FLEXIBLE CAMERA ARCHITECTURE FOR GENERIC SPACE IMAGING APPLICATIONS. Colin McKinney[1], Christophe Basset[1], Mark Schwochert[1], Robert Staehle[1], Justin Boland[1], [1]Jet Propulsion Laboratory—California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109

Introduction: The implementation of space-borne engineering and science imaging has historically required costly, fully-custom designs and development in order to succeed in the extreme operating environments of NASA missions. Wide-temperature operation and survival, radiation tolerance, and extended performance lifetime requirements resulted in large capital investments in custom imaging sensors, optical assemblies, packaging approaches, and qualification testing. Such custom developments routinely incur schedule risks or delays for advancing Technology Readiness Levels (TRL) and meeting demanding project delivery timelines.

We have developed an adaptable camera platform that takes advantage of screened and qualified commercial off the shelf (COTS) components to significantly shorten camera development time while reducing the overall cost and risk of the design. To date, this modular camera platform has been successfully infused (designed, tested, and delivered) within two Class-D camera systems at NASA's Jet Propulsion Laboratory (JPL)—NEAScout and the Orbiting Carbon Observatory 3 (OCO-3) Context Cameras. The flexible camera architecture can be tailored to meet the cost, schedule, and performance envelopes of major mission concepts, CubeSats, and SmallSats for future proposals.

Background: As part of the Mars 2020 program, a new enhanced engineering camera (EECam) was developed at JPL to fulfill the need for an upgraded visible-light imaging system aboard NASA's next Mars rover. This camera system is a follow-on to the highly successful engineering cameras (ECAM) developed for the Mars Exploration Rovers (MER) [1] and re-flown on the Mars Science Laboratory (MSL), Phoenix Lander, and InSight lander (scheduled for launch in 2018), and now as SkyCam for Mars 2020's Mars Environmental Dynamics Analyzer (MEDA). As part of the necessary screening and qualification for the EECam space-qualified hardware, the Mars 2020 program invested resources in screening COTS parts to evaluate packaging ruggedness, radiation sensitivity, and lifetime performance to meet mission requirements. The result of this qualification process is a state of the art COTS 20 Megapixel color CMOS detector [2] that is qualified for flight.

Camera architecture: A camera electronics platform based around the Mars2020 detector qualification and screening work was created to accommodate the variety of power and data interfaces, sensor technologies, and mechanical form factors that may be encountered for future missions. The first iteration of this camera platform consists of the Mars2020 COTS CMOS detector, radiation-hardened FPGA and memory, LVDS data interface, custom aluminum chassis, and an adaptable lens mount interface. Figure 1 shows the camera's electronics architecture.

Any component of the camera, including the detector, can be adapted or replaced with minimal non-recurring engineering to meet given mission requirements. The FPGA code is also scalable, allowing users to tailor data interface protocols, image processing, and camera functionality by reprogramming the FPGA to expand its capabilities.

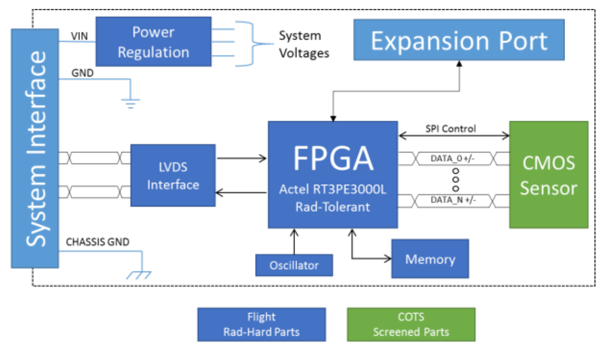

Figure 1. Camera electronics architecture

Table 1 summarizes the camera architecture capabilities using the Mars2020 upscreened detector.

Table 1. Camera architecture capabilities with Mars2020 COTS detector

Imaging Array Size	5120 x 3840 pixels
Pixel Size	6.4μm^2
Pixel Full Well	< 15k e-
Pixel Bit Depth	12 bits
Shutter	Global
Image Processing	Windowing, Subsampling, Binning
Power	< 5W @ +28V input
Mass (no lens)	371g
Volume (no lens)	61mm x 63mm x 65mm

Camera infusion: Several of JPL's smaller instruments have taken advantage of the qualification work performed by Mars 2020 by reusing the screened COTS imaging sensor, proven electronic designs, and scalable field-programmable gate array (FPGA) firmware to meet tailored mission requirements and lower resource availability. Larger Discovery or New Frontiers-class mission concepts may also benefit by leveraging the Mars 2020 build-to-print design to reduce risk and schedule.

