Slide Characterization for an Interferometric Beam Combiner

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The Magdalena Ridge Observatory Interferometer (MROI)

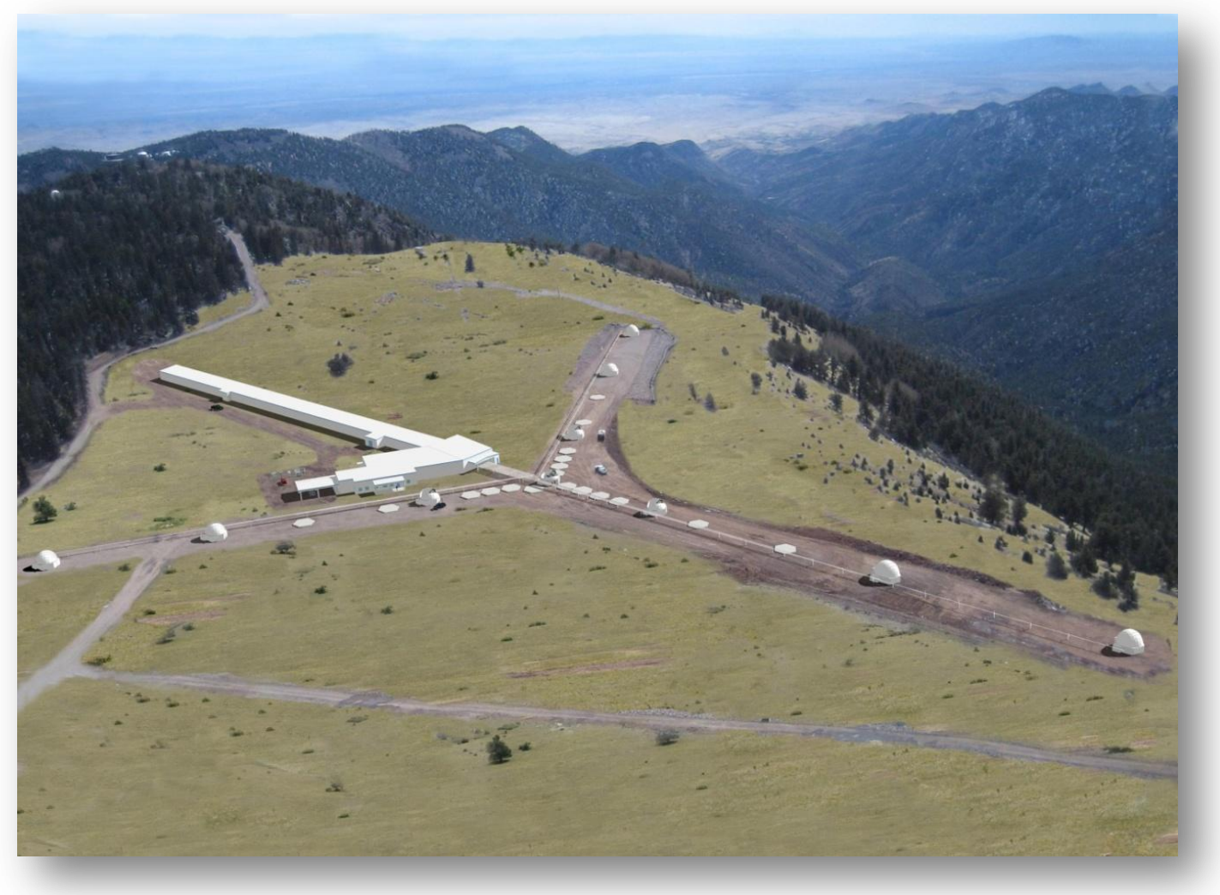


Figure 1. This is an aerial photo of the Ridge with a CAD drawing overlaid showing the future array arms, unit telescopes, and beam combining facility.

The Magdalena Ridge Observatory is in the process of building an optical/infrared (0.6-2.4 micron) imaging interferometer that will be comprised of a 10-telescope array with baselines up to 350m. Upon completion the infrastructure will support 28 telescope pads (9 in each arm, one central), allowing for 4 array configurations. The main science goal is to deliver model independent images of faint and complex astronomical targets with milli-arcsecond spatial resolutions. Construction of the array beam combining facility is now complete, and first fringes are scheduled for February of 2010.

