IMAGING SYSTEMS FOR PLANETARY EXPLORATION

Thomas Behnke,
Ekkehard Kührt, Alexander Lichopoj, Harald Michaelis , Stefano Mottola,
Rolf Schrödter, Matthias Tschentscher

Deutsches Zentrum für Luft- und Raumfahrt e.V., Institute of Planetary Research
Rutherfordstraße 2, 12489 Berlin, Germany
thomas.behnke@dlr.de
Phone: +49 30 670 55397

Planetary geology, in-situ exploration, cartography, 3D and spectral imaging plus navigation are strong coupled with the application of imaging systems based on CCDs and modern scientific CMOS (sCMOS) optical sensors. The development of such imaging systems requires high performance detectors, radiation tolerant IEEE circuits combined with a space qualified optical system on the input and a powerful digital processor unit on the output side.

When in November 2014 the ROSETTA Lander PHILAE landed on the comet Churyumov-Gerasimenko the Rosetta Lander Imaging System (ROLIS) performs the first images of a comet during descent and after landing. Figure 1 shows the first image taken by ROLIS after separation from orbiter. In addition to the comet body the image shows one landing leg of the PHILAE lander.

Figure 1: Churyumov-Gerasimenko after separation from orbiter

The cruise phase of 10 years, the harsh environment near the comet and the unknown terrain of the comet surface represent a huge challenge for hardware development and testing.

Imaging systems of active current missions (e.g. MarsExpress, ROSETTA, DAWN) based on charge coupled devices in 1D and 2D detector dimension. The architecture of line and array sensors consists of active pixels in combination with metallic covered storage areas. The application of storage areas allows exposure control and imaging without optical shutter. Due to the MOS technology of the pixel architecture high clock voltages are required to perform charge transport (clocking) and readout sequences. Two and three phase CCDs require clock amplitudes up to 18V with a driver capability of 10 nF at 10MHz pixel frequency. MOSFET drivers perform sufficient driver capability. The readout electronics consist of correlated double sampling, signal conditioning an analog-digital conversion. Control, readout and housekeeping acquisition will be implemented in non-volatile/anti-fuse FPGAs.

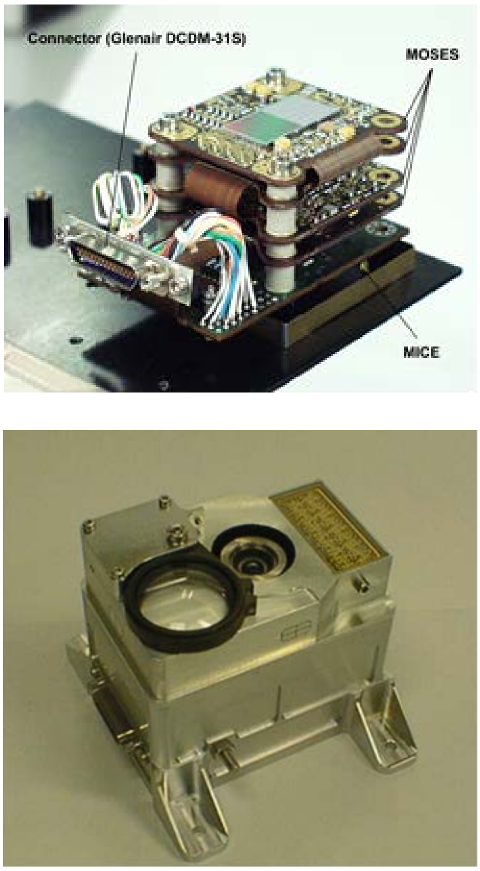


Figure 2: MOSES detector electronics (top) and ROLIS camera (down)

Proc. 'DASIA 2015', DAta Systems In Aerospace'
Barcelona, Spain, 19–21 May 2015 (ESA SP-732, September 2015)

During Descent and after landing images are taken by the ROLIS imaging system. ROLIS based on DLR's Modular Sensor Electronics System (MOSES) equipped with a 1kx1k CCD frame transfer CCD from e2v (former Thomson, later Atmel, now e2v). An advantage of the used frame transfer detector (CCD TH7887) is the fast frame transfer time of about 1 millisecond that reduces image smearing during the descent imaging phase. Figure 2 shows the modular system (left) and the camera completed with a removable lens and a RGB illumination tablet. The variable optics allows changing of the focus between infinity during descent and a fixed focus after landing of the comet. Separate RGB illumination generates color composite imaging.

