

ISUAL Flight Instrument

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ISUAL Functional Specification

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1. Scope

This document describes the functional capabilities of the ISUAL flight unit. There are four major subsystems within ISUAL. Of these four subsystems, three are scientific instruments and they are controlled by the fourth subsystem, which is the supporting electronics, as follows:

1. Intensified CCD (ICCD) Imager
2. Spectrophotometer, 6 channel
3. Array Photometer, 2 photometers with 16 anodes each
4. Auxiliary Electronics Package (AEP).

These subsystems are described in the following sections. A major portion of the ISUAL electronics is contained in the AEP. Sensitive amplifiers, high voltage power supplies and other circuits requiring close proximity to the sensors shall be mounted with the sensor subsystem. The four ISUAL subsystems will be interconnected with an ISUAL power/data wiring harness. The AEP shall be connected to the S/C via the S/C wiring harness.

2. Reference Documents

1. <http://sprg.ssl.berkeley.edu/sprite/ago96/isual/ROCSAT.html>

3. Functional Requirements

3.1. States of Operation

Because the ISUAL instrument is fully programmable, it can operate in a variety of states. For example, some subsystems could be commanded OFF, while still operating others in a normal fashion. To avoid defining fixed modes of operation, that might preclude this very desirable level of flexibility, we will describe a few principal states of the instrument. These states could be described as operating modes, but they are really just a description of what is currently envisioned as normal states of operation.

- R1. Reset State ... By default, ISUAL turns on in a reset state wherein the individual scientific instruments are turned OFF and high voltage (HV) power is OFF. Heaters are OFF. Within the AEP, the DPU is the only active electronics, and it will be responding to telecommands (TC) and returning baseline housekeeping telemetry data. The Mass Memory, CIC, SI and API are OFF. In this, and all other instrument states, it can be assumed that the DPU is actively responding to commands and, at a minimum, generating housekeeping telemetry data.
- R2. Heated State ... ISUAL is commanded to turn ON whatever heaters are necessary to maintain a certain survival temperature level.
- R3. Non-observing State ... While in a Non-observing state, instruments may, or may not, be turned OFF, as commanded, however the HV power will be OFF. The instrument would be commanded to assume this state at a point in the orbit just prior to reaching eclipse. It would also assume this state after leaving eclipse, a period when the DPU and CIC will be engaged in processing any available data in memory, to compress it prior to transferring it to the spacecraft (S/C) data buffer. The telemetry interface will transfer data to the S/C as it is available and required.

3.1.1. Observing States

When the ISUAL instruments are fully enabled, with HV power on, there are two fundamental types of observations that are supported, described as follows:

- R4. Sprite observing ... During part of the nighttime period of orbit, primarily over mid-latitudes, ISUAL uses the Spectrophotometer to detect Sprite events. When detected, relatively short bursts of data from each of the three science instruments is collected and stored. During data acquisition, some of this data, especially from the ICCD, is compressed on-the-fly, i.e. in real-time, to increase the amount of data that can be acquired during the observing period. ISUAL has a Mass Memory to store this data, and then during the daytime period of the orbit, this data is further compressed prior to transferring it, via the telemetry interface, to the S/C buffer. The number of events that can be acquired and stored is limited by the ability of the S/C to transmit the ISUAL data to ground stations, a data rate that cannot exceed 1 Gbit/day.
- R5. Aurora/Airglow observing ... During part of the nighttime period of orbit, specifically over the polar latitudes, ISUAL collects data from each of the science instruments at a relatively low, fixed rate. This data is stored in Mass Memory, and then during the daytime transit, it is also compressed prior to transferring it to the S/C buffer.

3.2. ICCD Imager

From a functional viewpoint, the ICCD imager is illustrated in Fig. 1. Data output from the camera is in the form of parallel, digital data with accompanying clocks to synchronize transfer. Commands to the camera are in the form of serial, digital data with accompanying clocks to synchronize transfer. The Acquire, Interrupt and Busy signals are single bit logic levels. The Voltage Monitor is an analog, DC voltage output that is digitized in the AEP. Input Power to the Imager is provided by several low voltage DC voltages, that are switched on/off within the AEP.

An image intensifier functionally acts as a light amplifier and shutter for the CCD camera. These functions of the image intensifier are controlled by adjusting the High Voltage Power Supply. The Gate Enable is a logic level that controls whether the photocathode is gated on or off. The MCP voltage adjustment is an analog voltage that provides continuous level adjustment of the MCP high voltage, which in turn varies the MCP gain. The phosphor voltage adjustment provides continuous level adjustment of the intensifier phosphor voltage. Input Power to the High Voltage power supply is provided by +28Vdc that is switched on/off within the AEP.

A Thermoelectric Cooler (TEC) is used to cool the CCD and reduce dark current. It is controlled from a TEC power supply that is switched on/off within the AEP.

The ICCD imager uses a filter wheel to provide wavelength selectivity. The filter wheel is driven directly from a motor interface in the AEP, and the filter wheel position is read back and decoded by circuitry and software in the AEP. A resistive heater, mounted on the filter wheel is used to maintain the temperature of the filters at a nominal value. The temperature is controlled by switching the power to the heater.

To maintain focus stability, the lens is also heated by a resistive strip, and this is controlled by a power supply that is switched on/off within the AEP.

Several thermistors are employed to sense temperature in the instrument as shown. These devices are sensed and digitized within the AEP.

The ICCD imager is capable of taking images with maximum extent of about 512 x 80 pixels. Due to the architecture of the CCD, images are taken and sequentially shifted through a masked storage area before being read out. Exposures cannot be stored indefinitely in the storage area, because of dark current build up, therefore the desired image repetition rate determines whether each exposure is immediately read out and digitized, or is allowed to stack up in the storage area prior to read out. By stacking images in the storage area, several images can be taken in quick succession (approximately once every millisecond).

A more detailed description of the ICCD camera operation is provided in Appendix A.

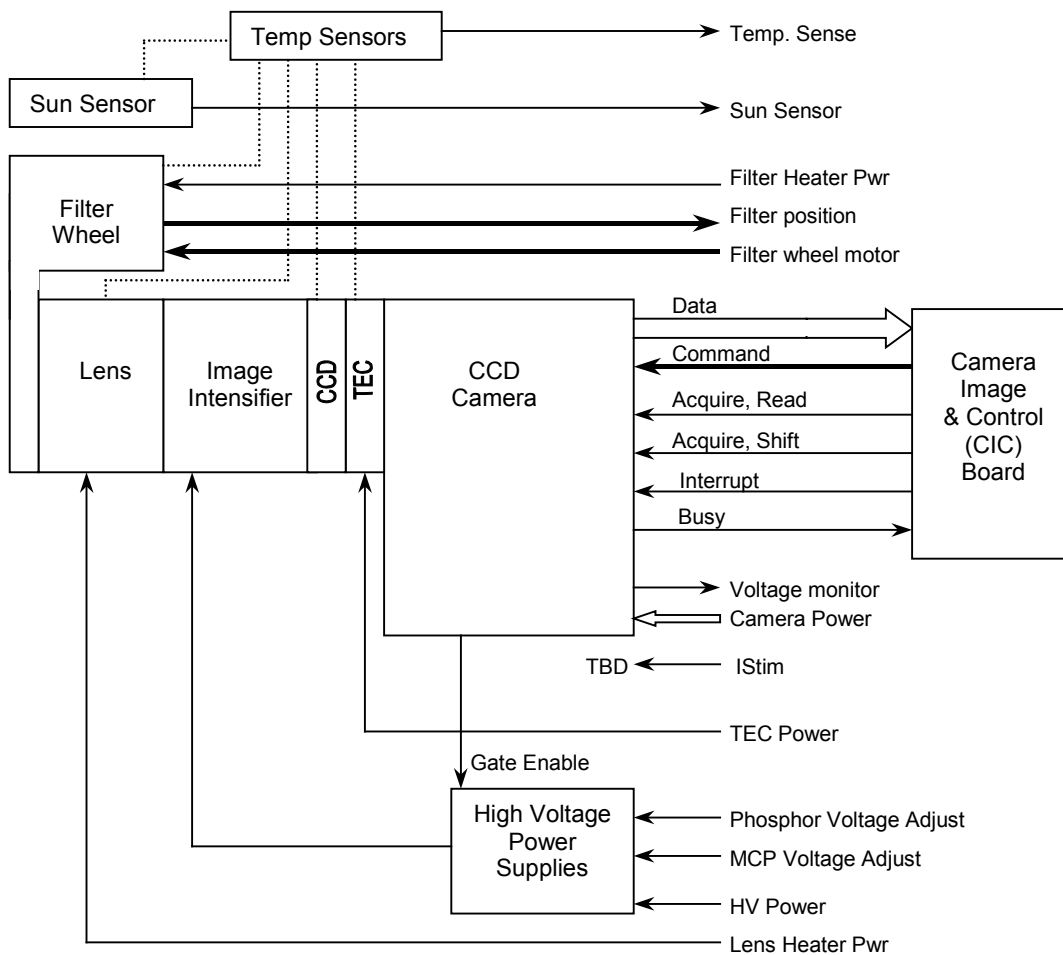


Fig. 1: Functional block diagram of ICCD Imager Subsystem

3.2.1. Functional Capabilities

For any operating mode of the ISUAL instrument, the imager subsystem shall be capable of implementing the following functions. An operating mode is defined by the setting of each of the functions, and parameters, as defined below. All parameters and status of all commanded functions shall be made available in the downlink telemetry.

