NGSLR Hardware Manual

Supporting the Next Generation Satellite Laser Ranging System

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Acknowledgements

NGSLR is a prototype Next Generation Satellite Laser Ranging system developed at NASA's Goddard Space Flight Center by the Laser Remote Sensing Lab of the Solar System Exploration Division in cooperation with NASA's Ground Network Project Office.

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A special acknowledgement and thanks goes to John Degnan who came up with the original SLR2000 concept, led its development for many years, and continues to support it.

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1 Introduction / Background

NASA's Next Generation Satellite Laser Ranging (SLR) Station, known as NGSLR, is the prototype for SLR systems which will be deployed around the world in the coming decade. NGSLR is an autonomous and eyesafe, photon-counting, satellite laser ranging station with an expected absolute range accuracy better than one cm and a normal point (time-averaged) range precision better than 1 mm. When operational, the system will provide continuous 24 hour tracking coverage to an existing constellation of approximately two dozen artificial satellites equipped with passive retro-reflector arrays.

Figure 1-1: NGSLR during tracking operations

The SLR2000 system concept was first proposed by John Degnan in 1994. The first detailed overview of the SLR2000 system concept and proposed technical approach was presented several years later at the 1997 Fall Europto Meeting in London, UK (Degnan, McGarry 1997). For further information on the individual subsystems, algorithms, and software packages that make up the current system, please refer to the proceedings of the International Workshops on Laser Ranging. The full proceedings for all workshops can be found online at:

http://ilrs.gsfc.nasa.gov/reports/workshop/index.html

During the first several years of NASA funding, prototypes of several "enabling" components essential to the feasibility of the system were successfully developed. These include:

(1) A sensitive, high-speed, quadrant micro-channel plate photomultiplier for simultaneous ranging and pointing correction (Degnan 1999; McGarry, Zagwodzki, et al. 2002).
(2) Oscillator-only (Degnan, Zayhowski 1998) and oscillator/amplifier (Isyanova et al. 2002) versions of a microchip-laser based transmitter.
(3) A "smart" meteorological station which includes an upgraded all-sky cloud sensor (Degnan, McGarry 1997; Mallama, Degnan 2002).

Once the key specifications on these advanced components were largely met, and system feasibility had therefore been established, attention then turned to the detailed engineering design and procurement of more conventional elements of the system such as the shelter and protective dome, arcsecond precision tracking mount, telescope, and optical transceiver. The principal challenge during this phase was to choose reliable, but low cost approaches to meeting our technical requirements and goals.

The prototype system is now built. During testing, it has demonstrated daylight tracking capability to retro-reflector equipped satellites in low earth orbit , to LAGEOS and LAGEOS-2 (altitude 6000 km), as well as night-time ranging out to GNSS altitudes (20,000 km). Ranging to LEO and LAGEOS satellites is very robust with the normal ILRS predictions when a recent starcal has been performed. The signal processing algorithm can extract mean signals as small as 0.0005 photoelectrons per pulse from solar background noise even during daylight tracking. Work continues to ensure the quality of the data products and to complete the full system automation.

Existing NASA SLR stations require operators to determine system viability, avoid direct contact of the laser beam with aircraft and ground personnel, select the objects to track, and interactively acquire and track. The NGSLR prototype has a laser hazard avoidance system, and is currently semi-automated. The system fires at 2 kHz and performs single photon detection, which ensures return rates similar to those from traditional higher transmit power, lower repetition rate SLR systems. While the system itself will be much different than existing stations, the final data products will be the same as those from current NASA SLR systems. Normal Points will be delivered hourly to CDDIS through the Mission Contractor and Full Rate data will be made available when needed.

When deployed, these stations will be placed so that they have full access to both internet and phone communication. Each system will regularly communicate via the internet with an External Facility (called *Home*) from which it will obtain the system prediction data for the week, determine the tracking priority of satellites, and send information on the system health and performance. Normal point data will be sent *Home* and/or to another archival facility. The *Home* Facility will send technicians periodically and/or when the system needs repair. There is also expected to be a “caretaker” present most of the time at each facility that will monitor the system and its operations.

In addition to the normal 2-way satellite laser ranging, the NGSLR system is capable of supporting other types of laser ranging, including 1 and 2-way asynchronous transponder ranging. Currently, the NGSLR prototype is supporting 1-way laser ranging to the Lunar Reconnaissance Orbiter(LRO). This is an uplink only range where NGSLR very accuracy records the laser fire times, and the spacecraft records the receive events. Analysts form ranges after the pass, by correctly associating fires with receive events. Details on the LRO operations at NGSLR can be found in the manual "Laser Ranging to the Lunar Reconnaissance Orbiter (LRO) from NASA's Next Generation Satellite Laser Ranging Station (NGSLR)" (NASA-NGSLR-OPS-LRO).[1]

[1] Further information on laser ranging to LRO can be found in various papers and presentations including: Zuber, et al. (2010); Mao et al. (2010); Clarke et al. (2008); Mallama (2008); McGarry et al. (2008); McGarry & Zagwodzki (2009)

2 System Overview

The NGSLR system approach is based on over 30 years of experience operating SLR systems at the Goddard Space Flight Center. Innovative hardware as well as new ideas, philosophy, and algorithms were developed during the design of this next generation system. The goals of autonomous operation, centimeter ranging accuracy, reduced hazards, automated scheduling data flow and processing, and lower replication and operating costs all dovetail well in the NGSLR system. This document will detail the hardware that makes up NGSLR system. For information regarding software design and function, please refer to the NGSLR Programmer's Manual.

2.1 General Theory

The NGSLR has taken a fresh approach in making the time-of-flight measurements to satellites. In the past, low repetition rate (typically 5 Hz) NASA systems operated with a single pulse in flight, enabling time interval unit measurement. Because these were single stop systems, the threshold was always set well above the noise and strong signal was always desired. For over 30 years, the NASA MOBLAS systems operated with high Signal to Noise Ratio (SNR) to prevent false detection. Supporting this philosophy of high SNR was the fact that transit time jitter of the early photomultiplier tubes (which contributed significantly to the RMS jitter) dropped off with an increase in signal. The installation of the micro-channel plate photomultiplier tubes (MCP PMTs) in NASA's systems in the 1980s changed the playing field significantly. The transit time jitter of the MCP PMT, even at the single photoelectron level, contributed very little to the overall system RMS. The implications are that systems can operate at the single photoelectron level as accurately as the multi-photon level. Hence, a SNR >1 is tolerable while enabling a reduction in laser pulse energy to levels approaching eyesafe limits. In addition, the laser pulse repetition frequency (PRF) can be increased to aid in acquisition and closed loop racking while still remaining eyesafe. This paradigm shift in operational philosophy required the development of new instrumentation, hardware, and control algorithms to realize system operation.

Key NGSLR instrumentation will be presented in the following sections, separated into ten major subsystems:

(1) Time & Frequency
(2) Telescope & Coelostat
(3) Transceiver Bench
(4) Laser
(5) Laser Hazard Reduction System (LHRS)
(6) Tracking
(7) Receiver
(8) Computer and Software
(9) Weather
(10) Shelter and Dome

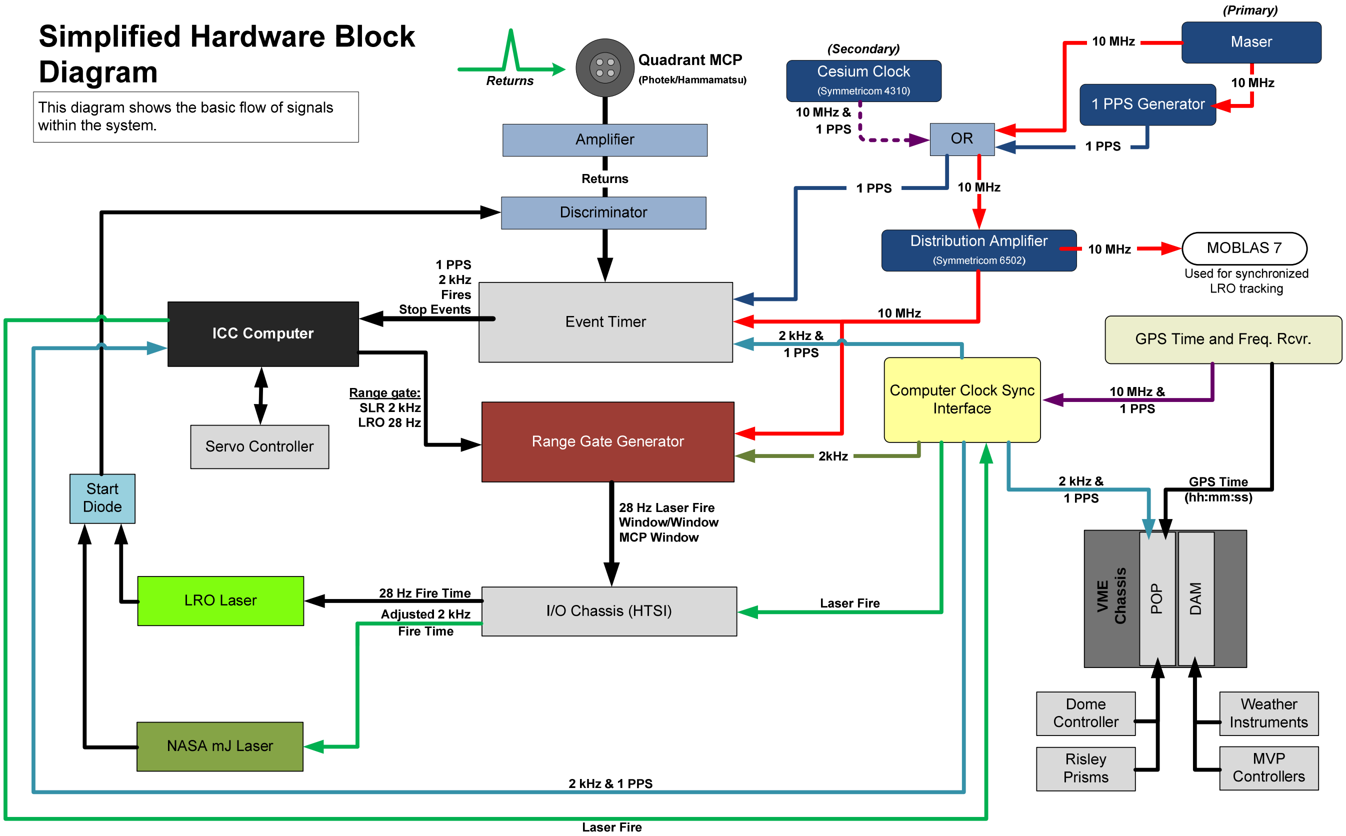


Figure 2-1: Simplified NGSLR Block Diagram

1) **Time and Frequency** - SLR tracking operations require accurate station time keeping to assure satellite pointing predictions are within the range of the mount pointing accuracy given the laser beam divergence. For one-way ranging, as with LRO/LR, station time keeping is much more stringent. Time-of-flight measurements in SLR require an accurate frequency or time base to assure the accuracy of the time interval measurement. Station time keeping is maintained by a GPS steered receiver, while a maser provides a stable 10 MHz frequency source.

2) **Telescope & Coelostat** - The telescope and coelostat subsystem includes all the optical components between the pit mirror and the optical port where the laser beam exits the telescope. This includes numerous folding mirrors, lenses, telescope mirrors, and anti-reflective windows. These components are used for both transmission and reception of the signal.

3) **Transceiver Bench** - The transceiver bench is an NRC breadboard which maintains position, spacing, and alignment of all the optical components in (both transmit and receive path) before entering the coelostat. It includes devices which control laser beam divergence, point-ahead, and receiver field of view (FOV).

4) **Laser** - The laser transmitter used by NGSLR is a 532 nm, 2 kHz system with a 200 ps pulse width (FWHM) at 1 mJ per pulse. The laser uses a diode seeder which fiber optically pumps a regenerative amplifier with an adjusted pulse repetition frequency (PRF) to avoid collisions (simultaneous transmit and receive events). A Northrop Grumman 532.2 nm laser with 5.5 ns pulse-width at 28 Hz is used for LRO tracking.

5) **Laser Hazard Reduction System (LHRS)** - The Laser Hazard Reduction System (LHRS) is a laser safety radar system needed for aircraft avoidance. Housed on an elevated tower approximately 30 feet from NGSLR, the radar is slaved to the pointing of the telescope and the laser. When an aircraft is detected within a 2 degree field of view (FOV), a beam block is activated to interrupt the laser transmit path, effectively cutting off the transmission of the beam. The beam block must be manually removed by the operator after each occurrence. Further details on the LHRS can be found in the GSFC Form *23-6RF*.

6) **Tracking** - The tracking system is comprised of the custom-built, elevation over azimuth mount and the mount controller. The coelostat is also part of the mount assembly as it directs the transmit/receive signal through the mount arm into the telescope.

7) **Receiver** -The receiver is a single photon detection, micro-channel plate photomultiplier tube (MCP PMT) coupled to an amplifier and constant-fraction timing discriminator. The current configuration utilizes a quadrant MCP PMT which, when placed in the system image plane, yields information on system pointing errors.

8) **Computer and Software** - Numerous computers control the system which include: the Interface Control Computer (ICC), the Pseudo Operator (POP), the Device Access Manager (DAM), the data analysis machine (ANA), the Camera computer (CAM), and the Remote Access Terminal (RAT).

9) **Weather**- The meteorological station consists of various instruments measuring pressure, temperature, relative humidity, sky clarity, precipitation, as well as wind speed and direction. Inputs from these devices are used to compute atmospheric corrections and will be used to determine whether tracking is possible.

10) **Shelter and Dome** - The shelter and dome subsystem provides a temperature controlled environment for the laser, optics, electronics, and computer systems, while enabling tracking coverage to any satellite above 10 degrees elevation. The dome rotates with the telescope, as it is slaved to the telescope in azimuth.

2.2 Safety Considerations

NGSLR is operated under the approval of NASA Goddard's Laser Safety Office (LSO) Code 350.2, and follows all guidelines and requirements established by that office and the American National Standards Institute (ANSI). The NGSLR laser fills the full 40 centimeter exit aperture of the telescope. The Maximum Permissible Exposure (MPE) established by ANSI standard Z136.1 is 8.6 x 10^{-6} W/cm^2. To operate within that limit for a 200 picosecond laser pulse, the energy on the transceiver table must be held to less than 60 µJ per pulse (with a measured 50% loss through transmit optics). Pulse energy above 60 µJ is not eyesafe, and requires use of the Laser Hazard Reduction System (LHRS). Note that LRO tracking cannot be made eyesafe, and must always utilize the LHRS.

2.2.1 Eye Safety/Laser Hazards

The NGSLR system is currently operated at the maximum laser pulse energy of 1 mJ. As this is above the MPE for a 200 picosecond pulse, the LHRS must be used during system operation. Future system developments will include operation in an eyesafe mode by reducing laser pulse energy to avoid the requirement to use the LHRS at all times. For instance, many Low Earth Orbit (LEO) satellites will be tracked in the eyesafe mode.

The NGSLR laser is not eyesafe on the transceiver bench; hence, it is behind light-tight black curtains that separate it from the rest of the system. In addition, eye protection of at least 6.5 ODs is required when near the transceiver table with the laser operating. The laser is confined to a well defined beam path around the table and up into the coelostat, while a dust cover on the transceiver bench prevents any scattered radiation from escaping.

The NGSLR system, because of its proximity to multiple airports in the Baltimore/Washington DC corridor, has additional constraints mandated by the Goddard Laser Safety Office. As the 532 nm beam is barely visible to the naked eye on a target, daytime tracking operations have no further restrictions applied. However, nighttime tracking operations, where pilot "startle" effects may occur, must include use of the LHRS. Please note that LRO tracking operations are never eyesafe, and will always require the use of the LHRS.

2.2.2 Electrical Hazards

Both the NASA 1 mJ laser and the LRO (Northrop Grumman) laser are diode pumped, and as such have no other electrical hazard other than the 120V A/C current used to provide power. This sidesteps the problems associated with older flash-lamped lasers that require large capacitor banks to run.

In addition, all other instrumentation in the NGSLR shelter operates on standard 120V, 20A service.

2.2.3 Other Hazards

No other hazards identified at this time.

3 Time and Frequency

NGSLR relies on accurate timing to effectively perform real time input and output functions including, but not limited to, time of flight measurements, control of the pulse repetition frequency (PRF), and avoiding transmit/receive collisions during satellite ranging.

There are two different timing systems, one for station time keeping and one as an ultra-stable frequency source. Station time keeping is provided by a GPS-steered Rubidium Time and Frequency Receiver, supplying the date and time to the POP computer, as well as providing 1 PPS and 10 MHz signals to the Computer Clock Sync Interface (CCSI).

The VLBI maser, co-located at GGAO, is used as the ultra-stable frequency source providing a 10 MHz signal to the Event Timer and the Range Gate Generator. In addition, this 10 MHz signal will eventually be used as a baseline to create a synchronized 1 PPS signal for use at NGSLR. As a backup frequency source for the maser, a Cesium oscillator located in the NGSLR shelter can be used to produce the 10 MHz signal with a simple cabling change. In the event of an emergency, the GPS-steered Rubidium Time and Frequency Receiver can also function as a backup for the 10 MHz signal.

3.1 Station Time - GPS-Steered Rubidium Clock (Symmetricom XL DC)

Station time keeping is provided by a GPS-steered Rubidium Time and Frequency Receiver, supplying the date and time to the POP computer, as well as providing 1 PPS and 10 MHz signals to the Computer Clock Sync Interface (CCSI). The date and time are provided to POP over an RS-232 connection in the following format: day of year, hour, minute, and second. For LRO-LR, this 1 PPS is used as a data input and not specifically for system timing.

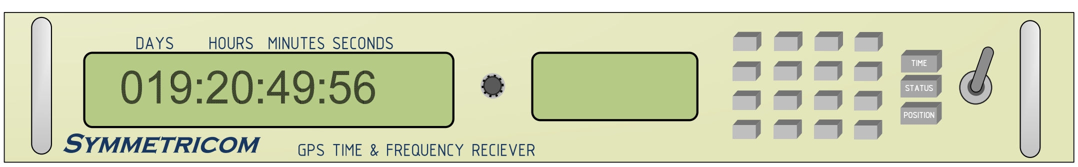


Figure 3-1: Front view of the GPS Time and Frequency Receiver

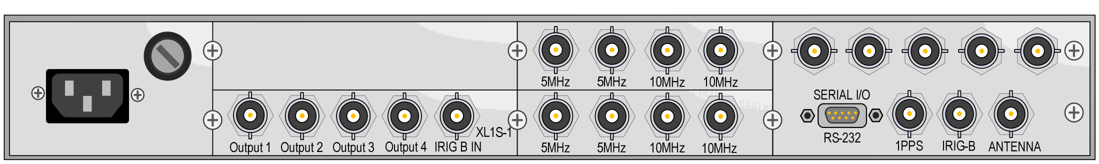


Figure 3-2: Illustration of the back of the GPS device

3.2 Primary Frequency Source - Hydrogen Maser (Symmetricom MHM-2010)

The VLBI maser, co-located at GGAO, is used to produce an ultra-stable 5 MHz signal. This signal is doubled to 10 MHz and sent to NGSLR for use by its systems. The 10 MHz signal is brought in via underground fiber optic lines from the VLBI facility and fans out through a distribution amplifier to provide the 10MHz clock source to NGSLR instrumentation.

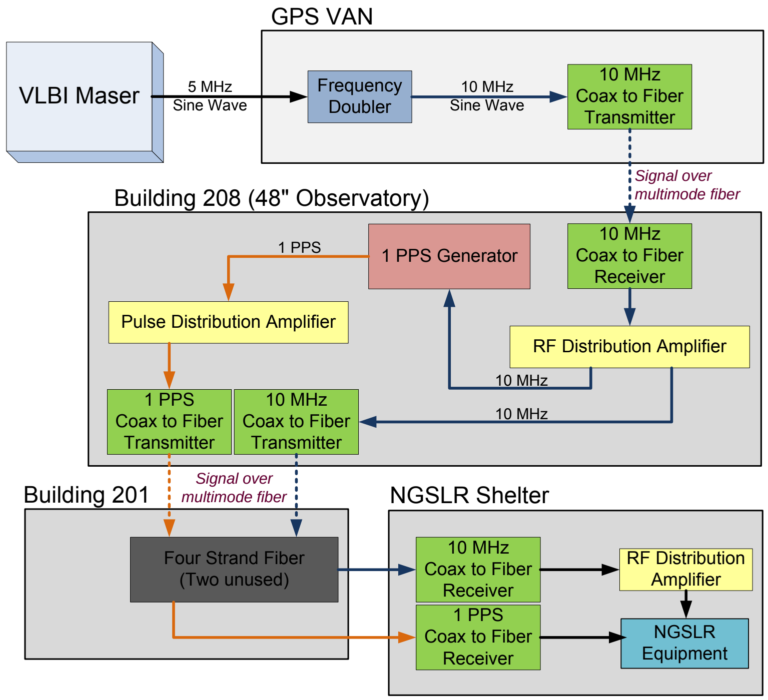


Figure 3-3: Block diagram of maser connectivity

All maintenance and monitoring of the maser is done by the VLBI team. The maser functioning is checked on a daily basis, with a data dump coming in every hour, sent from a laptop in the VLBI trailer to a processing computer. The maser is steered back to 5 MHz when it gets about $5x10^{-13}$ off frequency, which occurs about once or twice a year. Any time the maser is adjusted, the NGSLR team will be notified ahead of time by VLBI staff. This is to ensure that the adjustment won't happen during a period of tracking.

