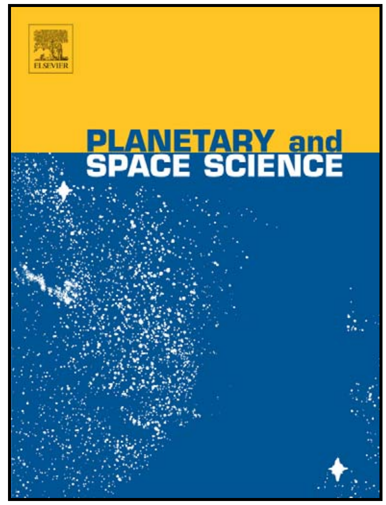

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Chandrayaan-1 X-ray Spectrometer (C1XS) – Instrument Design & Technical Details

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Abstract

The UK-built Chandrayaan-1 X-Ray Spectrometer (C1XS) is flying as an ESA instrument on India's Chandrayaan-1 mission to the Moon. The Chandrayaan-1 mission launched on the 22nd

October 2008 and entered a 100 km polar lunar orbit on the 12th November 2008. C1XS builds on experience gained with the earlier D-CIXS instrument on SMART-1, but will be a technically much more capable instrument. Here we describe the instrument design.

Keywords: Detectors; SCD; Swept Charge Device; X-ray Fluorescence; Moon

1. Introduction

The Chandrayaan-1 X-ray fluorescence Spectrometer (C1XS) is based upon the successful technology demonstration D-CIXS instrument that was flown on the ESA SMART-1 mission (*Grande et al., 2003; 2007*). The restructured C1XS instrument design had to take into account the different thermal environment, the shorter Earth-Moon transit time, and the lower lunar orbit of the Chandrayaan-1 mission compared to the SMART-1 mission. The scientific objectives of this instrument, which include mapping the abundances of the major rock-forming elements (principally Mg, Al, Si, Ti, Ca and Fe) in the lunar crust are discussed by Crawford et al., (*in press*). Here we describe the instrument design and technical challenges presented by the C1XS instrument which uses innovative swept charge device (SCD) detector technology (*Grande et al., 2003; Holland et al., 2004; Smith et al., 2007*).

The C1XS instrument, like its predecessor, will be accompanied by a X-ray Solar Monitor (XSM) instrument.

2. XSM Instrument

The XSM is very similar to the instrument for SMART-1 described in *Huovelin et al. (2002)* and *Alha et al. (2008)*. It consists of an aluminium enclosure containing a high purity silicon PIN (Positive Intrinsic Negative) diode detector, a Peltier cooler, front end electronics, and a shutter mechanism (Fig.1). The signal processing card is fitted inside the C1XS electronics module; the data produced is read by the C1XS processor, assembled into 512 bin spectra and transmitted to the spacecraft solid state recorder (SSR).

The PIN diode is formed on a square chip and has a circular active area. Three concentric guard rings surround the active detection area. To reduce the count rate an aperture stop made from a golden annular structure is centred on the surface of the detector. The detector window consists of a 13 μm beryllium foil coated with 0.25 μm polyimide and 90 nm aluminium. A collection of the XSM performance values are shown in Table 1.

The main differences from the SMART-1 XSM are: (1) improvement in the noise performance implying better spectral resolution as well as a lower energy cut-off, and (2) a smaller aperture resulting in decreased sensitivity to allow measurements of spectral signature of very strong flares.

3. C1XS Instrument

2 and Fig. 3) weighs 5.56 kg and has physical dimensions of approximately 250 mm wide by 150 mm tall by 190 mm deep (with the door closed). It is functionally and thermally divided into two parts. The larger section is the electronics module. This module contains the instrument main power switching and conditioning circuits, the switched mode power supply and five circuit boards. The circuit boards are arranged side-to-side, and are held in place with

wedge-locking card guides. The electronics enclosure is a thick-walled (4 mm) aluminium box, which acts as the instrument's primary structure. The second section is the detector module. This houses the swept charge device (SCD) X-ray detectors together with their associated drive electronics, radiation shielding and cooling interface. It is supported by the electronics module in a cantilever fashion.

The instrument (Fig. 1) weighs 5.5 kg and the instrument is bolted down to the Chandrayaan-1 spacecraft deck using 4 screws to provide a good thermal interface between the instrument and the spacecraft panel/radiator. Table 2 gives a list of requirements together with the actual values measured during the C1XS calibration and test.

3.1 Overview of C1XS Instrument Operation

C1XS uses a form of Charge Coupled Device (CCD) developed by e2v specifically to detect X-rays. When an X-ray in the 0.5 to 20 keV energy range arrives at the device it deposits a charge which is proportional to the energy of the X-ray. This charge is read by the C1XS and converted to a digital amplitude value. (Detail of how the detectors operate is provided in more detail in section 3.3.) The digital value is compared with a software configured threshold, any event above the threshold is considered to be a valid X-ray event (see section 3.4). The validated event is either assembled into a data packet or used by the C1XS data processing system to create a spectrum for each SCD. The generated spectrum is made up of 512 energy bins, for each event the C1XS software calculates within which energy bin the event would fall and increments that bin's number of counts. Every 8 seconds each SCD spectrum is assembled into a data packet and the bin counters are reset to zero.

3.2 Detector Module

The detector module is mounted on the front of the electronics module via a 12 mm thick GFRP (glass fibre reinforced polymer) spacer. The heads of the bolts used to hold the two parts together are also insulated from the detector module. The GFRP spacer is covered with stainless steel foil, designed to provide electromagnetic shielding without adding a significant thermal connection. The void between the 2 modules is filled with a 10 layer multi-layer insulation (MLI) blanket to reduce the radiative coupling between the hot video processing electronics and the back of the cold detectors. The electrical interface between the two parts is via a flexi-rigid circuit board which has been designed to minimise heat transfer (Fig. 3).

The SCD clock driver PCB (printed circuit board) is fixed to the rear of the detector module and contains the power drive stages for the SCD clocks and the interface connectors for the SCD modules. There are 3 SCD modules, each with an interface PCB. Each module contains two strips of SCDs with 4 SCDs in each strip. The SCD strips are mounted on a 3 mm copper and a 6 mm tantalum heatsink, which is thermally isolated from the rest of the module. The tantalum is included for proton shielding but also provides additional thermal mass. The copper protrudes from the bottom of each SCD module to allow the external radiator to be connected to the instrument via a heatpipe (Fig. 3).

To constrain the detector field of view, a CNC (computerised numeric control) machined copper collimator (Fig. 4) is mounted above each detector. This provides an angular acceptance of 28° (i.e. +/- 14°) from the 100 km orbit of Chandrayaan-1, the C1XS field of view being equivalent to a 50 km square (full width) on the surface of the Moon. The dimensions of the machined holes in the copper are 1.5 mm square with a wall thickness of 0.15 mm. The signal loss due to the copper walls is just 17 %. This is a superior performance to the D-CIXS collimators which lost ~30%. To allow the walls to be made this thin the maximum machining depth is 1 mm. Therefore, a complete collimator is composed of six machined copper sheets stacked up to give the necessary opening angle. As part of the CNC process extra holes are machined to allow the individual sheets to be accurately aligned and fixed together to ensure correct construction of each collimator stack.

SCDs are not just sensitive to X-rays; light and low energy electrons can also mimic an X-ray signal. A 0.2 μm aluminium foil supported on 0.2 μm polyimide is therefore mounted to the top and bottom layers of the collimator stack. The reason for having two thin foils rather than one thicker foil is to eliminate possible problems with pin-hole defects in the foils. It is very unlikely that an individual column would have a pin-hole present in both of the foils and even less likely that the two holes would line up to provide a light path through to a detector. One of the internal collimator layers has additional vent paths included to ensure that the trapped volume of air does not cause the aluminium foil to rupture during the decompression experienced during the launch. The vent paths are designed to reduce the possibility of light entering one collimator getting to another if the external foil is ruptured. Unlike D-CIXS where seven of the detectors were mounted behind a magnesium foil collimator assembly (*Grande et al., 2003*), the new C1XS instrument only employs aluminium foils. A photograph of a partly built collimator stack and a schematic of the collimator assembly are shown in Figure 4.

