GEMINI

8-M Telescopes Project

Gemini MCAO Program

CoDR Material – Electronics, Sensors & Actuators in the Beam Transfer Optics

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Revision Control

1. Final version; 5/9/2000. Appendix to MCAO CoDR material.

Table of Contents

1. Purpose

This document contains material intended for the Conceptual Design Review (CoDR) of the Gemini Multi-Conjugate Adaptive Optics (MCAO) program. It considers the hardware required to implement the fast and slow steering mirror loops and associated equipment within the Beam Transfer Optics (BTO). This document does not address the structure of a control scheme for the mirror positioning and steering loops, nor does it describe the BTO layout on the telescope. These issues are addressed elsewhere.

2. BTO performance specifications

The following performance specifications relate to the operation of the BTO steering mirror system.

Parameter	Min.	Nom.	Max.	Units
BTO open-loop single-axis tilt accuracy (on sky)	-	1	-	arcsec
BTO closed-loop single-axis tilt accuracy (on sky)	-	0.05 @ 1kHz 0.05 @ 10-20Hz	-	arcsec

The parameters given below influence the selection of the position sensors and the mirrors.

Parameter	M2	M3	M6	M7	Units
Mirror clear aperture diameter	25	25	50	25 or 50	mm
Mirror open-loop one-axis tilt dynamic range	1	TBD[*]	TBD[*]	8	mrad
Mirror open-loop one-axis tilt accuracy	150	150	150	150	rad
Mirror closed-loop sampling frequency	800	10 – 20	10 – 20	10 – 20	Hz
Mirror closed-loop one-axis tilt accuracy	15	9	9	9	rad

3. Sensors and actuators

3.1 Beam Position Sensing Detectors (PSDs)

In order to servo the beam alignment mirrors it is necessary to be able to detect and measure the departure of the laser beam from the target position. This beam sensing may be accomplished by a number of methods, for example a CCD camera observing the front face of the mirror or by a silicon photodetector behind it, operating on leakage light passing through the mirror surface. In either case, the output of these sensors will need to be processed by external electronics and/or software in order to produce outputs proportional to change in beam position that may be used by the loop control system.

The key requirements are:

- **Photodetector responsivity** – moderate to low. The beam power is such that highly sensitive detectors will not be required; a neutral-density filter may even be needed between the mirror and the detector to

[*] Defined by BTO/LLT alignment tolerance analysis

limit illumination. However sufficient photocurrent must be generated at the laser wavelength of 589 nm.

- **Size** – critical. The sensor must cover as much of the mirror area as possible, preferably 100% of it. This may have to be accomplished by imaging the incident spot onto a smaller detector via optics, or using an auxilliary method of beam steering when errors are large.
- **Mounting** – critical. Depending on the size of the detector it may have to be mounted directly behind the steering mirror.
- **Speed** – low. The beam steering sensors are part of loops that have a low bandwidth, on the order of a few Hertz. High-speed sensors are therefore not required.
- **Noise** – not critical. For the same reasons as above.

3.1.1 Quadcell PSDs

Segmented PSDs or *quadcell* detectors are suitable in situations where the beam is nominally centered on the detector, and the ability to detect position of a beam that is not incident on all the detector quadrants is not required. It is debatable whether these devices are the best choice for this application for this reason, given that at system start-up the beam may not be coincident on all four detector quadrants.

3.1.2 Lateral effect PSDs

LE-PSDs are single-element devices that offer position detection over the entire active area with no inter-cell gaps or inactive areas. They have a wider dynamic range than quadcells, do not need the beam to illuminate all quadrants in order to give position information, and are independent of the effects of beam size, shape, spot profile and intensity distribution. Drawbacks are poor operating temperature range (normally not rated below 0 °C), slightly nonlinear position detection, especially at the edges of the cell, and a lack of devices with a circular sensing area.

UDT provide LE-PSDs with an active area of up to 31 mm square.

Example: UDT Tetra-lateral PSD, type SC-50D. Responsivity approx. 0.35 A/W at 590 nm. Operates in photoconductive mode, low capacitance.

3.1.3 Cameras

Compact CCD cameras may be used to monitor the beam remotely and assist in manual steering. They would not be part of a closed-loop system but simply be used to allow an operator to guide an errant beam onto a mirror, and to ensure that it was approximately in position before loops are closed. Compact, rugged ultra-miniature black-and-white cameras are available for approximately $70.00. Video multiplexing and signal amplification equipment may also be required as the cable runs will be long.

