OPTICON JRA2
Fast Optical Detector for AO
Gent - April 2004

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JRA2 Coordinator
LAOG, France
Talk Overview

- Scientific considerations
  - Brief Review of Available Technologies (PN Sensors and L3CCDs/EMCCDs)
  - AO simulations
  - Detector Procurement Strategies

- JRA2 organisation
  - Work packages description
  - Timelines, deliverables...

- Conclusion
Scientific considerations
Goal of the JRA2

- New JRA2 title: "Fast Optical Detectors for AO"
- Goal: define, fabricate and fully characterize the best possible detector working at visible wavelengths for Adaptive Optics (AO) wavefront sensors (first priority).
- For 10m. class telescopes, ELT’s taken into account: 256x256 pixels detector appropriate.
- Closely linked to JRA1: Adaptive Optics
- Closely linked to JRA3: fast detectors for all applications except AO (see JRA3’s presentation by Stefan Wagner)
Brief Review of Available Technologies
Detector Availability

- Development: time frame of 18 months to 2 years.
  - Restricts to conventional CCD already under development
- Either:
  - “Many channels” solution
  - “Minimal channels” solution
Many Channels Solution

- Increase number of channels to decrease required readout speed of output amplifier.
- Use ASIC to multiplex channels down to 8 or 16 to reduce back-end complexity.
- Existing detector: MPE/HLL - Max-Planck-Institut für extraterrestrische Physik Semiconductor Laboratory
Use special techniques as electron multiplication (EMCCD = Electron Multiplying CCD) to reduce output amplifier read noise at very high readout rates (e.g. L3-Vision of E2V or IMPACTRON of TI).

Require high speed, high voltage clock drives and high speed signal processing (33Mpix/s for 2 kframes/s).
EMCCDs theory
Electron Multiplying Charge Coupled Device

- EMCCD structure

Gain G \rightarrow "zero" readnoise
EMCCDs theory

Generalized SNR formula for EMCCDs:

\[
SNR = \frac{S}{\sqrt{F^2(S + S_{dark} + S_{spurious}) + \frac{\sigma_{readout}^2}{G^2}}}
\]

- \( G \) = multiplication gain (tunable with a voltage level)
- \( F \) = excess noise factor = \( \sqrt{2} \)
- If \( G \) is sufficient (\( G > 100 \)), readout noise contribution is \( \approx 0 \)
- Readout noise decreases with \( G^2 \)
Noise comparison between CCD and L3CCD

- Hypothesis: we assume that the multiplication gain of the L3CCD is high enough to provide a readout noise $\sigma_R$ close to 0

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<thead>
<tr>
<th></th>
<th>CCD</th>
<th>L3CCD</th>
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<tbody>
<tr>
<td>Number of e- / pixel</td>
<td>$n$</td>
<td>$n$</td>
</tr>
<tr>
<td>Readout noise (RMS)</td>
<td>$\sigma_R$</td>
<td>$\sim 0$</td>
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<tr>
<td>Total noise (e-)</td>
<td>$\sqrt{n + \sigma_R^2}$</td>
<td>$\sqrt{2} \sqrt{n}$</td>
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Excess Noise Factor F
S/N computations

Comparison of S/N of L3-Vision CCD when output amplifier is run in unity versus multiplication gain mode for different amplifier read noises

[Graph showing the comparison of Signal/Noise (S/N) for different conditions, including Photon Shot Noise S/N, Multiplication Gain Mode S/N, and Unity Gain Read Noise set to various values.]
EMCCDs theory

Possible working modes for an EMCCD:
- No amplification (\(G=1\))
  - the CCD is a normal CCD with high read noise (no interest)
- Low to medium amplification (\(1<G<1000\))
  - The CCD has no readout noise but has excess noise
- High amplification (\(G>1000\))
  - The CCD is used in photon counting mode.
    - No readout noise, no excess noise
    - possible non linearity at high fluxes
- It’s possible to switch between modes at any time!