The requirements on the image sensor, as the key-element of planetary scientific imaging system depend mainly on:

- The scientific and instrument requirements
- the environment at which the instrument + sensor has to operate

Particularly, it is important what the observational conditions are:

- Detection or observation of star-like or areal objects
- Object brightness and contrast?
- The dwell-time?
- The spectral range and spectral bandwidth?

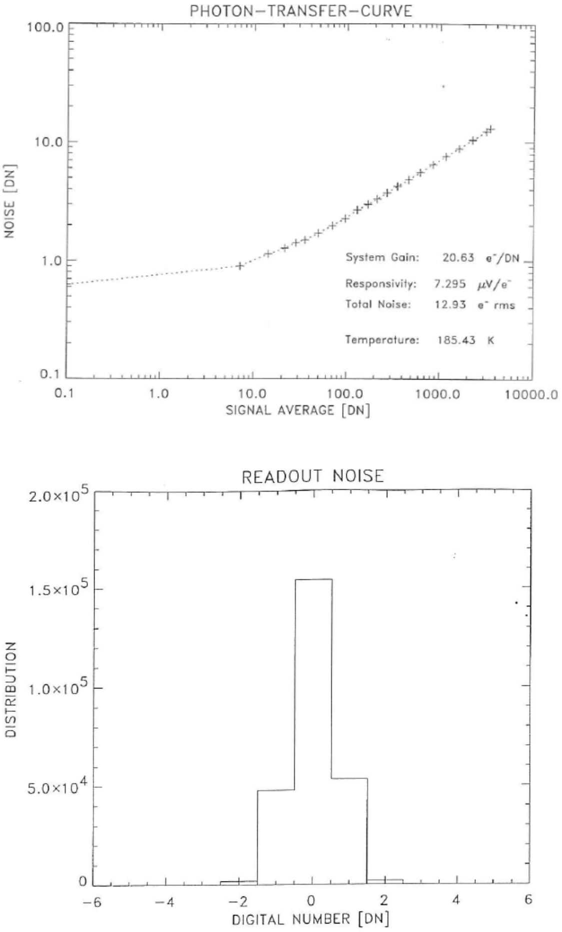
Generally, planetary imagers are much smaller devices than most space-based astronomical and earth observation imaging instruments because they are part of a complex payload on-board space-craft with demanding limitations on mass and power consumption. The environmental conditions, particularly in terms of temperature and radiation are in most cases harsher than for astronomical (and earth-observation) space-telescopes. For instance, missions to the inner solar system (e.g. Venus, Mercury) have to cope with high temperatures and thermal gradients while missions to the outer planets, to the asteroid belt and to comets have to operate and to survive very cold temperatures.

The radiation environment, particularly at Jupiter and at the Jovian satellites is extremely harsh, reaching total doses >1Mrad. The mass limitation for lander cameras is often below 1kg while the power consumption may not exceed few Watts.

Furthermore, there is a strong limitation in data-volume that can be transmitted to ground because of the large distances between Earth and the investigated planetary object. Therefore, large sensors (in terms of pixel-number) or sensor-mosaics like in astronomy-missions are exceptions.

Spectral sensitivity and noise are not always as important as in astronomy because many objects are sufficiently bright. However, dark objects like comets, asteroids and the outer planets require high radiometric sensitivity. This is also important when imaging through tight spectral bandwidth- filters.

