University of Durham
Astronomical Instrumentation Group

Design Proposal for Gemini South Adaptive Optics

Proposed Architecture for a Multi-Conjugate Deformable Mirror Drive System

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April 2001

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1 : Introduction

This report contains a proposed architecture for the deformable mirror drive system for the Gemini South Adaptive Optics (GSAO) system. The overall space envelope for the drive system is described along with the associated thermal load and power supply requirements. A summary of the design of the high voltage amplifier cards and associated DAC and DAC Interface cards is included.

The proposed architecture is based on a modular design allowing common spare cards to be used for all three mirror drive systems. The physical size and relative location of the amplifier and DAC cards have been carefully considered to allow effective forced air cooling of the system.

Aspects of the design upon which this report is based are the intellectual property of the University of Durham. This information is provided to Gemini for the sole purpose of the Preliminary Design Review of GSAO and must not be used for other purposes or commercial exploitation by Gemini or any other parties.

Summary of space envelope requirements

The space envelope occupied by the drive system will be approximately 45U of 19" cabinet space at a minimum depth of 483mm. The 241 actuator mirror drive will occupy 9U (6U for the high voltage amplifier cards and 3U for the associated DAC cards and DAC Interface card). The 468 and 349 actuator mirror drives will occupy 18U each (12U for the high voltage amplifiers and 3U+3U for the associated DAC cards and DAC Interface cards). The complete drive system will weigh approximately 148 kg.

Summary of heat load and mains power requirements

The total heat load created by the complete drive system and the corresponding mains power requirement will be approximately 820 W. Forced air cooling of the drive system should be provided at 10 m^3/min and at a maximum temperature of 40°C to avoid excessive heat build-up within the amplifiers.

2: Drive System Architecture

The essential features of the drive system for Gemini South Adaptive Optics comprise:

1) High voltage amplifier cards which supply the drive signals to individual deformable mirror actuators
2) DAC cards which provide the analog input signals to the high voltage amplifiers
3) DAC Interface card which routes the digital data from the real-time control system to individual DAC cards.

Drive System Architectural Overview

The architecture of the drive system is summarized in Fig. 1.

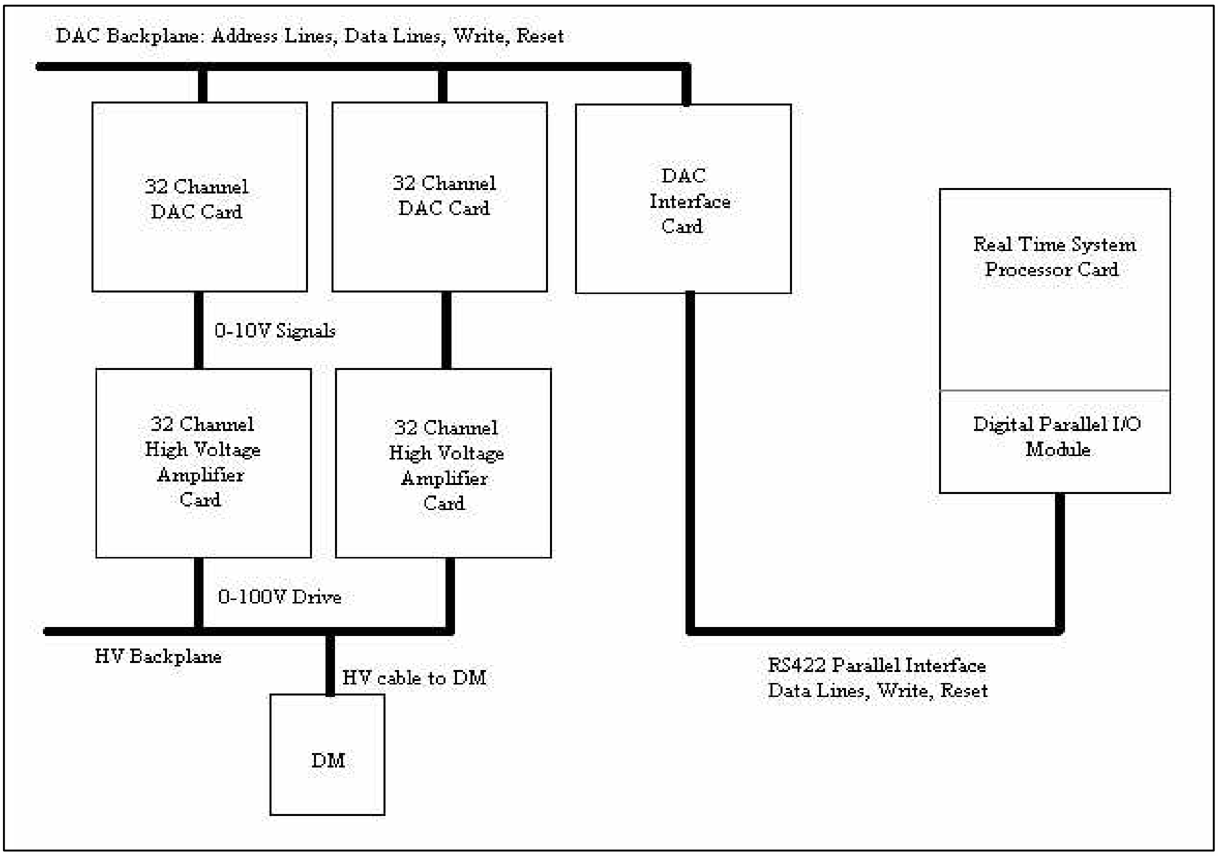

Figure 1: Drive System Overview

Drive System Space Envelope

The space envelope of the drive system is summarized in Fig. 2. The full AutoCAD 2000 drawing is available at: http://star-www.dur.ac.uk/~pclark/mcaodmsys.dwg

