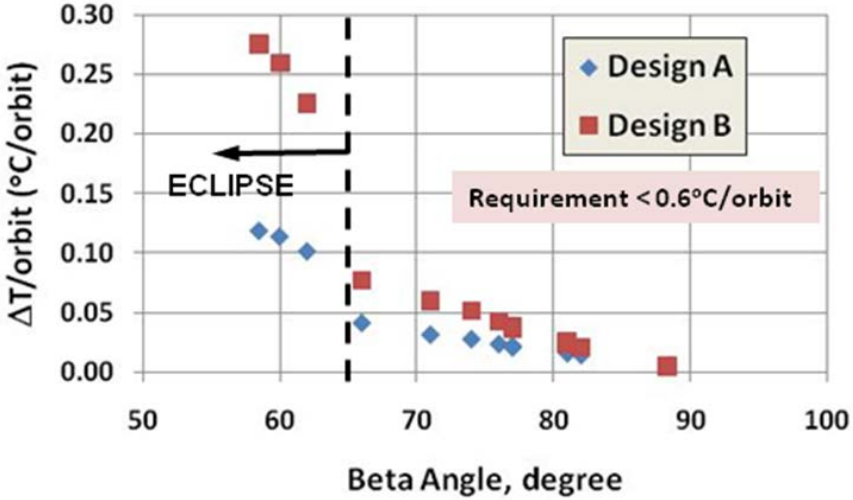
Orbital variations during last year of mission

