Infrared Sensor Specification

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REVISION SUMMARY:

1. Date: Oct 6, 2020
   Revision: A
   Changes: Initial release
2. Date: Oct 30, 2020
   Revision: B
   Changes: Scope clarifications
3. Date: Nov 16, 2020
   Revision: C
   Changes: Changed physical size, CDS Reads added, definitions clarified.
4. Date: Nov 30, 2020
   Revision: D
   Changes: Further definition clarification, change of integration time to frame rate.

Table of Contents

1 INTRODUCTION

The Daniel K. Inouye Solar Telescope (DKIST), located in Maui, Hawaii, USA, provides diffraction-limited, solar observations to the solar physics community. As part of its mission, DKIST instrumentation performs science observations in visible and infrared wavelengths using state-of-the art optics, electronics and cameras.

The DKIST Infrared Sensor Specification provides the detailed specifications for current and future IR instrument needs for IR sensors. This document defines the requirements for a Digital Focal Plane Array (DFPA), readout electronics, packaging, and interfaces. Other components of an IR camera, including the frame grabber and high-level control system are not provided as part of this work package, although interfaces between the two work packages are part of this scope.

1.1 DEFINITIONS

The following words and terms as defined herein shall be the applicable definitions as used in all requirements.

- ADU: Analog to Digital unit.
- Bad pixel cluster: Two or more blemished pixels that are horizontally, vertically, or diagonally adjacent.
- Blemished pixels: Those pixels that after application of linearity, dark, and gain corrections fail to meet all performance requirements, including but not limited to read noise, dark current stability, gain stability, and deferred charge.
- Column: A linear set of pixels that constitute the slow readout direction.
- CDS: Correlated double sampling (pedestal value of the pixel after it is reset is subtracted from the signal value of the pixel at the end of the exposure).
- Digital Focal Plane Array (DFPA): An image sensing device consisting of an array of light-sensing pixels at the focal plane of a lens that performs analog-digital conversion on the sensor.
- EMVA 1288 Release 3.1. Standard for Characterization of Image Sensors and Cameras. (https://www.emva.org/standards-technology/emva-1288/)
- Exposure: Integration of photo-electrons by sensor pixels after a reset.
- Exposure time: Time during which sensor pixels integrate photo-electrons.
- Frame: The data from a single readout of the sensor. This could be the full frame or a region of interest.
- Frame time: Time necessary to readout a frame.
- Frame rate: 1/Frame time.
- Full array: All the photo-sensitive pixels in the sensor array.
- Full well: Linear full well capacity, computed using the criterion of a maximum 5% deviation from the *best fit linear polynomial* to the pixel-intensity-versus-exposure-time curve. The *best fit linear polynomial* is computed over the range defined by the minimum exposure time value measured and the exposure time for which the first derivative of the pixel-intensity-versus-exposure-time curve drops below 70% of its maximum value.
- NIC: Not in Contract.
- Non-Destructive Read: Consecutive readouts of frames while the array is integrating, without resetting.
- Non-Linearity: Peak-to-Valley deviation, in percent, from the *best fit linear polynomial* to the photon transfer curve, fitted within the intensity signal range up to full well. The *best fit linear polynomial* is defined as

$$f_i = a_0 + a_1 \cdot H_i$$

where a_0 and a_1 are the parameters of the *best fit linear polynomial*, and H_i is the abscissa value of the *i*-th measurement of the pixel response curve (representing the intensity signal). With this, the deviation in percent from the *best fit linear polynomial* f_i for each measured value *i* is then defined as

$$\delta_i = \frac{y_i - f_i}{f_i} \cdot 100$$

where y_i the *i*-th measured value (representing noise signal) at abscissa value H_i.

- Pedestal: reference (bias) value of pixel read immediately after it has been reset.
- Quantum efficiency: Ratio of electrons produced in the photosensitive layer of the array to the number of photons of a given energy incident on the array.
- Ramp: The data represented by multiple non-destructive readouts of the array.
- Region of Interest (window): A rectangular set of pixels that provide a smaller area to read out than the full frame. The purposes for a region of interest include reducing the data volume and decreasing the readout time.
- Row. A linear set of pixels that constitute the fastest possible readout time.
- Sensor: See Digital Focal Plane Array (DFPA).