3.2.1.1. Image Acquisition Modes of Camera

These functional requirements are implemented in the camera, and most are also commands, from the CIC, to which the camera shall respond.

- R6. Gated operation enable ... In normal operation, the photocathode is gated ON during exposure and OFF during readout or other CCD shift operation. However, when not enabled, the controller can leave the gate continuously ON, or OFF (see R7).
- R7. Gate On/Off ... When gated operation is disabled, the photocathode is commanded to be continuously gated ON (i.e. open) or OFF (closed). This command sets an internal parameter that only takes effect if gated operation is disabled.

- R8. Single frame mode ... On leading edge of “Acquire, Read”, stop clearing, gate ON for duration of “Acquire, Read”. Immediately shift image out of storage and digitize. Continuous clear thereafter, awaiting next “Acquire, Read” pulse. “Acquire, Shift” is ignored.
- R9. Multiple frame mode ... There is no continuous clear between images. The controller is responsible for image timing and dark current accumulation. Camera shall respond to either “Acquire, Read” or “Acquire, Shift” as described in the following:
- “Acquire, Shift” ... On leading edge of “Acquire, Shift”, gate ON for duration of “Acquire, Shift” pulse. On trailing edge of pulse, gate OFF and wait for period of GDELAY (see R19), then immediately shift image into upper storage area, with no read out. Lower storage area will continuous read out, with or with out digitization depending on whether images are present from an earlier event. The upper storage area is not shifted, while awaiting next Acquire signal.
- “Acquire, Read” ... On leading edge of “Acquire, Read”, gate ON for period of “Acquire, Read” pulse. On trailing edge of pulse, gate OFF and wait for period of GDELAY, then shift image into upper storage area. When this is complete, halt read out of lower storage, shift upper register into lower register and commence to read out entire lower storage area.
- R10. Interrupt signal ... On leading edge of “Interrupt” signal, stop current exposure, gate OFF, shift current image into storage area.
- R11. Busy signal ... This signal shall be active during exposure, shift and read status of camera, thus signalling to controller when its ready to take another image.
- R12. Test image acquire command ... On leading edge of either “Acquire”, take one image, keep gate OFF, generate test pattern image (TBR).

3.2.1.2. Set Up Parameter Commands to Camera

The camera shall have programmable parameters that can be externally commanded, from the CIC, as follows:

- R13. Set exposure duration time (EXP) ... Duration of exposures taken in subsequent images. Exposure time determines the time the intensifier is gated ON for each exposure. An exposure of 0 indicates that the “Acquire” pulse determines exposure duration.
- R14. Set number of vertical shifts per frame (VSHIFT) ... Number of rows which comprise a frame in the storage area.
- R15. Set vertical shift rate (VRATE) ... The rate at which the CCD vertical shift is applied.
- R16. Set max number of frames in storage (SMAX) ... Maximum number of frames which can be stored in CCD storage area, i.e. specify size of storage area.
- R17. Adjust $\phi V12Hi$ voltage ... A four level adjustment of vertical phases 1 & 2, high voltage level.
- R18. Adjust $\phi V3Hi$ voltage ... A four level adjustment of vertical phase 3, high voltage level.
- R19. Set Gate closing delay (GDELAY) ... An adjustable delay that determines when CCD shift and readout can begin after the intensifier has been gated OFF. This allows the phosphor to decay to a suitable level.
- R20. Set Binning factor (TBR) ... Set CCD on-chip binning.
- R21. Set Region of Interest (TBR) ... Set coordinates of subarray readout.
- R22. Set Attenuation (A/D Gain) (TBR) ... A two level adjustment of gain in amplifier prior to the A/D converter.

R23. Set Readout Rate (TBR) ... A two level adjustment of horizontal readout clock rate.

R24. Disable continuous clear (TBR) ...

3.2.1.3. Status and/or Utility Commands to Camera

These commands are additional functions required in the camera.

R25. Reset imager subsystem ... Reset all parameters to default values.

R26. Select monitor voltage ... A 16 channel selector for the monitor voltage output.

R27. Abort/Cancel commanded exposure cycle (TBR) ...

R28. Enable BIT (Built-In-Test) (TBR) ...

R29. Get camera ID (TBR) ... A unique serial number that specifies the CCD and other device configuration data.

3.2.1.4. Imager Subsystem Functions, controlled directly from DPU

The ISUAL instrument shall be capable of implementing the following functions. This group of functions are implemented in ISUAL directly by software and circuitry in the AEP, i.e. they do not involve a command to the camera. These functions are initiated by software, based on the operating mode of the ISUAL instrument. Each function either: 1) sets a state in hardware or software, or 2) returns discrete data that is available for downlink telemetry.

R30. Imager High Voltage enable ... Turn high voltage power ON to enable, or OFF to disable.

R31. Imager Power enable ... Turn low voltage power ON to enable, or OFF to disable.

R32. TEC Power Enable ... Thermoelectric Cooler (TEC) is turned ON when enabled.

R33. Set MCP "No-Sun" level ... Adjust this voltage according to desired MCP gain. This setting is normally used to set the MCP gain for all observing periods, as contrasted to the "Sun" level which defines the MCP setting for the condition when the sun sensor is active.

R34. Set MCP "Sun" level ... When sun sensor is active, the MCP voltage will automatically be set to a predetermined, low, value, other than OFF. This is an internal parameter that is used to set a hardware default, and it can be varied on telecommand. It is a useful failsafe mechanism in the event of a sun sensor failure.

R35. Set Phosphor voltage ... Operating voltage for intensifier phosphor.

R36. Set CCD temperature in °C ... Set the temperature control set point, an internal parameter that governs the TEC controller (see R122).

R37. Get CCD temperature ... Read CCD temperature (diagnostic).

R38. Disable Auto TEC shutdown ... TEC is automatically turned OFF when TEC temperature reaches a pre-determined threshold. This automatic shutdown can be disabled using this command.

R39. Get TEC heat sink temperature ... Read TEC hot side temperature (diagnostic).

R40. Lens heater enable ... Lens heater control (see R123) is turned ON when enabled.

R41. Set Lens temperature ... Set the temperature control set point, an internal parameter that governs the lens temperature controller.

R42. Get Lens temperature ... Read Lens temperature (diagnostic).

R43. Get sun sensor status ... Read current status of sun sensor, i.e. ON or OFF.

- R44. Get sun sensor temperature ... Read sun sensor temperature (diagnostic).
- R45. Get filter wheel motor temperature ... Read filter wheel motor temperature (diagnostic).
- R46. Get filter wheel position ... Read current filter wheel position in counts.
- R47. Reinitialize filter wheel position ... Rotate filter wheel to angular reference point to reinitialize position feedback, i.e. the position corresponding to zero counts.
- R48. Set filter wheel position ... Move filter wheel to position N, where N is the desired filter position in counts. Each filter position and/or park position will have a predetermined count position relative to the initialization point.
- R49. Filter heater enable ... Filter heater control (see R124) is turned ON when enabled.
- R50. Set Filter temperature ... Set the temperature control set point, an internal parameter that governs the filter temperature controller.
- R51. Get filter temperature ... Read filter temperature (diagnostic).
- R52. Read Voltages ... Select and digitize the voltage output from camera “voltage monitor” (see R26). These values shall be updated at a TBD rate and provided in downlink telemetry.
- R53. ICCD Stim Enable (ISTIM) ... A test mode, when enabled, a test lamp is activated in the ICCD optical train, and data is acquired, according to the mode selected.

