ZERO NOISE WAVEFRONT SENSOR DEVELOPMENT WITHIN THE OPTICON EUROPEAN NETWORK

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Abstract: This activity, funded by ESO and the European Commission through the Opticon Network will attempt to define, fabricate and fully characterize the best possible detector working at visible wavelengths which is suitable for wavefront sensors in Adaptive Optics (AO) systems. The detector will be a split frame transfer array built by e2v Technologies and called CCD220. The frame rate will be very fast (up to 1.2 kHz) while the readout noise will be kept extremely low (typically below 1 e-). The goal of this paper is to justify the choice that has been made for the detector: an EMCCD with 240x240 pixels and 8 outputs that will provide sub-electron readout noise at 1-1.2 kHz frame rate. This paper shows that despite the fact that EMCDDs have an excess noise factor of 1.4 due to the charge multiplication process; their virtually zero read noise should allow them to outperform the classical CCD. Such detectors do not exist yet and have to be developed. Moreover, this paper explains how the OPTICON European network is organized.

Key words: Adaptive optics, Electron Multiplying CCD, readout noise, wavefront sensor, Strehl Ratio.

1. THE NEED

The next generation of Adaptive Optics (AO) systems for 8 to 10-m class telescopes requires an increased number of degrees of freedom, which will increase the number of actuators required typically by a factor of 5 to 10 (>1k degrees of freedom).

This leads to very tight requirements on the detector. For example, a typical Shack Hartmann system with 6 pixels/sub-aperture and 40x40 sub-apertures will require a detector size of 57600 pixels (240x240). In addition, detectors with high frame rate (1-1.5 kframes/s) are mandatory. In order to reach the required limiting magnitudes, the detector must have a readout noise as low as possible (< 1e-) and a dark current adding a negligible noise at this level. Existing wavefront sensor detectors do not have the image area size, read out speed or low noise performance to meet these increased performance requirements. The need therefore to develop a new generation of detectors is clearly established.

2. DESCRIPTION AND INTEGRATION OF THIS ACTIVITY INSIDE THE OPTICON EUROPEAN NETWORK

OPTICON is a project which has been approved for funding by the European commission as part of its Sixth Framework Programme (FP6). The OPTical Infrared Coordination Network for astronomy (OPTICON) brings together all the international and national organizations which fund, operate and develop Europe's major optical and infrared astronomical infrastructures.

The OPTICON network is divided into 3 main activities:

- The Joint Research Activities (JRA) are technical developments in the field of visible and infrared instrumentation for astronomy.
- The Networking Activities are promoting scientific and technical networks (Adaptive optics, Key Technologies, Interferometry, High Time Resolution Astrophysics…).
- The Access Program enables the sharing of telescope time from medium size telescopes (4 meters and less). This Access Program allows the access of such telescopes to all the astronomers from Europe.

The JRA described here is named “JRA2: Fast Detectors for Adaptive Optics”.

3. CHOICE OF THE DETECTOR TECHNOLOGY AND FEATURES

The study presented hereafter was performed in the framework of the VLT Planet Finder concept study. The VLT Planet Finder is the next AO system for the ESO VLT. This system is mainly dedicated to the discovery of extra-solar planets and necessitates the use of high contrast AO system. A preliminary study has showed that a visible wavefront sensor with 240x240 pixels is the best compromise for the wavefront correction of this AO system.

3.1 Choice of the detector technology: classical CCD or EMCCD?

Two types of detectors were investigated: the first one, called CCD1, is a classical back-thinned CCD having a high QE optimized in the red, the second one called CCD2 is an EMCCD with an excess noise factor of 1.4. Because high-resistivity silicon is yet untried with EMCCDs, the red QE assumed for CCD2 is much poorer than that of CCD1 which has the red QE of the best known classical CCD. Moreover, CCD2 suffers from the typical excess noise factor of 1.4 due to the electron multiplication gain of EMCCDs. This effect was taken into account in the simulations for CCD2.

3.2 AO system assumptions for the simulations

- 8m diameter telescope, the ESO VLT at Paranal.
- Atmospheric conditions: 0.85 arscec of seeing, a wind speed of 12.5 m/s, i.e. a turbulence coherence time τ_0 of 3 ms.
- System assumptions: 40x40 sub-apertures Shack-Hartman wavefront sensor, 2 frames of delay, Weighted Centre of Gravity measurements (an optimized way to compute the centroid of a Shack-Hartman spot[1]), optimal modal integrator, wavefront sensor average wavelength: 0.65 μm, imaging wavelength of the science camera: 1.65 μm.

Different types of guide stars were considered: A0, G0, M0 and M5. The spectral types of these guide stars are different; A0 emits more in the blue and M5 more in the red.

3.3 Effect of the detector technology on a XAO system

The Figure 2 and 3 show the Strehl Ratio (SR) evolution as a function of the visible magnitude of the guide star. The SR was optimized by varying the frame frequency for a given detector type, a given noise and a given magnitude: between 250 and 2500 Hz for CCD1, 250 and 1500 Hz for the CCD2. Results for two types of guide stars are shown, a blue type A0 and a red type M5. These figures show that for the VLT-PF instrument and the typical conditions at Paranal, the EMCCD gives always higher SR, except for visible magnitude below 8.5 with an A0 type guide star and below 10.5 with a M5 type guide star. The gain of SR for a good classical CCD (CCD1 with 3e- read noise) at low magnitude is just 1% whereas the interest of EMCCD (CCD2) is clear at high magnitudes (faint guide star). Moreover, building a classical CCD with < 3 e- of read noise at 1.5 kHz of frame rate is extremely challenging. These simulations lead to the following conclusions:

- An EMCCD (CCD1) with a read noise lower than 1e- is the best option, especially if the QE can be improved in the red by using deep depletions devices.
- A classical CCD (CCD2) may be interesting (in particular because of its very good red QE) if a readout noise lower than 2 e- at high frame rate could be achieved.

