MROI's Automated Alignment System

Alisa V. Shtromberg, C.A. Jurgenson, M.T. Paz, J.M. Steenson, L. Berger [1]

[1] Magdalena Ridge Observatory New Mexico Institute of Mining & Technology Socorro, NM Email: ashtromberg@mro.nmt.edu

ABSTRACT

The Magdalena Ridge Observatory Interferometer (MROI) will be a reconfigurable (7.5-345 meter baselines) 10 element optical/near-infrared imaging interferometer atop Magdalena Ridge, 30 miles west of Socorro, NM. Depending on the location of each unit telescope, light can travel distances ranging from 460 to 660 meters via several reflections that redirect the beam's path through the beam relay trains, delay lines, beam reducing telescope, switchyards and finally to the beam combiners. All of these sub-systems comprise the three major optical axes of the MROI defined by the unit telescope (UT), the delay lines and the beam reducer (DL/BR), and the beam combiners (BC). The purpose of the alignment system is to provide a method of coaligning these three axes. One major obstacle in designing the automated alignment system (AAS) is the required simultaneous measurements from the visible through near-IR wavelengths. Another difficulty is making it fully automated, which has not been accomplished at other optical/near-IR interferometers. The conceptual design of the AAS has been completed and is currently in its preliminary design phase with some prototyping already commenced. Here is presented the current outline and progress of MROI's automated alignment system design and some results of the prototyping.

INTRODUCTION

The MROI is comprised three major optical axes defined by the unit telescope (UT), the delay line & the beam reducer (DL/BR), and the beam combiners (BC) (Figure 1). The DL and the BR are considered to be on the same optical axis because there are no turning mirrors between the two systems. *The purpose of the AAS is to provide a method for coaligning these three axes.*

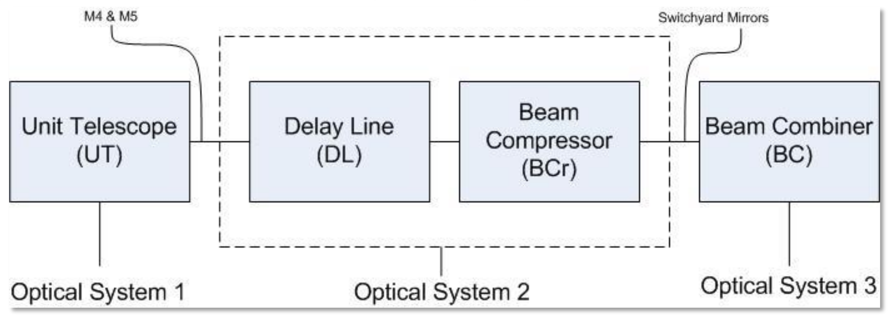


Figure 1 Diagram showing the optical axes of MROI

Depending on the location of the UT from start to finish the beam will travel distances ranging from 460 to 660 meters via several reflections that redirect the beam's path through the beam train into the delay line area (DLA) and finally into the beam combining area (BCA).

