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Implementation of Active Thermal Control (ATC) for the Soil Moisture Active and Passive (SMAP) Radiometer

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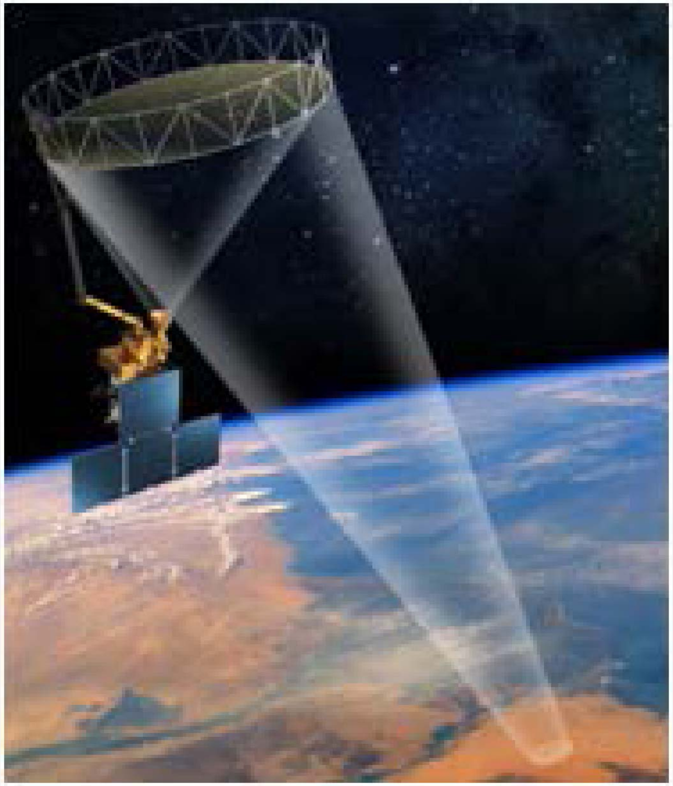
SMAP Mission Objectives



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

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:

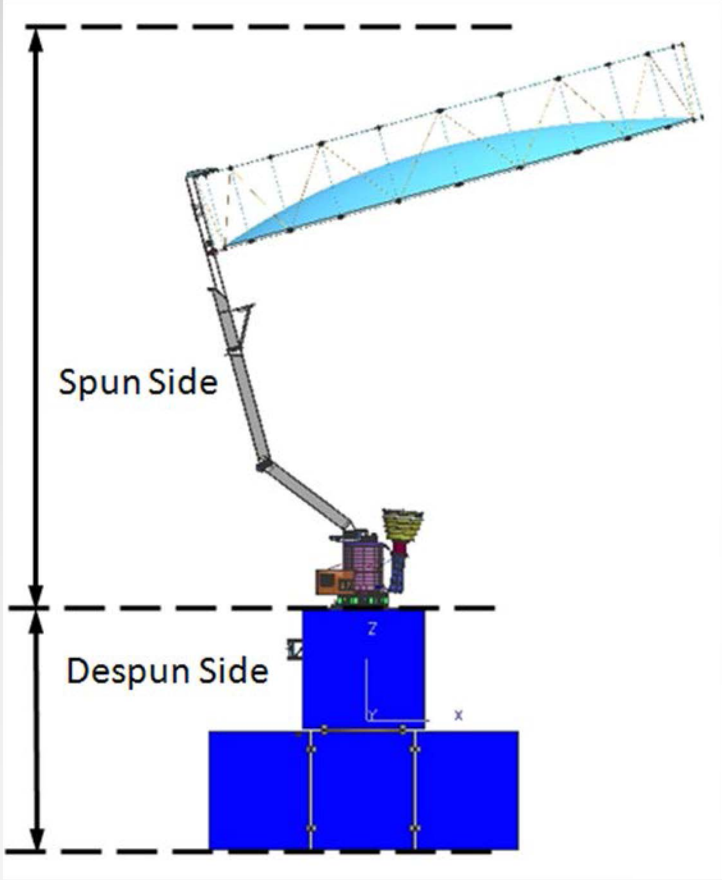
SMAP

- Measures soil moisture and freeze/thaw states
- Single feed horn exposed to the sun
- Spinning platform
- 6m deployable spinning antenna
- 0.7^{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