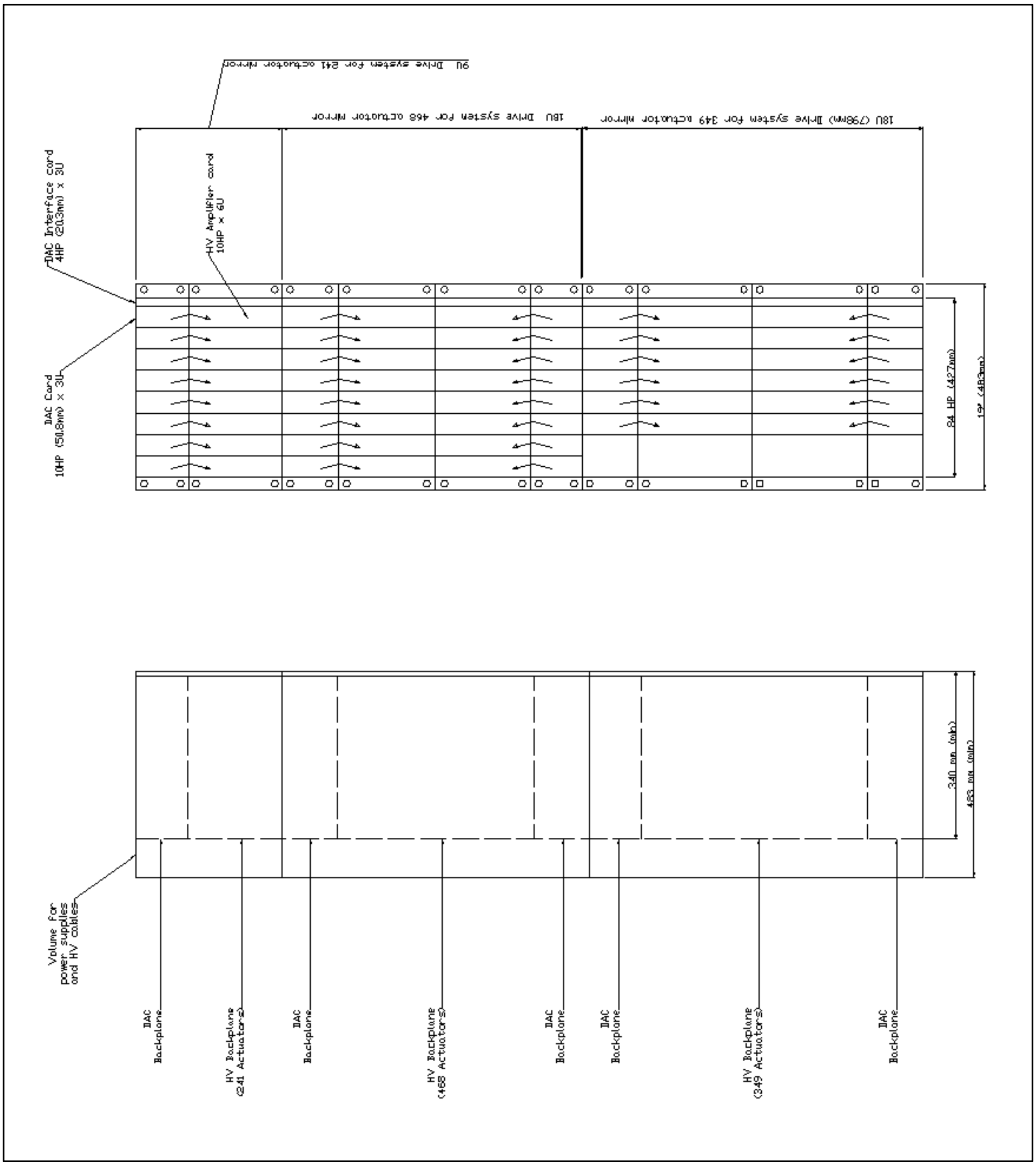

Figure 2: Drive System Space Envelope

3: High Voltage Amplifier Card

The high voltage drive system for GSAO will be required to drive three deformable mirrors with 349, 468 and 241 actuators respectively. The mirrors are likely to be procured from Xinetics Inc. (Devens, MA). Xinetics mirrors are currently manufactured using lead-magnesium-niobate actuators which have an operating voltage of 0-100V and a typical capacitance of 1.85µF. This places non-trivial requirements on the mirror drive system which must be capable of moving the actuators at frequencies up to 1kHz (at limited stroke).

