| Solar-B<br>EIS<br>*<br>EUV<br>Imaging<br>Spectrometer | CCD Characterisation |
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# 1 Introduction

## 1.1 Scope

This document describes the characterisation measurements to be conducted on the Engineering model and the Flight model CCDs which will be used on Solar-B EIS. The purpose of these measurements is to derive a matrix of imaging characteristics which can be used to select the two best CCDs for flight.

The results will also contribute to the overall calibration of the system although the majority of the calibration measurements will be taken during the instrument calibration stage at the Rutherford Appelton Laboratory.

## 1.2 Abbreviations

ROE Read Out Electronics

## 1.3 Test procedures

The majority of the measurements will be conducted using the Read Out Electronics designed for INTEGRAL. There are a number of reasons for this:

1. The INTEGRAL electronics (or slightly modified versions of it) has formed the basis of the SXI test equipment. Thus, it is a validated design.
2. The Solar-B EIS ROE is designed to be operated in proximity to the CCD itself. This means that to operate the CCD in the test camera facility the ROE themselves must be place in the vacuum chamber. Thus, measurements will not be possible until the flight electronics are available.

However, a sub set of the overall CCD tests must be conducted using the Solar-B EIS ROE to ensure that the imaging behaviour of the CCDs is identical using either set of electronics.

## 1.4 Referenced Documents

[1] Protection of electrostatic sensitive devices *MSSL/EE/PS/H001.02*

[2] Receipt of CCDs *MSSL/PA/PS/H001.02*

[3] INTEGRAL OMC ROE design OMC/MSL/51000/TNO/001

[4] Contamination Control Plan for CCD Test Chamber #2 *Draft 0.A*

[5] Test plan for the measurement of charge transfer inefficiency in the Solar-B EIS CCD cameras MSSL/SLB-EIS/SP32.01

[6] Quantum Efficiency Test Plan MSSL/SLB-EIS/SP33.01

# 2 General Operating Procedure

## 2.1 Operating the Chamber

### 2.1.1 Adding/removing the CCD to/from the test facilities

The MSSL procedure for the protection of electro-static devices (reference [1]) must be followed at all times. The CCD should be removed from its transport packaging (see ref [2]) and placed into the focal plane array (FPA), described in reference TBD. If there has been any changes to the electronic configuration to the test system (this includes assembly and dissassembly of the connectors to the FPA) then the voltages at each test point shall be checked before connecting up the new CCD.

### 2.1.2 Closing up the chamber

Check that the O ring is free of particles which may affect the sealing of the chamber. Put on the lid and bolt it down. Switch on the pump.

### 2.1.3 Cooling down the chamber

Once the chamber pressure is below $1 \times 10^{-4}$ mbar then the liquid Nitrogen reservoir may be filled. The cold finger should have completely cooled down after about two hours.

### 2.1.4 Warming up the chamber

During warm up of the chamber and the CCD, the CCD must be warmer than the chamber/cold plate temperature (to prevent condensation of contaminants). To ensure this, the heaters next to the CCD will be switched on.

### 2.1.5 Venting the Chamber

Venting the chamber should only be done with the CCD at room temperature or slightly above (up to 30°C) and the $N_2$ reservoir greater than about 10°C to prevent condensation. The $N_2$ reservoir should be at the bottom.

Switch off pump, vent Nitrogen into the chamber once the turbo-pump has slowed down to 50% of its initial speed.

Once the pressure has equalised it will be possible to remove the chamber lid.

## 2.2 The INTEGRAL Camera

A diagram of the test set-up with the INTEGRAL electronics is shown in figure one. This set up is described in reference [3]. An assessment of the contamination requirements can be found in reference [4].

The following components are required for the INTEGRAL camera:

Within the chamber

- Focal plane array

Outside the Chamber:

- INTEGRAL ROE containing three boards: the clocking board, bias board and Analogue to Digital Conversion Boards.
- Bias box.

Optical Bench - to allow the CCD to be illuminated with a series of test targets.

### 2.2.1 To Switch on the CCD and power supplies

The order in which each power supply is switched on is not important. Switch on the bench supplies for the ROE, FPA and CCD jitter/bias box (+38V, +18V, ±5V).