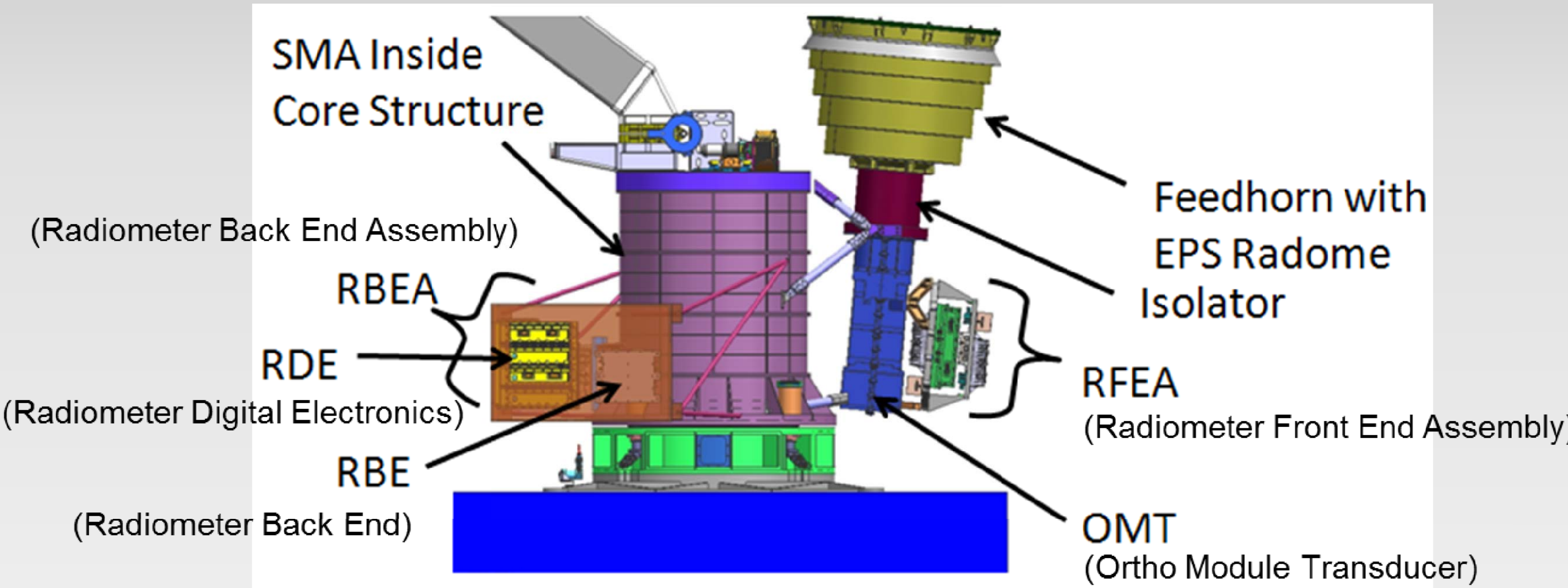
Instrument Configuration



- The L-band radar components are on the despun side of SMAP

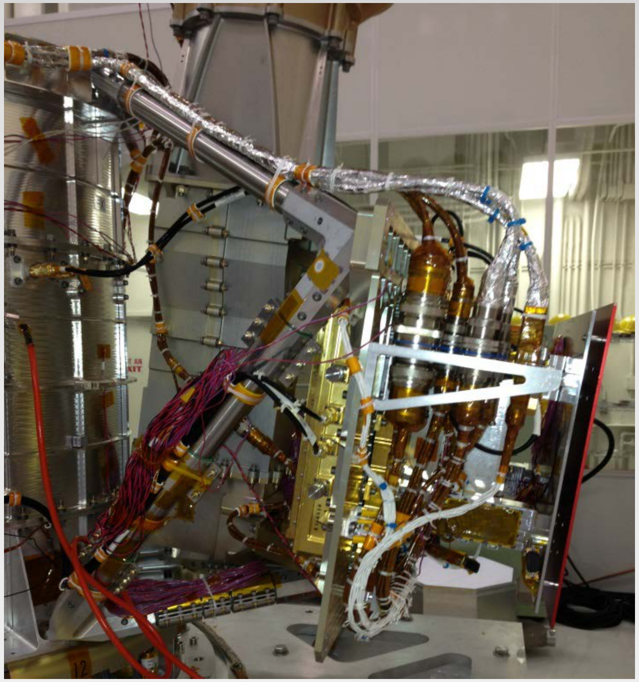
- The L-band radiometer resides on the spun side of the observatory
  - - Cylindrical core structure (CS) houses Spin Mechanism Assembly (SMA)
  - - 4 major assemblies mounted on CS
    - - Reflector Boom Assembly (RBA)
    - - Integrated Feed Assembly (IFA)
    - - Radiometer Back End Assembly (RBEA)
    - - Instrument Control Electronics(ICE)

