NuSCIS: A multi-sensor imager platform for situational awareness, science and planetary applications

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ABSTRACT

NuSCIS is a NewSpace Camera Imaging System, capable of working with a broad range of CMOS and CCD image sensors enabling rapid tailoring to a variety of end-use applications. There are five flagship variants of the NuSCIS system using sensors from AMS Osram, Fairchild Imaging and Teledyne e2v. A dual/stereo option uses the popular 4Mpix CMV4000 sensor from AMS Osram which can be used to take simultaneous images in near/far field applications. We are actively developing a variant using the Fairchild Imaging HWK4123 sCMOS imager, with 10 Mpixels, capable of low-light, high frame rate detection, and <0.3 e- rms read noise. Finally, we present a variant using the Teledyne e2v CIS120 sensor for applications requiring the highest quality and space-heritage. In addition we have two variants using CCDs from e2v. We describe the NuSCIS imager system with sensor options and some of the existing applications. A trade-off study of the three variants based on measured and modelled performance parameters is discussed. Finally, we discuss the results of several radiation test campaigns that used gamma-rays for TID, and protons and heavy ions for latchup performance.

Keywords: NuSCIS, camera, CMOS, CIS, CCD, AXIS, WindCube

1. INTRODUCTION

XCAM has over 30-years' experience in the design and manufacture of digital imaging solutions for the scientific and industrial markets, covering the visible, UV, EUV and X-ray bands. In the 2010's XCAM extended its activities into development of camera systems for space applications; starting with sounding rocket and CubeSat experiments, growing into scientific instrumentation, EO and space situational awareness (SSA). Figure 1 gives a photograph of an early triple camera system on the AlSat Nano 3U spacecraft whilst Figure 2 gives results of an in-orbit image taken during operations.

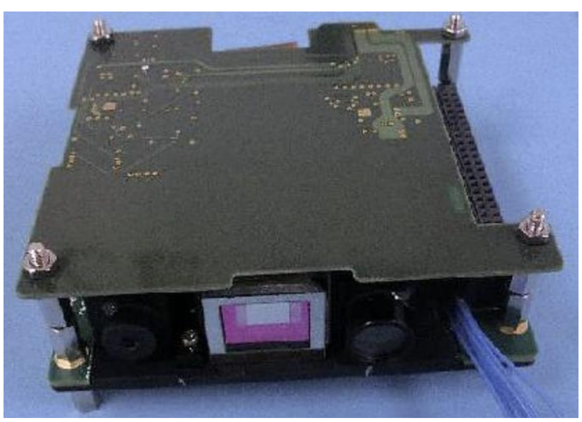

Figure 1: C3D2 payload launched on AlSat Nano

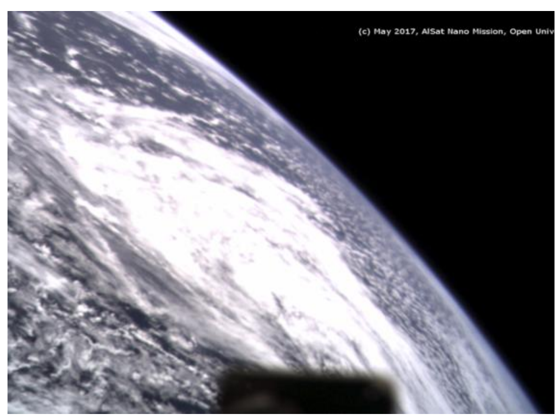

Figure 2: Earth image from AlSat Nano in LEO taken in 2017 with deployed boom in the foreground, from [1]

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2. THE NUSCIS IMAGER PLATFORM

The NuSCIS imager system has been designed to work with a range of image sensors, including CCD, EMCCD, CMOS and sCMOS technologies. Figure 3 shows the range of sensors which are operated using the NuSCIS system, and which have been delivered to customers in either EM or EM+FM designs at the time of writing this paper. The sensors range from true COTS components to scientific sensors with high performance and in one case designed for space use. The camera systems delivered operate in the visible and soft X-ray bands (although some of the variants can also work in the UV and EUV). These systems are used in a variety of applications ranging from Earth Observation, situational awareness, to space science including atmospheric research and astronomy.