## 2.3 The Solar-B EIS ROE

TBD

# 3 Characterisation of imaging performance

## 3.1 Introduction

Both Flight and Engineering model CCDs will be fully tested at Marconi before delivery to MSSL, and the results included in the deliverable data packs. Test items are:

- Amplifier Responsivity;
- Readout Noise;
- Dark Signal;
- Traps;
- Defects in Darkness;
- Photo-Response Defects;
- Quantum Efficiency (at visible wavelengths);
- Photo Response Non Uniformity;
- Image Area Full Well Capacity;
- Readout Register Full Well Capacity;
- Charge Transfer Efficiency (CTE);
- Chip Alignment;
- Flatness;
- External Visual Inspection.

Thus, Marconi subject the CCDs to a range of tests before delivery. However, the purpose of these tests are to ensure that the CCDs are of flight quality and meet all of MSSL's requirements. Marconi will not be providing a detailed characterisation report on each CCD which could then be used in calibration.

Consequently, the purposes of the characterisation at MSSL is:

- to confirm the Marconi measurements and establish confidence in the behaviour of the CCDs;
- to obtain more detailed information on the behaviour of the devices for a range of operating values.

The measurements at MSSL will consist of characterisation of image quality, and characterisation of the CCD operating values.

## 3.2 Image Quality

### 3.2.1 Flat field and Dark current maps

*Purpose*

The purpose of this measurement is to take a flat field image and a dark current image which can then be saved to disk.

*Procedure*
Flat field and dark maps shall be taken and saved to disk. Images shall be taken at the following temperatures:

+20°C
0°C
-20°C
-40°C

A flat field image shall be obtained by placing a diffuser in the optical light path between the light emitting diode (led) and the CCD. The Intensity of the led shall be varied such that a figure of about ¾ full well capacity is obtained using a shutter (or led flash) time of around 2 seconds.

A dark current measurement shall be made by keeping the shutter closed (or leaving the led off) - the optical bench is light tight. Two dark current frames are recorded each of 1 second, 5 seconds and 100 seconds integration time. To eliminate Cosmic Rays the two 1 second integration frames are compared pixel-by-pixel, the lowest pixel value being used in each case. The same procedure is used on the two 5 seconds and the two 10 seconds integrations. The 5 seconds files are then used for comparison with the Photo-Response Non Uniformity flat fields.

*Expected Performance*
The mean pixel intensity and standard deviation shall be noted. A flat field and dark current map will be obtained and saved in the FITS format. The number of column defects in the image will be obtained by visual inspection. A clearer picture of the overall uniformity can be found if all the values above and below 3 standard deviations are set to 0 or 256 respectively and the image re-displayed.

A histogram of the data should be plotted showing the variation in signal.

### <u>3.2.2 Hot Pixels</u>

*Purpose*
A hot pixel is a pixel that produces charge at a rate of at least 25,000 electrons/pixel/second at +20°C. This test will identify all the hot pixels on the CCD and produce a map showing the position of all the defects.

Maps shall also be produced showing the number of pixels having dark current values which are 2 sigma, 3 sigma, and 5 sigma above the mean dark current value.

*Procedure*
Flat field and dark maps shall be taken to measure the number of hot pixels on each CCD. Flat field and dark maps shall be saved to disk. Images shall be taken at the following temperatures:

+20°C
0°C

-20°C
-40°C

The Flat field and dark current maps obtained in test 3.2.1 shall be used.

*Expected Performancet*
The hot pixels can be identified using the flat field image. Pixels with a count rate over 25,000 electrons per pixel per second can be readily identified by setting all pixels with values below this to zero and displaying the new image. Pixels which are significantly higher than the mean value (but not technically hot pixels) can be identified by showing only those pixels with intensities greater than three times the sigma level. This can be done by setting all pixels below this value to zero. All images shall be saved to file as FITS files.

### 3.2.3 Dark pixels

*Purpose*
A dark pixel has an output below 80% of the average output of a uniformly illuminated device at the given operating temperature. This test will identify all the dark pixels on the CCD and produce a map showing the positions of all the defects.

*Procedure*
Flat field and dark maps shall be taken to measure the number of hot pixels on each CCD. Flat field and dark maps shall be saved to disk. Images shall be taken at the following temperatures:
+20°C
0°C
-20°C
-40°C

The flat field and dark current maps obtained in test 3.2.1 will be used.

*Expected Performance*
An image shall be displayed with all pixels having counts less than 80% of the mean being set to the maximum grey scale value, and with all other pixels being set to zero. The percentage of pixels below 80% of the mean should be calculated. The image map of dark pixels shall be saved in FITS format.

### 3.2.4 Response Non Uniformity (PRNU)

*Purpose*
This test will show the variation in the PRNU. The PRNU is defined as the standard deviation in the flat field image, having first removed image defects.