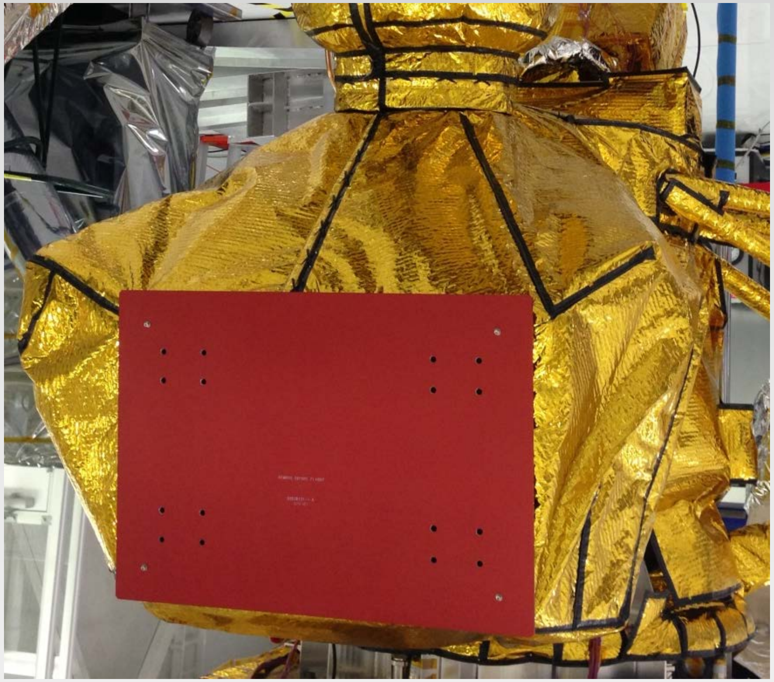
Radiometer Configuration



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

RFEA Configuration



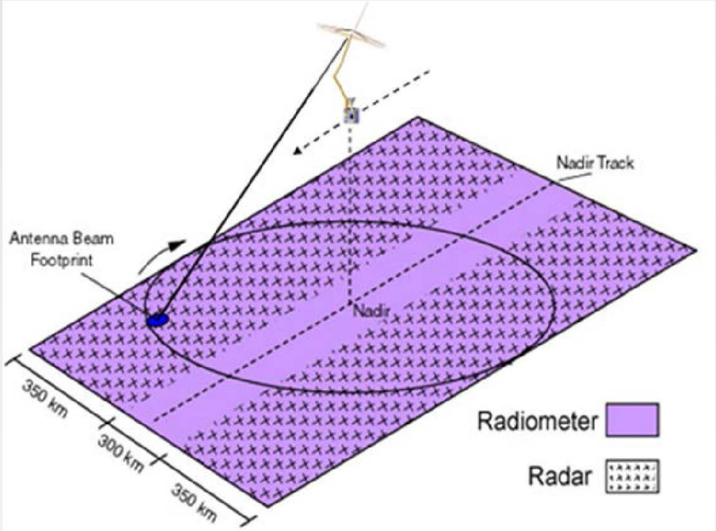


- RFE is the component with the tightest thermal stability requirement
- MLI cocoon is implemented around the RFEA
  - Isolates components from the environment

