OG 4.5.10

A Steerable Laser System for Atmospheric Monitoring at the High Resolution Fly's Eye

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Abstract

A steerable laser system has been installed at Camel's Back Ridge, Dugway Utah to provide atmospheric monitoring for the High Resolution Fly's Eye cosmic ray observatory. In this paper, we discuss this system that provides a pulsed beam of 355 nm light that can be steered in any direction above the horizon. The direction, energy, and time of each pulse is measured and recorded locally. Different energies and polarizations can be selected. The entire system is operated remotely.

1 Introduction:

The High Resolution Fly's Eye detector (HiRes) detects cosmic rays in a volume of about 30,000 cubic kilometers of atmosphere. Because atmospheric clarity is susceptible to changes in weather and aerosols, it is necessary to "probe" the atmosphere with a calibrated light source. We have installed a steerable laser system to do this. The HiRes2 Steerable Laser System (HR2SLS) is located on Camel's Back Ridge on the site of the HiRes2 detector. Light scattered out of the beam is measured by the HiRes detector located approximately 12.6 km. distant.

The HR2SLS is robust, self-contained, and remotely operated. Operators running the HiRes1 detector also operate this system. The time, energy, direction, and polarization of each laser pulse is recorded locally and later matched with the corresponding measurement by the HiRes1 detector.

2 System Description

Figure 1 shows the components of the HR2SLS. The HR2SLS uses a pulsed YAG laser[1]. The laser is configured, with dichroics, to produce a linearly polarized beam at 355nm. This wavelength is close to the 351nm line of the nitrogen fluorescence spectrum in air. Each pulse has a duration of approximately 5.5 nanoseconds. The laser has been designed for use in field applications. The laser head is mounted to an enclosed optical table that also houses all of the other optical components.

The energy of each laser shot is monitored by sampling 10% of the beam by using a microscope slide. This fraction of the beam is measured by a calibrated photo-diode probe and radiometer[2]. The energy released into the sky is determined by multiplying this measurement by a calibration constant. The calibration constant is the ratio of monitor measurements and measurements from a second probe temporarily positioned where the beam exits the system.

Following the microscope slide, the beam passes through a quarter wave plate[3], oriented to produce a circularly polarized beam. The beam then passes through two computer-controlled filter wheels[4]. The filter wheels give an operator the ability to vary the intensity of the beam and also control the polarization of the beam remotely. The filters make it possible to measure the beam when it is very close to the HiRes detector without saturation. Each filter wheel can accommodate eight, one-inch filters or other optical elements. The first filter wheel is loaded with six neutral density filters (with transmission coefficients ranging from 48.0% to about 0.7%), one open filter position, and one blocked position that is used as a safety precaution. The second filter wheel houses two quarter wave plates (oriented with their retarding axes perpendicular to one another), four neutral density filters (with transmission coefficients from about 48.0% to 12.0%), one open filter position, and another blocked position.

