New Optical Detectors - TDI CMOS
A Sensor For VHR EO

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CEOI Emerging Technologies Workshop

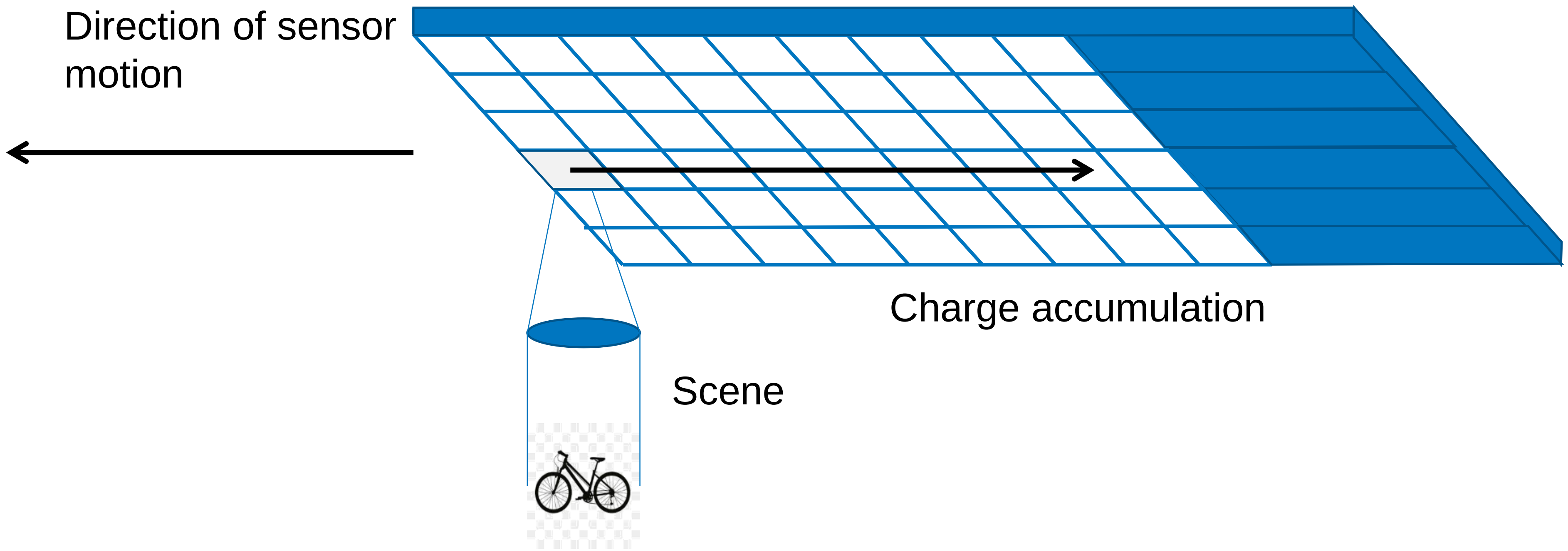
Definition & background

- Time delay and integration (TDI) combines integration with charge transfer such that integration occurs as the charge is been transferred.

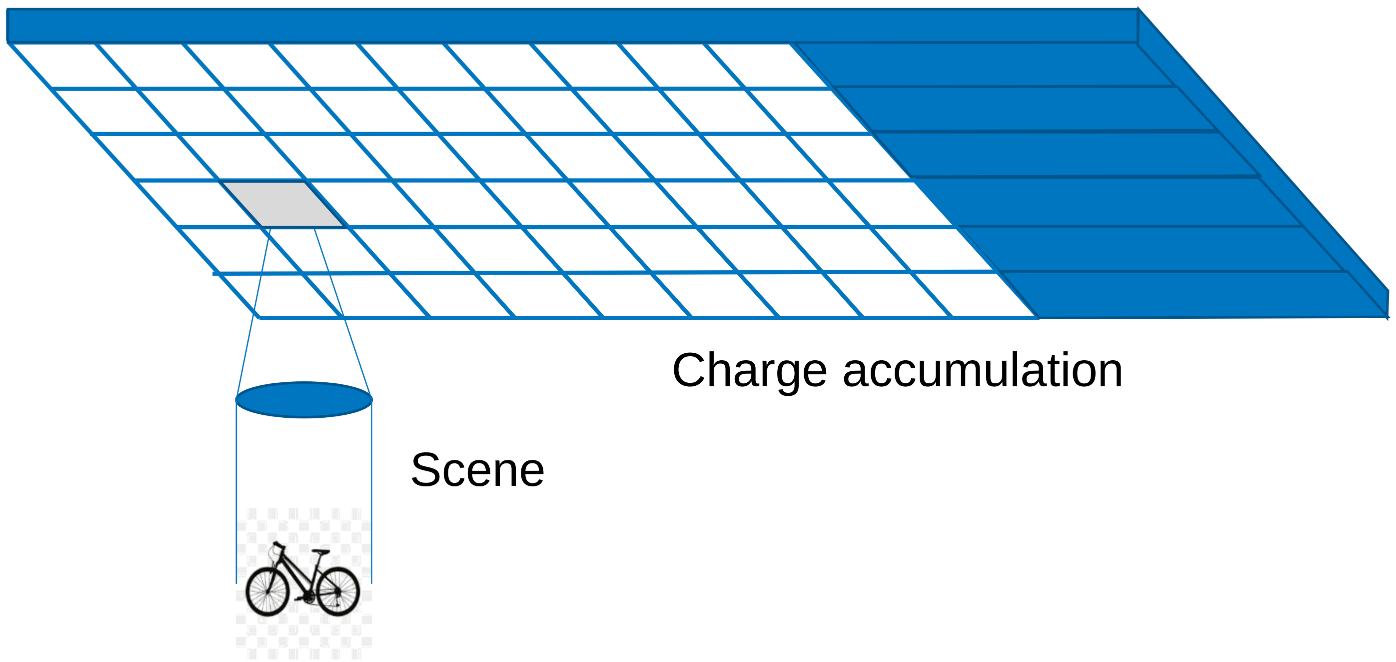
- Competing technologies:
  - Charge Coupled Devices (CCDs)
  - Complimentary Metal Oxide Semiconductor (CMOS)

Traditionally TDI has been implemented in a CCD architecture…

What?



