STELLAR Technical Goals (U)

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Version 13

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The Staring Technology for Enhanced Linear Line-of-sight Angular Recognition (STELLAR) program is designed to push the state-of-the art for visible sensors for application in radiation hardened star trackers. The goal of this program is the development of high-performance, high-functionality visible sensor chip assemblies (SCA) for applications against very low backgrounds. Desired features of this SCA include high conversion gain, and large format. On-chip A/D conversion is optional. This document details the performance capabilities and goals of the STELLAR program. Key features are discussed below.

Requirements specifying the configuration of the STELLAR SCA are listed in table 1. Performance goals for the STELLAR SCA are listed in table 2. Performance goals are to be met under the conditions of the nominal temperature, nominal frame rate, and nominal integration time specified in table 1 at end-of-life (*i.e.* after exposure to ionizing radiation total dose specified).

Tables 1, 2, and 3 list requirements and goals for two different SCA configurations: a base configuration and an optional advanced configuration. Design, fabrication, and testing of the base configuration is the basic task of the STELLAR program. The design, fabrication, and testing of the advanced configuration is a separate priced option.

For both the base and advanced configurations, the ability to accurately and predictably centroid star images is essential. Therefore, all design precautions should be taken to avoid cell-to-cell variations in layout. In particular, adjacent unit cell layouts should not be mirrored imaged.

1 Digital Command Interface

A digital command interface is required. This interface will allow external programming of most biases, integration times, and windowing modes. The digital command interface shall be capable of changing operating mode or conditions on a frame-by-frame basis. This capability may be provided by a side-car support integrated circuit.

2 Windowing

Operation in a windowing mode shall be provided. In windowing mode, multiple blocks of rows will be readout. The position of each block shall be command-able by the Digital Command Interface. In window mode, all simultaneous windows will have the same frame time and integration time. Frame time and integration time will be set by the Digital Command Interface. Details of window operation are listed in table 3.

3 On Chip A/D Conversion

On chip A/D conversion is an optional feature. Different requirements are listed in the tables depending on whether or not on-chip A/D conversion is present.

The minimum number of bits of A/D resolution is specified in Table 2. For test and other reasons, the SCA shall have optional analog output drivers. It shall be possible to turn off the analog output drivers for power savings purposes. The A/D converter may be provided on a separate integrated circuit that can be mounted within very close proximity to the SCA.

A/D conversion capability maybe provided by a side-car integrated circuit.

4 Standby Mode

The STELLAR SCA shall have a standby mode. In standby mode, non-essential functions will be powered off, reducing power consumption. The goal is to reduce power consumption in the standby mode by at least 50% from normal operating mode. Transition from standby mode to normal operating mode with stable response ($< 1\%$) shall be within 5 frames.

Parameter	Base Requirement	Advanced Requirement	Units	Ref.
Detector Pitch	12	12	μm	1
Array Configuration	1024 × 1024	2048 × 2048		2
Non-operating Temperature Range	-50 to 70	-50 to 70	Centigrade	3
Nominal Operating Temperature	0	0	Centigrade	4
Operating Temperature Range	-50 to 60	-50 to 60	Centigrade	5
Spectral Band	0.4 - 0.9	0.4 - 0.9	μm	6
Integration Mode	Snapshot	Snapshot		7
Nominal Integration Time	70	70	msec	8
Integration Time Range	0.5 - 1000	0.2 - 1000	msec	9
Nominal Full Frame Rate	10	10	frames/sec	10
Full Frame Rate Range	0.2 - 10	0.2 - 10	frames/sec	11

Table 1: Configuration requirements of the STELLAR program.

Table 1 References

1. Detector Pitch
   Center-to-center spacing of pixels. Since requested devices are square, and have square pixels, the center-to-center spacing should be the same in both directions.

2. Array Configuration
   Layout of pixels on the SCA. Number of outputs and output ordering are not specified.

3. Non-operating Temperature Range
   This is the range of temperatures to which the SCA may be exposed over the system's lifetime. The SCA must survive non-operational storage for indefinite periods at these temperatures.

4. Nominal Operating Temperature
   All measurements and specifications are for an SCA operating at the specified temperature.

5. Operating Temperature Range
   This is the range of temperatures over which the SCA must function. It is not required to meet radiometric goals over the full temperature range of operation.

6. Spectral Band
   This is the spectral band over which device performance is to be evaluated.

7. Integration Mode
   The SCA shall operate in snapshot mode. Either integrated-then-read or integrate-while-read operation is acceptable.

8. Nominal Integration Time
   This is the integration time at which all radiometric measurements are to be made. Read noise, *etc*, are to be evaluated at this integration time.

9. Integration Time Range
   The SCA shall be capable of operating over the specified range of integration times. Some longer integration times may only be possible at longer frame times.