3.2.2. Camera Functional Command Summary

	Range of Values
Camera Image Acquisition commands	
R6 Gated operation enable	yes / no
R7 Gate Open/Close	open / close
R8 Single frame mode (Aurora)	yes / no
R9 Multiple frame mode (Sprite)	yes / no
R12 Test image acquire (TBR)	yes / no

	Range of Values
Camera Setup parameter commands	
R13 Set exposure duration time (EXP)	0.1 - 5000 ms
R14 Set number of vertical shifts per frame (VSHIFT)	0 - 1024
R15 Set vertical shift rate (VRATE)	1 – 100 μ s
R16 Set max number of frames in storage (SMAX)	1 - TBD
R17 Adjust ϕ V12Hi voltage	0 - 3 integer
R18 Adjust ϕ V3Hi voltage	0 - 3 integer
R19 Set Gate closing delay (GDELAY)	0 - 3000 μ s
R20 Set Binning factor (TBR)	1 - 4 integer
R21 Set Region of Interest (TBR)	x1, y1, x2, y2
R22 Set Attenuation (A/D Gain) (TBR)	hi / lo
R23 Set Readout Rate (TBR)	hi / lo
R24 Disable continuous clear (TBR)	yes / no

	Range of Values
Camera Status/health and Utility commands	
R25 Reset imager subsystem	yes / no
R26 Select monitor voltage	1 - 16 integer
R27 Abort/Cancel commanded exposure cycle	yes / no
R28 Enable BIT (Built-In-Test) (TBR)	yes / no
R29 Get camera ID (TBR)	

3.3. Spectrophotometer

From a functional viewpoint, the Spectrophotometer is illustrated in Fig. 2. It consists of six channels, each of which is comprised of an optical filter and photomultiplier tube, therefore giving each channel sensitivity to a different wavelength or passband. Data output from each channel of the instrument is in the form of an analog voltage, each of which is a high level analog of the photo current in each tube. Two high voltage power supplies are incorporated in the instrument, each of which powers three of the photomultiplier tubes. The High Voltage adjustment is an analog voltage that provides continuous level adjustment of the high voltage applied to each bank of tubes, thus controlling the gain of the tubes. Input power to the HV supplies is provided by +28Vdc that is switched on/off within the AEP. The temperature of the photometer is controlled by switching the heater power on/off.

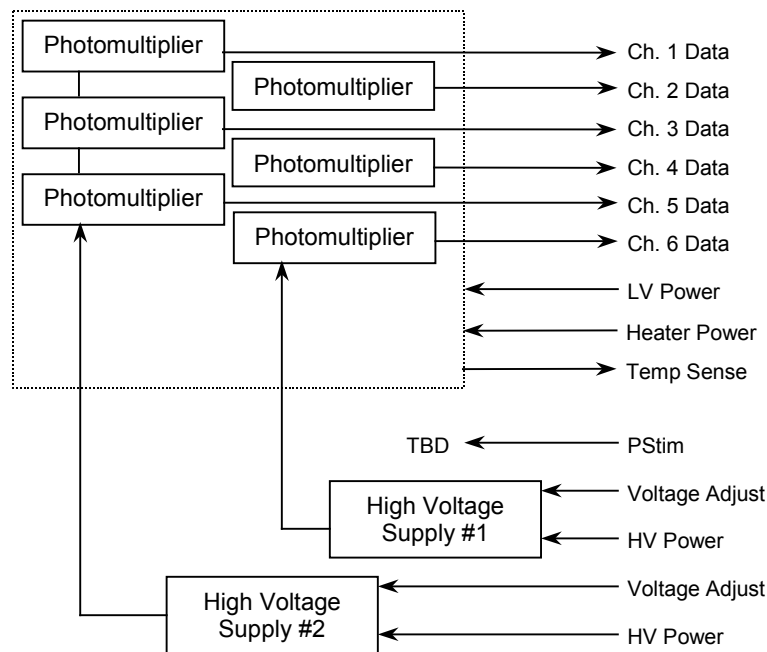


Fig. 2: Functional block diagram of Spectrophotometer

3.3.1. Functional Capabilities

These functions are initiated in the DPU.

- R54. Photometer power enable ... Turn low voltage power ON.
- R55. High Voltage Bank 1 enable ... Turn high voltage power ON to enable.
- R56. High Voltage Bank 2 enable ... Turn high voltage power ON to enable.
- R57. Set Bank 1 “No-Sun” HV ... Adjust this voltage according to desired gain. This is the setting used for “no-sun” condition, the normal operating voltage during observations.
- R58. Set Bank 1 “Sun” HV setting ... The setting used as hardware default when sun sensor is active.
- R59. Set Bank 2 “No-Sun” HV ... Adjust this voltage according to desired gain. This is the setting used for “no-sun” condition, the normal operating voltage during observations.
- R60. Set Bank 2 “Sun” HV setting ... The setting used as hardware default when sun sensor is active.

- R61. Photometer heater enable ... Photometer heater control (see R125) is turned On when enabled.
- R62. Set photometer temperature ... Set the temperature control set point, an internal parameter that governs the photometer temperature controller.
- R63. Get photometer temperature ... Read photometer temperature (diagnostic).
- R64. Stim Enable (PSTIM) ... A test mode, when enabled, a test lamp is activated in each photometer channel, and data is acquired, according to the mode selected.

3.4. Array Photometer

From a functional viewpoint, the Array Photometer (AP) is illustrated in Fig. 3.

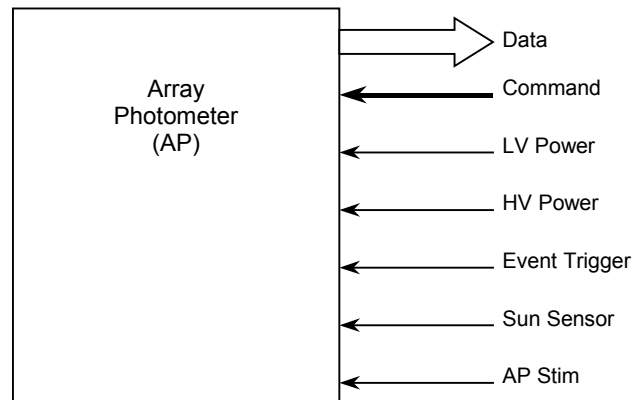


Fig. 3: Array Photometer functional block diagram

3.4.1. Power Control

- R65. AP Power enable ... Turn low voltage power ON to enable Array Photometer.
- R66. High Voltage enable ... Turn high voltage power ON to enable Array Photometer high voltage.
- R67. Array Photometer Stim Enable ... Turn ON internal source to stimulate AP.

3.4.2. Command Interface

Commands are issued as serial, digital data in a form TBD. The following commands are anticipated.

- R68. Set HV “No-Sun” level ... The setting used for “No-Sun” condition, sets the gain of the AP.
- R69. Set HV “Sun” Level ... This is an internal parameter that defines a hardware default HV level to which the Array Photometer is set when the sun sensor indicates ON.
- R70. Set “Sprite” mode ... In this mode, the leading edge of “Event Trigger” signal shall cause the AP to acquire time series data from each photometer channel and transfer this data in TBD format to the AP Interface (see section 3.5.3). Each time series shall consist of data sampled at a rate selected by the parameter APERATE (see R72). Each time series shall consist of two segments, the first of which is data sampled prior to the event, and the second segment is data sampled immediately after the event. The length of these two segments is specified by the parameters APRESCAN (see R73), and APOSTSCAN (see R74).
- R71. Set “Aurora” mode ... In this mode, the AP shall sample each photometer channel at a rate, specified by parameter APSRATE (see R75), that is considerably slower than sprite rate. For each sample acquired, the AP will transfer this data in TBD format to the AP interface. For the case

were APSRATE is set to zero (0), the AP will return a data sample each time this command is issued.

- R72. Set event sample rate (APERATE) ... Sprite event photometer sampling rate.
- R73. Event, pre-trigger, sample period (APRESCAN) ... For sprite, the duration of time series prior to the event to include in total data sample for that event.
- R74. Event, post-trigger, sample period (APOSTSCAN) ... For sprite event, the duration of time series after the event to include in total data sample for that event.
- R75. Slow sample rate (APSRATE) ... Sample rate during Aurora mode operation.

