Appendix C

World Space Observatory-Ultraviolet
Thermal Analysis of Spacecraft Electronics

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Abstract

The World Space Observatory-Ultraviolet (WSO-UV) is an upcoming mission led by Roskosmos that aims to provide a major space observatory operational at ultraviolet wavelengths. RAL Space is working in collaboration with e2v on the World Space Observatory UV Spectrographs (WUVS) instrument, with RAL Space being primarily responsible for the design, build and testing of the Camera Electronics Box (CEB) that drives the instrument.

This work at RAL Space follows on from previous electronics box projects on spacecraft such as the NASA Solar Dynamics Observatory (SDO) and the Geostationary Operational Environmental Satellite R Series (GOES-R). Thermal analysis of the CEB provides a difficult challenge, since in order to be meaningful the analysis must capture the hot spots within the electronics that are caused by high power dissipating components on the printed circuit boards. The thermal characteristics of these components are often poorly defined, which therefore introduces uncertainty in the results. The requirement to de-rate component temperature limits in accordance with product assurance standards such as ECSS adds additional challenge, since it significantly reduces any thermal margin within the design.

With the dissipated heat loads generated by on-board electronics expected to steadily increase as hardware becomes more sophisticated, these are issues that are likely to become more prevalent for future space missions. This talk will examine the rationale behind the modelling of the CEB, discuss possible thermal management solutions and describe the ways in which uncertainty is being defined and accounted for within the analysis.

World Space Observatory-Ultraviolet (WSO-UV)

Thermal Analysis of Spacecraft Electronics

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Science & Technology Facilities Council — RAL Space — e2v

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Outline

- WSO-UV Overview
- WUVS Instrument
- Camera Electronics Box (CEB)
- Heritage
- Analysis
- Uncertainty and Mitigation Strategies
- Testing
- Future

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WSO-UV Overview

- Also known as Spektr-UV
- Led by Roskosmos, with European involvement
- Launch currently planned for 2021
- Key objectives:
  - Continue to provide UV observation post-Hubble
  - To improve on Hubble
  - Study formation and evolution of our galaxy
  - Study exoplanet atmospheres and transits
- Contains a suite of instruments, including the WSO-UV Spectrographs (WUVS)
  - e2v are designing the cryostat and CCD assembly, RAL Space are designing the camera electronics box (CEB)

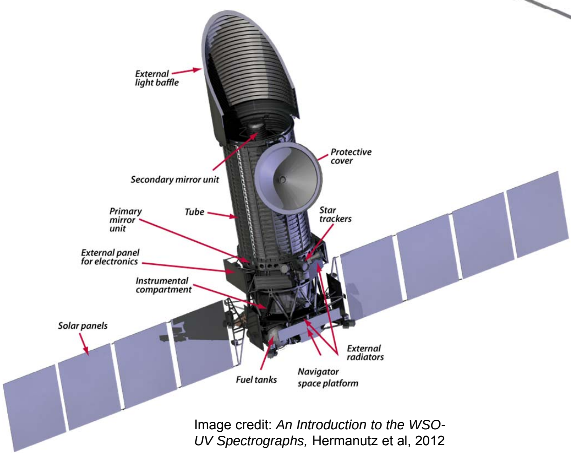

Image credit: *An Introduction to the WSO-UV Spectrographs,* Hermanutz et al, 2012

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WUVS Instrument

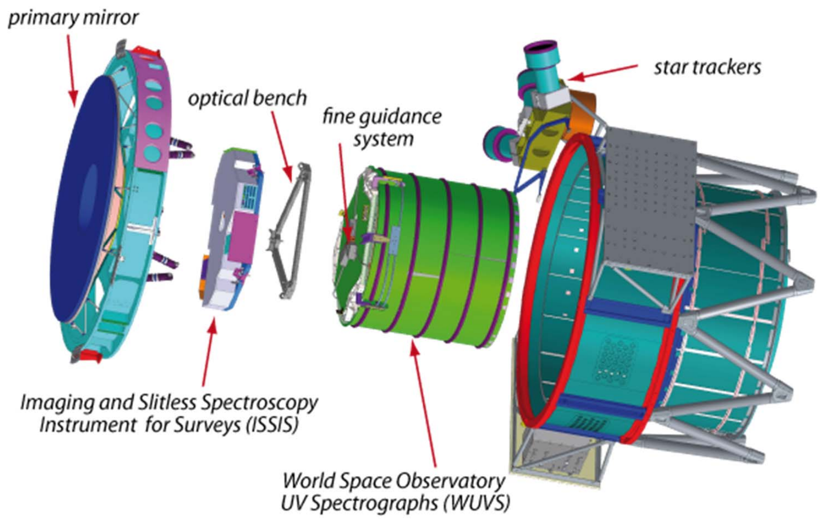

Image credit: WSO-UV Spanish Team Web Page: *http://www.wso-uv.es/index.php?id=12*