Based on Durham's own experience with Xinetics mirrors, and the successful development of a drive system for a 97 actuator mirror, we propose an design based on Apex Microtechnology (http://www.apexmicrotech.com) PA41 high voltage amplifiers.

The heat and power load calculations have been based on the use of Apex PA41 amplifiers driving Xinetics' current deformable mirrors. At the time of writing, Gemini are considering Xinetics' new 'Photon Module' mirrors for GSAO. Provided the operating voltage and actuator capacitance of the new mirrors does not differ substantially from the current design then this proposed architecture should remain valid. If these figures are substantially different then the proposed design will need to be reconsidered. In any event, it would be wise to re-make the calculations upon which this report is based when the actuator characteristics are available.

High Voltage Amplifier Card Design

The PA41 amplifiers are housed in 8-pin TO3 packages. These devices must be forced air cooled to prevent damage due to heat build-up in all but the most docile of applications. The devices have a low but significant typical quiescent current of 1.6mA (2mA max). Operating from a 112V supply (to allow 100V p-p output) the devices dissipate 0.22W continuously.

Apex can provide a number of heatsinks to suit the PA41 depending on the target application. Having taken the demands which will be placed on the amplifiers into consideration (see 'Amplifier Power Dissipation' below) the smallest heatsink (HS09) will suffice. This heatsink is only slightly larger than the TO3 package footprint and stands approximately 20mm above the PCB. Taking into consideration: the height of the heatsink; the fact that components will need to be mounted on both sides of the circuit board; and that clearance will be required between adjacent cards for ventilation, it is proposed that each amplifier card occupy a rack width of 10HP (50.8mm).

The footprint of the HS09 heatsink is 42mm x 32mm (13.4cm^2). Allowing space outside this for the other amplifier circuit components and signal traces, the final footprint of each amplifier circuit is approximately 47.5mm x 47.5mm (22.5cm^2). Designing the card around the height of a standard VME card (6U, 233.3mm) 32 amplifiers can be placed on a card 340mm deep (a standard depth for 19" mounted cards). The selection of 32 amplifiers per card is based on the availability of 8-channel 14-bit DAC chips which will provide the signals to the amplifiers.

A standard 19" rack will allow eight of these amplifier cards to be placed next to each other, providing 256 amplifier channels in total. Thus the 241 actuator mirror can be driven from a single rack. The 349 and 468 actuator mirrors will require a dual height (12U) rack to hold the 11 and 15 amplifier cards respectively. It may be more effective to make use of 12 and 16 cards for the two larger mirrors when the wiring of the inter-actuator protection diodes is taken into consideration.

Inter-Actuator Protection

An essential feature of the drive amplifier design is the ability to limit inter-actuator stroke (<2µm for Xinetics' current deformable mirrors). If adjacent actuators are given demands which exceed this figure then there is the risk of detaching one or more actuators from the rear of the mirror surface.

Inter-actuator protection can be implemented using transient suppression type diodes. These devices act like bi-directional zener diodes, the voltage of which can be chosen to match the inter-actuator limit. The wiring of these diodes does present a challenge however, and necessitates the use of a backplane to cross-wire all adjacent actuators. When considering this cross-wiring it may be advantageous to use additional 'redundant' amplifier channels (mentioned above) to allow the cross-wiring to be routed in a symmetrical, non-chaotic manner.

Amplifier Circuit Design

The PA41 amplifier circuit design used by Durham is based upon the schematic shown in Fig. 3.