3.4.3. Data Interface

- R76. Data output ... Data output from the AP is in the form of parallel, digital data with accompanying clocks to synchronize transfer. The form and data order of this data is TBD.

3.5. Auxiliary Electronics Package (AEP)

ISUAL shall have an Auxiliary Electronics Package to house digital and analog electronics. This separate subsystem shall control the imaging subsystems of the ISUAL instrument, process the image data, and provide the command, data, and power interfaces to the S/C. The AEP shall be composed of seven modules, each of which shall be implemented on printed circuit assemblies mounted in an aluminum frame. The stacked assembly of frames shall form the AEP enclosure. The mounting location of the AEP may be chosen to assist in the mass balancing of the S/C.

The functional capabilities of the AEP are broken down as follows:

1. Camera image and control (CIC),
2. Spectrophotometer interface (SI),
3. Array Photometer interface (API),
4. Mass Memory (MM) unit,
5. Data processing unit (DPU),
7. Low voltage power supply (LVPS), and
6. Power Controller (PC).

3.5.1. Camera Image and Control

The ICCD Imager, or camera, data is acquired by the Camera Image and Control (CIC) Board in the AEP. This board also acts as a high level Camera Controller. It's functional inputs and outputs are illustrated in Fig. 4. In its role as Camera Controller, the CIC is either sending commands to the camera as required by the modes executing in the CIC processor, or it could simply be relaying commands from the DPU.

- R77. Camera Command ... When either requested by the DPU or under its own control, the CIC board shall generate commands to the camera using the serial command interface. All commands as specified in para. 3.2.1.1, 3.2.1.2 and 3.2.1.3 shall be implemented.
- R78. Communication with DPU ... Control data between the CIC and DPU shall consist of tables of data stored in shared memory, with the DPU writing to one table to initiate commands to the CIC, and the CIC writing to a separate table to return status data to the DPU.

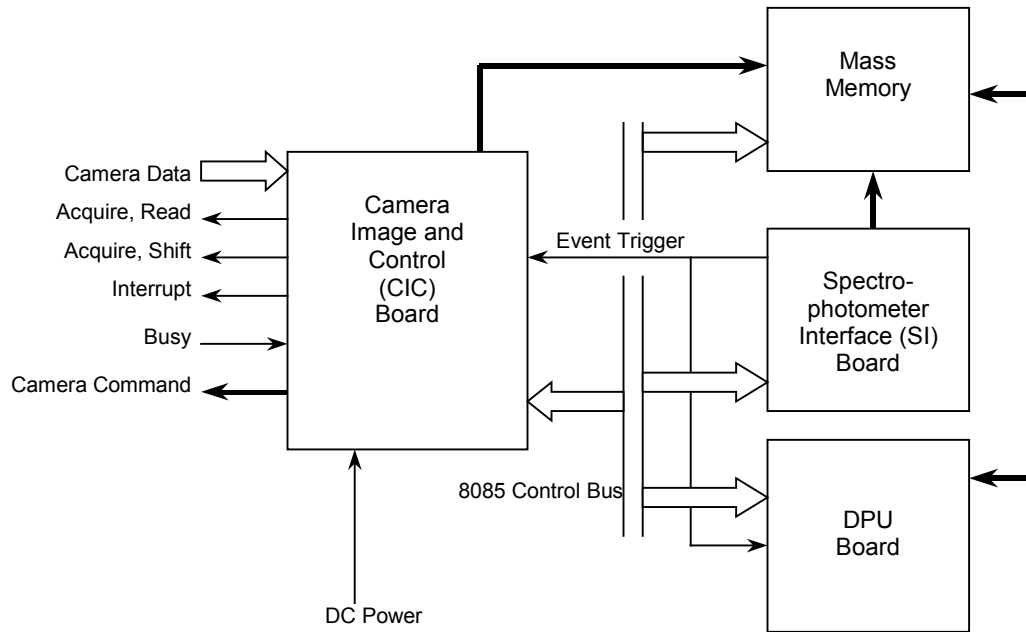


Fig. 4: Image Acquisition and CIC Functional Block Diagram

3.5.1.1. CIC Image Acquisition Modes

R79. Single frame acquire (Aurora/Airglow) ... In this mode, repetition period is greater than TBD (> 1 sec), and single frames are read out using the “single frame mode” function of camera (see R8). Images are taken using “Acquire, Read” wherein image is not stored in CCD for any length of time. Exposure duration is controlled by duration of “Acquire, Read” signal, as specified by parameter EXP (see R87). Images are taken with a repetition period as specified by parameter REPTIME (see R88). With REPTIME set to zero (0), the DPU can initiate single frames on command.

See section 3.5.1.2 for image data processing and storage.

R80. Multiple frame acquire (Sprite) ... In this mode, repetition period is relatively short (< 100 ms), and frames are continuously initiated, using the “multiple frame mode” function of camera (see R9), while waiting for trigger events. Between events, images are taken continuously, of exposure duration EXP, at a rate as fast as possible, using “Acquire, Shift” pulse to initiate each image.

On leading edge of “Event Trigger”, immediately terminate current exposure by asserting “Interrupt” signal to camera. This will cause the gate to turn OFF, and the camera will shift the last exposure into the storage area.

CIC will delay for a period of SDELAY (see R89), then execute a series of fast frames, of exposure EXP, using “Acquire, Shift”, at a rate as fast as possible. The number of fast frames will be determined by the parameter SMAX (see R16). This will stack up images in the storage area without read out. Thereafter, CIC will execute frames using “Acquire, Read”, until the desired number of images, set by POSTTRIG, are acquired. The “Acquire, Shift” process shall then continue until the next event.

For each image acquired, the CIC will either process, (i.e. compress), the image, or not, prior to storing the image in memory. If processing is selected, the repetition period shall not increase by more than TBD%. See section 3.5.1.2 for image data processing and storage.

R81. Dark image acquire ... Command single frame acquire mode and photocathode to OFF and take one image of exposure duration EXP. Data is stored the same as “single frame acquire” (see R84).

- R82. Bias image acquire ... Command single frame acquire mode and photocathode to OFF and take one image of exposure duration zero (0). Data is stored the same as “single frame acquire” (see R84).
- R83. Test image acquire ... Command test image acquire mode and take one test image, and keep gate OFF. Data is stored the same as with “single frame acquire” (see R84).

3.5.1.2. CIC Image Data Processing and Storage Modes

- R84. Single frame acquire ... This mode is enabled during Aurora mode (see R79) and is used for all images, other than “multiple mode” images. As image data is transferred from the camera to the CIC during image acquisition, the raw data is transferred to Mass Memory starting at memory location MEMSTART. For each image stored in memory, the CIC will log a table entry for the DPU that uniquely identifies the time for each image, e.g. the CIC will log an image number and corresponding count since the start of this mode. The DPU will use this data to create a time stamp for each image.

The CIC shall continue storing images until memory is filled, as determined by MEMSIZE, or it is commanded to stop by the DPU.

- R85. Multiple frame acquire ... This mode is enabled for Sprite mode (see R80). As image data is transferred from the camera to the CIC during image acquisition, the CIC stores data in either raw or processed (i.e. compressed) form depending on whether an event has been detected, and the type of real-time, or “fast”, processing selected by parameter FASTPRC. The number of images stored to memory is based on parameters PRETRIG and POSTTRIG, where the total number of frames acquired for each event is PRETRIG + POSTTRIG. Note that POSTTRIG can be either greater than or less than SMAX.

As image data is transferred from the camera to the CIC during image acquisition, the raw or FASTPRC'd data is transferred to Mass Memory starting at memory location MEMSTART. For each image stored in memory, the CIC will log table entries that uniquely identifies the time and type of compression for each image, e.g. the CIC will log a unique image number, event number, time count and processing code for each image. The DPU will use this data to create a time stamp for each image.

The CIC shall continue storing images until memory is filled, as determined by MEMSIZE, or it is commanded to stop by the DPU.

- R86. Standby processing ... During periods of standby operation, the CIC shall be capable of off-line image and photometer data compression, as commanded by the DPU. The type of compression is commanded by the DPU as selected by parameter STBYPRC. The DPU will command this process by specifying the type of processing, a memory location and a memory size parameter for each block of data (or image) to compress.