Derivation of Thermal Stability Requirements

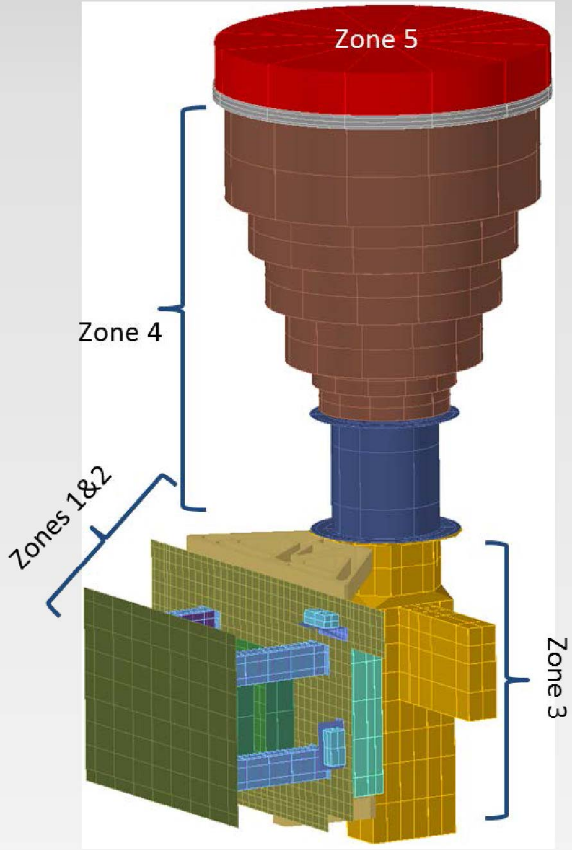
Soil moisture error budget → Antenna temperature calibration → Feed to Electronics input and RF loss and emission → Brightness temperature

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



Thermal Requirements

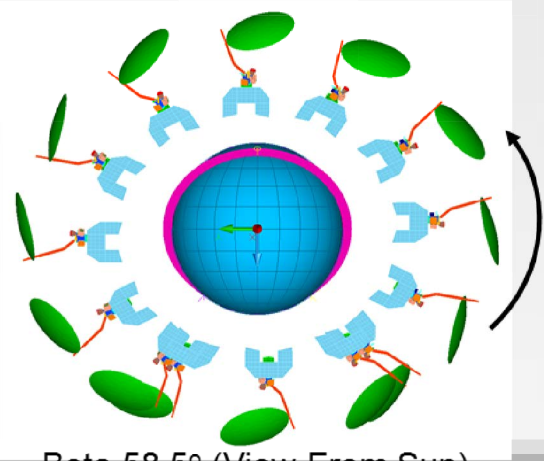
Radiometer Component	Zone	Short Term		Long Term	
		dT/dt (°C/min)	dT/dt (°C/orbit)	Monthly (°C/month)	3 Year Mission Life (°C)
RFE	1	0.05	0.7	4	4
Diplexers, Cal Noise Source, Couplers	2	N/A	2	10	10
OMT	3	N/A	3	10	15
Isolator & Feedhorn	4	N/A	8	20	60
Radome	5	N/A	170	60	170
RBE	N/A	0.1	N/A	N/A	N/A
RDE	N/A	0.5	N/A	N/A	N/A



