Hardware Implementation of the Primary Mirror Surface Heating System for the Gemini 8 meter Telescopes

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1. ABSTRACT

The Gemini 8m Telescopes Project is implementing two cooperating systems for thermal control of the monolithic primary mirror. The first system consists of temperature controlled radiation panels, behind the primary mirror, that are used to control the bulk temperature of the primary. The second system is the Surface Heating System which allows for adjustment of the optical surface temperature independent of the bulk mirror temperature. By heating just the reflective coating of the primary, a quicker thermal adjustment of the optical surface temperature can be achieved. The result is a minimizing of mirror seeing effects by better tracking of fluctuations in nighttime ambient temperature. A development effort and subscale prototype testing of this technique was completed by the Gemini staff in 1996 and presented at the SPIE Landskrona Conference[1]. This paper reviews the detailed hardware design and implementation of a Surface Heating System being installed on the Gemini 8-meter primary mirror.

Keywords: seeing, resistive heating, thermal control, primary mirror

2. INTRODUCTION

The principle behind the Surface Heating System is the use of the reflective optical coating as a resistive heating element; the control of current flow across the mirror surface results in a controlled increase of surface temperature above that of the primary mirror interior temperature. A Block Diagram for the Surface Heating System is shown in Figure 1. The system has the following four distinct subsystems: Mirror Electrode Interface, Secondary Voltage Distribution, Temperature Sensing, and Primary Voltage Control. Each of these, along with its design goals, is described below.

2.1 Mirror Electrode Interface Subsystem: This system is the hardware to make the electrical connections to the primary mirror reflective coating. Major design goals included: fault tolerant installation, reliability of connection, resistance to a harsh cleaning/stripping environment encountered annually, and a design which allows easy installation at the summit of 216 electrodes. It also accommodates slight variations in the geometry of the mirror edge.

2.2 Secondary Voltage Distribution Subsystem: This system is hardware to distribute the power to all 216 mirror electrodes. Current flows from the mirror electrodes across the primary, parallel to the horizon (Gemini X axis). As the distance across the mirror changes, the voltages delivered to each electrode pair must vary as a cosine function to maintain uniform power dissipation over the mirror surface. Major design goals included power efficiency and simplicity, delivered voltage accuracy, and ease of installation into the mirror cell.

2.3 Temperature Measurement Subsystem: This system is the hardware to sense the small relative temperature differences between the mirror's optical surface and adjacent ambient air temperature. Accurately relaying this temperature data to the Primary Voltage Control system is essential in order to meet performance specifications which require control of the mirror surface to within 0.2 ^{o}C warmer and 0.6 ^{o}C cooler than the surrounding air. Design goals included this temperature range and accuracy and maintaining the accuracy of these physically distributed sensors over the 8-meter mirror.