Future Implementation

The 10 MHz signal (and eventually its 1 PPS counterpart) will be monitored by the NGSLR team to verify the signal's stability. This will be accomplished using software currently under development at the 48" facility. If any instability is detected, the software will notify NGSLR staff via email. In the event of instability with the signal, the VLBI team will verify that the maser is functioning within specifications. If the maser is running correctly, the NGSLR team will then verify that all devices in the distribution path are functioning correctly.

Generation of the 1 PPS signal will be switched from the GPS-steered Rubidium Time and Frequency Receiver once the monitoring system is in place. The synchronized 1 PPS will be generated at the 48" facility by a TRAK 9000N 1 PPS generator, using the 10 MHz signal as a frequency reference. The 1 PPS will be regularly monitored to ensure that it stays within a 50 ns tolerance of the USNO GPS time.

3.3 Distribution Amplifier (Symmetricom 6502B)

The distribution amplifier is used to disseminate the 10 MHz sine wave to the Event Timer and Range Gate Generator. The signal can also be sent to a collocated SLR station (MOBLAS 7) to enable synchronized tracking or to function as a backup to their timing system. Output from the amplifier is nominally 1.4V (Peak to Peak) at 50Ω.

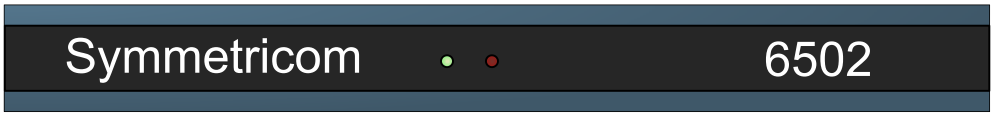


Figure 3-4: Front view of the Symmetricom Distribution Amplifier

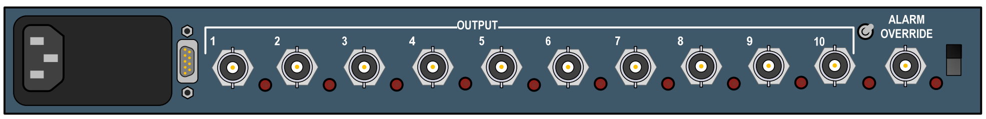


Figure 3-5: Rear view of the Symmetricom Distribution Amplifier

3.4 Alternate Frequency Source - Cesium Frequency Standard (Symmetricom 4301B)

The cesium oscillator is used as a backup timing source for the maser. Switching from the maser to the cesium frequency standard is relatively simple, requiring the transfer of the coaxial connection to the new timing source See Drawing D-07, Note 6 of the NGSLR System Drawing set for a graphic illustration of the device connectivity.

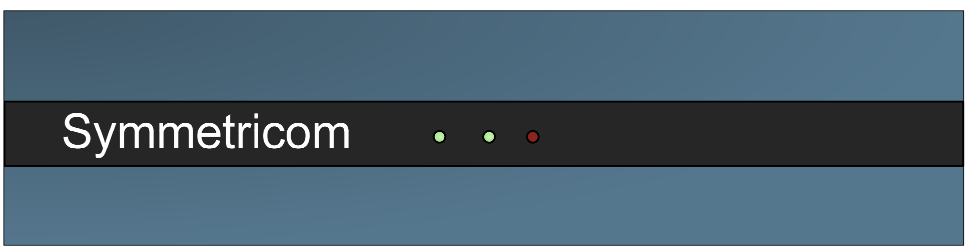


Figure 3-6: Front view of the Cesium Frequency Standard

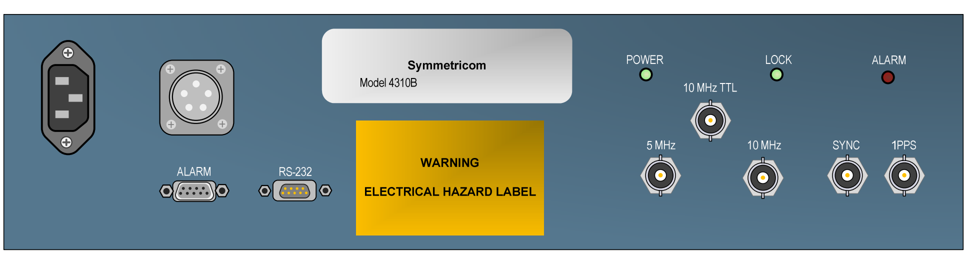


Figure 3-7: Illustration of the back of the Cesium Frequency Standard

3.5 Computer Clock Sync Interface (CCSI)

This device, built in-house, uses the 1 PPS and the 10 MHz signal from the GPS Time and Frequency Receiver to produce a synchronized, on-time, 2 kHz reference. The reference is produced by dividing down the 10 MHz signal to 2 kHz, and synchronizing it ~9.8 µs after the 1 PPS signal. This was done to ensure that the first 2 kHz interrupt would always come ***AFTER*** the 1 PPS. To ensure accurate fire times (or any event time), this 9.8 µs delay must be added in when the fire time is reconstructed on the POP computer. The 2 kHz and 1 PPS signals produced by the Timing Box go to the ICC timing card, the POP computer, and into the Event Timer, where they become part of the data stream that is read by the ICC.

The CCSI also functions as a pass through interface for SLR fire commands using the NASA 1 mJ laser. See the Laser section for more details on how the laser fire rate is adjusted.

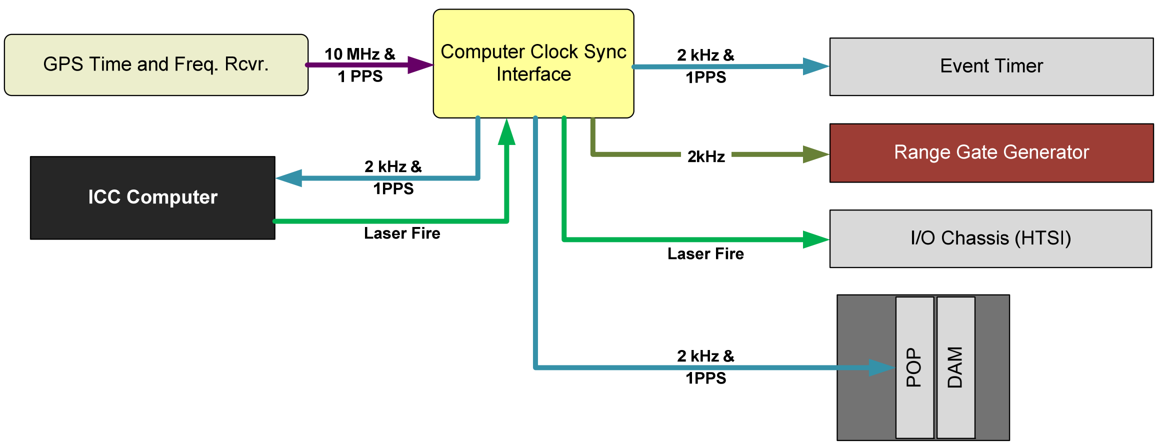


Figure 3-8: CCSI connectivity diagram

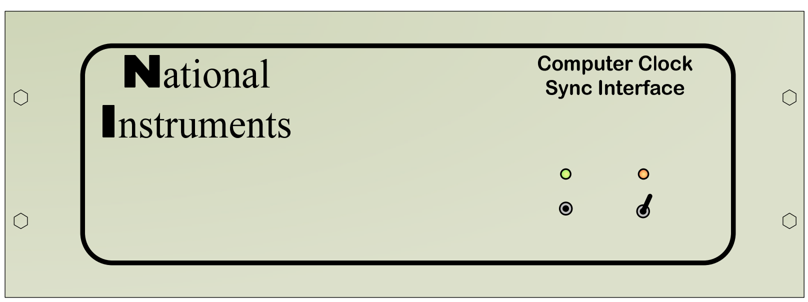


Figure 3-9: Illustration of the front of the CCSI Unit

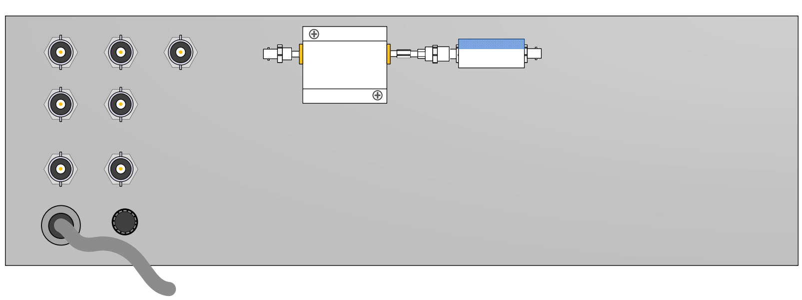
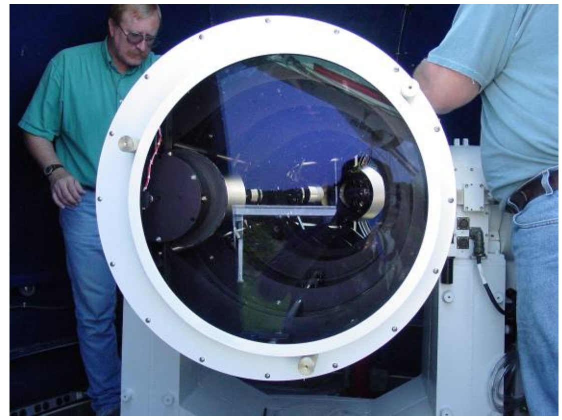


Figure 3-10: Rear of the CCSI Unit

4 Telescope and Coelostat

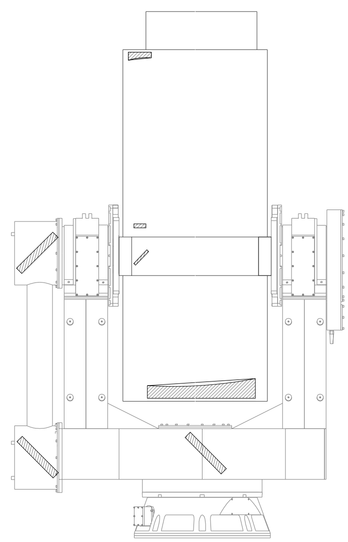
The telescope subsystem consists of all the optical components from the pit mirror through the telescope exit port. The telescope is a 40 cm off axis parabolic reflector built by the Orbital Science Corporation. Designed to operate from 20° F to 120° F, the spacing and alignment of the primary and secondary mirrors are passively maintained by the use of invar rods and Zerodur optical substrates, both of which have low coefficients of thermal expansion. Active control of focus is performed on the optical bench by the system, and is described in a later section.



The telescope can be sealed and purged with dry nitrogen, with inflatable bladders to accommodate for air pressure and temperature changes. The input and output windows are optically flat, anti-reflective glass with optional resistive heaters to prevent condensation.

4.1 Coelostat

The coelostat is a set of mirrors in the tracking mount* which direct the outgoing laser beam (and receive line of sight) along the azimuth and elevation axes of rotation out to the telescope. This allows for the laser to remain stationary on the bench while its output is directed in any direction the telescope can point to. The tracking mount for NGSLR was built by Xybion (later acquired by Cobham Sensor Systems). Within the mount are 2 azimuth mirrors and 2 elevation mirrors which establish the axes of rotation through 360 degrees in azimuth, and 0 to 180 degrees in elevation. Much care is taken to assure the optical axis through the coelostat is centered in the system, and parallel to the mechanical axis of rotation. Alignment procedures written up in (Document TBD) describe in detail how this operation is accomplished. Once alignment has been completed, a star calibration is always required to minimize pointing errors by solving for biases introduced by the tracking mount. Coelostat mirror alignment has been extremely stable. In general, a good alignment onto the mechanical axes of the system and a good star cal is all that is needed to track successfully. The coelostat is also in a sealed air environment with a desiccant and air bladder. Desiccant should be replaced [TBD].



**See the Tracking section for more information on the mount.*

4.2 Sun Shutter

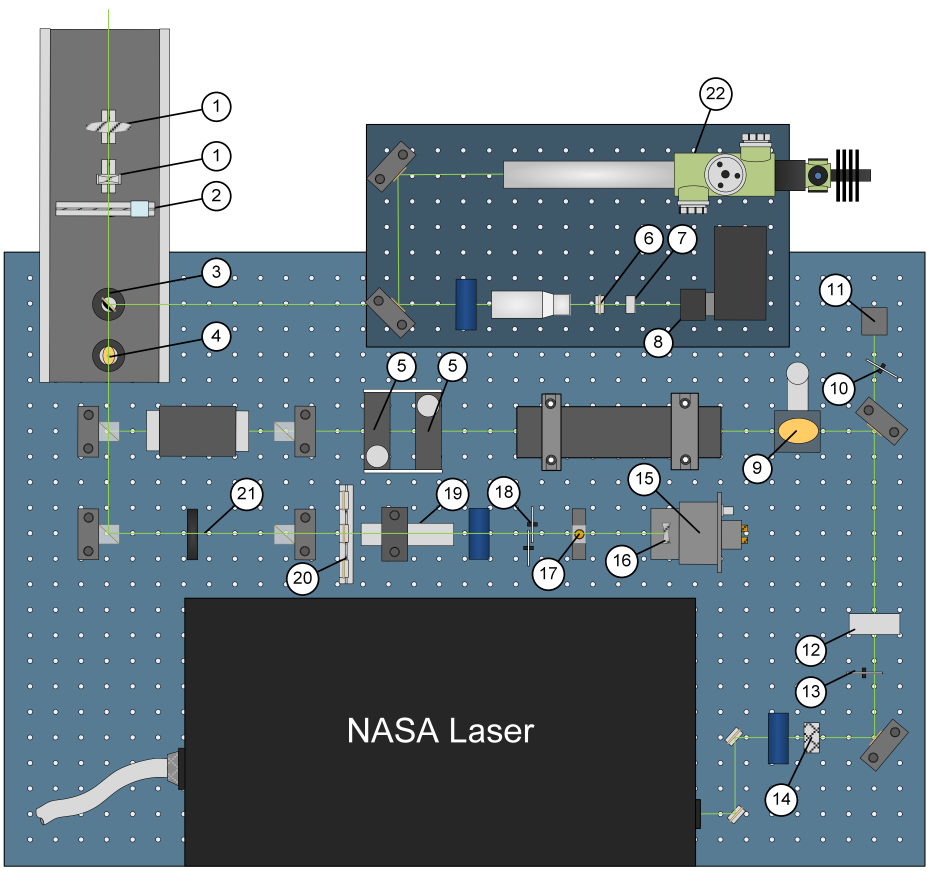
A removable sun shutter assembly consisting of thin black anodized aluminum honeycomb cells can be installed on the end of the telescope to significantly improve daylight tracking capabilities. The individual cells are approximately 5/8 inch diameter and are 6 inches in length. The sun shutter reduces the receiver background noise by limiting the telescope field of view.

Figure 4-1: Picture of the Sun Shutter

5 Transceiver Bench

The transceiver bench consists of an optical breadboard which has mounted on it the laser transmitter, the optical receiver and all the support optics and mechanical devices which control both transmit and receive optical paths before entering (or exiting) the coelostat. Also included on the transceiver bench are alignment optics needed to boresight stars, the laser transmit axis, and the receiver axis. Alignment procedures are done manually to boresight the star camera with the laser and the receiver field of view. Currently, during SLR operations, the laser beam divergence, transmitter point-ahead, and receiver field of view are under computer control.

Narrow laser transmitter beam widths (~5 arcseconds) and tight receiver field of view (~10 arcseconds) require precise control of transmit and receive paths to assure proper boresight and successful tracking. This can only be accomplished in a system which operates in a common optics mode. The transmit/receive (T/R) switch enables the NGSLR system to operate in a common optical transmit/receive path for SLR operations.



DRAWING NOTES:

1. Focus (3X Power Beam Expander)*
2. Alignment Cube*
3. Star CAM Insertion Mount
4. LRO Laser Insertion Mount
5. Risley Prisms (Set of 2)
6. ND Flip Filter
7. Star Camera ND Filter
8. 1" Focal Length Lens for the Star Cam.
9. Periscope Mirrors
10. Start Diode ND Wheel (0-2 ND)
11. Start Diode
12. Polarization Rotator
13. Alignment ND Wheel (0-2 ND)
14. Eye-safe ND Block
15. Detector (Quadrant or Single MCP)
16. Divergent Lens
17. Field of View / Iris
18. Recieve ND Wheels (2)
19. 900 mm Lens (EFL)
20. Band Pass Filter (BPF)*
21. Optical Path Length Comp.
22. Auto Collimator

5-1: Illustration of the Transceiver Table

5.1 Control of Motorized Devices on the Optical Bench

All motorized devices on the optical bench will be connected to the DAM computer via MVP controllers. It is the MVP controller that actually drives the device; the rate of communication depending upon the device. Typical communication entails the initialization of the device, followed by the retrieval of control values from the POP computer. These values are converted into motor steps either by conversion or look-up table and sent to the MVP controller which drives the device. The controllers move the devices and relay the device status upon request. From the status, the DAM computer sets device indicator bits based on its state: moving, in position, error etc.

Devices on the optical bench under motor control in the transmit path include: a 2X-8X power laser beam expander, a set of Risley prisms, and the 3X power beam expander used for system focus. Devices under motor control in the receive path include: the band pass filter (BPF), attenuating ND wheels, and receiver field of view (FOV) iris.

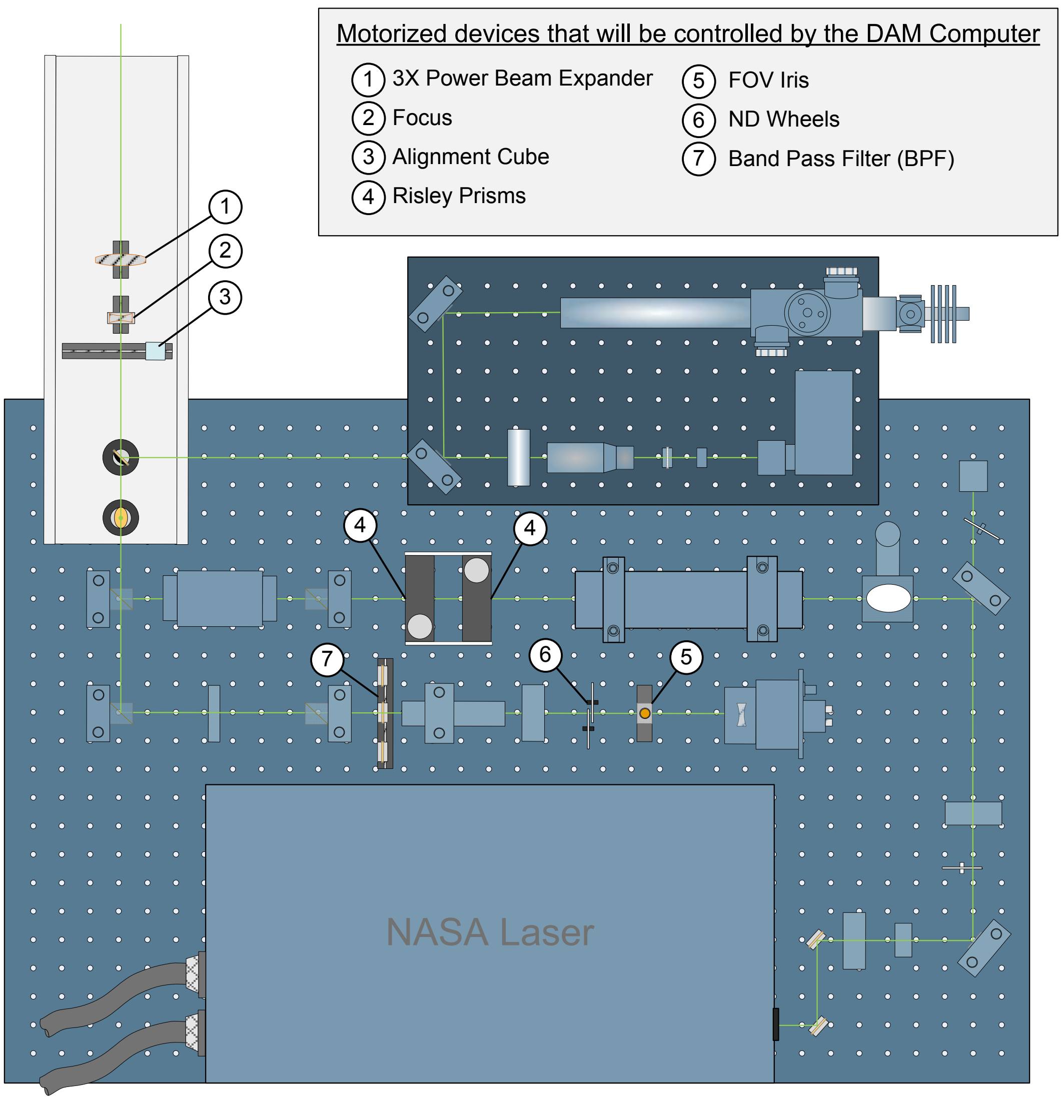


Figure 5-2: Diagram of Optical Bench with Motorized Devices

Figure 5-3 (Typical MVP Controller)

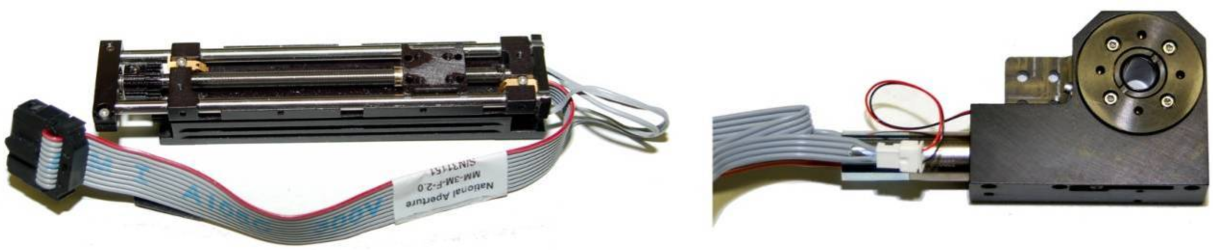


Figure 5-4 (Linear Stage and Rotational Stage)

Laser beam divergence can be adjusted by the DAM computer from 4 arcseconds (FWHM) to about 25 arcseconds (leaving the telescope). The 3X power beam expander is controlled by DAM and generally is only adjusted during star calibration exercises when the system focus requires adjustment. This adjustment can be made any time, including during SLR passes. The Risley prisms control the fine pointing offset of the transmitted beam (with respect to the receive line of sight) referred to as “point-ahead”. The point-ahead adjustment is updated every 2 seconds by DAM during SLR tracks to assure the transmit beam is optimally pointed.

