Laboratory characterization of an APD-based tip-tilt corrector

S. Esposito, E. Marchetti, R. Ragazzoni, A. Baruffolo, J. Farinato, L. Fini, A. Ghedina, P. Ranfagni, and A. Riccardi

Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
CISAS, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy
Osservatorio Astronomico di Padova, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy
Università di Padova, Dipartimento di Ingegneria Elettronica, via Gradenigo, I-35122 Padova, Italy
Università di Padova, Dipartimento di Astronomia, Vicolo dell’Osservatorio 5, I-35122 Padova, Italy

ABSTRACT

The atmospheric image motion control loop for the 3.6m Telescopio Nazionale Galileo (TNG) has been tested and characterized in lab using a turbulence generator. The tip-tilt sensor is based on four Avalanche Photodiodes and the tilt corrector is a voice coil actuated flat mirror. The feedback network is implemented using a DSP-based system. We have used the same focal ratios of the beam as it will be experienced by the system at the foci of the TNG telescope. The collected data are time-series useful to perform a Fourier analysis aimed to estimate the effectiveness of the correction. These data can be compared with: theoretical and measured tilt spectra obtained at the telescope site, in order to predict the degree of correction that can be achieved by such a system; measured data on single components, like the transfer function of the tip-tilt mirror, the latency of the DSP calculation and the characterization of the APDs tip-tilt sensor unit. The collected data are also suitable to perform further simulations in order to plan which will be the more effective correction at the telescope foci under several different conditions of reference brightness and seeing parameters.

Keywords: Tip-Tilt systems, Tilt correction, Avalanche PhotoDiode (APD)

1. INTRODUCTION

We present here final results obtained during laboratory test done to characterize the tip-tilt tracking system for TNG telescope. During the system development we have pursued two different aims. First, the implementation of a fully digital control loop that allows to tailor the system characteristics to the atmospheric behaviour in order to optimize the image motion rejection obtained. This feature is important in particular when considering that in the first year of operation the TNG AO system will perform tip-tilt correction only. Second, to realize a fully self consistent image motion control loop. This choice will allow us to reconfigure easily the tilt control loop when a Laser Guide Star aided wavefront sensing scheme will be performed. The paper describe the system and briefly discuss some results of its laboratory characterization that took place after extensive tests of its various components. First we describe the sensor unit of the tilt system and the hardware and software architecture of the acquisition and control system. After we consider the laboratory setup used for the system characterization. Finally we quantify the system performances. This is done measuring the open loop transfer function and the closed loop error transfer function of the system for a given set of operating conditions.

Figure 1. tip-tilt sensor hardware
2. THE TIP–TILT SENSOR

The tip–tilt is sensed through a four–quadrant optical arrangement using four different Avalanche PhotoDiodes (APDs). This goal is accomplished by means of a prismatic arrangement able to relay each quadrant to a different APD with a spot size of the order of 100μm while the sensitive area of each APD is of the order of 200μm in size. The tip–tilt sensor hardware is reproduced in fig. 1 showing the four APDs board mounted around the prismatic optical relay. The outer faces of the prismatic arrangement are anti–reflection coated while the UV–curing glue used is a BK7 matching index. The electronic boards that take care of the Active Quenching, High Voltage delivery and other functions like the peltier driving for the cooling of the photosensitive devices are firmly held to the mechanical structure. Each APD is electrically wired to the board by means of short (less than 20mm in length) wires and are placed into position by means of a copper cold finger. The latter is mounted on an XYZ micrometric stage so that the proper alignment of the system can be conducted for each APD separately.

The cold fingers glued with a thermal conductive product to the hot side of the micro–peltier built into the APD case terminates with a black anodized cooling plate. In the neighborhood of each of these plates a small pipe remove the hot air generated. The whole APDs, electronic boards, fingers and holding mechanism are located inside a cylindrical unit approximately 300mm both in diameter and in length.

3. THE ACQUISITION AND CONTROL SYSTEM

3.1. Hardware Architecture

Figure 2 shows the overall architecture of the tip–tilt Control System. It essentially consists of two subsystems:

- **Interface/Counter board**: a custom made board which holds both the counters for APD pulses and the interface logic needed to send data to the Steering Mirror, together with the housekeeping circuitry used for real-time monitoring of the APDs operation.
- **DSP board**: a commercial board hosting a Motorola DSP 56001 processor which communicates with a supervisor computer via the VME bus and with the IC board through a dedicated I/o port.

![Diagram of the tip–tilt Control System](http://proceedings.spiedigitallibrary.org/)

**Figure 2. tip–tilt Control System Architecture**

3.2. Software Architecture

The DSP software architecture is shown in Figure 3. The software is written in DSP 56001 Macro Assembler and was developed by means of the on-board Monitor program.
The figure only shows the software components which control the loop modes; other auxiliary parts are not shown for clarity. Each loop step is fired by the DSP internal timer which generates interrupts at a constant programmable rate.

