International symposium on the development of detectors

Electron multiplying CCDs

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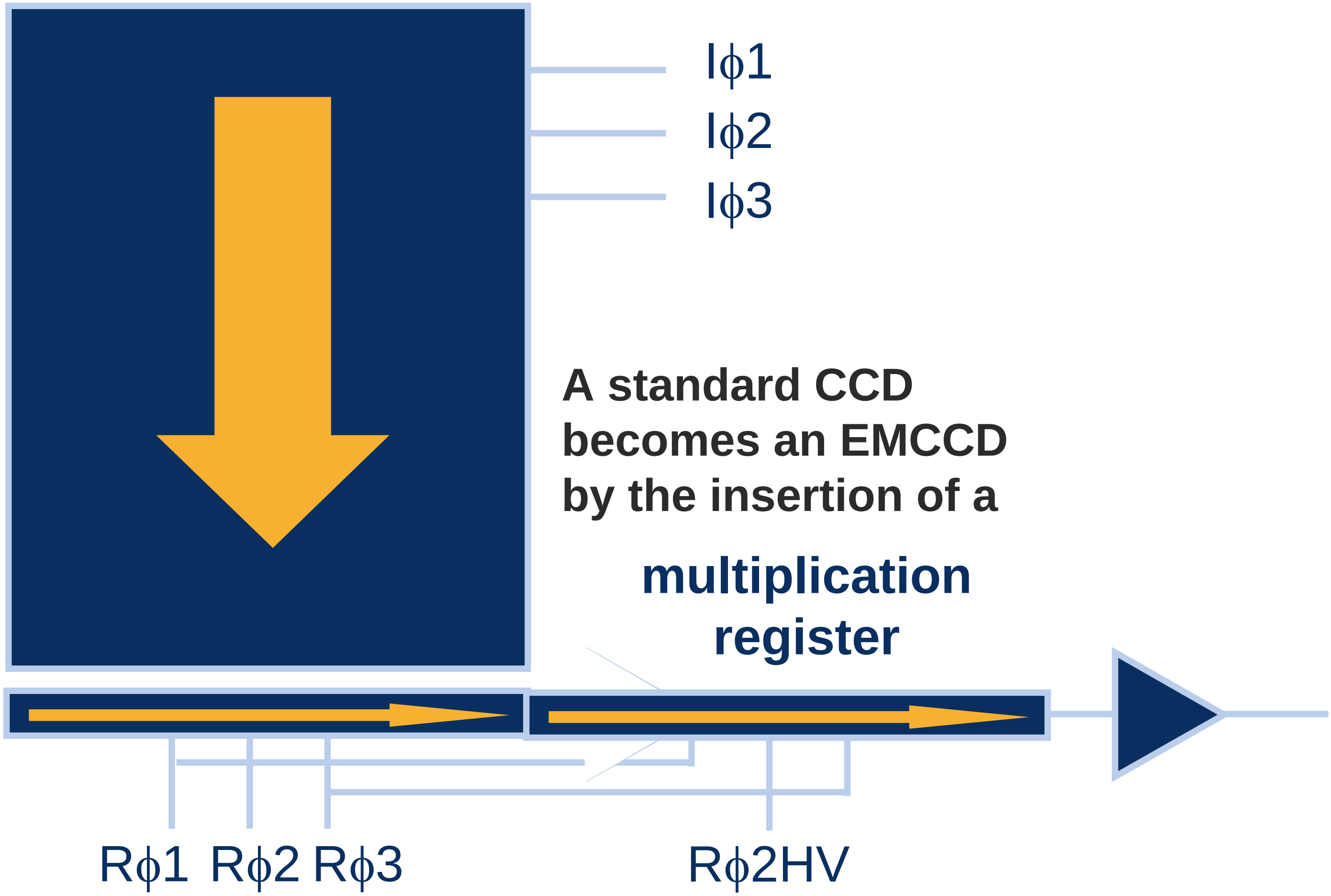
- **Brief Introduction to the EMCCD Structure**
- **Performance requirements**
- **Overview of non-space applications**
- **Possible applications in Particle, Astro-particle and synchrotron radiation detection**

