Prototype Small Footprint Amplifier for Piezoelectric Deformable Mirrors

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Introduction

Discrete-actuator continuous-faceplate Deformable Mirrors (DM) with piezoelectric actuators are commonly used in today's Adaptive Optics (AO) installations. The high voltages required to drive these actuators through the rated travel must be provided by the Deformable Mirror Electronics (DME). The ELT class telescopes will operate AO systems with an order of magnitude higher number of actuators in the DM compared to currently deployed systems. Simple scaling up of currently offered commercial DME systems would be prohibitively large, expensive and consume excessive power.
We are investigating a high voltage amplifier which could form the basis of DME for the ELT AO systems. It must provide cost, power and volume improvements compared to commercial DME systems while meeting all AO performance criteria.

Design Objectives

- Meet AO performance requirements for bandwidth, output span, drift and linearity.
- Low-power dissipation, target of 500 mW per amplifier.
- Component cost minimization, target of $20 per channel.
- Compact design, target 1200 driver channels in a 6U case
- Actuator slew rate limiting.

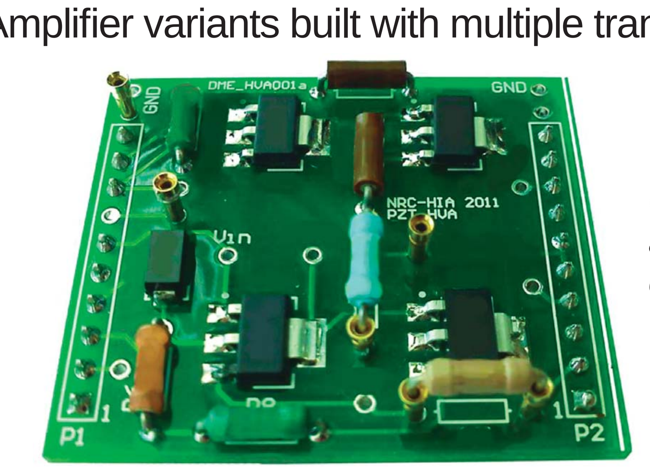
Experimental Milestones Reached

Investigation by simulation.

- Initial verification of design via simulation in SPICE.
- Optimized circuit parameters such as output range, bandwidth, power dissipation etc.

Printed circuit for amplifier investigation.

- Multiple single channel amplifier boards manufactured.
- Separate support circuitry board also built.
- Amplifier variants built with multiple transistor types



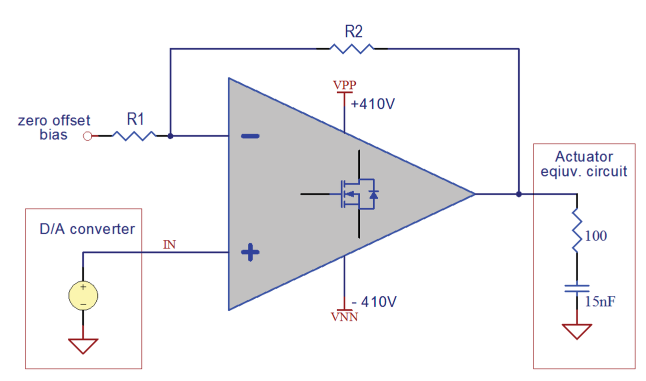
One of the prototypes assembled on a printed circuit board

Characterizing amplifier performance.

- Close correspondence found between measured and simulated behavior.
- Sufficient bandwidth achievable, up to 1.7kHz @ 38dB.
- Dissipated power of only 500 mW per amplifier achieved.

High Voltage Amplifier

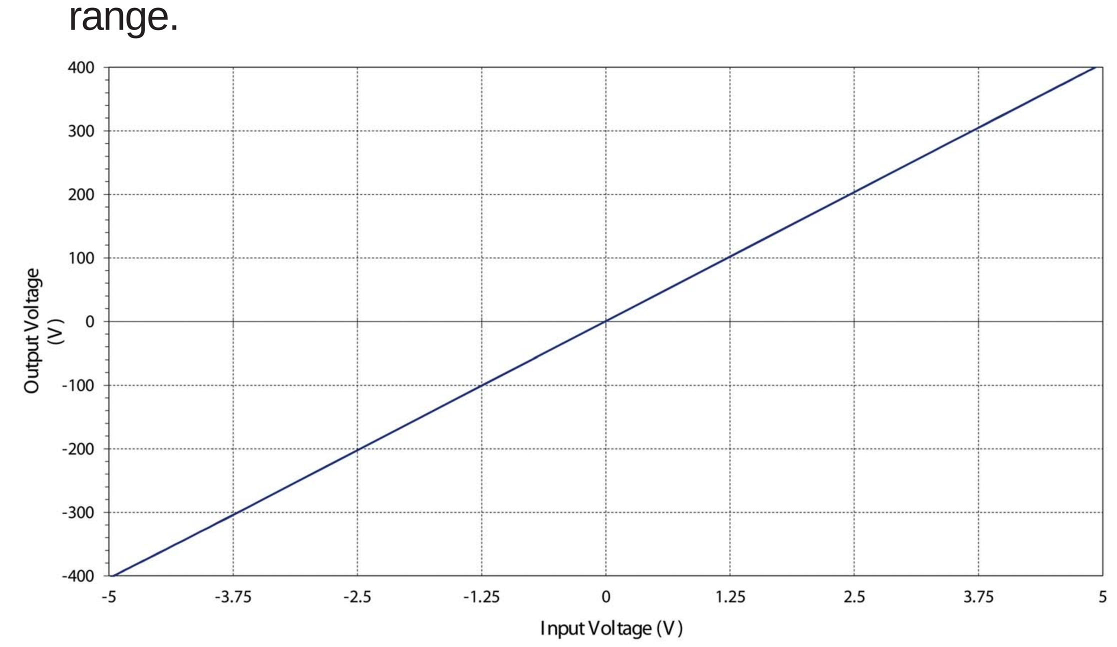
(Simplified Test Circuit)