The OCO-3 instrument was the first mission to use the flexible camera architecture, producing two Context Cameras that aid in the instrument's calibration campaign. Each Context Camera consists of an identical electronics chassis with either a medium- or narrow-angle lens. Two unique ruggedized COTS lenses are accommodated by the common electronics chassis, highlighting the modularity of the design. The OCO-3 Internal Context Camera is shown in Figure 2, using a COTS C-mount lens.

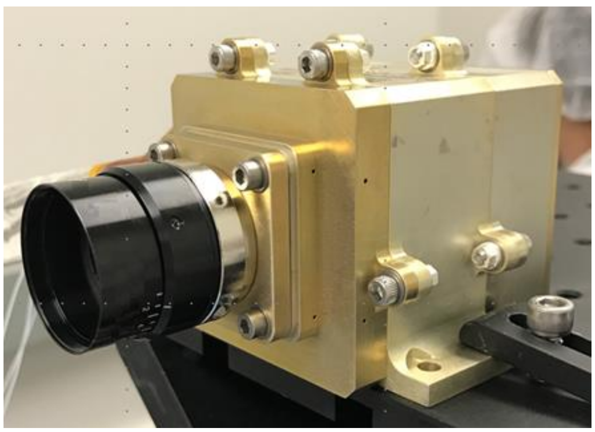

Figure 2. OCO-3 Internal Context Camera

The OCO-3 Context Camera design has since been re-used and tailored to meet the low cost cap of the NEAScout CubeSat mission. Modifications included a new COTS optical system using the standard C-mountlens interface, different electrical data interface protocol, and mechanical chassis modifications. These changes were easily and quickly integrated within a constrained CubeSat budget, highlighting the flexibility of the system.

Potential Applications: The modularity and scalable nature of the camera architecture is an enabling feature for low cost cap missions where proven imaging capabilities can aid in quality science return without increasing mission risk. Tailoring the camera design can be accomplished with minimal schedule and non-recurring engineering impacts, allowing customized science return that fits within limited mission resource constraints. CubeSats, SmallSats, and technology demonstrations can benefit from engineering- or science-grade imagery produced by this camera platform without sacrificing budget, schedule, or risk posture.

One exciting application for the flexible camera architecture is for planetary missions involving landers or rovers where visual odometry, or image-based motion tracking, is used during the spacecraft's entry, descent, and landing (EDL) phase. As is the case with the Mars2020 mission, a camera is used to supplement the landing radar system to provide image-based position and motion tracking for the spacecraft during EDL. The spacecraft compares real-time imagery of the Martian surface with known ground-truth maps to provide fine closed-loop control of the EDL sequence, effectively minimizing the spacecraft's landing ellipse error. Tighter control of the landing of the spacecraft enables a greater potential for science return in feature-rich areas previously deemed too risky to land due to neighboring hazards.

Further, the camera could be deployed as a monocular or stereoscopic tracking system for spacecraft attempting to rendezvous with other spacecraft, such as docking operations or small payload retrievals. The windowing and binning capability of the cameras allow scalable machine vision stereo ranging performance and centroiding accuracy at various object distances at the expense of frame rate, and could provide a drop-in solution for future missions to add this capability. The Mars Sample Return concept is one example, where the sample return payload will require precision rendezvous with the return spacecraft while orbiting Mars.

Summary: A flexible camera architecture based on the Mars2020 EECams was conceived to address the increasing demand for low-cost visible imaging systems in spaceborne applications. Two instances of the camera architecture have been successfully tailored, built, and tested at JPL and delivered to the OCO-3 and NEAScout projects. Significant non-recurring engineering was leveraged from Mars2020 Enhanced Engineering Cameras to enable rapid development on a cost- and schedule-constrained effort. The wide range of applications for these cameras and their modularity allow low-cost infusion of tailored visible imaging systems in future NASA missions.

References: [1] Maki, J. N., et al., Mars Exploration Rover Engineering Cameras, J. Geophys. Res., 108(E12), 8071, doi:10.1029/2003JE002077, 2003. [2] CMOSIS. "CMV20000 datasheet v2.3" *cmosis.com*, AMS Sensors Belgium, 2015. Web.