3.2 Mirror positioning stages

Correcting the beam alignment will be achieved by making tip/tilt adjustments to the appropriate mirror in the BTO. The mechanisms that position the mirrors must have high operational resolution and be relatively free from motion-retarding effects such as stiction, friction, backlash etc. Other characteristics such as low mass, small size and low power consumption are also highly desirable.

3.2.1 Piezoelectric micropositioning stages

Mirror steering and fast tip/tilt will be accomplished with Piezoelectric Translator (PZT) stages and actuators. These have many characteristics that are desirable in this application and have been widely used in similar situations in other projects.

In the BTO four tip/tilt mirrors or mirror arrays are used. These are:

- M2 – a fast tip/tilt mirror or mirror array
- M3 – slow tip/tilt
- M6 and M7 – beam steering

Of these, M2 is in the highest bandwidth loop. The remainder are essentially operating in a quasi-static or slow tip/tilt mode.

The choice of tip/tilt stage has not been finalised, but several good candidates exist within the Physik Instrumente product line. For example, the PI S-330.xx series Ultra-Fast Piezo Tip/Tilt Platform has a ±1 mrad angular range with sub- rad resolution. It is useable with smaller mirrors up to Ø50 mm. For larger mirrors or mirror arrays the PI S-340.xx series has almost identical performance, and is recommended for mirrors up to Ø100 mm. Both these platforms are available with internal position sensors; in the BTO these would not be necessary as the position loops would be closed on the PSD data, in the case of steering mirrors M7, M8, etc., or pointing and centering information, in the case of M3 and M6.

4. Electronics

Custom electronics may be required in the transmission of position detector signals. The goal is to ensure robust transmission of signals over required distances, ensuring good noise immunity and reliable operation of the control loops. Differential voltage or current loop transmission schemes are viable.

4.1 Position detector electronics

The beam position detectors will require additional electronics to interface them to the VME control system. The project is capable of designing printed-circuit boards and producing such circuitry in-house.

The goals are:

- Transmission accuracy
- Noise immunity
- Small physical size
- Low power consumption

For best performance the interface circuitry should be mounted close to the associated sensor. Figure 1 shows a possible system in block diagram form.

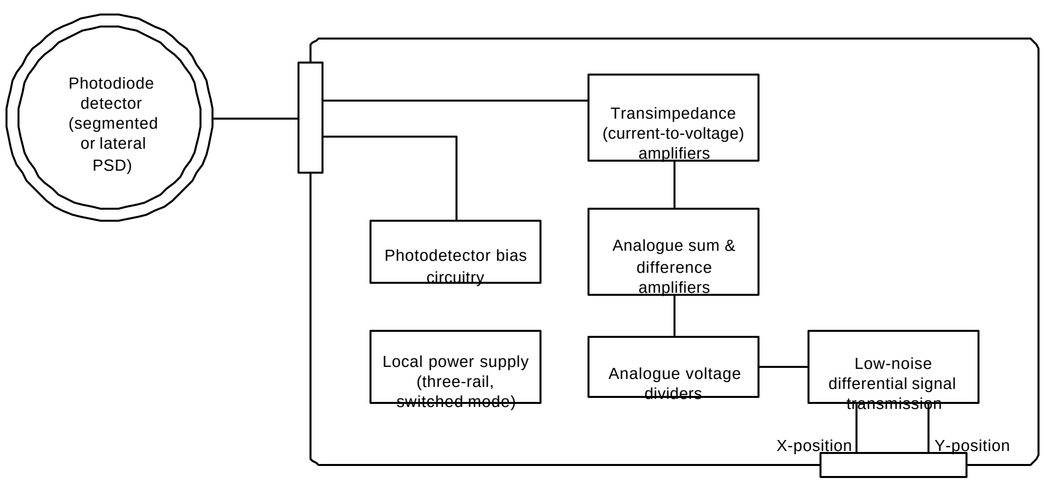

Figure 1: Electronics local to the position detector

The photodetector currents are bought to the electronics module by a short, screened cable. All the processing circuitry is mounted in a screened, diecast enclosure for reasons of noise immunity.

