Developments in Visible Image Sensor Technology for Earth Observation

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Introduction

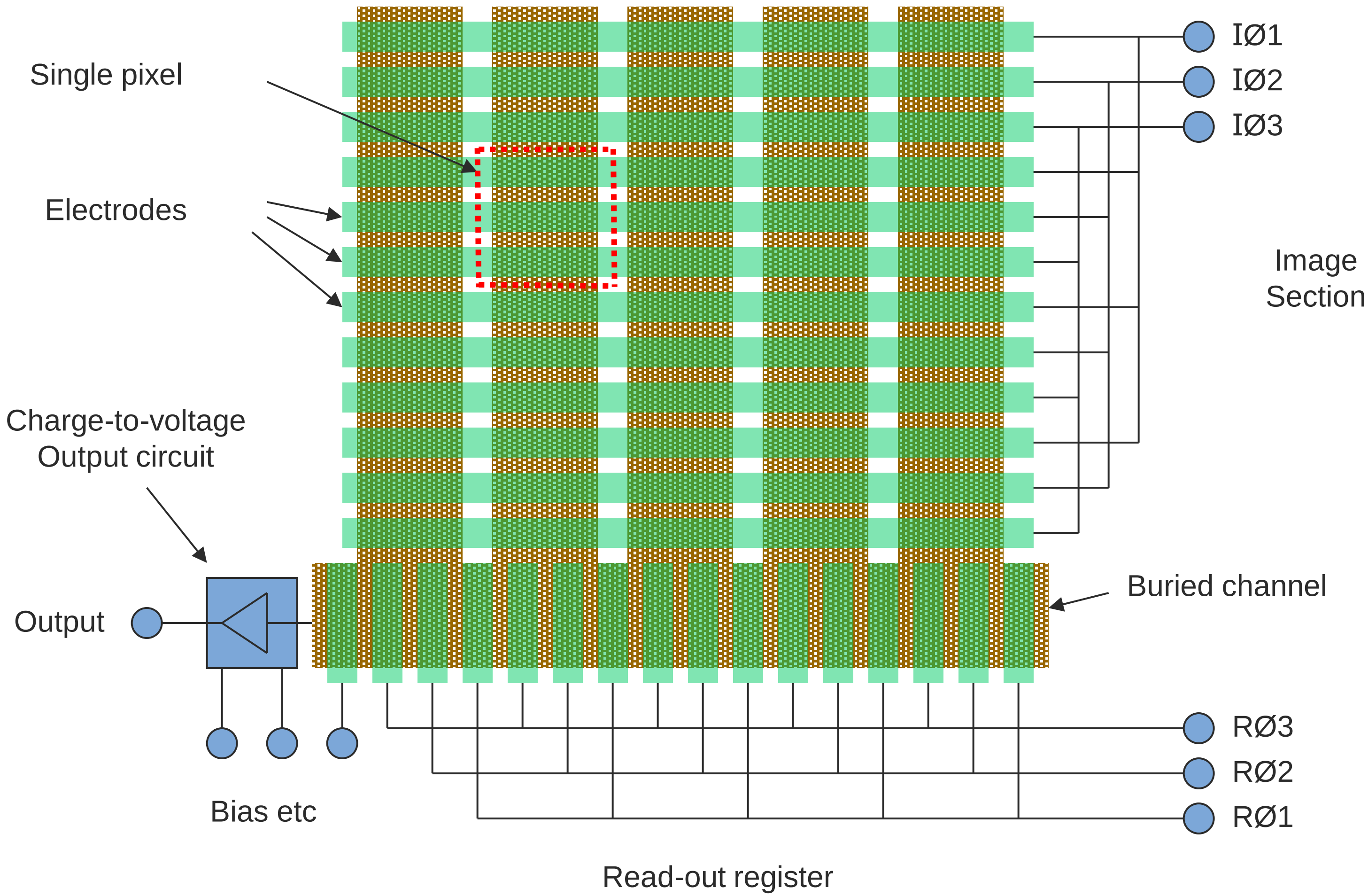
- This talk will cover:
- CCDs for high resolution Earth observation
- CMOS for high resolution Earth observation
- CCDs for Hyperspectral Imaging
- CMOS for Earth Science

