VERY LARGE TELESCOPE

TECHNICAL REPORT
MACAO-VLTI
Electronics – Overview

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Prepared :	J. Brynnel	6-Mar-2001	.
	Name	Date	Signature
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	Name	Date	Signature
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1. INTRODUCTION

Adaptive Optics (AO) goal is to reconstruct the incoming wavefront removing the effects of atmospheric turbulence in real time. It also removes any other source of optical aberration, provided the bandwidth and dynamic range of the servo-system are sufficient. For the VLT, the effects of atmospheric turbulence may be divided in two parts with different strength, image motion (or tip-tilt) being 87% of the wavefront variance, and image blur (or high-order wavefront distortion) being 13% of the variance. Image motion is by far the largest effect to be corrected.

ESO is presently developing a new curvature AO system, called MACAO-VLTI, targeted for the four ESO VLT unit telescopes.

1.1 Purpose

This document is describing the design of the Control Electronics for MACAO at the time of Final Design Review (FDR). It is an overview document, with the following purpose:

- Giving the reader an overview of all MACAO electronics sub-systems
- Providing information on global aspects of MACAO-VLTI Electronics

1.2 Scope

For FDR, MACAO control system is described in one overview document, being this document. Further, all control system parts are described in depth in separate documents:

- Local Control Units (LCU), see [RD1]
- APD's and APD counters, see [RD2]
- Deformable mirror control, see [RD3]

This document is intended to give the reader an overview of MACAO electronics, before going on to the more detailed descriptions.

1.3 Applicable Documents

[AD1] VLT-SPE-ESO-10000-0015 VLT Electronic Design Specifications
[AD2] VLT-SPE-ESO-10000-0002 EMC and power quality specification - Part 1.
[AD3] VLT-SPE-ESO-10000-0003 EMC and power quality specification - Part 2.
[AD4] VLT-TRE-ESO-15600-2251 MACAO for VLTI System Overview
[AD5] VLT-TRE-ESO-15600-2057 MACAO-VLTI Detailed Mechanical Design and analysis report of the Coudé AO facilities
[AD6] VLT-SPE-ESO-15600-2082 Top Level Requirements for MACAO-VLTI
[AD7] VLT-ICD-ESO-15600-2057 MACAO-VLTI Interface Control Document
[AD8] VLT-SPE-ESO-15600-2440 MACAO-VLTI Instrument Control Software – ICS Design
[AD9] VLT-SPE-ESO-15600-2353 MACAO-VLTI Real-Time Computer Software Design

1.4 Reference Documents

[RD1] VLT-TRE-ESO-15600-2270 MACAO-VLTI Electronics – LCU
[RD2] VLT-TRE-ESO-15600-2269 MACAO-VLTI Electronics – APD
[RD3] VLT-TRE-ESO-15600-2271 MACAO-VLTI Electronics – DM control
[RD4] VLT-TRE-ODP-11640-0001 Tip Tilt Mount: Preliminary Design Report
[RD5] VLT-SPE-ESO-11640-1943 ESO Adaptive Optics System: Deformable Mirror Control
[RD6] VLT-SPE-ESO-11640-2262 Technical Specification: MACAO APD Counter Module

1.5 Control Electronics Documentation

MACAO-VLTI Control electronics
J. Brynnel

Technical report:
VLT-TRE-ESO-15600-2268
- Overview (This document)

LCU *S. Moureau*	APD *R. Reiss*	DM control *J. Brynnel*
Technical report: VLT-TRE-ESO-15600-2270 *- IC LCU* *- RTC LCU* *-VLTI LCU*	Technical report: VLT-TRE-ESO-15600-2269 *- APD system* Technical Spec: VLT-TRE-ESO-11640-2262 *- APD counter board*	Technical report: VLT-TRE-ESO-15600-2271 Technical Spec: VLT-TRE-ESO-11640-1943 *- DM controller spec* Technical Report: VLT-TRE-ODP-11640-0002 *- DM tip-tilt mount design*

Figure 1.5 Control system documentation

In Figure 1.5 an overview of documentation for MACAO-VLTI control system with responsible persons is presented. The three parts (LCU, APD and DM control) are well defined and have clearly identified interfaces, compare with figure 2.2. The LCU part is mainly in-house design and assembly, whereas APD and DM controller are either commercially available items (APD modules) or ESO specified, sub-contracted developments (APD counter, DM controller and DM tip-tilt system).