3.5.1.3. Setup Parameters for CIC

- R87. Exposure duration (EXP) ... Set the exposure duration for each image.
- R88. Repetition period (REPTIME) ... Set the repetition period for “single frame acquire” mode.
- R89. Sprite event gate delay (SDELAY) ... Set the time delay from onset of event until gate is turned ON.
- R90. Number of Pre-trigger Sprite frames to acquire (PRETRIG) ... Set the number of frames to store prior to event.
- R91. Number of Post-trigger Sprite frames to acquire (POSTTRIG) ... Set the number of frames to store after the event.

- R92. Fast Processing Type (FASTPRC) ... Specifies the type of image compression performed in real-time, i.e. during image acquisition.
- R93. Standby Processing Type (STBYPRC) ... Specifies the type of image compression performed off-line, during standby periods.
- R94. Memory Location Start (MEMSTART) ... DPU specifies where the CIC shall start filling Mass Memory.
- R95. Memory Buffer Size (MEMSIZE) ... DPU specifies the size of the image buffer.

3.5.2. Spectrophotometer Data Acquisition

The Spectrophotometer, or photometer, data is acquired by the Spectrophotometer Interface (SI) Board in the AEP. This board provides data conversion and event detection. It's functional inputs and outputs are illustrated in Fig. 5.

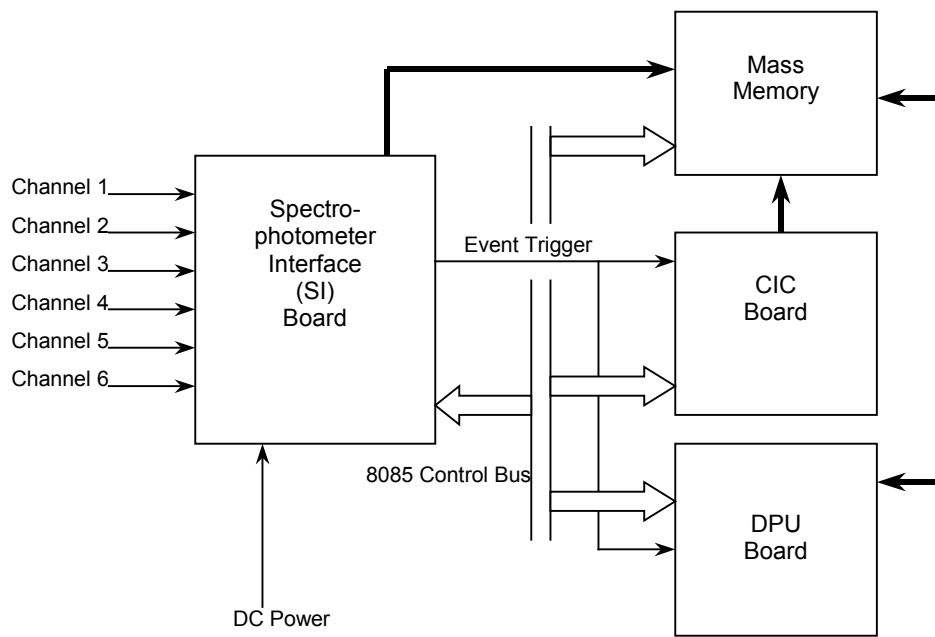


Fig. 5: Spectrophotometer Interface (SI) Board functional block diagram

- R96. Communication with DPU ... The SI and DPU shall communicate via shared memory, with each device writing to separate tables in memory to avoid race conditions.

3.5.2.1. SI Data Conversion and Storage Modes

- R97. Event data acquisition and storage (Sprite) mode ... The SI shall provide an analog interface for each of 6 photometer channels, digitizing each channel with 12-bit precision. In Sprite mode of operation, the SI provides high data rate conversion and storage for each channel, but the data saved corresponds to a time series of duration, PRESCAN, prior to the event and a time series of duration, POSTSCAN, after the event. Digital conversion rate during PRESCAN and POSTSCAN shall be specified by parameter ERATE.

After an event, the PRESCAN and POSTSCAN data series shall be stored in Memory, starting at PMEMSTART. For each block of data stored in memory, the SI will log a table entry for the DPU that uniquely identifies the time for each block, e.g. the SI will log a block number and

corresponding event number. The DPU will use this data to create a time stamp for each block of data.

The SI shall continue storing data until memory is filled, as determined by PMEMSIZE, or it is commanded to stop by the DPU.

- R98. Slow data acquisition and storage (Aurora) mode ... The SI shall provide an analog interface for each of 6 photometer channels, digitizing each channel with 12-bit precision. In Aurora mode of operation, the SI provides data conversion at a much slower rate than Sprite, a rate specified by SRATE. With SRATE set to zero (0), the SI will simply acquire one sample on command from the DPU.

All data acquired in this mode shall be stored in memory, starting at PMEMSTART, in blocks of size TBD. For each block of data stored in memory, the SI will log a table entry for the DPU that uniquely identifies the time for each sample. The DPU will use this data to create a time stamp for each sample.

The SI shall continue storing data until memory is filled, as determined by PMEMSIZE, or it is commanded to stop by the DPU.

- R99. Event detection (Sprite) ... When enabled, as specified by EON, the SI shall be able to detect an "event" as defined by a photometer signal exceeding a threshold level, TLEVEL, occurring in a minimum of TBD seconds. The SI shall be able to switch any one of the six photometer channels, as selected by parameter PSELECT, into the event detection circuit. When an event is detected, output signal "Event Trigger" shall switch to active state for TBD seconds. A software interlock shall prevent a change of TLEVEL or PSELECT while sprite data is being collected.

3.5.2.2. Setup Parameters for SI

- R100. Event sample rate (ERATE) ... Sprite event photometer sampling rate.
- R101. Event, pre-trigger, sample period (PRESCAN) ... For sprite, the duration of time series prior to the event to store.
- R102. Event, post-trigger, sample period (POSTSCAN) ... For sprite event, the duration of time series after the event to store.
- R103. Slow sample rate (SRATE) ... Sample rate during Aurora mode operation.
- R104. Event detection enable (EON) ... When enabled, the event trigger is active.
- R105. Event threshold (TLEVEL) ... Analog voltage threshold level for event detection.
- R106. Event channel select (PSELECT) ... One of six channel select.
- R107. Memory buffer start location (PMEMSTART) ... DPU specifies start location for data storage.
- R108. Memory Buffer Size (PMEMSIZE) ... DPU specifies the size of the photometer data buffer.

3.5.3. Array Photometer Data Acquisition

The Array Photometer data is acquired by the AP Interface (API) Board in the AEP. The API functional inputs and outputs are illustrated in Fig. 6.

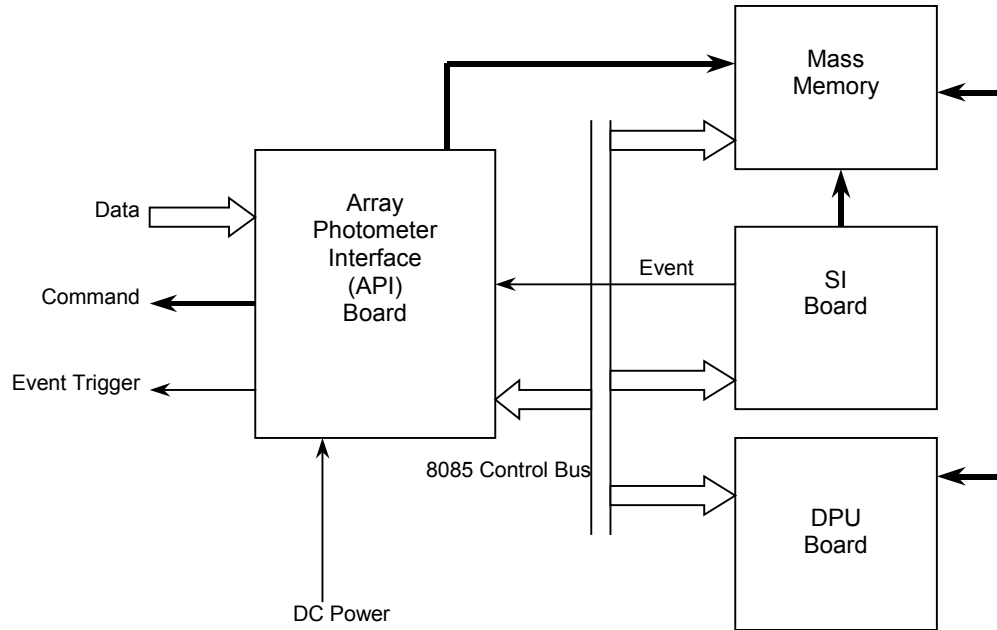


Fig. 6: Array Photometer data interface functional block diagram

R109. Sprite data mode ... With each event, the APRESCAN and APOSTSCAN data series shall be stored in Memory, starting at AMEMSTART (see R111). For each block of data stored in memory, the API will log a table entry for the DPU that uniquely identifies the time for each block, e.g. the API will log a block number and corresponding event number. The DPU will use this data to create a time stamp for each block of data.