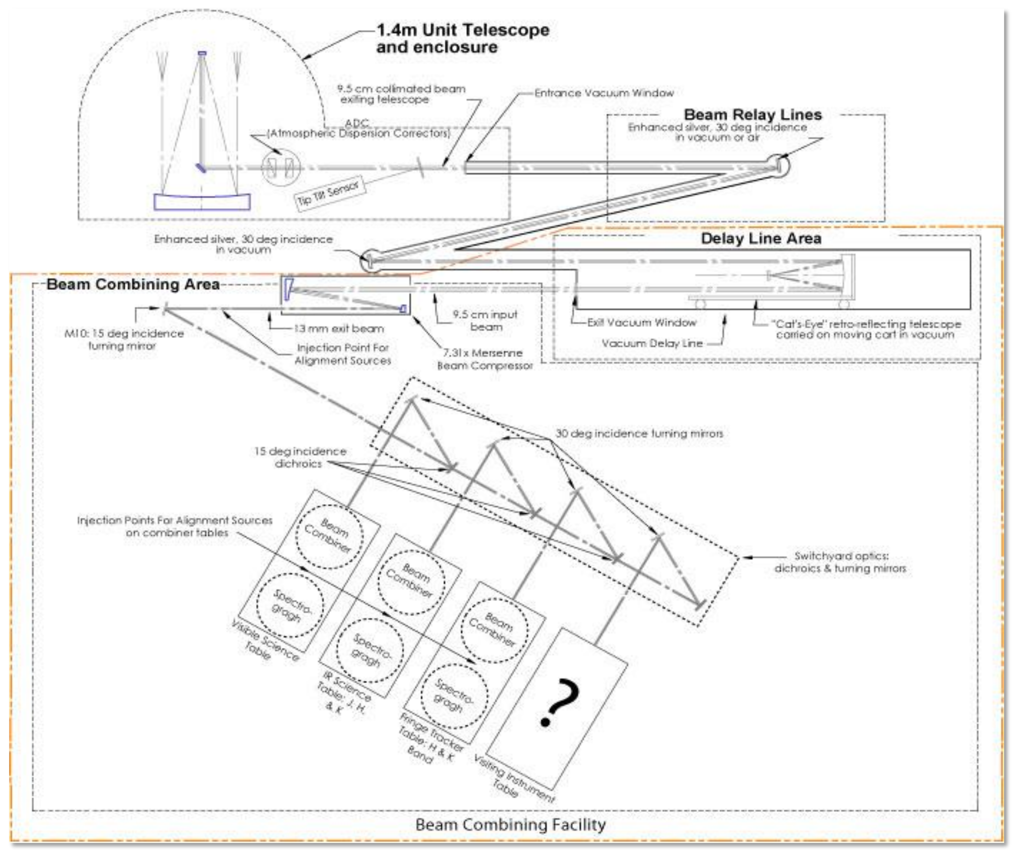


FIGURE 2: General optical layout of the beam's path from one unit telescope (UT) to the back end of the interferometer. Downstream a collimated beam exits UT at 95mm diameter, then propagates through the beam relay (BR) and the delay line (DL) pipes, finally entering the inner beam combining area (back end), where it first gets compressed by the beam reducer (BR) to 13mm diameter beam, before encountering the switchyard & the beam combining tables).

The BCs are in the BCA and will be comprised of four beam combining tables that will simultaneously operate at visible and IR wavelengths, with one undetermined visitor instrument table. The first table will be for visible science, the second table will be for IR science (in J, H, and K bands), and the third table will be for fringe tracking (in H and Ks bands). A switchyard system will be located in front of the beam combining tables which will consist of dichroics and turning mirrors optimized for the different band passes. Current discussions of the AAS omit the visiting instrument and its switchyard. However it is assumed that the AAS will be able to accommodate the BCs if necessary with minimal effort.

Wavelength, λ (μm)	Bandpass	Beam Combiner
0.656	H_α	**Visible**
1.1 – 1.39	**J**	**IR Science**
1.5 – 1.8	**H**	**IR Science, FT**
2.0 – 2.4	**K**	**IR Science**
1.99 – 2.31	K_s	**FT**

Table 1: Table showing the operating wavelengths and the corresponding beam combiners for the MROI.

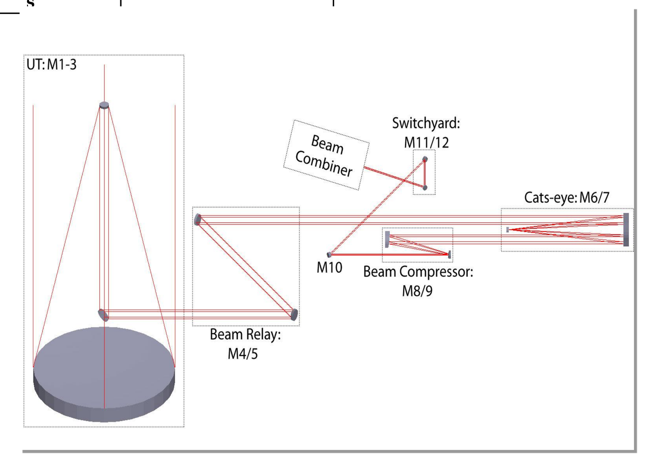


FIGURE 3: Abbreviated optical train for a telescope on the west arm through to the first switchyard. There are 6 optical assemblies that make up a single beam train of the interferometer's west arm to the first switchyard. Note that the beam path proceeding downstream starts at the UT and goes through the BR, then to the cats-eye, the BCr, the switchyard, and finally the BC.