The receive Band Pass Filter (BPF) has three positions which include day, twilight, and night operation which correspond to band passes of .2 nm, 10 nm, and none. The linear motor stage is under control of the DAM and generally is set in place before each pass. Two counter-rotating ND wheels, with a gradient of 0-2 ND each, are used to attenuate the receive signal during ground calibrations and are under control of the DAM computer. The zero ND position of both wheels has a hole bored through it so as not to introduce any stray reflections while in satellite tracking mode. The receiver field of view is under control of DAM, and can be adjusted continuously from a few arcseconds (FW) to about 25 arcseconds. Typical settings for tracking are 10 arcseconds for daylight, 16 arcseconds for twilight, and 25 arcseconds for night operation. A field of view of greater than 25 arcseconds is discouraged since laser transmitter back reflections may enter the receiver field of view. All optics within the transmit path are tilted slightly to avoid this problem but care must be taken to avoid this situation. RECEIVER LIFETIME OR DAMAGE ISSUES MAY RESULT!

5.2 Alignment Cube

An alignment cube corner is installed in the system on a linear stage to provide a means of co-boresighting the laser transmit with the star camera and the receive field of view.

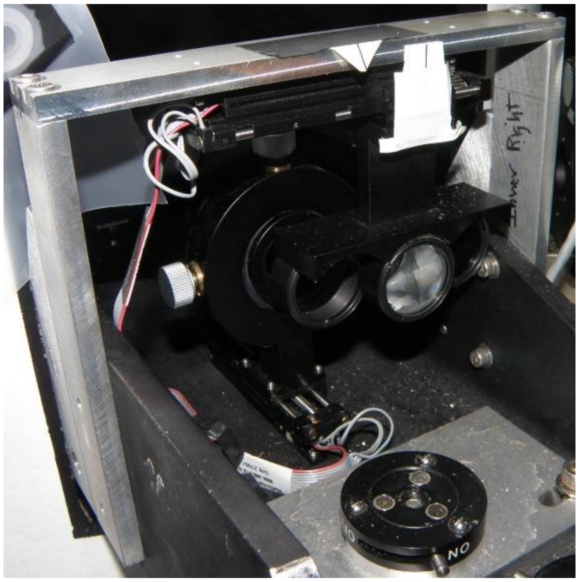


Figure 5-5: Alignment cube on linear stage

Boresighting is done by attenuating the laser beam to an appropriate level, translating the cube corner into the laser transmit beam, and inserting the star camera pellicle beam splitter. The star camera is boresighted to the retro return by adjusting the azimuth and elevation axis of the pellicle mount. At the same time the receive FOV iris and photomultiplier are co-boresighted. This requires both polarization legs of the T/R switch to be aligned both in the near field (at the entrance to the receive imaging lens) and the far field (FOV iris).

INSERT PICTURE OR DIAGRAM OF BORESIGHTING PATH

5.3 Focus (3X power beam expander)

This device controls the system focus and provides the ability to get the tightest image possible for the current conditions, resulting in the best collimated beam on the satellite and a higher energy density at the detector. The focus is controlled using a 3X power beam expander comprised of two lenses; a fixed positive output lens and a negative input lens mounted on a linear stage. System focus will be maintained by the DAM computer and checked when star calibrations are performed. The negative lens (currently adjusted manually) will be motorized so that it can translate to set the focus, with the best system focus determined by minimizing the size of a star's image in the star camera. This will be the only device that is commanded using relative instead of absolute positioning. During initialization, the device will be homed using its current position and utilize user defined range position limits.

INSERT PICTURE OF FOCUS ASSEMBLY

5.4 Day/Twilight/Night Bandpass Filter

These filters, placed in the receive path of the detector, provide varying degrees of spectral filtering for background noise reduction. During the day, a 532 nm spectral filter with a width of 2 nm is used to reduce extraneous noise, while the twilight filter is less restrictive with a width of 10 nm. The bandpass filter is generally removed for night operations. This produces a range bias between the amount of glass in the day/twilight receive path and the night receive path which must be taken into account.

Figure 5-6: Bandpass filters

5.5 Long Focal Length Lens

A 900 mm focal length lens assembly is used to image the receive ray bundle onto the receive FOV iris. Lens focal length is chosen as a trade off in package size to desired FOV given the quadrant PMT photocathode size and a convenient FOV iris size.

INSERT PICTURE OF LONG FOCAL LENGTH ASSEMBLY

5.6 Field of View (FOV) Iris

This receive spatial filter, set in the image plane of the receive telescope, controls the receive field of view. The current iris is manually adjusted but its replacement will be under control of the DAM computer. Nominal settings are 11 arcseconds (full-width) for daylight, 16 arcseconds for twilight, and 25 arcseconds (fully open) for night. Care must be taken not to exceed 25 arcseconds FOV aperture, otherwise unwanted optical component back reflections may enter the receiver and shorten the photocathode lifetime (NOTE: All optical elements in the transmit path must be angled slightly to avoid direct back reflections). Unlike the other devices, the iris does not have any limit switches or external sensors to limit excess motion. Instead, the MVP has been configured to stop the motor at its physical limits, then reports back that the device is now in position.

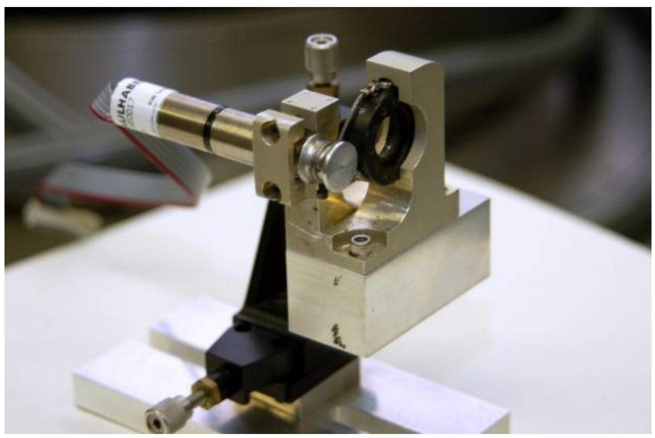


Figure 5-7 - Field of View/Iris

5.7 K&E Auto-Collimator

The Keuffel & Esser (K & E) Autocollimator serves as the absolute reference and starting point for all optical alignments and adjustments in the NGSLR. The K & E has an imaging eyepiece which allows an operator to visually inspect, align and boresight optics over its full focal range from inches to infinity. It also projects a collimated fiducial crosshair when set at infinity focus, which is crucial in transferring focus to the star camera, and hence, identifying system focus. The K & E is not used on a daily basis, rather it is a reference tool for all major system alignments.

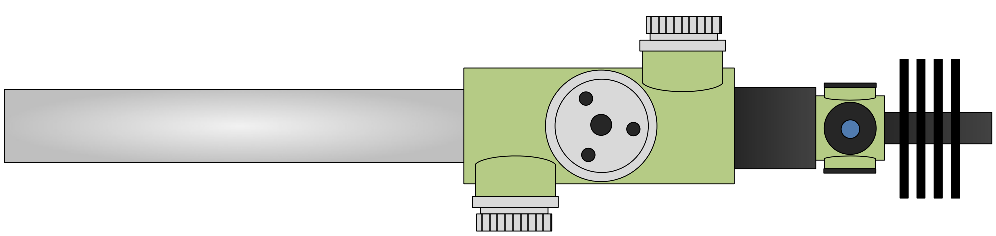


Figure 5-8: Illustration of K&E Auto-Collimator

5.8 Laser Beam Expander

A variable, 2X- 8X power beam expander under computer control is used to expand the raw laser beam divergence by a factor of approximately 5 while maintaining the desired overall beam divergence exiting the telescope. The beam expander is a Special Optics model 56C-30-2-8X beam expander with high power AR coated lenses. This device, in the transmit path of the laser, is comprised of two linear stages which work together to adjust the lens assembly. Commands are first sent through a serial port to a RS-232 to RS-485 converter which then relays the signal to two MVP Controllers daisy chained inside the device. (See *[Figure TBD*] for clarification). To ensure the lenses do not collide, the stages are moved into position one at a time. NGSLR laser divergence out of the telescope can be adjusted from 4 arcseconds to about 12 arcseconds FWHM. Table 5-1 shows the relative steps for each motor of the beam expander, with each step relative to its HOME position.

Figure 5-9: Beam Expander

Table of Motor Control Values													
	Beam Divergence (FWHM) in arcseconds												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Motor IMS1	-34056	-32075	-30013	-27854	-25590	-23212	-20710	-18075	-15295	-12354	-9250	-5956	-2459
Motor IMS2	-62429	-62596	-62668	-62640	-62505	-62255	-61882	-61375	-60723	-59913	-58934	-57768	-56398

Table 5-1

5.9 LRO Laser Insertion Mount

This removable magnetic mount hosts a 9 mm diameter, 45° mirror, which enables the system to switch between the NGSLR and the LRO laser. The magnetic/kinematic mount is manually inserted and locks into place onto the base plate bolted to the transceiver bench. Star camera measurements have confirmed that the insertion mount consistently locks into position at the arcsecond level as measured by the star camera. When not in use, the mirror mount is removed and stored in a safe location on the transceiver table. All NGSLR optics and alignments remain unaffected during LRO tracking.

Figure 5-10: LRO Insertion Mount

5.10 Neutral Density Filter (ND)

Two banks of ND filters are currently in use at NGSLR. They consist of a fixed set of ND holders that slide into the beam path on a translation stage (typically 5 NDs), and two variable zero-to-2 ND wheels which have gradient coatings. These NDs are used only in the ground calibration mode where signal level from a fixed ground target needs to be reduced by multiple orders of magnitude. Also used in ground calibrations are 2 to 3 NDs attenuation directly in front of the PMT internal to the support housing. These internal NDs are needed to provide an adequate attenuation from laser back scatter and multipath detection when using the ground calibration target. System automation in the future will configure a flip ND holder in a light tight enclosure and 2 motorized ND wheels under computer control. Set in the receive path, these provide a method of controlling the receive energy from the external ground calibration targets. The ND wheels provide a continuum of ND values from 0 to 4, all with the same amount of glass in the path, so that no range bias is introduced. For every increase in the ND value by 1, the energy transmitted is reduced by a factor of 10. The two wheels are mounted in line with the receiver line of sight on opposite sides (See Figure 3-20). The devices rotate in opposite directions allowing the beam to be attenuated evenly across the beam area. Each wheel has its own rotational stage, and operates independently of the other stage. Signal level on ground targets will be adjusted with the ND wheels to simulate satellite return rates. All NDs will be removed for SLR operations. The ND wheels have holes bored in the glass disc to pass the signal in SLR mode.

INSERT IMAGE OF FIXED ND FILTERS

INSERT IMAGE OF ND WHEELS

5.11 Transmit / Receive Switch

The NGSLR System utilizes a unique transmit/receive (T/R) switch which allows simultaneous use of the telescope for both transmit and receive functions (see figure 5.5). It is totally passive, independent of the laser PRF and pulse-width, and provides at least 3 orders of magnitude optical isolation between the transmit and receive channels. All surfaces are A/R coated and slightly tilted to minimize back reflections and scatter. The overall efficiency of the T/R switch is >95% in both transmit and receive direction.

The P polarization laser pulse enters the T/R switch and passes through the first polarizing beam splitter. The P polarized light is rotated 45 degrees by the Faraday rotator and an additional 45 degrees by the half wave plate to a total of 90 degrees (now an S polarization). This S polarization output beam is reflected in the second polarizing beam splitter into the coelostat and out through the telescope. On the return path (received light) the S polarization light reflected at the second polarizer is rotated 45 degrees by the half wave plate and then -45 degrees by the Faraday rotator (net rotation: 0, so it remains S polarization). At the first polarizing beam splitter the return S polarization is reflected into the MCP PMT path. A third polarizer is used as a beam combiner to bring both S and P polarizations together for the receive PMT.

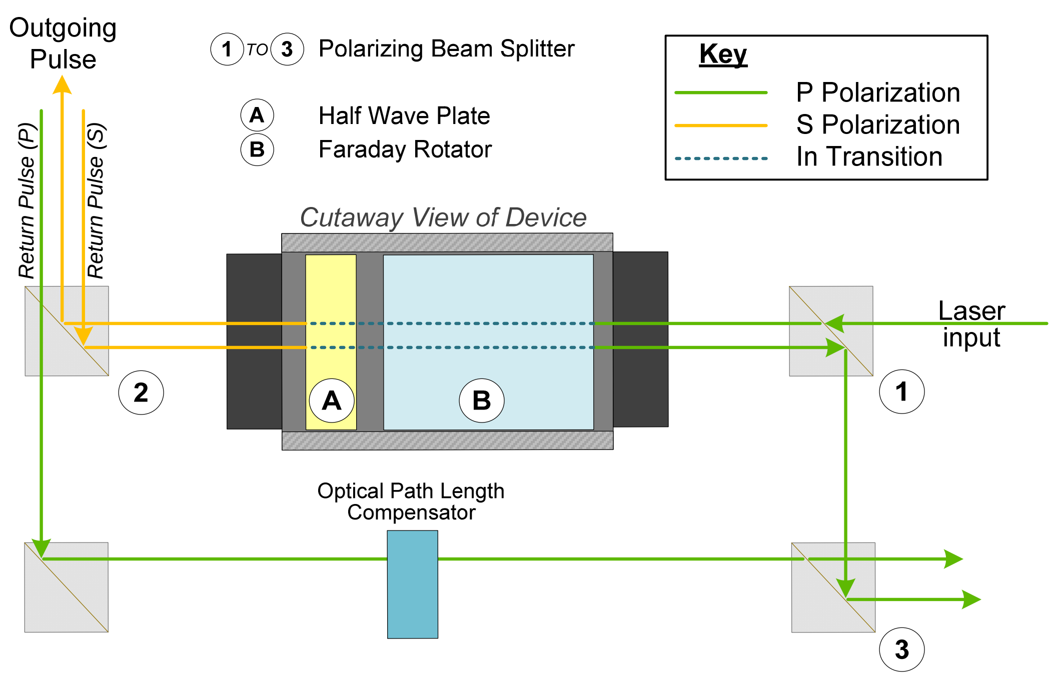


Figure 5-11: Transmit / Receive Switch

To avoid photon “collisions”, where outgoing and incoming pulses occur nearly simultaneously, two techniques are employed. The laser PRF is changed periodically from 2000 Hz to 1960, 1992 or 1996 Hz (depending on the altitude of the satellite) to actively avoid these conditions and a hardware blanking circuit is employed. The PMT gating signal passes through a hardware blanking circuit within the I/O chassis, which disables the gate from 20 µs before a laser fire to approximately 50 µs after a laser fire. This hardware blanking of the receiver effectively gates the PMT off during laser fire times and periods of high backscatter.

5.11.1 Optical Path Length Compensator

The optical path length compensator is an A/R coated, transparent, piece of glass mounted in the T/R switch in the leg opposite the Faraday rotator. The thickness of the glass is selected to match the optical path length of the Faraday rotator; hence, maintaining the exact same path length for both P and S polarized beams through the T/R switch. The path length compensator prevents a range bias between the two polarization states of the return signal.

5.12 Periscope Mirrors

The laser transmit beam height is lowered from 6.5 inches down to 3-inches using a set of two, vertically aligned*, 45° mirrors. The transition is needed to clear the receive PMT assembly which is mounted at a 3-inch height. The transmit optics, which include the laser beam expander, Risley prisms, and T/R switch, are mounted at a 3-inch beam height. See the figure [TBD] or refer to drawing D-10 of the NGSLR System Drawing set for details.

**Only the upper mirror has 2-axis adjustment for adjusting the beam path.*

5.13 Risley Prisms

The Risley prisms are used to independently steer the laser transmit beam with respect to the optical axis of the telescope. This fine steering is needed to "point-ahead" to the position where the satellite will be when the laser pulse reaches the satellite. The telescope remains aligned with the predicted receive path, a technique known as transmitter point-ahead. The Risley prism point-ahead is under computer control and ranges in magnitude from 4 to about 11 arcseconds as seen leaving the telescope. The actual point-ahead angle on the transceiver table must be approximated 28 times greater due to the beam reduction through the telescope system. The NGSLR Risley pair is capable of producing a point-ahead of up to 30 arcseconds, though angles greater than 15 arcseconds cause progressive clipping of the beam. As Earth orbiting satellites only require a maximum point-ahead of 11 arcseconds, beam-clipping is not a factor in day to day operations.

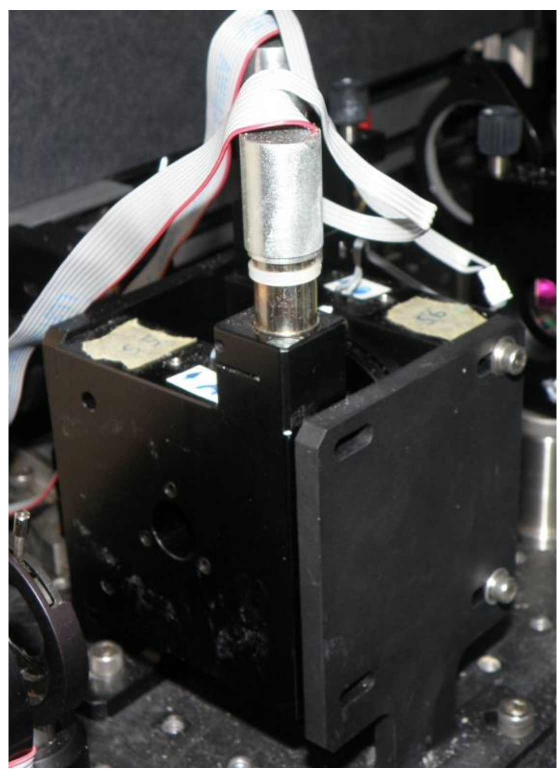


Figure 5-12: Risley Prisms

5.14 Quadrant Micro-Channel Plate (QMCP)

Please see the ***Receiver*** section for more information on this device.

5.15 Star Camera Insertion Mount

The star camera insertion mount is a 50/50 pellicle beam splitter installed on a ThorLabs SB1 magnetic/kinematic mount. This mount is manually inserted and locks into place onto the magnetic base plate (bolted to the transceiver bench). It is very repeatable angle but care must be taken at insertion/removal due to its fragile nature. Repeatability is generally good to the arcsecond level. It is only used for system alignment and star calibration, and is removed from the beam path when the system is tracking or performing ground calibrations. This mount may be replaced with a permanent beam splitter (passing 532 nm and reflecting visible starlight) to simplify system operation if front surface/back surface reflection issues can be resolved.

INSERT IMAGE OF STAR CAMERA INSERTION MOUNT

5.16 Star camera ND Filters

The star camera is used along with the pellicle beam splitter, alignment cube, and laser to align the transmit path to the receiver line of sight. To protect the star camera from excessive laser illumination a flip-in 1 ND filter is mounted in front of the star camera to reduce laser illumination when system alignments are conducted. In addition to the flip-in filter a second ND filter box is mounted in front of the star camera to reduce laser alignment illumination further. Both NGSLR and LRO lasers require further attenuation at their source. The NGSLR laser requires an additional 2 NDs attenuation (provided by a transmit ND wheel) and the LRO laser requires 5 NDs attenuation (provided by the I/O chassis eyesafe drop-in). Both camera filters are removed when star viewing is required. During SLR or LRO operations the pellicle beam splitter is removed and the camera is blocked and protected when either laser is firing.

INSERT IMAGE OF STAR CAMERA ND FILTERS

5.17 Star Camera

The star camera is integral to all NGSLR system alignments and focus operations. The star camera is focused for the best image using a collimated light source. It then becomes the focus reference for the receive telescope system. The star camera is also used to boresight the laser transmitter onto the optical axis of the telescope by imaging a star. The star camera*is used to perform star calibrations which tie the system to the inertial reference frame. Access to the telescope line of sight for the camera is achieved by inserting into the beam path a 50/50 pellicle beam splitter mounted in an NRC magnetic kinematic mount. Angular repeatability of the removable magnetic mount is typically 1 arcsecond. The star camera views through a 5X power beam reducer and a 1-inch focal length imaging lens to yield a FOV of 2 arcminutes. The image produced is 765 x 510 pixels in size with each pixel being represented by a 16-bit (2 byte) intensity level. This image is sent to the POP computer, which reads and controls the CCD camera.