Used in AO applications
E2V L3-Vision technology (EMCCD)

- E2V is pushing L3-Vision technology and reluctant to look at alternatives.
- E2V is commercial company that will deliver detectors that satisfy requirements.
- E2V has a relatively good reputation on delivering detectors on time.
MPE/HLL PN-Sensors

- Common research facility of Max-Planck-Institut für Physik in Munich.
- Provide commercially not available silicon detectors for particle physics and X-ray astronomy mainly for space applications.
- Work by best effort.
- Specialize in
  - Fully depleted PN-CCDs as opposed to more common MOS scientific CCD.
  - Large pixel size: 36 µm to 300 µm
  - Thick device with high red Quantum Efficiency (90% from 450nm to 1000nm) and very low (no) fringing.
  - Fast readout + low noise by having one amplifier per column.
- Success - detectors for XMM-Newton X-ray Telescope
- Advanced talk of collaboration to develop detector for ESO
- Link with the JRA3
Current MPE Detector

- 256x256.
- 51 $\mu m^2$ pixel.
- 500 $\mu m$ thick.
- Frame transfer PN-CCD device.
- 256 outputs.
- 2 ROIC (128:1 output MUX).
- 500 kframes/sec.
MPE/ESO Collaboration Detector

- 256x256, 51\(\mu\)m\(^2\) pixel, 450\(\mu\)m thick, split frame transfer PN-CCD device.
- 512 outputs, uses four ROICs for goal frame rate of 1500 frames/sec at 4e RON and 1000 frames/sec at 3e.
- This development is apart from the JRA2 but has close links with the JRA2 activity.

Diagram:
- 128:2-3 Mux.
- 2-3 Outputs
- 9 Mp/s
- ROIC
- 256 Outputs
- 128
- 128
- 256
- 128:2-3 Mux.
- 2-3 Outputs
- 9 Mp/s
- ROIC
- 256 Outputs
- 128
- 128
- 256
- 128:2-3 Mux.
AO simulations
Comparison of Quantum Efficiency (QE) for PNCCD/L3CCD

- MPE/HLL much better response expected in red (to be confirmed, optical measurements not done)
Impact of QE curve: assumptions

- AO range = 0.45 - 0.95 microns
- QE spectral response: 2 test cases «blue» and «red»
- Independent study of spectral response and RON cases (no correlation?)
- Various target spectral types
Quantum Efficiency effects

![Quantum Efficiency Graph]

- QE BLUE
- QE RED
- Dichroic

Parameter: lamda

Date: 1-2 April 2004
Magnitude gain of "red" vs. "blue"
Effect of Noise on WFS measurements

- **Shack-Hartmann WFS**:
  - Wavefront estimation from sub-aperture PSFs
  - Noise effects on wavefront estimation:
    - Photon noise: \( \sigma_{\text{phot}}^2 = \frac{\alpha}{n_{\text{ph}}} \) ➔ Optimisation of QE
    - Detector noise: \( \sigma_{\text{detec}}^2 = \beta \left( \frac{\text{ron}}{n_{\text{ph}}} \right)^2 \) ➔ Reduction of RON

- **Pyramid WFS**
  - Wavefront estimation from 4 quadrant intensity subtractions
  - Noise effects: same evolution than SH-WFS
Strehl Ratio: Comparison CCD / L3CCD

Impact on XAO performances

For XAO main goals: CCD > L3CCD only if RON < 2e-, and on a narrow magnitude range

For wider use: L3CCD better or not far behind

- Seeing = 0.65”, wind speed = 15 m/s
- 40x40 sub-apertures - 1 kHz frame rate

1-2 April 2004

OPTICON Board meeting - JRA2 - Gent
Detector Procurement Strategy
Detector Procurement Strategy

- Our Risk Level should remain **Low**, we need to deliver results.
- **Best Effort Detectors**
  - Example: MPE/HLL and MIT/LL
  - Only interested in producing devices not available from commercial manufacturer
  - Cannot respond directly to Tender Documents
  - Potential to obtain a more unique device with better performance

- **Commercial Company**
  - Example: E2V
  - Deliver devices that meet requirements or do not get paid
  - Higher probability in obtaining a device, however device will be more conservative