Finally it is important to define the key components of the AAS
:: Primary Fiducial
:: UT Nasmyth Table Hardware
:: BC Hardware
:: Secondary Fiducials
:: AAS Engine
The Design section of this poster describes these components in more detail.

DESIGN

Primary Fiducial

The purpose of the primary fiducial is to establish a reference axis, in this case the DL/BR axis to which the UT and BC axes must be coaligned to. The primary fiducial is located on the alignment (optical) table that is located in the inner BCA immediately following the beam compressor.

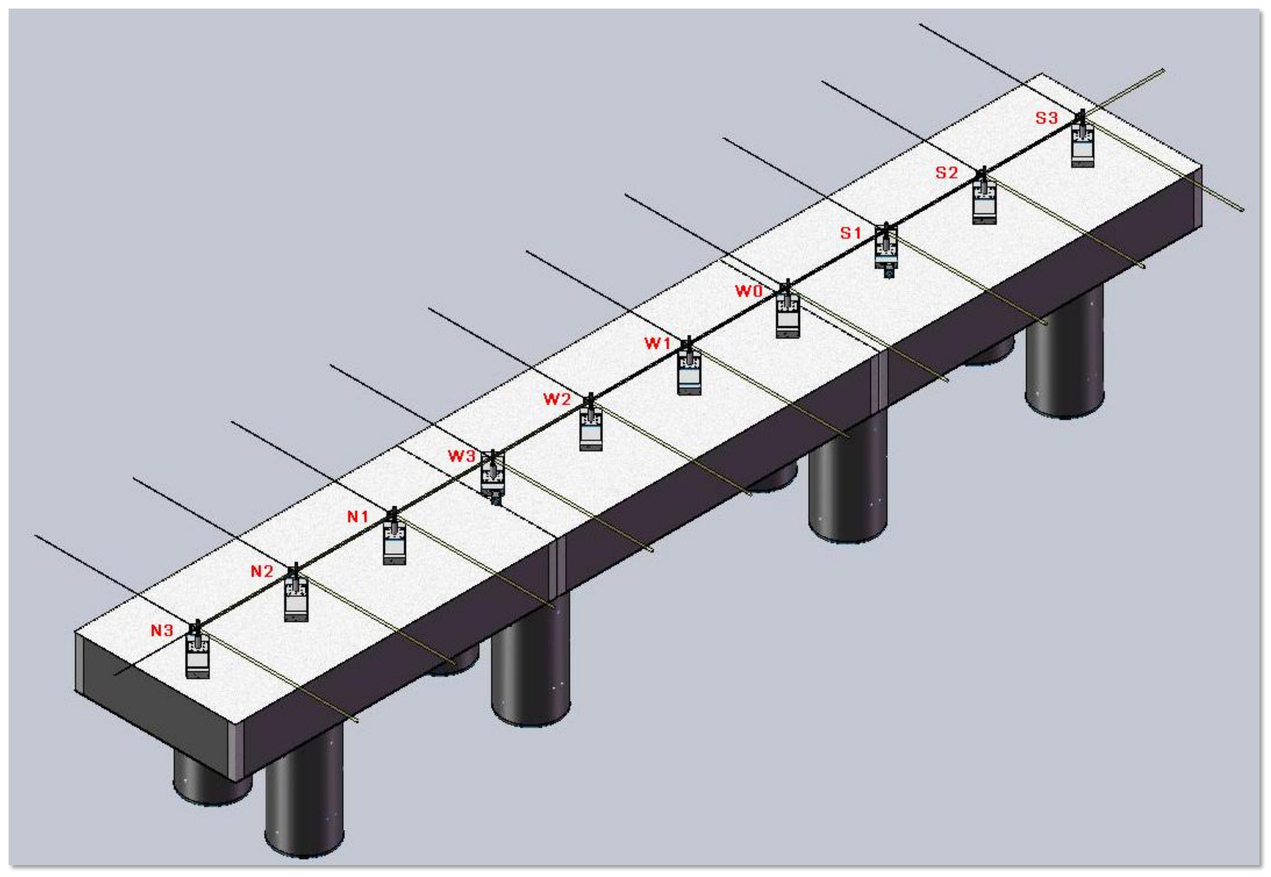


FIGURE 4: Alignment table with light sources that define the primary fiducial and the optics that direct the light beams in their respective directions. There are two light sources that will define the primary fiducial: a HeNe laser traveling upstream (toward the UT) and a white light source traveling downstream (toward the beam combiners). It is crucial that the two beams are parallel and colinear to each other as they define the central optical axis (Dl/BR axis). As shown in the diagram on the left the two light sources will be placed on the opposite sides of the table along the same axis. Beamsplitters will be placed on slides that will slide in an out of the beams' path as designated by the automated alignment procedure. The red HeNe laser will travel up to lengths of 660m depending on the location of the UT and will be used to make tilt and shear (see below) corrections with the M4 and M5 turning mirrors. A white light source is used to accommodate the switchyard optics that are optimized for specific wavelengths for their respective beam combiners. A pair of turning mirrors—in the switchyard—are used