The entire detector module is protected by a 5 mm thick aluminium door. This door is actuated with a stepper motor, using a rotary potentiometer for control. DCIXS used microswitches at each end of the door's travel and so the precise door position was never known. The potentiometer fitted to C1XS will allow the door position to be measured at all times. The door is secured for launch using a one-shot HOP wax actuator and contains 24 ^{55}Fe sources for calibrating the detectors when closed.

Each ^{55}Fe calibration source consists of a 220 kBq nickel coated electro-deposited source on an aluminium carrier which is mounted behind a 5 μm titanium foil. The titanium is used to produce an additional pair of calibration lines so the source gives a total of four X-ray energies; 4.510, 4.931, 5.895 and 6.4942 keV corresponding to the K-alpha and K-beta lines of Ti and Mn, respectively.

The source and foil are mounted in a holder, which is used to restrict the source viewing angle so that the measurements from the lunar surface are not ‘contaminated’ with the X-rays emitted by the calibration sources. Due to the titanium foil and the collimation the count rate seen by each detector is approximately 200 counts per second. At the beginning of the mission 10 minutes of calibration data will be taken once per day to monitor the SCD degradation, the time may be lengthened as the mission progresses due to the source half life (2.7 years).

3.3 Swept Charge Devices and Drivers

A schematic of the SCD internal structure is given in Figure 4 and the device characteristics, specified by the supplier, are given in Table 3. The device has 3 clock lines which are arranged in a design that, upon clocking, will ‘sweep’ any charge towards a low capacitance sense amplifier located in one corner of the detector (the bottom left-hand corner as shown in Figure 5). The device is clocked continuously at 87 kHz using a 10 V drive level, the clock waveforms produced by the field-programmable gate array (FPGA) are non-overlapping and the design relies on the SCD internal capacitance and a series resistor to ensure that sufficient overlap is present to give correct charge transfer. Switching the clocks simultaneously substantially reduces clock noise feedthrough leading to a significant improvement in detector performance. Using a lower clock frequency than that specified by the manufacturer increases the theoretical dark current by approximately 2 electrons per sample.

The design of the sense amplifier is based upon that used in traditional CCD technology, consisting of a very low capacitance sense amplifier and reset transistor, and operates in exactly the same way as in a conventional CCD. The SCD supply voltages are listed in Table 4. All 24 SCD use the same supply and clock voltages to minimise the complexity of the drive electronics and because the 24 SCD are contained on 6 substrates each of which has common bias voltage and clock connections. As part of the characterisation work done by Brunel University, the SCD drive voltages and biases were investigated in detail and it was found that all the flight candidate devices could perform well under a single set of optimised voltages. Figure 6 shows one parameter investigated in the study, the variation in noise as a function of output drain voltage. All the devices used in the final flight instrument were characterised using the specified optimal voltages and were the 'best' modules chosen for those operating conditions.

The four SCD bias voltages and logic-level clocks are generated on the video-digital PCB and are connected to the SCD via the video-analogue card. The clock driver board is mounted directly on the detector assembly module and uses flexi-rigid circuits to connect to the analogue card. Different flexible circuits are used to separate the drive waveforms/supplies to the detectors from the SCD video outputs to minimise interference.

The clock driver board carries the power driver ICs (integrated circuits) for the clocks, and the connectors which allow the SCD modules to be plugged in once the rest of the instrument is assembled. The PCB on the back of the SCD module holds the SCD supply filter components to provide decoupling as close to the device as possible.

The substrate and output gate voltages for the SCDs are each generated using a DAC08 digital to analogue converter followed by a power drive stage. The remaining two voltages come from a switched-mode power supply (SMPS) which is synchronised to the SCD readout system. The output of the SMPS is filtered and then the actual output voltage selected using linear voltage regulators. Control for these voltages comes from the video processing boards.

3.4 SCD Video Processing

The signals from each SCD flow through 3 main processing blocks: video amplification and sampling, digitisation, and event recognition (Fig. 7). As the output from an SCD is similar to a conventional CCD, a correlated double sampling (CDS) circuit is used to extract the wanted signal. The CDS circuit takes two samples from the SCD for each pixel, the reset level and then the X-ray event signal, and calculates the difference between the two values. This voltage is then fed, via a summing junction, to an analogue to digital converter (ADC) which gives a 14 bit number equivalent to the X-ray event energy. The summing junction allows the position of the zero voltage signal to be placed anywhere on the ADC range, in practice this position is chosen to be at a value of 350 so that when the temperature changes, both positive and negative drift of the zero position can be detected. The instrument uses a total of 24 SCD, each requiring its own CDS circuit, so an integrated solution is required to allow all the parts to be fitted on the Eurocard sized PCB. A Burr Brown 3 channel CDS integrated circuit was chosen as the main processing element. Four of these devices plus support logic were built into a module produced by 3D Plus and supplied by CESR with the support of CNES (Fig. 8). As the CDS parts are designed for optical CCD signals a pre-amplifier stage is used immediately before the CDS block to give sufficient resolution. The amplifiers have an enable input which is used to blank out the SCD reset pulse.

Each 3D Plus module, containing the CDS, is controlled using an Actel RTAX250 FPGA. This device provides the sequencing of detector readout and digitisation. It also is used to select valid X-ray events from the detector video streams. The event-selection logic stores samples from each detector and processes them according to a programmable criterion using two thresholds. The thresholds are selected such that X-ray events less than ~800 eV are rejected by the system (threshold one). Threshold two is used to reject events where a single X-ray is spread over two or more pixels. The two event selection modes used by C1XS (Fig.9) are:

1. 'Multi-pixel' mode – on pixel B greater than threshold 1, up to 5 consecutive pixels (hatched area) are stored in the FIFO.

2. 'Single pixel' mode – on pixel B greater than threshold 1, and both A and C less than threshold 2, store pixel B (crosshatched area).

In addition, on demand from the instrument processor, the FPGA can store one raw data sample from each detector without reference to the programmed thresholds which gives an event value somewhere within the ADC range. As the read-out rate for each detector is ~87 kHz and the highest expected X-ray event rate is 900 events per second (X10 flare conditions) the probability that the value read is an X-ray is 0.01. Therefore a non-thresholded event is most likely to be a measure of the system noise with respect to a zero energy value. The instrument software integrates these data to give a value of the zero energy position and adjusts the FPGA event thresholds accordingly. In addition these data are added to the telemetry packets transmitted from the instrument and are used to keep a check on the front-end analogue offsets which determine the zero-energy position in the accumulated X-ray spectra. All the validated X-ray events are stored in a FIFO which is read by the C1XS micro-controller 32 times per second. It is impossible to distinguish FPGA events generated by genuine X-rays from events related to the penetrating particle background. However, by using the measured spectra from very quiet solar conditions (<B1 GOES X-ray flux level), we can determine a background spectrum which can be used to remove the cosmic ray induced X-ray signal.

3.5 Data Processing System

Figure 10 shows a block view of the C1XS data processing system. An RTX2010 microcontroller is used for the main instrument processing. It is located on one of the plug in PCBs together with 256 kBytes RAM, 128 kBytes fuse linked PROM (programmable read only memory) and 256 kBytes EEPROM (electrically erasable read only memory). The software is written in a mixture of assembler and C code and has two main parts; the first is an emergency level system that allows basic communication with the instrument, the ability to read and modify RAM, start execution at a specific memory location and to boot from EEPROM having validated the integrity of the software to be run. The second part is the main instrument software which is run after the C run-time system has initialised. The instrument boots into ‘Standby’ mode which allows full commanding via the databus and produces housekeeping data every 64 seconds. The Standby mode functions include the following:

- C1XS Door open/close
- Collect and transmit instrument operating parameters
- Synchronise internal clock to spacecraft clock
- Accept commands

Instrument 'Operating' mode is entered via a telecommand and, on starting this mode, the software checks that certain temperatures have not been exceeded; powers on the video processing circuits and the SCD power supplies; loads various parameters into the integrated circuits and starts the XSM state machine. The state machine is used to control the operation of the XSM detector cooler, data collection and protective shutter. Some flexibility is built into operating mode which allows each of the two C1XS 3D Plus modules to be run on their own both with and without the XSM.

