VERY LARGE TELESCOPE

TECHNICAL REPORT
MACAO-VLTI
Electronics – DM Control

Doc. No. VLT-TRE-ESO-15600-2271
Issue 2.0
Date 6-Mar-2001

Prepared :	J. Brynnel	6-Mar-2001	.
	Name	Date	Signature
Approved :			.
	Name	Date	Signature
Released :			.
	Name	Date	Signature

Change Record

Issue/Rev	Date	Section/Page affected	Reason
1.0	22-Sep-2000	All	First issue
2.0	6-Mar-2001	All	Prepared for FDR

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. The correcting optical element in MACAO is a 60-element Deformable Mirror (DM). This mirror needs a controller, which generates the high voltages required for the 60 mirror elements. This unit is called DM Controller. The DM is physically mounted on a Tip-Tilt electromechanical unit, hereafter referred to as DM Tip-Tilt mount.

All main components described in this document are new developments, subcontracted to different companies:

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

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 design report is due for delivery to ESO, no detailed drawings of DM controller can be presented. However, all interfaces to MACAO-VLTI control system are well defined and described in this document. For the DM (see [RD8]) and DM Tip-Tilt mount (see [RD4]), design reports have been submitted to ESO.

1.1 Purpose

This document is describing the design of the DM Control Electronics and DM Tip-Tilt mount for MACAO at the time of Final Design Review (FDR).

1.2 Scope

DM controller and DM Tip-Tilt mount functionality and interfaces are described. Some performance analysis for those sub-systems is done.

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-SPE-ESO-15600-2245 MACAO-VLTI Technical Specifications

1.4 Reference Documents

[RD1] VLT-TRE-ESO-15600-2268 MACAO-VLTI Electronics – Overview
[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-11640-0002 MACAO-VLTI Tip Tilt Mount: Final Design Report
[RD5] VLT-SPE-ESO-11640-1943 ESO Adaptive Optics System: Deformable Mirror Control
[RD6] VLT-SPE-ESO-15600-2353 MACAO-VLTI Real-Time Computer Software Design
[RD7] VLT-TRE-ESO-11640-2429 Effect on DM dynamics on MACAO Performance
[RD8] DPCO-00.1630 Design Report MACAO-VLTI Deformable Mirror, CILAS