CCDs and CMOS imagers

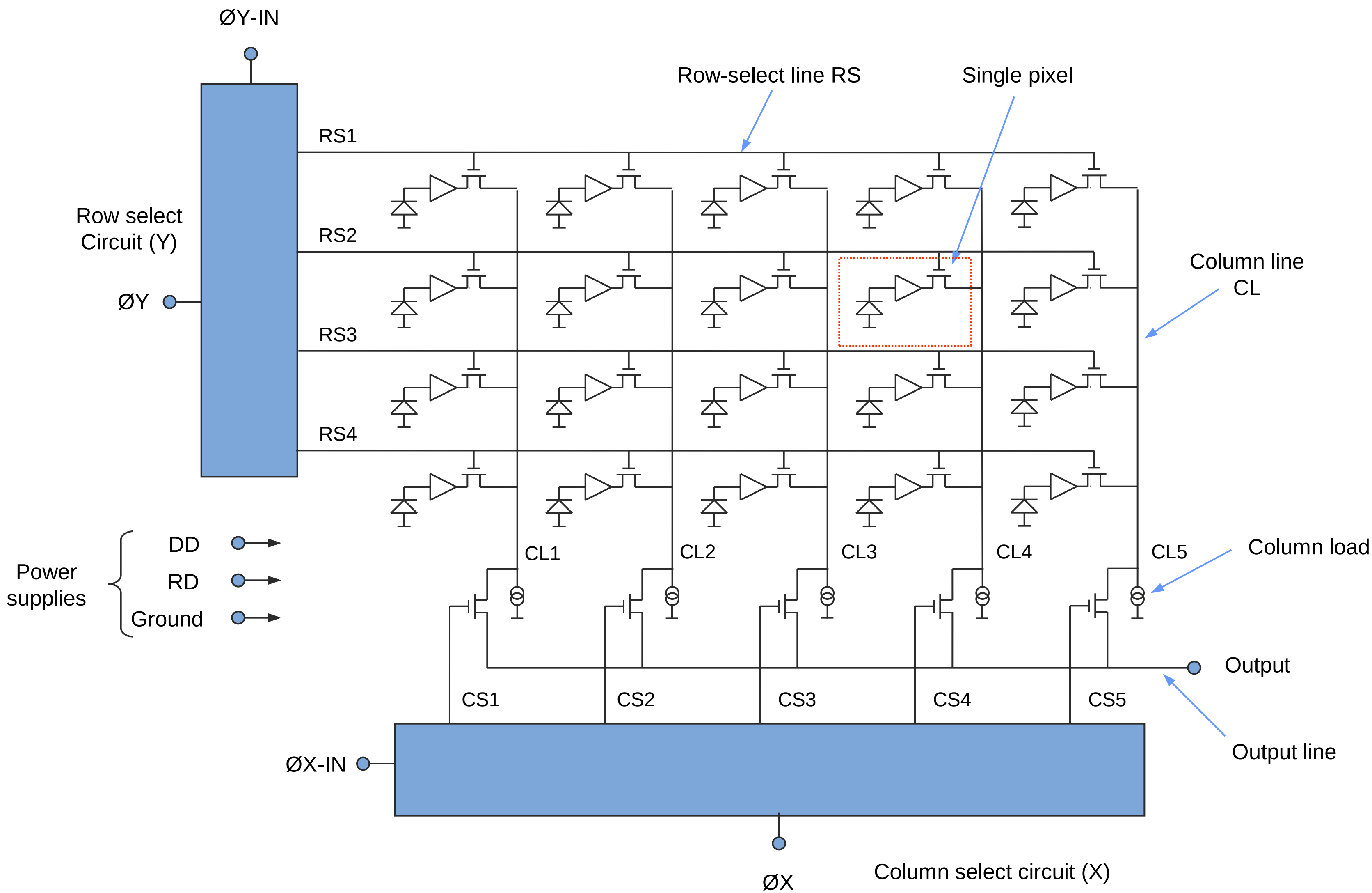
- In both CCDs and a CMOS imagers optical photons produce electrons that are collected in pixels. The difference is that in a CCD the charge is moved around the a device to an output where it is converted into a voltage on a capacitor. In a CMOS imager the charge to voltage conversion takes place within each pixel and the voltage is then read out.

- The other major difference is that CMOS sensors are made in (almost) standard CMOS wafer fabs. This means that there is almost no limit to the amount of circuitry that can be added to the image array.

CCD General Schematic



CMOS sensor general schematic



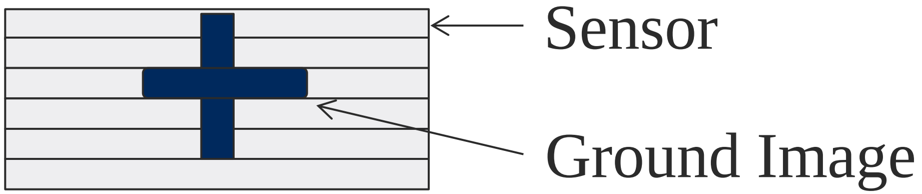
CCDs for High resolution Earth Observation

In general sensors are split into two categories

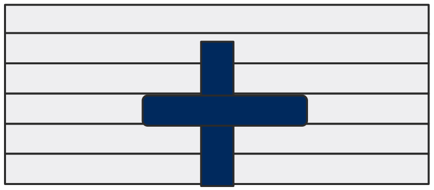
- High resolution earth observation (using pixel size of ~13µm) such as used for Pleiades.
- Medium resolution using smaller pixel sensors down to below 8µm pixels to provide a lower cost platform
- In both cases the trend is for sensors to be wider allowing the use of less sensors per instrumnet
- In both cases the panchromatic (Pan) sensor has the pitch shown above and will often be accompanied by a multispcetral (XS) sensor typically with a pixel pitch two or four times that of the Pan sensor
- Recent Pan sensors are nearly always TDI devices to give improved sensitivity. Up to 128 TDI lines but more typically around 20.
- Most XS sensors are linear but with a trend to TDI and a trend to more sensors on a single piece of silicon

TDI Imaging

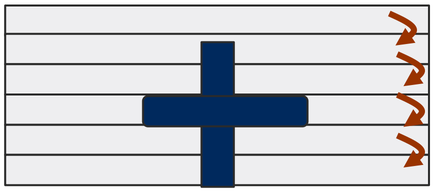
- An image of the ground is created on the sensor