All performance data derives from e2v L3Vision CCDs

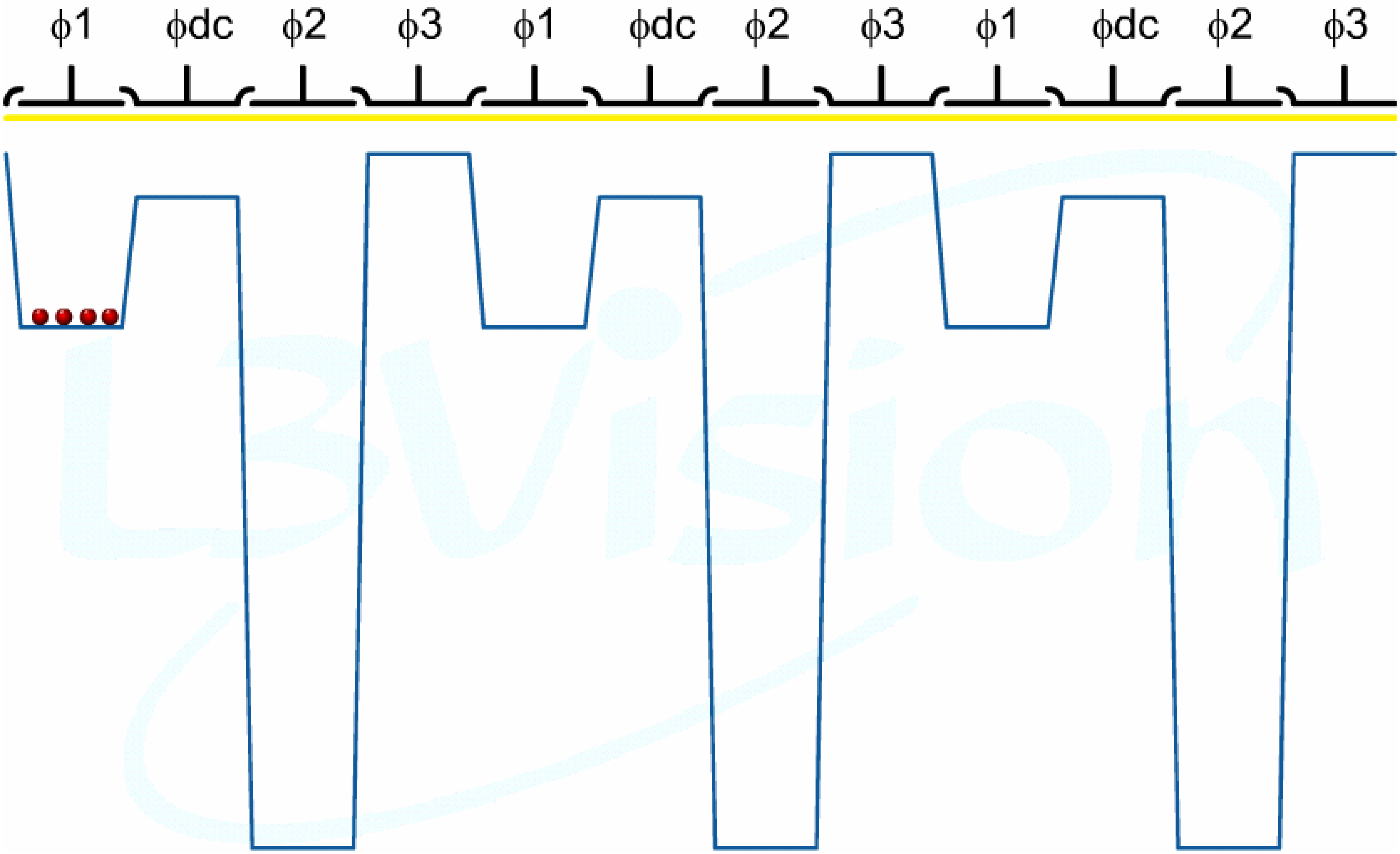
L3Vision CCD



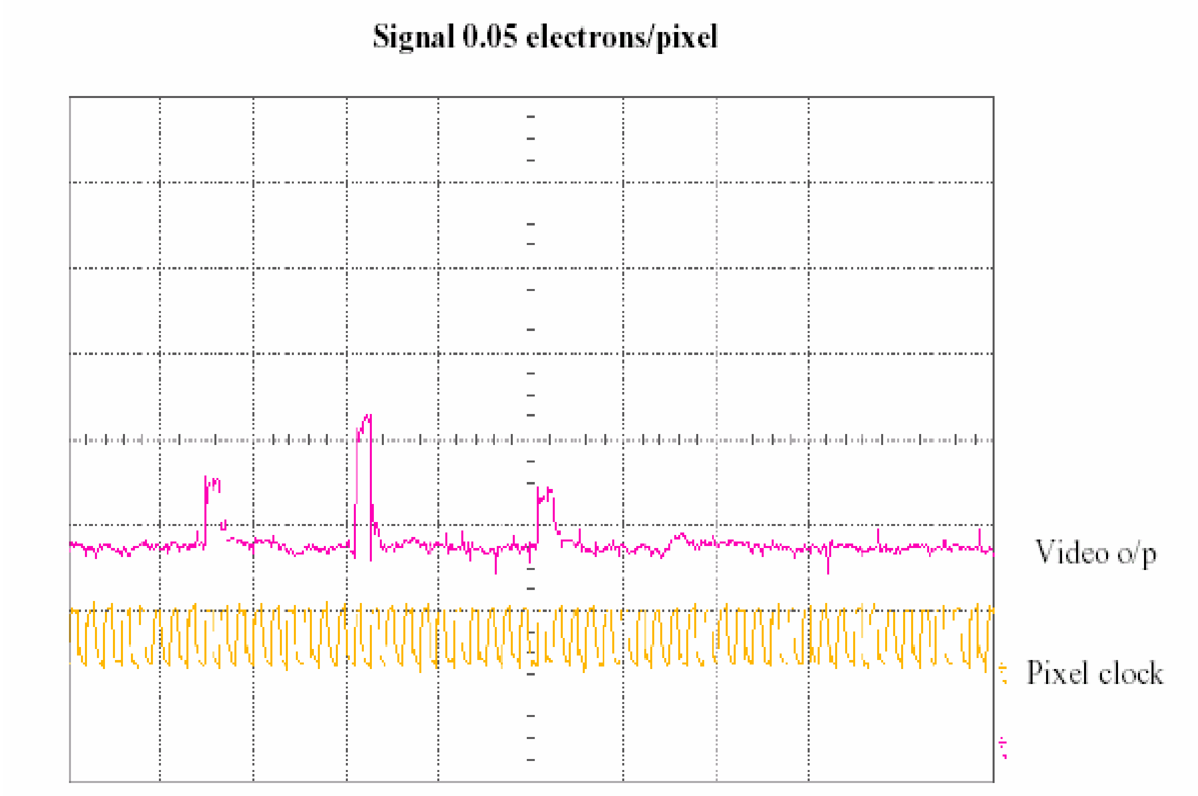
A standard CCD becomes an EMCCD by the insertion of a

multiplication register

Operation



Operation



…and this is the signal out from the device from single electrons. If you have spent your life looking at CCD waveforms this is really exciting.

Read Noise

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In a CCD, charge transfer is noiseless, so the only remaining noise source is in the charge detection circuit.