2. System overview

2.1 HW overview

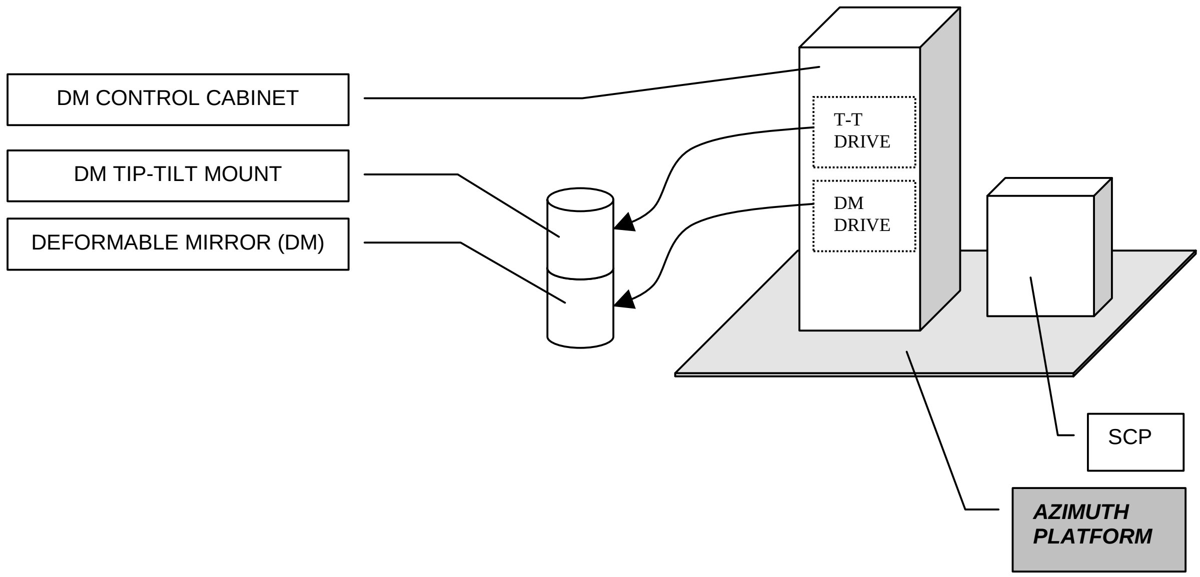

Figure 2. DM and T-T components overview

In Figure 2 an overview of MACAO DM and DM Tip-Tilt components is presented. Please note that the drawing is schematic only, and not to scale. Control electronics for the DM and its Tip-Tilt (T-T) mount is located on the telescope azimuth platform in a dedicated cabinet. Electrical power, cooling liquid (for cabinet cooling) and the fiber links from/to MACAO Real Time Computer (RTC) are all connected to a Service Connection Point, or SCP.

The Cabinet is a Knuerr Miracel IP55, H x W x D 1200x600x800. The Cabinet is thermally controlled by an ESO 4TE cooling system. In [RD1] detailed information on Cabinet cooling, power consumption etc. is given. Cable length between DM Control Cabinet and DM will be approximately 20 meters.

