Appendix T

Thermal Design and Analysis of the BroadBand Radiometer

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Abstract

The Broadband Radiometer is being designed and built by a UK consortium to fly on ESAs EarthCARE mission. The Rutherford Appleton Laboratory is responsible for the thermal, mechanical and optical design as well as procurement of critical components. The thermal design has undergone much iteration over the course of 2008. The thermal, mechanical and optical models have now converged on a solution that is being put forward for System Requirements Review in November 2008. Key challenges faced by the thermal design include overcoming the high Earth and albedo loads of a low orbit to passively cool internal black bodies to -10°C and achieving tight stability requirements on the three telescope assemblies. ESARAD and ESATAN models were created to model the low earth orbit radiative environment and the instrument thermal design.

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Thermal Design and Analysis of the BroadBand Radiometer

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Thermal Engineering Group
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Overview

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2. Instrument Overview
3. BBR Thermal Problem
4. Thermal Design Philosophy
5. ESARAD Geometric Modelling
6. ESATAN Thermal Modelling
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8. Modelling Issues
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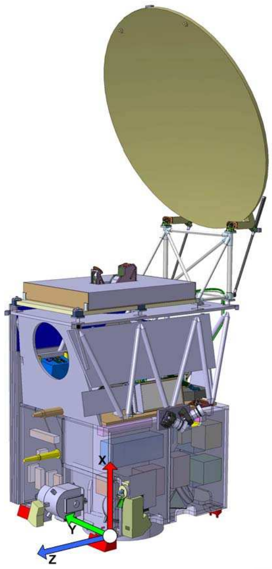
Introduction

- EarthCARE
- Earth Clouds Aerosols and Radiation Explorer
- Launch 2012
- Four instruments on board
  - Cloud Profiling Radar (ESA/JAXA)
  - Multi-Spectral Imager (SSTL)
  - Atmospheric Lidar (Astrium SAS)
  - BroadBand Radiometer (UK consortium)
- Science goals:
  - quantifying aerosol-cloud-radiation interactions to improve climate and numerical weather forecasting



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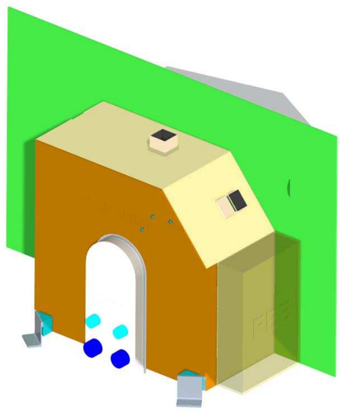
Instrument Overview

- Measures top of atmosphere radiances
- BBR is a mission critical EarthCARE instrument
  - Top of atmosphere radiances taken by BBR serve as a consistency check for the cloud radiance properties taken by the other active instruments

- BBR UK Consortium led by SEA Ltd
- SEA
  - Project management, systems engineering, software
- RAL
  - Thermal, mechanical and electronic design, AIT, procurement of critical components e.g. black bodies, detectors
- Sula Systems
  - Motors and Mechanisms



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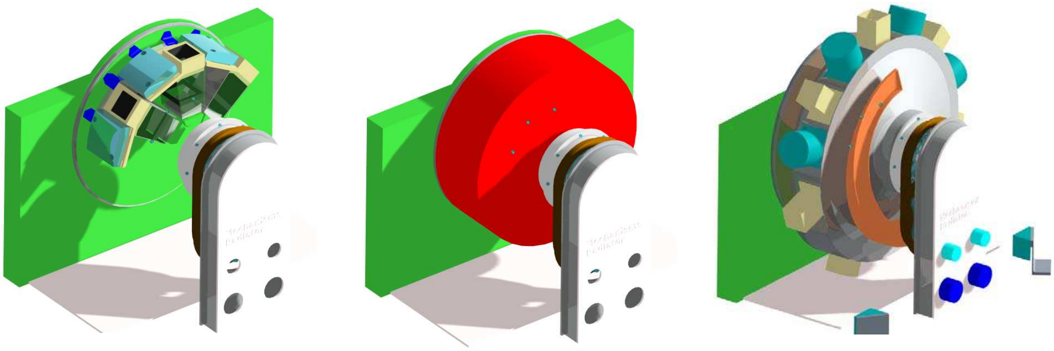
Instrument Overview