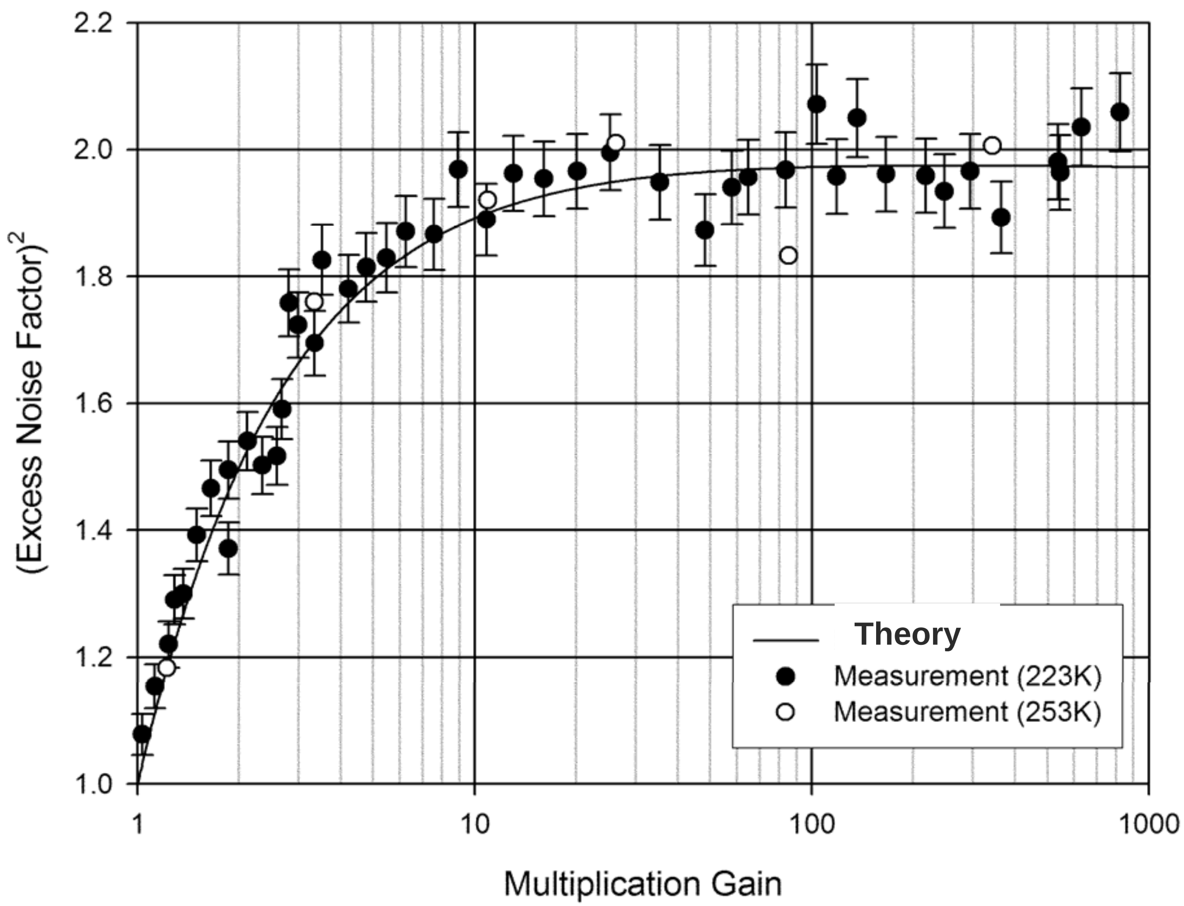
In the EMCCD impact ionisation in silicon provides gain in the charge domain before detection. This gain effectively reduces the read noise by the gain factor.

However, for high gain values, the gain is subject to statistical fluctuations which appears as noise of $\sqrt{N}$ electrons, where N is the input signal (electrons).

The combination of this excess noise factor, together with shot noise, results in a noise on the signal of $\sqrt{(2N)}$:

an excess noise factor of $\sqrt{2}$

Read Noise



The excess noise factor of √**2** has been shown to be present for the gain factors used in most applications.