2.2 Signal flow

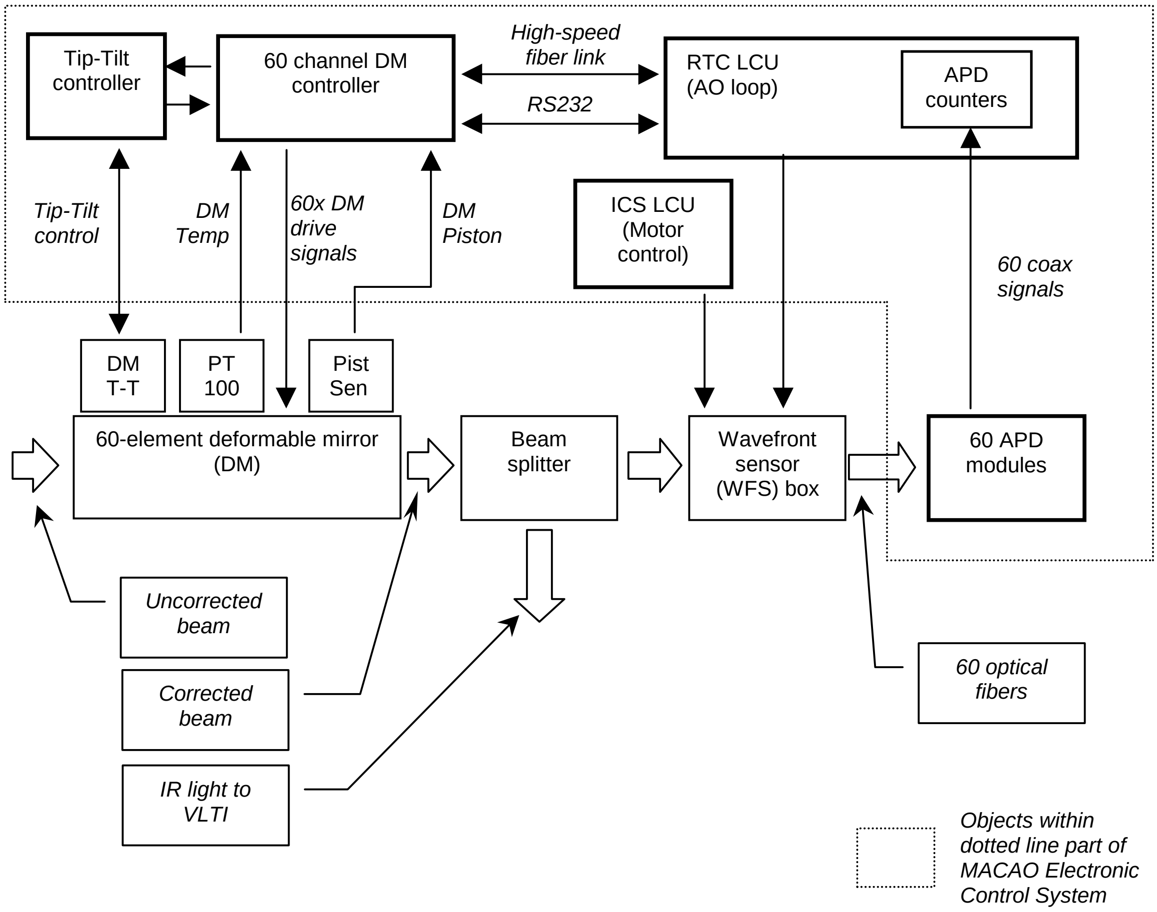

Figure 2.2 MACAO optical beam and signals flow

Figure 2.2 is a block diagram of MACAO control system, with light path indicated with block arrows, and electrical connections drawn with black arrows. This document will focus on the DM Controller and DM Tip-Tilt (T-T) system.

The deformable mirror, being the corrective element in the AO system, is mounted on the telescope structure, below the Azimuth platform. Since the DM has a limited stroke, it could happen that the required DM deformation would actually exceed the available stroke for Tip and Tilt corrections. The DM T-T mount position will then be updated, thus off-loading large tip-tilt corrections from the DM. All calculations are performed in the RTC, where both DM deformation pattern and T-T position are sent over a dedicated high-speed fiber link to the DM controller electronics. A detailed description of DM control algorithms and loops is provided in [RD6].

Two fiber links connect the RTC with the DM controller:

- **High-speed fiber link** – bi-directional link fast low-latency link used for real-time data transfer between RTC and DM controller. Using Reflective Memory technology.
- **RS232 link** – slow speed link used for diagnostic and house-keeping

3. DM controller

MACAO Deformable Mirror (DM) is a 60-element bimorph mirror requiring a drive voltage for each mirror element of +/-400 volts for nominal stroke. The DM controller, basically a 60-channel programmable high voltage generator, controls the mirror.

The DM controller has been specified in [RD5], and is currently being developed by 4D Engineering. First unit is scheduled for delivery in May 2001. See also [RD5] for details.