- As the system moves across the ground the image will move down the sensor



- This would create a blurred image but if the signal in the array is moved at the same rate as the image moves then the signal builds up as it moved down the array



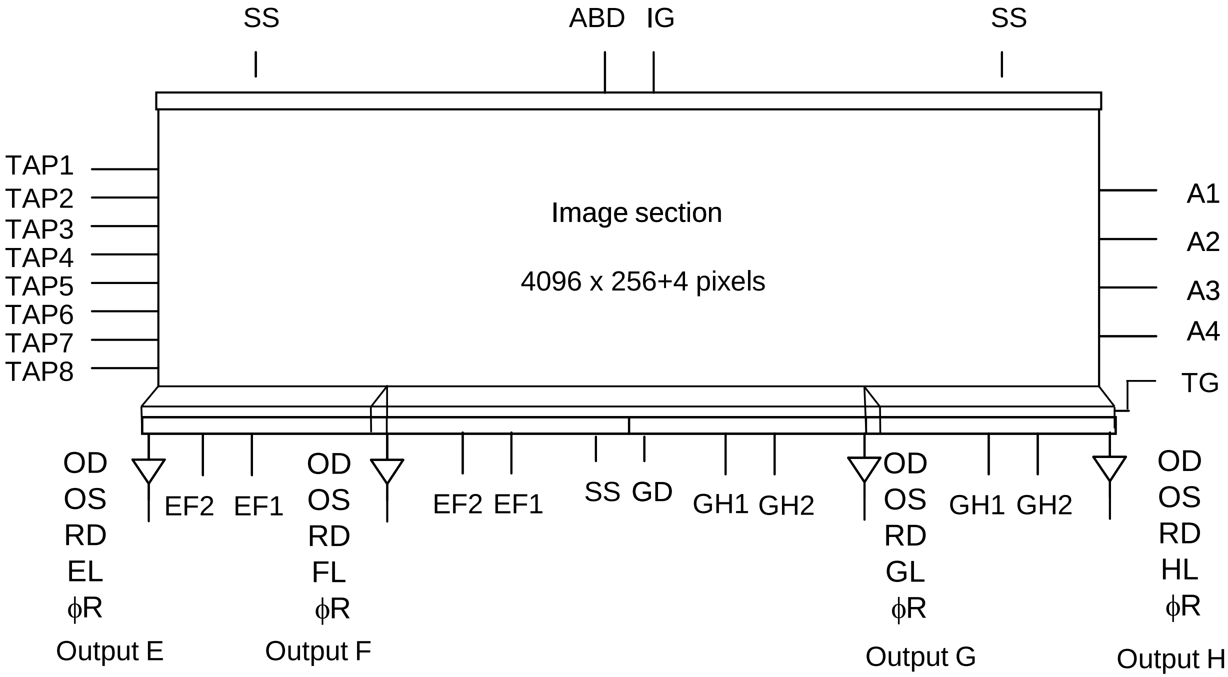
Panchromatic Imager

- Pleiades provide highest resolution images (of 50cm).
- 6000 pixel wide with 20TDI lines (selectable to 7, 10, 13, 16 or 20)13µ pixel size