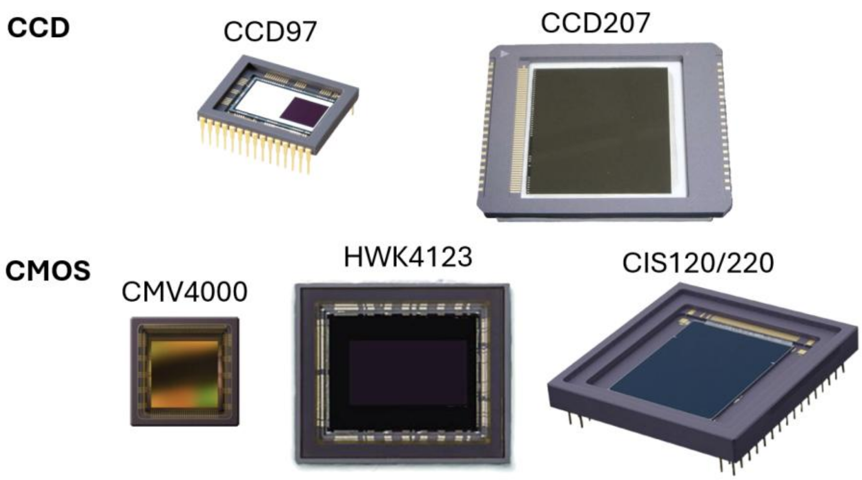

Figure 3: The CCD and CMOS image sensors used in the NuSCIS product range from Teledyne e2v, Fairchild and CMOSIS

Figure 4 gives a schematic of the NuSCIS imager controller board (ICB), designed to be directly coupled to CMOS image sensors. Whilst the core of the NuSCIS ICB is common across the product range, there are some minor differences when coupled to different CIS sensors, which have differing power and data interfaces. In the case of the CMV4000 sensor, provision is made for coupling to two sensors, so that the system can be used in a range of dual-imaging applications, including stereo imaging, or simultaneous narrow+wide field imaging for a range of situational awareness or EO applications. Figure 5 and Figure 6 give photographs of assembled NuSCIS camera systems with CIS sensors comprising the Teledyne e2v CIS120 space imager, used in the AXIS instrument[2], and the COTS Fairchild HWK4123 and Osram/CMOSIS CMV4000 sensors. The HWK4123 sensor has been tested achieving noise of <0.3 e- rms. which is capable of optical "photon counting" in some very low light applications.

The NuSCIS ICB unit used with the CMV sensors is also used in the CCD configuration. The schematic of this enhanced configuration is given in Figure 7 where an Auxiliary ("Aux") PCB is used to generate the specialized clock and bias signals to drive the CCD and EM CCD sensors, and provide analogue signal conditioning and digitization. The Aux board presents the CCD to the NuSCIS ICB at the same interface as the dual CMV CIS sensors. Figure 8 gives a photograph of the CCD97 variant of the NuSCIS system (temperature control PCB is not shown) which is used in the WindCube system[3].