- ESO already negotiating contract with best effort manufacturer MPE/HLL
- Need to compose and distribute Tender Document
- Should include minimum specifications + goals specifications
Management and organisation
JRA-2 organisation

European Community

Opticon board

Detector specifications
N. Hubin, M. Downing (ESO)

Cooling system
E. Stadler (LAOG)

JRA-2 Coordinator
P. Feautrier (LAOG)

Science group
Markus Kasper (ESO)
N. Hubin (ESO)
J.L Beuzit (LAOG)
D. Mouillet (OMP)
Thierry Fusco (Onera)
Mark Downing (ESO)

Industrial partner
Detector subcontract
LAOG

AO WFS
LAOG

Controllers
JL Gach (OAMP), + ESO and IAC

CCD characterization
JJ Diaz (IAC), + ESO and OAMP
The JRA2 mailing list:
opticong_ccd@listes.obs.ujf-grenoble.fr

- Saved archives
- Private list
- Discussions, information...

1-2 April 2004

OPTICON Board meeting - JRA2 - Gent
The JRA2 web site:
http://www-laog.obs.ujf-grenoble.fr/JRA2/

• Presentations, minutes.
• List of participants.
• Documents...
• Private site, public section still to develop.
• Common templates with Opticon FP6 website to be considered.

The OPTICON JRA-2 Website
Fast Optical Detectors for Adaptive Optics

OPTICON is an European project funded by the European commission as part of its Sixth Framework Programme FP6.

This Joint Research Activity is the Joint Research Activity 2 (JRA-2) of OPTICON, the Optical Infrared Coordination Network.

The JRA-2 is dedicated to fast optical detectors developments and characterization for the second generation of Adaptive Optics Systems.

What is OPTICON in the FP6? See presentation from John Davies, project scientist of OPTICON. Be careful, the list of the JRA's has changed since this presentation.

Documents
• Description of Work: for the Opticon Network: describes all the JRA's and Network activities. Workpackages, timetables and deliverables are described, including the JRA-2 activities (see Table of Content), update of the 2 March 2004.
• Annex A3.1: costs (direct costs, subcontracts, indirect costs, total eligible costs, requested EC contribution) for the JRA-2 only.

Presentations and minutes of meetings
• Presentation of the JRA-2 to the Opticon board in Chania: this presentation explains how we took the decision to give up with the IR applications and how we started the JRA-2. Minutes of the meeting here.
• First answer of E2V to the high level requirements after the Meeting of the 25/09/2003 videoconference of the 27/10/2003.
The Work Packages
WP1 : management

- Kick-off: 8 March 2004
- One progress meeting every 9 Months
- Coordinate the JRA activities
- prepare the key specifications for the other WPs
- monitor the WPs
- organize study and design reviews
- prepare the regular reports and detailed work plans for the OPTICON management
- Web-site responsibility
WP2: science group, detector specification, design and fabrication

- Detector Specification Leaders: Norbert Hubin and Mark Downing (ESO).
- Will be in close loop with the science group.
- Inputs:
  - Simulation results from Science Group which looks at two or three test cases to determine requirements.
- Description:
  - In close collaboration with the Science Group, compose the detector specifications and Call for Tender document. Monitor progress of detector development.
- Deliverables:
  - Detector specification document, Call for Tender document, Tender Results and detector progress reports, and Detectors!
WP2: science group activity

- Inputs:
  - Requirements from up-coming instruments such as VLT-PF and MUSE.

- Description:
  - Determine detector specifications by doing simulations and looking at high level requirements of up coming VLT and other instruments.