DC Response and Output Range

Requirement: +/- 400 V output range.
Output clipped at +/- 410 V.
Linear response attained due to feedback.

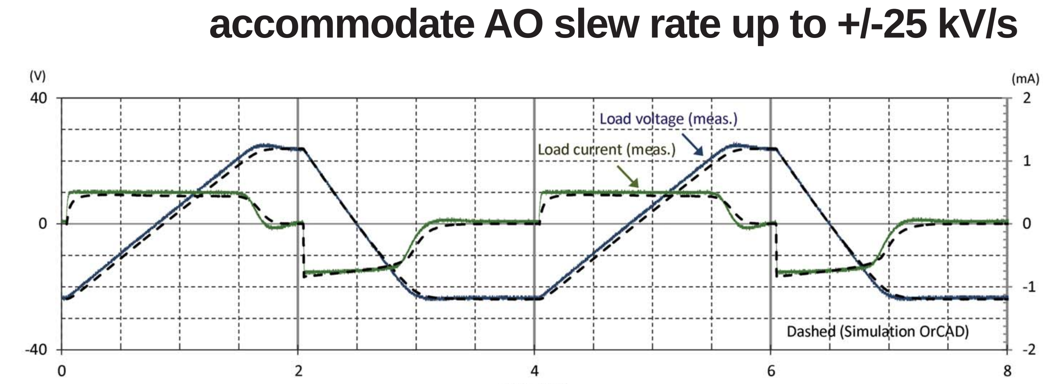
- Closed-loop gain is set arbitrarily via feedback resistors.
- Target gain of 80 (38 dB) for compatibility with +/-5 V drive signal typical to digital-to-analog converters.
- Proved highly linear, +/-0.5 % of full-scale across output range.



Actuator Slew Rate Limiting

Safe operation of piezoelectric DM actuators requires the DME to limit the voltage slew rate at a value specified by the DM manufacturer. For an AO system to function properly this limit must be higher than the maximum slew rate required by the AO control loop.

Target requirements:
hard limit slew rate below +/-100 kV/s
accommodate AO slew rate up to +/-25 kV/s



- +30 kV/s and -50 kV/s output slew rate limiting demonstrated in above figure.
- Capacity for independently programmable +/- slew rates.

Frequency Response and Bandwidth

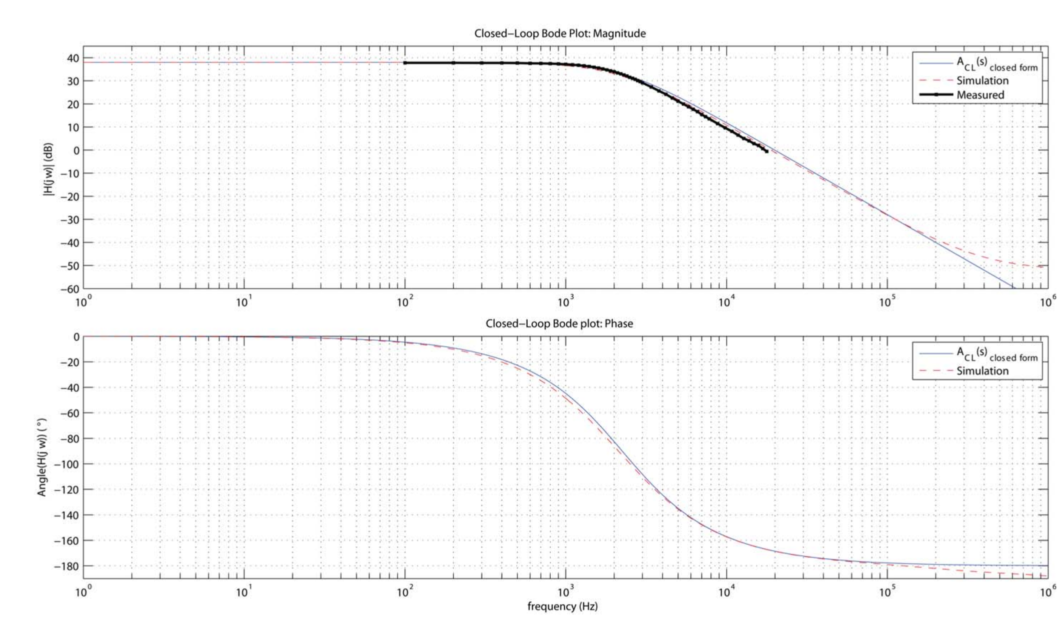
- Bandwidth of 0 to 1.7 kHz demonstrated (@ 38dB) on a dummy load of 15 nF to represent an actuator.
- Displays a second-order low-pass frequency characteristic.
- Closed-loop transfer function was determined from open-loop measurements.