TDI Explanation



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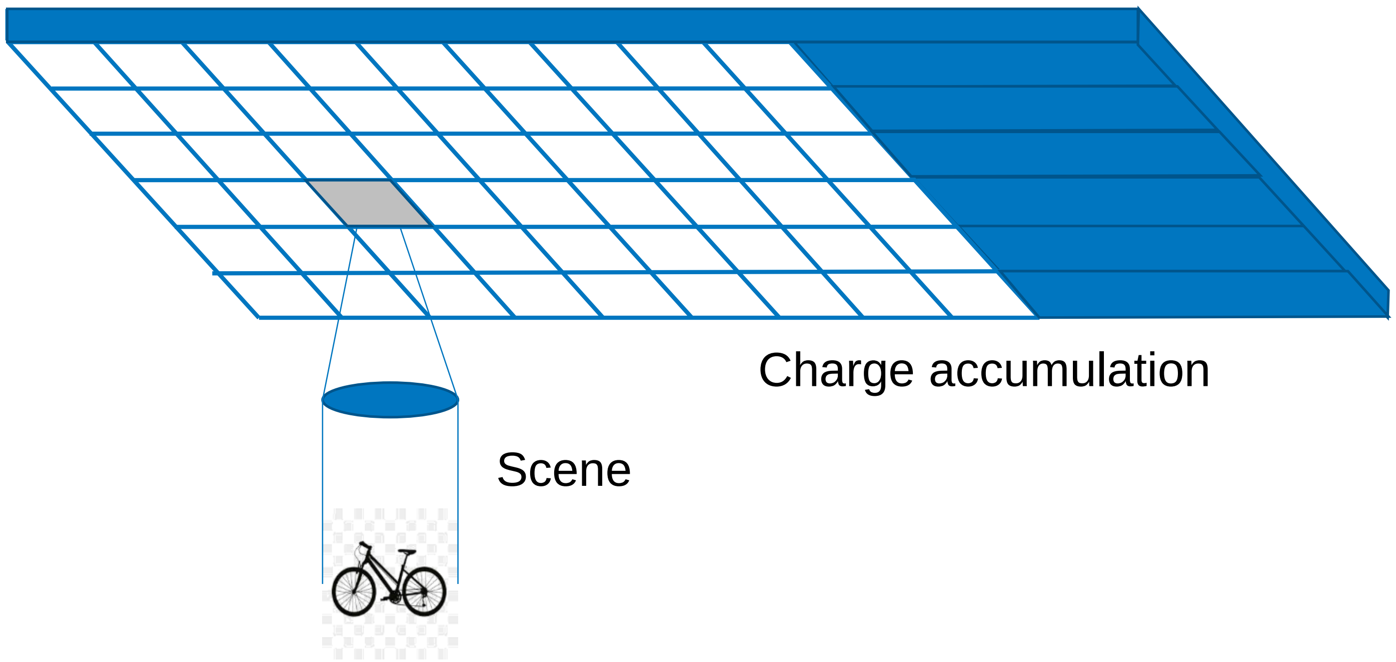

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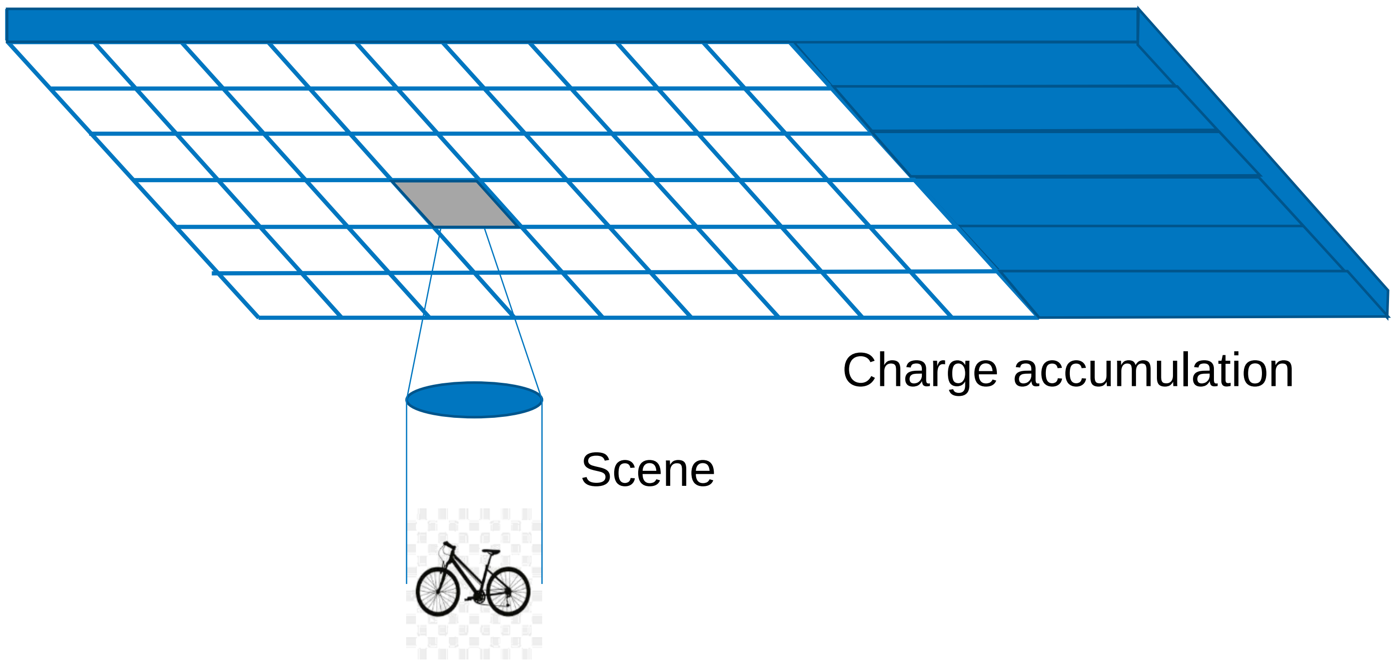