Noise v signal

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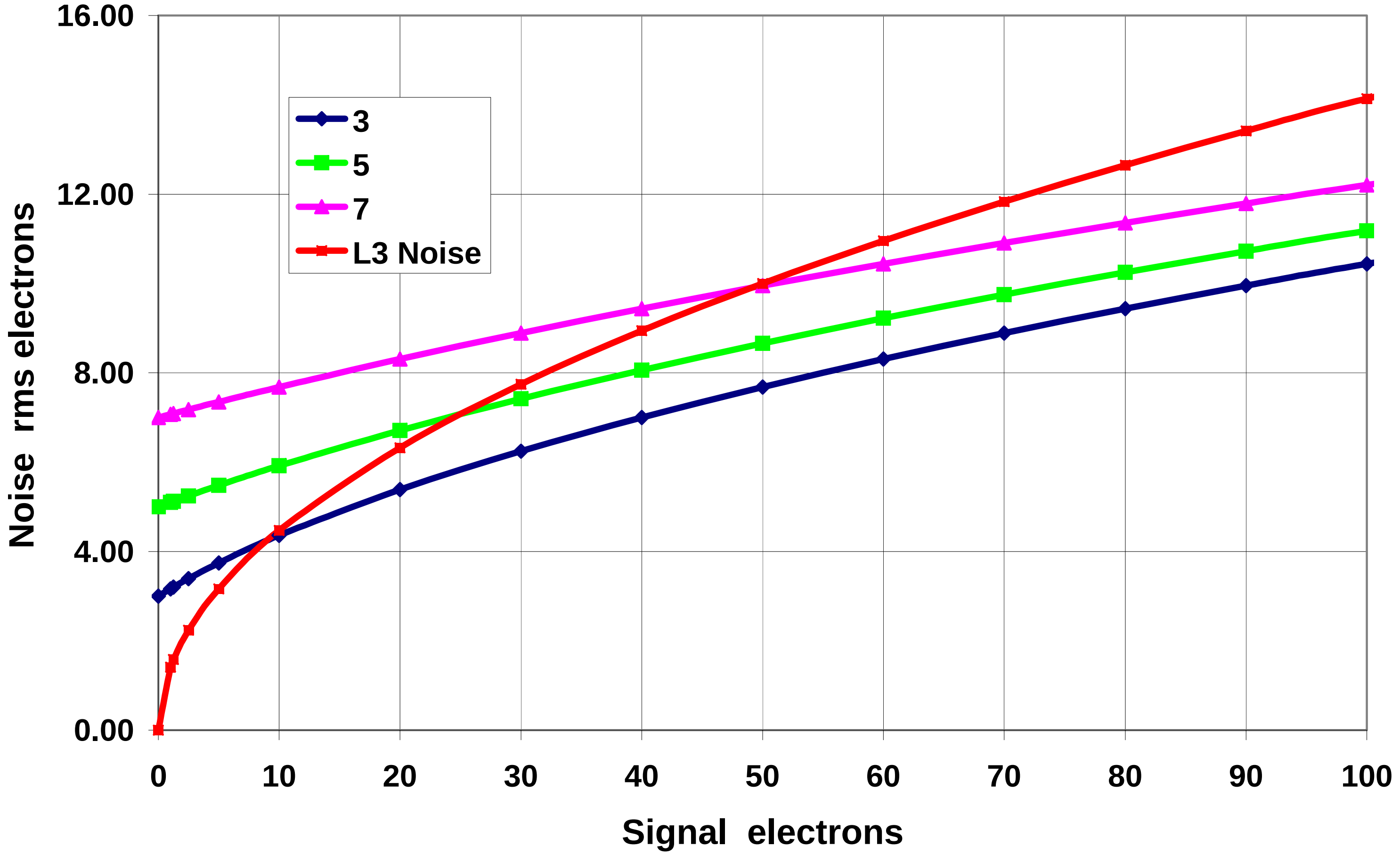
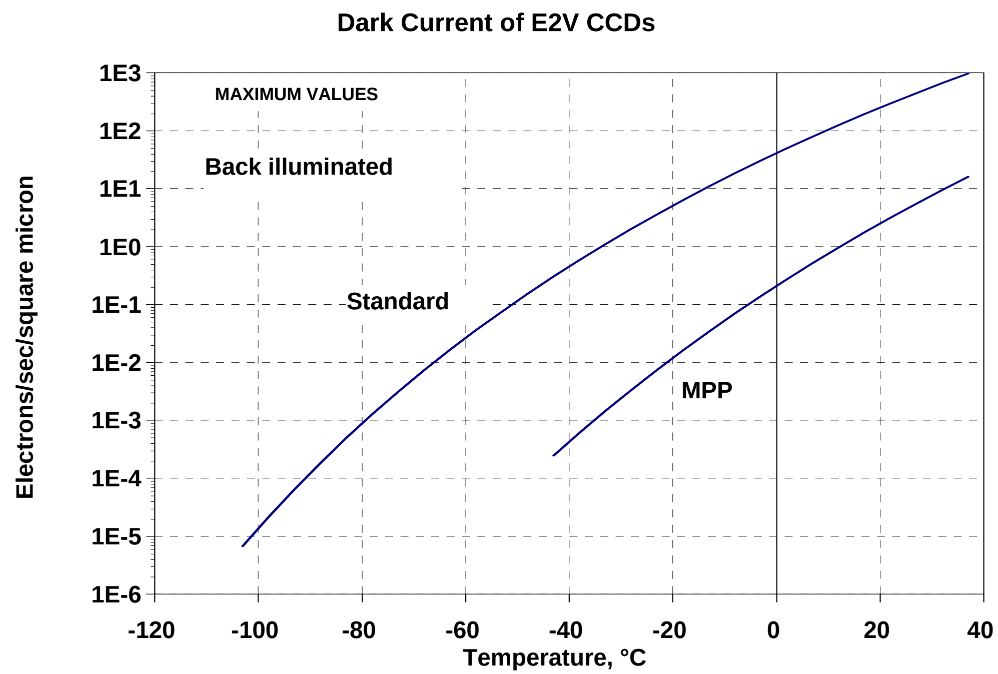


Consequently, EMCCD Noise is low for small signals, but higher for large signals.

However, EMCCD noise can be independent of pixel rate

Dark Noise



Having lost read noise, an EMCCD should be operated under conditions in which the dark charge/pixel does not contribute significantly to the noise.

Clock Induced Charge (CIC)