to make tilt and shear adjustments between beam reducer and the beam combiner axis. Note that the drawing on the left shows all beamsplitters in the beams' paths all at once. However during the alignment procedure at most two beamsplitters will be in the beams' paths sending two sets of beams in each direction for alignment measurements and corrections. For more alignment procedures see below.

Tilt & Shear Corrections

The essential task of the AAS is to remove tilt and shear errors from the beam's path that begins at the UT and ends at the BCs. As shown in Figure 4 pair of turning mirrors need to be present to remove each type of error.

Turning mirrors on mounts with actuators will be located at four locations within the optical train (beam's path). Tilt and shear removal will be available at two of those locations: (1) M4 & M5 located between the delay line and the UT (2) following the beam reducer in between M10 & switchyard optics (M11/M12, M13/M14, M15/M16) (se Figure 1). Tilt & shear detectors will be placed in those locations to measure for errors and allow for corrections. The detectors will take the form of CCD cameras and/or quad cells.

It is important to note that MROI's goal is to achieve a net beam shear of less than 1% of the beam diameter and a less than 1% visibility loss due to beam tilt at the beam combiner. This corresponds to a 0.95mm maximum shear allowed in the beam relay, a 0.13mm maximum shear allowed in the beam combiner area. For tilt the maximum allowed error would be 1.58μrad in the beam relay and 11.57μrad in the beam combining area (for tilt error $\theta = (0.0885)\lambda/D$).

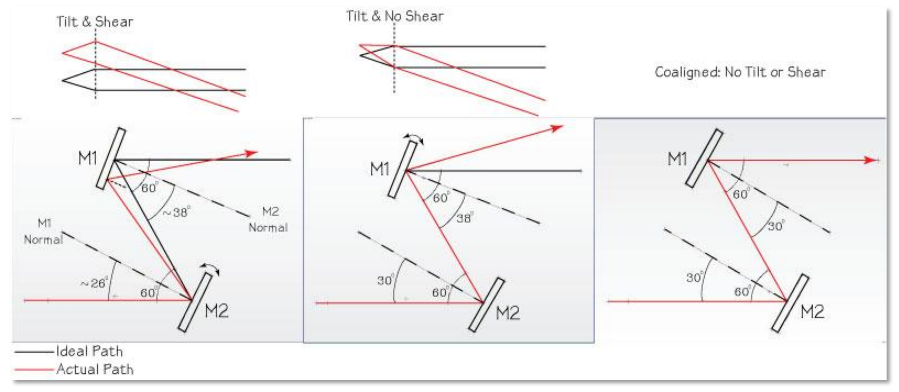
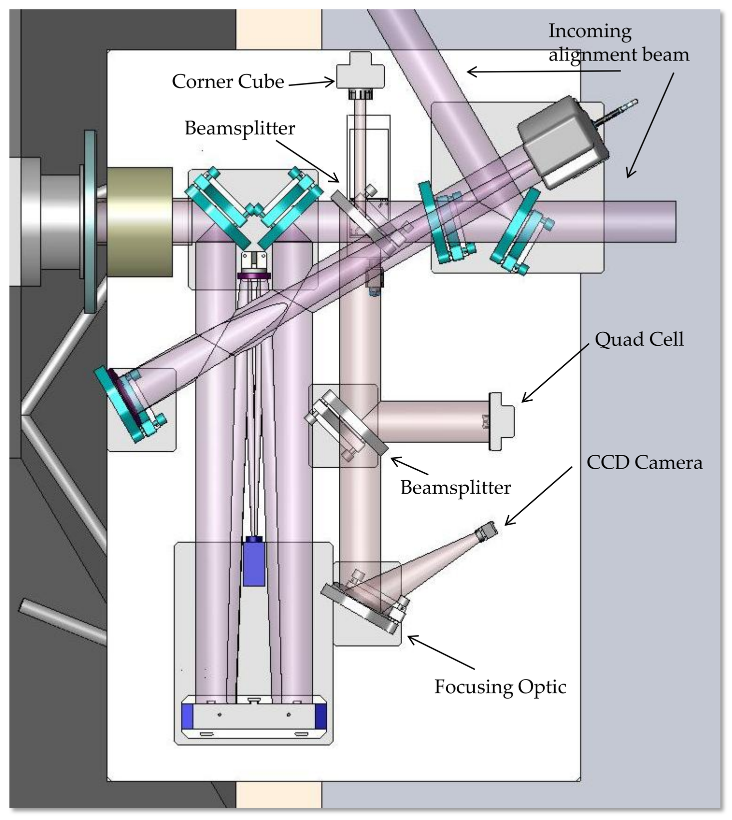