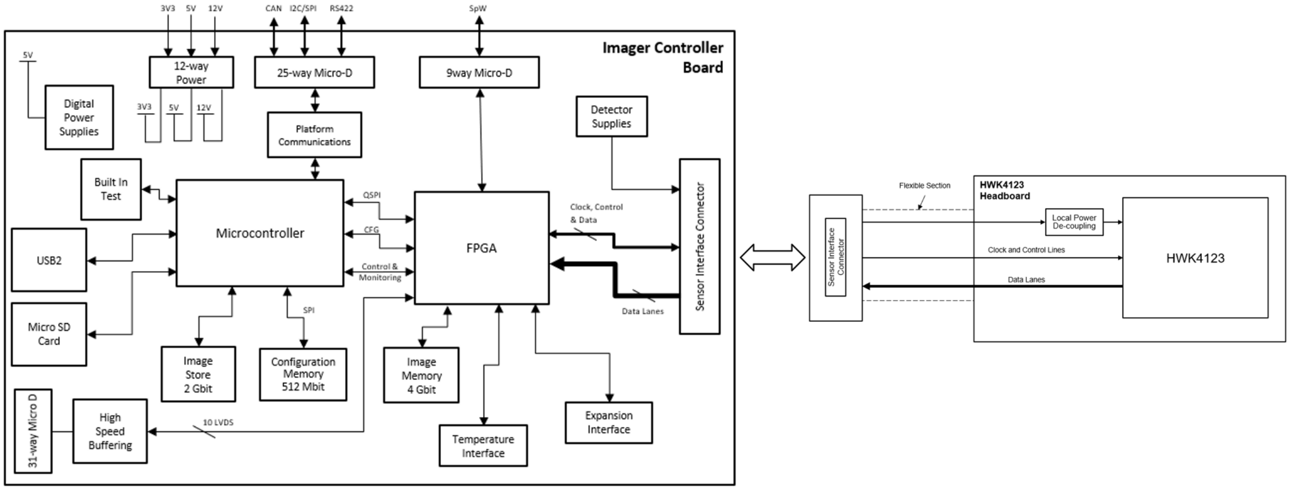

Figure 4: Schematic of the NuSCIS image controller board (ICB) key functions when coupled to a CMOS image sensor

Figure 5: Photograph of NuSCIS with a CIS120/220 from Teledyne e2v

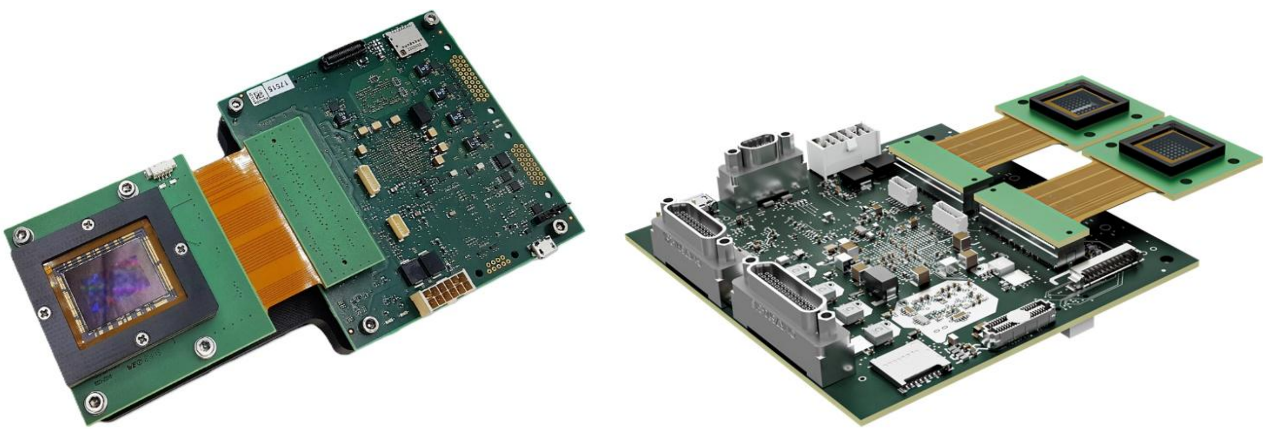

Figure 6: NuSCIS variants with the Fairchild HWK4123 (left) and dual CMOSIS CMV4000 sensors (right)