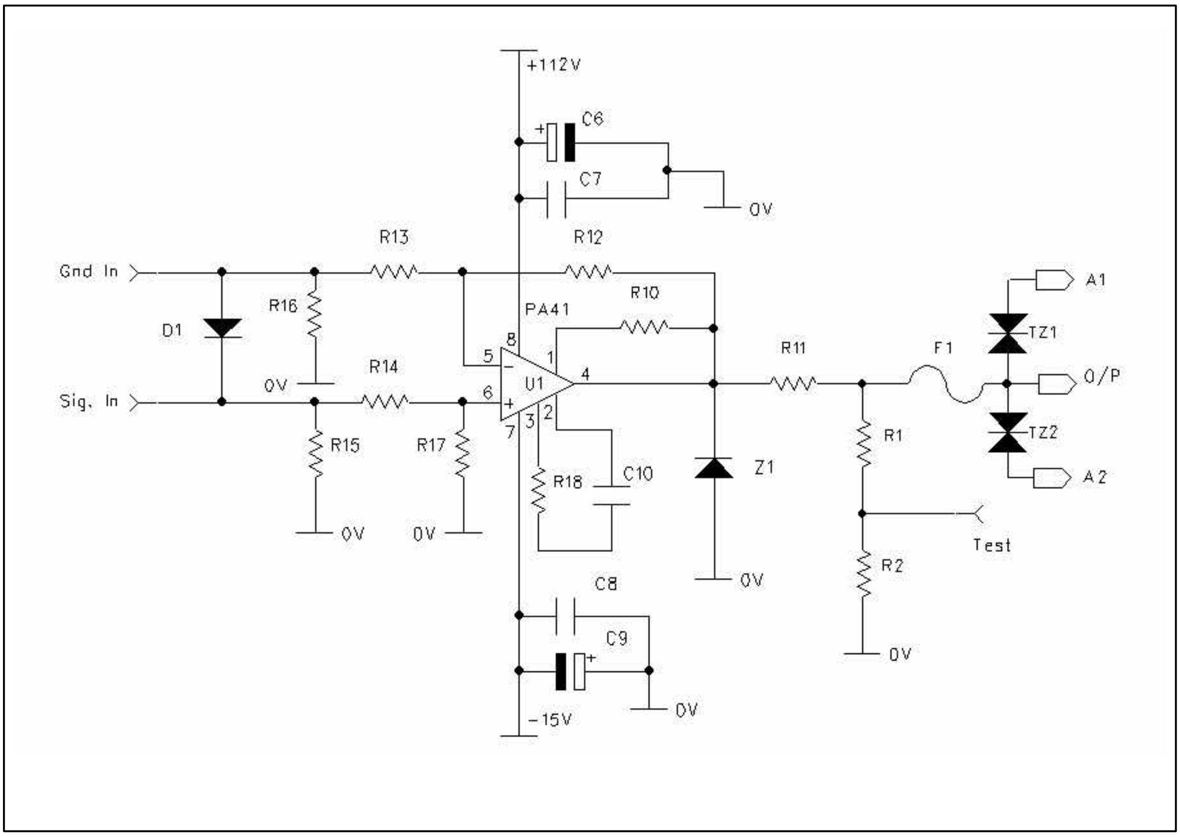

Figure 3: High Voltage Amplifier Schematic

D1 is a zener diode providing over-voltage and reverse polarity protection to the input of the circuit.
R15 and R16 provide input impedance.
R12, R13, R14 and R17 set the gain of the amplifier circuit (x10).
R10 sets the amplifier current limit.
R18 and C10 provide phase compensation.
C6 – C9 provide supply rail decoupling.
Z1 is a zener diode providing over-voltage and reverse output protection to the output of the circuit.
R11 limits the amplifier output current.
R1 and R2 divide the 100V output to a safe level for monitoring.
F1 provides short circuit and inter-actuator protection.
TZ1 and TZ2 provide inter-actuator protection to adjacent actuators.

Amplifier Power Dissipation

Gemini have provided figures for the worst case PSD demands (70% turbulence strength conditions at 60º pointing) that will be placed on individual DM actuators. These figures are shown in the first four columns of Table 1 and are single-sided microns_of_wavefront^2/Hz.

To convert these PSDs into actuator demands and then into amplifier power dissipation the following steps were followed. The amplifier power dissipation is heavily dependant on signal amplitude and frequency, so the final integration is not performed until after discrete power calculations have taken place.

1) Multiply each PSD by ([Sec 11] /2)^2 = 0.2594 to give microns_of_mirror^2/Hz (to allow for the 11º angle of incidence and reflective path length).
2) Perform a simple numerical integration of each DM PSD with frequency: $((DM{:}f_n + DM{:}f_{n+1})/2) * (f_{n+1} - f_n)$ resulting in discrete values of microns_of_mirror^2.
3) Sum these values over several frequency bands and take the square root to give RMS values of microns_of_mirror. The use of a larger number of frequency bands was explored but was found to have no significant effect on the power dissipation.
4) The RMS strokes from step 3 are actually +/- values. Multiplying these values by 2 gives the amplitude of the AC component of the DM signal. Thus the subsequent power dissipations are based on RMS values representative of "long term" behaviour.
5) Multiply the strokes by 18.3 (V/micron from Xinetics data) to give peak-peak amplifier voltage demands.
6) Calculate the amplifier power dissipation for these demands at the corresponding maximum frequencies using the power design spreadsheet (see below).
7) Remove the quiescent power component (Piq) from these values, sum and then add Piq once to calculate the total power dissipation per amplifier.
8) Multiply the power dissipation by the number of active channels and add the quiescent component from unused channels for each mirror to give the total system power dissipation.

Table 1 shows the PSD information supplied by Gemini and the corresponding discrete RMS microns_of_mirror actuator demands. The full Excel spreadsheet is available at:
http://star-www.dur.ac.uk/~pclark/psd_70_60.xls

Table 2 shows the discrete microns_of_mirror demands, the corresponding amplifier voltages, the discrete and total amplifier power dissipation values and the total system power dissipation. The full Excel spreadsheet is available at:
http://star-www.dur.ac.uk/~pclark/power_70_60.xls