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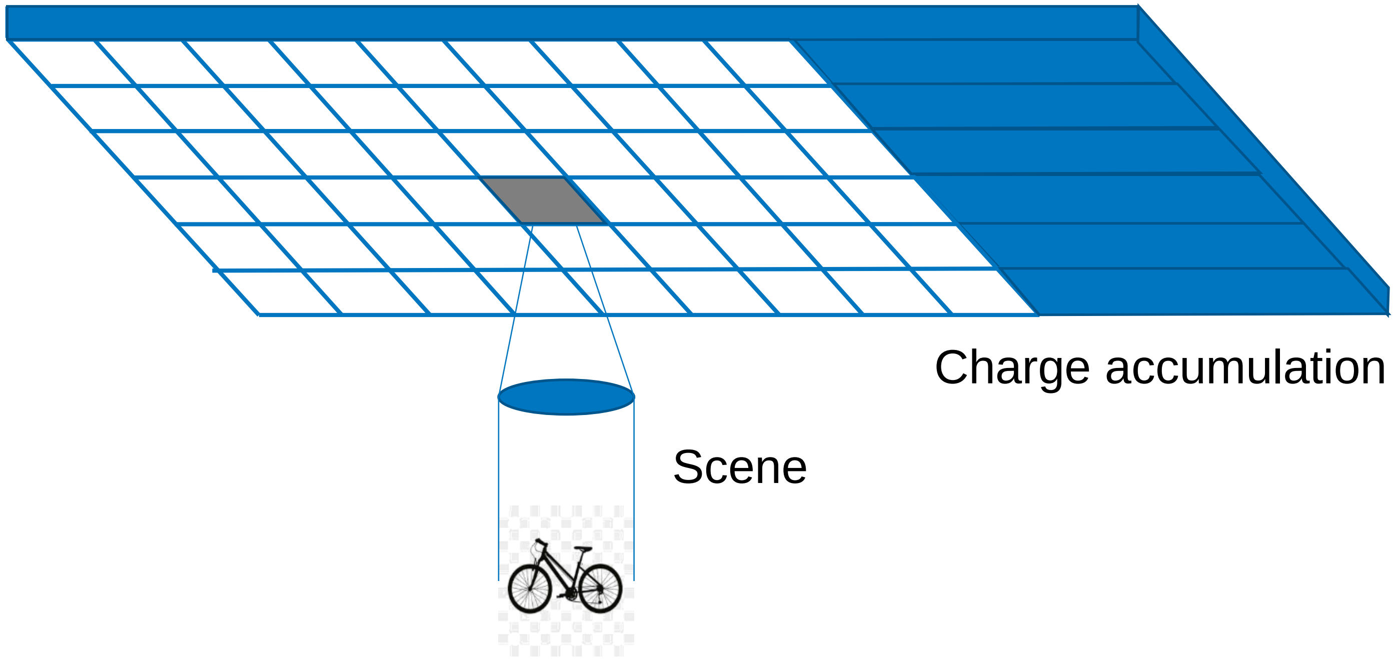

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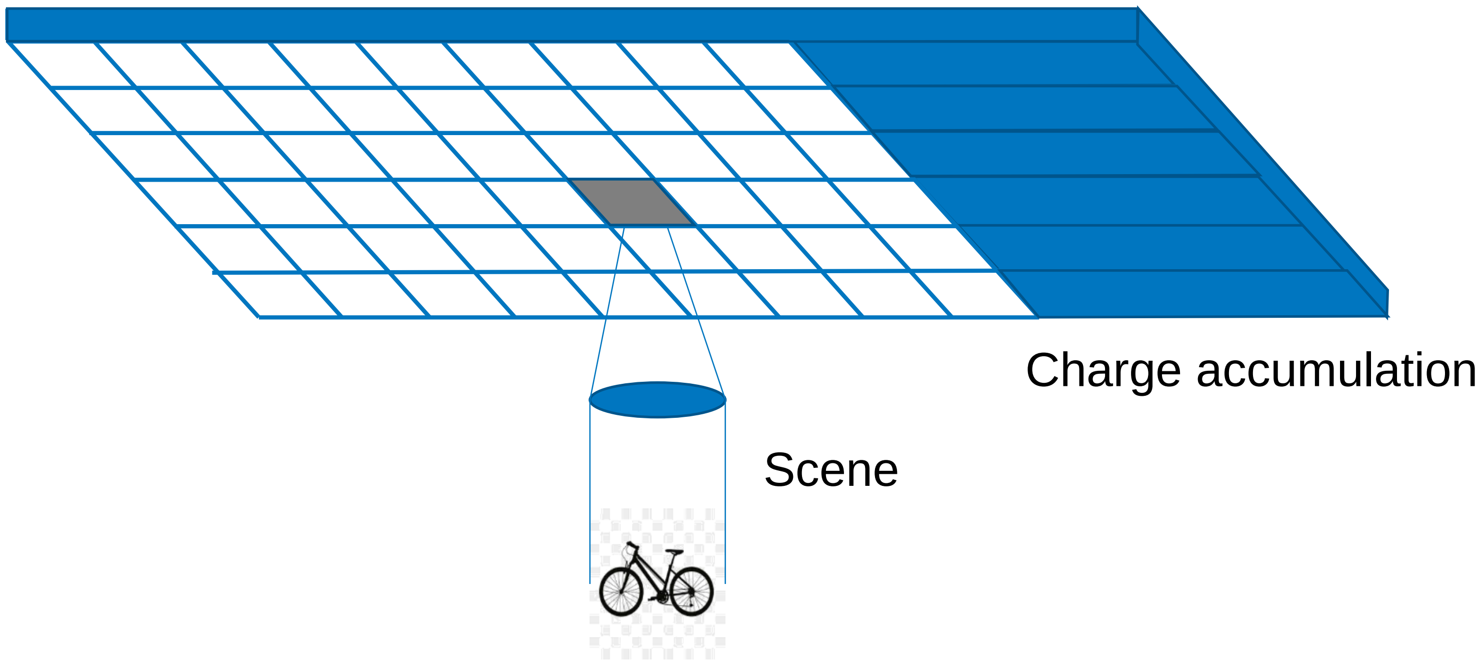