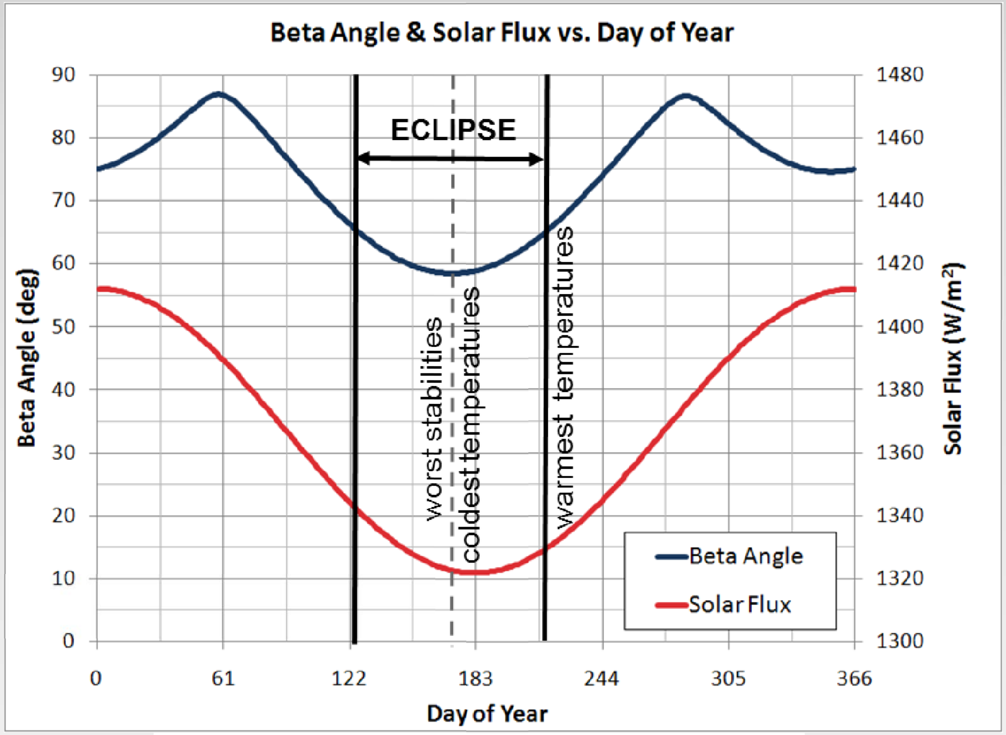
Thermal Environments

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

ATC Implementation

- ATC implemented to adjust RFE temperature set point due to undetected gain glitches
  - Short term stabilities are met passively

- Instrument Thermal tasked with delivering the ATC algorithm to Boeing for implementation into ICE

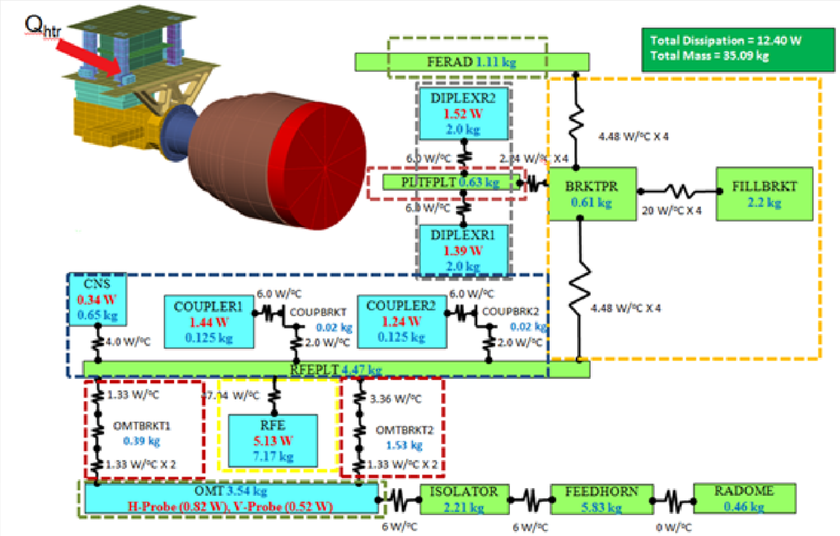
- Peer Review held to confirm recommended algorithm was sufficient for delivery to Boeing
  - Effects of ATC implementation on stability performance
  - All sources of error addressed in modeling and resulting algorithm selection

Thermal Models

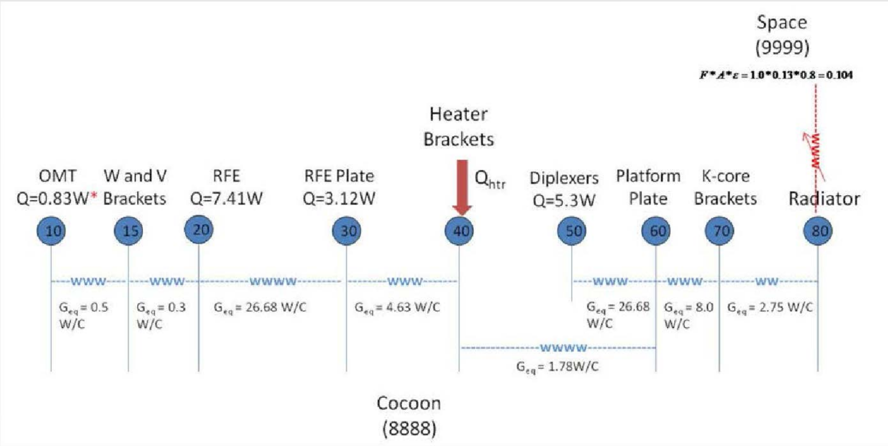
- ThermXL is an excel-based thermal model

- Used ThermXL to perform quick algorithm trade studies (10 minutes) compared to the detailed Thermal Desktop model (4 hours)