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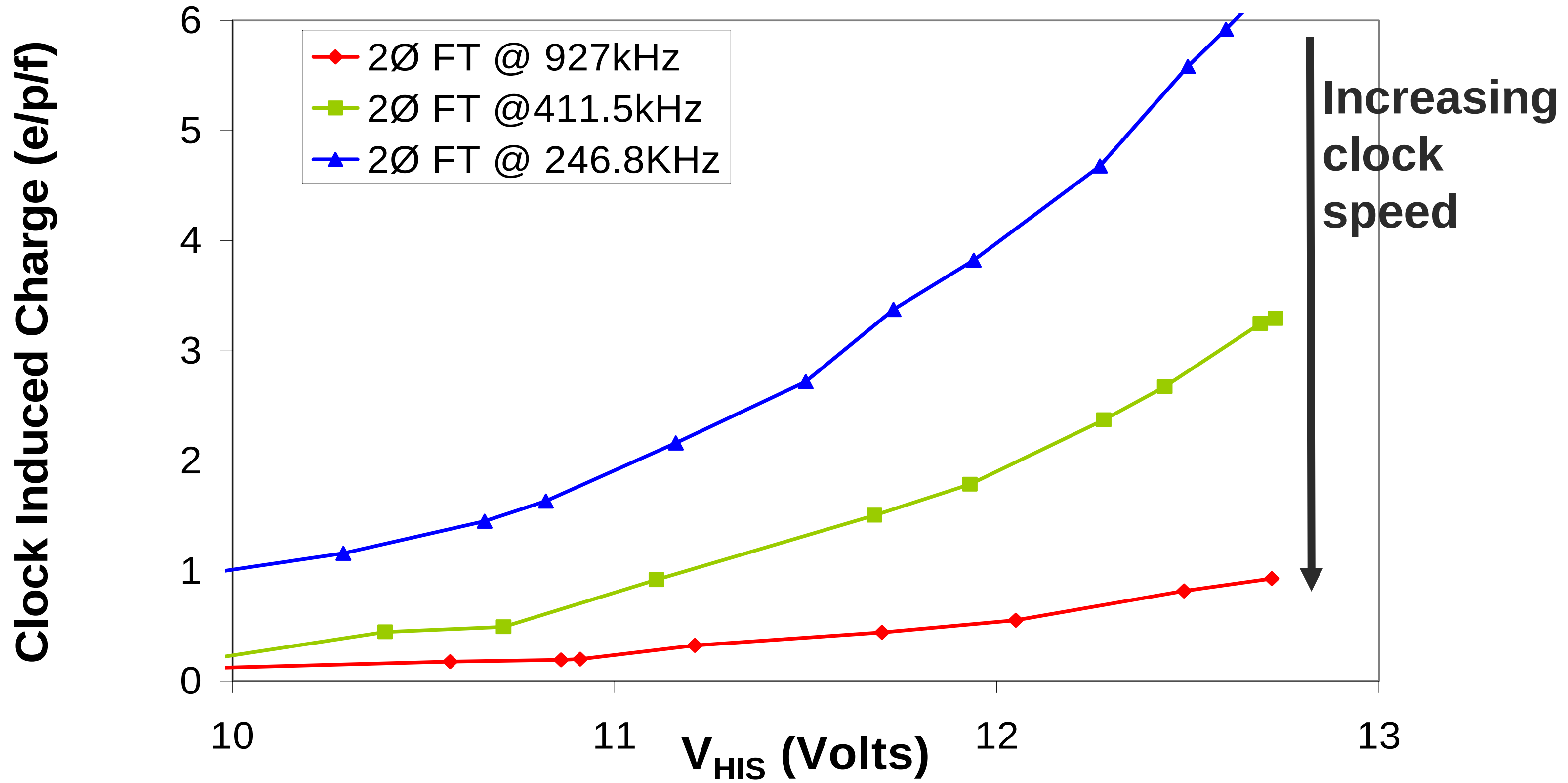
If sufficient cooling is not available, multi phase pinned (MPP) operation can be used. This makes the system susceptible to CIC, but this can be minimised by careful choice of operating conditions.

In MPP operation, the low clock inverts the silicon surface, saturating it with holes.

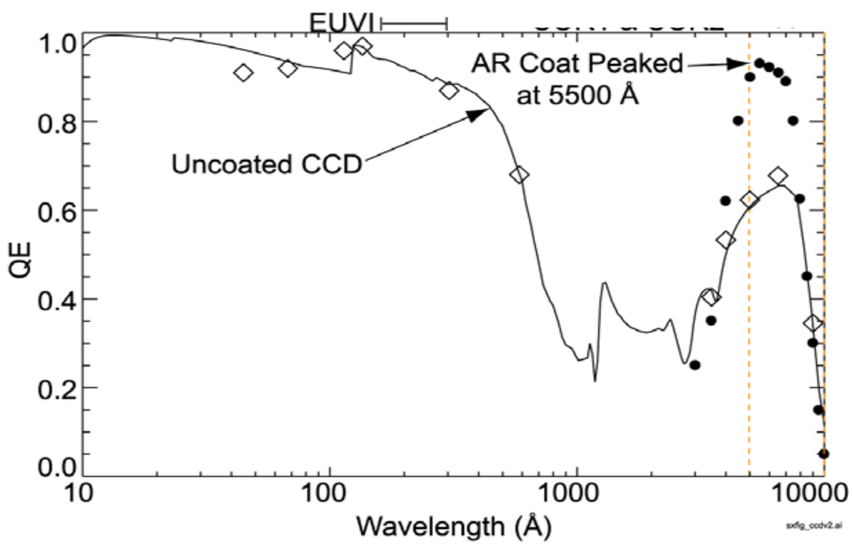
- **CIC is caused by impact ionisation of the holes as they move in and out of the Si/SiO_2 interface during clocking.**
- **The charge generated is dependent on the number of transfers through the CCD and not the integration time.**
- **Dependent on clock amplitude, transfer rate, and clock timing**

Clock Induced Charge (CIC)



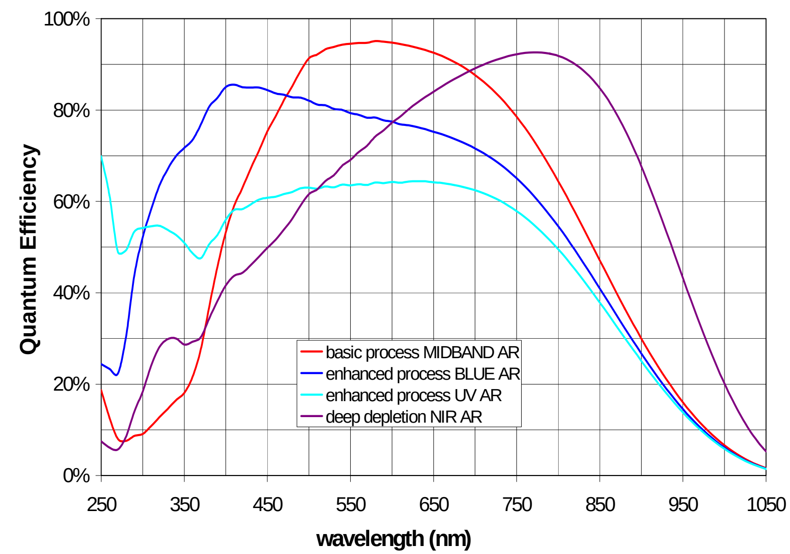
CIC minimised by low clock swing and high clock speed, in particular minimising the time a clock is held high.