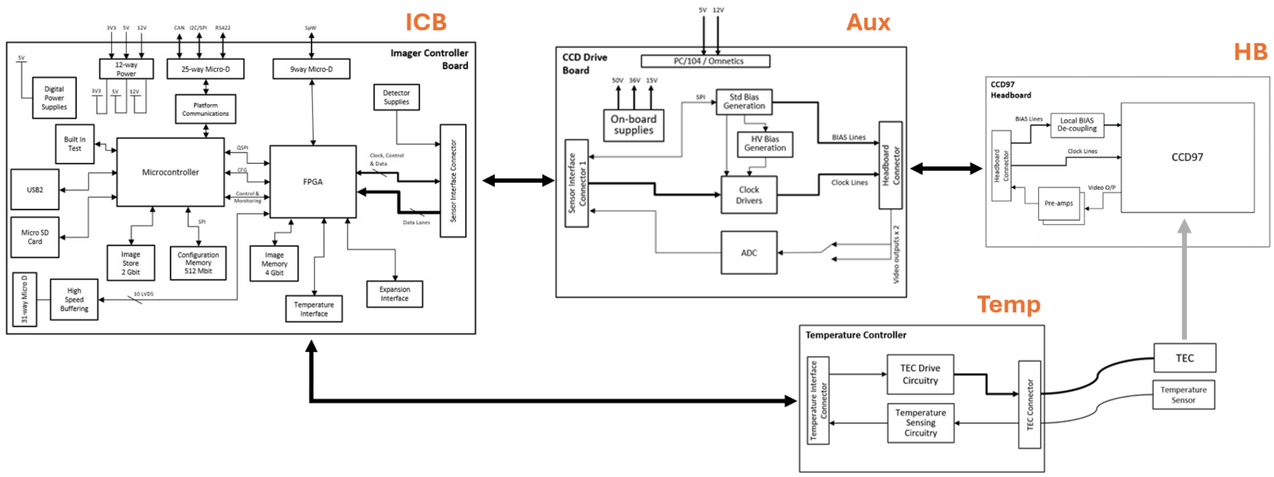

Figure 7: Schematic of the NuSCIS system components to drive a CCD, with optional temperature controller

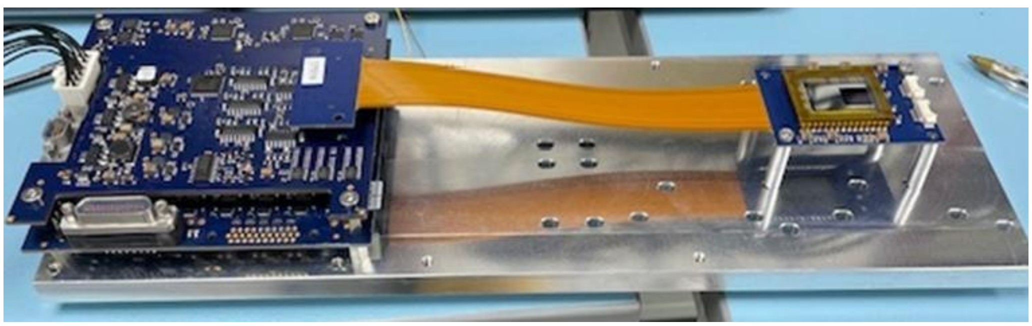

Figure 8: Photograph of the NuSCIS system with CCD97 delivered to the WindCube project [4]

3. RADIATION TESTING

Radiation testing has been conducted on the NuSCIS design, where for the CCD variant comprises the NuSCIS ICB, the CCD drive auxiliary board and the CCD and headboard, whilst for the CIS variants comprises ICB and CIS plus headboard. The headboards have only passive components and so are not relevant for the levels being tested. A total of 3 TID campaigns using Co-60 gammas, 2 high energy proton and one heavy ion irradiation (HWK4123) have been conducted to-date. The irradiations were conducted in stages with testing between each step. The key issue being tested was the system functionality under the different irradiation conditions (rather than changes to pixel dark current which occurs in the sensors). The NuSCIS electronics (ICB and where appropriate Auxiliary PCB) operated without issue after TID irradiations. The CIS HWK4123 was also subjected to heavy ion testing, since this COTS device had not been evaluated before for such radiation effects, and the heavy ion testing could be performed using sensor with temporary window removed. The summary of the various radiation test campaigns was that the NuSCIS camera system operates in LEO, even in polar orbit, where the dose levels can be high.