Manufactured by the Santa Barbara Instrument Group (SBIG), model ST-9XEI CCD.

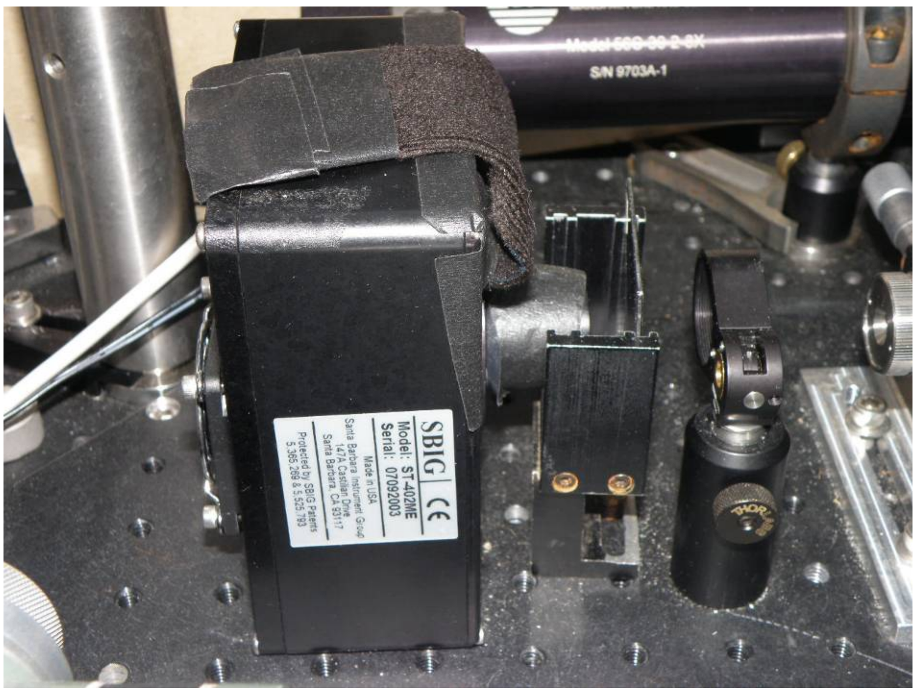


Figure 5-13: SBIG Star Camera

5.18 Start Diode

Please see the ***Laser*** section for more information on this device.

6 Laser

The NGSLR system uses two different doubled Nd:YAG lasers operating at 532 nm for SLR tracking operations and LRO one way measurements. Each laser is tailored to its specific use. SLR tracking requires the highest precision, and hence, utilizes a short pulse (~200 picoseconds FWHM) laser transmitter firing at 2 kHz. LRO tracking at lunar distances requires significantly more laser energy per pulse (~50 mJ) and a fire time synchronized to the LRO spacecraft clock to about 1 millisecond. Both lasers are co-boresighted into the NGSLR system and can individually be put into service by the insertion or removal of a magnetic/kinematic mirror mount on the transceiver bench.

6.1 Firing the lasers

The two lasers at NGSLR use different methods of fire control, each tailored to its unique function. The NASA 1 mJ laser fires at 2 kHz, with the fire rate varied slightly to avoid the "collision" of incoming pulses with outgoing transmit pulses. Only two frequencies at a time are need to prevent collisions; the base 2 kHz frequency and an alternate, the value of which depends upon the altitude of the spacecraft.

There are three possible alternate frequencies:

- Low Earth Orbiting (LEO): 1960 Hz
- LAGEOS/LAGEOS-2: 1992 Hz
- GNSS altitude: 1996 Hz

The alternate firing frequency assigned to each spacecraft is stored in the SATELLITES_S2K.dat file on the POP computer. The required PRF is sent as a command from the POP computer along with a flag indicating pulse repetition frequency (PRF) control is required. If the flag for PRF control is set, the ICC knows that it is dealing with the NASA 1 mJ laser and outputs its control through the CCSI to the I/O Chassis, where its arrival time is used to establish the blanking period for the receive PMT. The NGSLR laser has a trigger-to-fire time of 100 µs. Internal to the I/O chassis is the PMT blanking circuit which prevents the PMT gate from being energized from 20 µs before the laser output to 50 µs beyond the laser output. This prevents the PMT gate from ever being energized when the laser is firing.

The Northrop Grumman laser, used for laser ranging to LRO and some 2-way SLR, fires at 28 Hz with software controlling the actual time of the laser fire, set via channel 2 of the Range Gate Generator (RGG). The fire time command to the RGG represents the delay from the start of the 2 kHz on-time to the laser fire command. Once a command has been given to the RGG, it will continue to output that delay every interval (2000 times a second), until the software tells it to stop or gives it another command. To generate a 28 Hz command to fire the laser, the software outputs to the RGG at 2 kHz, but changes the width of the pulse being output from the RGG. The LRO laser fire command goes into the I/O chassis where wide pulses are output at 28 Hz and narrow pulses are suppressed at all other intervals. POP determines which intervals the laser should fire and the delay from the start of the 2 kHz on-time to the fire command. The laser actually fires somewhere from 150 µs to 300 µs after the command is issued from the RGG. POP must take this delay into account. The ICC computer simply takes the commands that POP puts into shared memory and executes them. It does no calculations to determine when to fire.

6.2 Start Diode

Both LRO and NGSLR systems have a dedicated Monsanto MD2 start diode positioned in a fixed location in the outgoing laser path. The MD2 start diode packages were fabricated into a Bud box with a 60V battery for biasing, and 1 meter long RG174 cable for analog output through a BNC connector. The MD2 is a sub-nanosecond detector with a positive output.

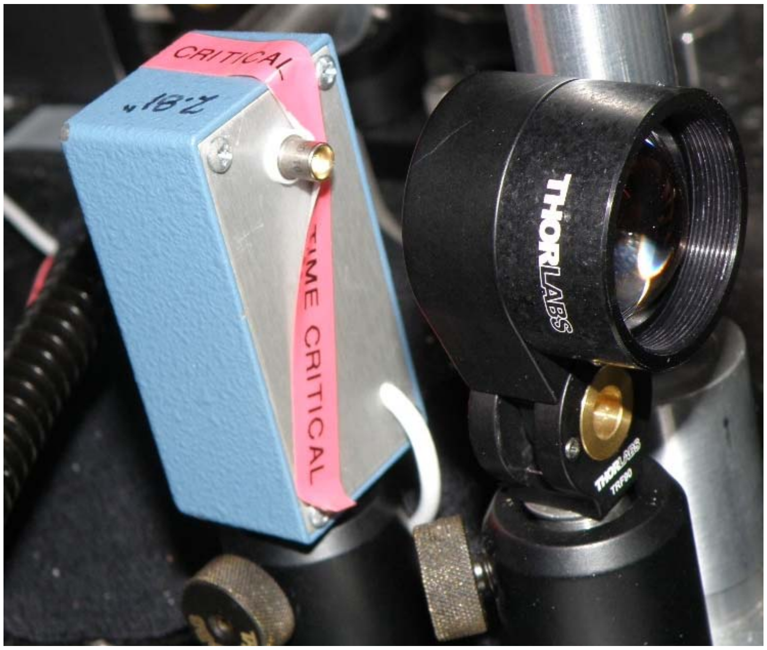


Figure 6-1: Start Diode

The LRO start diode is physically located on the NGSLR optical breadboard in a vacant spot. The optical pickoff for the LRO laser is located behind the first turning mirror in the transmit path leaving the laser. Leakage through that 45 degree mirror uniformly illuminates a small white screen which scatters light into one end of a meter long fiber optic bundle. The fiber bundle is brought down to the lower bench where it illuminates the MD2 start diode. A 1-inch diameter 50mm focal length lens is used to at the fiber output to set the optical signal level into the diode. The positive going pulse is inverted with a BNC pulse inverter and set with the lens to about 800mV amplitude.

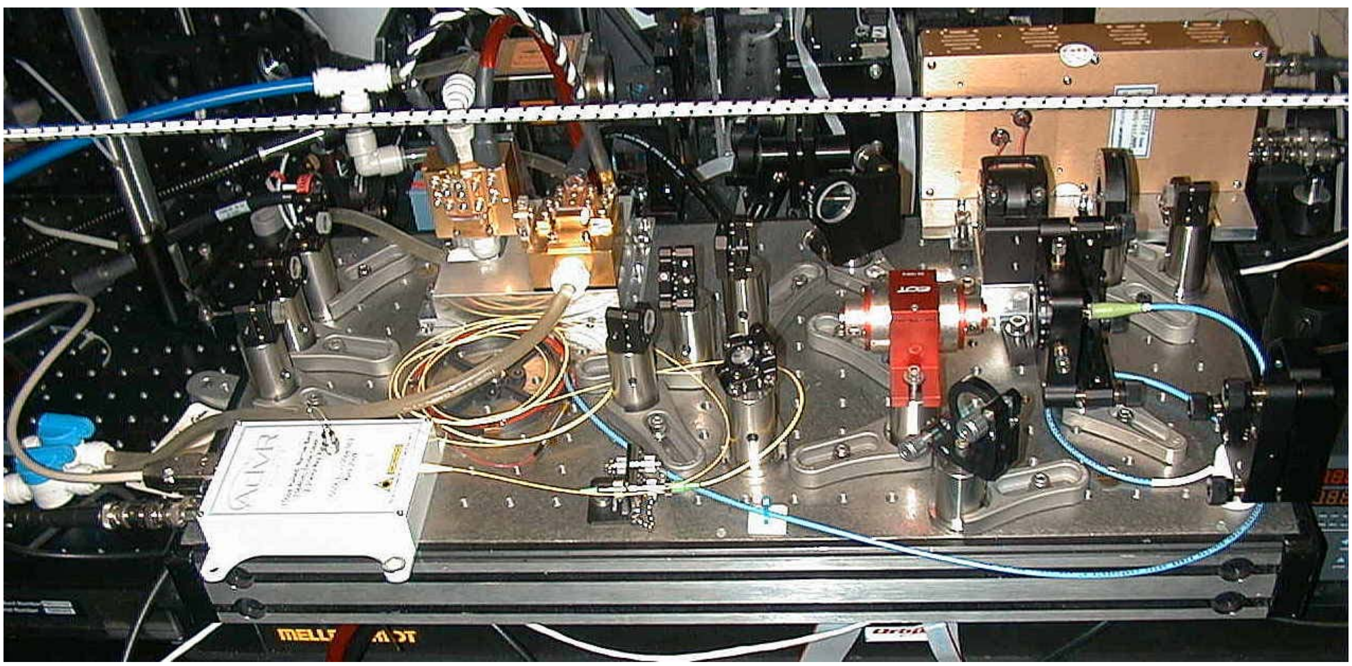
The NGSLR start diode is physically located on the NGSLR optical breadboard behind the second turning mirror out of the laser. A 0 to 2 ND wheel is used to set the optical level. The positive going pulse is inverted with a BNC pulse inverter and set with the ND wheel to about 800mV amplitude.

6.3 NASA 1 mJ Laser

The NASA mJ laser was built in house by Code 554 of NASA at the Goddard Space Flight Center. It is based on a regenerative amplifier seeded by a gain-switched fiber optically coupled diode laser. The regenerative amplifier cavity is 1.5 m long and utilizes a pair of Nd:YAG zigzag slabs in a crossed-head configuration as the gain medium. The seed pulse is trapped in the regenerative amplifier cavity using a Pockels cell, and after approximately 35 passes, switched out and directed through a KTP frequency doubler. The regenerative amplifier system is designed to run at a repetition rate of 2 kHz with ~1 mJ/pulse at 532 nm and a ~200 ps pulse width. Intended for SLR operations only, the maximum average power on the table is 2 W. This laser can be operated in an eyesafe mode by installing a O.D. 1.3 filter in the laser beam path.

Manufacturer: Goddard Space Flight Center

Built by:	Barry Coyle and Demetrios Poulios, code 554
Wave Length:	532 nanometers
Pulse Width (FWHM):	200 picoseconds
Repetition Rate:	2,000 Hertz
Energy:	1 millijoule
Average Power:	2 Watts



6.4 LRO Laser (Northrop Grumman - Nd:YAG diode pumped actively Q-switched laser)

The laser transmitter used to support the LRO tracking mission is a diode pumped 532 nm Nd:YAG system from Northrop Grumman. The laser has a 5.5 nanosecond pulsewidth and has a PRF of 28 Hz. The laser is mounted on an elevated breadboard above the NGSLR optical bench and is injected into the coelostat by inserting a 45 degree mirror on a ThorLabs SB1 kinematic mount into a magnetic base plate. This insertion mirror aperture shares the receive path with the NASA laser, enabling SLR operations with the LRO laser and NGSLR receiver. This utilizes the NGSLR alignment capability of the star camera and alignment cube. This laser is not eyesafe on the laser table, therefore laser operators are required to use protective eyewear with a minimum OD of 6.5 at 532 nm. During ground calibration, an OD 5 block is inserted by the laser interlock chassis for eyesafe laser levels. For aircraft avoidance, the Laser Hazard Reduction System (LHRS) controls a beam block interrupting the LRO beam path. If the laser is disabled due to a radar detect, the laser cannot be re-enabled until the field is once again clear. The operator must manually re-enable the laser interlock chassis to fire the laser again. The LHRS is described in greater detail in the next section. Beam divergence exiting the telescope is about 11 arcseconds (FWHM) and can be adjusted manually using a beam expander on the upper LRO laser optical bench. The start diode for the LRO system is located on the NGSLR optical bench with the optical signal delivered via fiber optic bundle. The fiber optic bundle picks off the start pulse from leakage through the first turning mirror out of the LRO laser on the upper optical bench.

Figure 6-2: Northrop Grumman Laser

The LRO laser is commanded to fire at 28 Hz synchronous with the opening of the 8 millisecond Earth range window in the LOLA instrument on LRO. LRO time and clock drift rate is well known on the spacecraft as is laser trigger delay at NGSLR and the time-of-flight to LRO. Section [TBD] describes the 28 Hz firing of the LRO laser with the 2 KHz RGG output.

7 Laser Hazard Reduction System (LHRS)

The NGSLR and LRO laser ranging programs use a combination of procedures, electromechanical systems, and software to ensure SLR operations are safe. Both systems offer multiple verifications and redundancies to make certain the operations of the system are properly conducted. The crew has a written set of start-up, operating, and shut-down procedures to follow, including checking the LHRS system and calling the FAA before operations commence and when operations end.

Figure 7-1: The LHRS Radar Tower next to the NGSLR Shelter

The NGSLR system employs electromechanical equipment to ensure safe operations. The Laser Interlock chassis is used to control hardware to block the transmitted laser energy. This laser energy beam block is permanently mounted at the output of the laser.

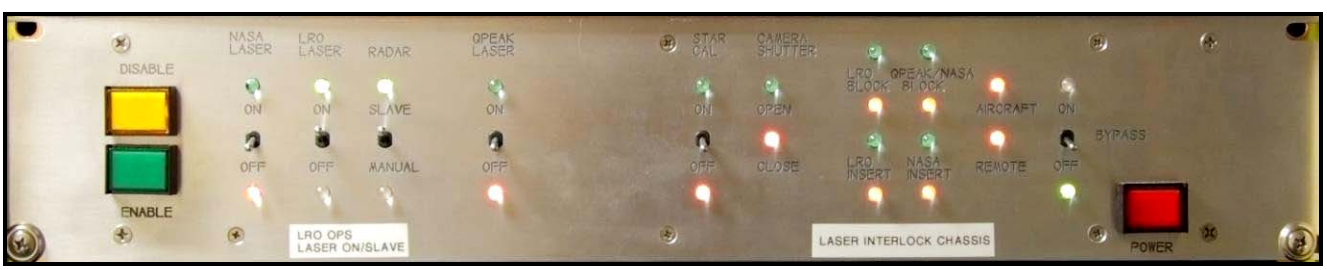


Figure 7-2: Laser Interlock Chassis

The beam block is a failsafe device that automatically rotates into the beam path whenever it loses power or connection. Before ground ranging or SLR operations begin, the operator ensures the beam block is in place by pressing the **Laser Disable** button on a hand control (Figure 7-4) located next to the operator. When laser operations begin the **Laser Clear** button is pressed removing the beam block. The Laser Interlock can also be used to terminate the transmitted laser energy on short notice should the need occur.

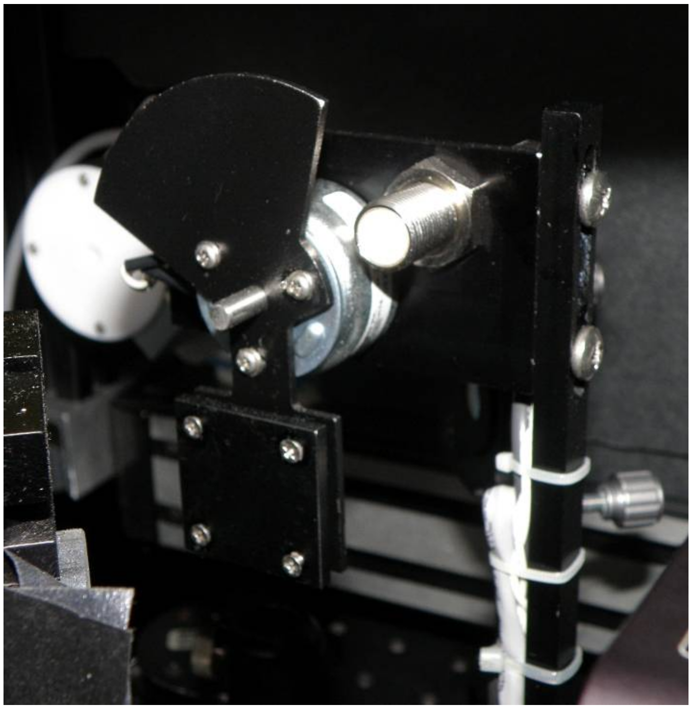


Figure 7-3: Beam Block

Figure 7-4: Beam Block Hand Control

The LHRS is a radar based aircraft detection system that monitors the airspace surrounding the transmitted laser energy. When an aircraft is detected, the LHRS signals the Laser Interlock to automatically block the transmitted laser energy. Once the aircraft has cleared the RF energy of the LHRS, the operator uses the **Laser Clear** button to once again begin SLR operations.

The Laser Hazard Reduction System (LHRS) is designed to detect aircraft within a 26 mile radius of the laser transmitter that are at risk of intercepting the transmitted laser energy. This is accomplished by slaving the radar transmitter to the laser transmitter and monitoring the cone of space that surrounds the transmitted laser beam for aircraft. The radar transceiver operates at a 750 hertz rate, producing 4 kilowatts of peak power at a 9.410 GHz frequency. All radar returns are subjected to a statistical algorithm to determine whether they are aircraft or spurious noise. The primary lobe beam width of the transmitted RF energy is 2.8 degrees, significantly greater than the 0.001 degree beam width of the transmitted laser energy. This difference provides more than sufficient time for the LHRS to detect aircraft and allow termination of the laser energy. Once an aircraft has been detected, the laser transmit beam is blocked at the output of the laser via the Laser Interlock system.

Figure 7-5: LHRS Radar and Gimbal

The LHRS radar gimbal is slaved to the laser transmitter gimbal. Pointing commands for the LHRS are generated from the raw encoder angles of the laser transmitter gimbal. Any sudden deviations in laser transmitter pointing are recognized within milliseconds by the LHRS, allowing the LHRS to exactly follow the laser transmitter gimbal at all times within a few tenths of a degree. When the radar antenna is properly calibrated and mounted, the pointing of the radar transmitter is coincident with the optical transmitter to within 0.09 degrees. The co-alignment between the radar transmitter and the laser transmitter is monitored by the LCU, using the position information generated by the encoder of each system. If the two systems fall out of alignment, the LCU signals the Laser Interlock to block the transmitted laser energy. ...many more pages of detail are available in the 23-6L .

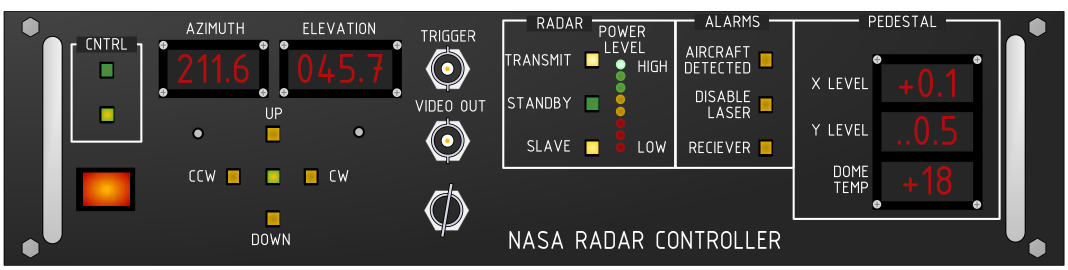


Figure 7-6: Front of Local Controller

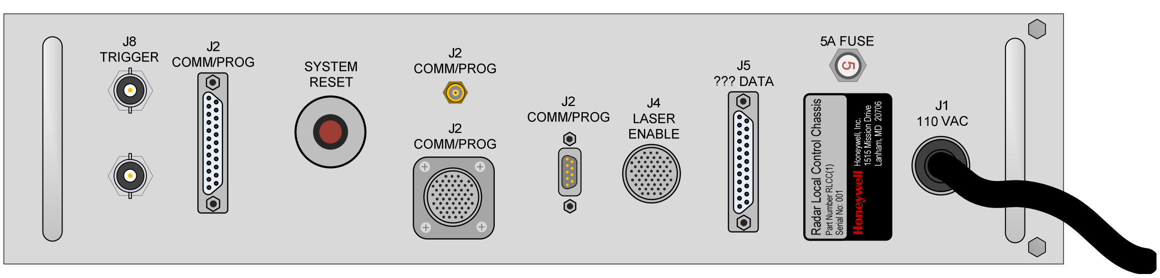


Figure 7-7: Back of Radar Local Controller

8 Tracking

The NGSLR tracking system is an elevation over azimuth gimbal mount. Slip rings in the azimuth axis enable un-encumbered rotation while the elevation axis spans from -3° to 183°.