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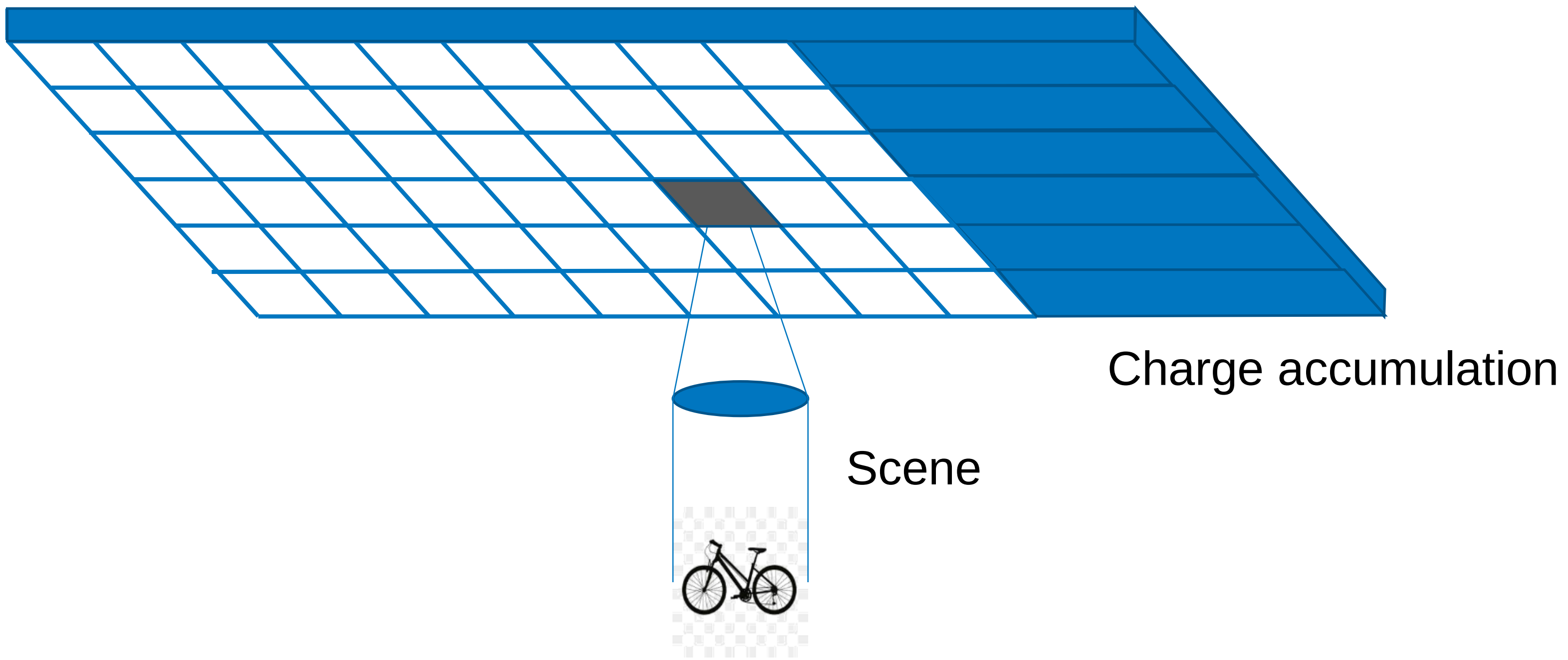

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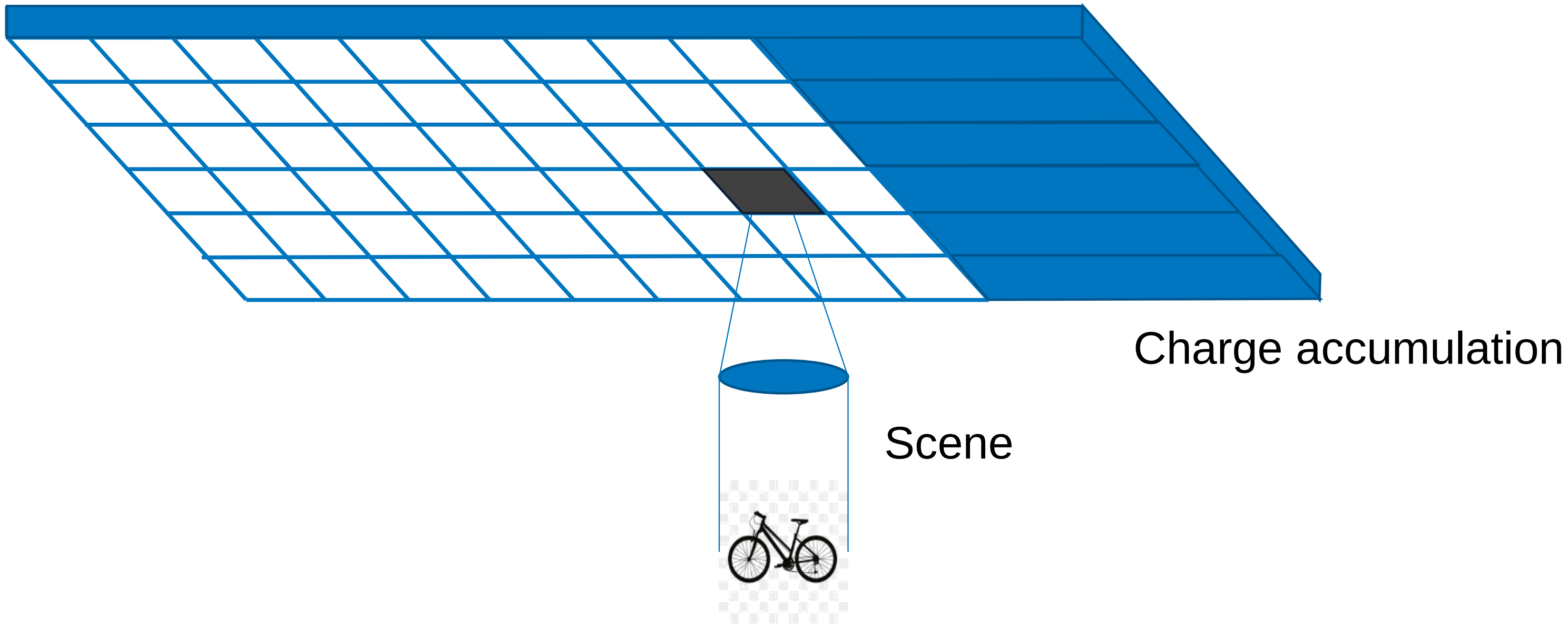