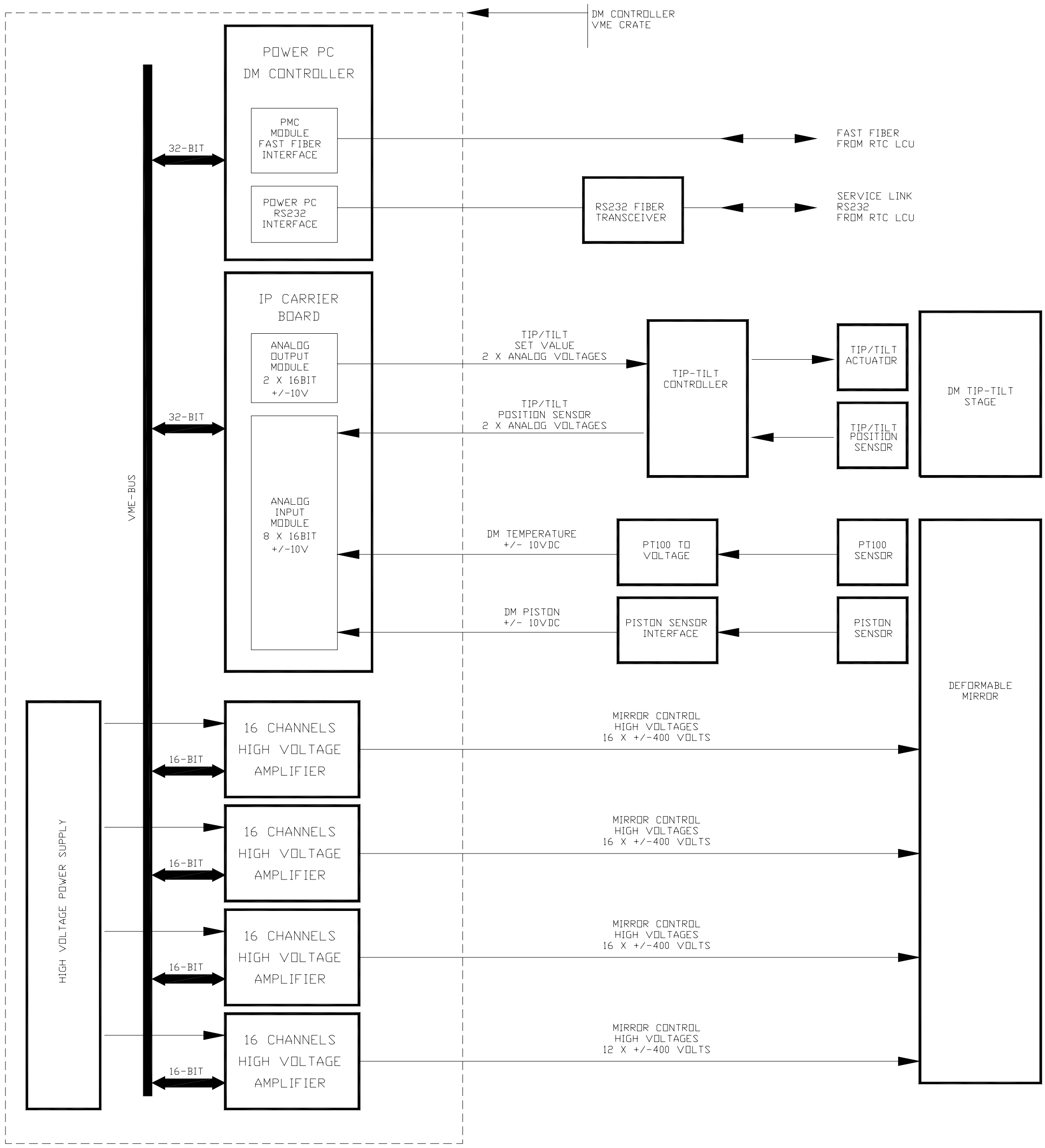

Figure 3. DM controller

The DM controller is a VME-bus system, using ESO standards to a large extent. It should be noted that the DM controller is not a part of the Paranal Ethernet LAN (as a "normal" LCU would be), and should be considered as a "black box". We will use the Paranal Optical Fiber network infrastructure as transport medium for the DM controller High-Speed fiber link and Service link (point-to-point connections).

The central element is a Motorola PowerPC board, running embedded VxWorks. This means that no connection to VLT LAN is required. This CPU receives data from the MACAO RTC LCU over a high speed, dedicated point-to-point Reflective Memory (RM) fiber connection. Additionally, a second bi-directional fiber RS232 link for slow command passing and diagnostics is used.

3.1 DM control

The DM controller receives a vector (one frame) assembled from 62 words of 2 bytes (14 bit data) each at a frame rate of 350 Hz. The first 60 words are passed on to the four High Voltage Amplifier boards where D/A conversion and amplification takes place. The 60 outputs are connected to the 60 elements of the DM. A synchronization mechanism ensures that all HV outputs update simultaneously. Each output has a voltage output capacity of +/- 400 Volts, and an output electronic current limit of +/- 6 mA.

Each DM segment (or electrode) represents a purely capacitive electrical load. Since the electrodes have different geometry (see RD8) they also exhibit different capacitance value. The DM mirror manufacturer CILAS has calculated the actual capacitance in the range from 4.5 nF for the smallest electrode (central electrode) to 10.4 nF for large electrodes (outer electrodes).

Below the key specifications for the DM controller from [RD5]:

- System overall latency 150 usec
- Output +/-400V (60 channels)
- Output current limit 6 mA per channel
- HV Amplifier bandwidth > 2 kHz
- Noise on HV outputs < 100 mV
- Output linearity within 0.1% over full range
- Output relay for each output
- D/A resolution 14 bit
- Output drive capacity 10 nF (one channel)
- All outputs should update synchronously
- Remote telemetry and trouble-shooting using RS232 link
- Form factor 19 inch / 6U
- Integrated high voltage power supply

3.2 DM dynamic properties

The DM itself has a transfer function that is not perfect. The estimated transfer function calculated by DM supplier CILAS exhibits strong resonance at 370Hz for VLTI DM and 810Hz for SINFONI DM. In figure 3.2 a typical bimorph DM behavior is shown. Possible means of suppression of this resonance frequency have been thoroughly analyzed in [RD7].