- 3 telescopes measure top of atmosphere radiance with forward, aft and nadir views
- Chopper drum slices the telescopes view
- References sources are provided by the on-board black bodies and a solar view
- Calibration drum slews round to provide views to the calibration sources



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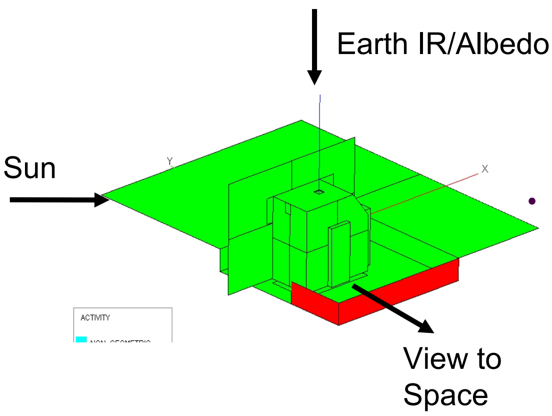
BBR – Thermal Problem

- Requirements Summary:

Component	Absolute temperature	Stability
	(deg C)	(mK/min)
Cold Black Body	-10	n/a
Hot Black Body	28	n/a
Chopper drum	n/a	77
Mirrors	n/a	390
Baffles	n/a	5
Detectors	-10	5



- Key challenges of thermal design
  - Low Earth Orbit (385km) so high Earth IR and Albedo Loads
  - Non-Optimal placement of instrument on spacecraft
  - Internal power dissipations of between 10-17W
  - Radiator size/location restricted by instrument volume envelope

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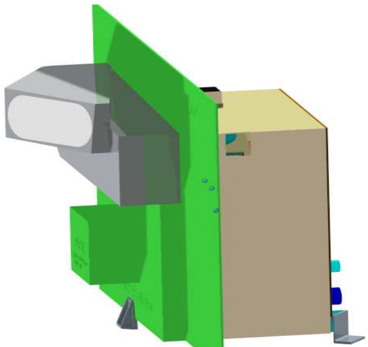
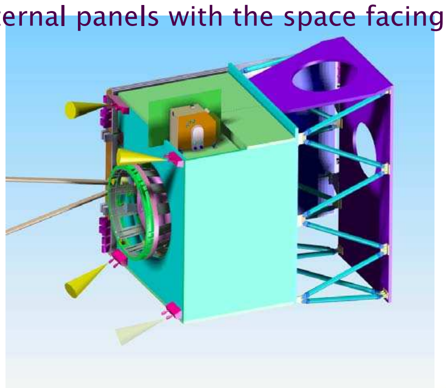
Thermal Philosophy

- Cold-biased design
- Passively cool instrument to -20˚C (includes 10˚C uncertainty margin)
- Use of heaters on telescopes and black bodies to achieve absolute temperatures and thermal stability
- Thermally isolate motors and electronics boxes as far as possible
- Minimise conductance to spacecraft interface
- Maximise radiator area on all external panels with the space facing panel oversized as required





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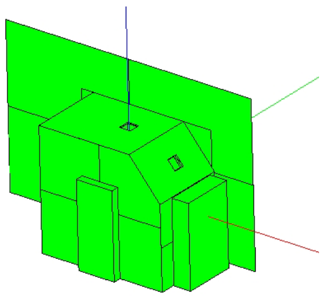
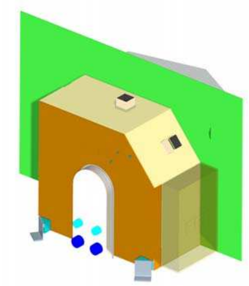
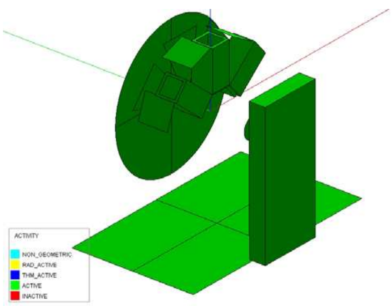
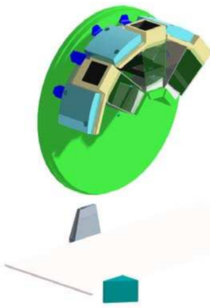
GMM

- ESARAD v6.2
- Created manually from examination of CAD model
- GMM updated as the Solid CA model evolved
- Orbit
  - Low/hot case 385km
  - High cold case 402km
  - 97˚ inclination