- Deformable Mirror (DM) : CILAS, France
- DM Controller : 4D Engineering, Germany
- DM Tip-Tilt mount : Observatoire de Paris
- APD counter module : SHAKTI, France

In order to keep up with the tight overall schedule for MACAO-VLTI, those developments all run in parallel. We expect delivery of the first DM + DM controller + DM Tip-Tilt mount in May 2001. After acceptance and (where applicable) EMC testing has been successfully performed, system testing will take place. Since this document is written before DM controller and APD counter board design reports are due for delivery to ESO, no detailed drawings of those sub-systems can be presented.

2. System overview

2.1 HW overview

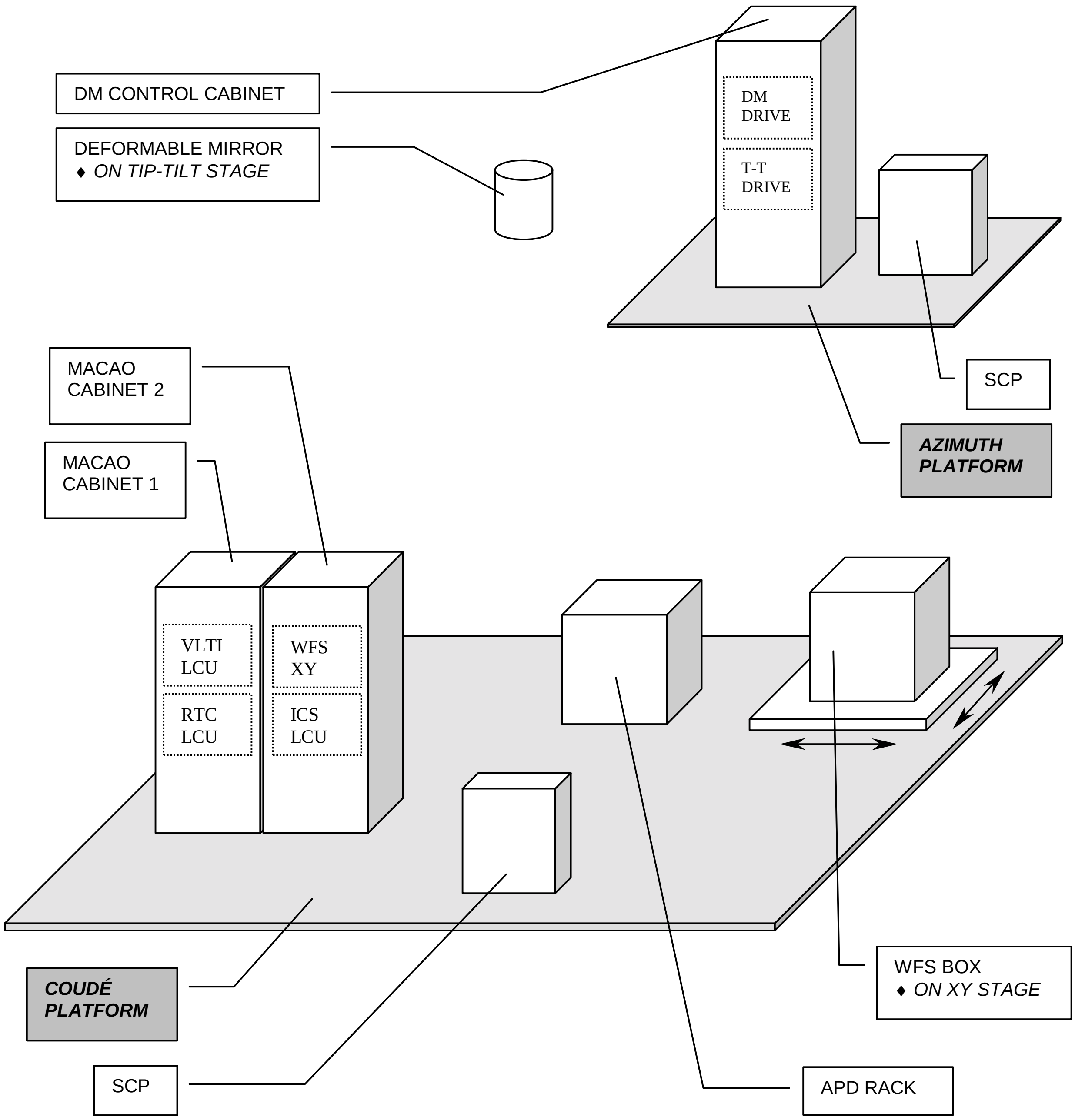

Figure 2. MACAO-VLTI control system main components overview

In Figure 2 an overview of all control system components is presented. Please note that the drawing is schematic only, and not to scale. Most MACAO HW components are mounted on the Coudé platform, with the exception of the Deformable Mirror (DM), which is mounted inside the telescope structure. Control electronics for the DM and its Tip-Tilt (T-T) mount are located on the telescope azimuth platform.