Quantum Efficiency



Data from the SECCHI programme (US Naval Research Laboratory)

BI QE Curves at -50 °C



To complement low read noise and minimal dark noise, EMCCDs benefit from the high quantum efficiency (QE) available from back illumination.

Appropriate processing promotes useful QE anywhere in the wavelength range 1 Ångstrom to 1 micron

Overview of three current applications

Surveillance

Ground-based Astronomy

LIDAR

24 Hour Surveillance
Daylight

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With variable gain and resistance to overload damage, the EMCCD is ideal for 24 hour surveillance applications.

As expected the EMCCD out-performs an intensified CCD in daylight, because gain can be turned down, so it's like a standard CCD.

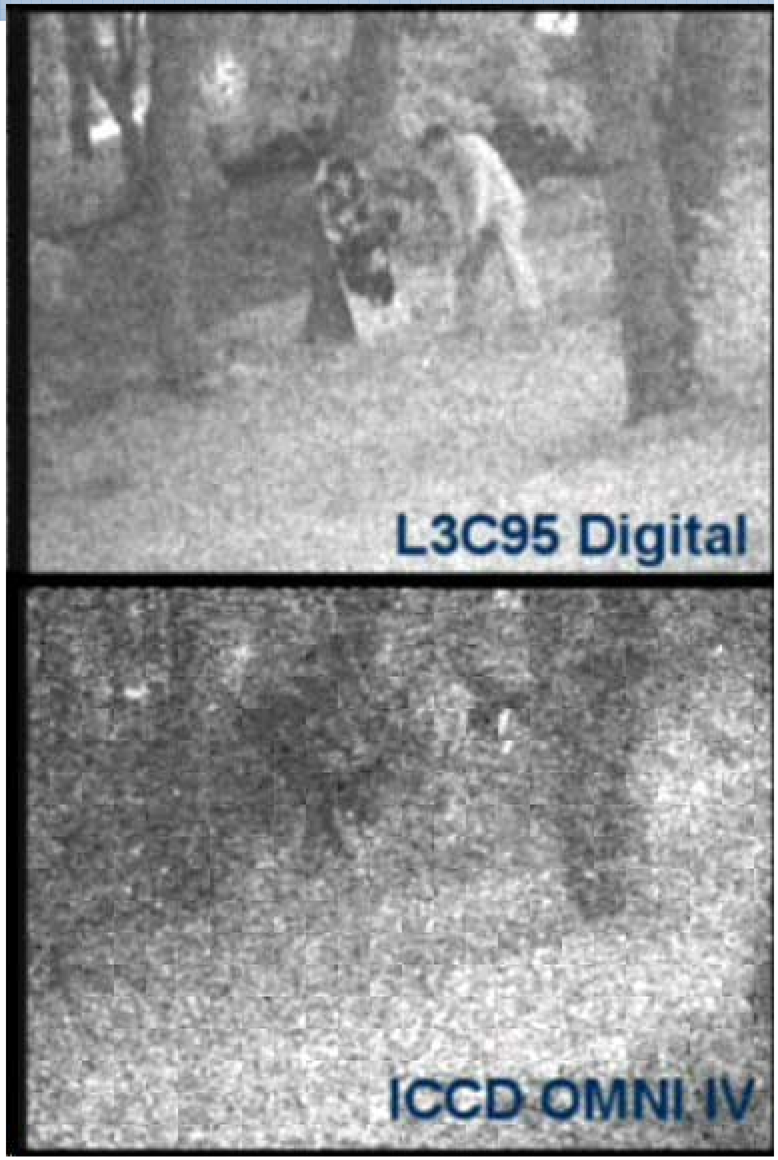
24 Hour Surveillance
Overcast Starlight

When it's seriously dark, the gain can be increased, so it still does the job.

This image represents
~1 electron/pixel/frame.

Some of you may have concluded that this does not show a real golfer.

Nobody has a good swing when it's this dark, so he was the only volunteer



Ground-based Astronomy.
Road-map for ESO adaptive optics

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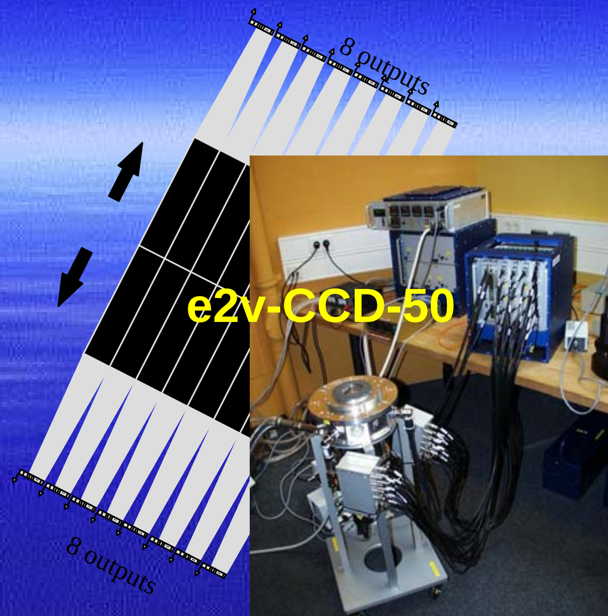