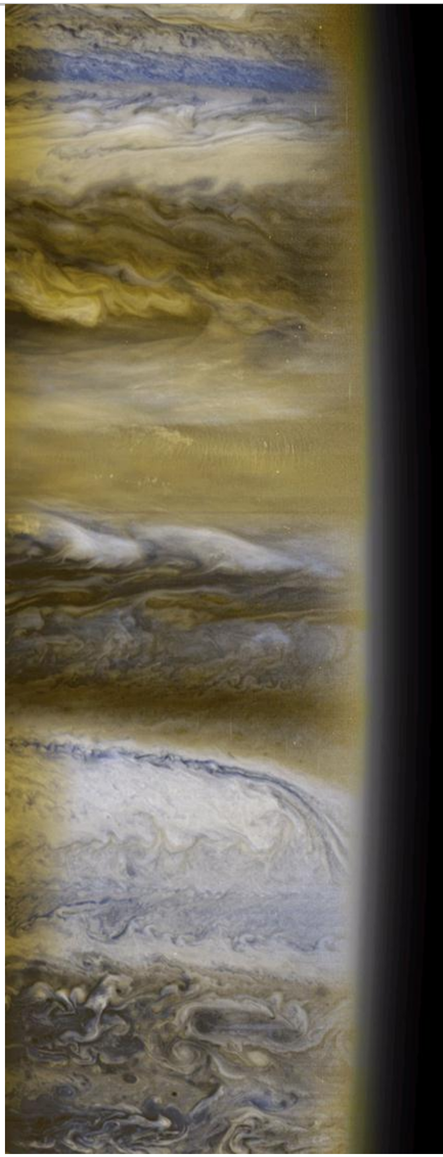
Pleiades

Panchromatic Imager

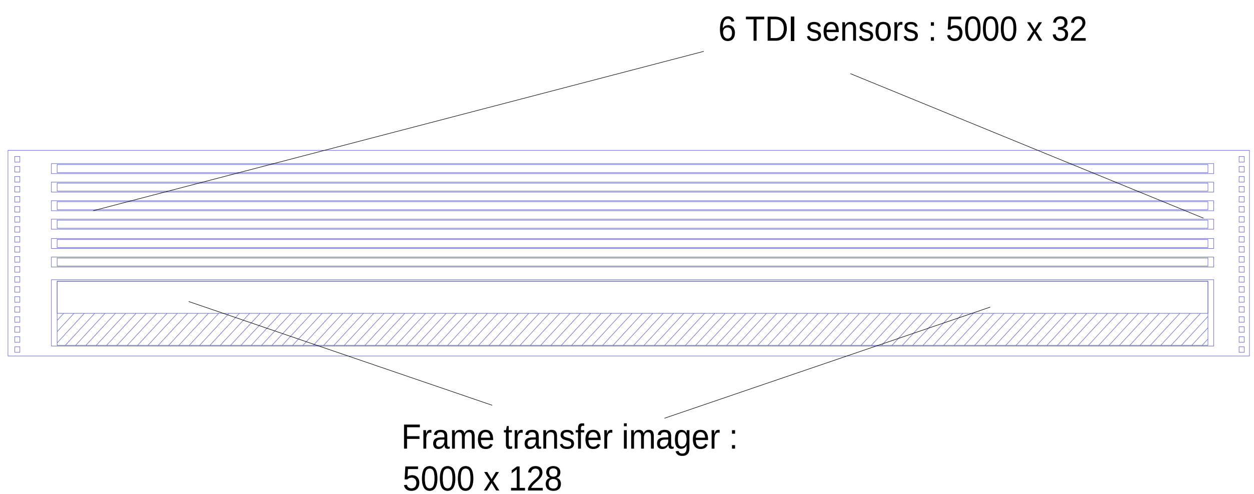
- For lower cost applications smaller pixels are requried.
- Current ESA programme is funding the qualification of a process to manufacture CCDs with 8µm pixels



XS CCDs



- The trend is very much towards inclusion of multiple XS lines on a single die
- Specific Earth Observation programmes are confidential but for example a TDI sensor on New Horizons included 6 separate TDI devices on a single die



CMOS sensors for EO

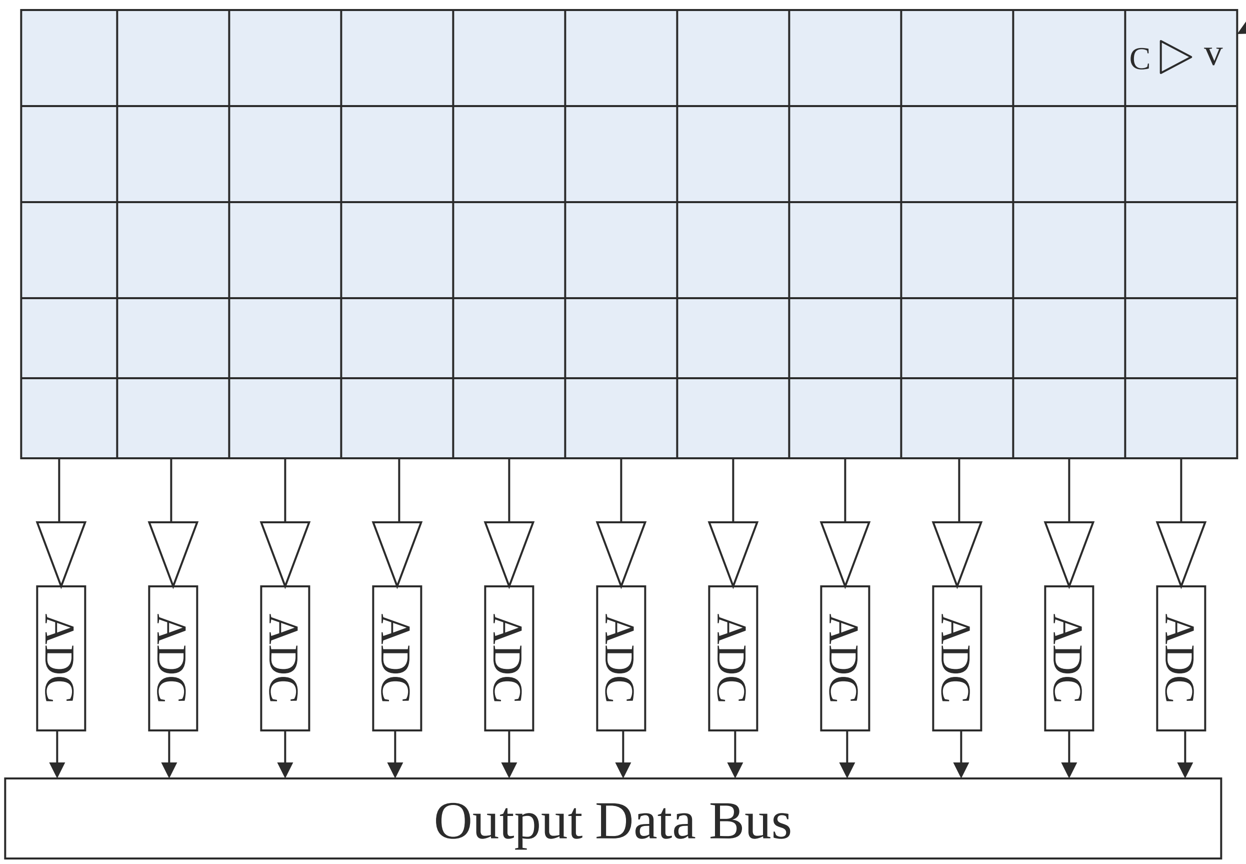
Earth observation presents a difficult target for CMOS sensors because whilst CCDs inherently have TDI capability CMOS does not. Fundamentally CMOS can operate in TDI mode in two ways:

1. Standard area arrays can be operated and read out at line rate and the separate TDI lines summed digitally.

2. Charge can be moved in the CMOS array in a CCD like structure and then read out in the normal manner for CMOS sensors.