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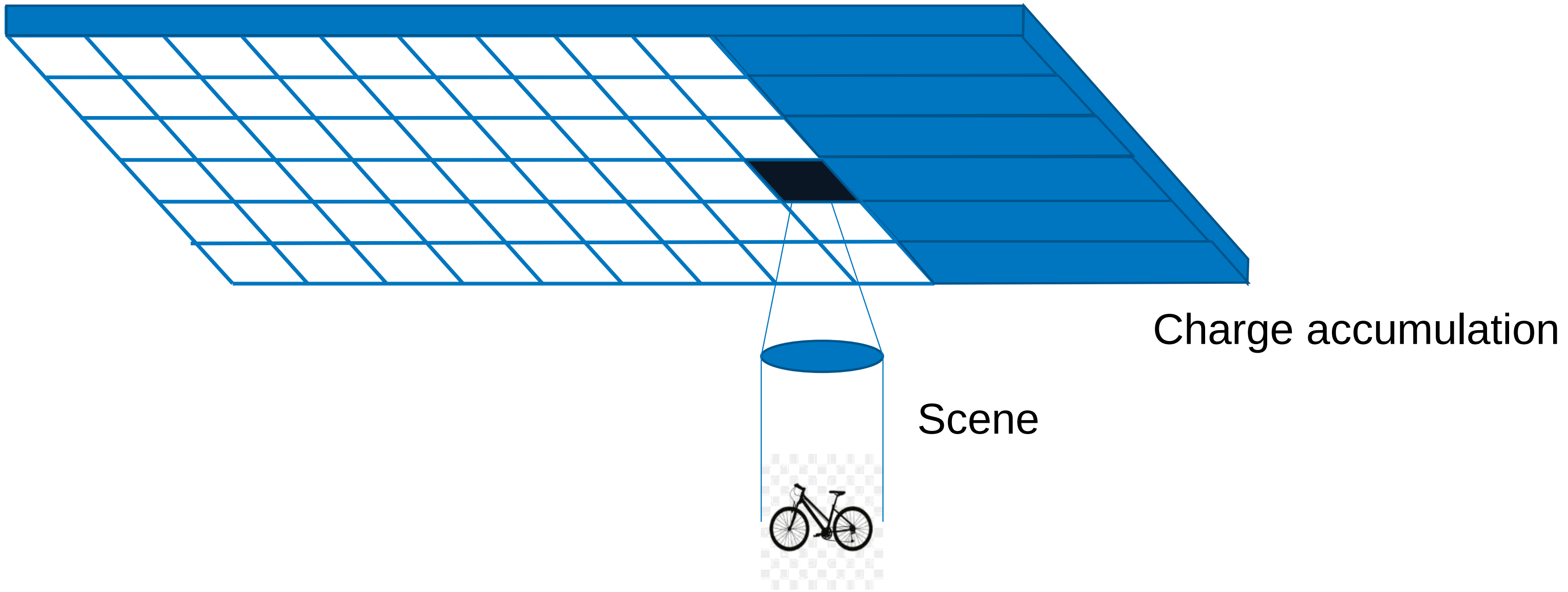
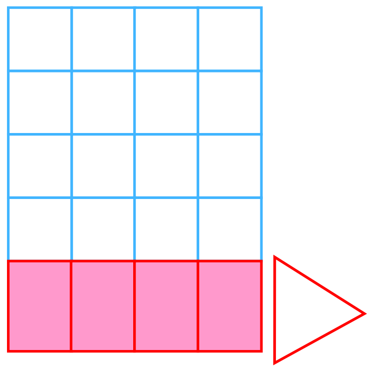


TDI Explanation

- TDI essentially allows an improvement in resolution beyond that available from staring mode for the same SNR.
- This behaviour is inherently available in CCDs which rely on charge transfer.



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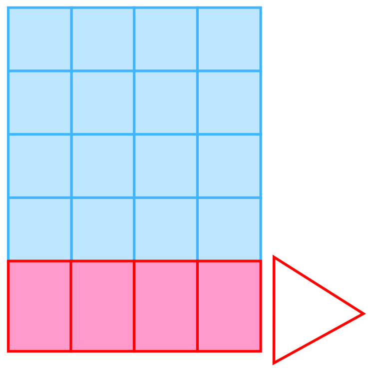

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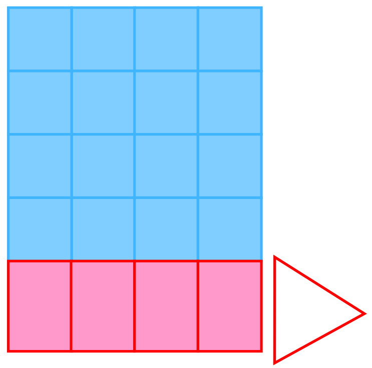

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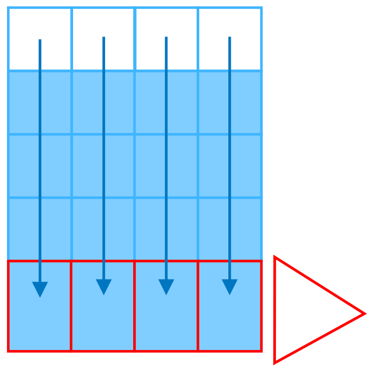

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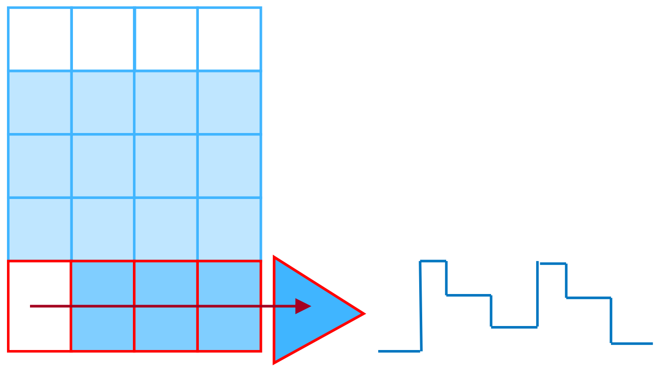

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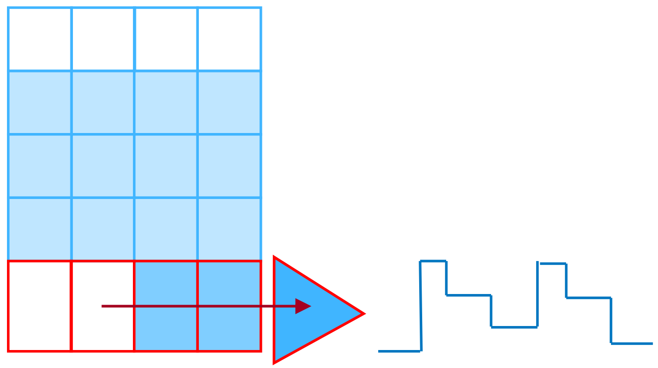


Also used in Earth Observation where the satellite is in motion relative to the scene. In LEO, this motion is extremely fast and limits the integration time available from staring mode without compromising resolution.