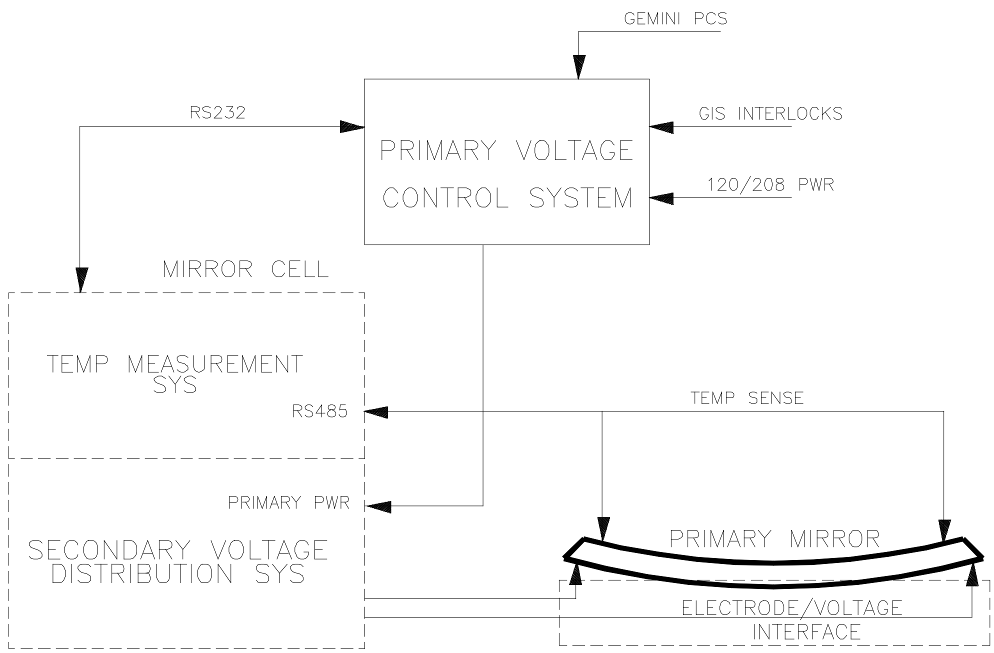


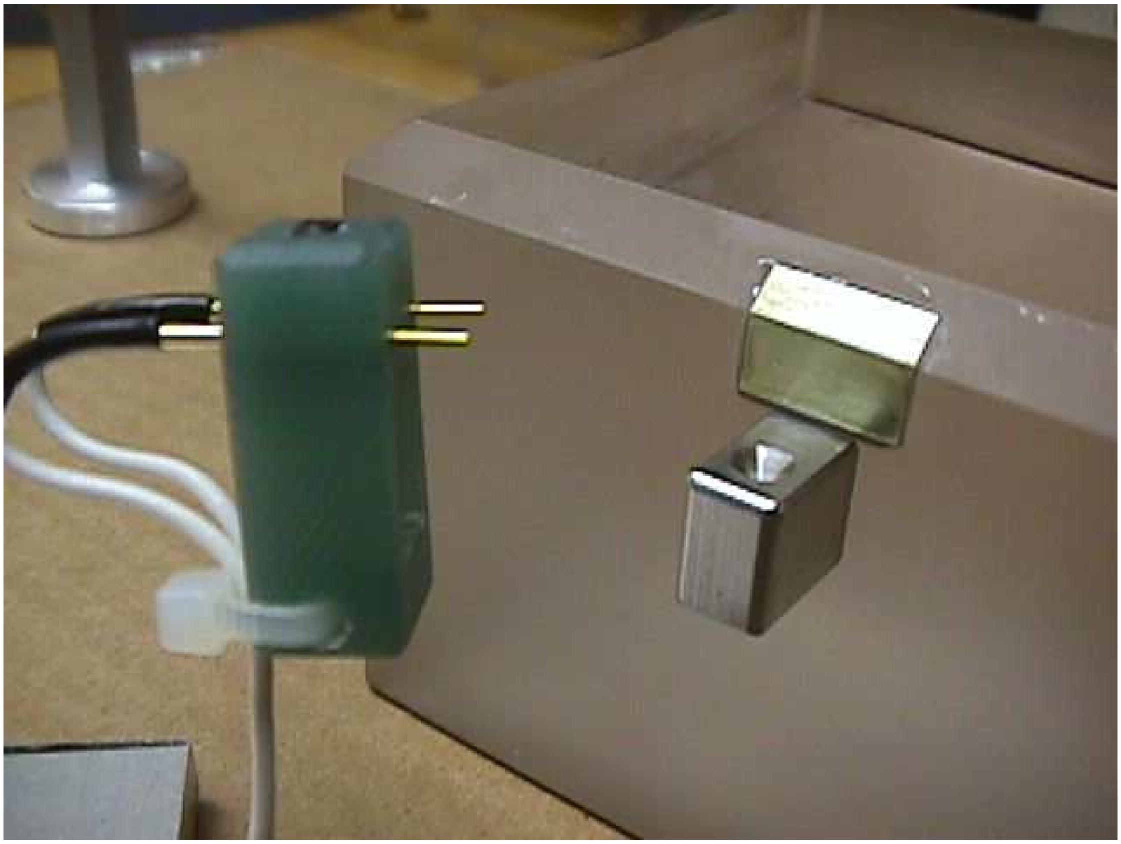
Figure 1
System Block Diagram for Gemini Surface
Heating System

2.4 Primary Voltage Control Subsystem: This system is the hardware to generate and control the voltage to the Secondary Voltage Distribution system, interface to the main telescope computer, safety interlocks, and temperature data gathering and reporting. Design goals were: using commercial off-the-shelf components, single chassis packaging, efficient power conversion, precision voltage control, and operational safety.