We will consider the advantages and disadvantages of these option

Digital TDI CMOS



Charge is converted to voltage within each pixel

Each row is read in turn with an ADC per column allowing all columns to be read in parallel

Digital TDI CMOS

Advantages

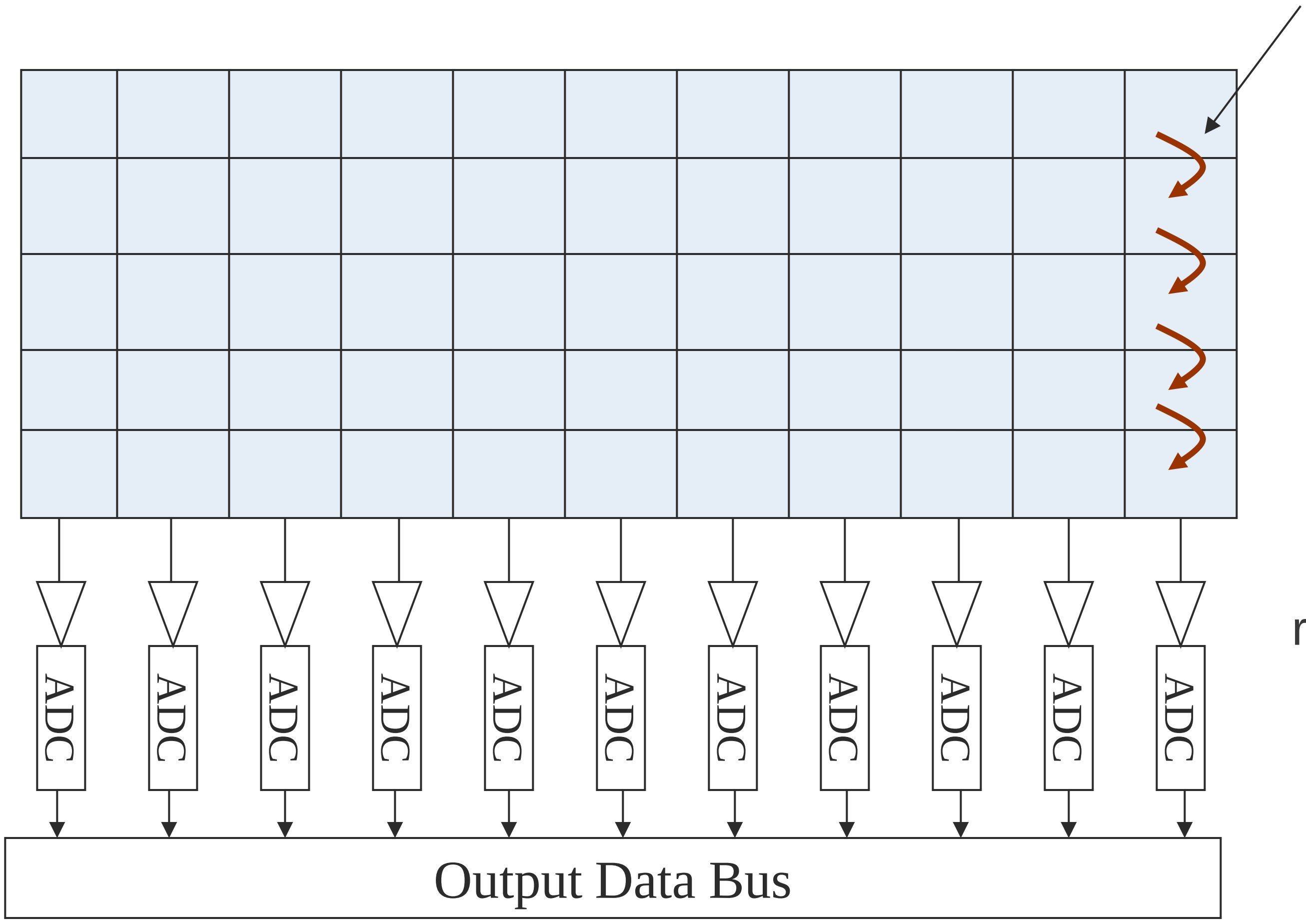
- Peak signals can be very high

Disadvantages

- The whole array must be read out for each line of data
- Or to maintain along track resolution pixels really need to be half (or less height) so each line should be read as separate sub-lines
- Very high level of data generated
- Read noise is multiplied by the number of lines but can be very low to start with

A good solution for a small number of TDI lines – better suited to XS devices

Chare Transfer TDI CMOS



Charge is transferred within the array in a similar manner to a CCD

When the charge reaches the bottom line it is read out though a column-parallel ADC circuit to give high line rates and low noise