*Procedure*
The flat field and dark current maps obtained in test 3.2.1 shall be used. Hot and dark

pixels as well as column defects shall first be removed.

*Expected Performance*
The PRNU is the standard deviation in the flat field image, having first removed the column defects, and hot and dark pixels (measured above). The mean intensity shall then be calculated along with the standard deviation.

### 3.2.5 Variation in the mean Dark current

*Purpose*
The mean level of dark current will be measured at different temperatures and substrate voltages ($V_{ss}$) to obtain the best operating points for the CCD.

*Procedure*
Images shall be taken at the following temperatures and values of substrate voltage:

| ***CCD temperature*** | ***Substrate voltage (V)*** | | | | | | |
|---|---|---|---|---|---|---|---|
| +20°C | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 |
| 0°C | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 |
| -20°C | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 |
| -40°C | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 |

The mean level of dark current shall be found by measuring the dark current obtained for a 60 pixel by 60 pixel area of the CCD.

The IDL program, ***solbdark.pro*** shall be used to automatically set the substrate bias voltages for each set of dark current measurements. The subsequent data can be analysed using the program ***darkanal.pro***.

*Expected Result*
A graph showing the variation in the mean dark current with substrate voltage shall be produced.

### 3.2.6 Charge Transfer Efficiency (CTE):

*Purpose*
This measurement will measure the CTE of each CCD over a range of operating temperatures.

*Procedure*

The CTE shall be measured at the following temperatures:
+20°C
0°C
-20°C
-40°C

*Expected Performance*
The measurement and performance of the CCDs for Charge Transfer Efficiency is defined in reference [5].

3.2.7 Quantum Efficiency

This measurment will not be made at MSSL and will be the subject of a separate measurement plan specifically written for the Quantum Efficiency measurements (reference [6]).

## 3.3 CCD Operating Response

### 3.3.1 Linearity and Output Amplifier Saturation level

*Purpose*

To measure the linearity of each CCD and also find the output amplifier saturation level. These values will change using different operating voltages and so a range of values of the Output Drain voltage ($V_{od}$) and the Reset Drain Voltage ($V_{rd}$) will used.

*Procedure*

A flat field image shall be obtained by placing a diffuser in the optical light path between the light emitting diode and the CCD. The time that the led is left on shall be varied such that a range of intensities are obtained on the CCD from about 10% expected full well to full well.

Two measurements shal be taken at each data point. The first frame is recorded with a vertical binning factor of 1, and the second is taken with a vertical binning factor of 10. Data from the first frames are binned in software by a vertical factor of 10 so that both signal levels should now be equal.

Measurements shall be made for the following values of $V_{od}$ and $V_{rd}$:

| $V_{od}$ | $V_{rd}$ | $V_{rd}$ | $V_{rd}$ |
|---|---|---|---|
| 28V | 15V | 17V | 19V |
| 30V | 17V | 15V | 19V |

| | | | |
|---|---|---|---|
| 32V | 19V | 15V | 17V |

The IDL program ***solbres.pro*** shall be used to control the bias voltages and collect the data. The program ***resanal.pro*** shall be used to process the data.

*Expected Result*
A graph shall be produce showing the values of the ratios for hardware binned data against software binned data. The result should be a straight line.

### 3.3.2 Full well

*Purpose*

To measure the full well capacity of each CCD.

*Procedure*
A flat field image shall be obtained by placing a diffuser in the optical light path between the light emitting diode and the CCD. The led shall be switched on for a range of times and the resulting signal intensity measured at the CCD. A graph of measured intensity versus led on time shall then be used to determine the full well capacity.

The data generated to measure the full well is a subset of the data required for the light transfer curve measurements (3.3.3 below).

*Expected Result*
A subset of the data obtained from the measurements of the light transfer curve shall be used to determine the full well capacity. The full well capacity is taken to be the exposure time at which the measured pixel intensity departs from that predicted by the straight line fit through the previously plotted data points by an amount exceeding 3% of the value.

### 3.3.3 Read noise and Bias offset value

*Purpose*
To measure the read noise and bias offset value with different values of the Output Drain voltage ($V_{od}$) and the Reset Drain voltage ($V_{rd}$).

*Procedure*
A light transfer curve (see appendix one) shall be obtained to measure both the read noise and the bias offset value.

With the diffuser attached to ensure a flat field a range of led on times are used to produce a signal intensity varying between 0.1 and 0.9 times the full well capacity. A graph of signal intensity (in electrons) versus total signal noise can be used to find the read noise and the bias offset value. The signal noise is found by taking two identical images and obtaining the difference in values for each pixel.