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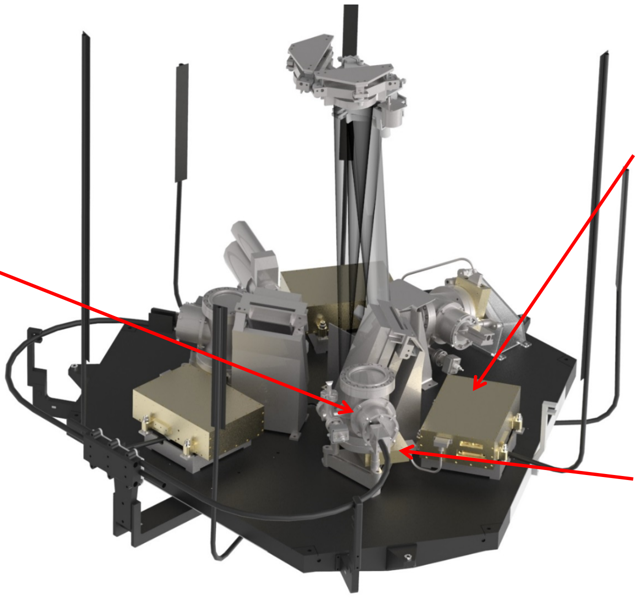
WUVS Instrument



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RAL Space Heritage

- NASA Solar Dynamics Observatory (SDO)
  - Provided flight electronics for two of three instruments
- NASA Geostationary Operational Environmental Satellite – R Series (GOES-R)
- Initially planned to re-use the GOES-R design for the WSO CEB
  - Unfeasible due to ITAR restrictions

Image credit: NASA

GOES-R Camera Electronics Box

Image credit: NASA

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Camera Electronics Box (CEB)

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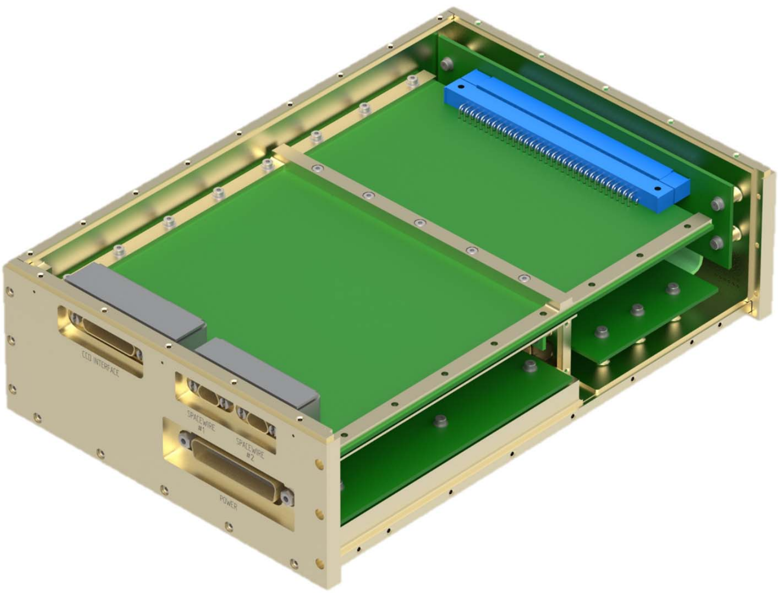
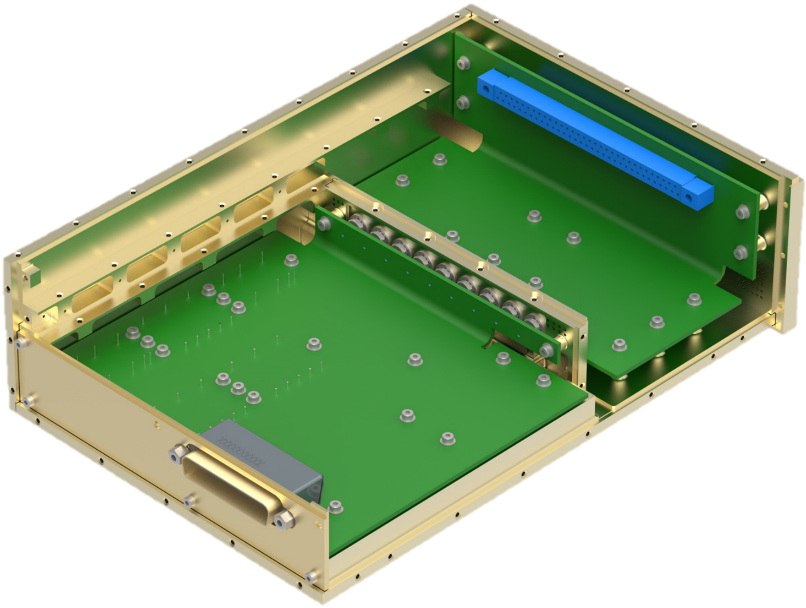
Camera Electronics Box (CEB)