10. Nominal Full Frame Rate
    Frame time is defined as the time between successive data integration and read out of the same pixel. Frame rate is the inverse of frame time. The full frame rate is a frame rate when all pixels on the array are integrating photons and being read out. The nominal full frame rate is the nominal rate for data integration and readout when operating at the nominal integration time and is the rate at which radiometric characteristics (dark current, read noise, linearity, *etc*) are to be measured.

11. Full Frame Rate Range
    This is the range frame rates over which the SCA must be capable of operating in full frame mode.

Parameter	Base Goal	Advanced Goal	Units	Ref.
Fill Factor	> 95	> 99	%	1
Solar Weighted Quantum Efficiency	≥ 70	≥ 70	%	2
Detector Thickness	≤ 30	≤ 30	μm	3
Full Well Capacity	100K	100K	electrons	4
Read Noise	≤ 25	≤ 15	electrons/sample	5
Read Noise Non-Uniformity (1σ)	≤ 8	≤ 5	electrons/sample	6
Dark Current @23°C	≤ 30	≤ 15	pA/cm^2	7
Dark Current Non-Uniformity (1σ)	≤ 30	≤ 15	pA/cm^2	8
Total Dose Hardness	≥ 100	≥ 100	Krad(Si)	9
Proton Fluence	6.3×10^{11}	6.3×10^{11}	protons/cm^2	10
Single-Event Latch-up	None	None		11
Popcorn Pixels	< 500	< 2000	pixels	12
Power Consumption†	≤ 200	≤ 800	mW	13
Power Consumption‡	≤ 150	≤ 600	mW	14
Effective A/D Resolution†	≥ 13	≥ 13	bits	15
Differential Non-Linearity†	$\frac{1}{2}$	$\frac{1}{2}$	LSB	16
Integral Non-Linearity†	< 25	< 25	LSB	17
Missing A/D Code†	None	None		18
Responsivity Non-uniformity (1σ)	< 10	$< \pm 10$	%	19
Response Non-linearity	< 5	< 5	%	20
Operability	> 99.5	> 99.9	%	21
Inoperable Sub-Windows	≤ 1	≤ 3	Sub-Windows	22
Crosstalk	< 5	< 5	%	23
Anti-blooming	100$\times$	100$\times$	Max Signal	24
Saturation Recovery	≤ 3	≤ 3	Frame	25
Frame-to-Frame Crosstalk	< 3	< 1	%	26
Global Flatness	$< \pm 10$	$< \pm 10$	μm	27
Thermal Cycles	50	50	cycles	28

Table 2: Goals of the STELLAR program.

†: With optional A/D conversion on chip or with side-car A/D converter
‡: Without on-chip or side-car A/D conversion

Table 2 References

1. Fill Factor
   This is the fraction of the detector pitch area that is optically sensitive.

2. Solar Weighted Quantum Efficiency
   This is the band averaged quantum efficiency of the SCA within the specified spectral band. The average is weighted by the spectrum of a 5800K black body (*i.e.* the sun).

3. Detector Thickness
   To minimize crosstalk, and the number and amplitude of proton events, it is desirable to minimize the thickness of the detector sensitive layers. This specifies the desired maximum detector sensitive layer thickness.

4. Full Well Capacity
   This is the number of photo-electrons that can be integrated per integration period with the response function still meeting the linearity requirements.

5. Read Noise
   When operated at nominal conditions with minimal visible irradiance and no net detector bias, the read noise from the SCA shall be less than or equal to the stated goal. The read noise goal can be with either on-chip or off-chip correlated double sampling (CDS).

6. Read Noise Non-Uniformity
   This is the standard deviation of read noise spatial non-uniformity.

7. Dark Current Density
   The detector dark current density, when measured at 23°C and nominal bias conditions, shall be less than the stated value. This is and EOL (end-of-life) requirement.

8. Dark Current Density Non-Uniformity
   This is the spatial standard deviation of the dark current when measured at 23°C and nominal bias conditions.

9. Total Dose Hardness
   After accumulating the specified total dose ionizing radiation, the SCA shall still meet the other requirements in this document.

10. Proton Fluence
    After irradiation with the specified fluence of 63 MeV protons, the SCA shall still be functional, shall meet dark noise requirements, and shall still operate over the specified irradiance levels.

11. Single-Event Latch-up
No single-event latch-up shall occur to an LET threshold of 100 MeV-cm^2/mg.

12. Popcorn Pixels
A pixel is considered a popcorn pixel if it exhibits popcorn noise (also known as burst noise or random telegraph noise). The criterion for popcorn noise is a kurtosis of > 5 (TBR) for a contiguous stream of at least 2048 frames of data. The kurtosis of pixel p, γ_p, is defined as

$$\gamma_p = \frac{1}{N}\sum_{i=1}^{N}\frac{(x_{i,p}-\hat{x}_p)^4}{\hat{\sigma}_p^4} - 3$$

where $x_{i,p}$ is the i^{th} reading of pixel p, $\hat{x}_p$ is the temporal mean of pixel p, and $\hat{\sigma}_p$ is the temporal standard deviation for pixel p.