In the normal operating mode the C1XS telemetry data format depends on the X-ray count rate, one of three possible science formats will be chosen. If the total X-ray rate for all 24 detectors is <320 events/sec then the FPGA uses the first event selection mode (multi-pixel data). Although this FPGA mode allows up to 5 pixels to be selected the instrument only uses three consecutive readout events – the actual event plus the before and after events (i.e. A, B and C in Figure 9). The science telemetry packet produced contains the event time and the 3 energy values and is called '3-pixel mode'. Above 320 events/sec the FPGA uses its second mode (single pixel) so that only one pixel of data is used (event B in Figure 9). Two telemetry formats use the single pixel mode, the first is a time tagged mode where the telemetry packet contains the event time and the energy value and the second is a spectral one which is used when the count rate exceeds 800 events/sec. The spectral format is an optimised 512 channel spectrum with variable bin widths to maximise the scientific return of the instrument. Spectra are generated every 8 seconds, an unprocessed spectrum generated from the on-board calibration source is shown in Figure 1l. In normal operations the instrument will autonomously select the data mode itself by checking the instrument data rate every second. Alternatively, the instrument can be commanded into one of the three C1XS science modes (time tagged – 3 pixel mode, time tagged – single pixel mode or high resolution low count spectral mode). For compatibility, we can also use one of the three earlier D-CIXS science modes (simple time tagged mode, low count spectral mode or compressed low count spectral mode).

The electronics monitors the SCD temperatures, using a thermistor mounted on the rear of the SCD copper heatsink, and switches to a low power mode (‘Resting’) if they get too hot (~ -5°C). This mode allows the detectors to cool down and data collection is re-enabled once the temperature has reduced sufficiently (to ~ -9°C).

Operating mode functions include:

- Monitor box and video processor temperatures, switch to standby if limit exceeded
- Monitor SCD temperatures, switch to low power mode (Resting) if limit exceeded
- Control and monitor XSM
- Monitor SCD X-ray event rate and generate appropriate science data packet
- Collect and transmit instrument and SCD operating parameters
- Synchronise internal clock to spacecraft clock
- Accept commands

Resting mode functions:

- Monitor box and video processor temperatures, switch to standby if limit exceeded
- Monitor SCD temperatures, switch to operating mode if SCD are cool enough
- Collect and transmit instrument operating parameters
- Synchronise internal clock to spacecraft clock
- Accept commands

3.6 Spacecraft Interface

The C1XS instrument uses a CAN bus to communicate with the rest of the spacecraft. The CAN protocol circuits were designed and supplied by Swedish Space Corporation using Actel RT54SX32 devices. The system implemented uses two CAN busses, one which is in use and the other as a hot standby. The protocol chip automatically selects the active bus depending on the presence of a 'use this bus' message which is repeated every second and, if no message is received, then the device automatically uses the other bus. The spacecraft time is also sent using a specific CAN message on the bus to synchronise the C1XS instrument time to the spacecraft time.

A second Actel on the interface board is used to provide control signals for the multiplexers and analogue to digital converter and to latch the converter result. This device is also used to control the door latch drive and the door stepper motor.

The door stepper motor drive waveforms are generated under software control, this allows the actual door movement to be fine tuned to give a smooth opening/closing action and means that the door drive can be adjusted, if required, as the mission progresses. The door latch drive takes power directly from the spacecraft side of the C1XS power supply as the mechanism requires 28 V. To maintain isolation between the spacecraft and instrument grounds a pulse transformer is used to drive the power switching transistors, this has the additional advantage that a short circuit failure on the C1XS side of the transformer will not permanently activate the HOP drive.

3.7 Power Supplies

The power input to the main switched mode power supply (SMPS) is routed via a pulse activated power relay. The 30 W SMPS and accompanying filter module is used to generate the main 5 V and ±12 V supplies. A RAL-designed PCB then contains the post SMPS filters and two additional supplies: a 1.5V rail for the XSM peltier cooler and a –5 V rail for the video amplifiers. All these items are assembled onto the –X face of the C1XS box prior to the assembly of the rest of the electronics module, when the backplane is fitted.

4. Calibration

Figure 9 also illustrates the predicted performance of the D-CIXS instrument after 15 months of radiation damage during transit to the Moon. The performance is greatly degraded by radiation damage from the trapped protons in Earth's radiation belts encountered on the long journey time to the Moon. In contrast, Chandrayaan-1 will arrive at its destination lunar orbit within one week, resulting in much greater spectral performance at the start of the mission

(*Smith et al., 2007*). An equally significant lesson we learned from D-CIXS is the requirement for greater detail *in press*). The typical measured instrument readout noise is 6-7 electrons rms.

Figure 12 also illustrates the performance of the D-CIXS instrument after 15 months of radiation damage during transit to the Moon for an equivalent input spectrum. The performance is greatly degraded by radiation damage from the trapped protons in Earth's radiation belts encountered on the long journey time to the Moon. In contrast, Chandrayaan-1 has arrived at its destination lunar orbit within three weeks, resulting in much greater spectral performance at the start of the mission (*Smith et al., 2007*). An equally significant lesson we learned from D-CIXS is the requirement for greater detail in the spectrum at low energies. To address this issue, C1XS has four times the number of channels over the energy range 0 to 4**.**

Conclusions

5. Conclusions

The C1XS instrument builds upon the experience gained during the build and lessons learnt during the operation of the D-CIXS instrument (*Grande et al., 2007; Swinyard et al., in press*). Table 2 details the design requirements based on the science case outlined in Crawford et al. (*in press*) and specifications from the Indian Space Research Organisation together with the actual values measured during the instrument test. The key requirement for a good scientific return from the instrument is the ability to discriminate between the aluminium and magnesium energies (240 eV) hence the better than 200 eV spectral resolution requirement. The C1XS instrument during calibration achieved a resolution of 85 eV and data from the initial lunar commissioning work shows that radiation damage during the Earth-Moon transit is minimal (<

30 eV) so the worst case beginning of life resolution is 115 eV, almost a factor of two better than the requirement.
The greatest improvement to the build process was the use of CNC to machine the collimator structures. The complete set of collimators was made within one month and each was of uniform thickness and quality - the D-CIXS parts took more than 6 months to make and suffered from poor flatness and lack of uniformity. The disadvantage of the C1XS approach was an increased collimator height (due to the larger hole size necessary to ensure that the loss due to the thicker walls was minimised). However, the C1XS collimators out-perform the D-CIXS ones because the thinner walls and larger holes lead to a factor ~2 smaller loss of X-rays to the walls.

During D-CIXS instrument operations it was found that the SCD temperature rose very quickly as the spacecraft traversed the sunlit side of the Moon, typically the SCD temperature was -30 °C at the terminator crossing and the instrument went into 'resting' mode (SCD temperature of -9 °C) near the equator. The thermal performance of the new instrument is expected to be much better due to the significantly greater level of design work that has taken place to reduce the overall instrument power and to more thoroughly isolate the SCD from the electronics module. The provision of a dedicated cooling system for the SCD by Chandrayaan-1 itself should help to ensure that the operating target temperature of –20 °C is maintained for greater than 95 % of the orbital configurations.