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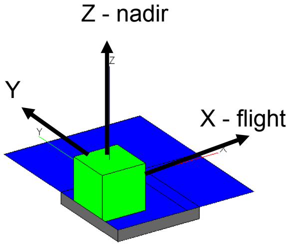
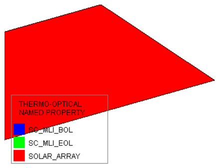
GMM

- Used simplified ESARAD GMM to understand external radiative environment
- BBR panels represented as a box



Panel	Solar Total	Albedo Total	Earth Total	Sum of Incident Loads	Steady State Temperature
	(W)	(W)	(W)	(W)	(deg C)
+Z	0.86	2.50	28.36	**31.7**	**-15.0**
-Y	0.21	1.28	10.19	**11.7**	**-41.0**
+X	3.34	1.55	10.73	**15.6**	**-25.0**
+Y	3.63	1.52	10.53	**15.7**	**-25.0**
-X	3.48	1.00	9.31	**13.8**	**-36.0**



- Very high Earth IR
- High Albedo
  → Focus on minimising absorbed Earth loads
  → For radiators low absorptivity more important than high emissivity
- All panels (except +Z) could be used as useful radiator area

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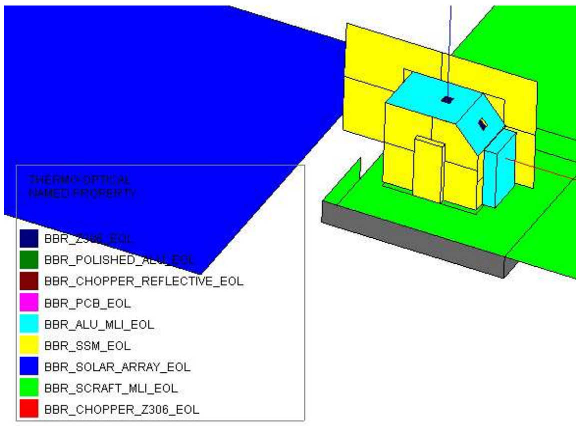
GMM

- Radiator
  - 0.78m x 0.31m
  - Mounted on +Y panel due to volume envelope constraints
- All panels as radiator except +Z
- MLI on +Z panels

- Assumed thermo-optical properties:
- Radiating Surface
  - Secondary surface mirrors
  - ε = 0.81, α = 0.12-0.15

- Internal surfaces
  - black paint
  - ε = 0.84-0.94, α = 0.96

- MLI
  - aluminised kapton
  - ε = 0.05, α = 0.14
  - Effective emissivity 0.02



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TMM

- ESATAN v10.2
- 108 thermal nodes
- 175 linear conductors
  - manually generated rather than ESARAD
- 3212 ESARAD radiative couplings
- Material properties taken from Thermal Group database
- Values for contact conductance based on standard assumptions

- Stability heaters
  - Modelled with ON/OFF control
  - Narrow set-points required to achieve stability (0.01degC)
  - Heaters on each of the 3 telescope assemblies

- Survival heaters
  - Modelled with wider set-points (5deg C)
  - Mechanical thermostats

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Predictions

- Summary of steady state predictions (extreme hot case, no heater control)

Label	Temperature (deg C)	
	Hot Case Nominal	Cold Case Nominal
Mechanism Housing	-6.75	-20.15
Nadir Mirror Assembly Base	-24.62	-38.51
Nadir Mirror	-24.62	-38.51
Nadir Mirror Mount	-24.62	-38.51
FPA - Nadir	-24.30	-38.18
Nadir FPA Mount	-24.44	-38.32
Nadir Internal Baffle Assembly	-24.65	-38.54
Black Body	-21.34	-35.67
Calibration Drum	-21.59	-35.80
Aluminium Base Plate	-26.32	-40.93
+X Panel	-26.22	-40.77
+Y Radiating Panel	-28.53	-42.46
+Z Sloped Panel	-26.75	-41.17
-X Radiating Panel	-27.55	-41.85
-Y Radiating Panel	-26.50	-41.18

- Good margin demonstrated on cooling of black bodies
- ≈15deg C between nominal hot and cold cases
- Thermally isolated mechanisms run ≈ 15-20deg C warmer

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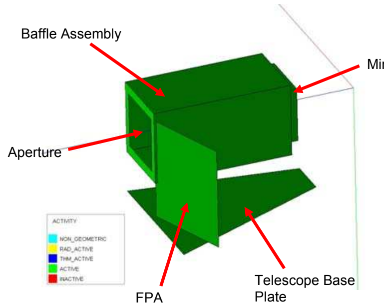
Predictions