Chare Transfer TDI CMOS

Advantages

- Moving charge means that it can be moved as sub pixels and so achieve bet along track MTF
- Readout speed is relatively low so data handling is simple
- Charge transfer is not likely to be as good as a CCD but for EO applications with high background signal this is not likely to be a problem. Means that the number of lines can be quite high
- Column Parallel readout means that noise is lower than CCD readout and much better than digital summation where noise increases as the square root of the number of rows (or sub rows) read

Disadvantages

- Main disadvantage is that peak signal is limited
- Also technology development is required by wafer fabs and in design to establish as a product

TDI CMOS

- We have now started to use a 4 line TDI CMOS sensor for Industrial applications
- New sensor platform
  - Scalability — 8k, 12k, 16k pixels // 5µm pixel size
  - High line rate — 100 klines per second
  - High sensitivity — multi-line solution
  - Versatility — compatible with color inspection

- New Camera platform
  - New data interface — high data rate
  - Low Noise electronics — high SNR
  - Design to Cost — competitive solutions

Earth Science - Hyperspectral CCDs

- There are a number of existing and new hyperspectral programmes being run or currently in planning for ESA

- Sentinel 3
- Sentinel 4
- Tropomi

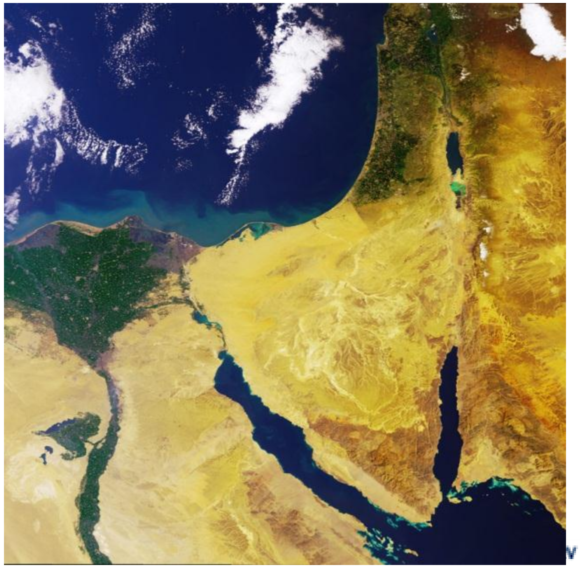
- Sentinel 5
- FLEX
- 3MI

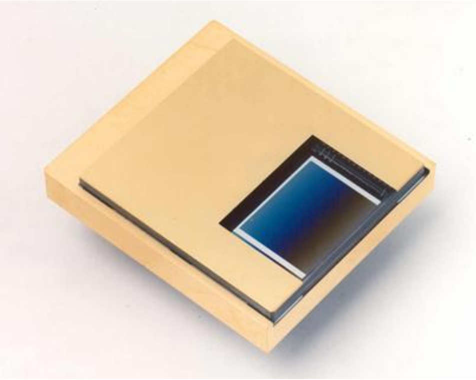
The general trend with this devices is for larger pixel sizes and multiple readout ports to give higher speeds and increased peak signal (or dynamic range).

Most hyperspectral imagers still use CCDs but there is a trend towards CMOS as it allows higher frame rate and less crosstalk but at the expense of dynamic range

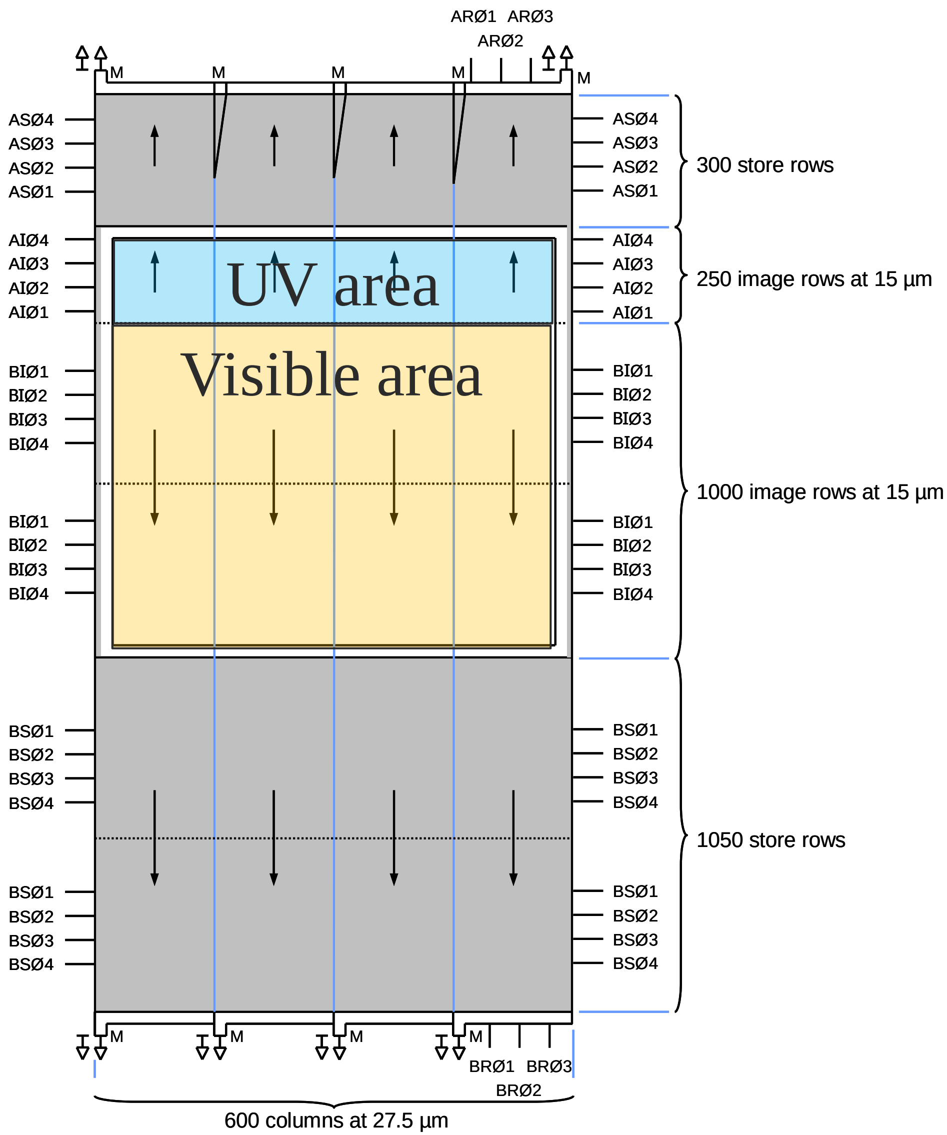
Previous Hyperspectral imaging missions have mostly been based on CCD55