The details of the electronics vary according to the type of PSD chosen, but the concept is the same in all cases. Photocurrents are converted into voltage signals, and analogue summing, differencing and division are used to generate voltage signals proportional to the beam position in terms of X and Y coordinates. These signals are then transmitted differentially over twisted-pair to the remote analogue-to-digital converter for that sensor.

4.2 VME interface electronics

The VME system, which is to implement the control of the BTO, has numerous requirements to input and output both analogue and digital signals. This can be accomplished using VME accessory cards as required. Where possible, cards listed in the Gemini *ICD 13 – Standard Controller* have been selected.

4.2.1 Analogue-to-digital conversion

The controlling VME system will have to accept analogue signals from the BTO beam position sensors. The signals are transmitted as differential voltages and must be digitised at the VME end. An example of a suitable VME card is the Xycom XVME-566 Fast Analog Input Module, which can perform analogue-to-digital conversions with a resolution of 12 bits. The thirty-two input channels may be configured as sixteen differential inputs, which would be required in this application.

4.2.2 Digital-to-analogue conversion

The beam-steering mirror loop position demands will be analogue voltages generated by the VME system, and will be fed directly to the piezo drive amplifiers. Cards are available to generate either voltage or current outputs – for example, the XVME-531 16-channel Analogue Output module which can generate uni- or bipolar voltage outputs at 12-bit resolution. A 4-20mA version is also available.

Where the DAC and the amplifier are not widely separated, a single-ended voltage output may be used to drive the input. For longer runs however, a current loop scheme may be considered as shown in Figure 2. Having a much lower impedance, this scheme has considerable noise immunity and is an alternative to the differential voltage scheme.

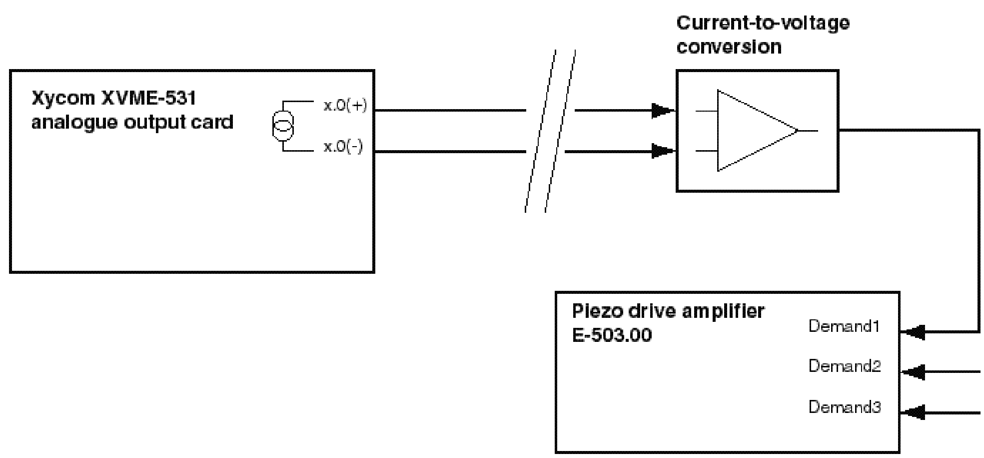

Figure 2: Using a current-loop scheme to drive a remote amplifier

4.2.3 Digital input-output

Some controlled elements of the BTO require only a two-state signal; for example, in the control of beam shuttering. It is therefore a requirement to both generate and receive binary signals under the control of the VME system.

Where interfacing to TTL signals is required, a suitable VME card is the Xycom XVME-240 Digital Input/Output Module. This provides sixty-four bidirectional TTL channels, eight interrupt inputs and eight flag outputs. For other applications, for example reading of non-TTL sensor outputs or driving solenoids, a preferred card would be the Xycom XVME-244, which has 64 channels of isolated I/O capable of directly driving small actuators (output drive capability to 30V, 400mA). This eliminates the need for additional circuitry that would be required if the VXME-240 were used instead.

For some special circumstances, such as the reading of limit-switches, the XVME-212 32-channel isolated digital input module should be considered. This has the capability to generate a VMEbus interrupt when an input changes state and does not require polling by the host. In safety-critical circumstances this approach is to be preferred over a reliance on software scanning of inputs.