The API shall continue storing event data until memory is filled, as determined by AMEMSIZE (see R112), or it is commanded to stop by the DPU.

R110. Aurora data mode ... All data acquired in this mode shall be stored in memory, starting at AMEMSTART, in blocks of size TBD. For each block of data stored in memory, the API will log a table entry for the DPU that uniquely identifies the time for each sample. The DPU will use this data to create a time stamp for each sample.

The API shall continue storing data until memory is filled, as determined by AMEMSIZE, or it is commanded to stop by the DPU.

R111. Memory buffer start location (AMEMSTART) ... DPU specifies start location for AP data storage.

R112. Memory Buffer Size (AMEMSIZE) ... DPU specifies the size of the AP data buffer.

3.5.4. Mass Memory

R113. ISUAL shall have a mass memory large enough to store TBD Mbytes of raw, or uncompressed, data per orbit. This same memory will be used to store compressed and telemetry formatted data

prior to its transfer to the S/C buffer. The mass memory shall be accessible by the CIC, SI, API, DPU and telemetry readout.

3.5.5. DPU Board

The DPU board in the AEP includes the primary control processor, and it also provides the interface with the S/C. A functional block diagram of the board is shown in Fig. 7.

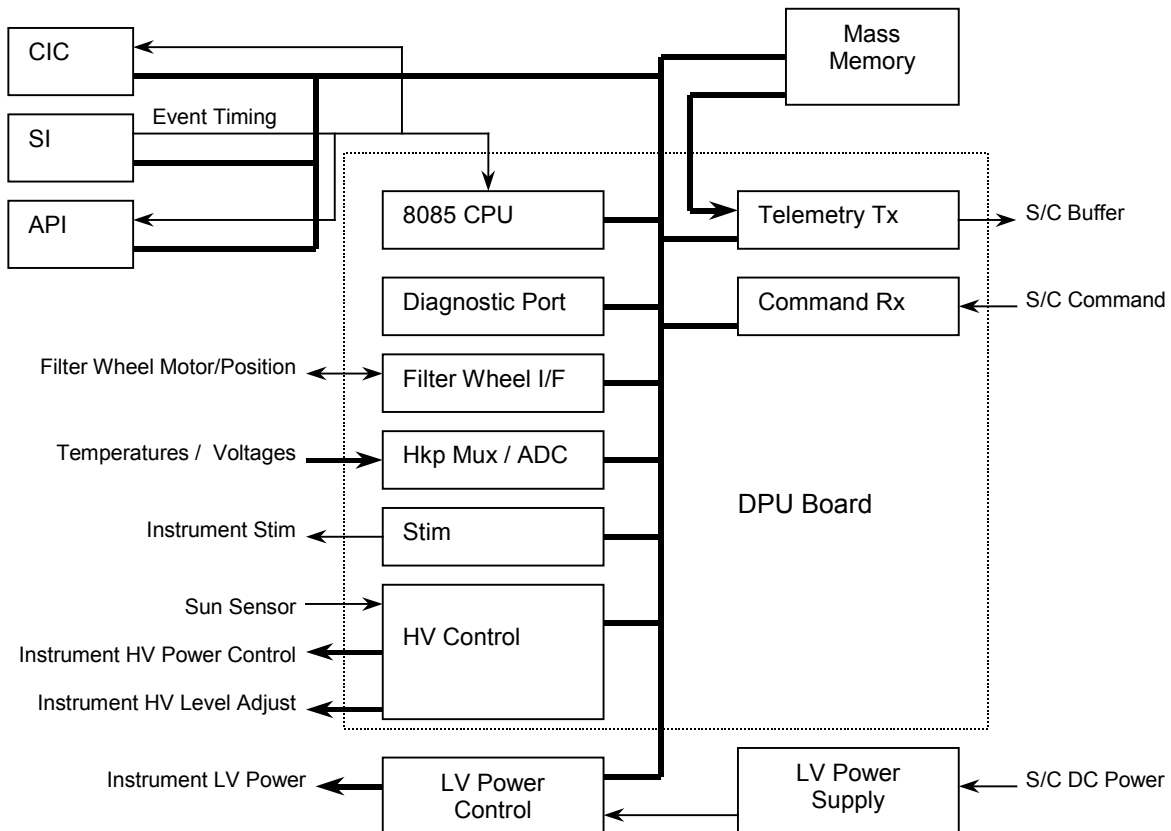


Fig. 7: DPU Functional Block Diagram

3.5.5.1. Space Craft Interface

R114. Command ... The DPU receives telecommands from the S/C that control current operation of ISUAL. Typically the commands are used to update the operating schedule of the instrument.

R115. Data Telemetry ... The DPU can read out the contents of Mass Memory and transfer data to the S/C buffer. The data shall be formatted in accordance with TBD specification. The DPU shall monitor the status of the Mass Memory and recognize the need (or the time) to transfer its contents when appropriate to free up this internal buffer for additional science data collection. The data telemetry output shall be able to transfer blocks of data, of any size and location in memory, as commanded by the DPU.

3.5.5.2. Subsystem Control

R116. ICCD Camera Control ... The DPU shall provide mode and parameter control of the ICCD subsystem in accordance with sections 3.2 and 3.5.1 as required for the current system mode.

- R117. Spectrophotometer Control ... The DPU shall provide mode and parameter control of the Spectrophotometer subsystem in accordance with sections 3.3 and 3.5.2 as required for the current system mode.
- R118. Array Photometer Control ... The DPU shall provide mode and parameter control of the Array Photometer subsystem in accordance with sections 3.4 and 3.5.3 as required for the current system mode.

3.5.5.3. Automated functions

These functions are implemented in the DPU, in either hardware or software, and operate without external command, however these functions may have programmable parameters that govern their operation.

- R119. Sun sensor ... The sun sensor is an important safeguard device in ISUAL. When the sun sensor has detected the sun, fast acting circuitry shall immediately put subsystem High Voltage power supplies at the setting corresponding "Sun" level. The "Sun" levels for each supply are individually commanded. When the sun sensor is active, the "No-Sun" settings will have no effect, and the "Sun" setting controls the HV level.
- R120. Sun Sensor Time Stamp ... The time at which the sun sensor activates shall be logged in the DPU and made available to telemetry. This shall be implemented as a DPU interrupt.
- R121. Sprite Event Time Stamp ... The time at which sprite trigger event occurs shall be logged in the DPU and made available to telemetry.
- R122. TEC temperature controller ... Control temperature of the CCD to within TBD degrees by controlling TEC power ON or OFF. The CCD temperature set point is commanded (see R36). The temperature and control action is implemented at a 0.5 Hz (TBR) rate. Monitor TEC heat sink temperature and automatically shutdown TEC power when temperature exceeds TBD threshold.
- R123. Lens temperature control ... Control temperature of the lens to within TBD degrees by controlling the lens heater power. The lens temperature set point is commanded (see R41). The temperature and control action is implemented at a 0.5 Hz (TBR) rate.
- R124. ICCD filter temperature control ... Control temperature of the filters to within TBD degrees by controlling the filter heater power. The filter temperature set point is commanded (see R50). The temperature and control action is implemented at a 0.5 Hz (TBR) rate.
- R125. Photometer temperature control ... Control temperature of the Spectrophotometer to within TBD degrees by controlling the photometer heater power. The temperature set point is commanded (see R62). The temperature and control action is implemented at a 0.5 Hz (TBR) rate.

3.5.5.4. DPU Control Summary

This summary provides a list of controls, by subsystem, that govern the state of ISUAL, i.e. its mode.

