The ESRF Fast Readout Low Noise Camera:

A fast multi-channel CCD based camera

High Pixel Throughput (20 Mpl/s) AND Low Noise (20 e) AND High Dynamic Range (28000 : 1)

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Introduction:

More and more scientists require that a 'scientific quality' image is kept with a fast readout time.
CCD cameras at present available on the market offer either high spatial resolution, dynamic range or readout speed. A compromise between signal dynamic and readout speed can be obtained by tuning the camera parameters, but these cameras have a poor duty cycle (i.e. the signal integration time is much smaller than the readout time).
In order to address scientific problems at the European Radiation Synchrotron Facility (ESRF), it has been necessary to develop a fast readout, low noise CCD camera which has a balance between high dynamic range and high readout speed to improve duty cycles.
The prerequisite of such an instrument is to cope with fast rise time, high current clocks and low level wide bandwidth signals from the CCD outputs.
Extreme care is needed to ensure the shortest possible connections between the CCD chip, the clock drivers and signal preamplifiers.
The system is made of 4 highly sensitive (16 bit), high bandwidth electronic chains. The main challenges of such a multi-channel instrument are:

- Accuracy of the measurement
- Stability of the dark image
- Absence of crosstalk
- Homogeneity of response over all four channels

This poster summarizes the performance of the FReLoN camera developed at the ESRF.

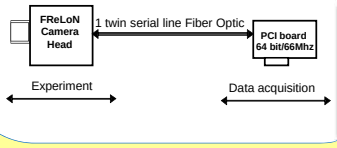
Layout:

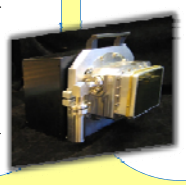
A Fast Readout Low Noise "FReLoN" camera has been developed by the Instrument Support Group at ESRF. The camera uses multi-channels chips with 2kx2k pixels, cooled to -15 ºC to reduce the dark current. This is operated either in full frame mode or in frame transfer mode. These chips give exceptional advantages as regards readout speed using different modes, made possible by its four parallel outputs.
A delicate routing of the electronic boards added to the high readout speed at four parallel outputs provides high frame rate and scientific grade images.

FReLoN2k16:
. CCD ATMEL chip 7899M
. 2k x 2k pixels,
. 14 um pixel size
. (4 x 20) Mhz max readout
. QE 24 % at 550 nm

FReLoN4M16:
. CCD KODAK chip 4320E
. 2k x 2k pixels,
. 24 um pixel size
. (4 x 10) Mhz max readout
. QE 65 % at 550 nm

The system is made of a camera head, a power supply unit, a PCI board for data acquisition and a twin fiber-optic cable. The PCI board 64 bit is plugged in a Linux or Window computer clocked at 66 Mhz on the PCI bus.





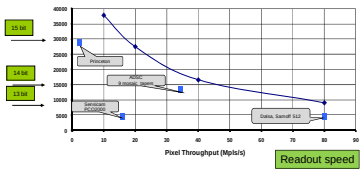
Main Specifications of the FReLoN cameras*:

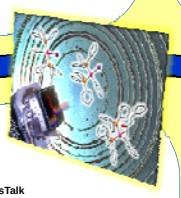
Readout speed (Megapixels/s)	4 x 2.5		4 x 5		4 x 10		4 x 20
Pixel throughput (Megapixels/s)	10		20		40		80
Resolution	16 bit		16 bit		16 bit		16 bit
Electronic noise	15		14 e⁻	20 e⁻	20 e⁻	35 e⁻	30 e⁻
Sensitivity (e⁻ / du)	9		5	9	5	9	5
Dynamic range (grey levels)	38000		19000	28000	13000	16000	9000
Integral non linearity (% full scale)	+/- 0.2		+/- 0.2	+/- 0.3	+/- 0.3	+/- 0.3	+/- 0.4
Dark current -15ºC (e/pixel/s)	1		1	1	1	1	1
Full frame mode: (images/s)							
No binning (2k x 2k)	2		4	3.3	8	6	15
Binning 2x2 (1k x 1k)	4		8	5	15	10	27
Frame transfer mode**:	no		Yes	no	Yes	no	Yes
No binning (2k x 1k)			8		16		27
Binning 2x2 (1024 x 512)			15		27		55