This approach is used for high resolution EO on missions such as Pleiades (e2v) and GeoEye (ITT) (both of which have (~0.5m GSD) :

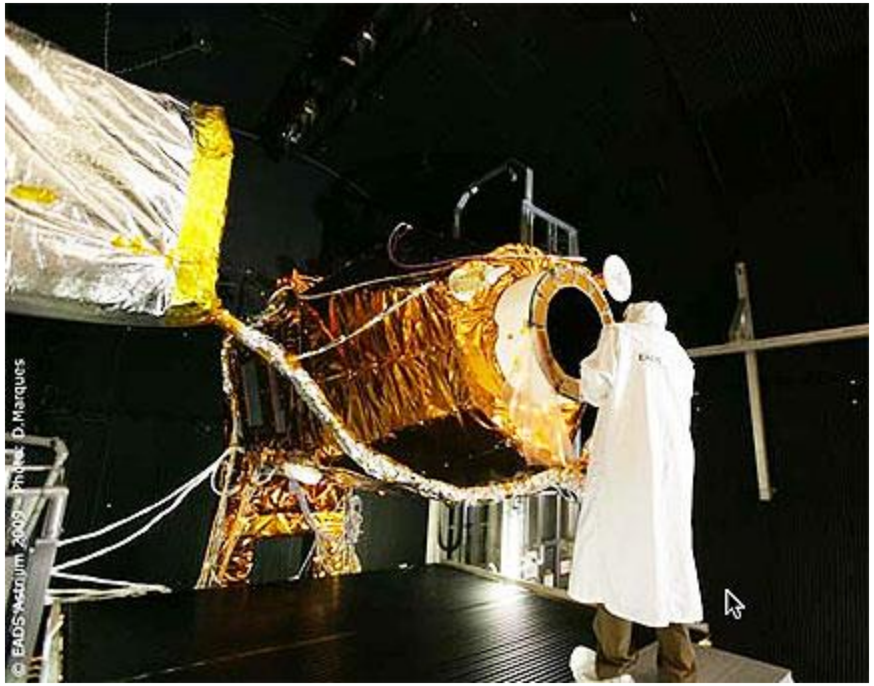
Limitation of CCD Technology

So why not continue with CCDs?

- Complex FEE (video chain electronics off-chip, higher voltage supplies)
  - High power consumption
- Big pixels (typically >8um)
- Low data rate (either low resolution or low swath width)

Leads to…

- Big solar panels
- Big telescope
- Big satellite
- HIGH COST SATELLITE



VHR Satellite Comparison




		KompSAT-3A	Pleiades-1A/B	GEOEye-1	WorldView-1
Launch		2015	2011 & 2012	2008	2007
Orbit Height	km	528	695	681	496
Focal Length	m	9	13	13	9
F#		10.75	19.85	12.09	14.67
Pixel Pitch	um	9	13	8	8
Imager Mass	kg	300	200	450	400
Satellite Mass	kg	1100	1015	1955	2500
GSD	m	0.54	0.70 (0.35)	0.41	0.45
GRD	m	0.54	0.85	0.36	0.68
Mission Cost		$250M	$425M	$450M	$500M

Advantages of TDI CMOS

Benefits of TDI CMOS:

Smaller pixel size possible (e.g. 5um PAN)

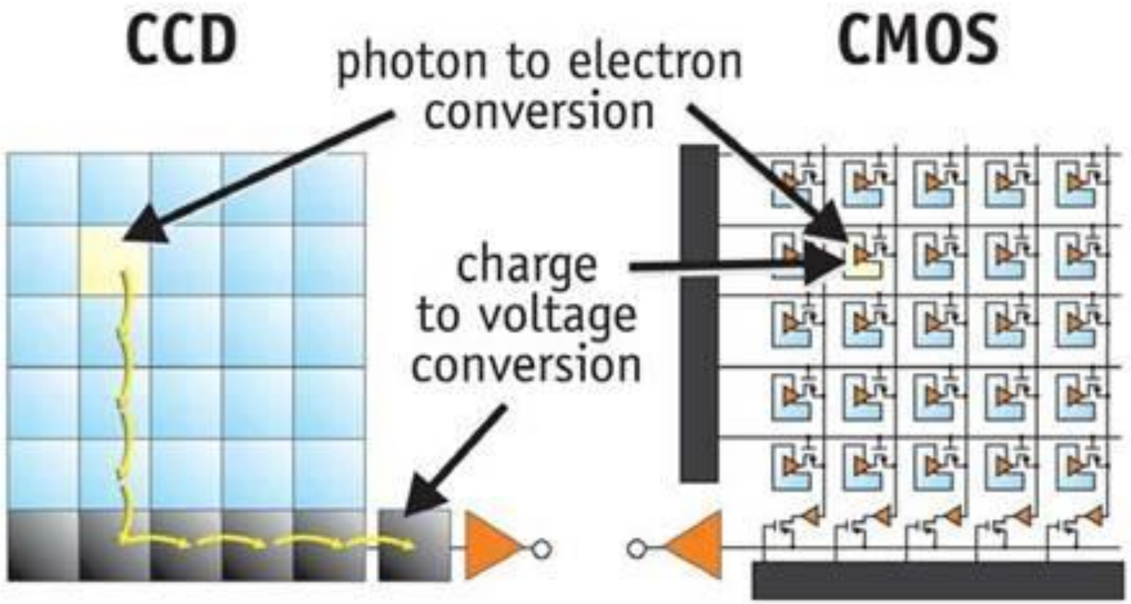
- Allows for **higher resolution** or **reduced telescope size** for similar resolution
- Allows for much **higher data rates**
  - ~0.7 Gbit/s for CCD compared to 60 Gbit/s for TDI CMOS (1.5 DVDs per second!)
  - Allows for higher swath widths and higher resolution
- On-chip functionality simplifies instrument design, reduces instrument mass
- Lower power consumption – smaller solar panels, lower FEE power consumption – lower instrument mass

All leads to significantly **lower cost instrument**

How it works

One small problem…

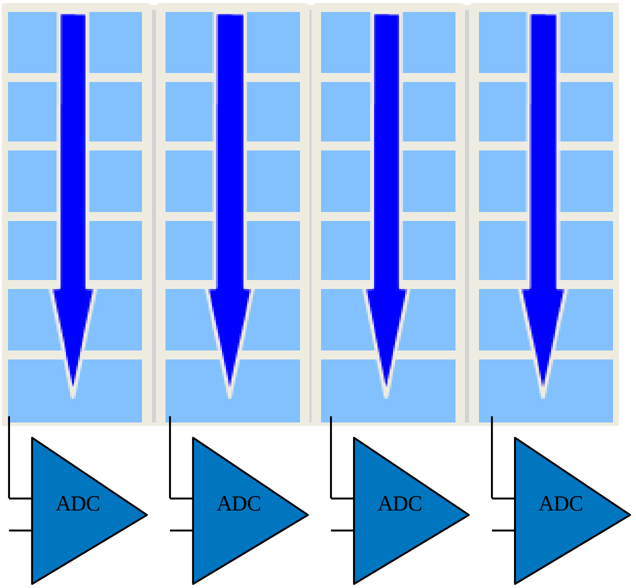
No charge transfer in CMOS detectors as read-out occurs per pixel.