Nominal environment

Feedhorn

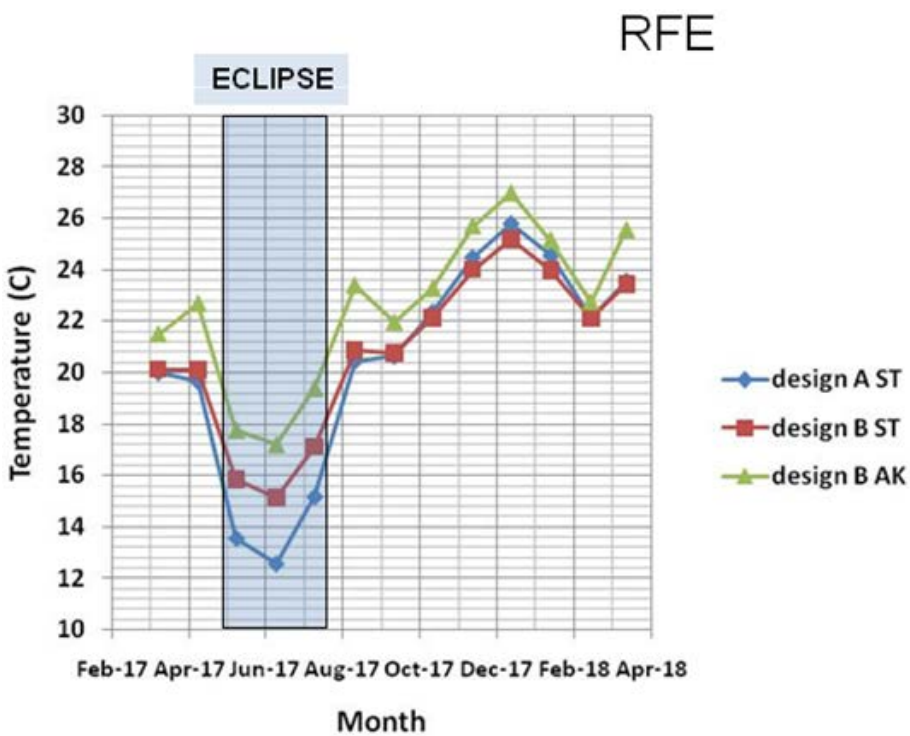


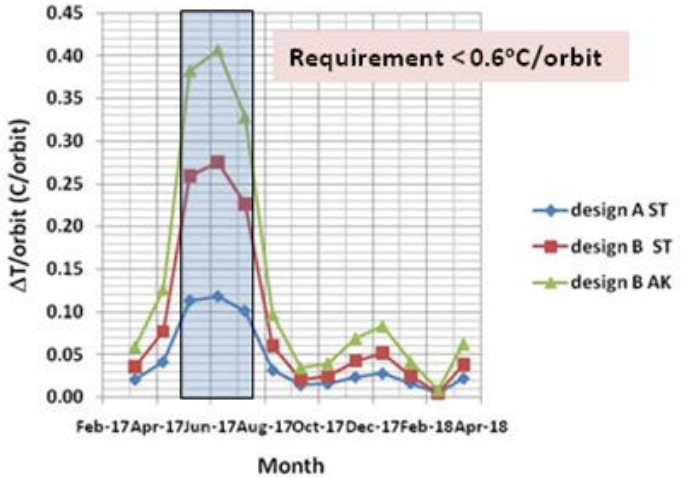
RFE

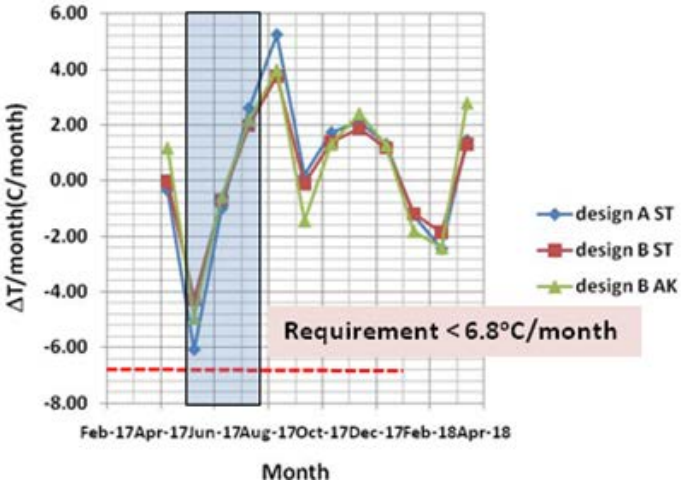


- Inversely proportional to beta angle
- Different slopes observed for eclipse and no-eclipse seasons