3. ELECTRODE INTERFACE SUBSYSTEM DESIGN

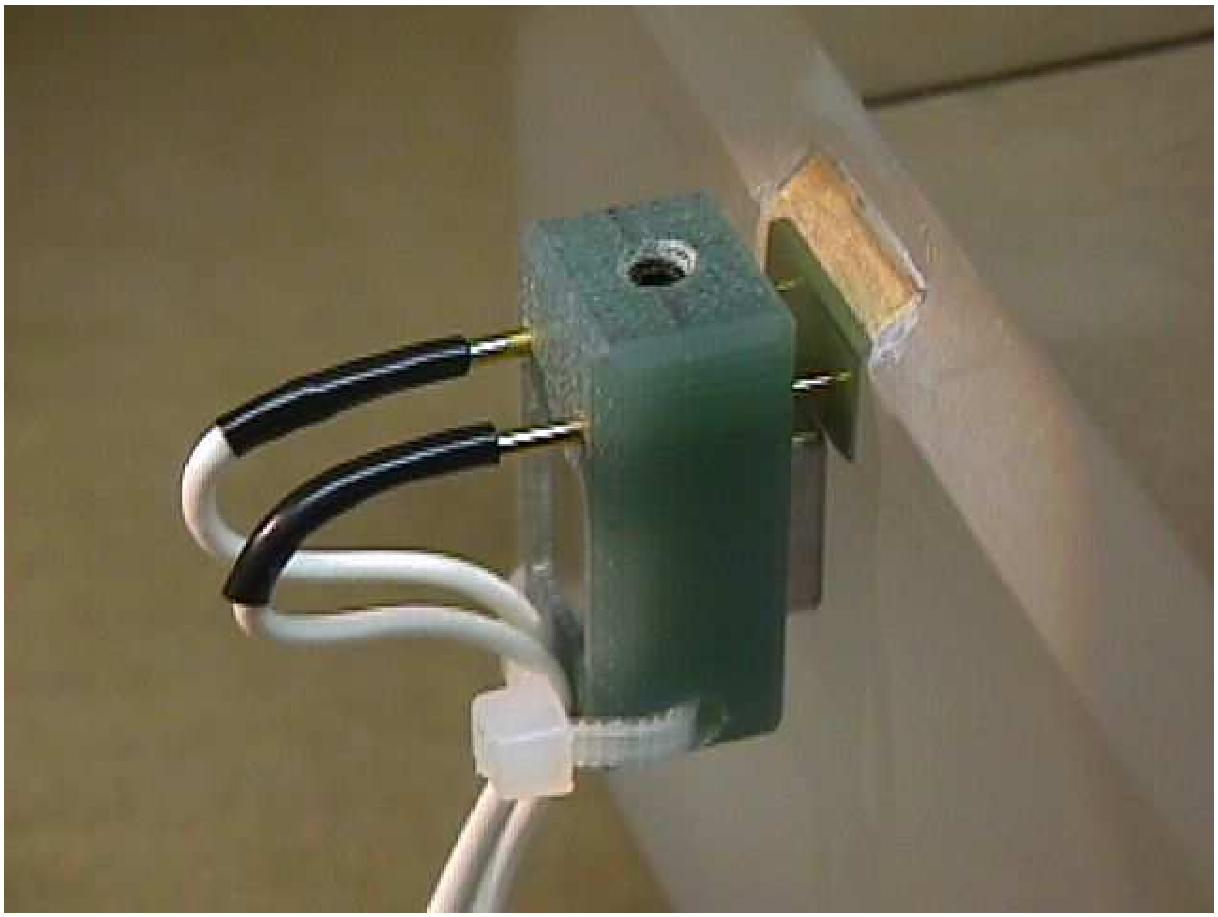
Initial development work by Rutherford Appleton Laboratories and Gemini staff on the 1 meter prototypes proved reliable electrical contact to the mirror coating could be made by bonding electrodes to an uncoated mirror first and then coating over the mirror and electrode together [1,2]. It was also found that creating a clean, smooth margin at the interface between the electrode and the glass is of the utmost importance in maintaining uniform coating thickness over the connection. An abrupt change in coating thickness must be avoided as it results in locally higher power dissipation, giving rise to localized heating at the electrode/mirror coating interface. Other design constraints included ease of installation and connection to the secondary voltage distribution system, low mass and minimizing risk of damage of the electrical connection after the coating. After testing a number of configurations, a three part design was chosen to satisfy all of the conflicting constraints. The three parts consist of the foil electrode, mounting block and spring probe holder as shown in Photographs 1 and 2; their descriptions are as follows:

3.1 The Foil Electrode is a 12mm x 10mm x 0.1mm thick piece of gold foil with a bend allowing the electrode to conform to the edge bevel of the mirror. The electrode is epoxied to the glass and the thin gold gives good conformance to the bevel / radius edge. After the epoxy has cured, the excess is trimmed with a hot knife leaving the required clean margin from electrode to glass. The close fit of the foil minimizes the risk of damage to the delicate electrode/coating electrical interface.



Photograph 1
The Foil Electrode, Mounting Block with the
Spring Probe Holder not attached.

3.2 The Mounting Block is a Nickel plated Invar part which is the anchor for the wiring from the electrode assembly to the Secondary Voltage cabling. The block has rounded corners and a small counter sink machined in the top for fastening and registering the Spring Probe holder. This block is epoxied to the mirror's conical outside surface. Since the mounting block must be compatible with the stripping, cleaning and coating process, there are no sharp edges or features which could trap cleaning fluids or create a virtual leak within the coating chamber.



Photograph 2
The Foil Electrode, Mounting Block with the
Spring Probe Holder installed

3.3 The Spring Probe holder provides the connection between the Secondary Voltage system and the electrode. Commercially available spring probes make contact with the base of the foil electrode, away from the critical coating to electrode interface. The self adjusting nature of the spring probes and the redundancy of two probes per assembly, make this connection very reliable and simple. The conical point set screw on the top of the spring probe holder seats into the counter sink of the mounting block. This makes removal or installation of the electrical connections to the mirror simple when it is taken out of the telescope for cleaning and stripping.

4. Secondary Voltage Distribution Subsystem Design

The purpose of the Secondary Voltage Distribution Subsystem is to take the power delivered by the Primary control system and distribute it to the 192 outside diameter and 24 center hole electrodes. The electrical current flow in the mirror coating is parallel to the horizon (X axis) of the primary mirror; therefore, the voltage distribution from the Y axis (minimum distance across mirror) to the X axis (maximum distance across mirror) must be a cosine function to maintain uniform surface power dissipation. For example, the closest opposing electrode pair is separated by roughly 0.26 meters and the farthest pair is separated by roughly 8 meters. The voltage distribution profile at the edge of the mirror must take this distance variation into account.

It was decided to use AC voltage for several reasons:

i) The peak power (100 watts/meter squared) is near the threshold where, with DC, metal migration might be a problem.[3]
ii) The peak power for the mirror is 5 kilowatts. Transformers can be 95% efficient which greatly eases the removing of unwanted heat from the cell.
iii) Calculations indicate that the tiny temperature fluctuations caused by the AC should not degrade the mirror even in the infrared.
iv) The power to the mirror can be controlled with a single variable transformer while the ratio of the 216 electrode voltages to each other is fixed by the secondary turn ratios.