1.2 VERIFICATION

Included in each major numbered specification listed in this document is a requirement verification method. These verification methods specify the minimum standards of verification required to ensure that the individual requirements and specifications are met.

Examples of verification methods include:

- **Design Review**. Verification by design review means that it is shown during an appropriate design review that the system meets specification by way of its intrinsic design and configuration.
- **Analysis**. Verification by analysis demonstrates that the design meets the specification through use of performance modeling metrics.
- **Test**. Verification by test and/or measurement means that it is demonstrated that the as-built system meets the specification through measurements of its operation performance. Testing is performed during acceptance testing and/or as part of a pre-ship readiness review.
- **Inspection**. Verification by inspection means that visual inspection verifies that the specification has been achieved on the as-built system during preassembly and/or during Site assembly.

2 REQUIREMENTS

2.1 OVERVIEW

IRCAM.SEN-0010 Scope of the IR Sensor
The "IR Sensor" shall include all hardware necessary to convert photons to digital data and to interface to a camera control computer (NIC). This includes an infrared-sensitive sensor array, on-sensor readout electronics, on-sensor clocking, on-sensor signal conditioning, and on-sensor firmware. The IR Sensor also includes a description and definition of the mechanical, electrical, and programmatic interfaces to the sensor, including external bias, trigger, or other signals.

Verification: Design Review, Inspection.

IRCAM.SEN-0020 Testing Standard
All camera and sensor testing shall use EMVA Standard 1288, Release 3.1 tests where defined and applicable.

Verification: Design Review.

IRCAM.SEN-0030 Cryogenic Operations
All electronics and cables shall be designed to allow the operation of the array inside a larger cryostat. Nominal operating temperature shall be 70K with a minimum survivable temperature of 20K. Sensor shall allow a cold cable length up to 900 mm without affecting performance.

Verification: Design Review.

2.2 SENSOR

The digital sensor focal plane array (DFPA) is composed of the area array used to convert photons to ADUs and the mount for the array.

2.2.1 Sensor Type

IRCAM.SEN-0100 Sensor Type
The sensor shall be a digital focal plane array where the analog to digital conversion is performed on the array.

Verification: Design Review

2.2.2 Sizes

IRCAM.SEN-0200 Physical Size
The sensor area array shall be at least 36 mm on each side, measured from first pixel to last pixel.

Verification: Design Review, Inspection

IRCAM.SEN-0210 Full Frame Size
The sensor array shall have a full frame size of at least 2048 pixels per row by 2048 pixels per column of contiguous photosensitive pixels.

Verification: Design Review, Test.

IRCAM.SEN-0220 Flatness
The sensor array shall be flat to ±36 microns.

Verification: Design Review, Inspection

2.2.3 Performance

IRCAM.SEN-0300 Full Frame Rate
The maximum frame rate shall be greater than or equal to 60 frames per second when reading out the full array.

Verification: Design Review, Test.

IRCAM.SEN-0310 Full Well
The full well of the sensor array pixels shall be a minimum of 100,000 photo-electrons.

Verification: Design Review, Test.

IRCAM.SEN-0320 Read Noise
The sensor array shall have a maximum of 30 e^- RMS read noise for a CDS.

Verification: Design Review, Test.

IRCAM.SEN-0330 Dark Current
The sensor array pixel dark current shall be less than or equal to 1,000 e^- per second at 77K.

Verification: Design Review, Test.

IRCAM.SEN-0340 Wavelength Sensitivity
The sensor array for shortwave IR shall identify the quantum efficiency greater than zero. The red and blue cutoff wavelengths shall be clearly established.

Verification: Design Review, Test.

IRCAM.SEN-0350 Quantum Efficiency—Shortwave IR Sensor
For shortwave IR sensors, the sensor array shall provide a quantum efficiency of greater than or equal to 80% average from 0.9 microns to 2.5 microns with no value below 70%.

Verification: Design Review, Test.