Camera Electronics Box (CEB)



Thermal Challenges

- The CEB sits on a thermal plate that varies between -25 ºC and 50 ºC during the mission
- The total power dissipation for the CEB is 14.7 W
  - This must be conducted away via the base
  - Radiated heat flows to/from the CEB are assumed negligible
- The PCB components have defined temperature limits, which are then de-rated by 40 ºC according to ECSS standards
- Compliance with this must be analytically demonstrated, with qualification and uncertainty margins included
- The analysis must therefore capture the hot spots on the CEB caused at the components

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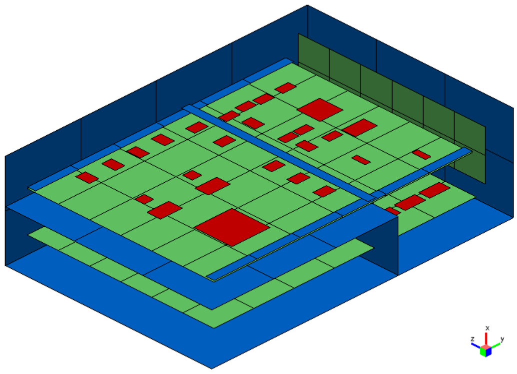
Thermal Model

- Constructed using ESATAN-TMS r7sp2
- Submodels representing the structure and each of the PCBs
- Simple ‘Enclosure’ type radiative case to capture radiative couplings
- Conservative modelling rationale
  - Lots of uncertainty in modelling PCB components



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PCB Modelling

- In-plane thermal conductivity is calculated as a function of copper thickness (t_{Cu}) and overall thickness (t_{Ov}):

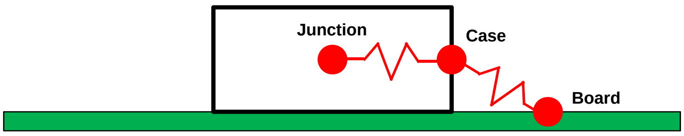
$$k = 385\frac{t_{Cu}}{t_{Ov}} + 0.87$$

Experimental Determination of Thermal Conductivity of Printed Wiring Boards, K. Azar and J.E Graebner, 1996

- Through-thickness conductance is ignored due to low thickness
- Conformance coating (ε = 0.878) is assumed

Component Modelling

- Components with either large surface area or large power dissipation are modelled.
  - Smaller components are accounted for by applying their dissipations directly to the PCB
- Each component comprised of junction (where heat is generated) and casing.
  - Junction-to-case conductance generally found in datasheets (although not always!)
  - Case-to-board conductance rarely found, and therefore estimated

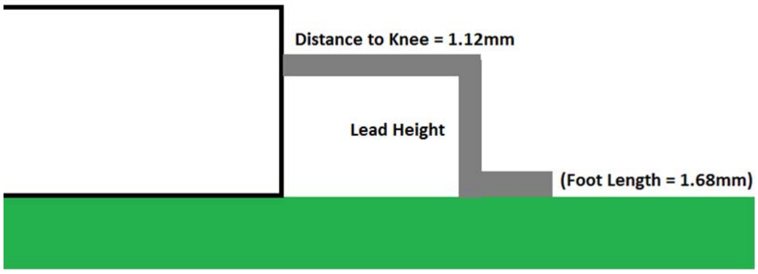


Case-to-board Conductance

- Estimated based on the number of pins and pin dimensions:

$$G = \frac{kA}{L} \times n$$

- Kovar (16 $Wm^{-1}K^{-1}$) assumed for all pins
- Area and number of pins varies from component to component
- Pin lengths are estimated based on the bending jig that RAL uses