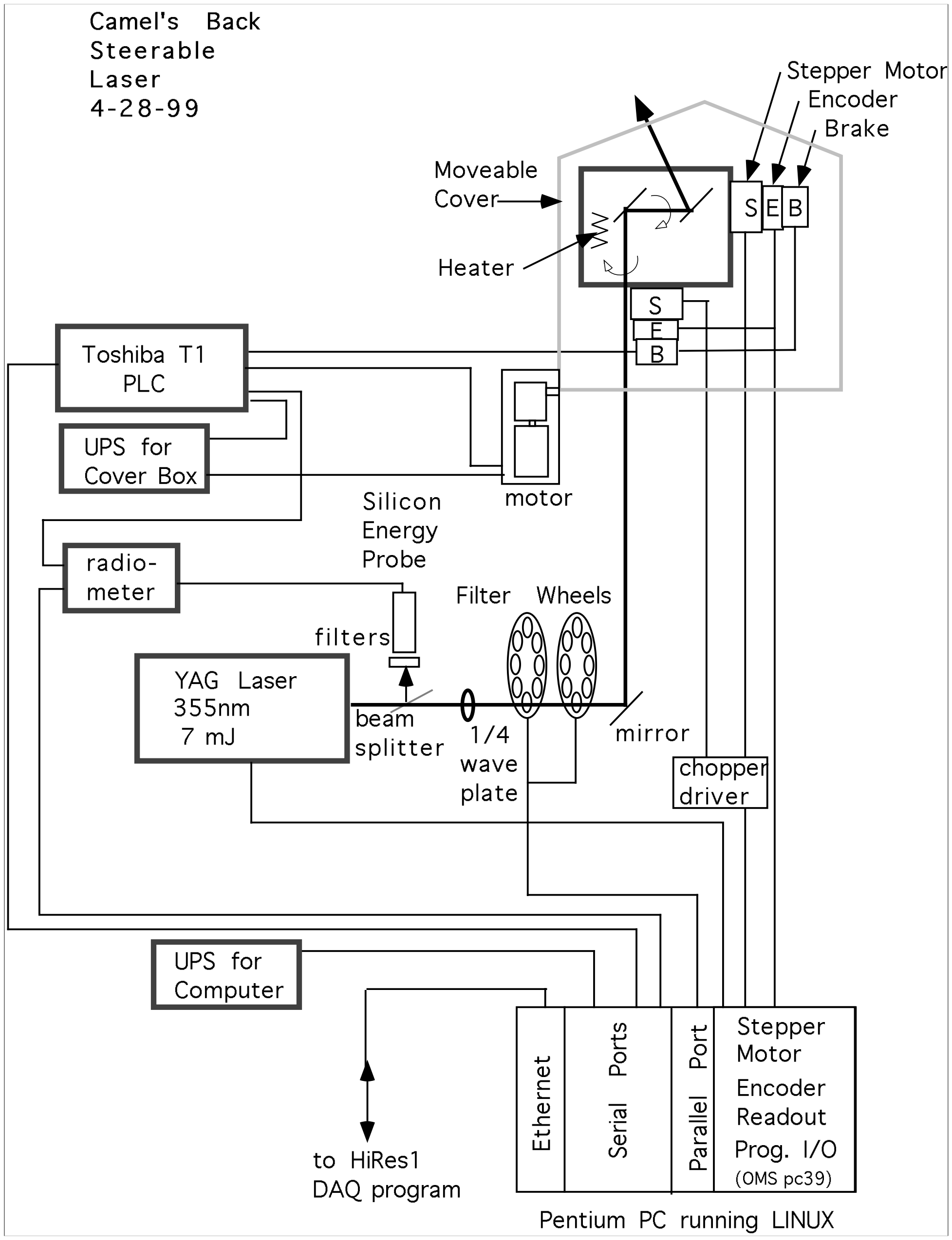

Figure 1: Components of the HR2SLS.

The quarter-wave plates have been configured to produce vertically and horizontally polarized light when the beam is shot towards HiRes (see figure 2). This simple arrangement provides linear or circularly polarized light while keeping the polarization optics inside the enclosure.

After the beam passes the two filter wheels, it enters a large vertical pipe that is mounted to the foundation of the shelter that houses the HR2SLS. The pipe extends above the roof. A 45° dielectric mirror[5] at the base of the pipe reflects the beam up the center. The laser steering head is mounted on top. It is a

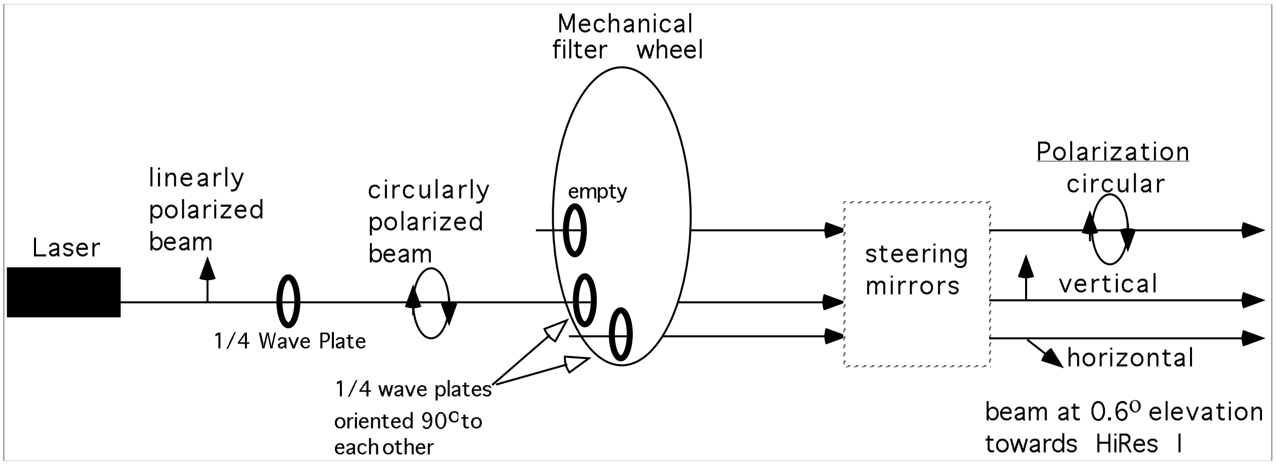

Figure 2: Schematic representation of polarizations available in HR2SLS. The steering mirrors consist of three dielectric mirrors that are positioned at 45° with respect to the incident laser beam.

custom-built mechanism that rotates two 45˚ dielectric mirrors about the axis of the beam, to direct it in any direction above the horizon. The laser direction is "read" by rotary encoders that measure the azimuthal and zenith angles of rotation. The accuracy of the encoders is listed in table 1.