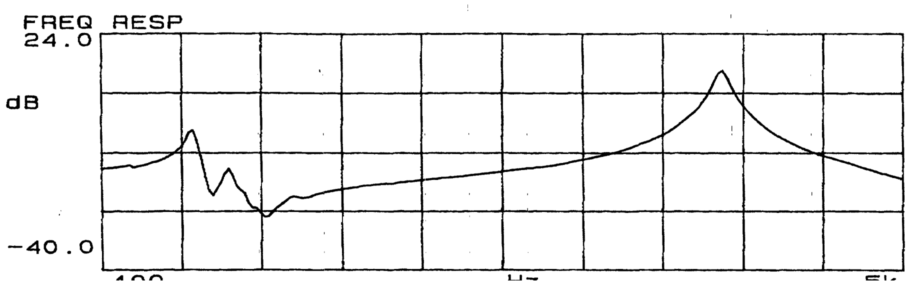

Figure 3.2 DM transfer function

The conclusion from this analysis is that it is technically very difficult to improve DM dynamic properties by pulse shaping or filtering. The system gain (Strehl gain) by implementing a pulse shaping filter is low, and does not justify the considerable added complexity. No filtering will be implemented except for a first-order analog Low-pass filter in the HV amplifier (noise suppression).

3.3 DM controller latency time

The Latency Time requirement from Section 3.1 is defined as the time from when the first bit of one frame leaves the RTC until the HV outputs update. Latency time budget can be split in the following parts (see also Figure 3.3):

- t_1 : Fiber link transfer time for one frame
- t_2 : Data handling in DM controller PowerPC
- t_3 : VME-bus transfer time for 62 words from PPC to HV boards
- t_4 : D/A converter propagation delay
- t_5 : High voltage amplifier delay
- t_6 : Time to charge DM electrode capacitance with current limited output