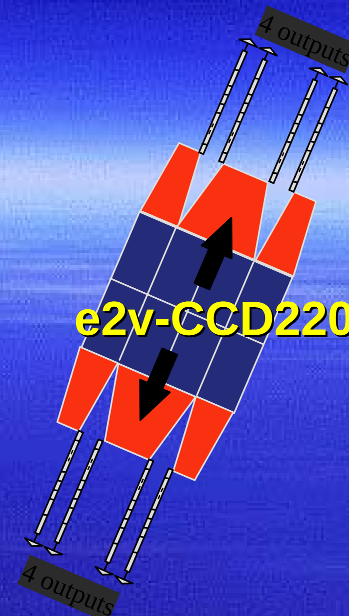

MAD-WFS CCD

80x80 pixels
4 outputs
500Hz frame rate
Noise: 8-6 e^- rms

NAOS-WFS CCD

128x128 pixels
16 outputs
25-600 Hz frame rate
Noise: 2.5-6.5 e^- rms

Future-WFS CCD220 CCD

240x240 pixels
8 L3 outputs
0.25-1.2 kHz frame rate
Noise: < 1 e^- rms

Single pixel CCD for LIDAR

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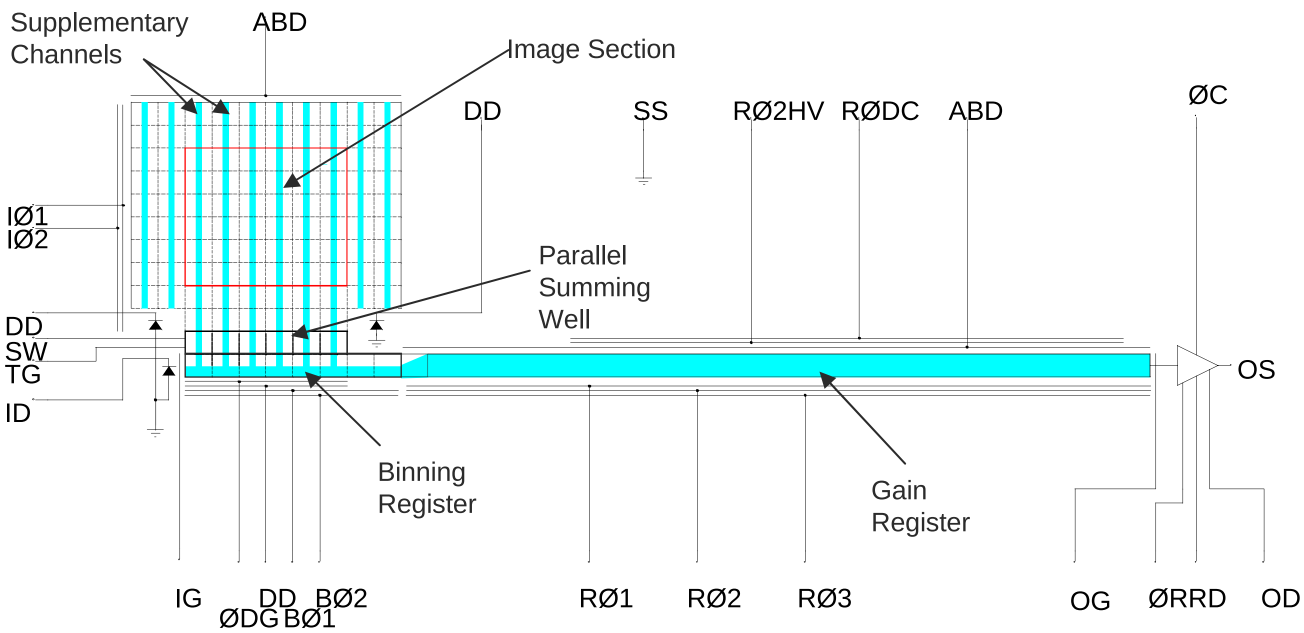
To operate at even higher rates – for example to look at the output from a single fibre a single pixel CCD could be used. A structure of the type below is currently being developed by e2v for LIDAR with ESA funding.