Frequency	DM1 (Microns_ wavefront^ 2/Hz)	DM2 (Microns_ wavefront^ 2/Hz)	DM3 (Microns_ wavefront^ 2/Hz)	DM1 (Microns_ mirror^2)	DM2 (Microns_ mirror^2)	DM3 (Microns_ mirror^2)		DM1 (RMS Microns_ mirror)	DM2 (RMS Microns_ mirror)	DM3 (RMS Microns_ mirror)
1.00E-02	7.93E-01	1.60E-01	7.75E-02	5.33E-04	1.07E-04	5.21E-05	0-2Hz	5.36E-01	2.51E-01	2.00E-01
1.26E-02	7.93E-01	1.60E-01	7.75E-02	6.70E-04	1.35E-04	6.55E-05				
1.59E-02	7.93E-01	1.60E-01	7.75E-02	8.43E-04	1.70E-04	8.24E-05				
2.00E-02	7.93E-01	1.60E-01	7.75E-02	1.06E-03	2.14E-04	1.04E-04	2-10Hz	1.90E-01	1.02E-01	1.88E-01
2.51E-02	7.93E-01	1.60E-01	7.75E-02	1.34E-03	2.70E-04	1.31E-04				
3.16E-02	7.93E-01	1.60E-01	7.75E-02	1.68E-03	3.40E-04	1.65E-04				
3.98E-02	7.93E-01	1.60E-01	7.75E-02	2.12E-03	4.28E-04	2.07E-04	10-100Hz	4.84E-02	2.59E-02	5.02E-02
5.01E-02	7.93E-01	1.60E-01	7.75E-02	2.67E-03	5.38E-04	2.61E-04				
6.31E-02	7.93E-01	1.60E-01	7.75E-02	3.36E-03	6.77E-04	3.28E-04				
7.94E-02	7.93E-01	1.60E-01	7.75E-02	4.23E-03	8.53E-04	4.13E-04	100-1000Hz	2.97E-03	1.59E-03	3.08E-03
1.00E-01	7.93E-01	1.60E-01	7.75E-02	5.33E-03	1.07E-03	5.21E-04				
1.26E-01	7.93E-01	1.60E-01	7.75E-02	6.70E-03	1.35E-03	6.55E-04				
1.59E-01	7.93E-01	1.60E-01	7.75E-02	8.43E-03	1.70E-03	8.24E-04				
2.00E-01	7.93E-01	1.60E-01	7.75E-02	1.06E-02	2.14E-03	1.04E-03				
2.51E-01	7.93E-01	1.60E-01	7.75E-02	1.34E-02	2.70E-03	1.31E-03		DM Microns_wavefront^2/Hz figures supplied by Gemini		
3.16E-01	7.93E-01	1.60E-01	7.75E-02	1.68E-02	3.40E-03	1.65E-03		DM Microns_mirror^2 calculated using (((Sec (11)/2)^2) * (DM:f[n] + DM:f[n+1])/2) * (f[n+1] - f[n])		
3.98E-01	7.93E-01	1.60E-01	7.75E-02	2.12E-02	4.28E-03	2.07E-03				
5.01E-01	7.93E-01	1.60E-01	7.75E-02	2.67E-02	5.38E-03	2.61E-03				
6.31E-01	7.93E-01	1.60E-01	7.75E-02	3.36E-02	6.77E-03	3.28E-03				
7.94E-01	7.93E-01	1.60E-01	7.75E-02	4.14E-02	8.53E-03	4.13E-03				
1.00E+00	7.59E-01	1.60E-01	7.75E-02	3.93E-02	9.31E-03	5.20E-03				
1.26E+00	4.11E-01	1.17E-01	7.75E-02	2.68E-02	7.64E-03	6.55E-03				
1.59E+00	2.22E-01	6.35E-02	7.74E-02	1.82E-02	5.20E-03	8.23E-03				
2.00E+00	1.20E-01	3.43E-02	7.74E-02	1.24E-02	3.55E-03	9.87E-03				
2.51E+00	6.50E-02	1.86E-02	6.98E-02	8.44E-03	2.41E-03	9.06E-03				
3.16E+00	3.52E-02	1.00E-02	3.77E-02	5.75E-03	1.64E-03	6.17E-03				
3.98E+00	1.90E-02	5.43E-03	2.04E-02	3.91E-03	1.12E-03	4.20E-03				
5.01E+00	1.03E-02	2.93E-03	1.10E-02	2.66E-03	7.59E-04	2.85E-03				
6.31E+00	5.53E-03	1.58E-03	5.93E-03	1.80E-03	5.15E-04	1.93E-03				
7.94E+00	2.98E-03	8.50E-04	3.19E-03	1.22E-03	3.48E-04	1.31E-03				
1.00E+01	1.60E-03	4.56E-04	1.71E-03	8.22E-04	2.35E-04	8.82E-04				
1.26E+01	8.52E-04	2.43E-04	9.14E-04	5.51E-04	1.57E-04	5.91E-04				
1.59E+01	4.51E-04	1.29E-04	4.84E-04	3.65E-04	1.04E-04	3.92E-04				
2.00E+01	2.36E-04	6.74E-05	2.53E-04	2.40E-04	6.85E-05	2.57E-04				
2.51E+01	1.21E-04	3.47E-05	1.30E-04	1.54E-04	4.39E-05	1.65E-04				
3.16E+01	6.09E-05	1.74E-05	6.53E-05	9.60E-05	2.74E-05	1.03E-04				
3.98E+01	2.95E-05	8.44E-06	3.17E-05	5.78E-05	1.65E-05	6.21E-05				
5.01E+01	1.37E-05	3.92E-06	1.47E-05	3.33E-05	9.52E-06	3.58E-05				
6.31E+01	6.07E-06	1.73E-06	6.51E-06	1.82E-05	5.21E-06	1.96E-05				
7.94E+01	2.55E-06	7.28E-07	2.73E-06	9.51E-06	2.72E-06	1.02E-05				
1.00E+02	1.02E-06	2.90E-07	1.09E-06	4.72E-06	1.35E-06	5.06E-06				
1.26E+02	3.88E-07	1.11E-07	4.17E-07	2.25E-06	6.42E-07	2.41E-06				
1.59E+02	1.43E-07	4.10E-08	1.54E-07	1.04E-06	2.96E-07	1.11E-06				
2.00E+02	5.16E-08	1.47E-08	5.54E-08	4.68E-07	1.34E-07	5.03E-07				
2.51E+02	1.82E-08	5.21E-09	1.96E-08	2.07E-07	5.93E-08	2.23E-07				
3.16E+02	6.37E-09	1.82E-09	6.84E-09	9.11E-08	2.60E-08	9.78E-08				
3.98E+02	2.21E-09	6.31E-10	2.37E-09	3.97E-08	1.13E-08	4.26E-08				
5.01E+02	7.61E-10	2.17E-10	8.16E-10	1.72E-08	4.91E-09	1.85E-08				
6.31E+02	2.61E-10	7.46E-11	2.80E-10	7.43E-09	2.12E-09	7.97E-09				
7.94E+02	8.95E-11	2.56E-11	9.61E-11	3.21E-09	9.16E-10	3.44E-09				
1.00E+03	3.06E-11	8.75E-12	3.29E-11							