4.1 Outside Diameter Electrode Locations: A series of custom wound, multi-secondary winding transformers are used to give a mirror outside diameter voltage profile of a quantitized cosine function. There are three different types and each is packaged in an assembly called a Heater Node Box. There are three Heater Node boxes (one of each type) per quadrant of the mirror supplying the 48 outside diameter electrodes in each quadrant. The three different transformers have 20, 16 and 12 secondary windings respectively. The Heater Node box package provides: thermal insulation, transformer cooling plates (which are connected to the Gemini mirror cell cooling system), interface connectors, and provisions for mounting the assembly within the mirror cell. Figure 2 shows the test data on Voltage Output verses Electrode Number. This test was performed as a check of proper wiring of the Heater Node Boxes. Photograph 3 shows one of the Heater Node Boxes (cover removed) as mounted in the Gemini Mirror Cell. Transformer efficiency was maximized by minimizing the number of secondary turns per winding. This resulted in the use of half turns and the need for flux balancing windings on the transformer cores.

The output voltages from the Heater Node boxes are connected to the appropriate electrode spring probe holder via cabling. To minimize voltage potentials on the primary mirror, the electrodes are divided up across the positive and negative X axis with opposite polarity of the primary supply voltage. This gives zero potential along the Y axis of the mirror. In order to minimize the possible unwanted electrical pickup of hum from the large current sheet flowing in the mirror coating, the return path for this current sheet is a set of 16 busses located as close to the back side of the mirror as feasible. This should confine most of the magnetic pickup to the interior of the glass where it obviously is not a problem. These 16 busses are connected to a common single point ground.

It is very important that both the lead for the electrode and the return lead for each winding leave the steel mirror cell through the same hole. If this is not done, then the steel of the mirror cell becomes the core of an unintended transformer, creating thermal and electrical pickup problems.

