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A flexible cost-effective detector controller for space

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EXTENDED ABSTRACT

Ground-based infrared observations are often limited by atmospheric absorption and emission. Space-based instruments avoid this, but introduce unique technical challenges. We present the design of a flexible, compact, and cost-effective detector controller for space, based on commercial off-the-shelf components. Its architecture provides up to 50 configurable clock sequences and 16 biases, 32 16-bit video channels and several general-purpose ports. This allows for full control of CMOS detectors including Leonardo ‘SAPHIRA’ avalanche photodiode arrays (APD) which represent current state of the art in low-noise infrared imaging.

The controller’s core logic is implemented on a Xilinx Kintex Ultrascale field programmable gate array (FPGA). The architecture includes a user-command set to load configuration registers and clocking sequences into RAM. A sequencer state machine controls sequential memory readout to generate the custom clock signals on the relevant outputs. DC biases are set using configurable digital-to-analog converter (DAC) control outputs. Analog-to-digital converters (ADCs) interface the pixel voltages to the controller’s video inputs, where the frame data is reformatted, buffered and eventually streamed off-chip over a high-speed interface such as CameraLink.

A combination of triple modular redundancy, scrubbing and error correction techniques are used to mitigate on-chip radiation-induced upsets. A fault-injection scheme will be used to test the error-recovery performance of the controller in a simulated low-Earth orbit radiation environment.

An early prototype system (see Figure 1) has been constructed as proof-of-concept for operation of a 320 * 256 SAPHIRA APD. A Xilinx Kintex-7 FPGA evaluation board acts as the primary controller, while in-house designed boards perform bias voltage regulation and sequencing, video signal conversion and cryogenic pre-amplification. A Python-based command line interface enables user control over USB3.0, providing up to 2Gbps data transfer.

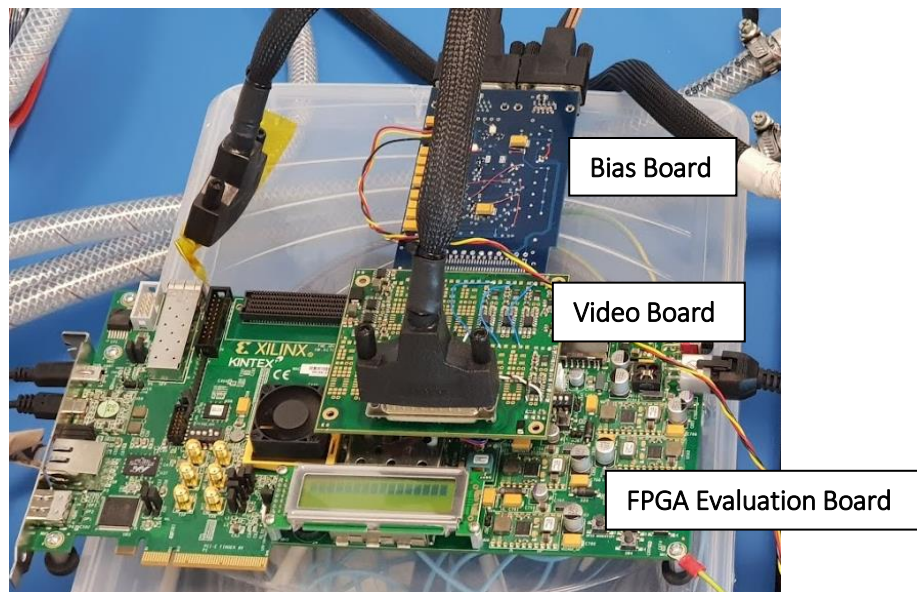


Figure 1. Early prototype of controller system using a Kintex-7 evaluation board

The controller prototype was tested on-sky in April 2019, at Siding Spring Observatory's 2.3-metre telescope. The prototype successfully resolved the HR4458 M=6 star-system using a 4-channel 30-Hz burst Fowler sample readout mode (see Figure 2). Low-frequency noise was observed in the resulting on-sky image. Subsequent modification of the video board to include additional shielding and a ground-plane successfully resolved the issue, assumed to be the result of external electromagnetic interference. Figure 3 shows a correlated double sample (CDS) image taken in the laboratory in August 2019 with no evidence of the original pattern noise.



Figure 2. Controller prototype on-sky image of HR4458 M=6 star-system with evident pattern noise (April 2019)

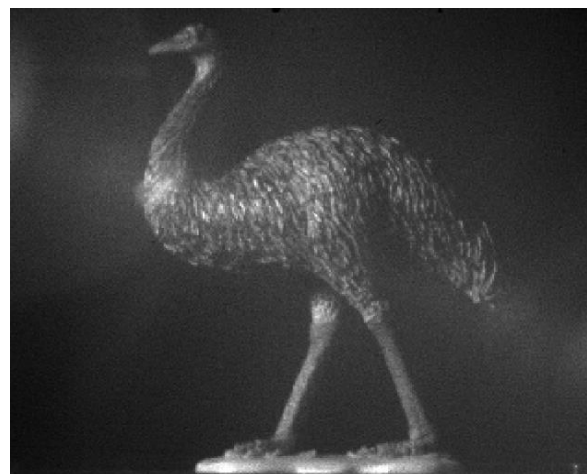


Figure 3. Prototype laboratory image with pattern noise resolved (August 2019)

Current effort is on design of the second generation Kintex Ultrascale prototype for SAPHIRA, capable of occupying less than 1-U of satellite volume. This system will eventually be flown as part of the 'Emu' mission, a 1.4- μm wide-field photometer to be hosted on the International Space Station in 2021. Table 1 summarises the controller performance requirements for Emu, the current prototype performance, and projections for the second generation controller. Fabrication and characterization of revision two hardware is expected early- to mid-2020.

Table 1. Detector controller performance requirements for Emu vs projected performance of hardware revision 2.0.

Performance Metric	Emu requirement	ANU DCON Rev. 1 Current performance (2019)	ANU DCON Rev. 2 Expected performance (2020)
Readout Window Size (pixels)	320*256	320*256	320*256
Output Channels (#)	32	4	32
Raw Output Framerate (Hz)	> 50	Up to 50	> 1kHz
Readout Noise (e-)	< 10	Not measured due to extensive low-frequency noise.	< 10
Data Resolution (bits)	16	16	16

Keywords: space-based detector controller, FPGA, SAPHIRA, infrared astronomy, space-telescope, space hardware, Kintex Ultrascale