The Optical Train

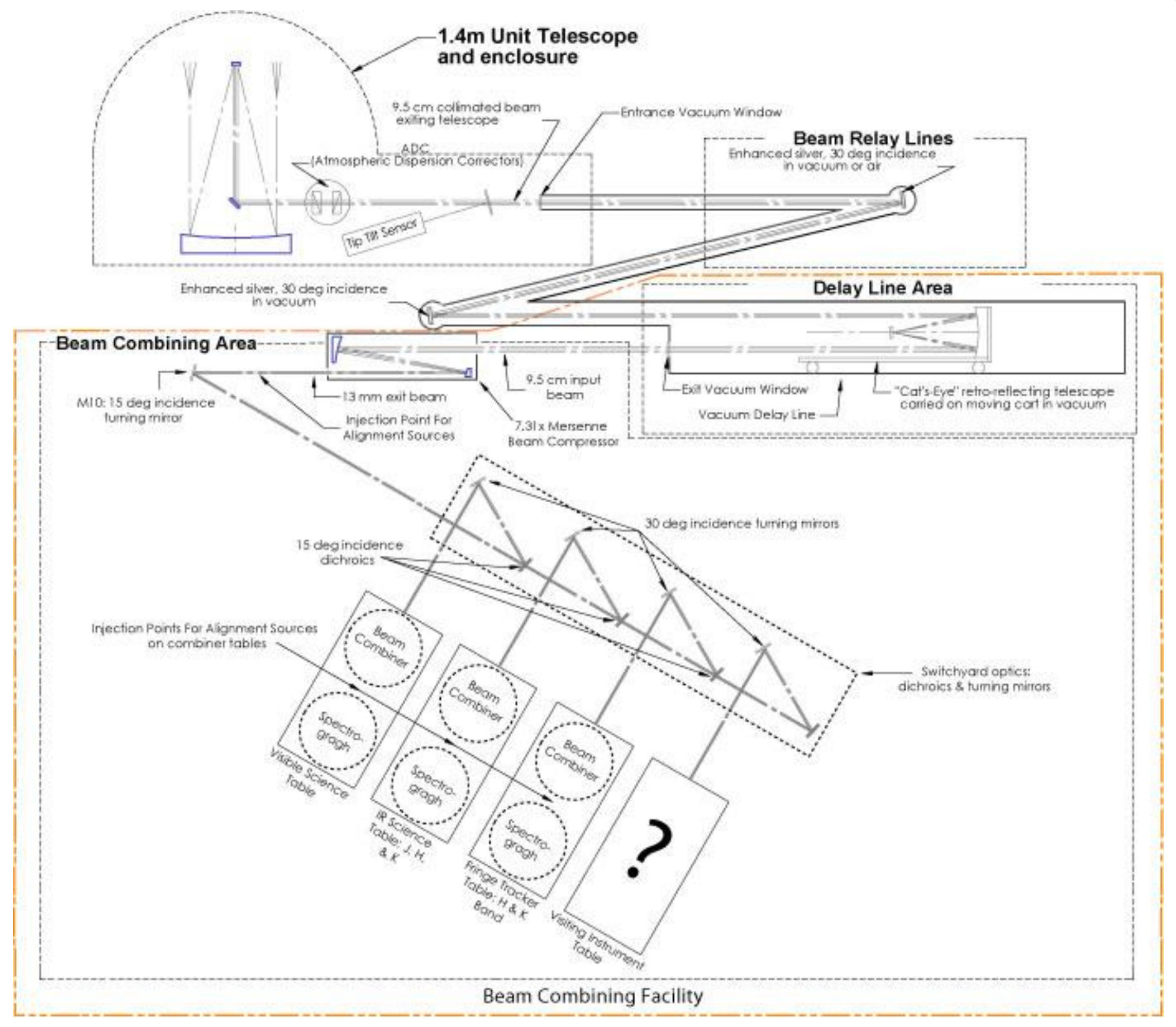


Figure 2. A 2D schematic of the MROI beam train (not to scale). This design minimizes the polarization effects on the beams as well as the total number of reflections. This ensures the best throughput with minimal wavefront distortions.

In the figure, light exits the 1.4 meter unit telescope and immediately enters the beam relay pipes which are under vacuum. Following the beam relay is the delay line area. This is where the light paths from all telescopes are matched to within the coherence length of the light being measured. Upon exiting the delay lines, the beams leave the vacuum and get compressed from 95 mm to 13 mm. They are then transported to the switchyards whose function is to direct light of a given bandpass to the appropriate beam-combining table. The beam combining area will house four different beam combiners to be used for optical science, infrared science, infrared fringe tracking, and as of yet undetermined visiting instruments.