FIGURE 4: In order to remove tilt, shear, or both tilt and shear in a beam's path, a pair of turning mirrors is necessary to achieve such correction. The figure above shows an example of a beam with tilt & shear error with respect to its ideal path, a tilt error only, and a coaligned beam with no tilt and shear errors. The red beam is back propagated (goes from M2 to M1) and represents the actual path of the beam and the black beam is the ideal beam path if the mirrors were properly aligned. To achieve the coalignment both M1 and M2 must be adjusted. A detector would be present after M1 that measures tilt and shear errors. M2 would first be adjusted to correct for the shear, then M1 would be adjusted to correct for the tilt, finally achieving coalignment.



The Hardware

UT Nasmyth Table Hardware: The UT Nasmyth table will consist of hardware and optics in order to direct the alignment beam to the detectors that will measure tilt and shear errors. From there as mentioned in the section above M4 and M5 will be used to correct these errors for the UT-DL/BR axes.

Beam Combiner Table Hardware: Because there will be four different beam combiners, each with their own designated purpose, and thus each with their own unique optical/hardware design the alignment hardware that will be present at each of these beam combiners would have to also vary in its design. Currently only the Fringe Tracker Beam Combiner is being designed, therefore the alignment optical and hardware is only being designed for this beam combiner. This hardware will also consist of two detectors one for tilt and one for shear measurements with a series of optical set ups to direct the beam to each detector. Both detectors will have to detect in J and K bands which means a quad cell will not work and thus most likely two IR CCD cameras will be used.

FIGURE 5: A SolidWorks drawing of the UT Nasmyth table located at the UT. All labeled components are part of the AAS. All other components on the table are part of other subsystems. The alignment beam is directed via a series of optics to a quad cell for shear measurements and to a CCD camera for tilt measurements. The alignment beam here representd the DL/BR axis which according to this drawing and depending on the location of the UT would be coming in from the top or the top right direction . Another beam would coming from the UT that would also be directed to these detectors. The two beams then would be compared for their tilt and shear and M4 and M5 would be used to correct any misalignments between the two beams.

Secondary Fiducials

Secondary fiducials will be installed to provide automated remote checks for the alignment with use of the light sources used for the primary fiducial. These checks will provide for means of making quick assessments of the alignment without having to do the whole alignment. There will be several types of detectors throughout the arms of the interferometer to achieve this. One type of a a secondary fiducial will be a quad cell (see prototyping section for more information). Quad cells would be installed throughout the arms of the array as well as in the beam combining area (the quad cells in the BCA will be smaller off the shelf version). CCD cameras will be installed at these locations for remote viewing. Another type of secondary fiducial will be an obstruction that rotates into the path of the laser 15 degrees relative to the M5 mirror. A video camera would be placed in its view which would allow for shear measurements. *Please see talk on Friday for more details about secondary fiducials.*

AAS Engine

The AAS engine is essentially the "brain" of the AAS. It will consist of a set of algorithms that will allow for specific procedures to run the aligning process. At the beginning of each night before observations the alignment system will be turned "on." The algorithm would then be started which would activate the primary fiducial along with all the necessary detectors and start the alignment process of each beam train. From start to finish it will take less than 1 hour to align all ten telescopes. From start to finish it will take less than 1 hour to align all ten telescopes.