The electronics design was improved in two ways. First, all the power supplies were changed to a switched mode design. This reduces the overall power drawn by the full instrument (helping to reduce the thermal load). Second, significantly more time was spent improving the SCD drive circuits and amplifiers to improve the readout noise performance. This has resulted in a readout noise figure of 6-7 electrons rms (*Kellett et al., forthcoming*). This is about a factor of 2 better than the readout noise performance of D-CIXS.

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Table Captions

Table 1. XSM Parameters

Table 2. C1XS Requirements and achieved values.

Table 3. Swept Charge Device Design Specification.

Table 4. SCD Voltages.

Figure Captions

Figure 1. View of the XSM instrument

Figure 2. View of the C1XS instrument on its vibration fixture. The door covering the SCD collimators can be identified by the radioactive warning symbol. The door HOP actuator is mounted vertically and the motor horizontally. The two connectors are the CAN bus and the XSM interfaces.

Figure 3. Schematic view of the C1XS instrument with one side of the instrument cut away.

Figure 4. Photograph of a partly built collimator stack. Schematic of the collimator assembly.

Figure 5. A schematic of the SCD internal structure. The electrodes are depicted by the dashed lines, whilst the charge transport channels are indicated by solid lines. The charge is swept towards the central channels and down to the output amplifier (bottom left corner) by the action of the clock signals.

Figure 6.Variation in SCD readout noise (electrons) with Output Drain voltage.

Figure 7. Block diagram showing the C1XS video processing system.

Figure 8. Video-analogue PCB component side view showing the two 3Dplus signal processors and associated amplifiers.

Figure 9. C1XS X-ray ‘single pixel’ event selection – an X-ray event is selected when pixel B is greater than threshold 1 and the pixels immediately before and after (A and C) are BOTH below threshold 2. Multi-pixel event selection – Up to 5 pixels (crosshatched area) are selected when pixel B is greater than threshold 1.

Figure 10. C1XS data processing block diagram.

Figure 11. Unprocessed Spectral Packet Data generated with X-ray events from the on-board calibration source. This shows the two 55Fe lines, the position of the titanium lines, the ‘zero’ noise peak, the FPGA cut-off point and some ‘split’ events not removed by the FPGA event detection.

Figure 12. An example RESIK spectrum from a flight SCD. The red histogram (C1XS) is a spectrum combined from two measurements a Cu-Mg anode and a pure Al anode to give the three peaks seen (Cu Lα: 0.92 keV, Mg Kα: 1.25 keV, Al Kα: 1.49 keV). The blue spectrum is a D-CIXS equivalent low count spectrum after 15 months radiation dose. Note that the red spectrum has x4 channels to maximise the scientific return of C1XS.

<u>Table Captions</u>

Table 2. XSM Parameters

Table 2. C1XS Requirements and achieved values.

Table 3. Swept Charge Device Design Specification.

Table 4. SCD Voltages.

Tables

Nominal energy range	1.2–20.0 keV
Energy resolution(BOF)	200eVat 5.9 keV
Number of spectral channels	512
FOV(circular) Diameter	104°
On-axis geometric area	0:001 cm^2

Table 1

Parameter	Requirement	Achieved
Supply voltage	28 to 42 V	20 to 45 V
Power	<10W (Standby) <30W (Operating)	6.3 W (Standby) 25.5 W (Operating)
Temperature range Electronics Detector module	 -50 to +80 (off) -20 to +40 (operating) -50 to +80 (off) -40 to +0 (operating)	 As requirement
Mass	5.8 kg	5.56 kg
Dimensions (door closed) width (Y axis) height (Z axis) depth (X axis)	 300 mm 200 mm 260 mm	 248 mm 151 mm 190 mm
Energy Range	1 to 10keV.	0.8 to 20 keV
Field of view	<15 degrees (FWHM) <30 degrees (full angle)	14 degrees (FWHM) 28 degrees (full angle).
Spectral resolution	<200 eV at 1.25 keV.	85 eV
Readout frequency	not specified	87,381 kHz
Data volume (average)	57 Mbits/orbit	36 Mbits/orbit

Table 2.

Sensitive area:	10 x 10 mm
Max. Count rate:	30,000 counts/sec
Output noise:	3 (typ.) to 5 (max.) electrons rms. (with 100KHz Correlated Double Sampling)
Energy Resolution:	140eV at Mn K_{α}
Detector Efficiency:	>30% at 280eV >30% at 10keV
Operating temperature:	-15°C

Table 3.

Substrate voltage	9 V
Output Gate voltage	3 V
Reset Drain voltage	17 V
Output Drain voltage	30 V

Table 4.