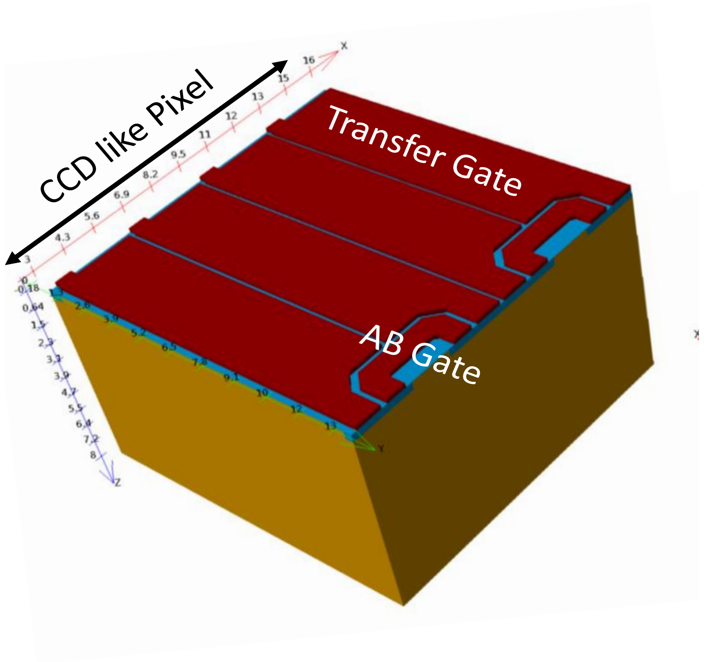


Could potentially sum in the digital domain of a staring array (digital TDI), but this comes at the expense of increased noise and increased power consumption and memory needs as well as lower MTF. (Would generate 700x as much data for the same usable output.)

How it works

Solution is a hybrid between CCDs and CMOS where charge is transferred through a column:





Current CEOI Activity

Collaboration between Teledyne e2v, Surrey Satellite Technology Ltd & Centre for Electronic Imaging (Open University)

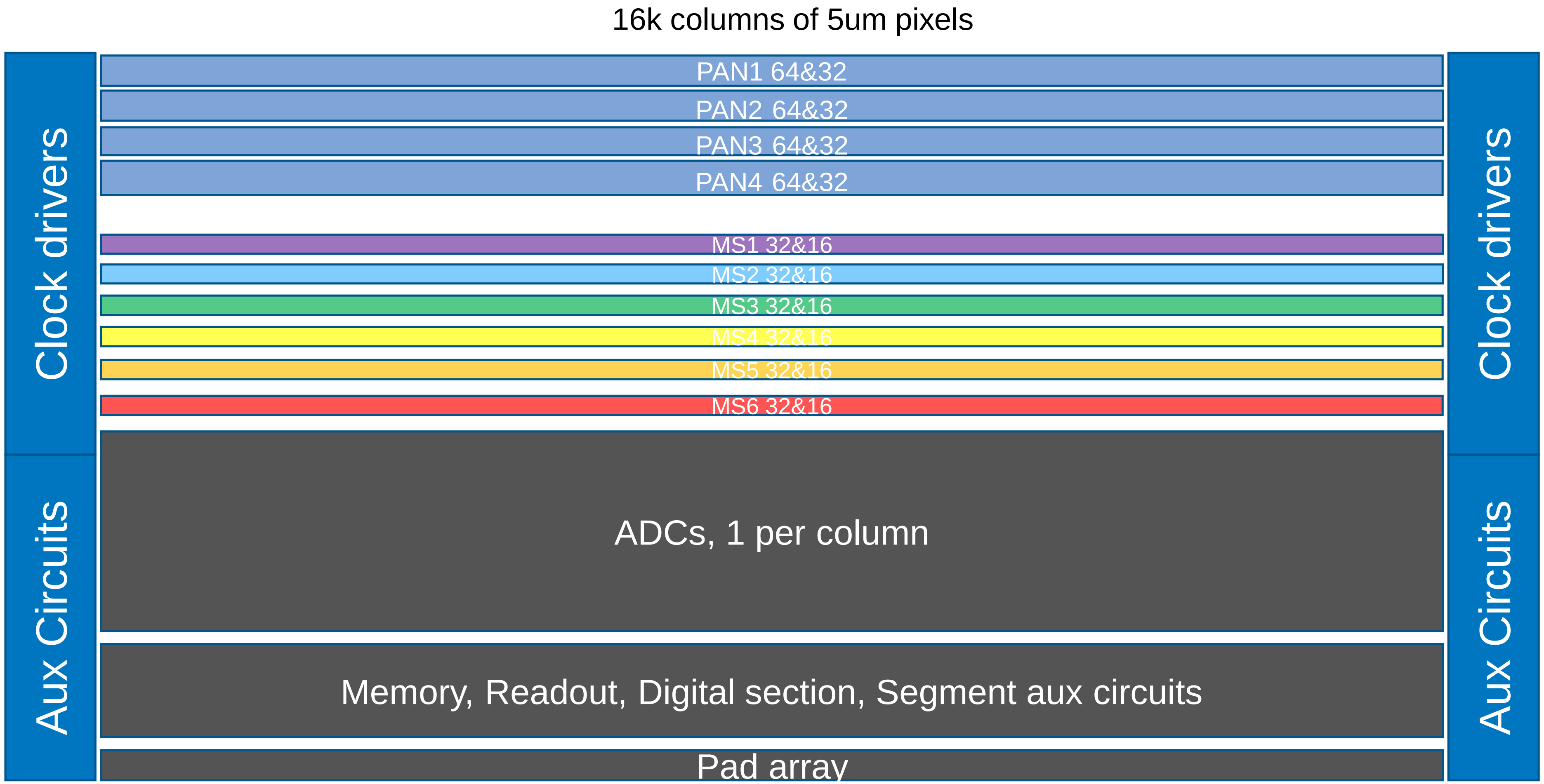
Design and manufacture device suitable for space application