- Deliverables:
  - Simulation results and detector specifications.
WP3: Controller

- **OAMP (Marseille) is the leader**
- **Inputs:**
  - Detector type, detector specifications and operating modes of the detector.
- **Description:**
  - Design, manufacture and test a detector controller to characterize and optimize the performance of the chosen detector. Controller should not limit the performance of the detector.
- **Deliverables:**
  - An operating controller that has sufficient performance to characterize the detector and to be transportable to run stand-alone at IAC.
  - Should take into account the operation on existing facilities.
WP4: Cooling system

- LAOG is the leader
- Inputs: Detector package and detector operating requirements.
- Description:
  - Design and manufacture a test cryogenic system to safely mount, cryogenically cool and temperature stabilize the detector.
- Deliverables:
  - Cryogenic system including detector head together with cryostat wiring.
Detector Packaging

- Application requires compact, low weight solution
- Peltier cooling produces most compact system with minimal support equipment.
- E2V
  - have experience and can produce Peltier cooled device but low JRA2 budget may require internal solution.
  - L3vision CCD have low enough dark current to enable Peltier cooling
- MPE/HLL
  - no experience with Peltier cooled package
  - we need to develop package
  - First, need to know whether dark current is low enough to allow Peltier cooling ~ 12 months for results
Work Package 5: detector test

- IAC is the WP responsible
- MPE contract is outside the JRA but the JRA is interested in the results of this contract.
- Inputs:
  - Detector type, detector specifications, and detector controller.
- Description:
  - Characterize and if possible optimize the performances of the detector. Compose a detector test plan. Compose a list of available tools and tools that are required.
- Deliverables:
  - Detector Test Plan, tools required, Detector Test Report.
Detector Test: Parameters To Measure

- **Critical Parameters**
  - Read noise (RON) vs read out speed (bias for RON and flats for gain)
  - Cosmetics (bias, darks and uniform flats for bright and dark pixels)
    (low level flats for pocket pumping)

- **Less critical parameters**
  - QE (uniform flats at different wavelengths and calibrated photodiode)
  - Dark Current (darks)
  - PSF (point source)
  - Smearing (test pattern)
  - Charge Transfer Efficiency
  - Crosstalk between channels (test pattern)
  - Linearity (flats)
  - Full Well (flats)
  - Fringing (flats with narrow optical bandwidth)
  - Detector surface flatness (surface measurement device)
Work Package 5: AO tests

- best effort activity
- closely linked to the JRA1 and the AO test bench facility
- Probably difficult to finish this activity before the end of the FP6
- Possibility to use the measured performances of the fabricated detector inside AO simulations.
Timelines, Milestones, Deliverables
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<tr>
<td>1</td>
<td>Start JRA2</td>
<td>31 Jan 2004</td>
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<tr>
<td>2</td>
<td>WP4 management</td>
<td>2 Apr 2004</td>
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<td>3</td>
<td>WP 2: Concept design</td>
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<td>4</td>
<td>M1: Science group discussions</td>
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<td>5</td>
<td>Concept discussion</td>
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<td>6</td>
<td>M2: Concept design review</td>
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<td>7</td>
<td>Detector Manufacturing</td>
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<td>8</td>
<td>Detailed design</td>
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<td>10</td>
<td>Demonstration devices manufacturing</td>
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<td>11</td>
<td>M4: Demonstration device deliverying</td>
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<td>12</td>
<td>Test facilities</td>
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<td>M5: Prototype devices testing</td>
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<td>Baseline devices testing</td>
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<td>M6: Detector deliverying and acceptance</td>
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<td>WP 3: Controller manufacturing</td>
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<td>M1: Controller conceptual design</td>
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<td>19</td>
<td>M2: Controller design review</td>
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<td>Controller manufacturing</td>
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<td>21</td>
<td>Controller test</td>
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<td>WP 4: Cryogeny</td>
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<td>25</td>
<td>Cryogeny manufacturing</td>
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<td>27</td>
<td>WP 5: LSCCD for AO evaluation</td>
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<td>28</td>
<td>M1: Complete detector test in laboratory</td>
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<td>M2: AO wavefront sensor manufacturing</td>
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<td>AO QWPS tests on sky simulations</td>
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<td>33</td>
<td>D1 test report deliverying of the AO results</td>
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Conclusions

- Interesting and challenging development
- Should be very useful for the astronomical community in the years to come where low RON + fast detectors are needed.
- Funding may be an issue: real detector cost is uncertain, trade-offs between specifications and available budget might be necessary...
Many Thanks For Listening