- Summary of stability heaters

Heater Location	Power (W)	Duty Cycle (%)	Upper Set-point (deg C)	Lower Set-point (deg C)
Forward Telescope Assembly	4.00	77	-10.00	-9.99
Nadir Telescope Assembly	4.00	77	-10.00	-9.99
Aft Telescope Assembly	4.00	77	-10.00	-9.99
Cold BB1	1.75	5	-10.00	-9.99
Cold BB2	1.75	5	-10.00	-9.99
Hot BB1	1.75	78	27.99	28.00
Hot BB2	1.75	78	27.99	28.00

- Predicted stabilities

Component	Predicted Stability (mK/min)	Requirement (mK/min)
Telescope Assembly Base	33	n/a
Mirror	9	390
FPA	3	5
Baffle	4	5
Chopper Drum	34	77



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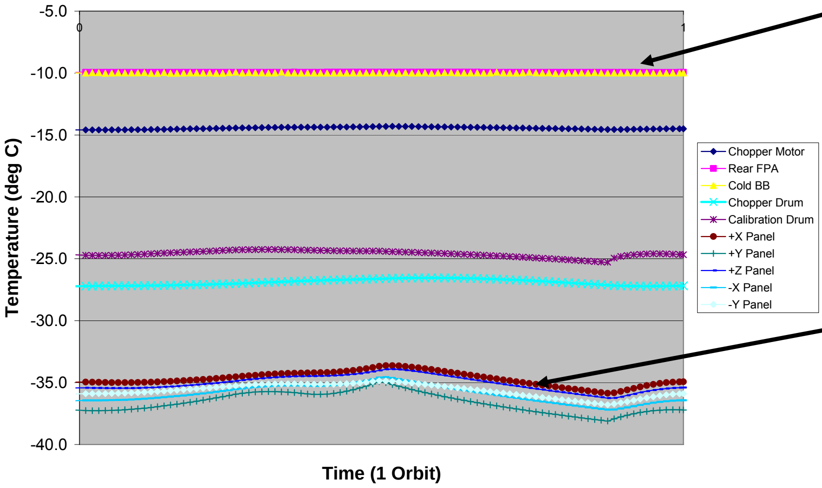
Predictions



Control Heaters stabilise temperatures of BB's and Telescope Assembly

Rest of instrument still subject to orbital variations

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Summary

- Thermal Design
  - Low absorptivity SSM's on external panels to cool instrument and minimise effect of Earth IR
  - Oversized +Y panel to achieve margin
    - Currently occupies full volume
  - Software controlled heaters on each telescope to achieve stability requirements on key components
  - Thermal isolation of mechanisms and electronics to reduce heat load on radiator
  - MLI on +Z panels
- Model Predictions
  - BB's at ≈-21˚C in hot case
    - Margin demonstrated in cooling black bodies
  - High heater powers as a consequence of large radiating area
    - Not a huge issue given instrument size
  - Stability requirements predicted to be met

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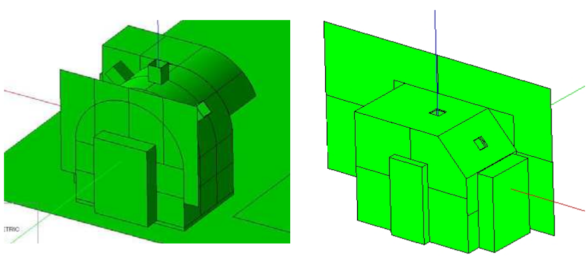
Notes on Modelling

- "Standard" model
- GMM
  - Constantly changing as design progressed
  - Beneficial to have easy and quick manipulation of shells
  - Ability to define shells through parameters useful
    - Could this be expanded to allow definition of reference planes, axes etc..
    - Similar to solid CAD packages



Evolution of BBR GMM

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Further Work

- Current thermal models and results have been submitted for System Requirements Review
- More detailed modelling required:
  - Black bodies (lumped mass assumed thus far)
  - Increase nodal density on primary radiator
  - Sensitivity analysis on key assumptions
    - Conductance from instrument to s/craft
    - Conductance between thermally isolated mechanisms and instrument structure
  - Stability heaters
    - Location
    - Size
    - Control regime
- Specification of
  - Heater circuits and redundancy
  - Temperature sensors and location

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