When the laser is not in use, the steering head is protected by a computer-controlled cover-box. The entire HR2SLS is housed in a climate-controlled shelter to ensure proper operating conditions for the optics and laser.

The HR2SLS is controlled by a 166 MHz. PC running under the Linux operating system. This computer is networked with other computers at HiRes 1 and 2 sites via fiber-optics. Two special boards are installed to control the laser system. A four-port serial board communicates with the radiometer, the laser, an Uninterrupted Power Supply (UPS) and a Programmable Logic Controller (PLC)[6]. A motion control[7] board is used to articulate the laser steering head. This board requires only simple ASCII commands, in units of degrees, to move the laser steering head. An onboard processor provides feedback between the encoders and stepping motors to achieve and maintain an accurate beam direction.

Back-up systems protect HR2SLS against the inevitable loss of power or network connection. The computer, the PLC, and the cover-box are all powered through UPS's. When power is lost, a UPS sends a command to the computer. The computer issues a command to the PLC to close the cover-box. The computer then shuts down gracefully. When power is restored to the system, the computer reboots and the system may be re-initialized

Laser, Wavelength	YAG, 355nm
Pulse Length	5.5 nS
Energy (to sky)	6 mJ (Maximum)
Filters (attenuation)	48% - 0.08% (24 combinations)
Laser Jitter	5% sigma
Energy Measurement	1% relative 5% absolute
Polarization Options	Circular, Linear (V or H)
Pointing Absolute	<0.1 degrees
Pointing Relative	<0.005˚ Elevation <0.03˚ Azimuth
Beam Divergence	<0.05˚
Time Stamp	±2mS
Computer	PC 166 MHz

Table 1: Specifications of HR2SLS.

remotely. If the system is idle for more than an hour, for example during network failure, the PLC automatically shuts the cover-box.

The software developed for the HR2SLS allows an operator to control every function of the system remotely. However, since operators are busy running the HiRes1 detector, the system typically reads commands from a file. This loop file allows one to specify the shot geometry, filter settings, polarization, laser energies, and firing rate for an unlimited amount of laser shots. HR2SLS runs through the loop file, executing all of the instructions specified, until it is stopped by an operator. Firing times may also be specified in the loop file to provide different shot patterns at different times throughout the night.

When the laser is operated, an automatic log records the session. All of the commands issued by an operator and any system warnings are listed. The log also contains the position, monitor probe energy, energy sent into the sky, filter settings, and the time of each laser shot. At the end of each night, a summary of the night's operation is created and mailed to interested parties to monitor the general status of the system.

The HR2SLS has been operating in this configuration for three months. The laser is run while the HiRes detector operates. Depending on the night, the laser may fire between 2,000 and 13,000 shots over a two to ten hour period. The normal firing rate is 4 Hz.

3. Conclusion

A steerable laser system has been installed at the HiRes2 site of the HiRes cosmic ray observatory. This remotely operated system provides a versatile beam to probe the atmosphere viewed by the HiRes1 detector. Construction of a complimentary system at the HiRes1 site is planned for this year.

4. Acknowledgements

We are grateful for the cooperation of Colonel Fisher and the staff of Dugway Proving Grounds. We acknowledge the support, and expertise of our technical staffs. We also thank Don Epand at the Fairbourn Observatory[8] for sharing his knowledge and driver software. This work was supported by NSF grant No's PHY-9321949 and PHY-9322298 and by the Australian Research Council.

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3. Quarter wave plates: CVI Laser Corp. part #:WQWPM-355-05-4 http://www.cvilaser.com
4. Computer-controlled filter wheel: ISI Systems Inc. model #:FW-1 http://www.imagingsystems.com
5. 45°mirrors: Melles Griot, part #:08MLQ003/412 (no longer made,replacement is 16MFB133) http://www.mellesgriot.com
6. Programmable Logic Controller: Toshiba Corporation. Model #:TDR116-6S http://www.toshiba.com
7. Motion control board: Oregon Micro Systems, Inc. Model #: PC39 http://www.OMSmotion.com
8. Fairbourn Observatory http://www.fairobs.org/fairborn.html