Abstract

The Magdalena Ridge Observatory Interferometer is being constructed atop the Magdalena Ridge at an altitude of 3,320 meters. The beam combiner down-select process for the near-infrared science instrument is dependent upon whether or not "fast switchyard" slides can be implemented. The fast switchyard slides must be able to re-direct a given unit telescope beam either into or out of the beam combiner optical path every few minutes with high repeatability. To test slide performance, the pitch, yaw, and optical path difference (OPD) errors as a function of slide travel have been measured in both directions. Phase one tests were developed in order to determine the long-term stability over the course of 24 hours, while phase two tests determined system stability under operating conditions. By knowing the repeatability of each slide hysteresis can be accounted for at every position by predetermined adjustments made by the mirror mount actuators on the slide. The final results of both tests will categorize the performance of the fast switchyard slides for selection within the science beam combiner. Initial test results are reported herein.

Beam Combiner Candidate Designs

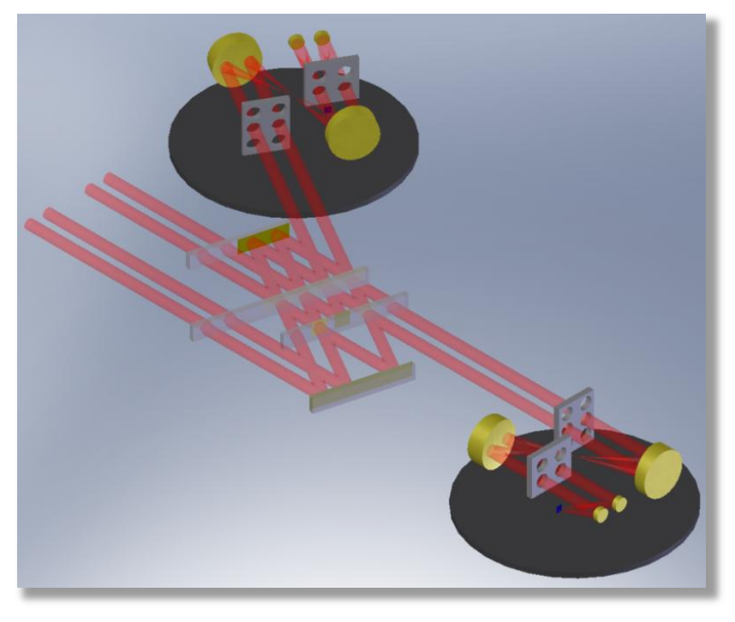


Figure 3. A 3D CAD model of a P4S combiner, one of four candidate designs for the beam combiner down-select process.

There are four candidate designs for the down-select process of the near-infrared science beam combiner, the contacted 4-way and 8-way pupil plane combiners (P4S and P8 respectively) as well as the 4-way and 6-way image plane combiners (I4S and I6 respectively). For a more complete discussion of the candidate designs, refer to the paper *Beam Combiner Studies for the Magdalena Ridge Observatory Interferometer* by Fabien Baron, David F. Buscher, Julien Coyne, et. al. (SPIE, Advances in Stellar Interferometry, Vol. 6268 62681R-1).

Phase A of the array construction calls for IR science and fringe tracking with a six-telescope array to be completed in 2012. Phase B would then build out the remaining four telescopes, and implement the optical combiner. Taking for example the case of a four-way pupil plane combiner (Fig. 3) and a six- telescope array, there are more input beams from the telescopes than there are input ports to the combiner. Therefore, a "fast switchyard" would have to be implemented in order to make all the desired measurements.

That is, a six- telescope array with a P4S combiner would use a fast switchyard to select 4 of 6 incoming beams, measure the interference patterns, reconfigure, and then select a different set of 4 beams. This would cover all 15 baselines, and 20 closure paths for the six- telescope array. In this case, a total of 5 successive switchyard configurations would be necessary.

The Fast Switchyard

The term "fast switchyard" is used to describe a pair of slides that automatically selects and directs a given unit telescope beam into or out of the beam combiner optical path. The switchyard layout reconfigures by moving optical elements consisting of dichroics and mirrors mounted on mechanically actuated linear slides. Reconfiguration must occur frequently, approximately every couple minutes, which highlights the need for automated slide alignment.

