pnCCD
First Test Results

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Talk Overview

- Background
- Setup
- Dark Measurement Results
  - Bias stability
  - Dark Current
  - Bright Defects
- Light Measurements
  - Photon Transfer Curve
  - QE
  - PRNU
  - Cosmetics
  - PSF
- Conclusions

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Contract between ESO and MPE/HLL (pnSensor) for:

- Three Test Runs
- Delivery of engineering and science device

Report on first Test Run.

MPE/HLL is a common research facility of the Max-Planck-Institut für Physik in München and the Max-Planck-Institut für extraterrestrische Physik in Garching

Produce pnCCDs for particle physics and X-ray astronomy

- Large pixel size 36-300um
- Thick 300-500um => >80% QE over 450-950nm
- Low ron of 3e
- Fast read out 1000fps
- High speed clocking – non-overlapping aluminum clock lines

Developed 264x264 51µm square pixel size by 450µm thick pnCCD that is interesting for AO WFS for VLT and ELT.
264x264 pnCCD

- 264x264 51um pixel
- 450um thick
- Split frame transfer
- One output amplifier per column
- Total 528 amplifiers
- 1000fps
- RON < 3e
- Integrated with CAMEX
  - Gain
  - Analog DCS signal processing
  - Multiplexing of 132 channel to 1 output

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Provides

- Load for CCD output amplifier
- Gain stages
- Analog DCS that average over several samples
- Multiplexer 132-column amplifiers to 1 output
Reference Pixels

4 Reference Pixels

Pixel closest to image not shielded sufficiently

Top pixel affected by charge leaking from bulk

- Purpose to subtract column to column variations
- Out of four only two are usable
Prescan pixels made by light mask

Image Area

Image Area

Overscan

Ramp on bias image during first few columns

Hot reference pixel [3, 100] causes column fault

Artifact on center two overscan columns

Plot of average of 20 lines

Bias before overscan subtraction

Hot reference pixel [3, 100]
DARK Measurement Results
10 biases taken every 10 minutes for several hours.

- Good long term stability
- Poor short term stability – up to 200ADU (20e) between successive images.
- Can be improved by overscan subtraction but cause should be investigated.
Dark Images

Reference Pixel/Overscan/Bias subtracted

10ms 20ms 50ms

100ms 200ms 500ms

1s 2s

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Darks are dominated by drift in the image area at different exposure times thus dark current is difficult to calculate, but for > 50fps, dark current is very low < 1e/pixel.

### Dark Current

<table>
<thead>
<tr>
<th>Amplifier</th>
<th>Frame Rate (Hz)</th>
<th>Dark Current e-/pix/sec</th>
<th>Dark Level e-</th>
<th>Bias Level e-</th>
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<td>100</td>
<td>-4.3287</td>
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<td>-23.42</td>
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### Bright Defects

<table>
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<tr>
<th>Frame Rate (Hz)</th>
<th>Hot Pixels &gt; 20e</th>
<th>Hot Pixels &gt; 10e</th>
<th>Hot Pixels &gt; 5e</th>
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<td>11</td>
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<td>23</td>
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<td>103</td>
<td>90</td>
<td>110</td>
<td>478</td>
</tr>
</tbody>
</table>

- Frame rate > 50Hz, no bright defect.
- Hot pixels scale with integration time as expected.

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Light Measurement Results
Photon Transfer Curve

- Poor linearity < 200e and >700e
DC Level Varies with Illumination

- > 700e analog signal chain (CCD output amplifier) saturating
- < 200e the image DC offset level varies with signal and the need to correct

Prescan pixels made by light mask

Overscan Offset level

Mean Signal [ADU]

Time [s]

Overscan Offset level changes

Image Area

Image Area

Overscan

Offset level changes
Care with use of Overscan

Overscan

- Plot of first column of overscan
- Plot of middle column of overscan
- Plot of last column of overscan
PTC Overscan Subtracted

**Photon Transfer Curve pnCCD**

- Median Signal [ADU]
- Variance

**Linearity Curve pnCCD**

- Mean Signal [ADU]
- Time [s]

**Calculated Gain pnCCD**

- Gain [Signal/Variance] [e/ADU]

**Signal Non-linearity pnCCD**

- % Deviation of Linearity

- Linearity improved

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Good Gain Uniformity

- Could do analysis without worrying about which amplifier pixel read from.

Photon Transfer Curve

Calculated Gain

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Lowering Gain, Full Well of 3200e possible

PTC 1/4 Gain 2nd Amplifier

PTC 1/4 Gain 1st Amplifier

PTC 1/8 Gain 1st Amplifier

Calculated Gain 1/4 Gain 2nd Amplifier

Calculated Gain 1/4 Gain 1st Amplifier

Calculated Gain 1/8 Gain 1st Amplifier

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Spatial Autocorrelation Analysis

- **Bias Image**: Central pixel off scale at 31%
  - Correlation between pixels in %
  - Bias image shows high correlation (5-10%) between pixels in a column due to the subtraction of the reference pixels.
  - This is less noticeable at higher illumination.

- **Flat ~ 400e**: Central pixel off scale at 85%
  - Correlation between pixels in %

- **% of Total Cross-Coupling between pixels**
  - Median Signal [ADU]
  - Saturation
  - Bias image shows high correlation (5-10%) between pixels in a column due to the subtraction of the reference pixels.
  - This is less noticeable at higher illumination.
QE Excellent

- Excellent QE into the “red”.
- Accuracy of results depends on knowing gain and subtracting offset.
PRNU Good; little structure or fringing

Probably due to dark features - long exposure times

Not fringing but dome-ing of image

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- No dark (<50% sensitivity) pixels.
PSF is Excellent

- Requirements ~ < 0.8 pixel
- Pixels size could be reduced to a much smaller size and still meet requirements
Conclusion

- pnCCD has
  - Good long term bias stability,
  - Low dark current (<1e) and no hot pixels for > 50fps and -45DegC,
  - Good gain uniformity between amplifiers and CAMEX,
  - Good PRNU (< 2% peak-to-peak) - little structure or fringing,
  - No dark (< 50% of surrounding) pixels,
  - Excellent red QE > 90% over 600-900nm and > 80% 580-980nm,
  - Excellent PSF of < 0.5pixel FWHM,
  - Low read noise 2-3e at 300fps.
  - Dynamic range of 3200e achievable by reducing CAMEX gain.
  - Spatial Autocorrelation Analysis showed correlation due to reference pixel subtraction and little else up to saturation level.
Challenges

- Poor short term bias stability; bias level can vary $> 20\text{e}$ from image to image. Possible to correct by overscan subtraction.

- Image offset level varies with illumination
  - Problem of accurately determining the offset and correcting for it.
  - For SH WFS maybe ok, need to be verified.
  - For Pyramid (ELT XAO) WFS where most pixels are illuminated could be problem.

- Optical design would have to take into account the larger central pixels (where the split occurs).

- Cause of artifacts in overscan need further investigation.
Suggestions for Improvement/ Further Testing

- Increase reference pixels from 4 to 11. Only need 240 out of 264 rows.
- Test different illumination patterns (e.g. illuminate only a portion of the CCD) to better understand how the offset varies with the level and type (full/partial/spots) of illumination.
- Preclock and/or mask columns to obtain better estimation of prescan offset level. As only need 240 pixels, 11 columns could be masked and used for determining offset.
- Investigate more complicated offset correction techniques; e.g. fit curve between prescan and overscan to obtain better offset estimation of intervening pixels.