MACAO opto-mechanics are integrated in the wavefront-sensor (WFS) box. This box is mounted on a high precision XY-table, which will be doing tracking of AO guide stars. In the WFS box several moving functions are mounted, controlled from the MACAO two Local Control Units (LCU's), see also [RD1].

60 optical fibers go from WFS box to the APD rack (fibers not shown in Figure 2). The fibers come from a lenslet array inside the WFS box.

2.2 Signal flow

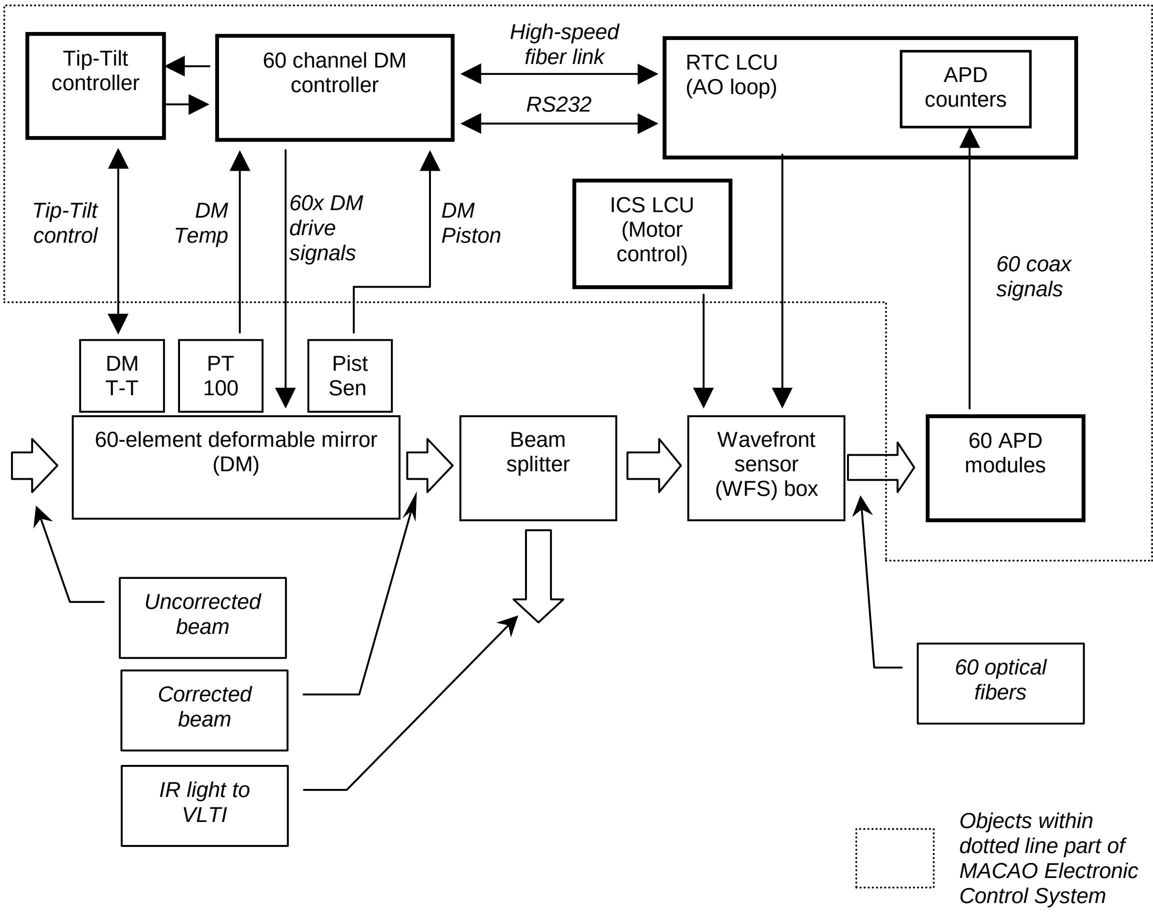

Figure 2.2 MACAO beam and signals flow

Figure 2.2 is a block diagram of MACAO system, with light path indicated with block arrows, and electrical connections drawn with black arrows. Components inside the dotted line are forming the MACAO Control System hardware. Main electronic components are:

- RTC and ICS LCU's, see also [RD1]
- APD modules and Counters, see also [RD2] and [RD6]
- DM controller and DM T-T, see also [RD3], [RD4] and [RD5]

The uncorrected beam from the telescope hits the Deformable Mirror (DM), which produces a corrected beam. A beam splitter splits the corrected beam to VLTI (IR) and MACAO WFS box (optical). Light from the lenslet array in the WFS box is transferred through 60 optical fibers to the APD rack, where 60 APD photon counters are mounted. An optical de-rotator is mounted in front of the lenslet array.