Table 1: PSD Demands

Strokes calculated from psd_70_60.xls						
Freq (Hz)	DM1 RMS Stroke(um)	DM1 V pp	DM2 RMS Stroke (um)	DM2 V pp	DM3 RMS Stroke(um)	DM3 V pp
0-2	0.536	19.618	0.251	9.187	0.200	7.320
2-10	0.190	6.954	0.102	3.733	0.188	6.881
10-100	0.0484	1.771	0.0259	0.948	0.0502	1.837
100-1000	0.00297	0.109	0.00159	0.058	0.00308	0.113
	Stroke p-p = 2 * Stroke RMS					
	Vpp calculated using 18.3V/um figure from Xinetics data					
Apex spreadsheet results						
Fmax (Hz)	DM1Watt*	DM2 Watt*	DM3 Watt*			
2	0.25	0.24	0.23			
10	0.27	0.25	0.27			
100	0.30	0.26	0.30			
1000	0.27	0.25	0.27			
	* Each value includes Piq					
Total power calculation						
Piq(W)	0.22					
Freq. Band (Hz)	**DM1Watt**	**DM2 Watt**	**DM3 Watt**			
0-2	0.03	0.02	0.01			
2-10	0.05	0.03	0.05			
10-100	0.08	0.04	0.08			
100-1000	0.05	0.03	0.05			
Piq (W)	0.22	0.22	0.22			
Totals (W)	**0.43**	**0.34**	**0.41**			
Used Channels	349	468	241			
(W)	150.07	159.12	98.81			
Unused Channels	35	44	15			
(W)	7.7	9.68	3.3			
System Total (W)	**428.68**					

Table 2: Amplifier Dissipation

The heat dissipation calculations have been made using an Excel spreadsheet provided by Apex. The spreadsheet contains models of Apex various products and can be used to calculate different parameters for a variety of applications. The spreadsheet can be downloaded at: http://www.apexmicrotech.com/support/pages/design_tools.html

The parameters shown in Table 3 were used within the 'Power Design Spreadsheet' to calculate the heat dissipation.

Model	PA41
Vs	112V
Fmin	0.0001 kHz
Fmax	The desired **Frequency** in kHz
Sig	The **Amplifier Output** voltage required to provide Actuator Stroke at the desired Fmax
Sig as ?	Vp-p
Res	11.3 Ohms (from Xinetics data)
Cap	1.85 uF (from Xinetics data)
Ind	0 mH
Rcap	11.3 Ohms (from Xinetics data)
Rind	8.8E+09 Ohms (from Xinetics data)
Ta max	40 ºC
Tj max	125 ºC (only used as a warning – not used to specify the actual working junction temperature)
Tc max	85 ºC (only used as a warning – not used to specify the actual working case temperature)
Bridge ckt?	No
# of Amps in parallel?	1
Unipolar or Bipolar?	Uni-polar
Actual HS	11.7 ºC/W (taken from Apex data for HS09 heatsink in free air with unobstructed mounting)

Table 3: Parameters used in 'Power Design Spreadsheet'

Total Amplifier Power Dissipation

The total worst case amplifier power dissipation is calculated as 430W.

The total power dissipation is heavily dependent on the amplifier supply voltage. A supply of 112V has been chosen to allow a full 0-100V output from the amplifier circuit. If the supply voltage were reduced to 100V (allowing a maximum output of 88V) the total power dissipation would reduce by approximately 35W. Selecting a supply voltage of 100V would ensure that the actuators could never be subjected to voltages higher than their working limit of 100V. By using a 112V supply there is the potential for the amplifier output to overshoot beyond 100V taking the actuators beyond their working voltage limit. Since the output from the high voltage power supply can be adjusted (see next section) this issue need not delay development and production of the GSAO drive system. The supply voltage can be selected based on an assessment of the need for full stroke output versus the possibility of exceeding the actuator working voltage and increasing the worst case power dissipation.