8.1 Gimbal and Controller

The tracking mount for NGSLR was built by the Xybion Corporation (later acquired by Cobham Sensor Systems). This elevation over azimuth gimbal was designed to handle the size and weight of the 40 cm off-axis telescope. The gimbal is sealed with entrance and exit anti-reflective (AR) coated windows and has a set of four internal flat mirrors to direct the collimated beam through the azimuth and elevation axes of rotation out into the telescope. DC brushless motors drive the system in both elevation and azimuth axes and 22-bit encoders provide positional feedback. The servo controller is interfaced to the ICC. Slip rings in the azimuth axis are used to communicate encoder positions from 0° to 360° degrees (unlimited azimuth movement) while the elevation (with a cable wrap) is limited in movement from -3° to 183°.

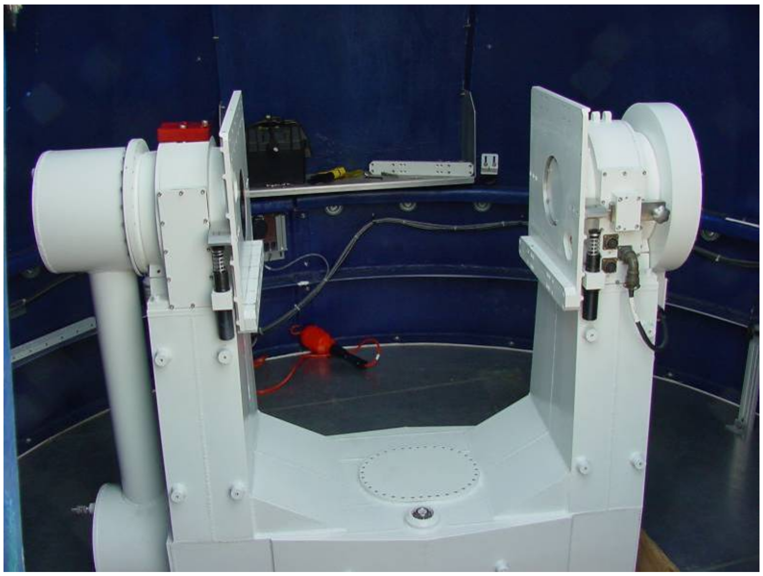


Figure 8-1: Mount before the installation of the telescope

8.1.1 Driving the mount

The Xybion mount is capable of driving at 20°/s in each axis, and accelerating at > 10°/s^2 in each axis. The mount is capable of arcsecond level pointing and tracking at speeds of several degrees per second. Encoder offsets read in from the site-file, and a mount model (which is applied to the data on POP) tie the mount to inertial space. For more information on the site-file and the mount model, please refer to the NGSLR Programmer's Manual.

The servo control unit is the interface between the ICC computer and the mount. The servo controller has the capability to drive the mount via position commands. However, since the laser is firing at 2 kHz, 50 Hz position commands would not be able to place the mount at the required positions for every fire. Therefore, the ICC controls the mount via velocity commands and the code implements a velocity feed-forward servo compensation loop that was developed at Xybion specifically for NGSLR. The servo coefficients developed at Xybion are contained in the servo coefficient data file on the ICC computer, and are read in at the start of the program. These coefficients should not be modified. Refer to the NGSLR Programmer's Manual for further details on the Algorithm and the servo coefficient data file.

Communication with the servo controller is via RS232 (COM1 on the ICC) at 50 Hz. Positional information is read in, corrected for encoder offsets, differenced with the commanded positions (which come from POP via shared memory), and sent through the servo compensation loop. The result of this calculation is then output via the RS232 connection to the servo controller to drive the mount. In addition, there is also a 2 kHz input of mount positions via parallel I/O which is used only for diagnostics.

9 Receiver

The receiver includes the optical detector, amplifiers, timing discriminators, and all timing electronics needed to time tag photon arrival times. With a 2 kHz PRF, the NGSLR system has multiple shots in flight when tracking satellites. A unique set of problems had to be solved for NGSLR tracking success. They will be detailed in further sections.

9.1 Optical Detectors

All receive detectors currently used in the NGSLR system are based on micro-channel plate photomultiplier tube (MCP PMT) technology. These photomultiplier tubes are capable of converting a single receive photon event into an analog pulse of sufficient amplitude to trigger the system event threshold. Raising system receive thresholds above the single photoelectron (1 PE) level is not possible since essentially all receive pulses are at the 1 photoelectron level, in fact, the average signal level is generally much less than 1 PE and as low as .001 PE. The NGSLR receiver lives in a harsh back scatter environment in sharing transmit and receive optics. The system must maintain single photon detection capability while transmitting as many as 10^{17} photons in an outgoing 2 kHz laser pulse. It is crucial that collision and back scatter problems be solved successfully, otherwise tracking will be compromised and detector lifetime or damage may result. The collision problem mentioned earlier in the blanking section has been addressed with both a software solution (laser PRF control) and a hardware solution (receiver blanking). Both techniques are required to assure proper system operation.

The current detector for the NGSLR is the 2-stage Hamamatsu model R4110U-74-M004C quadrant MCP PMT. The gain of the detector is nominally 6.1×10^5 with quantum efficiency in excess of 30%. Detector rise time (10-90%) is 230 picoseconds while the instrument response function (IRF) is about 115 picoseconds. The PMT is housed in a light tight enclosure, with only the receive path open to the photocathode. High voltage is applied to the tube through a HV-MVA connector on the rear of the tube housing, as well as a gating module input through an SMA connector. Signal output for the four quadrants are on four RG-174 cables about 2 meters in length. The detector/amplifier/discriminator combination yields single photon sensitivity for each of the 4 quadrants. The detector is mounted in the image plane of the receive telescope and aligned on axis just behind the receiver field of view iris. By accumulating statistics of the individual signal photon events in each quadrant a centroid of the receive signal can be computed and an off axis pointing error can be determined. This point error is used to close the servo tracking loop by moving the telescope in the direction to balance the receive signal over all four quadrants. The dwell (or stare) time needed to compute the signal centroid is dependent on the signal return rate and can vary from a second to many tens of seconds.

9.1.1 Quadrant MCP (Hammamatsu -Model R4110U-74-M004C)

The model R4110U-74-M004C is a quadrant MCP PMT built by Hamamatsu Photonics Incorporated. This detector with a GaAsP photocathode has a stated quantum efficiency of 30% to 34% (two tubes are available) and a gain of $6X10^5$. The manufacturer claims of single photoelectron timing jitter of 108 to 119 picoseconds have not been laboratory verified but are in order with other tested PMTs (Photek PMT308Q). The Hamamatsu QMCP tubes utilize the same gating module as the Photek tubes. The maximum supply voltage for the Hamamatsu QMCP is -2600 V. Anode output on the QMCP is on 4 RG-174 cables of 2 meters length. Single photoelectron voltage amplitude out of the PMT is typically 8-10 mV (into 50 Ω). A dynamic range of at least 3 to 1 can be expected.

INSERT HAMMAMATSU IMAGE

9.1.2 Quadrant MCP (PHOTEK - Model PMT308Q); *Optional – Not shown on drawing*

The model PMT308Q is a quadrant MCP PMT built by Photek Incorporated. This detector with a S20 photocathode has a stated quantum efficiency of 11% to 13% (three tubes are available) and a gain of $3X10^6$. The manufacturer claims of single photoelectron timing jitter of 28 to 40 picoseconds is not borne out in laboratory testing. Independent tests conducted by Allied Signal Aerospace in August of 1999 suggest the transit time jitter of the Photek model PMT309Q tube is in the order of 93 to 123 picoseconds RMS.

Figure 9-1: Photek Quadrant MCP

A Photek provided gating module is used with the model PMT308Q tube. A +12V power supply and TTL gate logic signal from NGSLR electronics is needed to gate the PMT on. The PMT requires a high voltage power supply of -4700 V and output on 4 anode SMA connectors. Single photoelectron voltage amplitude out of the PMT is typically 8 to 10 mV (into 50 Ω). A dynamic range of at least 3 to 1 can be expected.

9.1.3 Single Element MCP (Hammamatsu - Model R5916U-64); *Optional – Not shown on drawing*

The model R5916U-64 is a single element MCP PMT built by Hamamatsu Photonics Incorporated. This detector with a GaAsP photocathode has a stated quantum efficiency of >40% and a gain of $3X10^5$. The manufacturer claims of single photoelectron timing jitter of 136 picoseconds have not been laboratory verified but are in order with other tested PMTs (Photek PMT308Q). This Hamamatsu single element MCP tube requires a gating module providing a minimum of +10 V to gate the PMT on. The suggested supply voltage for the Hamamatsu R5916U-64 is -2750V ~ -2950 V. The anode output of this MCP detector is an SMA connector. Single photoelectron voltage amplitude out of the PMT is typically 10 mV (into 50 Ω). A dynamic range of at least 3 to 1 can be expected. This PMT does not support the quadrant detector configuration used to close the tracking loop in NGSLR, therefore other software techniques must be implemented when this detector is being used.

Figure 9-2: Hammamatsu Single Element MCP

9.2 Supporting Equipment

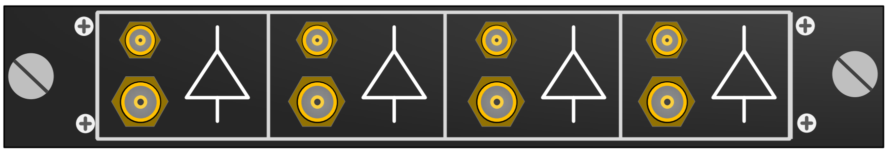
9.2.1 High Voltage Power Supply (Bertran - Model 315)

This is used to bias the photomultiplier tube (PMT). The high voltage power supply used by the NGSLR PMT receivers is the Bertran - Model 315. This is a double width NIM module with independent 120V AC input which provides operating PMT voltages as specified by the manufacturer (-2.7 kV to -4.7 kV).

Figure 9-3: Bertran High Voltage Power Supply

9.2.2 Amplifier (Phillips Scientific - Model 774)

PMT output for the NGSLR system requires an amplifier with sufficient gain to raise the single photoelectron voltage to mid-range of the timing discriminator for optimum system performance. The Phillips Scientific model 774-S-50 used in the NGSLR system is a 4 channel preamplifier with a gain of 50 in a single width NIM package. It is a non-inverting amplifier with SMA connectors and a 3db bandwidth of 1.5 GHz. The typical single photoelectron pulse amplitude out of the Phillips Scientific 774 amplifier is 400 to 500 mV.

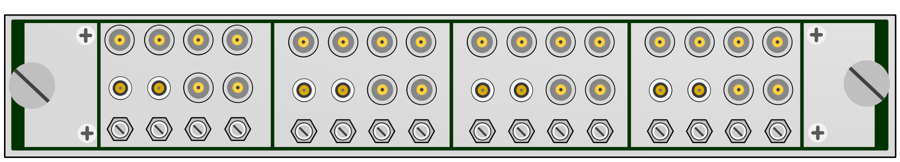


9-4: Phillips Scientific Amplifier – Model 774

9.2.3 Discriminator (Tennelec - Model TC454)

One advantage the NGSLR system has over other higher signal level systems is the limited dynamic range of the return signal level. Signal level is not stated in pulse amplitude but rather measured as a return rate. Since the NGSLR system always operates in a photon starved environment, the dynamic range in signal is dictated primarily by the statistical range contributed by the MCP detector (~3 to 1). In multi-photoelectron SLR systems the dynamic range generally spans from threshold (2 or 3 photoelectrons) to hundreds (or thousands) of photoelectrons depending on the satellite being tracked. This wide dynamic range which often exceeds 100 to 1 can significantly impact the measurement accuracy by introducing amplitude dependent time walk within the timing discriminator. In general, higher amplitude pulses tend to trigger timing electronics earlier than low amplitude pulses. The NGSLR system uses a 4 channel Tennelec TC454 constant fraction discriminator (CFD).

The constant fraction discriminator is designed to minimize amplitude dependent time walk. The CFD relies on a measurement technique where the input signal is split and one of the splits is attenuated and delayed. When both signals are recombined in the CFD a bipolar timing pulse is created. The zero crossing of this bipolar pulse is independent of pulse amplitude. When the zero crossing is detected a stable NIM logic output pulse is generated. The NIM pulse is used by the event timer to time tag that receive event. Peak performance of the timing discriminator is achieved only when an external cable delay has been tailored to the proper length to match the receive pulsewidth and a internal time walk delay adjustment has been set properly. Incorrect time walk settings or a cable delay mismatch will result in a higher system RMS in all ground calibration and satellite data.



9-5: Tennelec TC454

9.2.4 Event Timer

The Event Timer (ET) is a custom built, multichannel event timer which time tags all of the events needed to capture time of flight measurements for NGSLR. Built specifically for NGSLR by HTSI, it time-tags the fire events independently from the receive events, and is required due to the high pulse repetition frequency (PRF) used. With multiple shots in flight at the same time, the range is determined by correctly associating fires with returns using the predicted ranges and then differencing the time tag of the laser fire with the time tag of its return events. It operates on a 2 kHz cycle, time tagging 1 PPS events, 2 kHz on-time events, 2 kHz start events, and 4 channel (quad detector) stop events.

INSERT EVENT TIMER CONNECTIVITY DIAGRAM

The ET has 12 input connectors, each pertaining to a different stream of information, that all pass through one timing circuit. Timing events which occur within the 70 ns dead time of the ET must be externally delayed to avoid loss of that time tag. In the case of the 4 channel quadrant receiver, delays of 100, 200, and 300 ns are used to push quadrants 2, 3, and 4 beyond the dead time of the ET. See the System Connectivity drawing D-07 for a graphic illustration. System ground calibrations remove these fixed biases. Table 9.6 illustrates the association between the software and hardware channels, as well as the physical connector that the signals traverse.

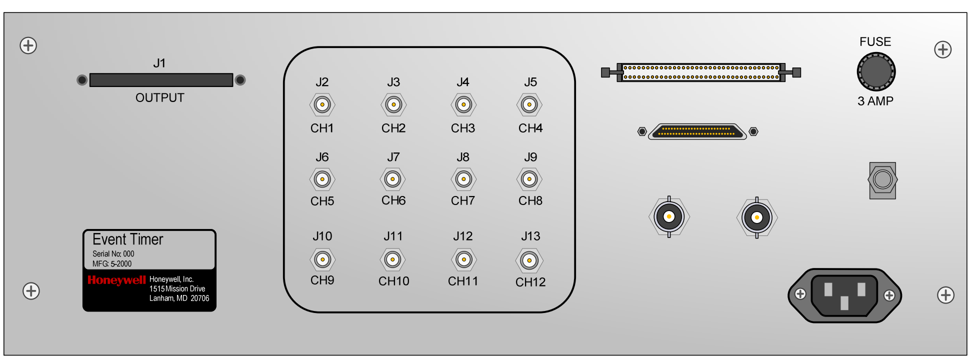


Figure 9-6: Back of Event Timer showing connector numbers

Event Timer Channels	Channels		
Description	Software	Hardware	Connector
Return from quadrant 0 of SLR Photo Multiplier Tube (PMT)	0	1	J2
Return from quadrant 1 of SLR Photo Multiplier Tube (PMT)	1	2	J3
Return from quadrant 2 of SLR Photo Multiplier Tube (PMT)	2	3	J4
Return from quadrant 3 of SLR Photo Multiplier Tube (PMT)	3	4	J5
Transponder return from 1064 nm detector	4	5	J6
48" or MOB-7 fire time	5	6	J7
48" or MOB-7 1 PPS on-time	6	7	J8
Maser 1 PPS	7	8	J9
NASA 1 mJ laser fire time (from start diode)	8	9	J10
LRO laser fire time (from start diode)	9	10	J11
1 PPS on-time from National Instruments Timing Box	10	11	J12
2 kHz on-time from National Instruments Timing Box	11	12	J13

Table 9-1: Event Timer Channels

Note: The channels listed refer begin with the software channel number. The hardware channel number is derived using 1 + the software channel number, while the connector identifier begins with "**J**" followed by 1 + hardware channel number.

Example:
The LRO laser fire time is on software channel 9, hardware channel 10, through connector J11.

The Event Timer raw measurement consists of two 32-bit words containing coarse counter and fine vernier information along with the channel from which it was read. When turned on, the ET counter starts at zero. The counter rolls over every 100 milliseconds. To relate the ET timing information to UTC, the 1 PPS and 2 kHz on-times are input to the ET. All SLR event times are referenced to the 2 kHz on-time and all LRO fire data is referenced to the 1 PPS.

Timing information is stored in a buffer on the Event Timer, which is read by the ICC Computer every 500 µs interval. The ICC reads all values that have been stored since the previous reading, moving on when it is complete. The ICC computer is only able to handle 20 data values at one time, without risking running over its 500 µs time limit. Occasional occurrences of this situation should not pose a problem; however if this happens frequently, it is possible for the ICC computer to get out of sync with the Event Timer.* To resynchronize the two devices, the Event Timer needs to be reset by the ICC, which can take up to several seconds.

The ICC verifies synchronization by verifying that the delay between the 1 PPS signal and the 2 kHz on-time is 9.8 µs in length. If the ICC sees several delays that do not match this, it determines that it is out of sync, and a reset of the Event Timer is necessary.**

**High noise rates can produce a larger than normal number of data values, making it more likely that the ICC will become out of sync with the Event Timer. Verify that the iris and the BPF are set correctly for the conditions.*
***If the 1 PPS is disconnected from the Event Timer, or it is receiving a bad signal, this can cause the Event Timer to continually reset.*

9.2.5 Range Gate Generator (Honeywell Technology Solutions, Inc.)

The Range Gate Generator (RGG) is a custom built, multichannel, delay generator which controls all of the programmable delays needed to operate NGSLR. It operates on a 2 kHz cycle outputting either NIM or TTL level signals to control range gates in SLR mode, and the laser fire when supporting LRO. The RGG outputs the pre-loaded delays in each channel to the I/O Chassis for every 500 µs interval. Input to the RGG is limited to 500 Hz because of system I/O limitations.

INSERT RGG CONNECTIVITY DIAGRAM

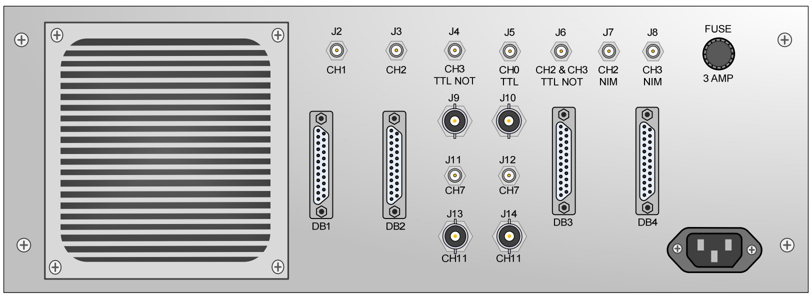


Figure 9-7: Diagram of back of the RGG showing various connectors

To fire the LRO laser at 28 Hz using the 2 kHz RGG output, the pulse is sent through the I/O chassis where a low pass filter effectively passes the 28Hz while suppressing the 2 kHz.

INSERT WAVEFORM DIAGRAM OF 2 kHz TO 28 Hz LOW PASS FILTER

9.2.5.1 Setting the Range Gate

If the system is expecting receive events, POP sends the delay and width of the range gate every 500 µs. The delay represents the time from the 2 kHz on-time to the opening of the range gate. The information which is sent over shared memory in interval “N” represents the gate needed for interval “N+2”. The ICC COMPUTER uses this information for the “window-window” output on RGG channel 1. The “window” output is an expanded region about the “window-window” which is output on RGG channel 0.

Table 3.1 - RGG Channels (4 Channels)

- 0 = Range-Gate (aka Window)
- 1 = Window-window
- 2 = LRO Fire Control
- 3 = not currently used

9.2.6 I/O Chassis (Honeywell Technology Solutions, Inc.)

The I/O Chassis is a custom built unit which controls and distributes the proper gate signals for the PMT and discriminator during ground calibrations and satellite tracking using its internal delay circuits and the RGG inputs. Both the blanking circuit for SLR operations and the 28 Hz LRO laser fire circuitry are housed in the I/O chassis. Switches on the I/O chassis front panel must be set manually in the desired mode: either ground calibration or SLR, and either LRO or NASA 1 mJ laser.