The WFS box contains several computer controlled opto-mechanical functions such as a linear beam switching unit and Neutral Density wheels. Motors are all DC-motors with encoders. Moving functions are described in [RD1].

On the Coudé platform, where MACAO is mounted, two cooled cabinets are holding electronics required for MACAO control system. Electrical power, computer network and cooling water is taken from a service connection point (SCP). For all MACAO components mounted on the Coudé platform, stringent thermal requirements apply, see also [AD6]. Cabinet layout is described in detail in [RD1], and cabinet thermal control is discussed in Section 6.2 of this document.

3. LCU

Two Local Control Units (LCU) are controlling MACAO HW. An LCU is essentially a VME-based computer, composed of ESO standardized VME boards. Operating system is VxWorks, and the LCU's have connection to the VLT fiber-optic LAN. Both LCU's are designed and assembled in-house at ESO.

3.1 ICS LCU

This LCU performs control of motorized functions in the MACAO WFS box, XY table and status monitoring. A detailed description of the ICS LCU HW can be found in [RD1], and Instrument Control SW is presented in [AD7].

3.2 RTC LCU

Two PowerPC CPU boards are mounted in the RTC LCU:

- Supervisory CPU
- Real-time Computer CPU (RTC CPU)

The RTC CPU performs the core AO calculations with the APD counter data as input, and DM controller data as output vector. A detailed description of the RTC LCU HW can be found in [RD1]. RTC SW is presented in [AD8].

4. APD's and APD counters

Avalanche Photo Diodes (APD's) are used as photon counting elements in MACAO. 60 APD modules from Perkin-Elmer are mounted in the APD rack. An APD module receives photons through an optical fiber, and sends one electrical TTL-level pulse for each photon detected. The pulses are counted in a 60-channel counter module, and counter values are used as input for the RTC LCU. See also [RD2].

As the APD's are sensitive for over-exposure of light, interlocks will be implemented to protect the modules, see [RD2].

The APD counters are commercial products. The APD counter functionality has been specified in [RD6], and a contract for development and manufacturing of 7 APD Counter modules has been awarded to SHAKTI, France. First APD counter module will be delivered to ESO in May 2001.

5. DM controller and DM Tip-Tilt

MACAO Deformable Mirror (DM) is a 60-element bimorph mirror requiring a drive voltage of +/-400 volts for nominal stroke. The mirror is controlled by the DM controller, which basically is a 60-channel programmable high voltage generator. The RTC calculates the correction vector, and sends the 60 values over a high-speed, low latency dedicated optical fiber (see Figure 2.2). The DM controller has been specified in [RD5], and a contract for development and manufacturing of 7 DM controllers has been awarded to 4D Engineering, Germany. See also [RD5] for details.

The DM is mounted on a high precision motor driven Tip-Tilt (T-T) mount. The T-T mount with control electronics is delivered as a fully tested system (tests performed using a dummy DM mirror) by Observatoire de Paris, see also [RD4].

The DM controller and DM T-T controller are mounted on the Azimuth platform of the UT, see also Figure 2. The RTC sends data to the DM controller using a fiber-optic point-to-point link. Tip and tilt values to the DM T-T controller are sent together with the DM correction values, and passed to the T-T controller as two analog voltages +/-10 volts with a resolution of at least 14 bits. The distance between electronics and DM/T-T stage is estimated to approximately 20 meters.

6. Thermal control

As already mentioned, for equipment installed on Coudé platform, stringent thermal requirements apply [AD6]. Requirements are (spec 2.1.14 of [AD6]):

- Surface temperature difference to ambient within +1/-5 degrees
- Power dissipation during observations limited to +10/-20 watts

It should be noted that the second specification is most likely the most difficult to fulfil, in particular as this value is specified as the sum of power dissipation for *all* MACAO components installed in Coudé room:

- Three cabinets
- XY table with encoders
- WFS box moving functions
- Cabling I*R losses

6.1 Power dissipation

Table 1 is a list of all functions associated with the Wavefront-Sensor (WFS) box. We have assumed a typical operational scenario, where MACAO is tracking an object. This means that only three motors are active:

- WFS X-Y table
- De-rotator

All other motors are assumed to have zero power in this mode. We can not switch off encoders, here we have assumed 100% duty cycle.