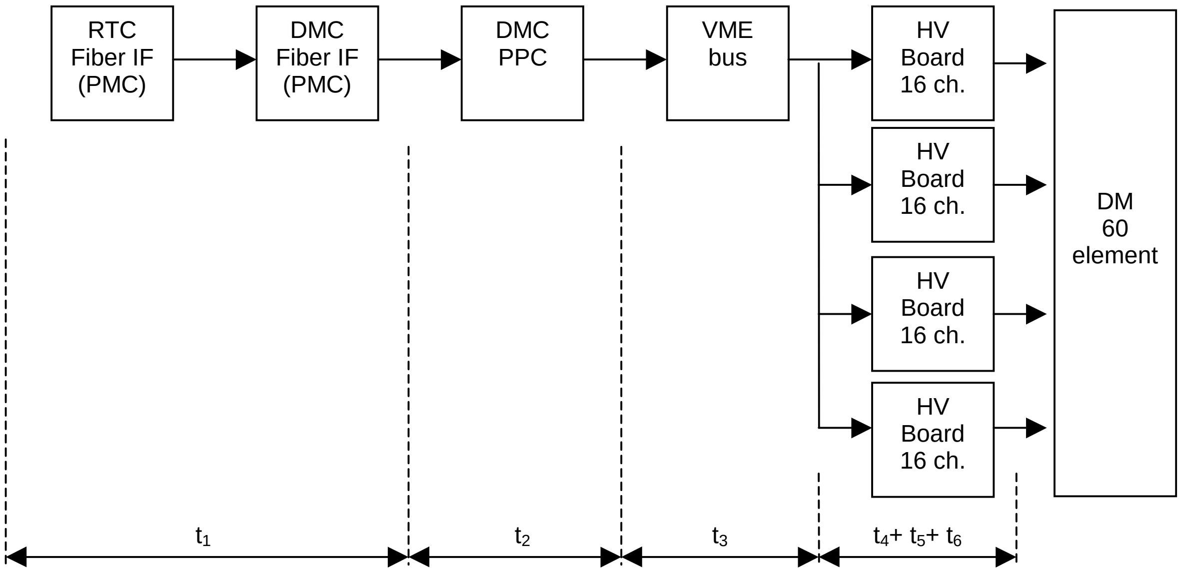

Figure 3.3 Latency time diagram

This requirement (150 usec overall latency for t_1+ t_2+ t_3+ t_4+ t_5) is very challenging to fulfil. It is, however, one of the key specifications as it has a direct impact on the total Strehl ratio, see also [RD6]. Below all contributions to overall latency are analyzed. For values t_1 to t_5 we can not present any hard numbers at this point.

3.3.1 t_1 : Fiber link transfer time

It is very important to select a fiber interface with low latency and no or little protocol overhead. This excludes general-purpose network interfaces like Ethernet. Only a few such interfaces are available on the market, and of those not all suppliers can (or will) give hard numbers on transfer latency time. Therefore, 4D Engineering is doing extensive benchmark testing with different interface modules. After conclusion of those tests, the interface type will be finally determined.

3.3.2 t_2 : PPC data handling

After receiving the vector with DM corrections, the PowerPC controller board must transfer data from the PMC module, and pass data to the VME-bus interface, using a pre-defined allocation table.

3.3.3 t_3 : VME-bus transfer time

Using a PowerPC VME-bus CPU, ESO has done VME transfer performance tests, and a typical value for one 16-bit transfer is 1 us. This would mean 60 usec for transferring one frame of 60 values to the HV boards.

3.3.4 t_4 : D/A converter time

A typical value for a 16-bit DAC would be in the order of a few usec.

3.3.5 t_5 + t_6 : High voltage amplifier latency time

If we assume a DM electrode driver current limit at 6 mA charging a capacitor (one DM electrode), a worst-case rise time calculation gives:

$t_{6max} = dU_{max} * C_{max} / I_{Limit}$ = 800V * 10nF / 6mA = 1300 usec

On the other hand, for more realistic corrections we get:

$t_{6realistic} = dU_{realistic} * C_{max} / I_{Limit}$ = 20V * 10nF / 6mA = 33 usec

To this value, add some marginal for phase delay in the HV amplifier.

It should be noted that 150 usec overall can only be achieved for small to medium stroke amplitudes.

3.4 DM Piston measurement

A capacitive sensor measuring displacement of the DM mirror at the position of its central electrode will be implemented in the DM. This sensor is described in [RD8]. The sensor has an accuracy of 2 nm RMS.

The sensor is mounted on the DM rear side, and measures displacements of DM central electrode, which has a metallized target for this purpose. The sensor has a bandwidth of several kHz. A special electronics box converts sensor signal to an analog voltage +/-10V. This sensor box will be mounted close to the sensor (maximal distance from sensor to the preamplifier 1.6 metres).

In the DM controller, the Piston Sensor analog signal is connected to an analog input channel on one of the IP modules, see Figure 3. The signal is read out from the DM controller PowerPC board, and passed on to MACAO RTC using the fast fibre link. Sampling rate will be the same as DM update rate, 350 Hz.

3.5 DM temperature sensor

A PT100 sensor measuring DM temperature will be implemented in the DM. This sensor is described in [RD8]. The sensor has an accuracy of +/-0.1C. The purpose of this measurement is to compensate for DM temperature dependent effects.

A special electronics unit converts sensor signal to an analog voltage +/-10V. This sensor box will be mounted close to the sensor, together with the Tip-Tilt stage preamplifier.

In the DM controller, the PT100 sensor analog signal is connected to an analog input channel on one of the IP modules, see Figure 3. The signal is read out from the DM controller PowerPC board, on request from the RTC over the RS232 Service Link (see Figure 2.2).

4. DM Tip-Tilt mount

The DM is mounted on a high precision motor driven Tip-Tilt (T-T) mount. The T-T mount with control electronics was specified by ESO, and developed and assembled by Observatoire de Paris (OdP), see also [RD4]. It should be noted that OdP is responsible for tuning and performance of the T-T mount. A dummy DM will be used during this procedure.