Beyond the definition of environmental condition (thermal, structural, radiation) the sensor electro-optical performance and readout electronics design form the baseline for scientific camera payload development. Charge transfer efficiency, dark current, linearity, system gain, readout noise and full well capacity define the radiometric performance of an imaging system. The photon-transfer technique provides a sufficient method to characterize an imager.



$$\frac{2}{\sigma\sqrt{2\pi}}\int_{-\infty}^{-0.5LSB} e\frac{-x^2}{2\sigma^2} = 0.61\,DN \qquad (1)$$

Figure 3: Photon-Transfer Curve of ROLIS and Noise Distribution @ 185K (Gaussfit)

Figure 3 shows a typical transfer curve at low temperature (185K). The correlation between signal S and signal noise equal to $\sqrt{S}$ (Poisson distribution) provides a slope of ½ in a double logarithmic plot. At low signal the noise is dominated by the invariant noise floor. This component is determined by dark current noise, readout noise and electronics noise. The level of this noise component is a benchmark for the imaging system performance. This method is powerful to characterizes gain (electrons to digital number), noise, full well and linearity

New generation detectors, so called sCMOS sensors based on standard CMOS process. sCMOS detectors allow to run with 5V single supply voltage. Each pixel is a high integrated active pixel cell. The architecture consists of a column and row bus to address each pixel. Readout and exposure control is organized in global or rolling shutter mode. The CMOS sensor is of an important feature to provide fast access to any region of interests on the array. Figure 4 shows the four transistor architecture of sCMOS pixel.

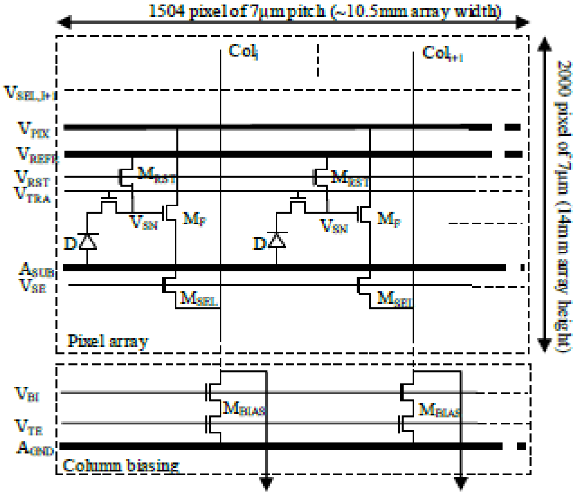
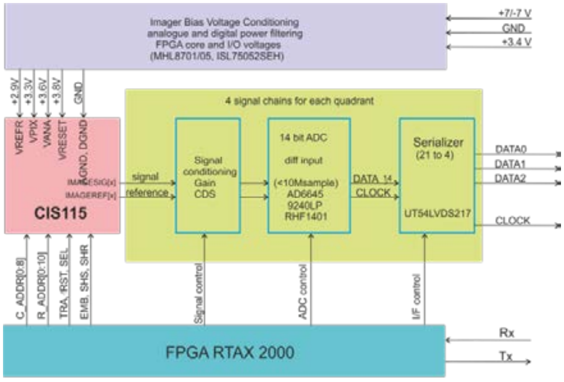


Figure 4: Pixel layout of CMOS sensor

The application of CMOS sensors in scientific research has been limited by the filling factor and QE of the devices. Hybrid visible CMOS sensor has been developed to overcome such drawback but with much higher cost. Recently, the development of monolithic CMOS sensor has shown promising performance. The performance of back side illumination thinned monolithic CMOS sensors is close to what CCDs can provide.

The e2v CIS115 is a high performance back illuminated sCMOS image sensor designed for space applications. The sensor has 3 million pixels and is manufactured on 0.18 µm image sensor CMOS process using 4T pixel architecture with pinned photodiodes for low dark current. The CIS115 has four analogue differential outputs, each serving 376 pixel wide column section of the device. The digital signals for row and column addressing are provided in Gray code format for flexible readout. The CIS115 is the baseline CMOS image sensor of the JANUS camera, part of ESA’s JUICE mission to Jupiter.



Note: Temperature Acquisition via IMAGEREF[1] and IMAGESIG[1] if column address is 0x00

Figure 5: JANUS Imaging System Architecture

The challenge of the JANUS camera development is the harsh radiation environment. A radiation analysis and corresponding IEEE part selection is a key task before detailed design. A block diagram of the electronics is given in Figure 5. Objective of the development is to provide a low power high performance sCMOS sensor for JUICE and further space mission.