4.3 Piezo stage drive electronics

Piezo-electric actuators in the tip/tilt stages are driven by amplifiers using voltages between one hundred and one thousand volts, depending on the actuator type. For example, the Physik Instrumente S-330, a tip/tilt platform with an angular range of ±1 mrad, uses so-called low-voltage drives of up to 120V.

The choice of drive amplifier will be driven by the actuator or tip/tilt platform. Representative examples are the PI E-503.00 3-channel LVPZT Amplifier Module and the PI E-505.00 LVPZT Single Channel Amplifier Module. Both have identical output voltage ranges of –20 to +120V, but the first is capable of supplying only 14W peak per channel while the second can supply 200W per channel. In the BTO the first would be appropriate for slow steering (quasi-static application) and the second for fast tip/tilt.

Both these amplifiers normally have to be mounted in a chassis that provides power. PI supplies two types, a 19-inch rack (E-500) that can power up to three amplifier modules (each of one or three channels), or a 9.5-inch rack (E-501) that can power only one amplifier module. In the BTO these racks would be located either in a thermal enclosure or, in the case of the fast tip/tilt mirror mounted on the top-end, in LEM-1.

The power supplies that are normally in these racks are available separately. It should therefore be possible to dispense with the racks entirely in space-restricted situations.

4.4 Stepper motor drivers

Numerous mechanisms in the BTO and associated systems require small motor drives, for which stepper motors are a suitable choice. Tasks appropriate to these drives would be:

- LLT primary mirror deployment (excluding fine positioning)
- Positioning of beam relay optics L2 & L3
- Rotation of polarizers and filter-wheels, where great accuracy is not an issue.

4.4.1 Single stepper driver modules

For mechanisms on the top-end and within the LLT the most practical solution is to use an individual stepper motor driver module located within one of the Laser Electronics Modules; a typical driver module is the CN0165 supplied by Centent. This module requires a +5V and an +18-80V power supply, dictated by the stepper motor in use, and only three other TTL signals (Reset/Fault, Direction and Step Pulse) to operate. These signals could be taken from an XVME-240 digital I/O card, meaning each stepper motor would require a four-wire interface as shown below.

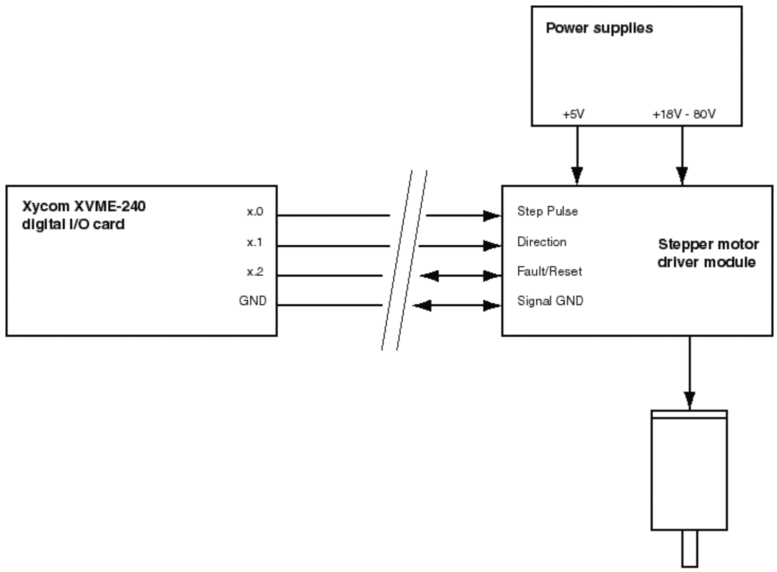

Figure 3: Interfacing to a stepper-motor driver module

4.4.2 VME-based stepper controller cards

For more complex control of stepper drives it may be necessary to use a motion-control card such as the Oregon Microsystems VME8-8. This card does not drive motors directly, but controls stepper driver modules, such as those mentioned above, through Motor Step and Direction outputs. Where complex control of motor moves are not required this approach is redundant, and the stepper motor driver module may simply be driven as shown in Figure 3. It is unlikely that the need to use a card of this type will arise in the BTO.

4.5 Locating the electronics

The LLT and some elements of the BTO will need to be mounted on the Secondary Support Structure. This frame also supports the Secondary Mirror Tip/Tilt system (M2TS) and associated equipment. While the potential problems of coexistance between these two systems are discussed elsewhere, here the location of the BTO electronics are considered.