INSERT DIAGRAM OF I/O CHASSIS CONNECTIVITY

The I/O chassis operates as a pass through of the 2 kHz laser fire for SLR operations. The 2 kHz laser fire command originates in the Computer Clock Synch Interface (CCSI) box and must be sampled in the I/O chassis to establish receiver blanking. The I/O chassis also provides convenient rear panel monitor points for all the signals passing through it.

INSERT IMAGE OF REAR PANEL OF I/O CHASSIS

9.2.6.1 BLANKING CIRCUIT in the I/O Chassis

The laser fire command is used in the I/O chassis to establish in time the required blanking period for the laser being used. The start of the blanking window occurs 20 µs before the laser output pulse and extends to 50 us after the laser pulse. This blanking period of 70 µs prevents in the hardware the PMT gate from coming on when the laser may be firing, or a significant amount of backscatter can be expected from back reflecting optics or atmospheric scatter. Transmit delay (the time between the fire command and actual laser output) for the NASA laser is 100.5 µs.

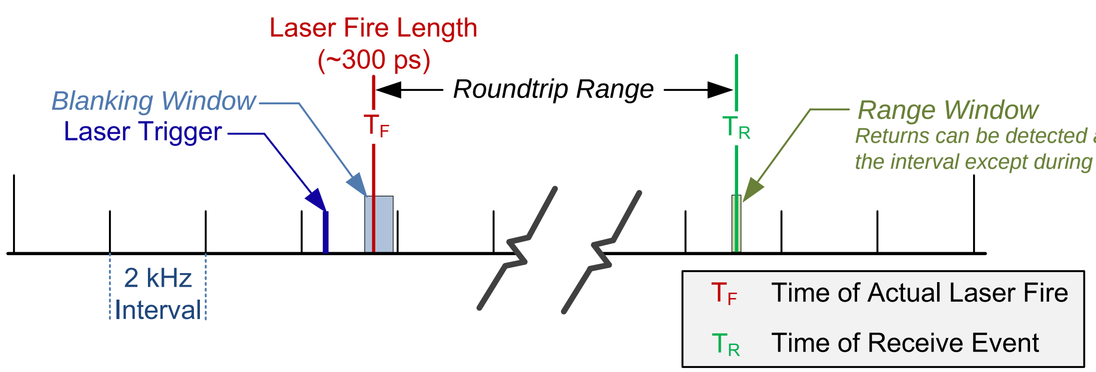


Figure 9-8: Laser Blanking Window and the Range Window

Laser fire is currently staggered to avoid the "collision" problem where transmit and receive occur simultaneously. This is done by controlling the laser PRF at two preset values (see section 6.1 for details on controlling the PRF). Window in Window gating (W/W) eliminates discriminator triggering on the range gate itself. The PMT range gate window and discriminator W/W originate in the RGG and are passed through the I/O chassis. The blanking circuit delay is preset in the I/O chassis.

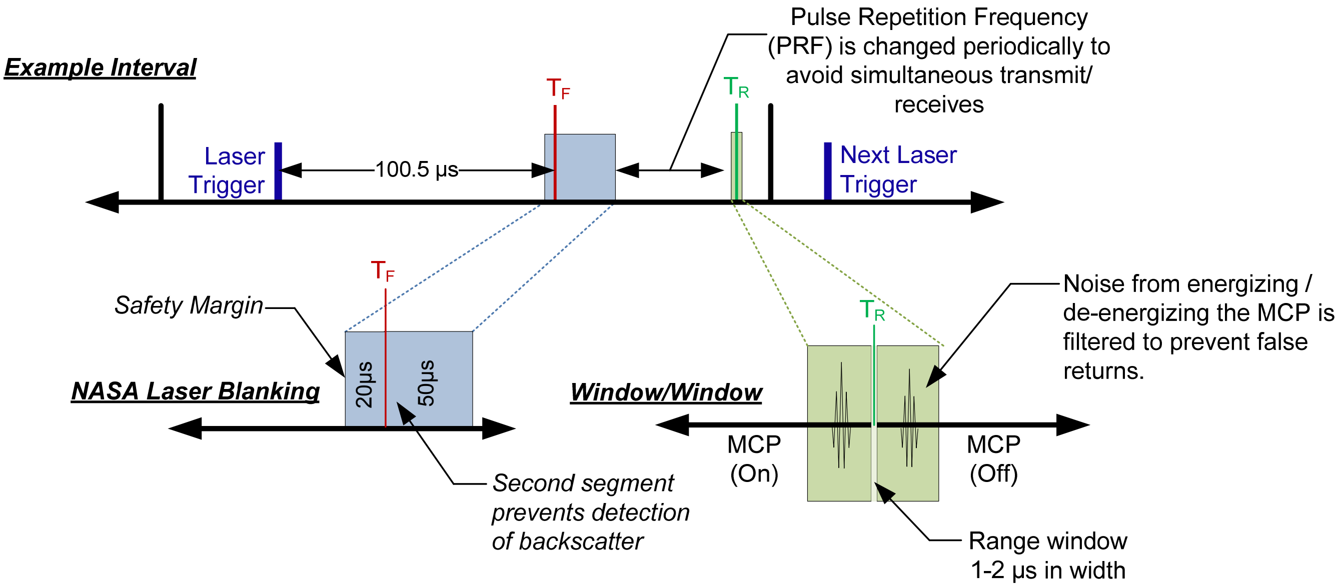


Figure 9-9: Detail on Laser Blanking and Window/Window

GROUND CALIBRATION PARAMETERS

In the ground calibration mode, the start of the MCP gate is set at 500 ns after the start pulse is detected. The MCP gate is 1 µs wide (set in the I/O chassis) and W/W occurs ~300ns after the start of the MCP gate. The W/W width is 400 ns wide. The I/O chassis switch setting of "GROUND CAL" is required to enable the receiver for ground calibrations. Three ground targets are visible for NGSLR use and all fall within the I/O chassis gates. For SLR operations the I/O chassis switch position must be manually moved back to the "SATELLITE" position.

9.2.7 Laser Fire Frequency Counter (HP 5131B)

To assist the operator in providing real time laser fire information a frequency counter (HP5131B) is used to visually display the laser PRF. The trigger source for the counter is a spare start discriminator output.

Figure 9-10: HP Universal Counter

10 Computers and Software

This section discusses the computers used in the system and the hardware connected to them. The computers were chosen for their ruggedness and availability, as well as to accommodate COTS hardware and software solutions. The operating systems were chosen for the 15+ years of experience programming in those environments. Please refer to the sections below and to Appendix B – System Specifications.

10.1 Interface and Control Computer (ICC)

The **ICC** performs real-time input and output functions to hardware devices via interface cards. No data processing is actually performed on the ICC; all data is passed to and from POP via shared memory. This DOS based system runs on a Pentium based processor with a mixed ISA/PCI bus. Software tasking is driven by 2 kHz interrupts from the timing system via a timing and digital interface card.

10.1.1 PCI Adapter (GE/FANUC S810)

POP and DAM have direct access to shared memory since they are located directly on the VME bus. However, the ICC is a standalone PC that requires the use of a PCI adapter to connect to the VME bus and shared memory. This enables a high speed, high bandwidth fiber optic connection between the two systems. The PCI card does not require any hardware based configuration.

10.2 VME Chassis – Including POP, DAM and Interface Cards

10.2.1 VME 7851 Card

The VME 7851 card is an Intel Pentium 4 dual slot single board computer utilizing 500 Mbytes of RAM. It includes a 60 GB IDE hard drive, Gbit Ethernet (1000 Base T), 2 serial ports, a parallel port, as well as several other options. Two of these boards are used to host the **POP** and **DAM** computers. The VME-7549 accompanies this board with a CD-ROM and an additional 80 GB IDE hard drive. See the VMIVME-7851 and the VME-7549 manuals for a complete list of specifications. See also Appendix B –System Specifications and Appendix C for a description of jumper and switch settings.

10.2.1.1 Pseudo Operator (POP)

POP communicates with the Dome Controller (DC) through one of its two serial ports. The other serial port is used with the GPS receiver. The parallel port is used to receive the 2 kHz signal from the Computer Clock Sync Interface (CCSI). POP also controls the VME-2510b digital I/O card to communicate with the I/O Chassis. Communication with the ICC and DAM is through the 8 MB shared memory daughter card hosted on the GE/Fanuc S810 VME-PCI adapter. The Ethernet is also used for communication with DAM.

10.2.1.2 Device Access Manager (DAM)

DAM communicates with the Risley Prisms using both of the serial ports. It uses the VME-6015 serial card to communicate with the remainder of the transceiver optics and the Paroscientific MET-3 and the Vaisala Precipitation sensor. DAM uses the VME-4514a analog to digital converter to communicate with the Young-Belfort anemometer. DAM communicates with POP and RAT over Ethernet.

10.2.2 VME-PCI adapter with 8 MB Shared memory (GE/FANUC S810)

The VME-PCI adapter consists of a VME card, a PCI card and a daughter card (GE/FANUC option 400-206). The daughter card provides the system with the shared memory utilized by the POP, DAM and ICC computers. POP and DAM have direct access to shared memory since they are located directly on the VME bus. However, the ICC is a stand-alone PC that requires the use of a PCI adapter to connect to the VME bus and shared memory. This enables a high speed, high bandwidth fiber optic connection between the two systems. The VME card requires multiple jumper settings to locate the shared memory on the VME bus, see the S810 VME card Jumper configuration in Appendix C. The PCI card and the daughter card do not require any hardware configuration.

10.2.3 Analog-Digital Converter (VMIC 4514)

The analog-digital converter original purchased from VMIC (now GE/FANUC) is used to connect the Young-Belfort anemometer to the DAM computer. See Appendix B-System Specifications, Appendix C-VME Board Configurations and Jumper Settings and the vendor manual for a further description of this device.

10.2.4 Serial Port Card – (VMIC 6015)

The serial port card originally purchased from VMIC (now GE/FANUC) is use to connect the Paroscientific MET-3, the Vaisala and the transceiver bench optics. See Appendix B - System Specifications, Appendix C-VME Board configurations and Jumper Settings and the vendor manual for a further description of this device.

10.2.5 Parallel Port Card (VMIC 2510b)

The parallel I/O card originally purchased from VMIC (now GE/FANUC) is used to connect the I/O Chassis to the POP computer. See Appendix B – System Specifications, Appendix C-VME Board configurations and Jumper Settings and the vendor manual for a further description of this device.

10.3 Analysis Computer (ANA)

ANA, the data analysis computer, is responsible for post processing and data delivery. Ranging data is sent through three processing systems: Calibration, Satellite and Normal Point, which produce the final data product in ILRS Normal Point format. These files are uploaded to a central distribution facility on an hourly basis for use by the scientific community. ANA runs on a Dell Optiplex 380, running Fedora LINUX.

10.4 Camera Computer

The **Camera** computer controls the two camera systems used on NGSLR and passes images from the star and sky cameras to the other computers via NFS mounted files. The first camera is a CCD that is mounted on the transceiver bench and is used to perform star calibrations. The second, an infrared camera, is located outside of the NGSLR facility and is used to determine cloud cover. The Camera computer also runs various COTS software packages, including the Q-Peak laser software control package, and the LRO-LR real-time website.

10.4.1 Star Camera

See the section on the Transceiver Bench for more information on the Star Camera.

10.4.2 Sky Camera

See the section titled "Cloud Coverage Device" for more information on this instrument.

10.5 Remote Access Terminal (RAT)

RAT allows one operator to remotely control, configure and troubleshoot all major systems over the NASA intranet. The RAT software resides on a laptop running Fedora LINUX, and will allow the operator to display data graphically on the monitor, and run software tests. RAT connects through a secure internet connection to a service on DAM, which provides access to information on the other NGSLR systems.

11 Meteorological Station

Weather information is crucial to the proper functioning of the NGSLR system. Mathematical models, which calculate atmospheric range correction, are driven primarily by local barometric pressure, but also temperature and relative humidity. These values must be captured accurately to enable precise pointing and tracking as well as data reduction and fit to an orbit. The metrological station must also provide data for system automation so a determination can be made when to operate due to the local weather conditions (i.e. precipitation, clouds, excessive winds, etc). Data is obtained once per minute from a variety of sensors measuring temperature, barometric pressure, humidity, precipitation, visibility, wind speed, wind direction and cloud cover information. These instruments include:

Figure 11-1: Weather Instrumentation Tower

Paroscientific MET3 Weather Station
Measures temperature, barometric pressure and humidity

Vaisala FD12P: Precipitation and visibility sensor
Measures precipitation and visibility

Belfort-Young Windmill Anemometer (Model 05103)
Measures wind speed and direction

Jenoptic VarioCAM: Infared Sky Mapping Instrument
Provides cloud cover information

These instruments are connected to dedicated boards on the VME chassis that read in data. See section 10.2 for more information on the VME chassis and the interface boards that it hosts. The only instrument that is not connected to the VME chassis is the Infrared Sky Mapping instrument, which is directly connected to the Camera Computer.

The MET3 sensor and the Belfort-Young anemometer are mounted on an instrumentation tower near the shelter (see figure 11-1). See figure 11-2 or drawing D-02 of the System Drawing Set for a diagram on how meteorological instrumentation is physically arranged around the NGSLR shelter.

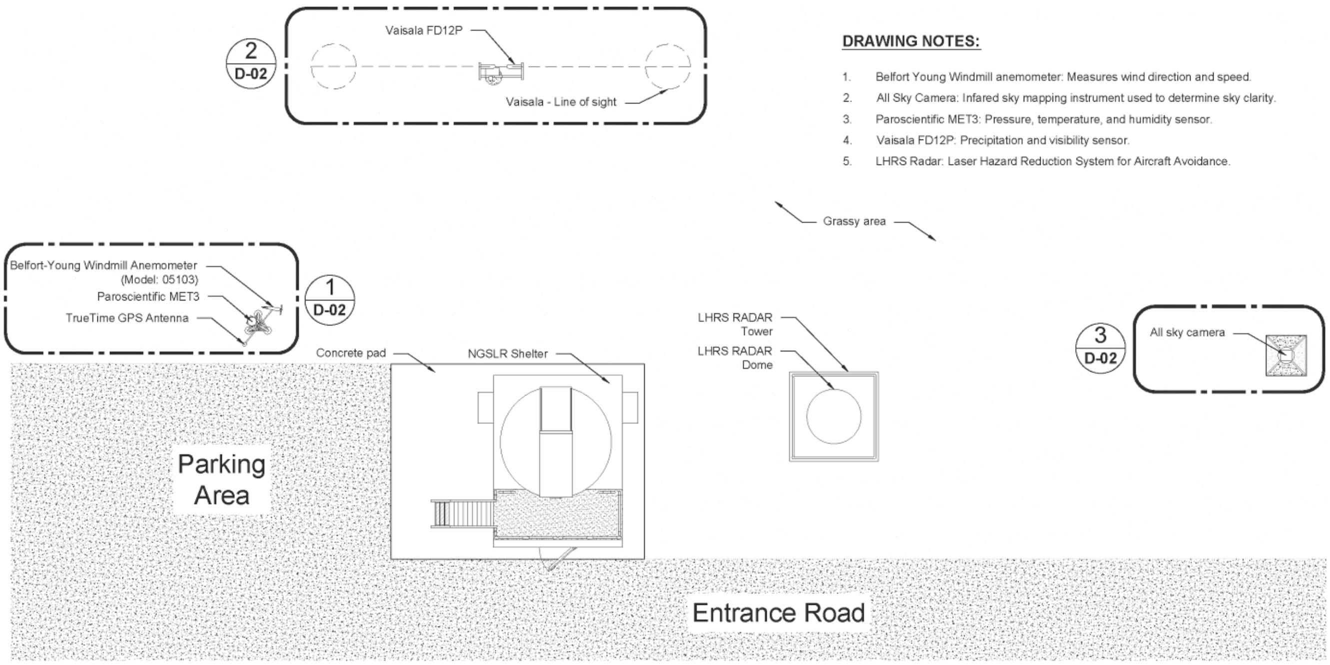


Figure 11-2: Site Layout of Weather Instrumentation

11.1 Pressure, Temperature and Humidity Device (MET3)

This instrument collects basic meteorological information, and sends that information to the DAM computer.

<u>PAROSCIENTIFIC MET3 WEATHER STATION</u>

- RS-232 Connection to VME Chassis (See drawing R-02)
- ±0.1 mB Pressure
- ±0.5 °C from -50 °C to +60 °C
- ±2% Humidity

11.2 Wind Velocity Instrumentation (R.M. Young)

The wind velocity and direction measurements are used to determine if the wind is above the safe range determined for tracking.

<u>BELFORT-YOUNG WINDMILL ANEMOMETER (MODEL 05103)</u>

- RS-232 Connection to VME Chassis (See drawing R-02)
- 0-100 m/s (Range)
- ±0.3 m/s (Wind Speed)
- ± 3° (Wind direction)

11.3 Precipitation Sensor (Vaisala)

This sensitive device checks for any precipitation or dust that could render tracking difficult, unsafe or possibly damage the system. If any of these situations hold true, tracking is terminated and the dome shutter closes.

VAISALA FD12P: PRECIPITATION AND VISIBILITY SENSOR

- RS-232 Connection to VME Chassis (See drawing R-02)
- Visibility measurement: 10m - 50 km
- Threshold of detection: 0.05 mm/h (within 10 min)
- Intensity: 0-999 mm/h

11.4 Cloud Coverage Device (SkyCamera)

The Infrared (IR) Sky Camera instrument was developed in-house specifically to support NGSLR. The purpose of the instrument is to allow autonomous operation of NGSLR by providing a map containing sky clarity information to the POP computer. The IR sensor at the core of this instrument is the VarioCam Head manufactured by Jenoptik. The VarioCam generates thermograms of the sky between zenith and approximately ten degrees elevation from the image reflected by a convex mirror. The Sky Camera program operates the VarioCam, processes thermographic data, and produces the cloud map which delineates regions of clear, hazy and cloudy sky.

JENOPTIC VARIOCAM: INFRARED CLOUD COVER CAMERA

- Firewire Connection to Camera Computer
- Detector sensitivity: (8-13 µm)
- Thermogram Resolution: 120 x 120 pixel
- Thermogram Image Coverage: 1.3° of the sky per pixel, down to 10° Elevation
- Calibration: -50°C to 100°C

12 Environmental Shelter with Azimuth Tracking Dome

12.1 Shelter

The NGSLR Shelter provides a temperature and humidity controlled environment for sensitive components of the system. In particular, this controlled environment aids in the stabilization of timing and prevents condensation and dust on the transceiver bench optics.

The NGSLR Shelter is a pre-engineered structure that can be easily transported and constructed at a remote site. Its modular construction consists of insulated 46” x 94” panels that are joined together to form a solid, weather-tight structure, roughly 12’ wide by 16’ long by 8’ high. The panels are held together by a fastening system that consists of hooked locking arms on one side and end of a panel, to matched locking pins on the adjacent panel. Interconnecting metal straps run between these locking points within each panel. Once all panels are connected, the metal strap effectively runs the perimeter of the building, adding to the structural strength. The structure’s size provides ample room for maintenance and upgrades of equipment during the lifetime of the station. ☺

Figure 12-1: Constructing the Shelter

A 10’ astronomical dome sits on top of the shelter to protect the NGSLR telescope and gimbal. In order to withstand the weight of the dome, the roof is constructed of 6” thick, insulated, reinforced panels. To allow the pier to extend through the shelter roof, a 32” by 32” cutout is engineered into the ceiling. The roof has a drip guard fastened to the perimeter of the building, which is then covered by a roof membrane that is sealed to the aluminum roof skin and the base of the dome, eliminating water leaks. This type of design and construction allows the panels to be relatively small in size and light in weight for a building.

Figure 12-2: Ceiling Cutout for the Gimbal

Wall panels, constructed of 20 gauge Galvalume steel, are 4” thick and filled with pour in urethane insulation. Each steel face is embossed and painted with a durable polyester coating. The interior of the shelter is painted white, while the outside surfaces are tan in color. Selected panels have the interior and exterior steel sheets lined with ½” pressure treated plywood to allow attachment of HVAC systems and electronic equipment. The floor is constructed of 4” thick, insulated panels faced with unpainted 14 gauge galvanized steel.

12.1.1 Shelter HVAC Equipment

The temperature and humidity controlled environment required by the system is maintained by a pair of self contained, wall mounted units on opposite sides of the shelter. Easily serviceable from the exterior of the shelter, they are critical to the proper functioning of the system. Each unit is designed to be able to independently carry the cooling load of the system and maintain the internal temperature at 70° F, ± 5° F.

The electronic master control system provides for equal operating time on both units, and will switch over to the functioning unit in the event of a failure. Typical operating time on any one unit is 24 hours.

Basic HVAC Specifications

- Cooling Capacity 18,300 BTUH
- Heating Capacity 5 kW
- Power Requirements 230/208 VAC, 60 Hz, single phase

12-3: Wall Mounted HVAC Unit

12.2 Dome

The NGSLR telescope and gimbal are protected by a 10’ fiberglass observatory dome that sits on top of the shelter. The dome contains a motorized shutter and an azimuth control drive managed by microprocessor based control systems, designed by HTSI. The dome controller, which directs the dome azimuth drive, is slaved to the azimuth of the tracking mount via the software, allowing the dome to rotate with the telescope. Further information on the Dome Controller, POP, and the Shutter and the Azimuth drive can be found under:

NGSLR - Dome Hardware and Users Guide: (NASA-NGSLR-HWR-Dome)

12-4: NGSLR Dome with Open Shutter

12.2.1 Dome Controller (DC)

The Dome Controller is the device used to control the shelter dome. Dome Controller communicates with the POP computer at 1 Hz over an RS-232 interface, which provides the current azimuth of the mount, along with the predicted velocity and acceleration. This information is processed by the embedded AMD 186 on the Dome Controller, and then sent to two DC amplifiers as a +/- 10 volt signal. Based on this 10 volt signal, brushless DC motors turn at a certain speed and direction. These motors are coupled through a clutch to two friction drive wheels, which in turn move the dome.