Thermal Desktop



ThermXL



Radiative coupling to Cocoon not modeled

Algorithm Options

Proportional-Integral-Derivative Control

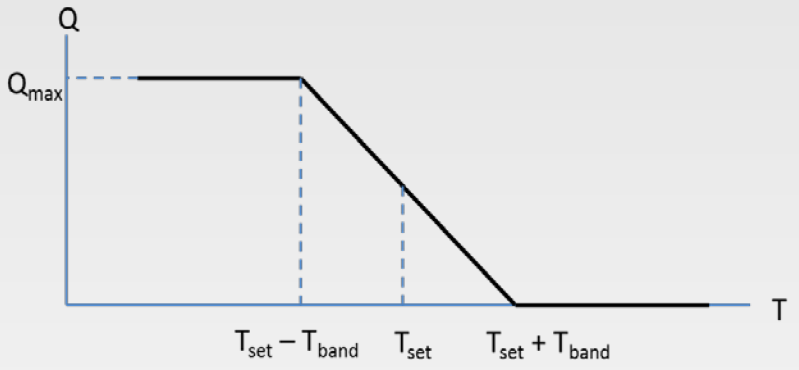
$$Q \propto K_p \times (T_{set} - T) + K_i \times \int (T_{set} - T)dt + K_d \times \frac{d(T_{set} - T)}{dt}$$

Proportional Control

$$Q = K_p \times (T_{set} - T)$$

Modified Proportional Control

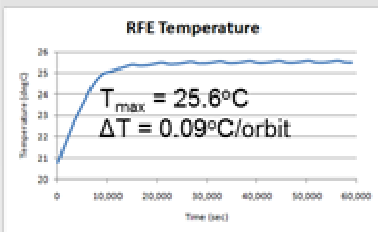
$$Q = K_p \times (T_{set} - T) + C_{offset}$$



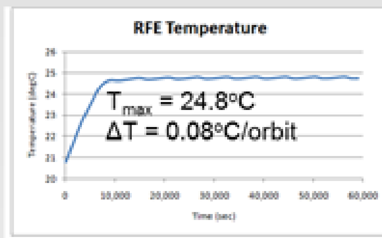
Algorithm Selection

$T_{set} = 25^oC$ $T_{initial} = 20.8^oC$

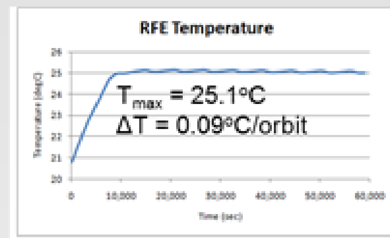
Modified P-control
$T_{band} = \pm 1^oC$
$K_p = 5$ W/C
$C_{offset} = 5$ W



P-control
$K_p = 10$ W/C
$K_i = 0$ W/C-s



PI-control
$K_p = 10$ W/C
$K_i = 0.001$ W/C-s



- Modified P-control is good enough to meet all stability requirements
- Q_{max} (26W) not large enough to benefit from K_i term for PI control
- Not dependent on time therefore no memory of previous temperature needed
- No reset problem
- Easy to change the set temperature
- Short term stabilities and temperature variations could be improved by tightening T_{band}

Sources of Error

- Temperature Sensor

Description	Comments	Value
Thermistor Tolerance	Tolerance included in specification to vendor. Value will be known at installation since calibration curves provided.	N/A
Harness	Interested in relative temperature readings as opposed to absolute. Can be calibrated out.	N/A
mA current source	0.005mA value is assumed negligible.	N/A
12-bit ADC	Absorbed in sampling rate.	N/A
12-bit coefficients	Temperature sensor quantization error based on thermistor selected.	TS Quantization = 0.0335ºC/count
Delays	Absorbed in sampling rate. Not concerned due to large thermal mass.	Sample Rate = 30 seconds
Noise	Not modeled.	N/A

- Heater

Description	Comments	Value
Heater Tolerance	Tolerance included in specification to vendor. Value will be known at installation.	N/A
Harness	Can be calibrated out.	N/A

- Controller

Description	Comments	Value
12-bit DAC Voltage	Heater quantization error. Voltage variation of 29.5V ± 6%.	Heater Quantization = 0.007326V/count