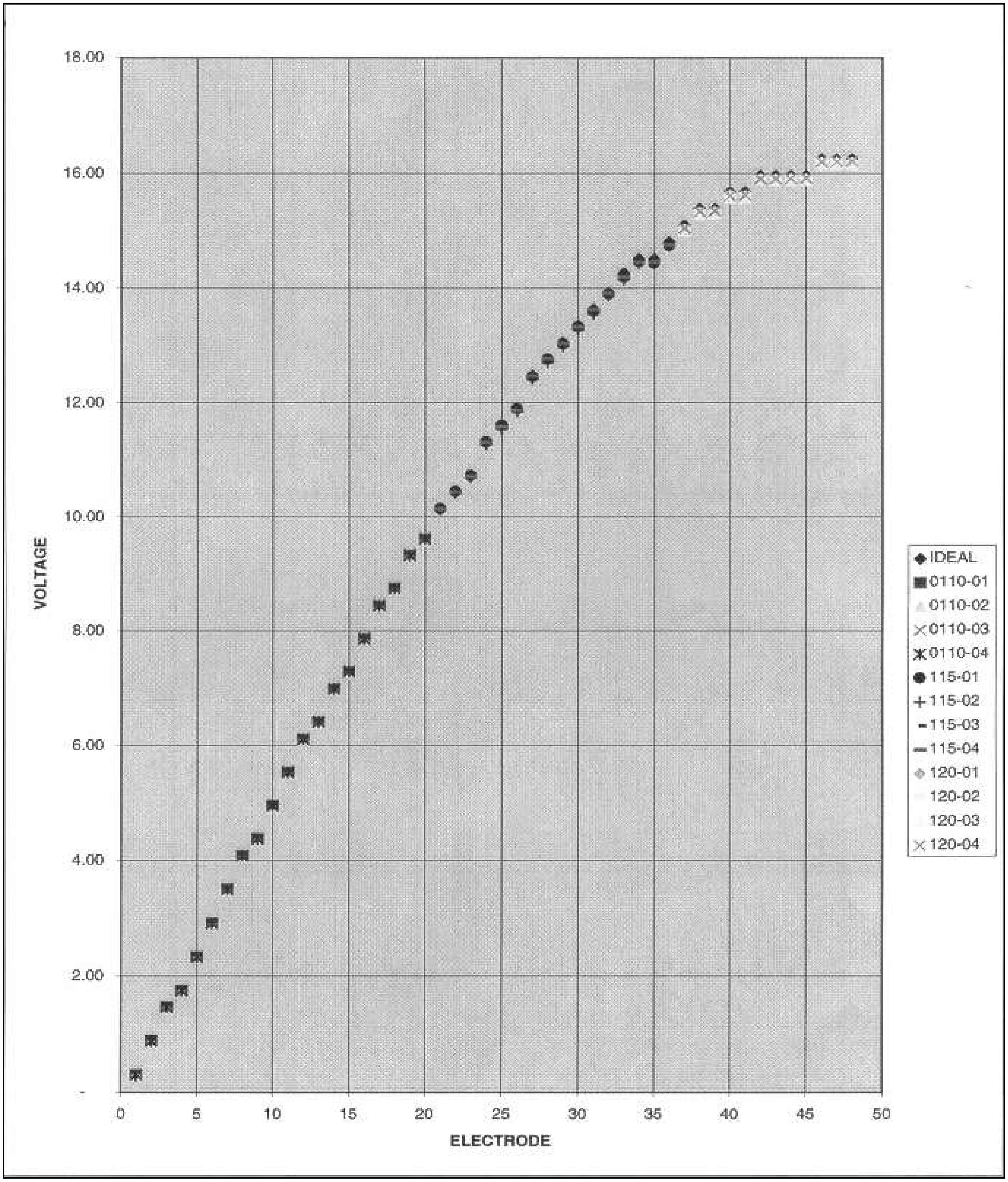
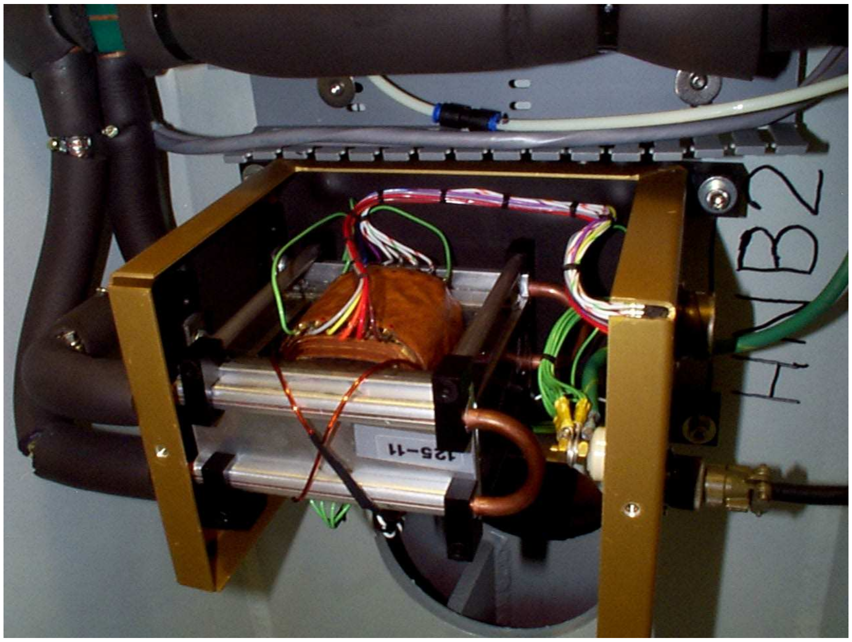


Figure 2
Voltage Output verses Electrode Number



Photograph 3
Heater Node Box (cover removed) installation within the Gemini Mirror Cell

4.2 Center Hole Electrode Locations: The absence of a mirror surface and therefore coating at the center hole causes the current to concentrate around the edge of the center hole. To compensate, electrodes transfer this excess current across the hole to the corresponding electrodes on the other side. Two additional custom transformers, each with 12 secondary windings, are used. Packaged in Heater Node Boxes in the central section of the mirror cell, these transformers take the primary supply voltage and distribute it to the 24 center hole electrodes using the secondary windings to complete the circuit across the center hole void. Figure 3 depicts the secondary winding connections across the center hole. The primary windings of the transformers are not shown.