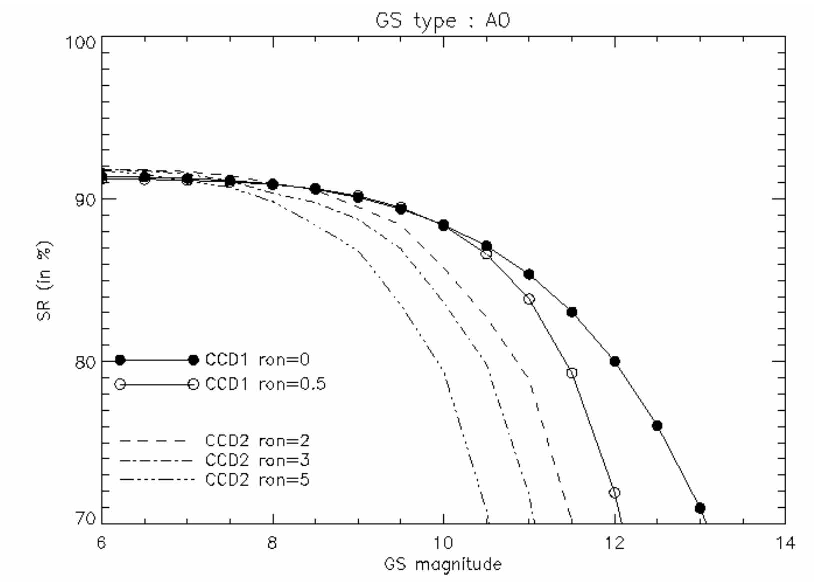

Figure 1. Strehl Ratio comparison of CDD1 (classical) and CCD2 (EMCCD) for an A0 guide star type (blue guide star);

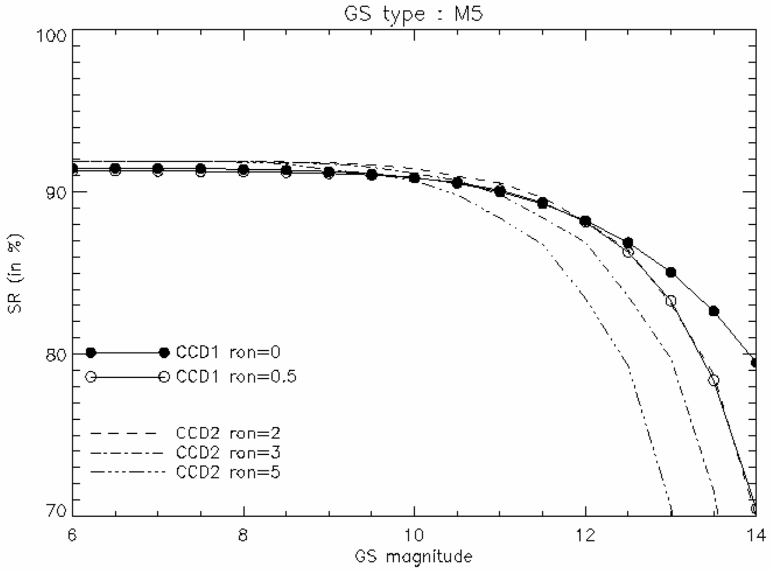

Figure 2. Strehl Ratio comparison of CDD1 (classical) and CCD2 (EMCCD) for a M5 type guide star (red guide star).

4. CONCLUSION

The results of these simulations show the strong interest in EMCCD for AO wavefront sensors despite the fact they have lower red QE (because high resistivity silicon is yet untried) and an excess noise factor due to the electron multiplication process. In August 2004, a Call for Tenders was issued for the Development and Supply of 240x240 pixels, very low noise (1e- or less), fast readout (1.2 kframes/s) CCD detectors that meet set requirements. This culminated in a contract between e2v and ESO in April 2005 to start a detector development. Full details of this detector development and trade-offs are presented in [2]. The technical challenges of the detector controller are detailed in [3]. This new detector will be used for the next generation of ESO instruments requiring AO systems, and among them the ESO VLT Planet Finder, a high contrast AO system dedicated to the research of extra-solar planets. Figure 6 illustrates a Peltier cooled package similar to the one that will be used for the CCD220.

To conclude, this study clearly shows that for an AO wavefront sensor, a low readout noise is more important than high red QE.

Table 1. AO wavefront sensor detector main characteristics

Item	Specifications
Manufacturer	e2v technologies, UK
Name of the detector	CCD220
Detector format	240 x 240 pixels, split frame transfer
Technology	EMCCD, excess noise factor 1.4
Number of outputs	8
Frame rate	25 Hz – 1.2 kHz
Read noise	< 1e- at 1.2 kHz frame rate

Figure 3. CCD65 Peltier cooling package. The AO CCD220 detector will use a similar Peltier package.

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REFERENCES

1. T. Fusco et al, "Optimisation of Shack-Hartman-based wavefront sensor for XAO system", Proc. SPIE Int. Soc. Opt. Eng. 5490, 1155 (2004).
2. M. Downing et al, "A Dedicated L3CCD for Adaptive Optics Applications", this conference.
3. J-L. Gach et al, "A dedicated controller for Adaptive Optics L3CCD developments", this conference.