High Voltage Power Supply

The 112V supply for the amplifiers can be provided by suitable switch mode units, such as the Schaefer C1397 100-130V 3A 400W 6U x 14HP (http://www.schaeferpower.com).

The efficiency of these supplies can be as low as 60%, which raises the likely total high voltage power requirement from 430W to **720W**.

As with all high altitude installations, the high voltage power supplies should be de-rated by at least 50%. This will certainly necessitate the use of one power supply per deformable mirror.

High Voltage System Weight Estimate

The total weight of the high voltage system is estimated at 117 kg. This figure has been estimated as follows:

Weight of Durham 25 channel HV Amp card	1.1 kg
Weight of Durham 97 channel HV cable	2.5 kg
Weight of Schaefer PSU	2.3 kg
Estimated weight of 32 channel card	1.4 kg
Estimated weight of 36 cards	50 kg
Estimated weight of 30U 19” rack & backplanes	30 kg
Estimated weight of power supplies	7 kg (3 x 2.3 kg)
Estimated weight of high voltage cables	30 kg (12 x 2.5 kg)
Estimated total weight of amplifier system	117 kg

Table 4: High Voltage System Weight Estimate

4: DAC Card

DAC Card Design

To complement the 32 channel amplifier cards, 32 channel DAC cards need to be constructed. The dimensions of these cards will be 340mm deep (to match the depth of the amplifier cards) by 3U high (standard ‘Eurocard’ height allowing adequate clearance for the 64 way output connector). The DAC cards should also have the same 10HP separation as the amplifier cards to allow unobstructed air flow through the system.

A minimum DAC resolution of 14 bits will be required to provide sub-nanometer steps over the 6µm throw of the piezo actuators. The actual step size will be 0.4nm (6µm / 2^{14}) assuming that the 14-bit DAC output can be matched closely (without overhead) to the throw of the actuator. The speed (settling time) of the DAC chips will need to be less than 1ms to match the 1kHz upper frequency requirement of the drive system.

8-channel 14-bit DAC ICs are readily available from Maxim (http://www.maxim-ic.com) in surface mount packages. The output of these devices is typically 5V. It would be advantageous to include a differential output amplifier circuit on each channel to add noise immunity to the DAC to high voltage amplifier interface. Introducing a gain of 2 into this circuit (10V output) would still allow the DAC cards to operate from a 12 or 15 V supply and would have the advantage of reducing the required gain of the high voltage amplifier to 10. Additionally, a low pass function could be included in the gain circuit to match the mirror actuator frequency response (4kHz for Xinetics’ current design).

A suggested schematic for the DAC card is shown in Fig. 4.

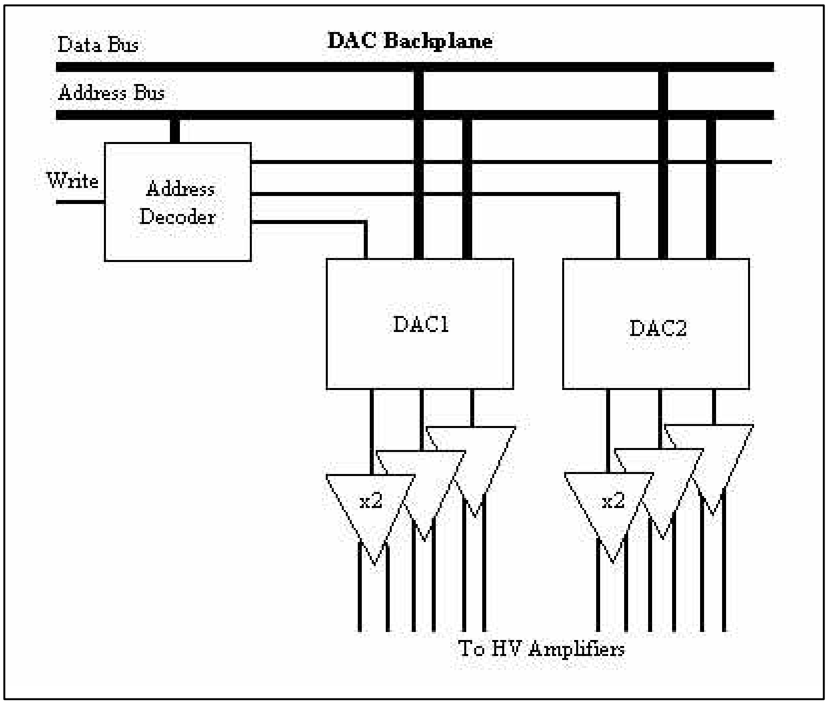

Figure 4: DAC Card Schematic

DAC Card Power Requirements

The DAC card is likely to consume 1.5W. This is estimated from the consumption of the existing Durham DAC card. Assuming a power supply efficiency of 70%, the total power consumption per card is likely to be 2.2W.