It is essential that as little extra mass and power-dissipating equipment as possible be added to the SSS. This provides an incentive to locate any dissipative or heavy electronics off the SSS but as close to it as practical. It is feasible to provide a small enclosure, LEM-1 (Laser Electronics Module 1), for this purpose at a point on the top-end ring, in a similar manner to the M2TS Control Electronics Module. Because electronics and interfaces will probably also be required on the SSS itself, a smaller and uncooled enclosure (LEM-2) could be placed there. This parallels the SEM (Sensor Electronics Module) of the M2TS.

4.5.1 LEM-1 (Laser Electronics Module 1)

This enclosure could be actively cooled if required. It may contain:

- servomechanism and drive interface electronics (i.e. stepper driver modules, drive amplifiers)
- power supplies
- data and control signal interfaces to downstream systems

4.5.2 LEM-2 (Laser Electronics Module 2)

This enclosure may not be cooled – coolant is not available on the SSS. It may contain:

- sensor interface electronics
- camera interface electronics
- cable interfaces

The maximum dimensions of these enclosures is to be determined.

5. BTO mechanisms

The following sections break down the BTO into subsystems and estimate the hardware requirement for each. Refer to the BTO system diagram, in Section 5.4 of the CoDR documentation.

5.1 LLT main mirror

The LLT M1 is deployed by the LGSCS. If fine positioning of the LLT mirror is handled by a separate mechanism, an open-loop stepper drive may be used with a limit switch at each extremity to register that the mirror is approximately in position. An electromechanical brake may be used to prevent mirror movement once deployed; this will depend on the final mechanical design.

It is unlikely that both deployment of the mirror and fine positioning could be accomplished by the same drive mechanism; however if this were to be attempted then a better choice of drive would be a brushless DC servomotor driven under closed-loop control. This would require position encoder feedback and a PWM drive amplifier to be situated in LEM-1.

Quantity	Part No.	Description	Note
1	TBD	Stepper motor driver module	Drives LLT in deploy/retract
1	XVME-240	TTL I/O module	3 channels used for stepper motor interface
1	XVME-244	64-channel isolated digital I/O module	2 channels for reading limit switches