Figure 1

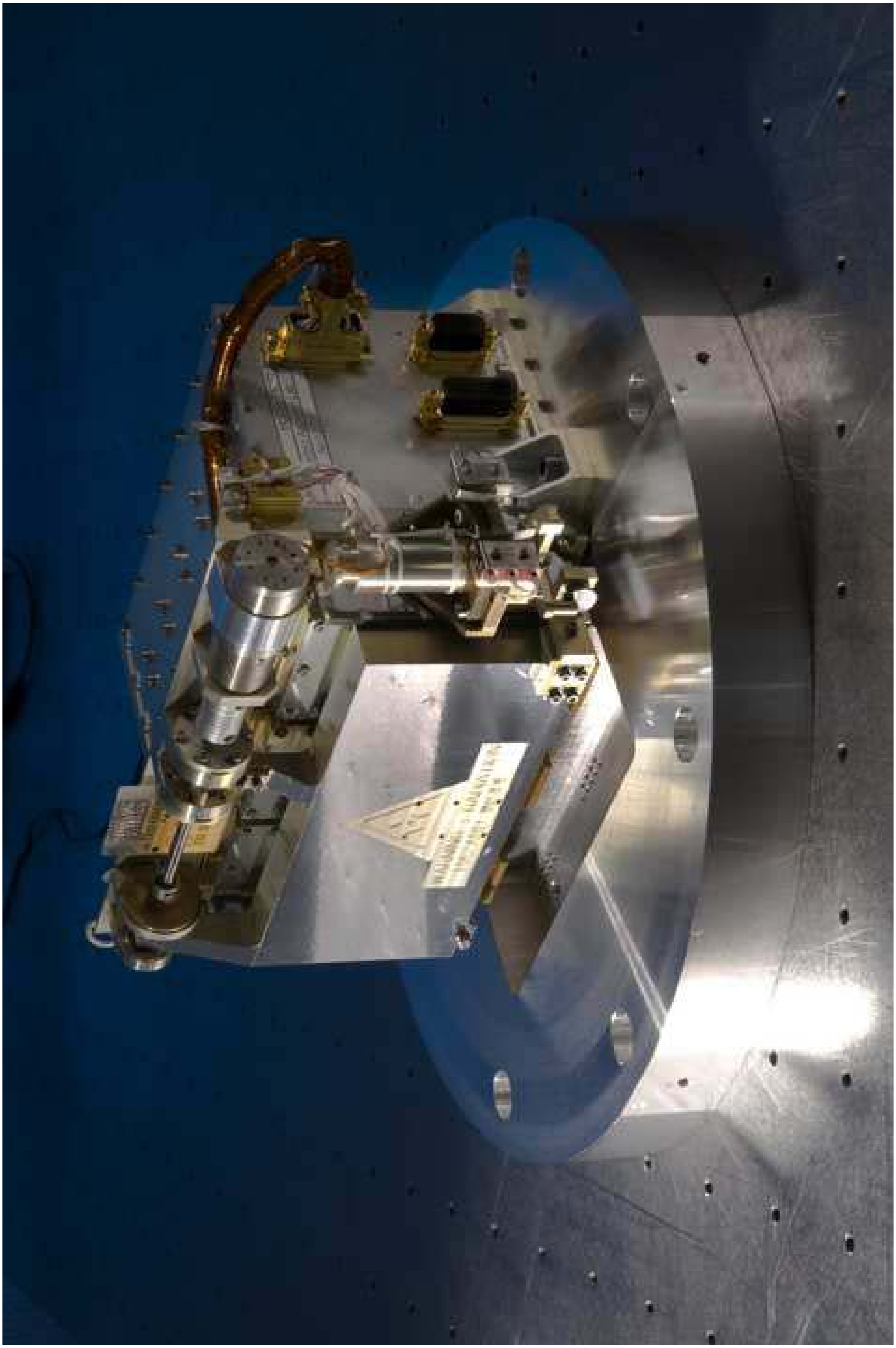


Figure 2

Figure 3

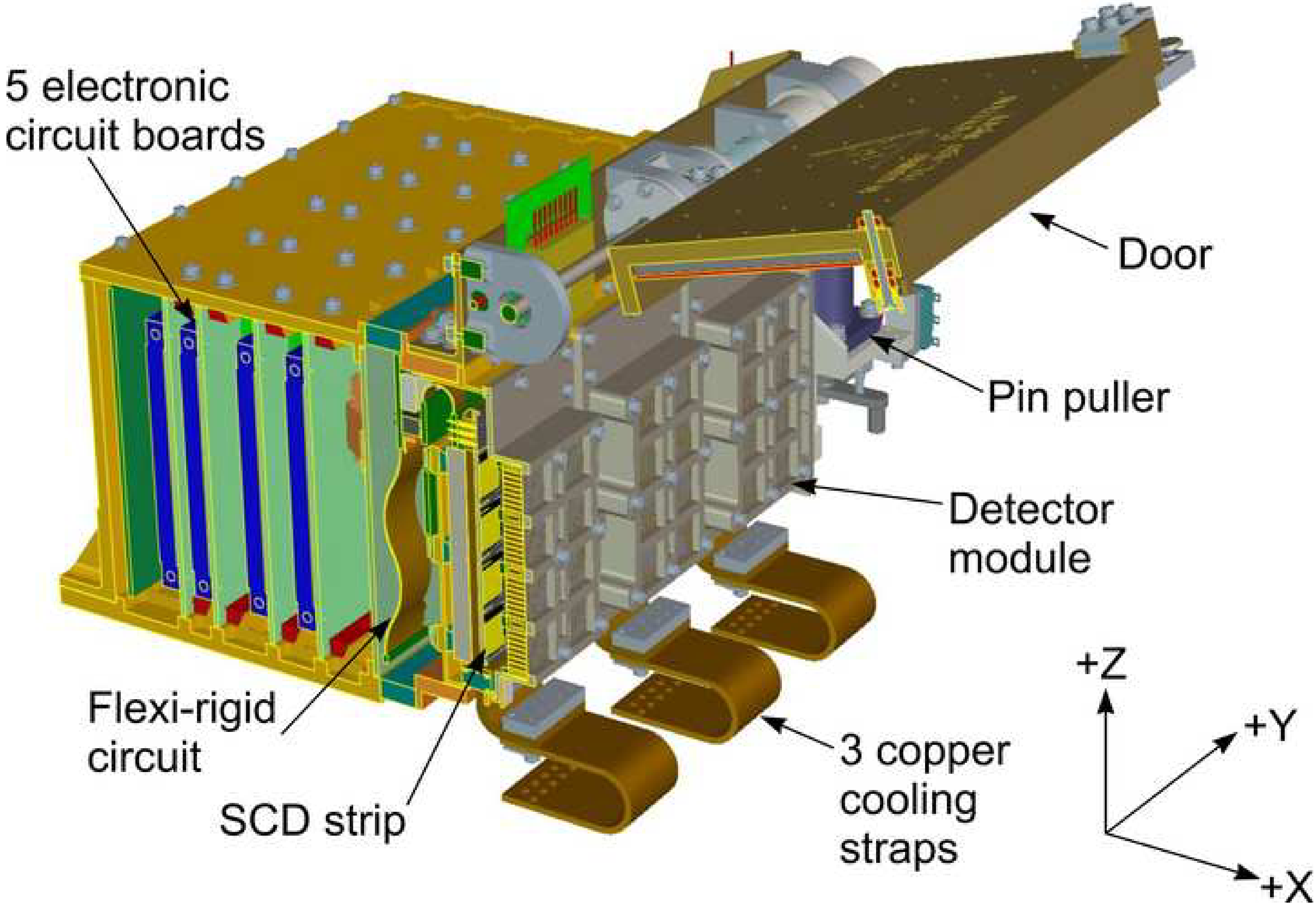

5 electronic
circuit boards
Door
Pin puller
Detector
module
Flexi-rigid
circuit
SCD strip
3 copper
cooling
straps
+Z
+Y
+X