Table 1: Radiation testing configurations and levels

Configuration	**Sensor Type**	**TID**	**Protons (200 MeV)**	**Heavy Ions (Sensor)**
ICB + Aux + Sensor	CCD (CCD97)	15 krad(Si)	>1E11 cm^{-2}	N/A
ICB + Sensor	CIS (HWK4123)	30 krad(Si)	>3E11 cm^{-2}	Yes

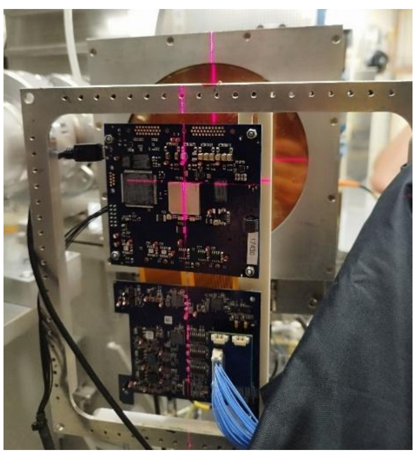

Figure 9: NuSCIS ICB being aligned for proton irradiation at PIF in PSI, Switzerland

4. NUSCIS CCD AND CMOS SENSOR SUMMARY

Table 2 gives a summary of the NuSCIS variants which have been designed, tested and delivered into applications at the time of writing, including the key parameters of the sensors. Table 3 gives a list of the key specification parameters for the NuSCIS controller, including size, mass and power. NuSCIS has been designed to provide a flexible interface to often complex scientific CMOS (and CCD) image sensors, with a common interface to enable standardized testing. For flight, the CSP protocol also provides a simple interface for command and control. The data return depends on pixel number, digitization and frame rate. The primary data return for flight is SpaceWire, and the MIPI interface is only present on the system with the Fairchild HWK sensor which can provide a much higher data return to the onboard computer.

Table 2: Current variants available on the NuSCIS platform

	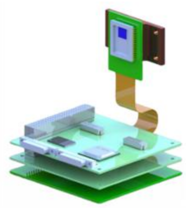	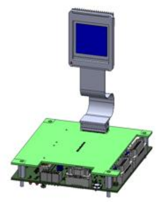	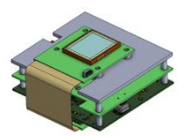	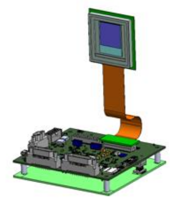	
Sensor	**CCD97**	**CCD207**	**HWK4123 sCMOS**	**CIS120/220 CIS221-X**	**Dual CMV4000**
Resolution	0.26MP	2.5MP	>9MP	4.2MP	4.2MP
Array Size	512 x 512	1.6k x 1.6k	4k x 2.3k	2k x 2k	2k x 2k
Pixel Size	16µm	16µm	< 5µm	10/40µm	5.5µm
PCBs required	ICB, CCDDB, CCD97HB	ICB, CCDDB, CCD207HB	ICB, HWK4123HB	ICB, CIS120HB	ICB, CMV4000HB, (1 or 2 per ICB)

Table 3: NuSCIS CIS ICB controller key parameters

Parameter	**Specification**
Dimensions	9.5 x 9.1 x 2.7 cm^3
Format	PC104 1/4U
Mass	100g (depending on sensor configuration)
Power interface	5 V
Peak Power Consumption	4-5W (depending on CIS being used)
Command interfaces	CAN-Bus (lab or space use), USB (lab testing only)
Data interfaces	SpaceWire, MIPI (lab or space use), USB (lab testing)
Command protocol	Python to API, or CubeSat Protocol (CSP-2 or CSP-1)
Design lifetime	3 years LEO

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