	Range of Values
ICCD Image Acquisition commands	
R6 Gated operation enable	yes / no
R7 Photocathode gate open / closed	open / closed
R79 R84 Single frame acquire mode – Aurora mode	yes / no
R80 R85 Multiple frame acquire mode – Sprite mode	yes / no
R81 Dark image acquire – as required	yes / no
R82 Bias image acquire – as required	yes / no
R83 Test image acquire – as required	yes / no
R83 Standby processing – as required	yes / no

	Range of Values
ICCD Image parameter commands	
R87 Set Exposure duration (EXP)	1 – 5,000 ms
R88 Set Repetition period (REPTIME)	10 – 60,000 ms
R89 Set Sprite event gate delay (SDELAY)	0 – 10,000 μ s
R90 Set number of pre-trigger frames (PRETRIG)	0 – 50
R91 Set number of post-trigger frames (POSTTRIG)	0 – 50
R92 Set fast processing type (FASTPRC)	0,1,2 ...
R93 Set standby processing type (STBYPRC)	0,1,2,3 ...
R94 Set memory start location (MEMSTART)	0x hhhh hhhh
R95 Set memory buffer size limit (MEMSIZE)	0x hhhh hhhh
R14 Set number of vertical shifts per frame (VSHIFT)	70 - 100
R15 Set vertical shift rate (VRATE)	1 – 100 μ s
R16 Set max number of frames in storage (SMAX)	1 - TBD
R17 Adjust ϕ V12Hi voltage	0 - 3 integer
R18 Adjust ϕ V3Hi voltage	0 - 3 integer
R19 Set Gate closing delay (GDELAY)	0 - 2000 μ s
R20 Set Binning factor (TBR)	1 - 4 integer
R21 Set Region of Interest (TBR)	x1, y1, x2, y2
R22 Set Attenuation (A/D Gain) (TBR)	hi / lo
R23 Set Readout Rate (TBR)	hi / lo
R24 Disable continuous clear (TBR)	yes / no

	Range of Values
Camera Status/health and Utility commands	
R25 Reset imager subsystem	yes / no
R26 Select monitor voltage	1 - 16 integer
R27 Abort/Cancel commanded exposure cycle	yes / no
R28 Enable BIT (Built-In-Test) (TBR)	yes / no
R29 Get camera ID (TBR)	

DPU Control Summary, con't.

	Range of Adjustment
Imager functions implemented by DPU	
R30 Imager High Voltage enable	yes / no
R31 Imager Power enable	yes / no
R32 TEC power enable	yes / no
R33 Set MCP "No-Sun" level	400 - 1000 Vdc
R34 Set MCP "Sun" level	Preset value parameter
R35 Set phosphor voltage	1000 – 5000 Vdc
R36 Set CCD temperature in °C	-50 to +50
R37 Get CCD temperature	-50 to +50
R38 Disable Auto TEC shutdown	yes / no
R39 Get TEC heat sink temperature	-50 to +75
R40 Lens Heater enable	yes / no
R41 Set Lens temperature set point	-50 to + 50
R42 Get Lens temperature	-50 to + 50
R43 Get sun sensor status	on / off
R44 Get sun sensor temperature	-50 to +50
R45 Get filter wheel motor temperature	-50 to +50
R46 Get filter wheel position	1 - 6 integer
R47 Reinitialize filter wheel position	yes / no
R48 Set filter wheel position	1 - 6 integer
R49 Filter heater enable	yes / no
R50 Set filter temperature set point	-50 to +50
R51 Get filter temperature	-50 to +50
R52 Read Voltages	TBD
R53 ICCD Stim Enable	yes / no

DPU Control Summary, con't.

	Range of Adjustment
Spectrophotometer functions implemented by DPU	
R54 Photometer power enable	yes / no
R55 High Voltage Bank 1 enable	yes / no
R56 High Voltage Bank 2 enable	yes / no
R57 Set Bank 1 "No-Sun" HV	TBD - TBD Vdc
R58 Set Bank 1 "Sun" HV setting	TBD
R59 Set Bank 2 "No-Sun" HV	TBD - TBD Vdc
R60 Set Bank 2 "Sun" HV setting	TBD
R61 Photometer heater enable	yes / no
R62 Set Photometer temperature	-50 to +50
R63 Get Photometer temperature	-50 to +50
R64 Photometer Stim enable	yes / no
R97 Enable Event mode – Primary Sprite mode	yes / no
R98 Enable slow data mode – Primary Aurora mode	yes / no
R99 R104 Enable event detection, set EON	yes / no
R100 Set sample rate for Sprite mode (ERATE)	1 - 10 kHz
R101 Set pre-trigger sample period (PRESCAN)	0 – 1000 ms
R102 Set post-trigger sample period (POSTSCAN)	0 – 2000 ms
R103 Set slow sample rate (SRATE)	0.01 – 10 Hz
R105 Set event threshold level (TLEVEL)	0 – 5000 mV
R106 Set event channel select (PSELECT)	1 – 6 (integer)
R107 Set memory start location (PMEMSTART)	0x hhhh hhhh
R108 Set memory buffer size limit (PMEMSIZE)	0x hhhh hhhh

	Range of Adjustment
Array Photometer functions implemented by DPU	
R65 Array Photometer power enable	yes / no
R66 AP High Voltage enable	yes / no
R67 AP Stim Enable	yes / no
R68 Set HV "No-Sun" Level	TBD
R69 Set HV "Sun" Level	0 – TBD Volts
R70 Set "Sprite" mode	yes / no
R71 Set "Aurora" mode	yes / no
R72 Set AP event sample rate (APERATE)	1 – 20 kHz
R73 Set AP pre-trigger sample period (APRESCAN)	0 – 1000 ms
R74 Set AP post-trigger sample period (APOSTSCAN)	0 – 2000 ms
R75 Set slow sample rate (APSRATE)	0.01 – 10 Hz
R109 Enable API sprite mode	yes / no
R110 Enable API aurora mode	yes / no
R111 Set API memory buffer start location (AMEMSTART)	0x hhhh hhhh
R112 Set API memory buffer size (AMEMSIZE)	0x hhhh hhhh

3.5.6. Low Voltage Power Supply

R126. ISUAL shall have a low voltage power supply (LVPS) to receive 28-volt power from the S/C and convert it to voltages required by the ISUAL subsystems, generally +12, -12, +5, and -5 volts. It shall use off-the-shelf commercially available space rated DC-DC converters. It shall maintain d.c. isolation between S/C power ground and ISUAL signal ground and shall include an input filter to block electrical noise on its 28-volt input. If redundant power inputs are provided by the S/C, they shall be applied through isolating diodes to the LVPS input.

3.5.7. Power Controller

R127. ISUAL shall have a Power Controller (PC) module. The PC shall route d.c. power from the LVPS to various parts of each ISUAL subsystem, provide on/off switching for each power circuit, limit current in each power circuit, and allow continuous monitoring of each voltage and current. The PC shall provide approximately twenty independent power circuits.

3.6. Survival Heaters

R128. ISUAL shall have a set of survival heaters powered and controlled by the S/C. The heaters, when used, shall maintain minimum non-operating temperatures at the ISUAL subsystems. The survival heaters shall be served by a single 28-volt circuit from the S/C, and this circuit shall be independent of the 28-volt supply to the AEP. A heater shall be attached to each subsystem box, and all heaters shall be wired in parallel. The S/C shall control the survival heaters based on (TBD) algorithm using readings from thermistors mounted on ISUAL subsystems but wired to the S/C.

4. Test Requirements

Table 4.1: Test Requirements Matrix

TBD

Appendix A

“Sprite” CCD Camera Theory of Operation

To provide some background on the operation of the CCD camera used in ISUAL, the following discussion of its operation is provided.

Since the ISUAL CCD camera will be imaging the Earth’s limb, the resulting image of interest has an aspect that is much wider (horizontally) than it is tall (vertically). For this reason, the CCD, which has a total of 512 x 512 pixels in its image register, will be masked to create an active image area that has an aspect ratio, h:v, of approximately 6:1. This is illustrated in Fig. A-1. Typically a frame transfer CCD has an image area and a storage area that equal in size. The image and storage areas can be clocked independently. Using a CCD of this type, we will mask both of the CCD’s image and storage registers, leaving a small active image area that is approximately 512 x 80 pixels. This “mini-frame” will be shifted into the masked area, which is now an extra large storage area, prior to being read out.