The DM T-T unit is driven by direct drive motors, in closed loop with position sensors as feedback elements. System overall bandwidth is 100 Hz. Input to the T-T controller is two analog voltages +/-10V, coming from the DM controller (see Figure 4.1 and 4.2).

The DM controller receives a vector with 62 words of 2 bytes (14 bit data) each. The two last words (#61 and #62) in each frame represent tip and tilt absolute values. The two words are D/A converted to two analog signals +/-10 volts, which are connected to the (analog) input of the T-T controller. Sensor position value (analog voltage) is connected to two analog inputs of the DM controller. This signal can be read back to the RTC LCU for diagnostic and trouble-shooting purposes.

Required Tip-Tilt mechanical resolution is 40 mas (angle resolution) / 240 as (stroke) = 1 / 6000 (minimum 13 bits). A 16-bit D/A is used in the DM controller.

Cable length between T-T controller and T-T unit will be approximately 20 meters. A signal preamplifier box for the T-T unit position sensors must be mounted close (within 1.7 meters) to the T-T unit itself in order to avoid performance degradation due to the relatively long cables.

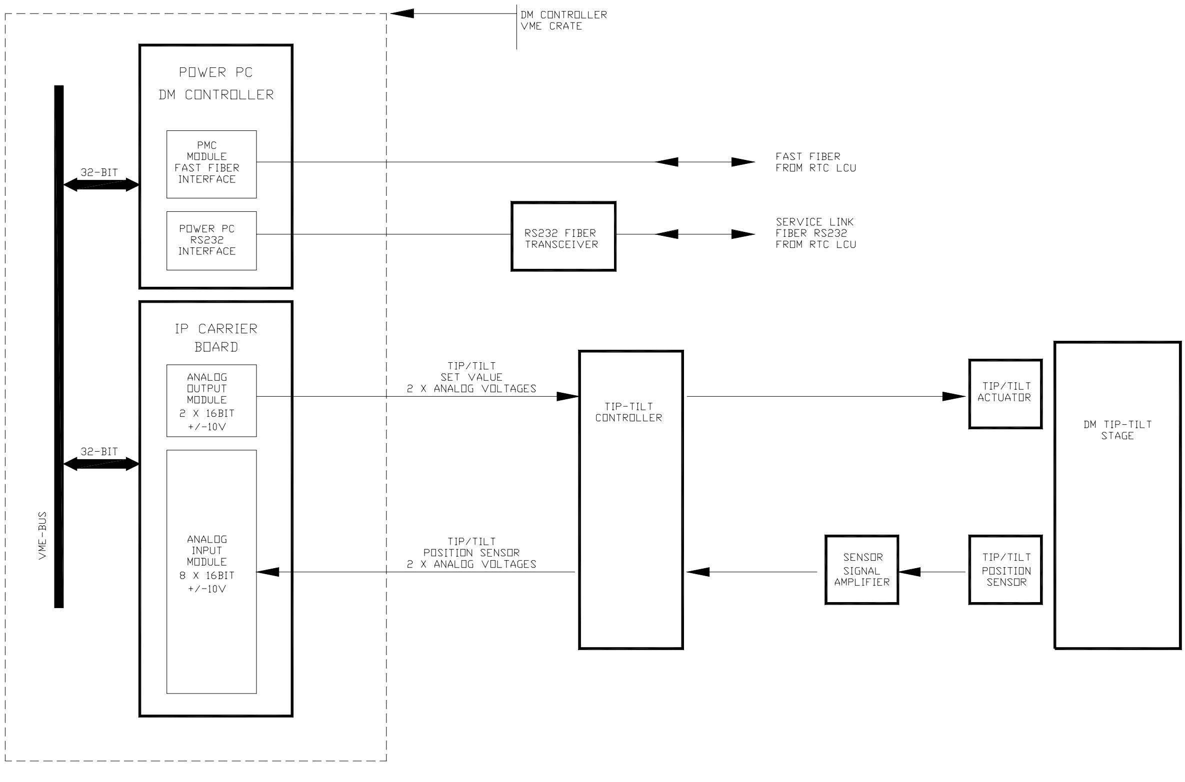

Figure 4.1 DM Tip/Tilt control

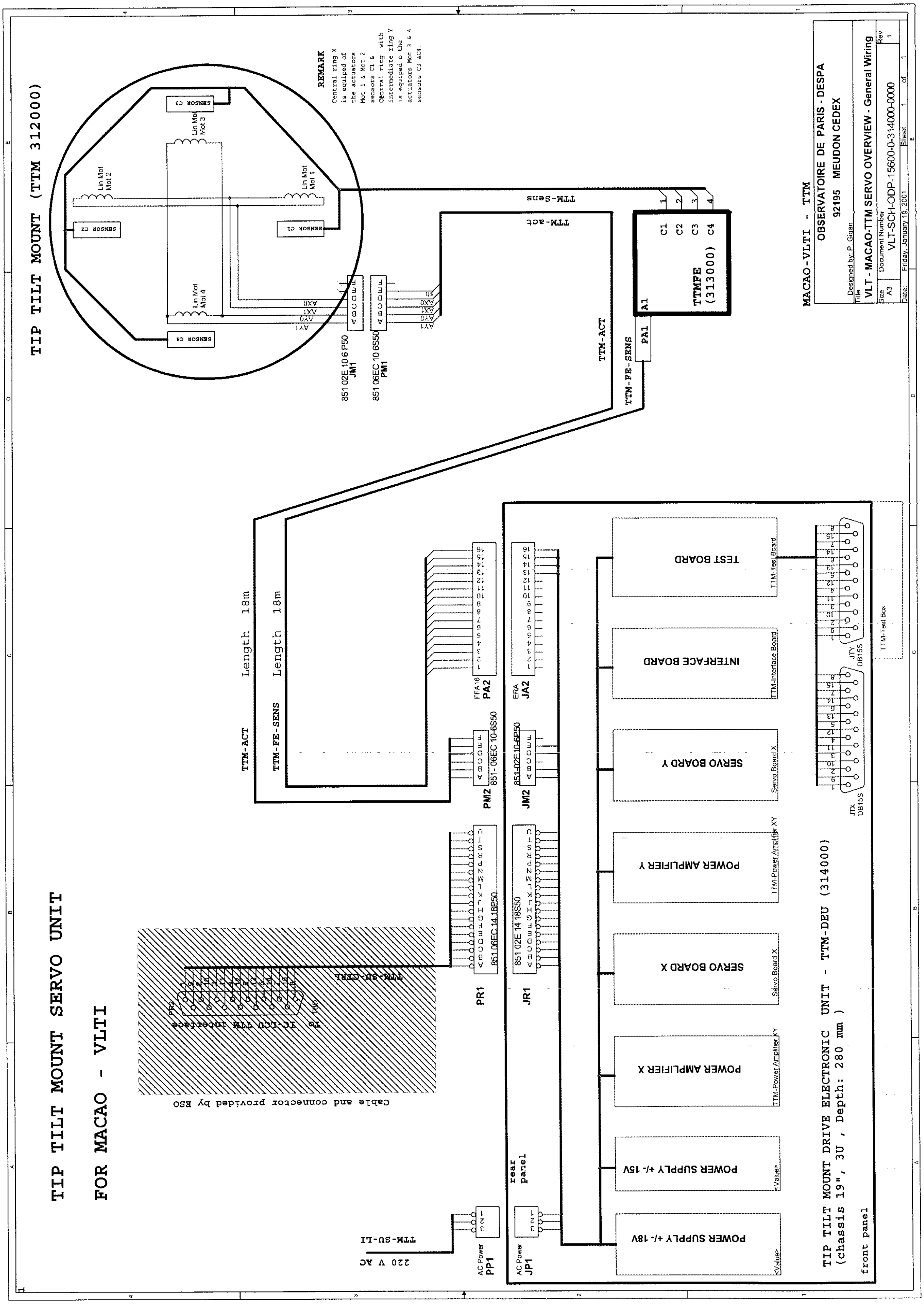

Figure 4.2 DM Tip-Tilt unit

__oOo__