* Each camera has 2 pre-configured readout speed
** The image (n-1) is recorded during exposure time of the image n

FReLoN camera based on Kodak chip 4320 | FReLoN camera based on Atmel chip 7899

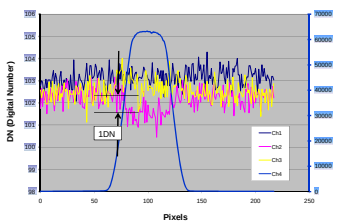
Accuracy — FReLoN cameras performances versus the mass market





5. Crosstalk between channels

Multi-chanels CCD chip: CrossTalk



A 50 pixels saturated spot is sent on channel 4 (blue curve on right axis) and the crosstalk values (arrow space) are recorded in time on the 3 other chanels (left axis).

The Crosstalk value < 1 / 60000 DN

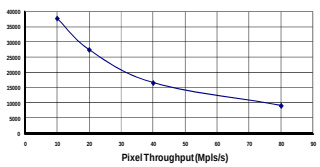
Challenge of the multi-output readout: (1)

to reach a homogeneous response over the 4 channels

Despite the high effective throughput:
1.The Dynamic Range goes from true 13 bit till 15 bit
2.The 4 photon transfer curves for one event provides the same response whichever channel is involved
3.The Integral Linearity Error is less than +/- 0.3%
4.The stability of each of the 4 backgrounds (dark image) is better than +/- 1 count over 60000 Digital Numbers (2^{16} DN)
5.The crosstalk between channel is less than 1 : 60000

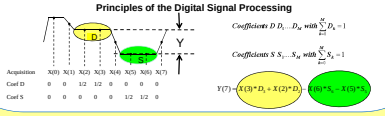
1. Dynamic Range versus Pixel Throughput

Dynamic Range (grey levels) versus Pixel Throughput (Megapixels/s)



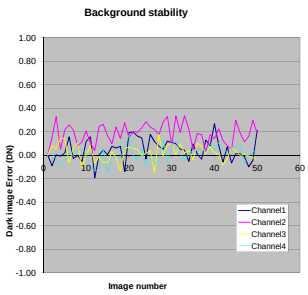
A versatile Digital Signal Processing Board has been developped to cover different CCD chips

Principles of the Digital Signal Processing



4. Background stability of the 4 channels in a burst of 50 images

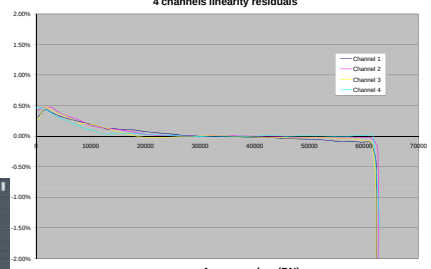
Background stability



The Background Stability < 10^{-5}

3. Linearity Residuals < +/- 0.3% (% of the full scale)

4 channels linearity residuals

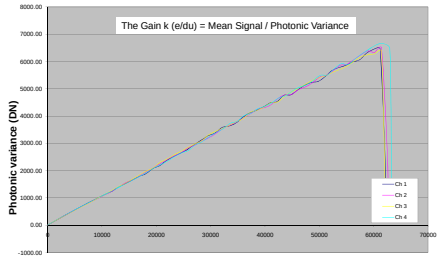


$LR = 100 \times ((1 - (S_m/T_m))/(S/T)) \quad < +/- 0.3\%$

Where: S_m, T_m are signal and time at middle scale, S and T signal and time

2. Photonic variance versus the mean signal of the 4 channels

Photonic variance versus Mean Signal



The Homogeneity of the 4 channels

Conclusions:

A balance between a scientific grade image camera with a high frame rate has been successfully developed
Currently, 25 systems run at the ESRF Beam Lines
On going development: New FReLoN Camera at Dynamic Range 15 bit and QE 90 %

1 **JC Labiche et al, Rev. Sci. Instrum. 78 (2007) 091301.**

Acknowledgments: Mechanical design: **J Borrel, P Duboc, JF Ribois**
Image Pro & G.U.I.: **JL Pons**, Linux & G.U.I.**A Homs**