Particle and Synchrotron radiation detectors

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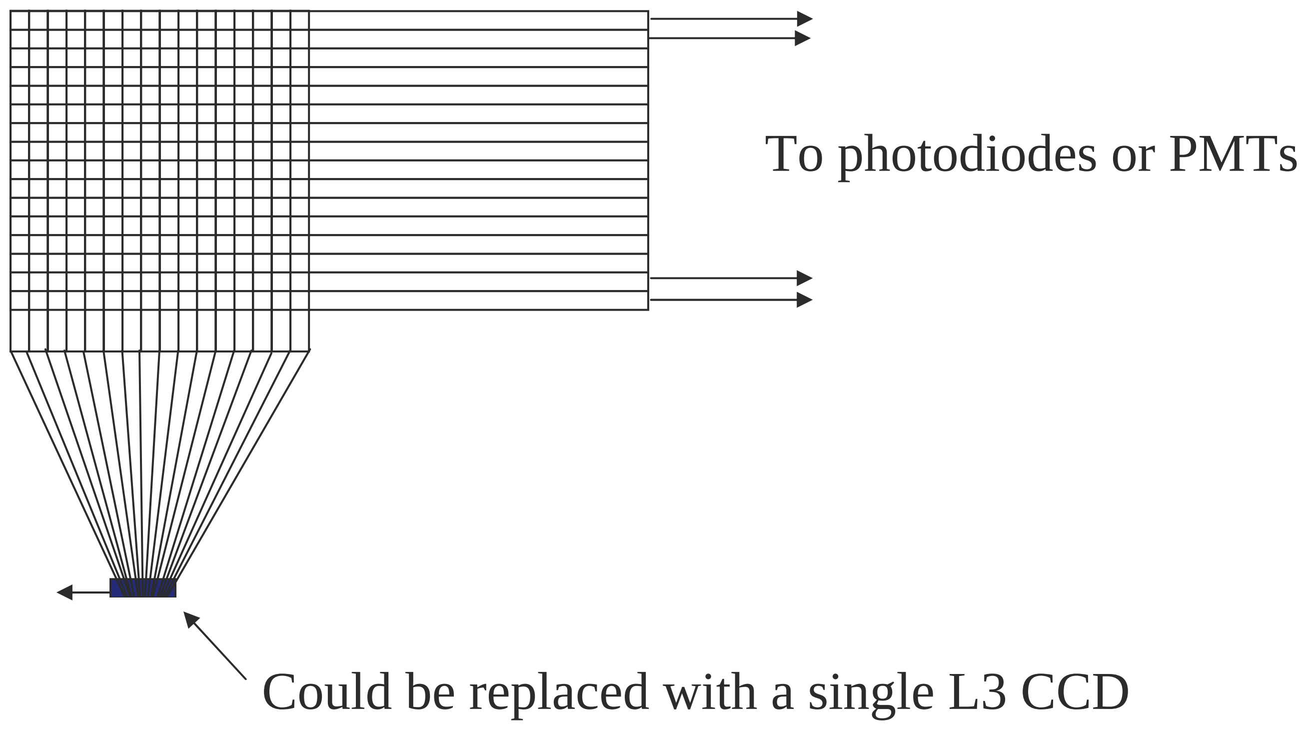
- L3 devices provide significant advantage when:
  - A high frame rate is required at low noise
  - The signal is very low – single photons
  - Frame rate can be >1kHz with an equivalent noise of <1 electron
  - Single pixel frame rate can be > 1MHz

- But give no advantage – or degrade performance when noise is dominated by shot noise

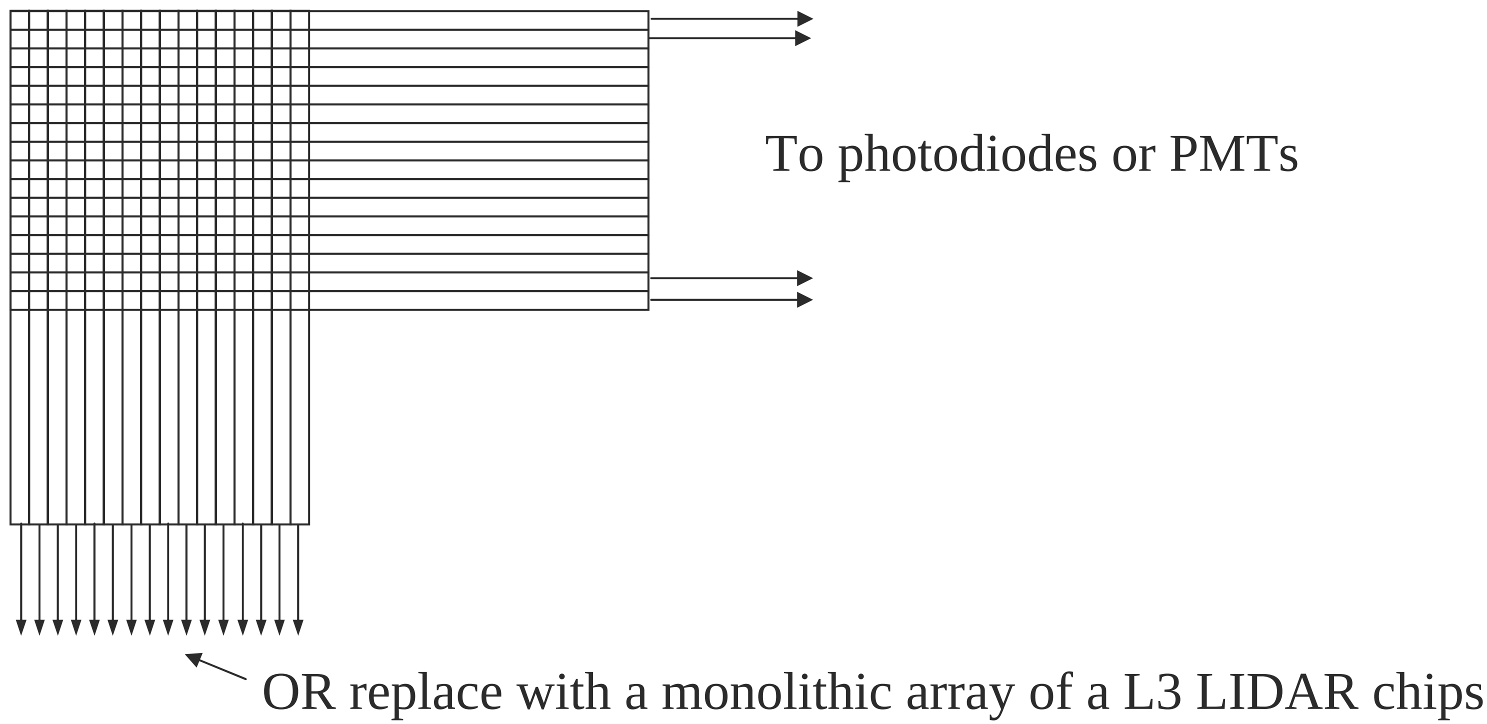
Particle Detection

For example for the detection of light from scintillating fibres in a positron detector. The photodiodes could be replaced by an L3 CCD with the fibres bundled onto the CCD.



Particle Detection

For example for the detection of light from scintillating fibres in a positron detector. The photodiodes could be replaced by an L3 CCD with the fibres bundled onto the CCD or with LIDAR devces.



Particle detectors

……any other applications?

Thanks for your attention

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