RFE Monthly Results: Last Year of Mission

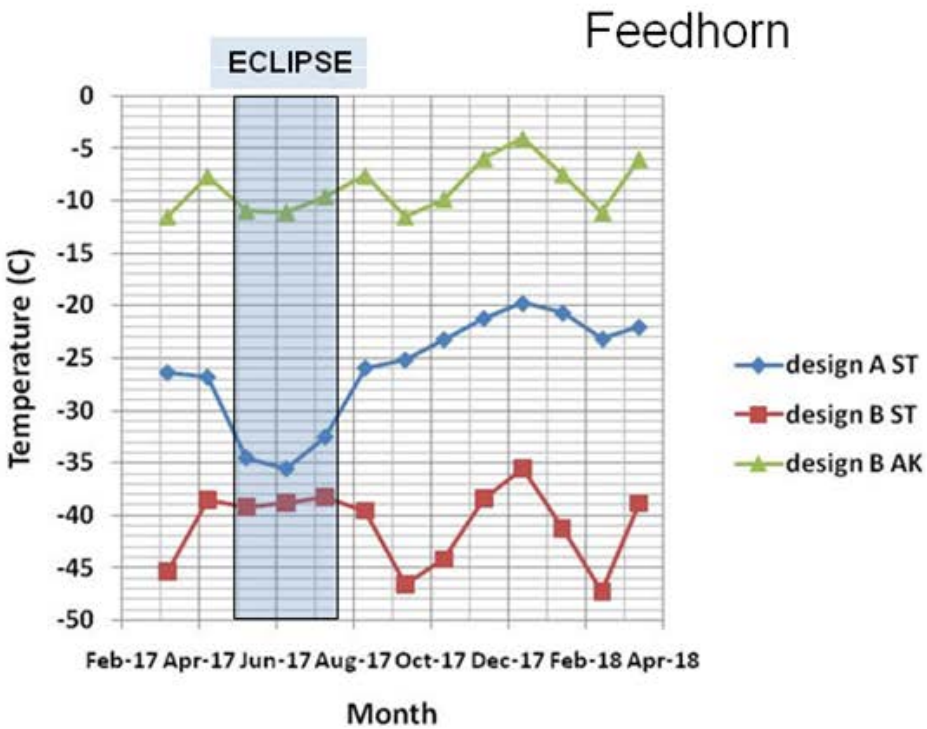


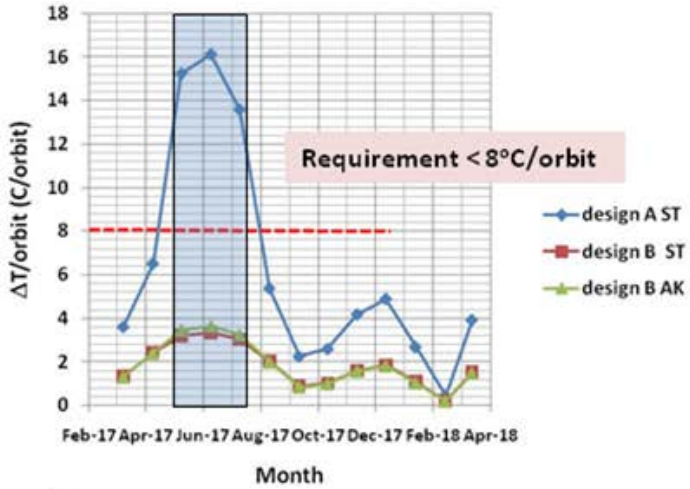


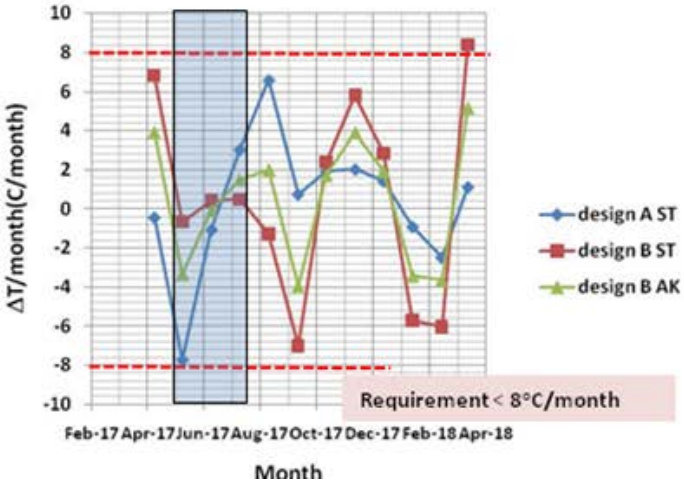


- Meets all orbital and monthly stability requirements for all 3 design cases

Feed horn Monthly Results







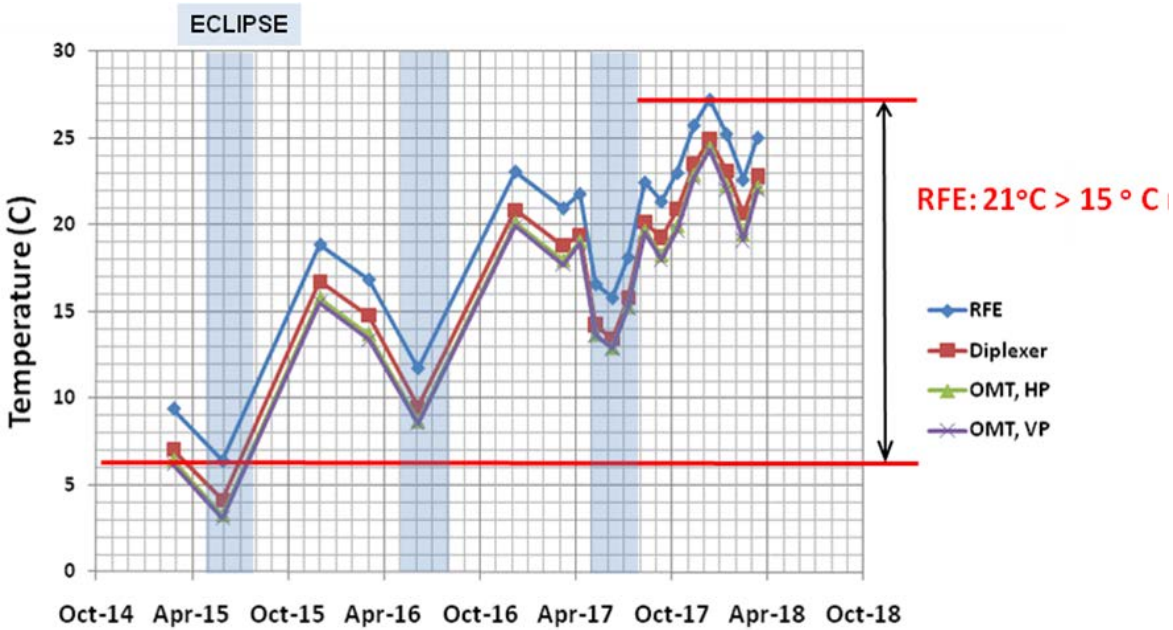
- Exceeds orbital requirement for Design A
- Design B: using ST MLI makes feed horn temperature colder and monthly stabilities worse compared to results with AK MLI

Mission Life Requirement

Nominal environment

- None of 3 designs meets the requirement
- Mitigation Plan
  - Reduce ST EOL α from 0.2 to 0.18
  - Revised Earth IR Flux range of 222 to 243 W/m^2

Design B AK 3 year results



Design	Results	Mitigation
A	24.5°C	18°C
B ST	19°C	12.5°C
B AK	21°C	14.5°C

} Does not meet requirement

Design B AK Compliance Table

Radiometer Component	Zone	Short Term				Long Term			
		dT/dt (°C/min)		dT/orbit (°C/orbit)		Monthly (°C/month)		3 Year Mission Life (°C)	
		Req't	Predict	Req't	Predict	Req't	Predict*	Req't	Predict
RFE	1	0.05[a]	0.025+	0.6	0.47	6.8	5.3	15	21
Diplexers, Cal Noise Source, BP Filters, Couplers	2	N/A	N/A	1.2	0.99	6.9	5.3	15	21
OMT	3	N/A	N/A	2.4	1.93	7	5.4	19	21
Isolator & Feedhorn	4	N/A	N/A	8	4.3	8	5.1	30	21
Radome	5	N/A	N/A	120	38	60	11	100	21
RBE	N/A	0.1[b]	0.053	N/A	N/A	N/A	N/A	N/A	N/A
RDE	N/A	0.5[c]	0.08+	N/A	N/A	N/A	N/A	N/A	N/A
Radiometric Budgets (≤):		0.45 K				2.4 K		0.8 K	

* With IR = 190-250 W/m² as recommended by Aquarius Thermal Team

\+ Includes eclipse period, although not required

Conclusion

- Design A meets all short term and monthly stability requirements except the feed horn
  - The feed horn is exposed to the sun to serve as a radiator

- Design B meets all short term and monthly stability requirements utilizing Silver Teflon or Aluminized Kapton exterior MLI surface

- A passive design was developed to meet all temperature and stability requirements
  - A mitigation plan was developed to meet the 15°C mission requirement

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