Table 1: LLT hardware requirement

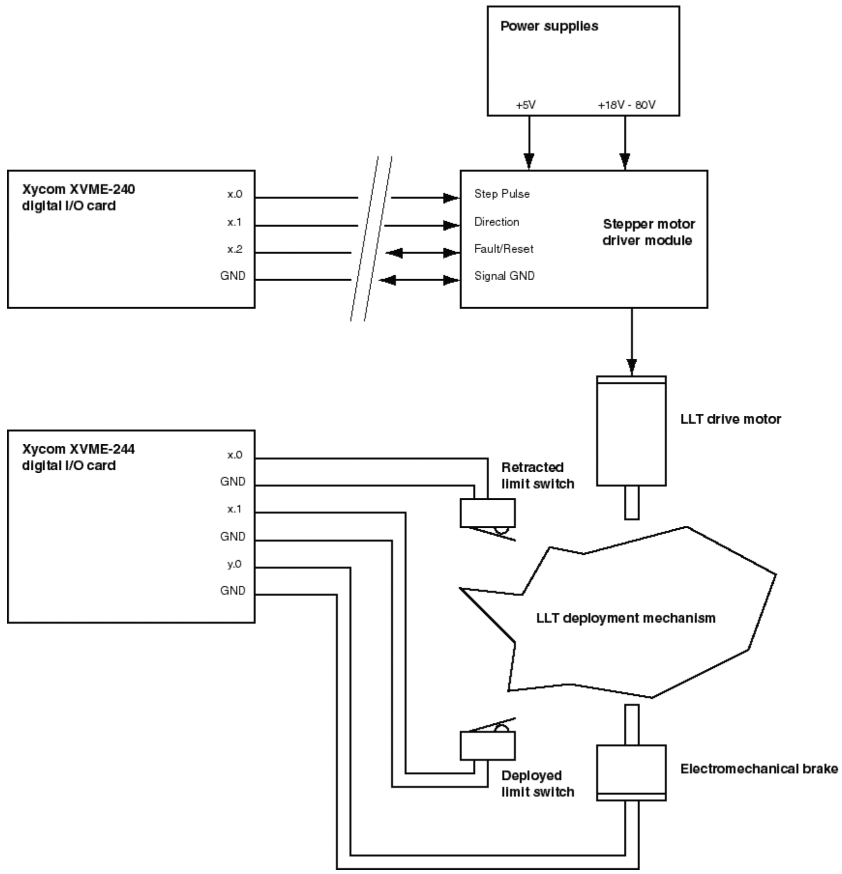

Figure 4: LLT drive interface

5.2 Beam shutter flip-mirrors

This and other simple solenoid-based mechanisms may be driven directly from a XVME-244. This card is capable of supplying up to 400mA at 30V.

Quantity	Part No.	Description	Note
1	XVME-244	64-channel isolated digital I/O module	2 of 64 channels for driving flip-mirror solenoids

Table 2: Beam shutter hardware requirements

5.3 Beam rotation optics

This mechanism rotates a set of optics to maintain correct orientation of the guide stars as the telescope tracks. Motion is therefore analogous to that of the Cassegrain rotator and must be precise. A geared stepper motor system is unsuitable due to poor angular resolution and vibration, so a brushless DC servomotor with an appropriate encoder would be used to close a velocity loop.

Quantity	Part No.	Description	Note
1	XVME-531	16-channel analogue output module	1 of 16 channels drive amplifier input
1	TBD	Brushless DC PWM amplifier	Drives rotation optics
1	TBD	Optical shaft encoder	Closes velocity loop in

			amplifier

Table 3: Beam rotation optics hardware requirement

5.4 Tip/tilt & steering mirrors

The tip/tilt and steering mirrors are under the closed-loop control of the VME system, which generates steering commands for the mirrors based on beam position information read from analogue sensors comounted with the steering mirrors. The system diagram for one mirror and position sensor is shown in Figure 5.

Quantity	Part No.	Description	Note
4	TBD	θ_x, θ_y tip/tilt stage	Tip/tilt of M2, M3, M6 and M7
8	TBD	LVPZT drive amplifier	Drives tip/tilt stage actuators
1	XVME-566	32-channel analogue input module	4 of 16 differential channels read beam position sensors
1	XVME-531	16-channel analogue output module	8 of 16 channels drive amplifier inputs
2	TBD	Lateral-effect Position Sensing Detector	Generate beam position feedback
2	None	PSD electronics module	In-house electronics module for PSD interfacing