FUTURE WORK

The conceptual design complete and is awaiting internal review. The next phase of the design will be the preliminary design with an expected completion date in sometime this sprint. Prototyping of the Quad Cells will continue through the Spring of '08. Other prototyping is expected to commence in full in Ferbruary. Most parts of the alignment system will be purchased off the shelf. Therefore a lot prototyping will involve testing factory specs for tolerances, accuracies, and repeatability. Most of the prototyping will be involved with interfacing with the other major subsystems of the interferometer. Prototyping is expected to finish by Spring of 2009 at which point the AAS will go into its final design phase. The AAS is expected to pass its site acceptance test in July of 2009 in time for the arrival of the first unit telescope.

CURRENT PROTOTYPING

Secondary Fiducials – Quad Cells

There will be two types of quad cells necessary for shear measurements. A very large quad cell will be needed to accommodate a 95mm beam coming out of the UT. Smaller quad cells (50 x 50 mm) will be sufficient for various locations in the arms of the telescopes. Quad cells will be placed in these locations to perform "quick checks" of the alignment. For the beam combiners there will most likely not be any quad cells for shear measurements since the optics will prevent visible light to pass through to the IR and the FT Beam Combiners. There CCD cameras or special photodiode quadrant detectors that specifically work on the IR wavelengths will be used for the shear measurements. The two quad cells mentioned in the beginning of the paragraph are being developed in house.

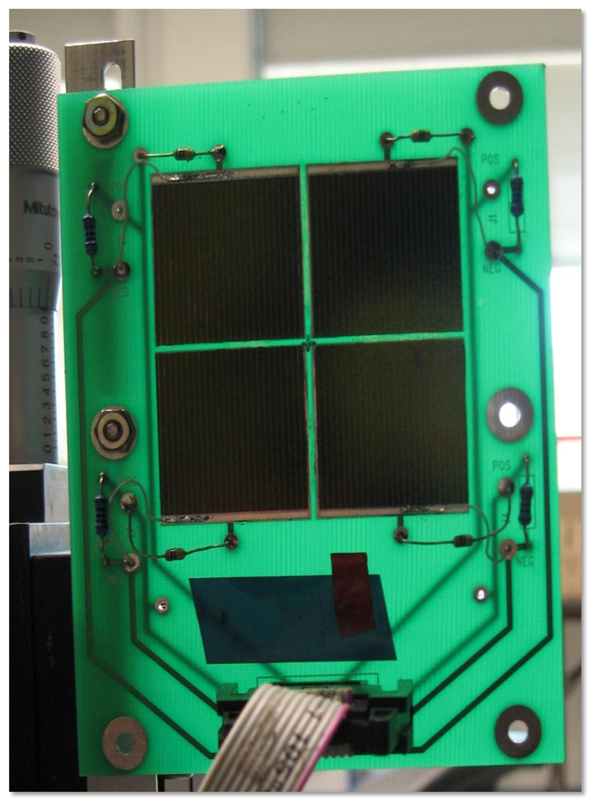


FIGURE 6: Custom made quad cell (50 x 50 mm) prototype

The custom made quad cells use space-qualified solar cells so that the positional errors can be measured. The solar cells are soldered onto a pre-wired circuit board. They are card like and light weight which makes them a perfect candidate to use as pop-up targets.

As shown in Figure 6 there are 4 solar cells are placed in a quadrant fashion. Each solar cell outputs a voltage when a beam shines on it. Based on the location of the beam on the quad cells the 4 voltages change. Thus the voltages can be used as a means for determining the location of the beam. If the beam is not centered, corrections c an be made by the alignment system.