ThermXL Algorithm Trade Studies

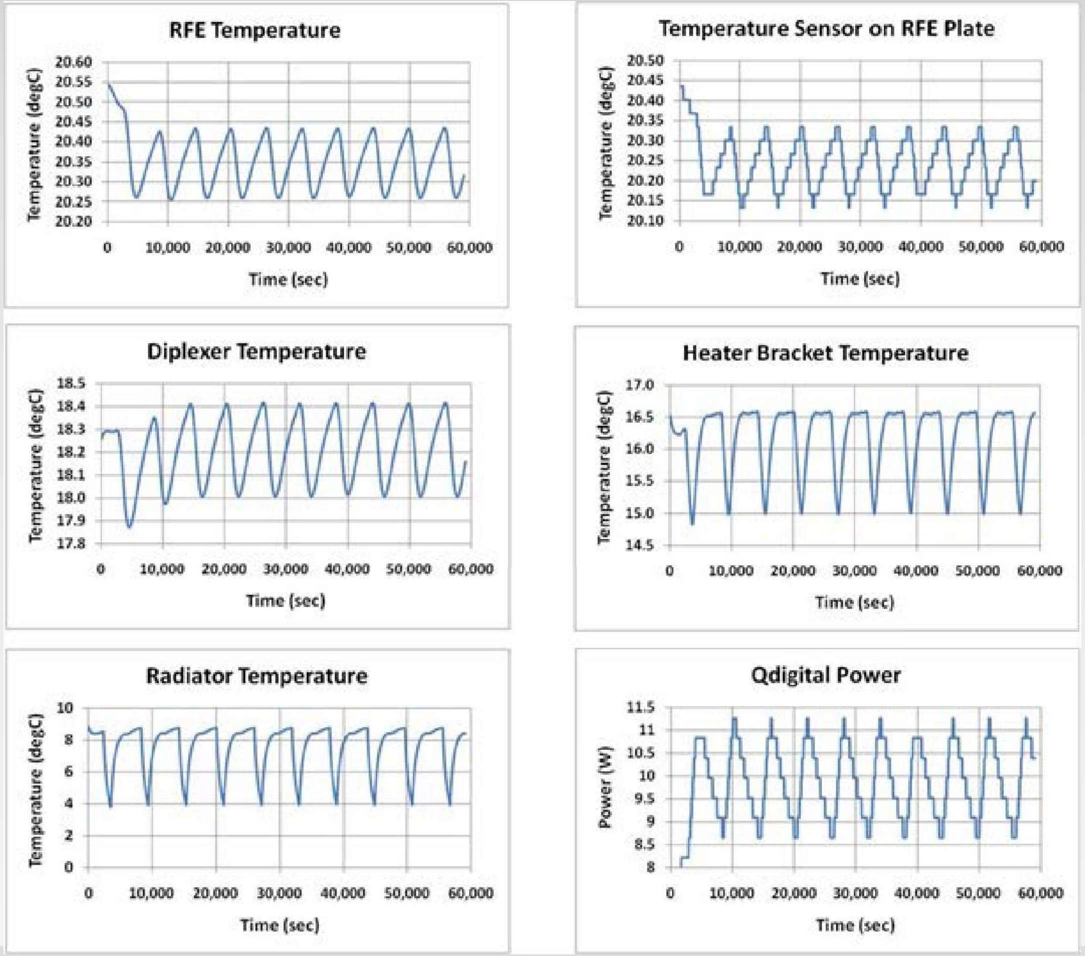
- Simple model performs rapid studies to determine Modified P algorithm effects
  - - Quantization of temperature reading and applied voltage for heater power
  - - Gain margin
  - - T_{band} (error band)
  - - Voltage variation

- Examined by comparing orbital stability of RFE (most sensitive component) for the worst case variation in environmental conditions (58^{o} with hot conditions) with a temperature set point of 20^{o}C (most likely initial set temperature)

Quantization Effects

- Digitization step value of operational heater depends on Q_{max} and T_{band}
    - Heater size = 26W
    - 0.43W per step for T_{band} = 1.0°C

- No significant impact of RFE orbital stability due to digitization of Q



Gain Margin and Error Band Effects

- For the Modified P algorithm, the gain is proportional to the heater power.