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Uncertainty

- There are large uncertainties in this method, due to a lack of information from component manufacturers
- Characterising this in simple terms is difficult, because it varies from component to component
- In accordance with MIL-STD-1540, an uncertainty margin of +17 ºC has been applied
  - Based on experimental data
  - General practice on instrument projects until a thermal balance test has been performed

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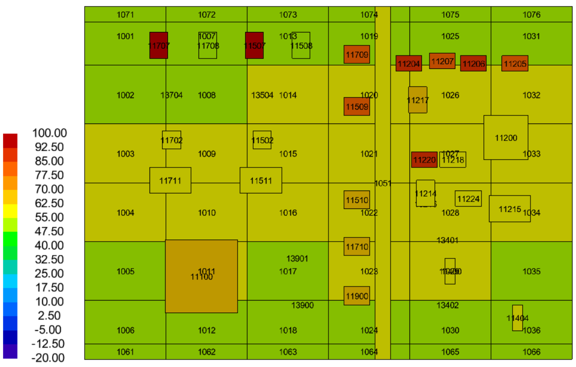
Results

This uncertainty presents issues, as some of the components are predicted to be within this margin during the hottest case (thermal plate at 50 ºC)



Component	Case Temperature (ºC)	Junction Temperature (ºC)	Derated Maximum Junction Temperature (ºC)	Junction Margin (ºC)
IC100	66.2	70.9	85	14.1
IC200	62.2	62.7	85	22.3
IC204	87.9	95.6	110	14.4
IC205	84.6	91.6	110	18.4
IC206	88.2	95.9	110	14.1
IC207	83.7	90.3	110	19.7
IC214	56.4	56.4	85	28.6
IC215	57.3	58.2	85	26.8
IC217	68.6	69.3	110	40.7
IC218	60.2	60.8	110	49.2
IC220	88.0	95.3	110	14.7
IC224	59.2	59.8	110	50.2
IC400	61.5	62.8	85	22.2
IC404	60.6	61.9	85	23.1
IC502	59.4	65.4	110	44.6
IC507	94.5	97.0	110	13.0
IC508	54.4	54.4	110	55.6
IC509	79.7	81.2	110	28.8
IC510	67.9	68.6	110	41.4
IC511	60.4	63.1	85	21.9
IC702	59.1	65.1	110	44.9
IC707	94.2	96.7	110	13.3
IC708	53.9	53.9	110	56.1
IC709	78.4	79.8	110	30.2
IC710	68.5	69.3	110	40.7
IC711	60.1	62.8	85	22.2
IC900	68.9	69.7	110	40.3

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Mitigation Strategies

- Thermal filler
  - Improves case-to-board conductance, and analysis suggests significant temperature reductions
  - However it's messy and complicates the assembly process
- Testing
  - Conduct a thermal balance case during qualification thermal vacuum testing
  - Determines suitability of uncertainty margin

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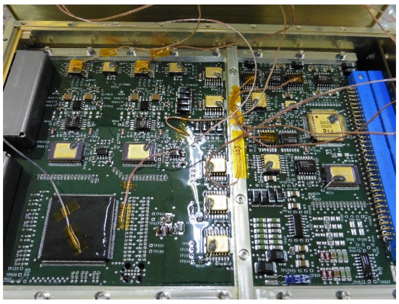
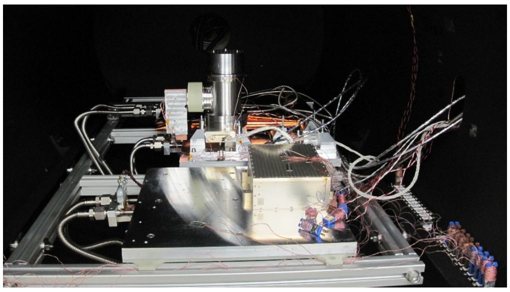
Testing

- Test carried out last month on Engineering Qualification Model (EQM)
- Thermocouples attached to problematic components
- Results demonstrate compliance with requirements, and components were cooler than the analysis predicted
  - Analysis too pessimistic?
  - Uncertainty approach unsuitable?





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Future

- The thermal balance case has confirmed that thermal filler is not required for the flight model
- Correlation of thermal model required
- Future approach for uncertainty is challenging
  - Root sum squared (RSS)? $\Delta T_i = \sqrt{\sum_{k=1}^{n_p} \left(\Delta T_{p,k}\right)_i^2}$
  - Difficult to accurately characterise individual sources of uncertainty

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