The program ***solbltc.pro*** will produce the data for an light transfer curve for given values of $V_{od}$ and $V_{rd}$. Two flat field images are taken, and a 60x60 image area saved to disc. For room temperature measurements, a dark signal shall also be taken and subtracted from the two flat field images.

Measurements shall be made at the following values of $V_{od}$ and $V_{rd}$.

| $V_{od}$ | $V_{rd}$ | $V_{rd}$ | $V_{rd}$ | $V_{rd}$ | $V_{rd}$ |
|---|---|---|---|---|---|
| 27V | 15V | 16V | 17V | 18V | 19V |
| 28V | 15V | 16V | 17V | 18V | 19V |
| 29V | 15V | 16V | 17V | 18V | 19V |
| 30V | 15V | 16V | 17V | 18V | 19V |
| 31V | 15V | 16V | 17V | 18V | 19V |
| 32V | 15V | 16V | 17V | 18V | 19V |

The simplest way to find the bias offset value is to use the value from the 50 lead in pixels at the start of each row. The mean value for the pixels is the offset bias.

*Expected Result*
Use the program ***sltcanal.pro*** to analyse the data taken. The program uses a 20x20 area of the flat field image and calculates the mean signal value and the variation in the signal value.

Light transfer curves shall be drawn for all of the bias voltage combinations. A straight line fit to each curve will allow the sigma squared noise contribution (in DN) to be obtained from the intercept. The gradient of the straight line fit is the reciprocal of the gain of the amplifier. Consequently, multiplying the noise contribution in DN by the gain of the amplifier will give the rms noise contribution in electrons.

### 3.3.4 Responsivity with varying reset drain and output drain voltages

*Purpose*
This test will establish the variation in responsivity with different reset drain ($V_{rd}$) and output drain ($V_{od}$) voltages.

*Procedure*
The procedure to measure the full well capacity described in 3.3.2 shall be used.

Measurements shall be made for the following values of $V_{rd}$ and $V_{od}$:

| $V_{od}$ | $V_{rd}$ | $V_{rd}$ | $V_{rd}$ |
|---|---|---|---|
| 32V | 20V | 18V | 17V |

| | | | |
|---|---|---|---|
| 30V | 20V | 18V | 17V |
| 28V | 20V | 18V | 17V |

*Expected results*
The responsivity can be found from the light transfer curve data. It is the reciprocal of the gradient of the light transfer curve. A table shall be produced showing the variation in the responsivity for varying voltages of $V_{od}$ and $V_{rd}$.

# 4 Test Flow

In section three the tests are arranged in the most logical sequence, i.e. Image characterisation tests followed by investigation of the optimum operating conditions. The actual test flow will differ slightly, being arranged in an order more suitable to the actual measurement processes themselves. The actual test flow is shown in figure two.

# 5 Appendix One

## 5.1 The Light Transfer Curve

The noise on the digitised CCD output is the sum in quadrature of the readout noise and the shot noise on the signal. Using the relationship between the shot noise and the light signal the system gain can be calibrated as follows:

$\sigma_{tot}^2 = \sigma_r^2 + \sigma_{sh}^2$

where $\sigma_r$ = readout noise, electrons RMS

$\sigma_{sh}$ = shot noise on the light signal, electrons RMS

The relationship between the shot noise and the light signal is:

$\sigma_{sh}^2 = N$

where N= signal in electrons. Therefore,

$\sigma_{tot}^2 = \sigma_r^2 + N$

We can substitute into the above equation using:

$\sigma(DN)_{tot} = \sigma_{tot}/K$

$\sigma(DN)_r = \sigma_r/K$

$N(DN) = N/K$

where $\sigma(DN)_{tot}$, $\sigma(DN)_r$ and N(DN) are the quantities defined above measured in units of DN), and K is the gain of the amplifier (i.e electrons to DN).

Hence:

$\sigma(DN)_{tot}^2K^2 = \sigma(DN)_r^2K^2 + N(DN)K$

Dividing through by $K^2$ gives

$\sigma(DN)_{tot}^2 = \sigma(DN)_r^2 + N(DN)/K$

N(DN) and σ(DN)tot can be measured from the digitised data. N(DN) can be measured by using different intensity values from (say) a light emitting diode. The error on the measurements σ(DN) can be found by taking two measurements at each intensity value. The difference between the two signals will provide σ(DN).

A straight line plot of N(DN) against $\sigma(DN)^2$ will have a straight line slope of 1/K and an intercept at N(DN)=0 of $\sigma(DN)_r^2$.