Note: The values below only refer to *electrical* power dissipation. It is important to point out that motor power used for moving bearings will be converted to friction, or heat, hence the real heat generation values will be *higher* than listed below.

Item	Motor	Enc.	Total
WFS table X	1W	0[1]	1W
WFS table Y	1W	0[1]	1W
WFS Brake	-	-	0[2]
De-rotator	3W	1W	4W
Mode selector	0	1W	1W
Membrane Mirror Diaphragm	0	0.5W	0.5W
WFS ND wheel	0	1W	1W
STRAP filter wheel	0	1W	1W
STRAP diaphragm	0	0.5W	0.5W
Membrane mirror tip	0	0.5W	0.5W
Membrane mirror tilt	0	0.5W	0.5W
Membrane mirror focus	0	0.5W	0.5W
Membrane voice coil	-	-	0.5W
WFS entry shutter	-	-	0[3]
		Total Motors	**12W**

Table 1: WFS box power dissipation

[1] Encoder electronics are mounted inside one of the cooled chassis. Encoder heads only.
[2] Electro-mechanical pneumatic valve mounted inside one of the cooled chassis.
[3] Bi-stable, two-coil entrance shutter.

In Table 2 the global heat dissipation of MACAO-VLTI components in the Coudé room is added up.

Item	Quantity	Dissipation	Total
Motors/Encoders[4]	1	12W	12W
Cabinets[5]	3	0	0
Cabling I*R losses	1	2W	2W
		Grand total	**14W**

Table 2. MACAO Total power dissipation

It is noted that the MACAO overall heat dissipation exceeds the maximal specified value (10W). However, the following points should be considered:

- A significant part of the dissipated power will be sunk into the mechanical structure of MACAO and the Coudé platform.
- At present, no means of reducing the dissipation can be identified. It is not practical to cool motors and encoders (main contributors), and those devices can not be switched off.

[4] Value from Table 1
[5] Specially insulated and cooled cabinets, see also Section 6.2.1

6.2 Cabinet thermal control

MACAO has four electronics cabinets, which need thermal control:

- MACAO cabinet 1 and 2 (Coudé platform)
- APD cabinet (Coudé platform)
- DM controller cabinet (Azimuth platform)

Different requirements apply to those cabinets, and different cooling concepts will be applied.

6.2.1 MACAO cabinet 1 and 2

It is intended to use standard cabinets, Knuerr Miracel IP55, and ESO standard cabinet cooler (large type). With careful internal layout of cabinet and efficient internal airflow guiding, very good results have been achieved with this configuration for VLT “normal” applications (i.e. Nasmyth location). For MACAO cabinet 1 and 2 on Coudé platform, where requirements are more stringent, we plan to use the same concept with the following changes:

1. Limit cabinet internal heat dissipation to 500 Watts (not including heat exchanger fans)
2. Use air flow guidance plates inside cabinet
3. Thermally insulate cabinet (external insulation)

Measurements have been performed on one prototype cabinet built identical to MACAO-VLTI cabinets, using this concept. Results are very promising:

- Measured power net flow from cabinet to ambient = 0W
- Temperature difference between outer surface and ambient temperature: Not measurable.
- Images taken with IR camera showed no hot or cold spots on outer surface.

The following cabinet internal heat dissipation has been calculated in [RD1]:

Cabinet 1 internal power dissipation: **265W** + heat exchanger **280W**
Cabinet 2 internal power dissipation: **530W** + heat exchanger **280W**

6.2.2 APD cabinet

In this cabinet 60 APD modules and power supplies will be mounted (see [RD2]). Previous experience with this type of APD modules has shown that they are very sensitive to vibration. No fans may be used in this cabinet. The APD modules and power supplies will be mounted on specially designed liquid cooled cold plates.

Calculated internal heat dissipation [RD2]: **200 Watts.**

6.2.3 DM controller cabinet

It is intended to use standard cabinets, Knuerr Miracel IP55, and ESO standard cabinet cooler (large type). With careful cabinet internal layout and efficient internal airflow guiding, very good results have been achieved with this configuration for VLT “normal” applications.

Estimated internal power dissipation: **230 Watts.**

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