- MERIS (on Envisat) Launched in 2002 and lasted 10 years until communications failed.
- OMI launched 2004 (NASA)
- CHRIS – reuse of MERIS devices launched in 2001
- Sentinel 3: Devices delivered Launch in 2015





Sentinel 4

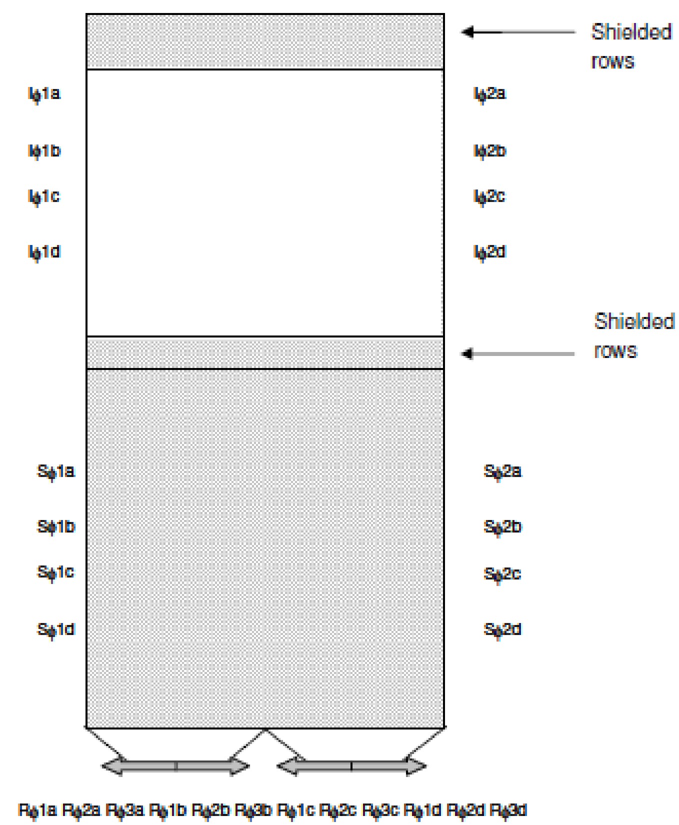


- Readout speed is 1.2MHz with a noise of approximately 20e at 1.4µv/e (using real and dummy outputs for common mode noise suppression)
- Frame transfer frequency 400kHz
- Peak Signal 1.4Me
- 97dB dynamic range

TropOMI – Sentinel 5 precursor

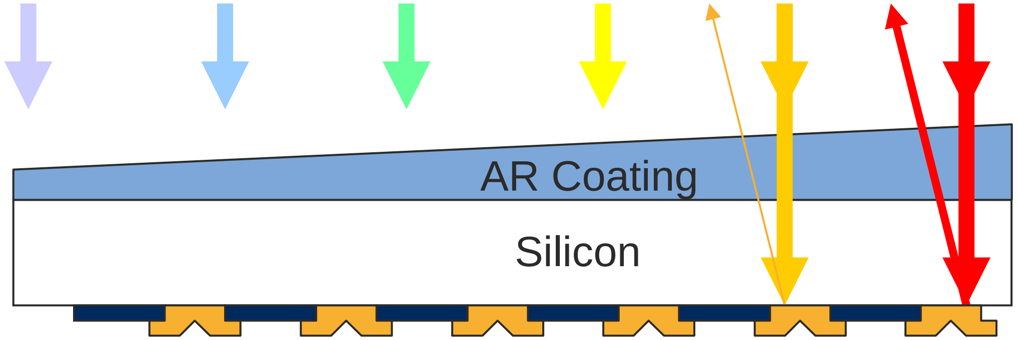
- TropOMI – Tropsheric Ozone Monitoring Instrument
- Aim to bridge the gap between Envisat / Aura and Sentinel 5 (2020)

- UV, VIS and NIR imagers from e2v
- CCD275
- 1024 x 1024 image area with 26 μm square pixels
- 2 phase image and store pixels with metalisation for fast line transfer
- 0.75μs per line
- 5MHz pixel frequency



CCD Design for hyperspectral imaging
Wedge coating

- e2v have a unique capability whereby optical cross-talk can be reduced by minimising reflections. This is carried out using a wedge coating that is ¼ of a wavelength thick for all spectral bands. Giving almost zero reflection from the back surface



But note that at longer wavelengths the silicon becomes transparent and so reflections are seen from the front surface.