Table 4: Tip/tilt & steering mirror loop hardware requirement

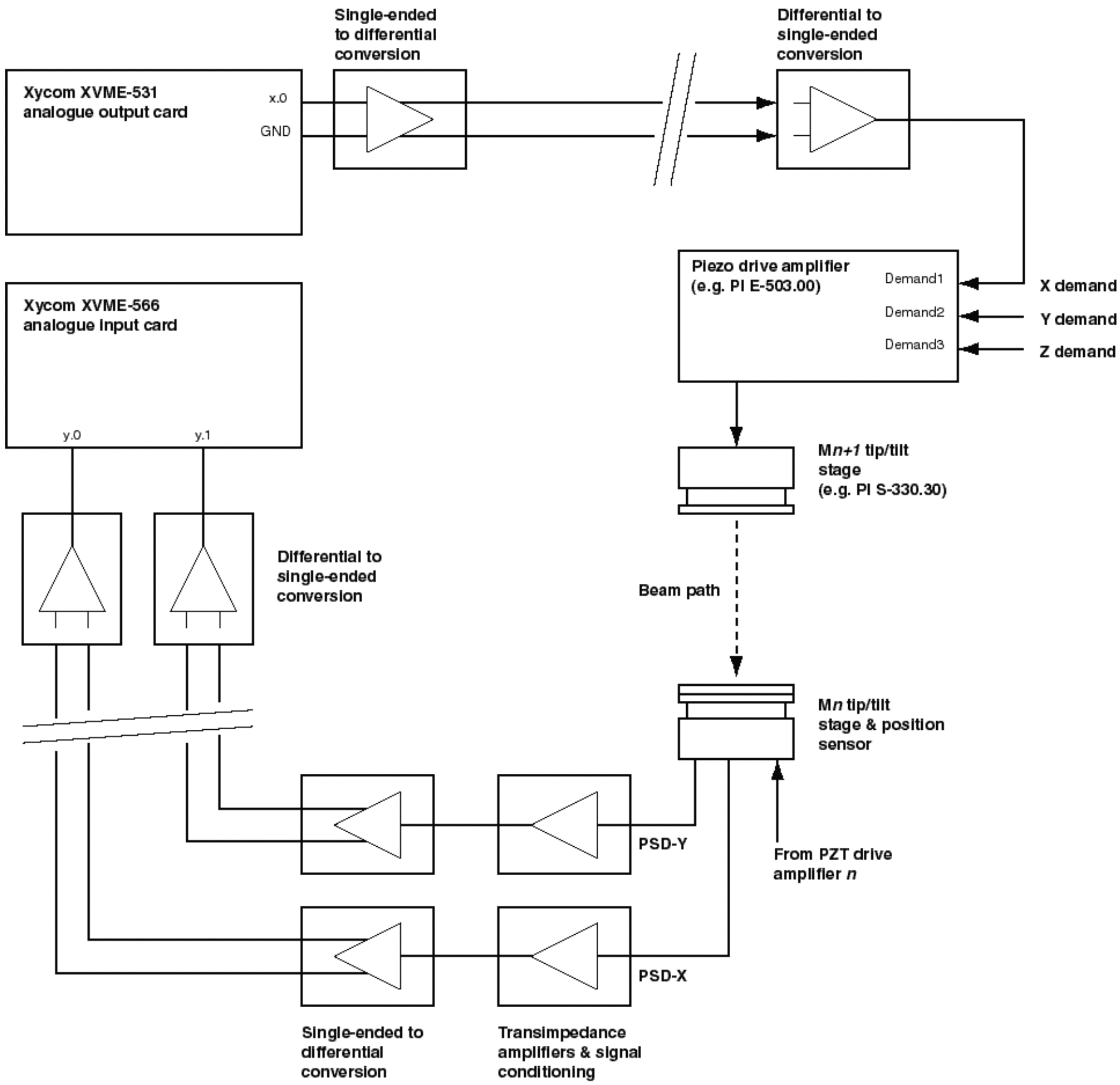

Figure 5: Steering mirror interface electronics

6. Inventory

Below is an outline inventory of the BTO electronics. This is an estimate based on the system requirements as outlined in the preceding sections. In the case of the VME boards the unused percentage of each may be freely assigned to other MCAO subsystems.

VME Cards			
Quantity	Part No.	Description	Approx. % Used
1	XVME-240	TTL I/O module	5%
1	XVME-244	64-channel isolated digital I/O module	6%
1	XVME-566	32-channel analogue input module	13%
1	XVME-531	16-channel analogue output module	57%

Mirror Positioning Stages & Drivers			
Quantity	Part No.	Description	Function
4	TBD	Tip/tilt PZT micropositioning stage	Tip/tilt stage for BTO mirrors M2, M3, M6 and M7

Stepper Motor Drivers			
Quantity	Part No.	Description	Function
1	TBD	Microstepping stepper motor driver module	Drives stepper motor in the LLT

Beam Position Sensing Detectors			
Quantity	Part No.	Description	Function
2	TBD	Lateral-effect PSD	Detection of laser beam position, for beam steering loop closure

7. References

1. *ICD 13 – Standard Controller*, Gemini Controls Group Interface Control Document; B. Goodrich, A. Johnson, 1994.
2. *Physik Instrumente Product Catalogue*, 1998.

8. Manufacturers & suppliers

8.1 Position Sensing Detectors

1. UDT Sensors, Inc.: *http://www.udt.com/*
2. SiTek: *http://www.sitek.se/* (U.S. distributor is *http://www.on-trak.com/*)
3. Melles Griot: *http://www.mellesgriot.com/*
4. Analog Modules, Inc.: http://www.analogmodules.com/
5. Coherent Auburn Group: http://www.cohr.com/

8.2 Piezoelectric micropositioning stages

1. Physik Instrumente: *http://www.physikinstrumente.com*
2. Burleigh Instruments: http://www.burleigh.com/Pages/pztact.htm

8.3 VME cards

1. Xycom Automation: http://www.xycom.com/products/vmebus/
2. Oregon Micro Systems, Inc.: http://www.omsmotion.com/

8.4 Motors and drives

3. Centent Co.: http://www.centent.com/