Evolution of Earth Observation With TDI Sensors

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Earth Observation Programmes have application in a number of fields, including:

- Weather
- Climate Change
- Security/Defence
- Mapping
- Disaster monitoring
Earth Observation

System and Sensor Requirements

- Cost
  - Reduced Weight + Increased Integration.
  - Constellations → Greater Revisit Time
  - LEO → Reduced Focal Length

- Spatial Resolution
  - Small Pixels → High GSD
  - High Data Rates → High Swath Widths

- Spectral Resolution
  - Well Defined Channels
  - Optimised Modulation Transfer Function (MTF)
  - Optimised Quantum Efficiency (QE)
  - Strong Out-of-band Rejection

- Radiation Hardness
  - Small Interaction Cross Sections
  - Shielding
  - Optimised Operational Modes
Time Delay and Integration (TDI) sensors combine integration with charge transfer such that integration occurs as charge is being transferred.

- Charge transfer speed is synchronised with the relative speed between satellite and object of interest.

- Repeated exposure of a scene from pixel to pixel effectively increases optical gain.

- Since charge is summed in the transfer process, SNR improves with number of transfers.

- Integration times on the scale of sensor readout rates make for improved resolution of moving targets compared with staring mode operation.
**Sensor Technology**

**TDI CCDs**

- Charge Coupled Devices inherently support TDI mode of operation through their characteristic charge transfer process.

- In Low Earth Orbit (LEO), the relative motion between satellite and target is extremely fast. TDI becomes crucial to maintain resolution over staring mode.

- E.g. Pleiades (e2v) and GeoEye (ITT), both of which boast ~0.3m GSD.

  ✓ Inherent Charge Transfer Capability
  ✓ Low Noise

- Speed Limited to read out rate
- Typically Larger Pixels than CMOS
- Off Chip Video Chain and Clock Generation Electronics
- High Power Consumption

- The Above contribute to High Cost
## VHR Satellite Comparison

<table>
<thead>
<tr>
<th></th>
<th>KompSAT-3A</th>
<th>Pleiades-1A/B</th>
<th>GEOEye-1</th>
<th>WorldView-1</th>
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<tbody>
<tr>
<td><strong>Orbit Height</strong></td>
<td>km</td>
<td></td>
<td></td>
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<tr>
<td>km</td>
<td>528</td>
<td>695</td>
<td>681</td>
<td>496</td>
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<tr>
<td><strong>Focal Length</strong></td>
<td>m</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>m</td>
<td>9</td>
<td>13</td>
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<td>9</td>
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<tr>
<td><strong>F#</strong></td>
<td></td>
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<tr>
<td>F#</td>
<td>10.75</td>
<td>19.85</td>
<td>12.09</td>
<td>14.67</td>
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<tr>
<td><strong>Pixel Pitch</strong></td>
<td>um</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>um</td>
<td>9</td>
<td>13</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td><strong>Imager Mass</strong></td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg</td>
<td>300</td>
<td>200</td>
<td>450</td>
<td>400</td>
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<tr>
<td><strong>Satellite Mass</strong></td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg</td>
<td>1100</td>
<td>1015</td>
<td>1955</td>
<td>2500</td>
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<tr>
<td><strong>GSD</strong></td>
<td>m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>0.54</td>
<td>0.70</td>
<td>0.41</td>
<td>0.45</td>
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<tr>
<td><strong>GRD</strong></td>
<td>m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>0.54</td>
<td>0.85</td>
<td>0.36</td>
<td>0.68</td>
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<tr>
<td><strong>Mission Cost</strong></td>
<td>$250M</td>
<td>$425M</td>
<td>$450M</td>
<td>$500M</td>
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</tbody>
</table>
Sensor Technology

TDI CMOS

- Minimum possible pixel size capability in CMOS is significantly smaller than for CCDs:
  - Allows for improved resolution for the same sized telescope → Performance Driver:
  - Or, a smaller sized telescope for the same resolution → Cost Driver

- CMOS allows for much higher data rates:
  - Each pixel has its own readout → massively parallel read-out compared with CCD
  - Approx. 0.15Gbit/s for CCD compared with 60Gbit/s for TDI CMOS
  - Permits higher swath widths without compromising on satellite speed → Higher resolution

- On chip functionality – Video chain and bias control.
  - Lower power consumption
  - Lower voltage requirements reducing the need for high capacity power supplies → reduced mass

But charge transfer is not inherent to CMOS devices as it is for CCDs.
Sensor Technology

Optimising TDI CMOS

- One option used is to sum in the digital domain of a staring image (Digital TDI)
- Using traditional CMOS architecture, improvements still to be made around noise, power consumption, memory requirements and MTF.