IRCAM.SEN-0360 Quantum Efficiency—Midwave IR Sensor
For midwave IR sensors, the sensor array shall provide a quantum efficiency of greater than or equal to 80% average from 0.9 microns to 5.0 microns with no value below 70%.

Verification: Design Review, Test.

2.2.4 Modes of Operation

IRCAM.SEN-0400 Integrate While Read
Exposure shall be concurrent with readout.

Verification: Design Review, Test.

IRCAM.SEN-0410 Non-Destructive Reads
The sensor array shall be capable of reading out the pixel digital values multiple times after resetting, without modifying the ongoing accumulation of signal. If pedestal subtraction is not performed on chip in this mode, then pedestal frame is delivered to the user with the other data frames.

Verification: Design Review, Test.

IRCAM.SEN-0420 On-Chip Pedestal subtraction
The sensor array shall be capable of performing a pedestal subtraction on the chip.

Verification: Design Review, Test.

IRCAM.SEN-0430 Exposure Time
The sensor array shall support adjustable exposure times from 1 msec or less, to at least 10 seconds. The increment of exposure time shall be less than or equal to 0.5 milliseconds when the exposure time is less than the frame time.

Exposure time shall be stable to less than 0.001 RMS of the frame time.

Verification: Design Review, Test

IRCAM.SEN-0440 Regions of Interest
The sensor array shall support at least one region of interest within the sensor active area. At least one dimension (horizontal or vertical) of the region of interest shall be changeable with increments of 1 pixel.

The location and size of the region of interest shall be changeable via the control interface.

Verification: Design Review, Test.

2.2.5 Pixel Operability

IRCAM.SEN-0500 Pixel Format
The sensor array pixels shall be square.

Verification: Test.

IRCAM.SEN-0510 Blemished Pixels
There shall be less than 2% of all pixels blemished.

Verification: Test.

IRCAM.SEN-0520 Bad Pixel Clusters
There shall be less than 1% of all pixels in blemished pixel clusters.

There shall be less than 0.1% of all pixels in blemished pixel clusters with cluster size of 10 or larger.

Verification: Test.

IRCAM.SEN-0530 Parasitic and Residual Charge
A pixel shall have no more than 0.5% of its signal due to the signal of other pixels or previous reads of that same pixel, when measured at less than one half of the full well depth.

Verification: Test

2.2.6 Power

IRCAM.SEN-0600 Power Dissipation
The digital focal plane array should dissipate less than 1W.

Verification: Design Review, Test

2.2.7 Timing

IRCAM.SEN-0700 Exposure Triggering
The sensor array shall be capable of initiating one or more exposures in response to an external trigger. The exposures shall start deterministically according to the exposure Trigger to Exposure Latency requirement (IRCAM.SEN-0710) and Exposure Start Time Stability requirement (IRCAM.SEN-0720) while meeting all other Sensor requirements.

Verification: Design Review, Test

IRCAM.SEN-0710 Trigger to Exposure Latency
The delay between receipt of a trigger and start of exposure integration shall be no more than 10% of the maximum frame time.

Verification: Design Review, Test

IRCAM.SEN-0720 Exposure Start Time Stability (Jitter)
The variation in the Trigger to Exposure Latency shall be equal to or less than ±0.1 millisecond RMS.

Verification: Design Review, Test.

IRCAM.SEN-0730 Duty Cycle
The Sensor shall support exposure times up to 99% of the trigger time to the extent possible consistent with exposure time and increment.

Verification: Design Review, Test

2.2.8 Analog to digital conversion

IRCAM.SEN-0800 Linearity
The Sensor non-linearity shall be less than 1.0%.

Verification: Design Review, Test.

IRCAM.SEN-0810 Pixel Digitization
The Sensor shall digitize the pixel level signal with a minimum of 14 bits.

Verification: Design Review

2.2.9 Interface

IRCAM.SEN-0900 Standard Interfaces
The command and data interfaces between the sensor array and the camera computer shall adhere to a documented and well-defined interface standard. External equipment to run the sensor array, such as ultra-stable power supplies, frame grabbers, and signal cable conditioning, shall be specified and documented.

Verification: Design Review, Test