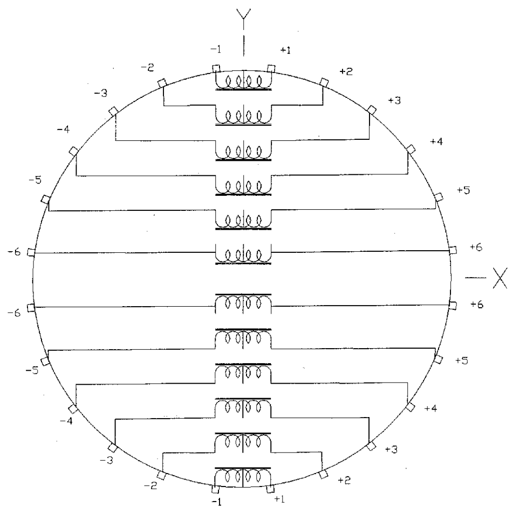


Figure 3
Center Hole Transformer Circuits to Compensate for Void

5. Temperature Sensing Subsystem

The temperature sensing subsystem for the surface heating system is based on a proven design currently in use on the Wisconsin-Indiana-Yale-NOAO (WIYN) 3.5 meter telescope at Kitt Peak, Arizona [4]. As mentioned earlier, accurate measurement and control of the mirror surface to within 0.2 ^{o}C cooler to 0.6 ^{o}C warmer of the surrounding ambient must be achieved to reduce seeing levels to within specified limits [1].

The chosen temperature sensor is a type T thermocouple, the main advantage being it is a passive device and will not inject heat into the optical coating being measured. For surface temperature measurement, a low thermal capacity micro-foil junction will be used. Reading of the junction voltage will be accomplished using commercially available milli-volt digital transmitters that have a 15-bit measurement resolution and transmit the data over RS485 computer bus. The analog to digital conversion close to the junction allows for the measurement system to have the sensors and transmitters distributed throughout the mirror cell without the risk of noise or signal loss due to line lengths. Each quadrant will have several sensors for measuring the temperature difference between the mirror surface and the adjacent air. This is a further advantage of thermocouples; they measure differences directly, rather than requiring the subtraction of relative large numbers. Other sensors will measure the temperature of the mirror back and the radiation panels. It is intended that this data will be used in a thermal model of the system, as part of the servo, which keeps the mirror surface matched to the air temperature. The Primary Voltage Control chassis houses a RS485 / RS232 converter for data gathering by the control PLC.

To mitigate the effect of offset errors of the milli-volt transmitters, a computer controlled relay will be added to the transmitter assembly to periodically reverse the input leads to the milli-volt transmitter. This allows for the system to calibrate itself in real time and virtually eliminate offset errors, which can be as high as 5 micro-volts [4]. This system has been demonstrated to reliably measure temperature differences of 0.4 micro-volts on type T thermocouples or 0.01 ^{o}C.

6. Primary Voltage Control Subsystem

This system is the hardware to: generate and control the voltage to the secondary voltage distribution system, interface to the main telescope computer (PCS), provide safety interlocks (GIS), and perform temperature data gathering and reporting. The system is packaged in a 19 inch, rack mount chassis and contains the full control system within a 17 unit high volume. Photograph 4 shows the assembled chassis before wiring. A description for each of the major system components is given below. A System Block Diagram for this chassis in shown in Figure 4.

6.1 Control PLC: The control PLC is a Omega model 110CPU61203. The advantage of this device is multitude of I/O connections (16 input / 12 output), 4 input A/D and 2 output A/D and 2 RS232 ports all contained in DIN rail mountable package.

6.2 Variable Transformer (Variac): To provide the primary voltage source to the secondary voltage distribution system, the chassis contains a motor driven 5.1 kVA Variac. This unit has switch connections that when driven by the outputs of the PLC, raise or lower the output voltage level at a prescribed rate. The Variac package also contains rotational travel limit switches to internally protect the drive system.

Photograph 4
Primary Voltage Control Chassis

6.3 AC Voltage/Current Transmitters: The system contains two transmitters for converting the Variac output voltage and current (using a current sense transformer) to a 0-10Vdc signal. The analog output of these units will be wired into two of the PLC input A/Ds to sense and control the power output of the control chassis.