Characterisation testing and performance after radiation

Integration into an instrument for further testing

By completion, we will have demonstrated the suitability of the sub-system for space applications

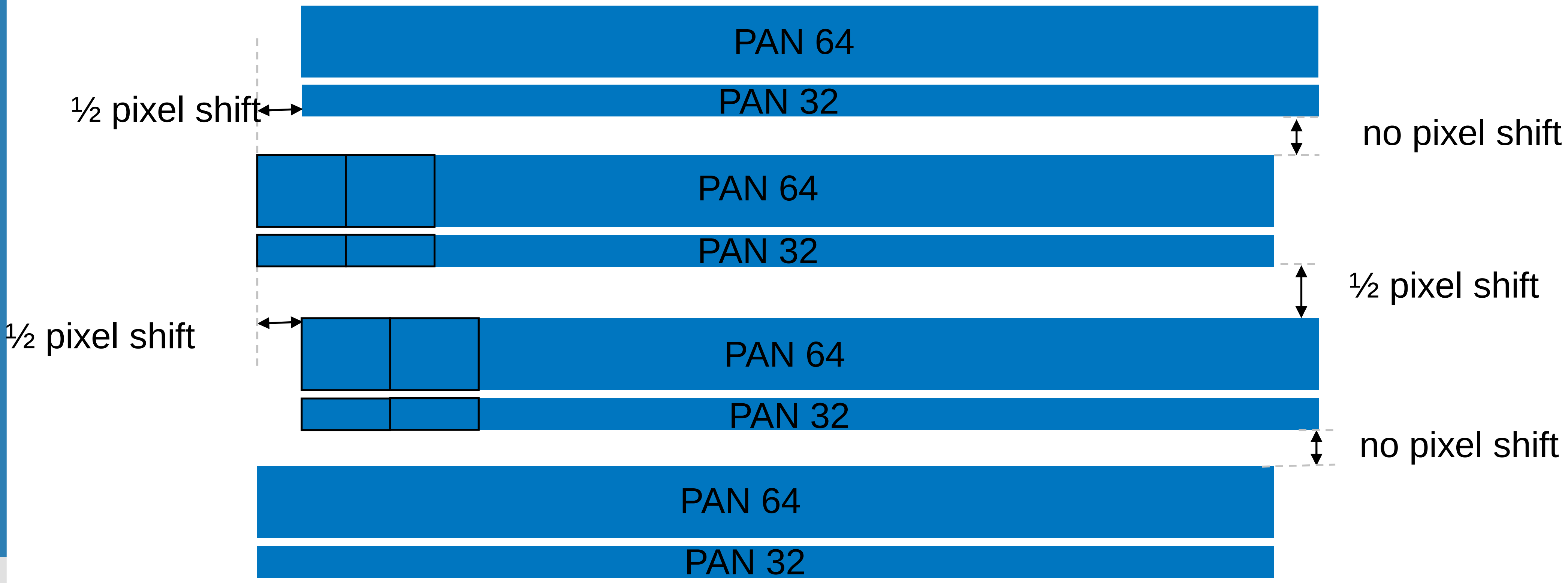
CIS125 - Design



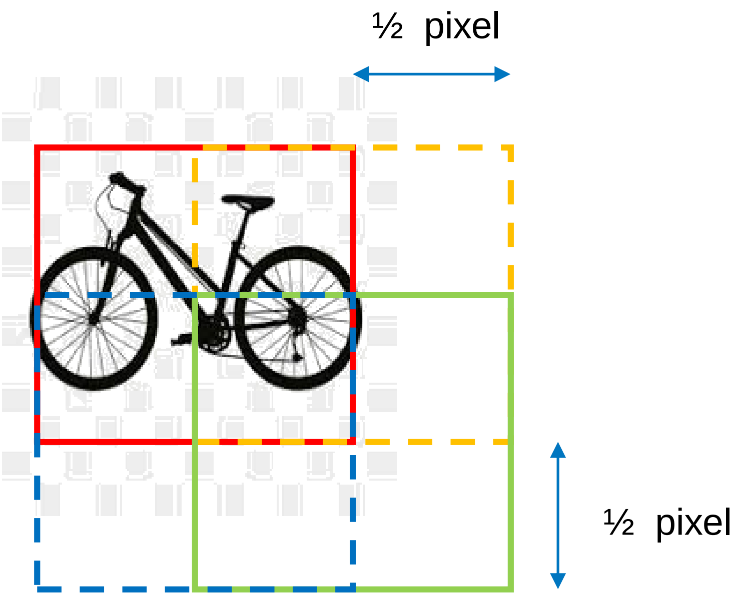
TELEDYNE e2V Everywhereyoulook™

Pan Channels	4 Pan – each made up of 2 sub TDI pan: 64 lines and 32 lines
MS Channels	6 MS – each made up of 2 sub TDI MS: A & B 32 lines and 16 lines
Pixel pitch µm	5µm Pan, 10µm MS
Number of pixels	Pan: 16k columns MS: 8k columns
Full Well Capacity (per pair)	Pan: 60ke- MS: 240ke-
Max. Line Rate	Up to 30 klines/s (14 typical)
Read-out speed at max. line rate	3.0 Gbit/s at 12 bit resolution

Super resolution on chip



Super-resolution on PAN band can improve GSD by a factor of 2.



Impacts

Access to missions:

- ESA
  - Copernicus 2.0
- UK Space Industry
  - Allows for UK space industry growth with partnership (SSTL) developing instrument and satellite solutions
- Export/Bilateral
  - End-to end EO infrastructure for single satellites or full constellations available to countries with limited space heritage (developing counties)
  - Sensor and instruments also available as stand-alone product for countries who wish to develop their own capabilities (e.g. India)
  - Sensors available for traditional high-end market

Impacts

Mission enablement – what new missions/methods are envisaged?

- Sensor development will allow reduced-cost VHR missions
- This in-turn enables VHR constellations so VHR imagery with high revisit times becomes possible
- Also enables ‘Extremely High Resolution’ Earth Observation within the high-end market (<0.1m GSD?)

Science enablement – what new science will come out of it?

- **People spotting and counting**

- Constellations enable high revisit rates for applications like forest monitoring (sub-tree resolution), migration studies, defence etc.
- Multiple spectral bands allow for more accurate VHR spectrometry than traditional PAN / MS detectors
- ‘Deep Learning’ required for challenges of scale of data.