The Dome Controller is also tasked with returning the actual operating status of the hardware involved.

Figure 12-5: Dome Controller and Motor Driver

12.2.2 Dome Motor Driver and Azimuth Drive

The dome controller commands a drive mechanism employing dual, heavy duty brushless motors and electric clutches that add durability and provide redundancy. Dome rotation is provided by two .25 HP brushless DC servo motors via separate transmissions and clutches. The dome can continue to operate (with reduced performance) on one motor in the event of a failure. ☺

The maximum velocity of the dome is 20°/s, with an acceleration of 15°/s^2. Pointing accuracy during periods of large velocity and acceleration is about 5°. Fine pointing accuracy for non-moving targets is ¼°. An incremental optical encoder tracks the position of the dome, with proximity switches used as "home" locators.

The Dome Motor Driver chassis contains the interface modules and DC amplifiers for the two DC brushless motors located in the dome. The dome drive assemblies are located against the dome wall and provide mechanical support for the brushless DC motors, magnetic particle clutches and drive wheels. Springs are used to push the drive wheels against the dome, providing a friction drive to, in turn, rotate the dome.

Figure 12-6: Azimuth Drive Wheel (1 of 2)

12.2.3 Shutter Drive Mechanism

The dome shutter opening and closing mechanism uses a motorized chain drive that is operated by a wireless controller. The shutter rides on trolley assemblies that consist of two upper nylon wheels and one lower nylon wheel that grip the two curved aluminum bars attached to each side of the shutter opening. An upper and lower drive shaft with sprockets on each end drives the chain that is attached to the shutter and provides the means for the opening and the closing of the shutter. Nylon guide wheels on the side of the shutter allow the chain to follow the curvature of the dome.

Figure 12-7: Endless loop chain and guide

Figure 12-8: Upper and lower trolley wheels

The chain drive that opens and closes the shutter is powered by a 12 V battery, charged using an externally mounted solar panel on the dome. A storage battery with a separate controller located on the moving portion of the dome allows for emergency closure of the shutter in the event of a power failure or loss of communication.

Figure 12-9: Battery for the Shutter Control

Figure 12-10: Solar Panel to Charge the Battery

The shutter control electronics consists of two parts: the Local Dome Shutter Controller and a Remote Dome Shutter Drive chassis.

12.2.3.1 Local Dome Shutter Controller

The Local Dome Shutter Controller accepts command inputs from the operator and displays shutter status information.

The Dome Controller chassis contains the following parts:

- A 386 computer used to communicate to POP and control the dome
- Power supplies for 5, 12,-12, and 24 volts

The Dome Controller chassis connects to:

- POP via a RS232 connection
- The home switch located in the dome
- An incremental encoder that measures the dome rotation
- North and south motor clutches, via power supply lines
- Dome Motor Driver via the motor speed control (+/- 10 volts) line

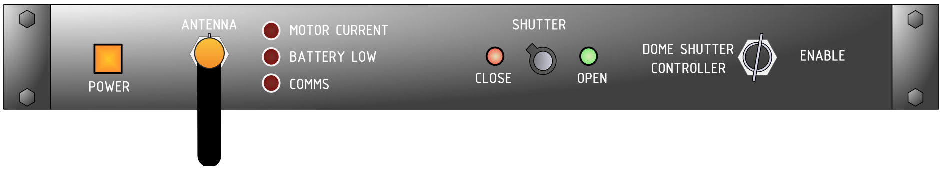


Figure 12-11: Front Panel for the Local Dome Shutter Controller

Figure 12-11 shows the front panel of the Local Dome Shutter Controller. On the front panel the power switch is to the far left side. Next to it is the transmit/receive antenna. To the right of the antenna are three red LED status lights. The top LED will flash if the ‘Motor Current’ exceeds 9.5 Amps; the middle ‘Battery Low’ LED will flash if the battery voltage drops below 10 volts. If either of these status lights are active, the shutter will still operate. The bottom ‘COMMS’ LED will flash if the data transmission between the Local and Remote Drive chassis is lost. If the data link is lost the LED will appear solid and the shutter will not move. The ‘COMMS’ LED is on solid for 2.5 seconds when the unit is first powered on.

In the center of the front panel is the shutter command switch. If the switch is turned to the right, the Green LED flashes; this indicates the shutter is opening. Once the shutter has reached the “Open” limit switch, the LED will turn solid. If the switch is turned to the left, the Red LED will flash while the shutter is closing; the LED will turn solid once the shutter has reached the “Close” limit switch.

At the far right side of the Controller is an ‘Enable’ Key switch. The shutter will only move when the key is turned to the “Enable” position. J1 on the rear panel provides five volts from a wall transformer for the Local Dome Shutter controller power.

12.2.3.2 Remote Dome Shutter Drive

The Remote Dome Shutter Drive chassis controls the motor operation, accepts inputs from the open and close limit switches, monitors motor current, and battery voltage. It is located at the top of the dome next to the drive motor (see figure 12-11). Figure 12-13 shows the layout for the power switch and cable connectors. To the far left is the main power switch; next to it is connector J3 (limit switch connections). Connector J1 is for the battery connection (12 volts DC), and at the far right is connector J2 (motor connection).

Figure 12-12: Location of Remote Shutter Drive

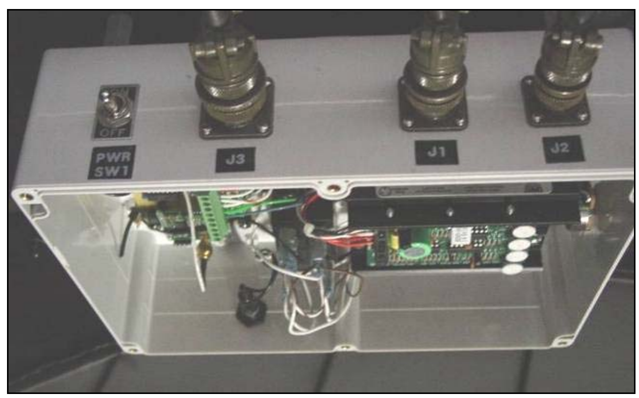
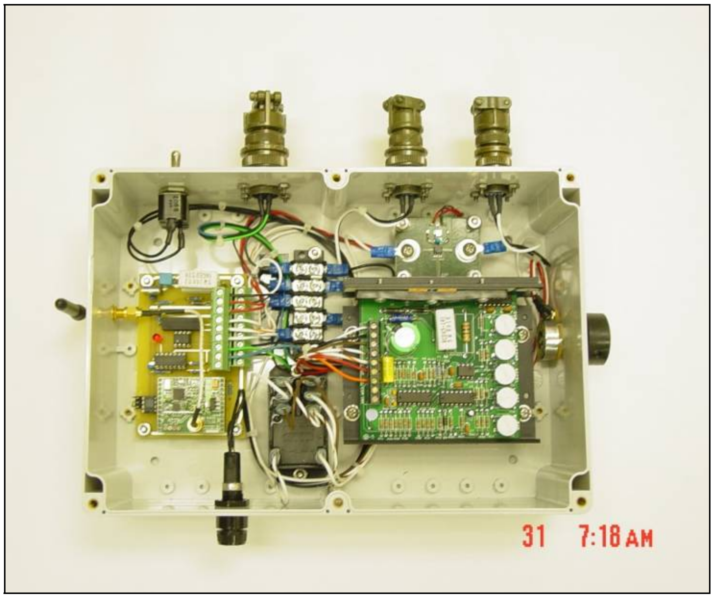


Figure 12-13:Cable Connections

Figure 12-14 shows the internal components of the chassis. They are the Shutter Drive Module PCB, direction power relay, motor controller card, and the current sensing PCB.



12-14: Components of the Remote Shutter Drive

Appendix

Appendix A – Acronyms

Acronym	Definition
A/R	Anti-reflective [coating/paint/finish]
AGU	American Geophysical Union
ANA	Data ANAlysis computer
API	Application Programming Interface
ASCII	American Standard Code Information Interchange
ATS	Acquisition, Tracking and Scheduling
AZ	Azimuth
AZ/EL	Azimuth/Elevation
BIH	Bureau International L'Heure (International Time Bureau)
BPF	Band Pass Filter
CAD	Computer Aided Drafting
CCB	Configuration Control Board
CCD	Charge Coupled Device
CCR	Calibration Capture Record
CCR	Configuration Change Request
CCSI	Computer Clock Sync Interface
CDDIS	Crustal Dynamics Data Information System
CLK	Clock
CMD	Command
COSPAR	Committee on SPACE Research
CPF	Consolidated Prediction Format
CPU	Central Processing Unit
CRD	Consolidated Laser Ranging Data Format
CRR	Correlation Range Receiver
CWL	Central wavelength
DAM	Device Access Manager computer
DCN	Documentation Change Notice
DCS	Dome Control System
DMA	Direct Memory Access
DORIS	Doppler Orbitography and Radiopositioning Integrated from Space
DOY	Day Of Year
EL	Elevation
EPP	Enhanced Parallel Port
ET	Event Timer
ETALON	Russian Geodetic GNSS - Altitude Satellite
FDF	Flight Dynamics Facility
FITS	Flexible Image Transport System
FIZ	Alternate file extension for the Flexible Image Transport System
FK5	Fifth Fundamental Catalog *(Astrometric Star Catalog)*
FM	Focal Metric
FOV	Field of view
GEO	Geostationary Earth Orbit
GGAO	Goddard Geophysical and Astronomical Observatory
GLONASS	Russian GNSS Satellite
GNSS	Global Navigation Satellite System
GORF	Goddard Optical Research Facility, now known as GGAO
GPS	Global Positioning System - US GNSS Satellite
GUI	Graphical User Interface
HEO	High Earth Orbit [satellites]
HTSI	Honeywell Technology Solutions, Incorporated
HVAC	Heating, Ventilation and Air Conditioning
I/O	Input / Output
ICC	Interface Control Computer

Acronym	Definition
ILRS	International Laser Ranging Service
IR	Infrared
IRIG	Inter Range Instrument Group *(time codes)*
ISA	Industry Standard Architecture - 8/16/32 bit bus
LAGEOS	US/Italian Laser Geodynamics Satellite - Geodetic SLR Satellite
LEO	Low Earth Orbit
LHRS	Laser Hazard Reduction System
LIDAR	Light Detection and Ranging
LOLA	Lunar Orbiter Laser Altimeter (instrument on the LRO orbiter)
LR	Laser Ranging
LRO	Lunar Reconnaissance Orbiter
LRO-LR	Lunar Reconnaissance Orbiter - Laser Ranging
LSO	Laser Safety Office
MCP	Micro-Channel Plate
MEO	Medium Earth Orbit
MOB-[n]	MOBLAS site identifier *(i.e. MOB-7)*
MOBLAS	Mobile Satellite Laser Ranging System
MVP	Device that controls linear or roational stages
ND	Neutral Density
NEMA	National Electrical Manufacturers Assocation
NENS	Near Earth Network Services
NFS	Network File System
NGSLR	Next Generation Satellite Laser Ranging
NIM	Nuclear Instrumentation Module/Method
NP	Normal point
O-C	Observed minus Calculated
OD	Optical Density
PCI	Peripheral Component Interconnect - 16/32 bit bus
PCR	Pass Capture Record
PMT	Photo Multiplier Tube
POP	Pseudo OPerator computer
PRF	Pulse Repetition Frequency
QE	Quantum Efficiency
QMCP	Quadrant Micro-Channel Plate
RAT	Remote Access Terminal
RGG	Range Gate Generator
RMS	Root Mean Square
S2K	Now known as NGSLR
SBIG	Santa Barbara Instrument Group
SGT	Stinger Ghaffarian Technologies
SIC	Satellite Identification Code
SIDB	Site Information Database
SLR	Satellite Laser Ranging
SLR2000	Legacy name for the NGSLR Project (*See NGSLR)*
SPICE	Planetary Science Division's Ancillary Information System
STARLETTE	French Geodetic SLR satellite
STELLA	French Geodetic SLR satellite
STK	Satellite Tool Kit - Software developed by Analytical Graphics Incorporated
T/R	Transmit/Receive
TCP	Transmission Control Protocol *(part of TCP/IP protocol suite)*
TTL	Transistor-Transistor Logic
UPS	Uninterruptible Power Supply
USB	Universal Serial Bus
USGS	United States Geological Survey
UTC	Universal Time, Coordinated
VLBI	Very Long Baseline Interferometry
VME	VersaModule Eurocard - Card based systems sharing the same VME Bus
VMEbus	16/32 bit backplane for VME systems based on the IEEE 1014 standard

Appendix B – System Specifications

NGSLR System Specifications

Major Systems	Vendor	Model	Description	Characteristics
(1) Time & Freq				
Station Time (GPS)	Symmetricom	XL-DC		
			Frequency/Timing	3x10E-12 @ 1 day
			Oscillator Stability	2xE-06 (When the unit is not locked on satellites)
			GPS Antenna Input	One BNC Connector
			Core Receiver Frequency	1575.42 MHz (L1 signal)
			1 PPS Output	One BNC Connector
			Accuracy	GPS Time ±150 ns
			5 MHz Output	Four BNC Connectors
			10 MHz Output	Four BNC Connectors
			IRIG-B	One BNC Connector
			IRIG-B IN	One BNC Connector
Cesium Frequency Standard	Symmetricom	4310B		
			Accuracy	4.5xE-13 @over two hours
			Input/Outputs	5 & 10 MHz, 10MHz TTL, 1 PPS Sync Input, 1 PPS Output (All BNC)
Hydrogen Maser (alternate)	Symmetricom	MHM 2010		Located remotely; Connected via fiber link
			Accuracy	3.0 E-14 over two hours (estimated)
			100 MHz Output (1)	1 V (RMS), 50 ohm, 13 dBm
			10 MHz Output (1)	1 V (RMS), 50 ohm, 13 dBm
			5 MHz Output (3)	1 V (RMS), 50 ohm, 13 dBm
			1 PPS Output	Amplitude: 3 V, 2 µs wide Jitter, <10 ps RMS
Frequency Doubler	Wenzel	LNHD-5-10		
			Phase Noise	-155 dBm/Hz
			Harmonics	<-30 dBm
			Input/Outputs	1 Coax Input, 1 Coax Output
Coax to Fiber Transceiver	Symmetricom	144-691-(1/2)	*For 10 Mhz Signal*	
Coax to Fiber Transceiver	Symmetricom	144-693-(1/2)	*For 1 PPS Signal*	
Distribution Amplifier	Symmetricom	6502B		RF Distribution (Used for 10 MHz signal)
			Input	2 BNC Inputs (50 Ω), Frequency Range: 0.1 to 10 MHz
			Outputs	10 outputs (All BNC), Frequency Range: 0.1 to 10 MHz

NGSLR System Specifications

Major Systems	Vendor	Model	Description	Characteristics
(2) Optical				
Telescope	Orbital Sciences			40 cm off-axis
T/R switch				Passive
(3) Transceiver Bench				**50% Transmit/Receive Efficiency**
Auto Collimator	Keuffel & Esser	71-2022		
Receive ND Wheel	Thorlabs		On Rotary Stages	ND wheel with gradient from 0 - 2 ND
Star Camera ND Filter	Thorlabs			1 ND
Alignment Cube				1" Diameter, solid
Band Pass Filters	Thorlabs		*Day/Twilight/Night*	.2 nm @ 532 nm (CWL) / 1.0 nm @ 532 nm (CWL) / No filter
Beam Expander	Special Optics	56C-30-2-8X		(8X Power)
Beam Reducer	Special Optics			(-3X Power)
Field of View (Iris)	Sigma Space		*Day/Twilight/Night*	11 arcseconds / 16 arcseconds / 25 arcseconds
Gating Power Supply	Photek	GM-150-20		Gating Power Supply
High Voltage Power Supply	Bertran	315		
Inverter	BNC			Inverting Transformer (Berkeley Nucleonics Corporation)
Iris Focus Lens				900 mm (EFL) lens takes collimated beam and focuses it at the iris
Linear Stages	National Aperture	MM-3M-F-2.0		
LRO Laser Insertion Mount				Magnetic/Kinematic Mount (Manual)
Stage Controllers (MVP)	National Aperture	Micro-Mini	Stage Controller	Vertical-Drive Kinematic Mount
Mirror Mount	Newport	HVM-1		
LRO Start Diode	Monsanto	MD2		
ND Flip Filter	Thorlabs		Manual	
Optical Path Length Comp.				
Periscope Mirrors				
Polarization Rotator				
Risley Prisms	Orbital Sciences			Point-ahead: ≤30 arcseconds
Rotational Stage	National Aperture	MM-3M-AR		
Star CAM Insertion Mount				Magnetic/Kinematic Mount (Manual)
Star Camera Lens				1" Focal length lens for the Star Camera
Start Diode	Monsanto	MD2		1/2 volt out
Star Camera	SBIG	ST-402ME	*CCD Camera by*	Santa Barbara Instrument Group (SBIG)
			Description	Low noise, high QE camera
			CCD Size	765x510 pixel
			Sensitivity	< 8th magnitude stars
			Interface	USB 2.0
Quadrant Micro Channel Plate	(See the below Receiver section for information on the detector)			

NGSLR System Specifications

Major Systems	Vendor	Model	Description	Characteristics
(4) Laser				
Q-peak laser	Q-Peak	MVP-2001		Legacy Eye safe Laser (no longer used)
			Type	Doubled Nd:YVO4
			Wavelength	532.2 nanometers
			Pulse Width (FWHM)	350 picoseconds
			Repetition Rate	2 KHz
			Energy	115 micro Joules
			Average Power	0.230 Watts = (.000115 J/pulse x 2000 Hz)
			X-mit Beam Diameter	1.084 millimeters vertical
				0.467 millimeters horizontal
			Beam divergence	0.855 milliradians vertical
				1.821 milliradians horizontal
			X-mit Divergence (full angle, 1/e)	19 microradians
	The following are the specifications of the laser energy transmitted from the output of the telescope with the MPV-2000 as the source:			
			Energy from the telescope	58 microjoules
			Average Power (from telescope)	0.116 Watts
			X-mit Beam Diameter	40 centimeters
NASA 1 mJ Laser	n/a	n/a		Custom built laser by NASA
			Wavelength	532.2 nanometers
			Laser Pulsewidth	200 ps
			Fire Rate	2 kHz
			Pulse Energy	1 mJ/pulse
			Average Power	2 W = (.001 J/pulse x 2000 Hz)
			Beam Diameter out of laser	1.4 mm
			Beam divergence from laser	1.4 mrad
			Beam divergence from telescope	~5-10 arcseconds
NASA Laser Cooling Equipment	Solid State Cooling	ThermoCube		Solid State Cooling System
LRO Laser	Northrop Grumman			Nd:YAG (532nm)
			Laser Pulsewidth	5.5 ns (FWHM)
			Fire Rate	28 Hz
			Pulse Energy	50 mJ/pulse
			Beam Diameter out of laser	9 mm
			Beam divergence	12 arcseconds Full Width
LRO Laser Cooling Equipment	Polyscience			
(5) Laser Safety/RADAR				
RADAR	HTSI	LHRS Radar		
			Type	Azimuth / Elevation
			Azimuth Range	Unlimited
			Elevation Range	-2° through 182°
			Maximum Slew Velocity	~15°/second
			Transmitter Center Frequency	9410 MHz, ±30 MHz
			Minimum Detection Range	~200 m
			Maximum system capability for target detection	~40 km for a 20 m² target (calculated value)

NGSLR System Specifications

Major Systems	Vendor	Model	Description	Characteristics
(6) Tracking				
Mount	Xybion	SPS Series 2715		Note: Xybion was bought out by Cobham North in 2003
			Command Type	Velocity Feed Forward
			Command rate	50 Hz (Via serial connection)
			Maximum Elevation	-3° to 185°
			Maximum Velocity	20°/second on both axes
			Maximum Acceleration	20 degrees/s²
			Tracking errors	~ 1 arcseconds RMS each axis
(7) Receiver				
Detector	Photek			Quadrant MCP PMT
			Gain	3.00E+06
			Quantum Eff.	13% at 532 nm
			Active area	144 mm²
			Image Size	6 mm across (masked)
			Field of View	10 to 25 arcseconds
Amplifier	Phillips Scientific	774		Quad Fast Rise time Amplifier (information from 2009 manual)
			Wideband Performance	100 KHz to 1.8 GHz
			Gain	5 to 50 Volts
			Rise time	180 psec
			Insertion Delay	Typically 1.0 nsec
Discriminator	Tennelec	TC 454		(Company now owned by Canberra; information from 2009 manual)
			Count rate capability	200 MHz
			Dynamic Range	1000:1
			Typical Walk	±30 ps for 100:1 Dynamic Range
Discriminator	Phillips Scientific	6915		
Frequency Counter	Hewlett Packard	5316B		Used to verify laser fire rate (PRF) pulse rate frequency
Event Timer	HTSI	n/a		
			Resolution	1.5 ps
			RMS	30 ps
			Inputs (NIM)	12
			Other Inputs	10 MHz
Range Gate Generator	HTSI	n/a		
			Precision	30 ps
			Step	30 ps
			TTL Channels	4
			NIM Channels	2
			Inputs	2 kHz, 10 MHz