6.4 Control Relays / Interlocks: The system contains two contactors for switching of the main power to the Variac and to the secondary voltage distribution system. The control system can apply power to the Variac and adjust its output without having the power connected to the secondary system. Signals from the Gemini Interlock System (GIS) are also in the loop to lock out closure of these contactors if needed. The PLC uses separate solid state relays to apply voltage to the actuation coils of the contactors.

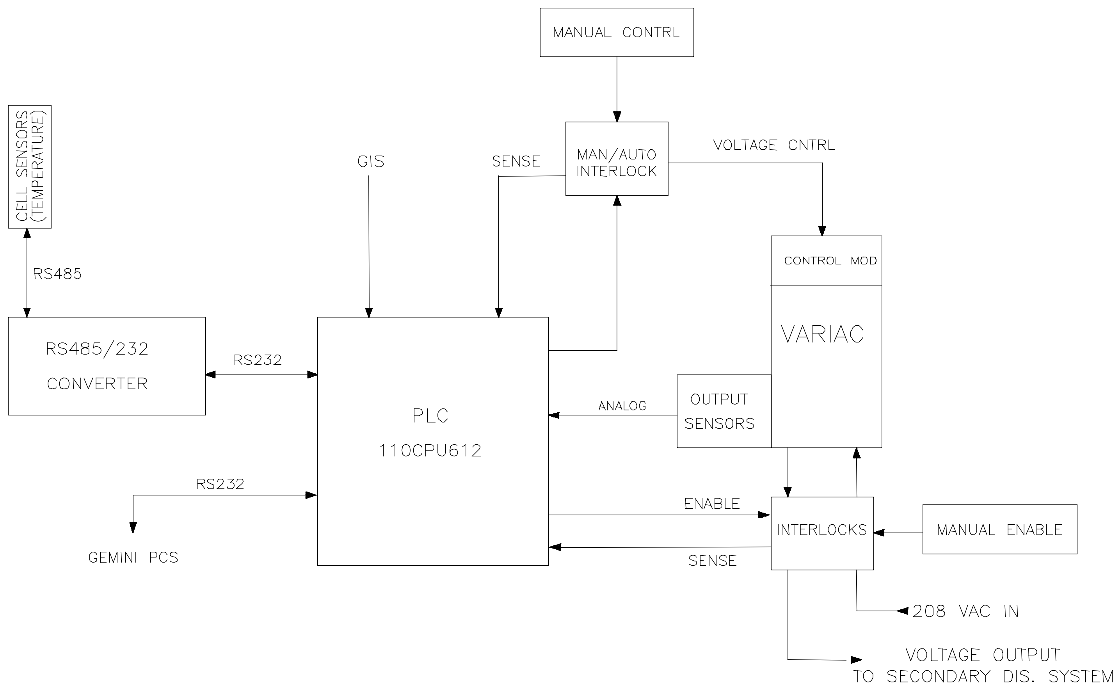


Figure 4
Primary Voltage Control Chassis Block Diagram

6.5 RS485/RS232 Converter: In order to communicate with the temperature measurement system within the mirror cell, the control chassis needs an RS485 bus. The PLC will use one of its RS232 ports, through this converter, to read the temperature data of the primary mirror.

6.6 Front Panel Controls: The front panel of the chassis has switches and indicators for enabling/disabling automatic control of the chassis and panel meters to aid in manual operation and check out. During normal operation of the telescope, these controls will be placed in the automatic mode and no manual adjustment will be required.

7. Conclusions

The Gemini Primary Mirror Surface Heating System described here represents the results of ongoing hardware development and testing aimed at delivering the first operational surface heating system for astronomical optics. A number of critical issues identified during the early development effort [1] have been addressed and the scaling of the design concept to an 8 meter primary mirror completed. The final system integration and testing of the system will provide additional opportunity for refinement of control and process techniques needed to ensure the Gemini Telescopes have the minimum attainable seeing effects.

8. Acknowledgments

The authors would like to thank the National Optical Astronomy Observatories for providing additional equipment and resources used in this effort, Richard Fowler and Sang Nguyen of NOAO for assembly and testing of the Heater Node Boxes and distribution cabling.

9. References

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