Figure 4a

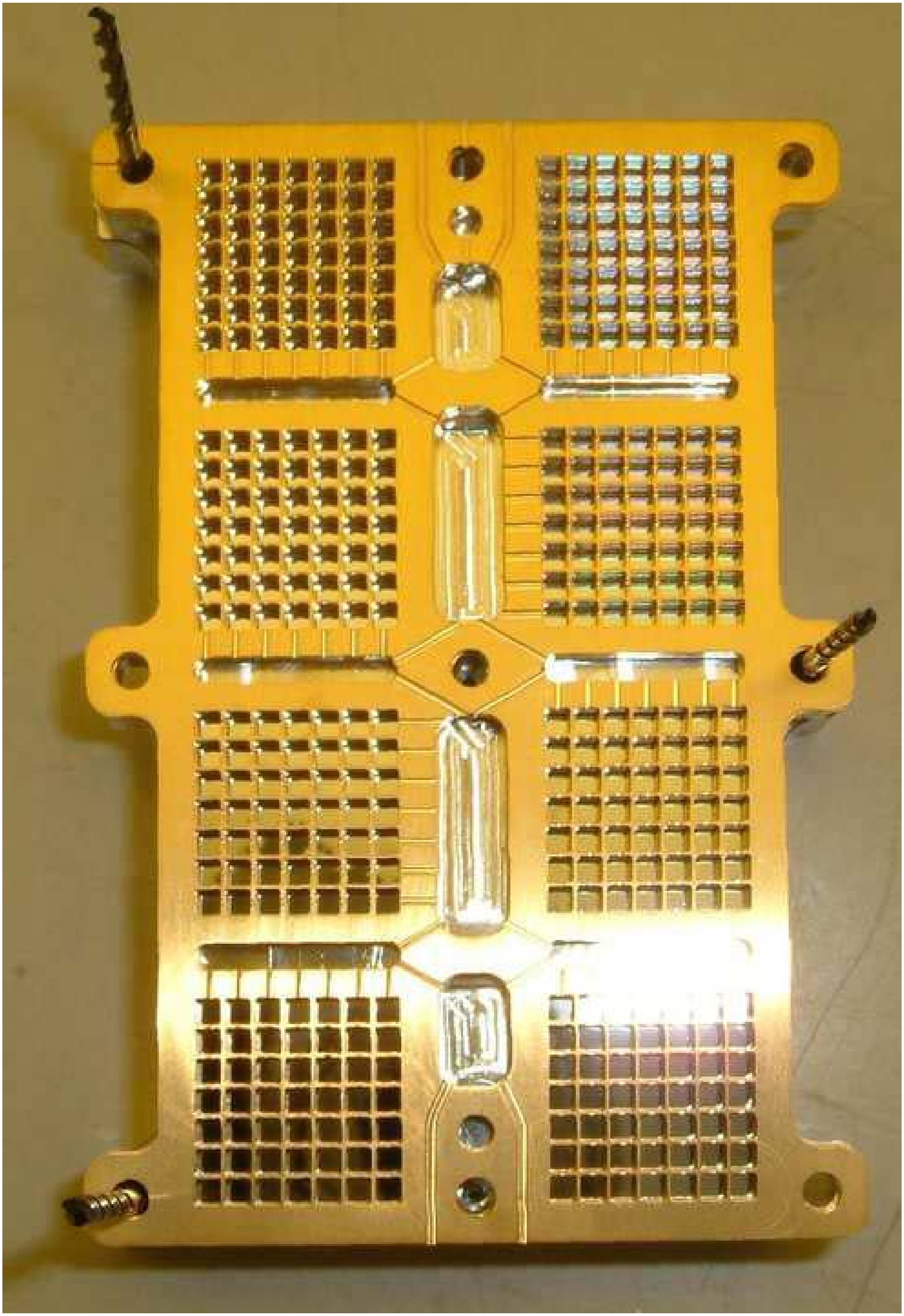


Figure 5

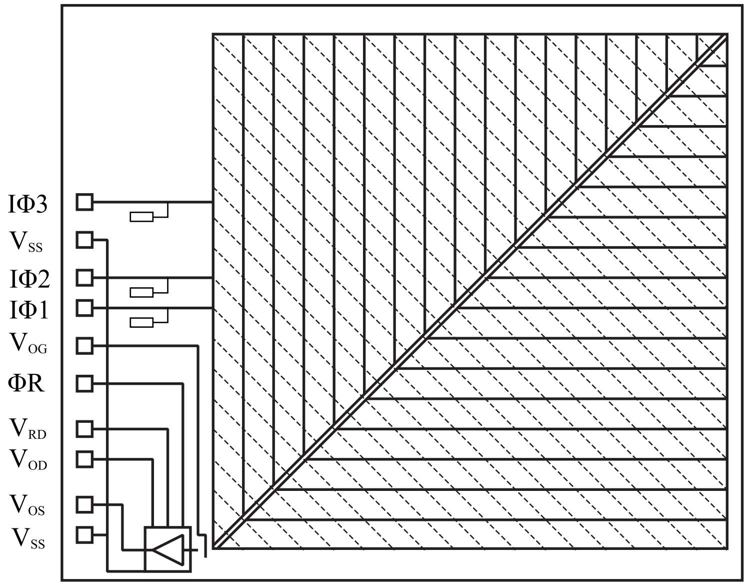
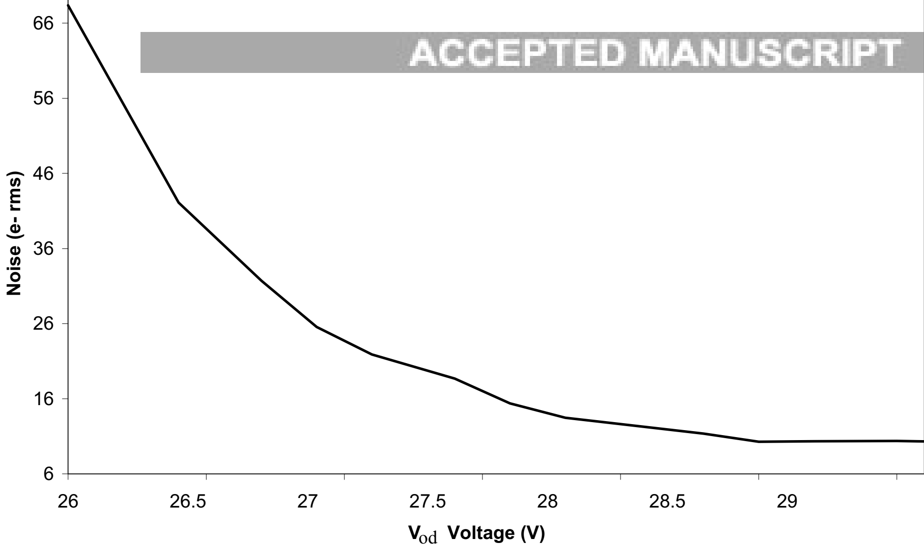
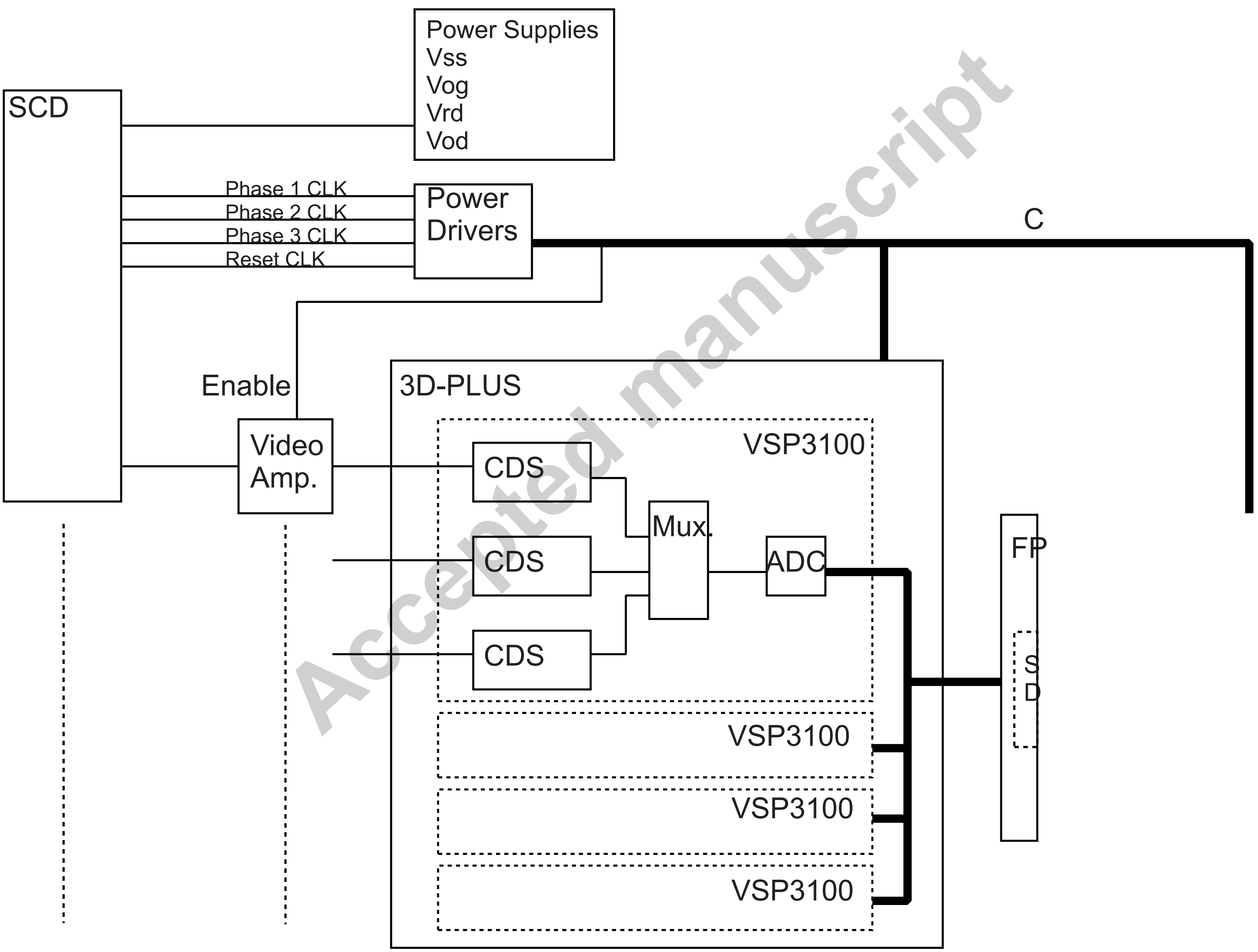


Figure 6



Noise (e- rms)
66
56
46
36
26
16
6
26
26.5
27
27.5
28
28.5
29
V_{od} Voltage (V)

Figure 7



Power Supplies
Vss
Vog
Vrd
Vod
SCD
Phase 1 CLK
Phase 2 CLK
Phase 3 CLK
Reset CLK
Power
Drivers
C
Enable
3D-PLUS
VSP3100
Video
Amp.
CDS
Mux.
CDS
ADC
FP
CDS
S
D
VSP3100
VSP3100
VSP3100