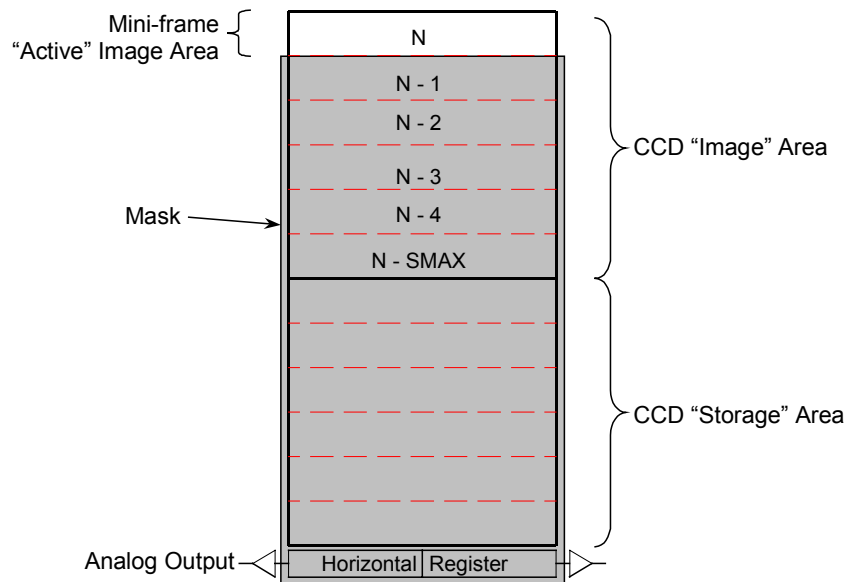


Fig. A-1: The ISUAL CCD. The CCD will be masked to create an active image area with a size of approximately 512 x 80 pixels.

In the “sprite” mode of observing, as each exposure is made on the CCD, the upper vertical register is clocked such that the charge representing each image is shifted downward, as viewed in Fig. A-1. For the “Nth” image taken with the camera, images N-1, N-2, and so on, will end up being temporarily stored in the masked, storage area. The maximum number of frames that we will store in the CCD is defined by a parameter, SMAX (see R16). Even though the size of the CCD is fixed, we treat SMAX as a variable, because we may want to limit the number of images we store in the CCD to minimize dark charge accumulation in the stored images. In addition, the vertical size of each image, or frame, is also treated as a variable, defined by the parameter, VSHIFT (see R14). Since the mask is not applied directly on the CCD, the edges of the resulting area shadowed by the mask will be somewhat soft, and we need to add a few extra lines of blank area between images to provide a buffer zone. So by setting VSHIFT, we can vary the amount of blank area between frames on the CCD.

The readout of the ISUAL CCD is somewhat more complicated than a typical frame transfer application, which would generally only have storage for one image. During Sprite observing, the camera will be

continuously taking exposures, and shifting images into the storage area. As images are shifted through the vertical register, unwanted images will simply be shifted into the horizontal register, without horizontal read out, or digitization. (Note: We may periodically clear the horizontal register to prevent over-saturation or blooming, although we won't digitize during that clearing operation.)

When the sprite event is detected, we will interrupt the current exposure, gate OFF the intensifier and shift the image into the storage area. At this point, we will delay the next exposure by the interval set by SDELAY (see R89), and then commence taking post-trigger exposures as quickly as possible. Note, that SDELAY can be as small as zero. Fig. A-2 illustrates the state of the CCD after taking a few post-trigger frames. In the figure, the Nth image is the exposure that was interrupted by the sprite event. The CCD storage area contains both pre-trigger frames and post-trigger frames. The illustration is an example of the case where PRETRIG (see R90) is set to 1. After the N+4 exposure is completed, the entire upper register, the CCD's "image" area, will be shifted into the lower "storage area". From there, each mini-frame will be sequentially read out through the horizontal register. While the lower, storage area is being read out, the upper area will be ready to receive the next Sprite event.

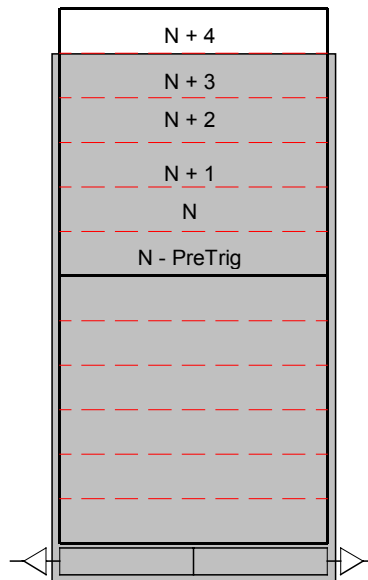


Fig. A-2: CCD After Sprite Event. One pre-trigger frame and several post-trigger frames will be stored in the CCD prior to readout.

As an example of the image time resolution possible with this technique, we will assume the following scenario, where the CCD size is 512 x 1024, and the nominal mini-frame size is 512 x 80.

Vertical transfer rate:	1 MHz (provides mini-frame shift time of < 100 μ s)
Horizontal transfer rate:	10 MHz (provides mini-frame readout time of ~ 5 ms)
VSHIFT:	85 (85 shifts required per 80 line frame)
SMAX:	5 (only 5 frames stored, before shift into lower area)
PRETRIG:	1 (save 1 pre-trigger frame)
POSTTRIG:	5 (save 5 post-trigger frames)
EXP:	2 ms (exposure duration of 2 ms)
SDELAY:	4 ms (delay 4 ms after event)

This scenario is illustrated in Fig. A-3. In this figure, the time that each exposure is initiated is shown in the first line above the time line, and the time that each frame is read out is shown on the second line above the time line. Prior to the event trigger, the frame rate is continuous, at intervals of approximately 2 ms. When the event occurs, the exposure in progress is interrupted, and the intensifier gate is turned off for an interval set by SDELAY. Exposures then begin again, at a frame rate that is largely a function of the exposure duration. When the CCD upper, “image” area is full, as limited by SMAX, the entire upper register is quickly shifted into the lower, “storage” area. Once the images are in this lower register, we begin to read them out, and the time that each image has been read out is shown in the figure. While this read out is occurring, however, we can independently use the upper area to store another set of mini-frames. Hence, no dead time between the first and second event is incurred. Because of the storage buffer, there is a latency between capturing an image and reading it out. For example, the last image of interest in the first event, #9, is taken at $t=18$ ms, but it is not completely read out until 33 ms later.

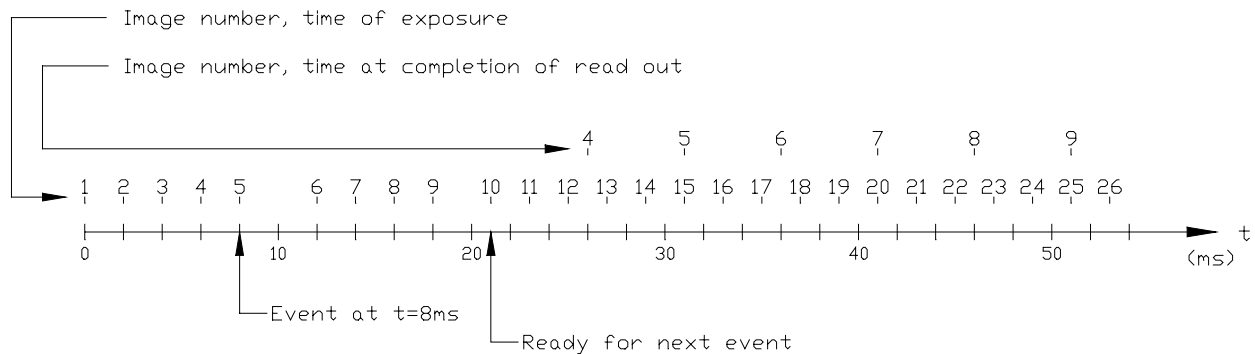


Fig. A-3: Timing diagram for example scenario

Referring to Fig. A-3, the difference between the two different “Acquire” signals discussed in section 3.2.1.1 can be explained. Frames 1 – 8 are taken with “Acquire, Shift”, i.e. after an exposure of duration EXP, the resulting charge is only shifted down in the upper area, without read out. The parameter GDELAY (see R19), is an internal camera parameter that sets the delay from commanding the gate OFF to starting these vertical shifts. Frame 9 is taken with “Acquire, Read”, after which the entire upper register is shifted in the lower, storage area. Once in the lower register, this entire storage area is simply read out, automatically, as quickly as possible. After frame 9 is taken, and the shift is completed, then we will continue the “Acquire, Shift” method, waiting for the next event.

This example is only relevant to the Sprite mode of operation. In Aurora mode, the situation is somewhat simpler, in that we will not attempt to store images in the CCD. With each image acquire, we will immediately shift the image all the way through the storage area, and read it out. As an example, using the same parameters used in the previous scenario, the time to read out an Aurora mode image will be approximately 6 ms, i.e. the time to read out one frame plus the time to shift the entire vertical register.