- Combining the benefits of CCD and CMOS is a CCD-on-CMOS approach (charge domain CMOS TDI)

- Noiseless charge transfer across CCD-like pixel structure produced on a CMOS process
  - Reduced power consumption
  - Increased radiation hardness
  - Very high data rates
  - High spatial resolution
  - On-Chip Functionality
## Teledyne Multispectral qTDI CMOS

IC-47 (FSI) and IC-49 (BSI)

<table>
<thead>
<tr>
<th>PAN Channels</th>
<th>2 (half pixel offset)</th>
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<tbody>
<tr>
<td>MS Channels</td>
<td>4</td>
</tr>
<tr>
<td>Pixel pitch</td>
<td>7µm PAN, 28µm MS</td>
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<tr>
<td>Number of pixels</td>
<td>PAN: 12k columns MS: 3k columns</td>
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<tr>
<td>GSD at max line rate (cm)</td>
<td>11</td>
</tr>
<tr>
<td>Swath width at line rate ~10KHz (km)</td>
<td>4.2</td>
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</tbody>
</table>

### Diagram

- **Clock Drivers**
- **Timing**
- **SPI**
- **Column Data Path**
  - (Col Loads, S/H, ADC, GrayCounters)
- **PLL**
- **DATA FORMATTER+TIMING**
  - SERDES

### Table

<table>
<thead>
<tr>
<th>Channel</th>
<th>Dimensions</th>
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<tbody>
<tr>
<td>P1 (PAN1)</td>
<td>12k x 128 (7µmx7µm), half pixel offset from P2</td>
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<tr>
<td>P2 (PAN2)</td>
<td>12k x 128 (7µmx7µm)</td>
</tr>
<tr>
<td>B4 (MS4)</td>
<td>3k x 32 (28µmx28µm)</td>
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<tr>
<td>B3 (MS3)</td>
<td>3k x 32 (28µmx28µm)</td>
</tr>
<tr>
<td>B2 (MS2)</td>
<td>3k x 32 (28µmx28µm)</td>
</tr>
<tr>
<td>B1 (MS1)</td>
<td>3k x 32 (28µmx28µm)</td>
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</tbody>
</table>

### Graph

- **IC47**
- **GSD (Super Res)**
- **Swath Width**
### Teledyne Multispectral qTDI CMOS

**CIS125 – In Development**

**Clock drivers**
- PAN1 64&32
- PAN2 64&32
- PAN3 64&32
- PAN4 64&32
- MS1 32&16
- MS2 32&16
- MS3 32&16
- MS4 32&16
- MS5 32&16
- MS6 32&16

**Aux Circuits**
- ADCs, 1 per column
- Memory, Readout, Digital section, Segment aux circuits
- Pad array

**Pan Channels**
- 4

**MS Channels**
- 6

**Pixel pitch µm**
- 5µm PAN, 10µm MS

**Number of pixels**
- PAN: 16k columns
- MS: 8k columns

**GSD at max line rate (cm)**
- 7

**Swath width at line rate ~10KHz (km)**
- 11

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[1] Customisation required to use 2 x PAN only

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![Graph showing GSD and Swath Width vs Line Rate](image_url)
# CIS125 Roadmap

<table>
<thead>
<tr>
<th>Year</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
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<tbody>
<tr>
<td></td>
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<td>CIS125 (32k) Development</td>
<td>2D Stitched TDI CMOS Development</td>
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<td>CIS125 Demo Kit Dev</td>
<td>Filter Development</td>
<td>Potential Focal Plane Development</td>
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<td>CIS125 (16k) Flight model Processing</td>
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<td>CIS125 (16k) Design, Fab, Test and Validation</td>
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<td>CIS123 Pixel Test Vehicle</td>
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<td>TRL:</td>
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<td></td>
<td>7</td>
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</table>

**On Roadmap**
- Functional CIS125
- Characterisation
- CIS125 Test inc. flight electronics
- Radiation Testing

**Potential Roadmap**
Thank you