$$K = 10{,}000 \quad (Open-loop\ DC\ gain)$$
$$p_1 = 10 \cdot 2\pi \quad (dominant\ open-loop\ pole)$$
$$p_2 = 4{,}000 \cdot 2\pi \quad (second\ open-loop\ pole)$$

- Large pole separation provides high gain/phase margin and ensures stability.

$$A_{CL}(s) = \frac{A_{OL}(s)}{1 + A_{OL}(s)F} = K_{DC} \cdot \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \cong 80 \cdot \frac{14{,}100^2}{s^2 + 25{,}100s + 14{,}100^2}$$

$$where\ K_{DC} = \frac{K}{1+KF} \cong 80, \quad \omega_n = \sqrt{p_1 p_2 (1+KF)} \cong 14{,}100\frac{rad}{s}, \quad \xi = \frac{p_1 + p_2}{2\omega_n} \cong 0.893$$

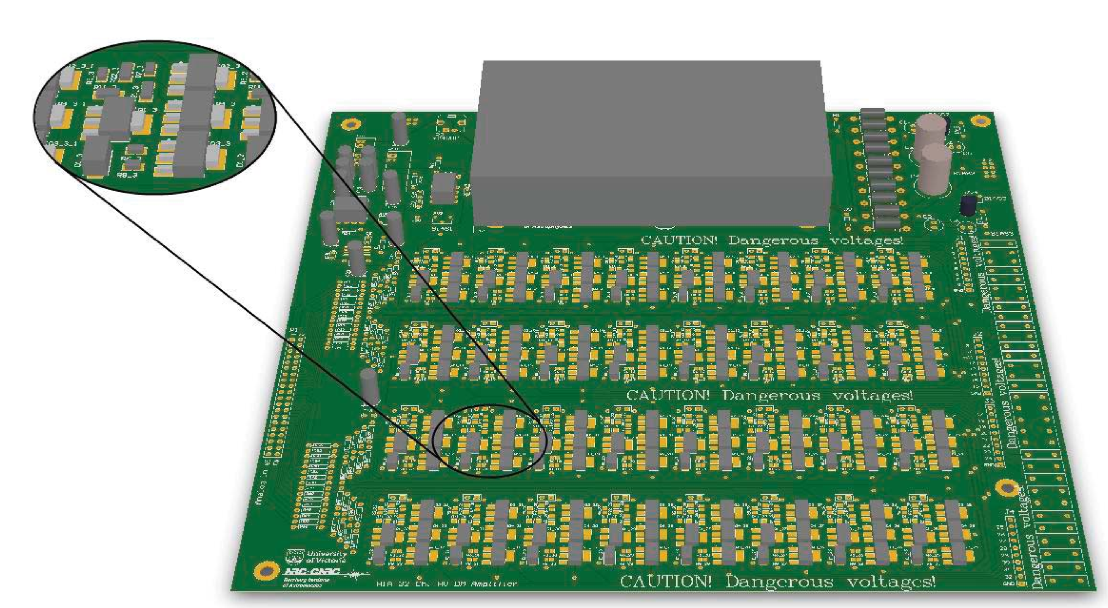


- Bandwidth can be tuned easily by moving open-loop pole p_1 via resistor variation

Current Status

Multichannel proof of concept board designed and fabricated.

- Includes 32 channels and on-board support circuits.
- Tightly arranged, using all surface-mount components.
- Allows driving multiple channels simultaneously via computer interface and digital-to-analog converter.



Future Goals

Perform experiments with 32 channel board:

- To begin immediately.
- Investigate channel crosstalk/interference issues.
- Determine gain and bandwidth variance across channels.
- Investigate reliability and failure modes.
- Test with DM actuators as load.

Final Objective:

- Design and build a high-density, 96-channel amplifier board prototype with on board DACs, diagnostics and support circuits.
- The 96-channel prototype board will be based on the Euro-card format allowing 6U VME crates to be populated with 12 boards to drive 1152 channels.

Conclusions

- AO systems for ELT telescopes will require DME of a higher channel density, lower power consumption and less cost per channel than in currently available systems.
- We have developed a discrete component linear amplifier that meets the ELT AO requirements.
- We are currently assembling a 32-channel prototype board to test 32 amplifier circuits in a realistic multi-channel operation including driving 32 piezoelectric actuators of a DM.
- We will use the 32-channel board experience to prototype a 96 channel DME module, integrating analog, digital and power supply circuits in a fully functional building block for a large scale DME system.

Acknowledgements

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