13. Power Consumption (with on chip A/D)
This is the steady state power consumption of the SCA. This goal is for SCA's with on-chip A/D conversion.

14. Power Consumption (off chip A/D)
This is the steady state power consumption of the SCA. This goal is for SCA's without on-chip A/D conversion.

15. Effective A/D Resolution
The number of bits of resolution of the on-chip A/D converters shall be greater than or equal to the specified number. This only applies if the optional on-chip A/D converter is present.

16. Differential Non-Linearity
Differential non-linearity is defined as the maximum value of

$$DNL(d) = \left|\frac{(V_{d+1} - V_d)}{V_{LSB}} - 1\right|$$

over all output bit codes, d, where $DNL(d)$ is the differential non-linearity, V_d is the analog input to the A/D converter that gives digital code d, and V_{LSB} is the ideal voltage corresponding to $1LSB$.

17. Integral Non-Linearity
Integrated non-linearity is defined as

$$INL = \left|\frac{(V_N - V_0)}{V_{LSB}} - N\right|$$

where INL is the integrated non-linearity at for full scale output of N bits, V_N is the analog input to the A/D converter that gives digital code N, V_0 is the analog input to the A/D converter that gives digital code of 0, and V_{LSB} is the ideal voltage corresponding to $1LSB$.

18. Missing A/D Code
When ramping the A/D output from 0 counts to full scale counts, there will be no missing A/D codes.

19. Response Non-uniformity
For all operable pixels, their responsivity shall be within the specified range of the responsivity of the median pixel. For this requirement, responsivity shall be measured as specified over the range from 5 times the dark noise floor to the maximum irradiance at which the non-linearity requirement is met.

20. Response Non-linearity
Non-linearity is measured by the maximum difference between the measured response and the best fit straight line versus integrated irradiance. Non-linearity is measured as a percentage of full scale response.

21. Operability
Operability is defined as the number of pixels that meet the goals for dark noise, the responsivity uniformity goals, and the linearity goals. A pixel exhibiting popcorn noise classified as a popcorn pixel is not an operable pixel.

22. Inoperable Sub-Windows
For the purpose of measuring clustering of inoperable pixels, conceptually dividing the SCA into 16×16 sub-windows. Any sub-window with more than three non-adjacent inoperable pixels, or with two or more adjacent inoperable pixels, is considered inoperable.

23. Crosstalk
Crosstalk is defined as the fraction of signal induced in a another pixel by a point source reimaged to the center of a pixel. Measurements are to be made at wavelengths of 400 nm, 633 nm, and 905 nm with a point source much smaller than a pixel dimension. The specification is for any pixel on the SCA, except the illuminated pixel.

24. Anti-blooming
When illuminated with a point source from the Maximum Irradiance to the specified level above saturation, the SCA shall not exhibit blooming. Blooming is defined as crosstalk in excess of crosstalk measured in the above non-saturated specification.

25. Saturation Recovery
After removal of a saturating source up to $1000\times$ saturation, the SCA shall recover to normal operation within the time specified.

26. Frame-to-Frame Crosstalk
    Frame-to-frame crosstalk is the fraction of pixel's signal which persists in the succeeding frame after the source of that signal has been removed.

27. Global Flatness
    After assembly, the SCA shall have a peak-to-peak flatness less than the specified amount across the entire array.

28. Thermal Cycling
    The SCA shall be capable of being thermally cycled between room temperature and -50C over the specified number of cycles without any degradation in performance.

Parameter	Base Goal	Advanced Goal	Units	Ref.
Width of Each Window	4 - 16	4 - 32	rows	1
Number of Simultaneous Windows	1 - 8	1 - 32	Non-overlapping Windows	2
Positional Placement of Each Window	1	1	row	3
Maximum Window Frame Rate	30	30	Frames / sec	4
Switching Time Between Window Modes	2	2	Frame	5

Table 3: Window Mode Operation

Table 3 References

1. Width of Each Window
   In windowing mode, each window shall integrate and read out signal in all rows of the specified number of contiguous columns. Pixels not in a window are not read out in windowing mode.

2. Number of Simultaneous Windows
   In windowing mode, the SCA shall be capable of operating from 1 to the maximum number specified of row windows. The windows do not have to overlap, but may be contiguous.

3. Positional Placement of Each Window
   In windowing mode, the placement of each window shall be to within the specified number of columns. Knowledge of window position shall be exact.

4. Maximum Window Frame Rate
   In windowing mode, all active windows shall be readout at the specified number number of frames per second.

5. Switching Time Between Window Modes
   The maximum time allowed to switch between full frame made and window mode, or between window mode and full frame mode, or between window modes with different numbers or positions or timing shall be the specified number of frames. The number specified is the maximum number of frames of lost or corrupted data between window mode switches.