The control software essentially consists of two tasks which run concurrently:

- **Task A** continuously sends statistical data gathered during operation to the supervisor computer. It is fired by a proper signal by the running Task B when a buffer with data is ready.

- **Task B** is fired by the timer interrupt and performs the elementary step of the loop algorithm. We currently provide three different loop modes:
  
  B1 Closed loop: at each interrupt the next counts from the APD counters is read, the *tip-tilt* components are computed and filtered, and the resulting correction is applied to the steering mirror. At the same time statistics on data are computed to be sent to the Supervisor.
  
  B2 Open loop: at each interrupt the counts from the APDs are read and the statistics are computed.
  
  B3 Mirror drive: at each interrupt the mirror is fed with the next sample of a tabulated signal.

A Supervisor program (not shown in figure) can use the statistical data blocks periodically sent by the DSP to verify the loop functioning and possibly modify the loop parameters to optimize the performances of the system.

### 4. THE EXPERIMENTAL SETUP

We describe here briefly the experimental setup used to evaluate the closed loop performances of the *tip-tilt* correction system. The bench setup is showed in fig. 4 We illuminated the *tip—tilt* sensor with an F/100 beam provided by a single mode fiber coupled to an achromat relay lens. The beam is folded twice by a 10mm diameter Physik Instrumente agile tip—tilt mirror and by the ThermoTrex voice coil activated tip—tilt mirror making part of the close—loop system. We insert in the first portion of the beam a turbulence generator characterized by an experimentally verified Kolmogorov spectrum.
In this way one can introduce as a noise disturbance a sinusoidal signal at a given level of frequency and amplitude through the PI mirror, or a Kolmogorov spectrum tip-tilt disturbance.

The resulting position sensed by the APDs tip-tilt sensor is fed to a VME-based acquisition board operating at 20 kHz. In addition a dual-trace digital oscilloscope has been used to check occasionally the resulting data.

When the transfer function is to be evaluated a programmable frequency generator signal is fed both to the tip-tilt PI mirror and to the VME acquisition board. This run is compared, both in amplitude and phase to the APDs tip-tilt sensor signal both in Open- and Closed-Loop.

Because we care of the relative difference between the Open and Closed-Loop instead of the absolute values with respect to the driving sinusoidal signal we automatically rule out the effects of the intrinsic transfer function of the PI tip-tilt mirror. The last statement is, in principle, alway strictly true but, for Signal to Noise reasons, it is true, in practice, only when the amplitude transfer function of the smaller tip-tilt mirror is higher than the larger one. Moreover the measurements should be made well away from the first resonance frequency of the larger mirror.

Both the conditions have been met in our experimental measurements.

5. EXPERIMENTAL RESULTS

We report here some results obtained during the laboratory test done at Arcetri. We operate the system with an integration time of one millisecond and a number of photons per frame equal to about one hundred photons per APD per integration times. The system transfer function was compensated using a dominant pole scheme where the pole was placed at a frequency of 5 Hz. In fig. 5 we report the open loop and closed loop tip-tilt power spectral density obtained introducing in the optical path the turbulence generator. In our setup the used D/r0 ratio was about four corresponding to the situations where tip-tilt correction is most effective. * These curves show the correction behavior in the frequency range 0-250 Hz. In fig. 6 we report the ratio of these two spectra that represent the system closed loop error transfer function. In this last figure we overplot the error transfer function behavior as obtained from open loop transfer function measurement. Comparison between this two show a good agreement between calculated and measured error transfer function. The discrepancy regarding the low frequency values is probably mainly due to the different operating condition in open and closed loop mode. In fact, measurements of the open loop transfer

*Seeing measurements done at the TNG telescope site show that, considering J, H, and K bands, the D/r0 ratio for the TNG ranges between 3 and 7.
Figure 5. Measured open loop and closed loop PSD

Figure 6. System error transfer function. The smooth curve represent the error transfer function inferred from open loop measurement.
function are performed with input amplitude bigger then the perturbations amplitudes that the system has to deal with in closed loop. From the reported experimental data we can estimate an $f_{-3db} \approx 150Hz$ and a DC gain of about 100. Using the two curves showed in fig.5 it is possible to calculate the tilt attenuation factor reached by the system. This reduction factor for the one axis tilt standard deviations in open and closed loop respectively turns out to be about 14. Finally in fig.7 we report an histogram of the one-axis spot displacement in open and closed loop. This shows the substantial reduction of the image motion obtained when the system is working in closed loop.

6. CONCLUSIONS

We have reported the performances obtained during a laboratory qualification campaign of the image motion control loop to be used at the 3.6m Telescopio Nazionale Galileo. The system is based on four Avalanche PhotoDiode (APD) delivered by EG&G (Canada) and has a fully digital acquisition and time-filtering control. The obtained results show a closed loop reduction of the tilt standard deviation of a factor of 14. Moreover the control system, with no particular filtering optimization, appears to have well behaved error transfer function characterized by a $f_{-3db} \approx 150Hz$. Measured performances seem to be adequate to obtain a good correction of the turbulent induced image motion at the TNG telescope.

REFERENCES