- To demonstrate gain margin and its effects on temperature stability, an increase in 26 W heater power was modeled, although not physically possible

- No significant improvement in thermal stability (>0.03°C/orbit) until at least at least 4X 26 W for T_{band} of 1.0°C and 2X 26 W for T_{band} of 0.1°C

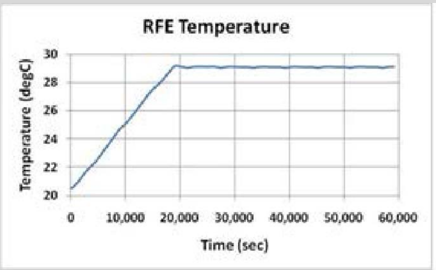
Q_{htr} [W]	Predicted Stability [°C/orbit P-P]	
	±1°C T_{Band}	±0.1°C T_{Band}
0	0.160	0.160
10	0.166	0.135
26	0.175	0.079
52	0.166	0.035
104	0.137	0.034

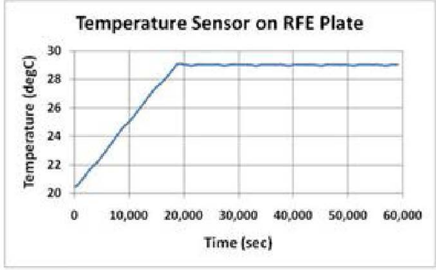
Voltage Variation Effects

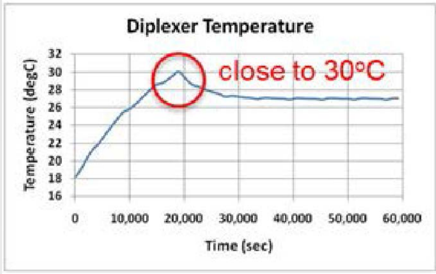
- Voltage variation of 29V ±6% effects the stability by approximately 0.06°C/orbit with T_{band} of 1.0°C, but it can easily be absorbed since the design includes large margins

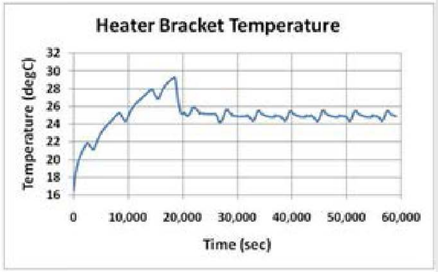
- One concern is the overshoot on nearby components due to the offset between the heater and temperature sensor locations

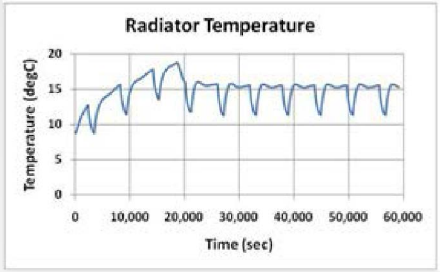
Q_{max}	T_{band}	V_{var}	Overshoot Temp, °C			dT/dt	dT
W	+/- °C	+/- %	Heater	Diplexer	RFE	°C/orbit	°C/orbit
26	0.1	0	4	3	0.1	0.071	0.04
26	0.1	6	6	4	0.1	0.111	
26	1.0	0	3	2	0	0.173	0.06
26	1.0	6	5	3	0	0.231	

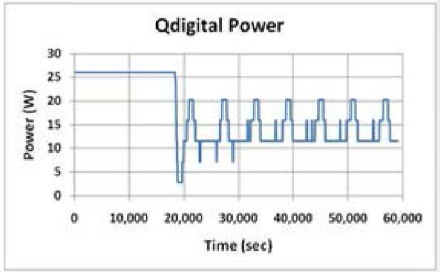












Conclusions

- 10-node ThermXL model allows a quick and detailed parametric study of ATC with Modified P-control
  - - Over 200 ThermXL model scenarios were evaluated to demonstrate that the ATC implementation does not violate temperature stability requirements
  - - ATC implemented to adjust RFE temperature set point due to undetected gain glitches

- Digitization errors in the temperature sensor reading and applied heater powers were shown to be insignificant

- Short term stabilities are effected using ATC with T_{band} of 1.0°C but improved with T_{band} of 0.1°C

- Voltage variation of 29V ±6% effects the short term stability by approximately 0.06°C/orbit with T_{band} of 1.0°C, but it can easily be absorbed since the design includes large margins (0.32°C/orbit vs. 0.7°C/orbit for RFE)