CMOS for Earth Science

CMOS sensors are now starting to be used be ESA for some Atmospheric Imaging applications

- Sentinel 2 multi-linear CMOS delivered ~3 years ago
- MTG – sensor currently in characterization
- MetImage design study in progress

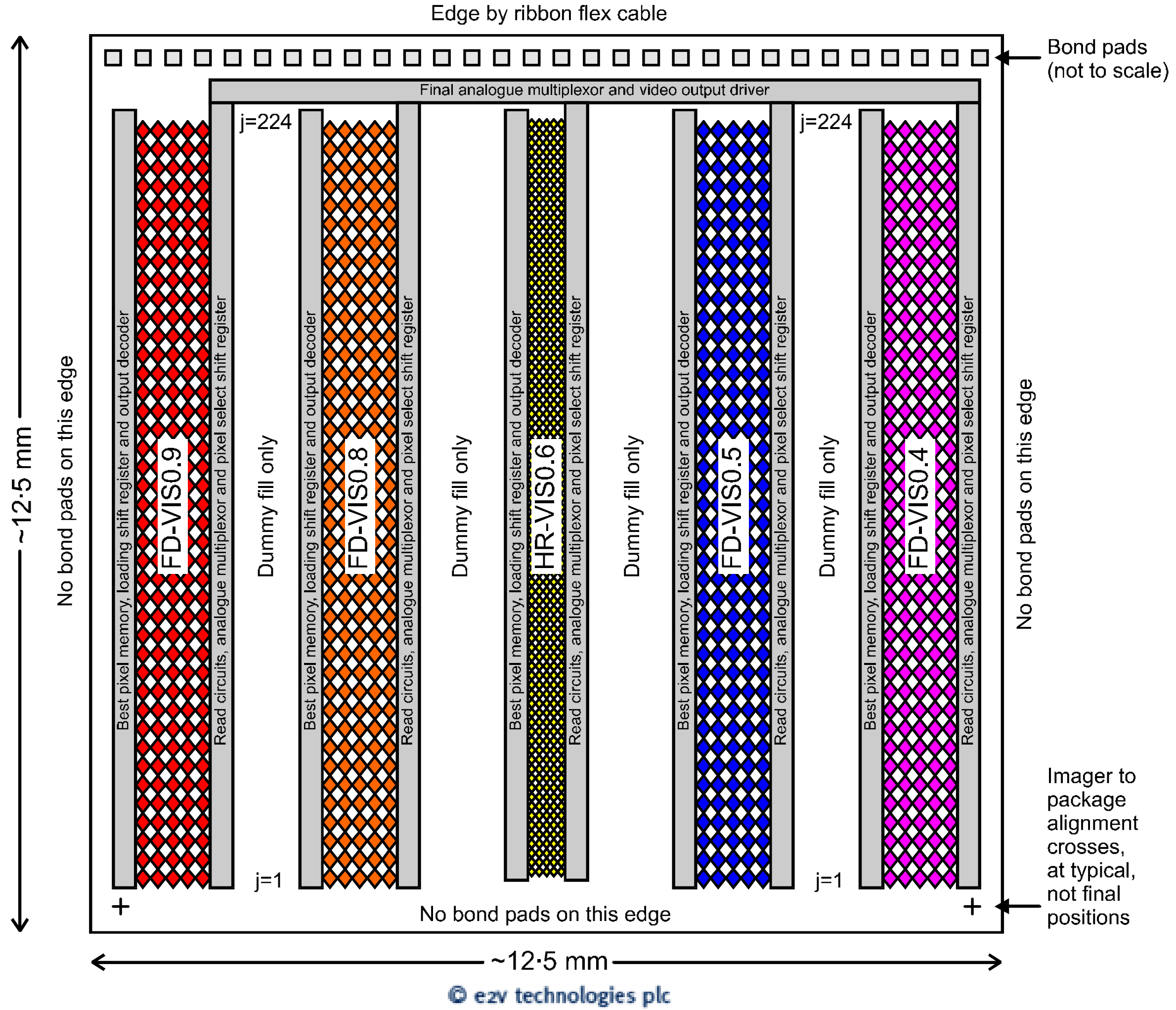
These sensor have extremely large pixels but running at very high pixel rates. MTG could have been CCD but the requirement was that the output was similar to the IR sensor

MetImage would be difficult with CCDs because of the output rate

In addition Ukube is flying a commercial CMOS

MTG FCI sensor

- The format of the sensor is shown below with 5 channels of rhombus shaped pixels operating at different wavelengths



Conclusions

- CCDs still very dominate these applications however the trend to CMOS is starting to accelerate
- CMOS sensors will also get much more complex with more integraed on chip