Currently there are two prototypes assembled that are being tested in lab. Figures 7 and 8 show the lab set up necessary to test these quad cells.

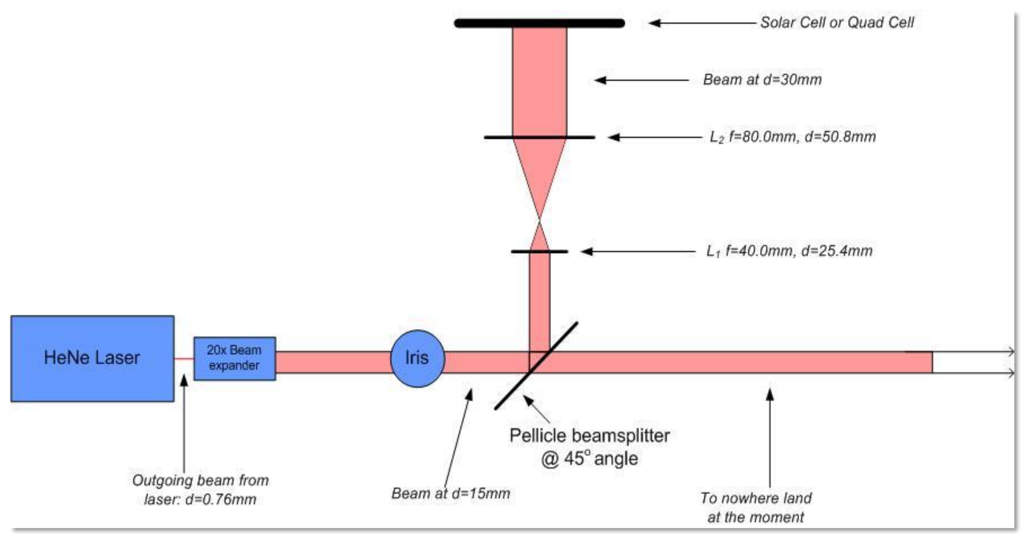


FIGURE 7: Sketch diagram of the lab set up for testing the quad cells.

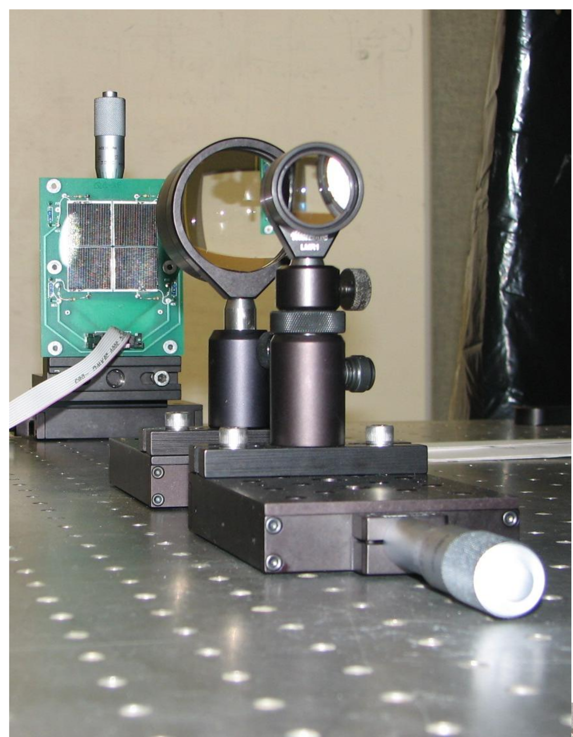


FIGURE 8: Photos showing the sketched test set up for the quad cells. A .78mm HeNe laser beam expanded 20x by a beam expander where it is then stopped down to 15mm beam by an iris and is diverted 45 degrees using a pellicle beamsplitter. It then travels through a pair of lenses which expands the beam to 30mm finally arriving at the quad cell. The quad cell is mounted on a x-y translation micrometer slide.

The tests consist of determining the physical center of the quad cell. Accuracy tests are performed to determine the sensitivity of the solar cells. And finally repeatability tests are done to check for solar cell/quad cell repeatability accuracy.

Currently the results are still very preliminary and thus inconclusive because the testing is in its early stages. All results are expected by end of January.