NGSLR System Specifications

Major Systems	Vendor	Model	Description	Characteristics
(8) Computers/SW				
VME Chassis	GE/FANUC			6U Double slot Eurocard format
	GE/FANUC	7851RC Card	*POP Processor Card*	LynxOS
			Processor	Pentium IV (2.2 GHz)
			RAM/HD	1 GB SDRAM/60 GB (IDE)
	GE/FANUC	7851RC Card	*DAM Processor Card*	LynxOS
			Processor	Pentium IV (2.2 GHz)
			RAM/HD	1 GB SDRAM/60 GB (IDE)
	GE/FANUC	7459 Card (Two)	*Additional storage*	Single slot CD-RW (IDE) and 80 GB Hard Drive (IDE)
	GE/FANUC	S810 Card	*PCI-VME Bridge*	PCI-VME bridge via single mode fiber
	GE/FANUC	400-206	*Dual Port 8 MB RAM Card*	Optional Memory Card for S810 Card
	GE/FANUC	6015 Card (Three)	*Serial port expansion*	Hosts 4 serial ports per card
	GE/FANUC	2510b	*Parallel I/O*	Hosts two 64-pin DIN connectors
	GE/FANUC	4514A	*Analog/Digital I/O Board*	16 Channel, 12 bit Analog I/O Card with Analog to Digital Converter
ICC Chassis	Trenton Technology	TR-P2LX		Pentium running DOS 6.22; ISA/PCI bus
			Processor	Intel Pentium II (233 MHz)
			RAM	64 KB (Maximum usable due to the use of DOS)
ANA	Dell	Optiplex 380		Fedora 12 (LINUX) (32 bit)
			Processor	Intel Core 2 Duo, E7600 (3.02 GHz)
			RAM/HD	4GB RAM, 250 GB
Camera	Superlogics	SL-R4U-MB-775		Windows XP SP3
			Processor	Pentium IV (2.2GHz)
			RAM/HD	256 MB RAM/80 GB
RAT	Dell	Precision M6400n		Fedora 10 (LINUX) (32 bit, 4 GB RAM)
			Processor	Intel Core 2 Duo, P8700 (2.53GHz)
			RAM/HD	8 GB RAM/ 160 GB
Languages (All systems)				Assembly Language, C, Perl, UNIX scripts
(9) Meteorological station				
Bar/Temp/Humd	Paroscientific	MET3		±0.1 mB Pressure ±0.5 °C from -50 °C to +60 °C ±2% Humidity
Wind	Belfort/Young	Model 05103		0-100 m/s (Range) ±0.3 m/s (Wind Speed) ± 3° (Wind direction)
Precipitation/Visibility	Vaisala	Model FD12P		Visibility measurement: 10m - 50 km Threshold of detection: 0.05 mm/h (within 10 min) Intensity: 0-999 mm/h
SkyCamera	Jenoptik	VarioCAM		Infrared (8-13 µm) Camera in NEMA 4 enclosure
			Detector	320x240 pixel resolution
			Image coverage	1.3° of the sky per pixel, down to 10° Elevation,
			Calibration	-50°C to 100°C (special order)
			Interface	Fire Wire (IEEE 1394)
			Mirrored Dome	Rhodium coating (0.050-0.060 in thick)

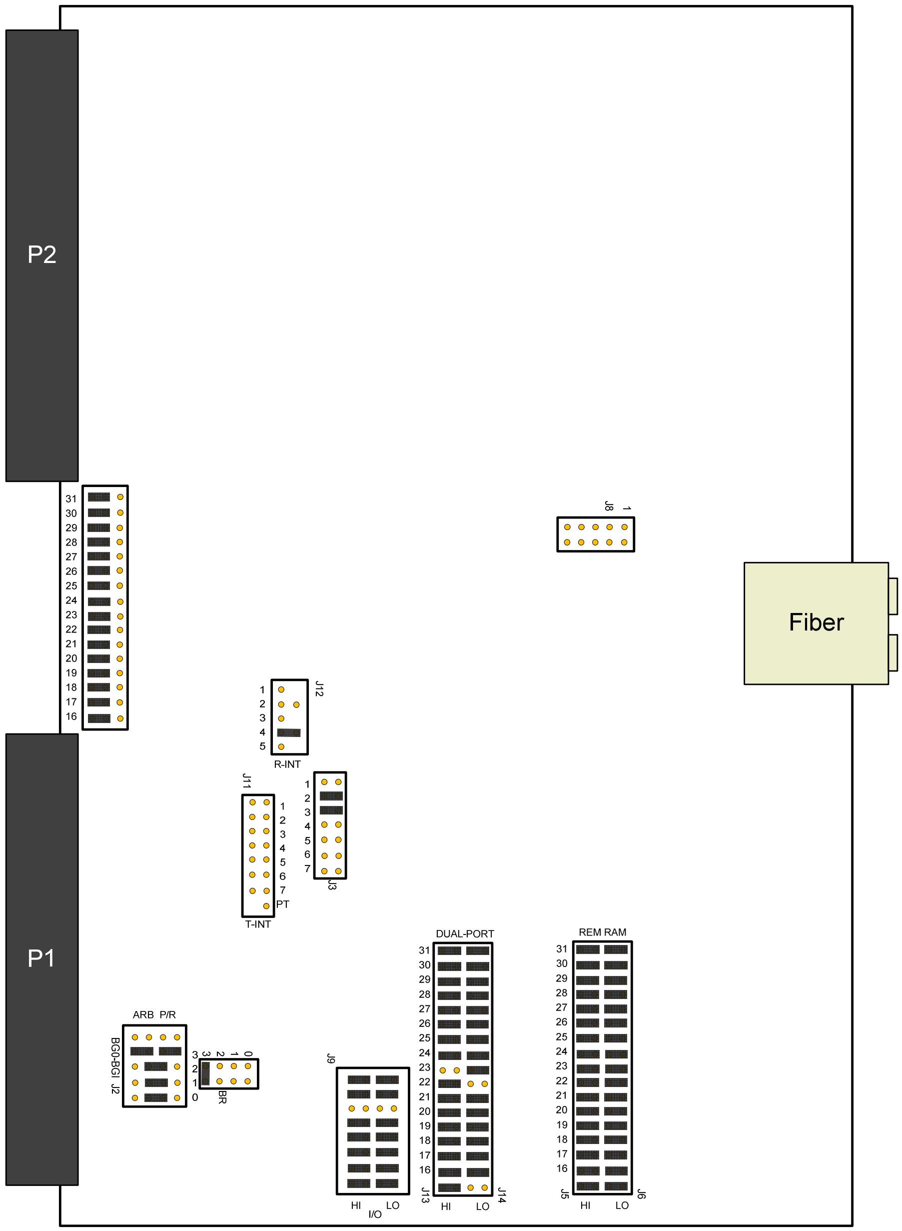
NGSLR System Specifications

Major Systems	Vendor	Model	Description	Characteristics
(10) Shelter and Dome				
Shelter	Bally Refrigerated Boxes			11'x15' Insulated shelter
Dome	Technical Innovations, Inc.	PD-10		10' diameter dome
Wall Mounted HVAC	Bard	WA191-A05	*HVAC Cooling Package*	Cooling Capacity: 18,300 BTUH
				Power requirements: (230/208 VAC; 1 Phase; 30 A)
	Bard	EHWA02-A05	*HVAC Heater Package*	Heating Capacity: 5 kW
				Power requirements: (230/208 VAC; 1 Phase; 30 A)

Appendix C: VME Board Configurations and Jumper Settings

VME S810 Board:

This board hosts shared memory on a daughter card and allows the ICC computer to connect directly to shared memory over a fiber optic connection.



VME 2510b Parallel I/O Card

See the vendor manual for a layout of the jumpers and resistor packs on this board.

Jumpers:

J1 - installed

Resistor Packs:

RP1-RP8 - no resistor packs installed

Address Blocks:

S1 1-8 on

S2 1-4 off 5-8 on

S3 1 on 2-4 off 5-8 on

S4 1 on 2-4 off 5-8 on

VME 4514 Analog to Digital Board

See the vendor manual for a layout of the jumpers and resistor packs on this board.

Jumpers:

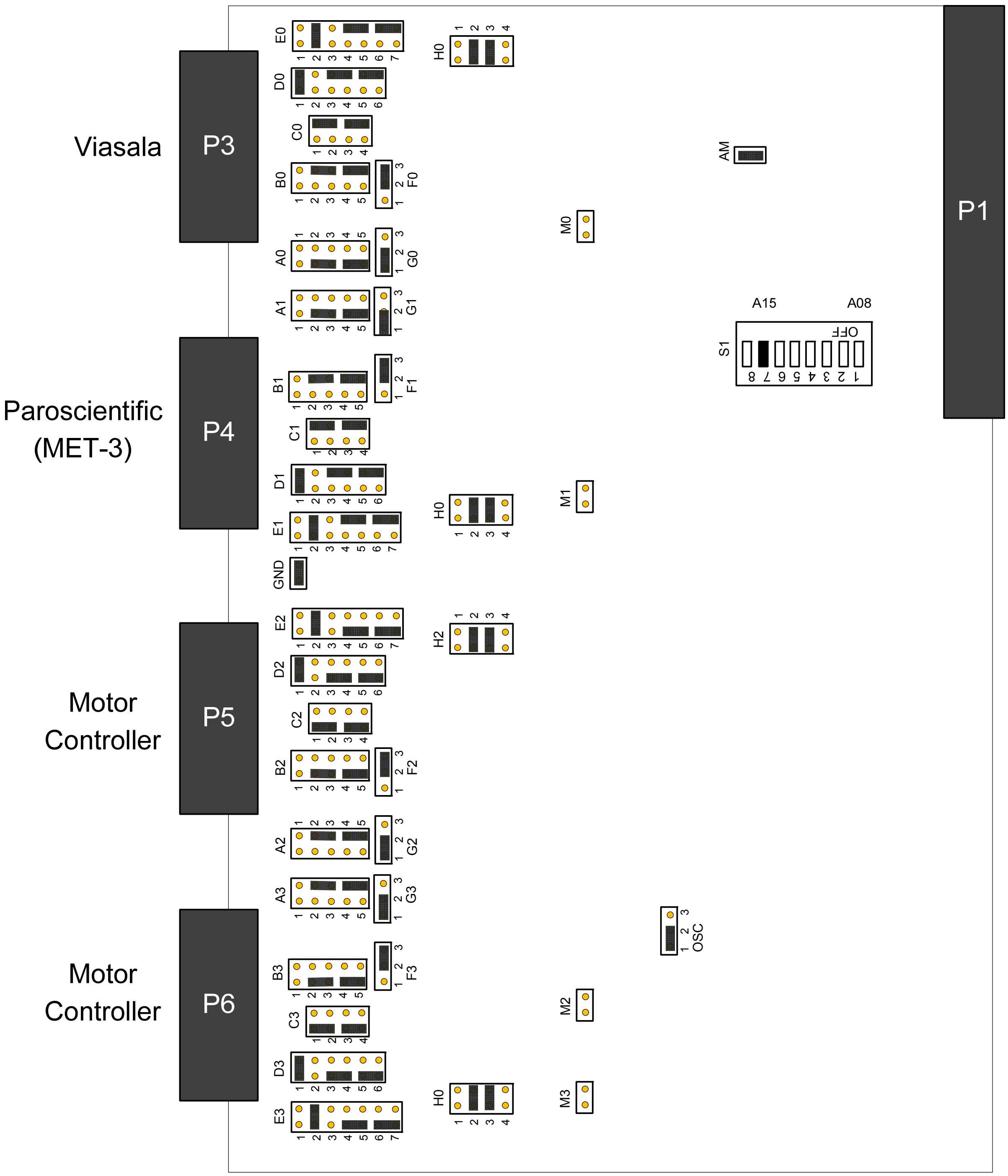
J1 - Jumper installed
J2 - Jumper installed
J3 - 3 pins; jumper installed on bottom 2 pins
J4 - 3 pins; jumper installed on top 2 pins
J5 - 3 pins; no jumpers installed
J6 - 3 pins; jumper installed on left 2 pins
J7 - Jumper installed
J8 - Address block (A8-A15: all jumpers installed)
J9 - Jumper installed
J10 - Jumper installed

Unlabeled jumper (next to removable resistor packs) with 3 pins; Jumper installed on bottom 2 pins

Resistors:

Resistor packs should be installed only on RP7, RP9, RP10, RP12, RP13, RP15, and RP16.

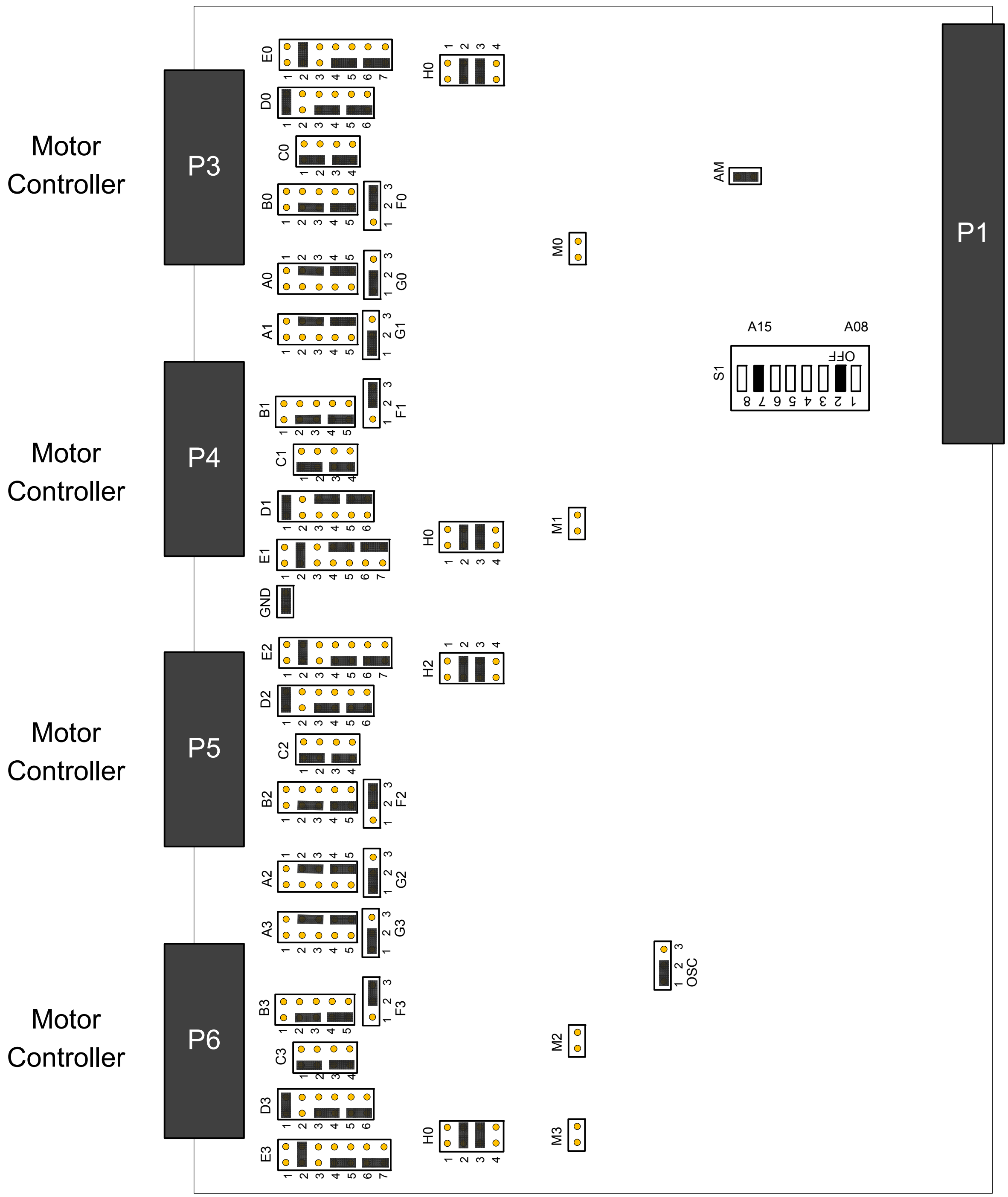
VME 6015 (Board 0): For Vaisala, Paroscientific and other Motor Controllers



Note: Dark color in S1 denotes OFF

Removable Resistors: R1-R6, R8-R13 are all removed.
These are located between Ax and Bx.

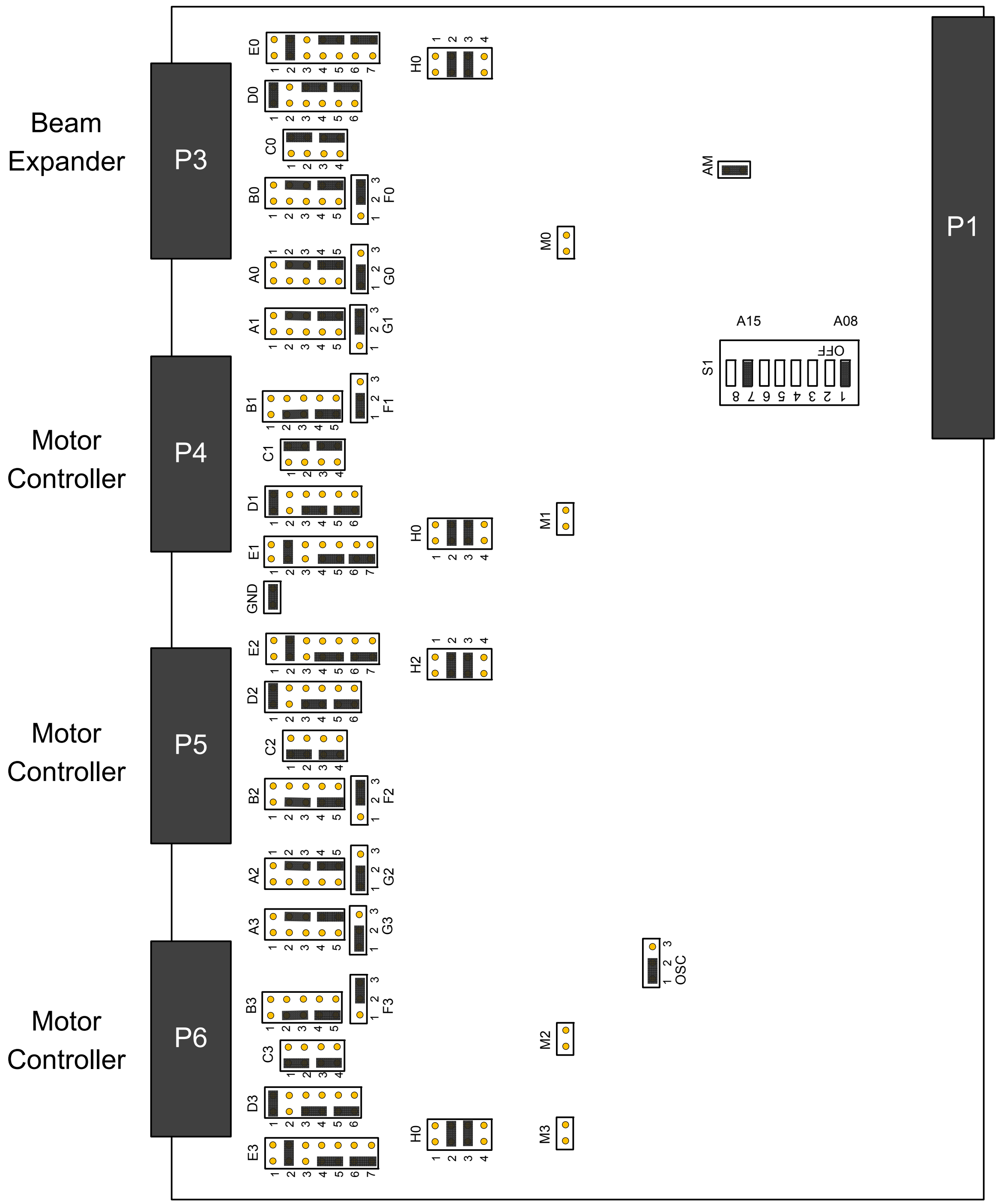
VME 6015 (Board 1): For Motor Controllers



Note: Dark color in S1 denotes OFF

Removable Resistors: R1-R6, R8-R13 are all removed.
These are located between Ax and Bx.

VME 6015 (Board 0): For Beam Expander and other Motor Controllers



Note: Dark color in S1 denotes OFF

Removable Resistors: R1-R6, R8-R13 are all removed.
These are located between Ax and Bx.

VME 7549 IDE CD/Hard drive

See the vendor manual for a layout of the jumpers and resistor packs on this board.

Jumper:

A jumper should be installed on E2.

VME 7851 Single Board Computer

See the vendor manual for a layout of the jumpers and resistor packs on this board.

Jumpers:

Ensure there are no jumpers installed on jumpers E4 and E6
Jumper E5 should be set between 2 and 4.

Switches:

Switch S6 has 2 switches that need to be turned off. This switch is located such that you must gently pry apart the two boards to reach the 2 switches.

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