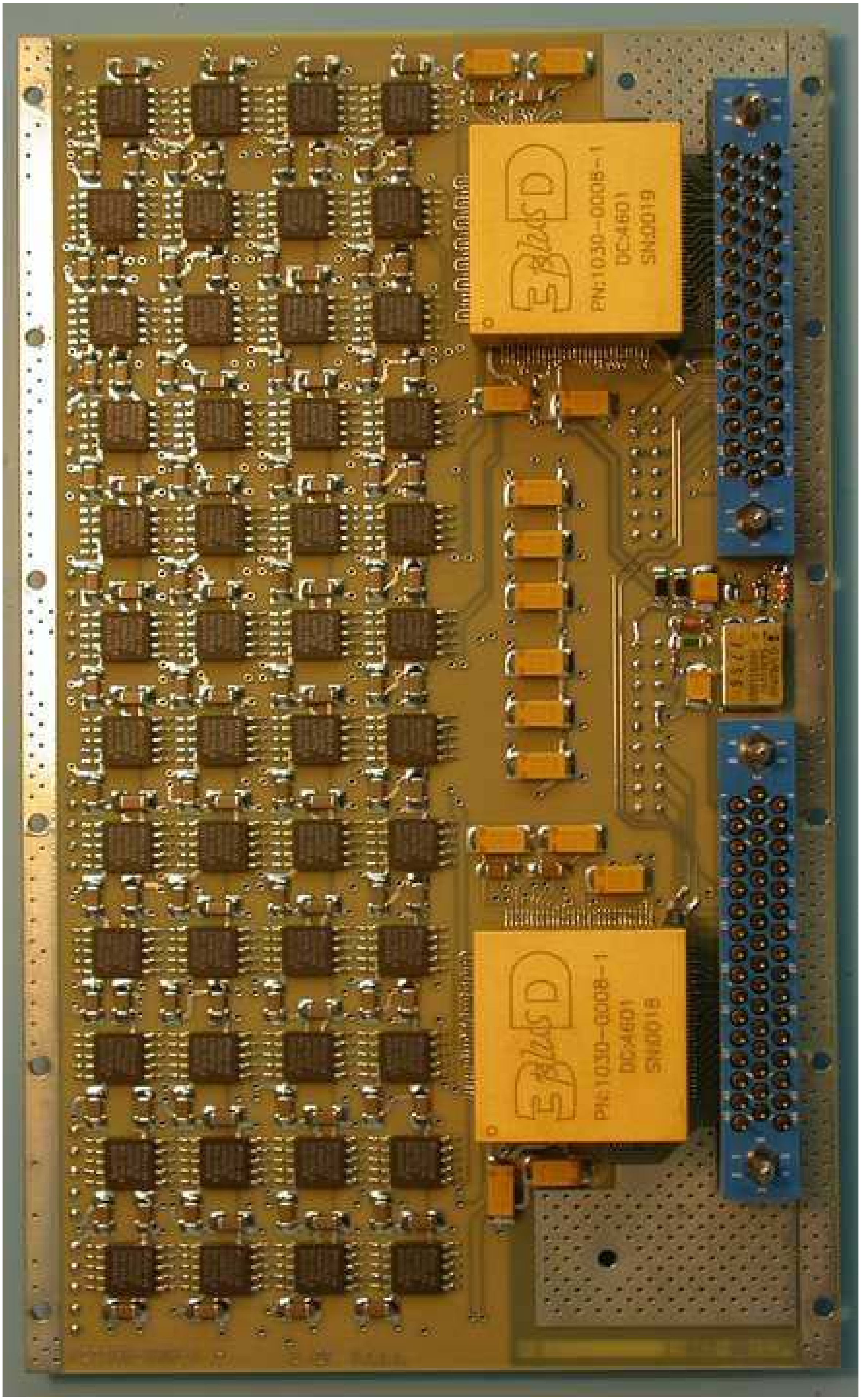


Figure 8

Figure 9

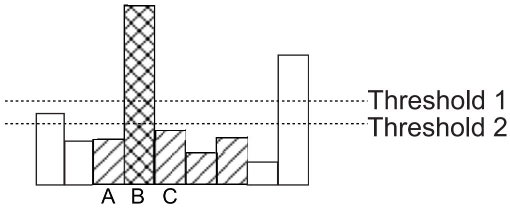


Figure 10

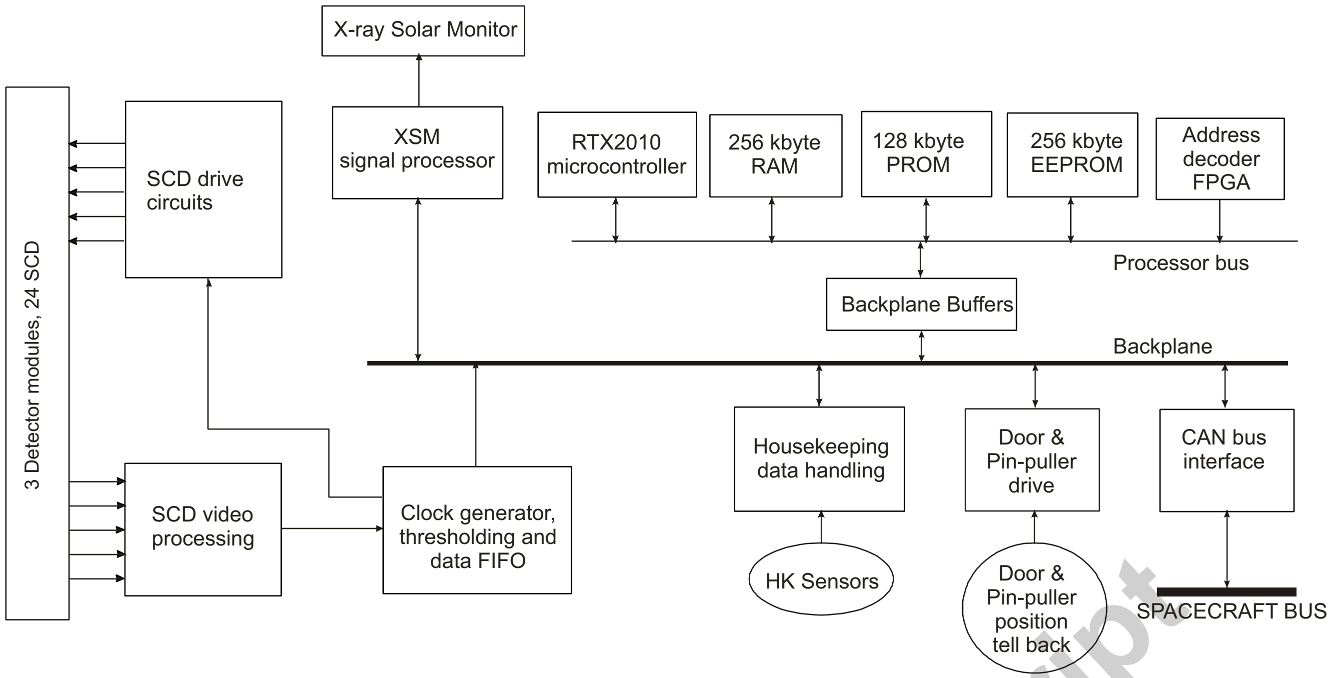
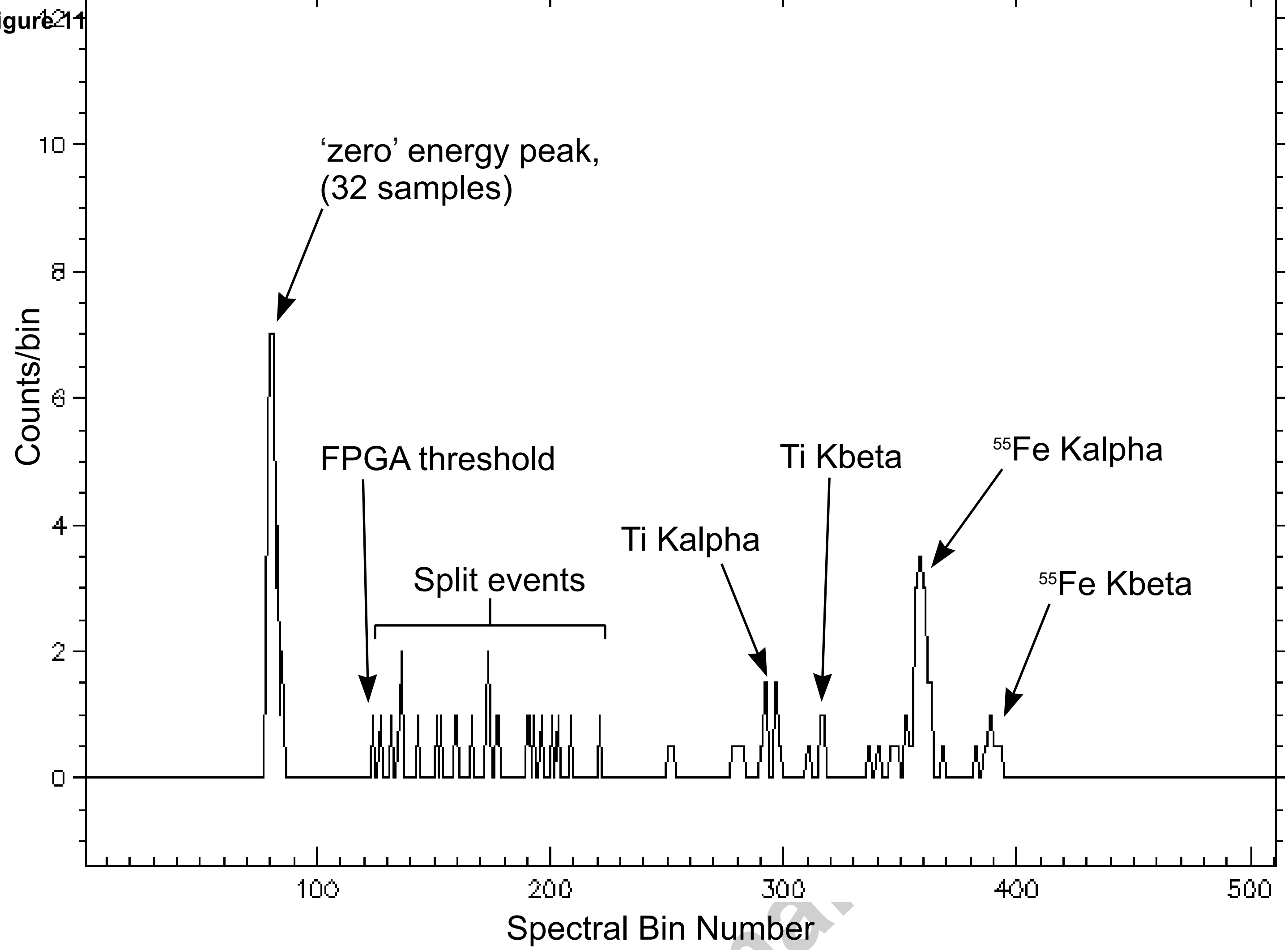
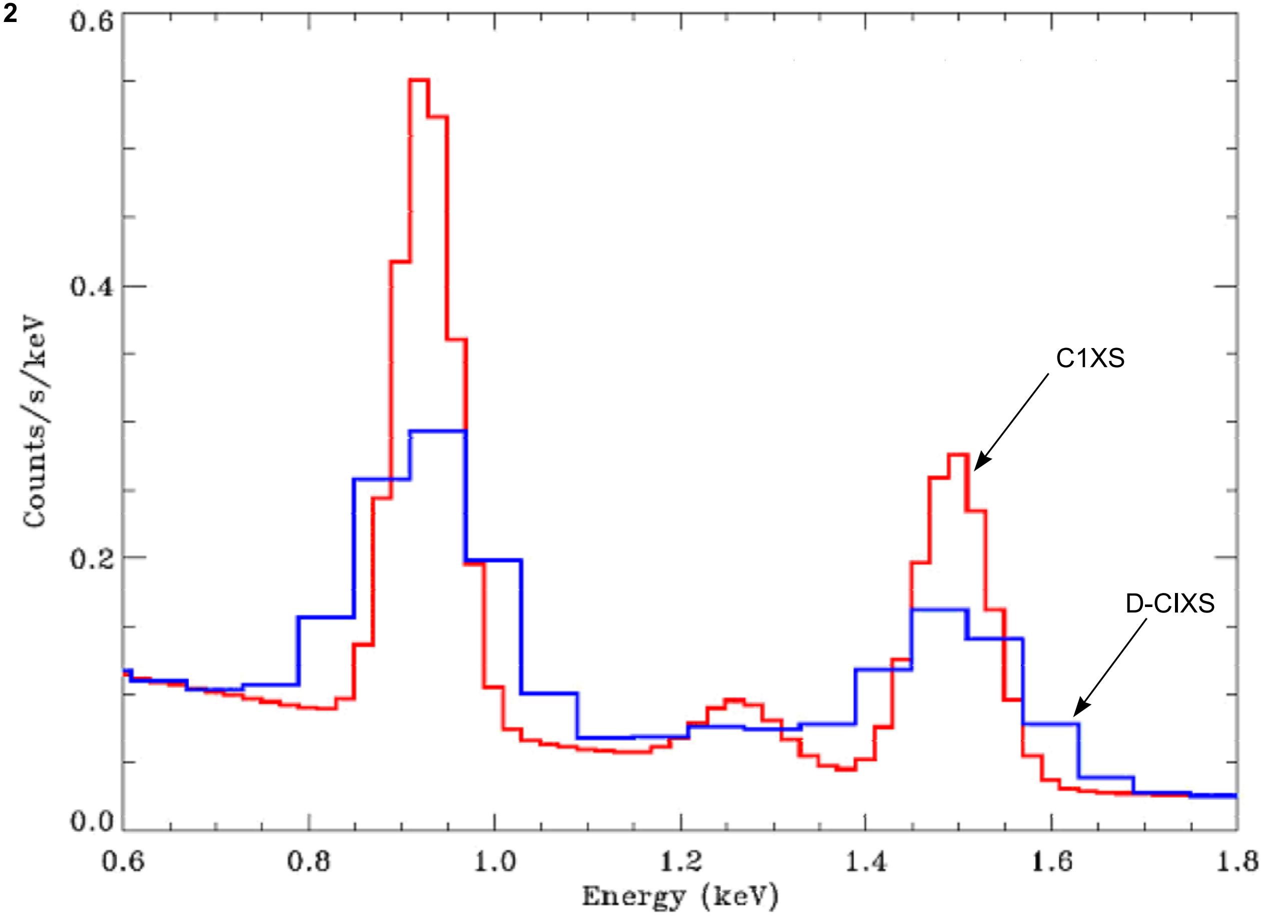

X-ray Solar Monitor
3 Detector modules, 24 SCD
SCD drive circuits
XSM signal processor
RTX2010 microcontroller
256 kbyte RAM
128 kbyte PROM
256 kbyte EEPROM
Address decoder FPGA
Processor bus
Backplane Buffers
Backplane
Housekeeping data handling
Door & Pin-puller drive
CAN bus interface
SCD video processing
Clock generator, thresholding and data FIFO
HK Sensors
Door & Pin-puller position tell back
SPACECRAFT BUS

Figure 11



'zero' energy peak,
(32 samples)
FPGA threshold
Split events
Ti Kalpha
Ti Kbeta
55Fe Kalpha
55Fe Kbeta
Counts/bin
Spectral Bin Number
0
2
4
6
8
10
12
100
200
300
400
500

Figure 12



Counts/s/keV
0.6
0.4
0.2
0.0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Energy (keV)
C1XS
D-CIXS