5: DAC Interface Card

DAC Interface Card Design

The DAC Interface card will be required to buffer the actuator demand data from the real-time control system to the DAC cards. The functionality of this card could include the following features:

1) RS422 reception of demand data
2) Generation of an incrementing address counter (post-write increment)
3) Broadcast of the demand addresses and data to the DAC cards via a backplane

By generating the actuator channel addresses on the DAC Interface card, the link from the real-time control system is made more efficient. The RS422 interface could simply entail the sending of a reset signal (to reset the address counter) followed by a write of all the actuator demand values in ascending order. This technique is efficient but does entail the sending of all actuator values to change a single actuator value. This should not present a problem for the real-time control system as this is likely to be computing and outputting all actuator values at a well-defined update rate. A further effect is that there will be a small delay from the writing of the first actuator value to the writing of the last. If this presents a problem and all actuator values are required to be updated simultaneously then the DAC cards could be enhanced with a ‘sample and hold’ output function synchronized by a further signal from the real-time system.

A suggested schematic for the DAC card is shown in Fig. 5.

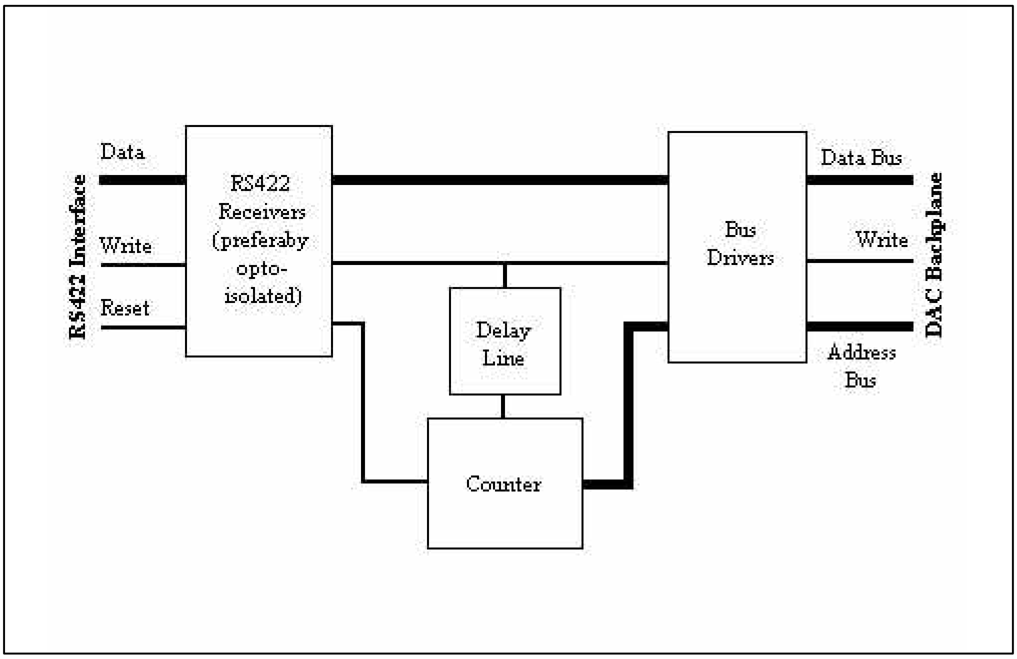

Figure 5: DAC Interface Card Schematic

The size of the DAC Interface card will be 3U high x 340mm deep. The width of the card will be 4HP allowing one DAC Interface card and eight DAC cards to be contained in the same 19” rack.

DAC Interface Power Requirements

The DAC Interface card is likely to consume 2.8W. This is estimated from the current consumption of the existing Durham interface card. Assuming a power supply efficiency of 70%, the total power consumption per card is likely to be 4W.

DAC and DAC Interface System Weight Estimate

The total weight of the DAC system is estimated at 31 kg. This figure has been estimated as follows:

Weight of Durham 32 channel 6U DAC card	275 g
Weight of Durham 6U DAC Interface card	250 g
Weight of Durham 6U 19” rack, backplane & PSUs	8.9 kg
Estimated weight of 32 channel 3U DAC card	150 g
Estimated weight of 3U DAC Interface cards	140 g
Estimated weight of 36 DAC cards	5.4 kg
Estimated weight of 15U rack, backplanes & PSUs	25 kg
Estimated weight of 5 DAC Interface cards	0.7 kg
Estimated total weight of DAC system	31 kg

Table 5: DAC System Weight Estimate

6: Summary

Total heat load and power requirement

The complete drive system is likely to generate a total power load of 820W. This comprises the power requirement figures shown in Table 6.

Individual DAC Card Power Requirement	2.2 W
Individual DAC Interface Card Power Requirement	4 W
Total DAC Power Requirement (36 cards)	80 W
Total DAC Interface Power Requirement (5 cards)	20 W
HV Amplifier Power Requirement	720 W
Total Power Requirement	820 W

Table 6: Total System Power Requirement

Total weight estimate

The complete drive system is likely to weight 148 kg. This comprises the 117 kg of the high voltage system plus the 31 kg of the DAC system.