The opti-mechanical design of the fast switchyard slides was optimized in order to minimize slide length and allow enough configurations of the switchyard to ensure beam combiner accessibility to all visibilities and closure phases.

Traditional beam combiners that do not utilize fast switchyard slides combine data from all inputs simultaneously. In contrast, the beam combiner with fast switchyard slides only measures a subset of these visibilities and closure planes before re-configuring the fast switchyard slide to capture another subset; eventually capturing all incoming data.

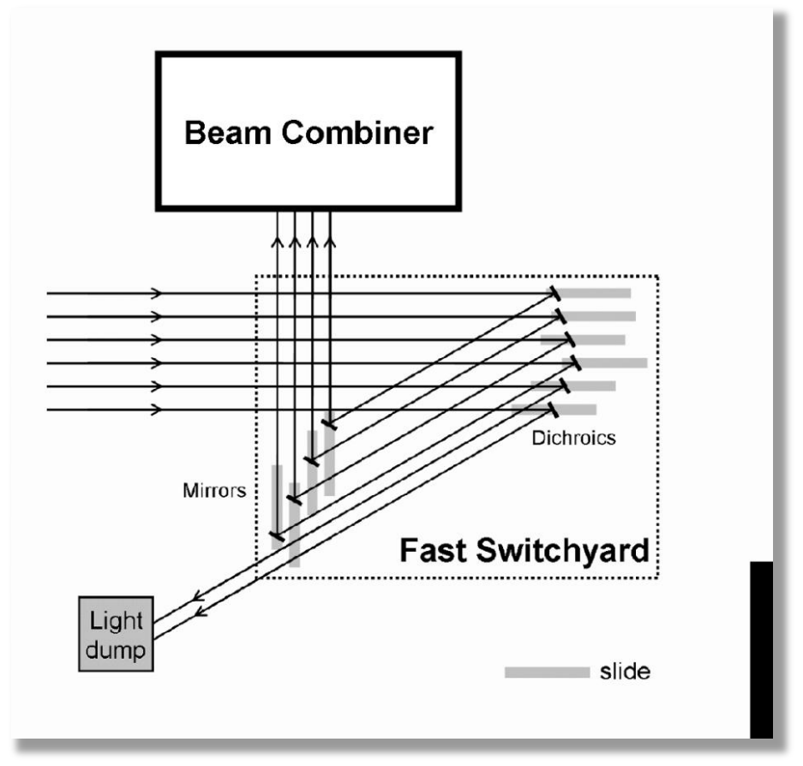


Figure 4. (Above right) A 2D CAD illustration of the fast switchyard. In this case 4 of 6 available input beams are selected and directed into the beam combiner. The remaining two are halted outside the switchyard.

Fast Switchyard Slide Experimental Setup and Test Procedures

The purpose of these tests are to measure the pitch, yaw, and OPD error as a function of slide travel in both directions as a means of characterizing the system's repeatability/hysteresis. From these measurements the repeatability of the slides will be characterized. The results are intended for use in the evaluation of feasible candidate designs for the science beam combiner down-select process.

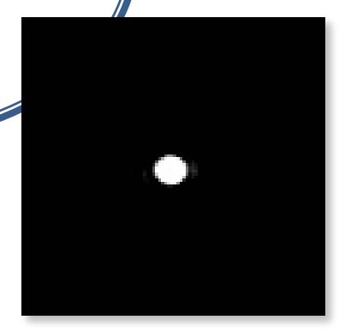


Figure 5. Example CCD Image for Pitch Yaw Tests.

Phase I Tests

Phase I tests determined beam drift in pitch, yaw, and OPD over the course of a day with the slides off and in a stationary position. The causes of wandering in this case are environmental changes, e.g. changes in room temperature and building stability. To monitor temperature changes, samples were acquired every minute by temperature probes placed both on and around the slides.

Phase I Test procedures for pitch and yaw investigation consisted of taking burst of exposures at known increments of time over the course of 10 hours, Phase I OPD Test procedures consisted of taking a series of metrology detector readings at know increments of time over the course of 24 hours.

It was found that the slides wandered significantly, even on short timescales, when not turned on.

Phase II Tests

Phase II tests determined beam drift in pitch, yaw, and OPD under operating conditions. Larger drift values in this case can be attributed to imperfections in slide mechanism and optical table.

Phase II test procedures consisted of taking a series of exposures and metrology readings at known position increments of the slide travel while moving the slide in one direction (e.g. front to back) and then repeating the process for motion in the opposite direction (e.g. back to front).

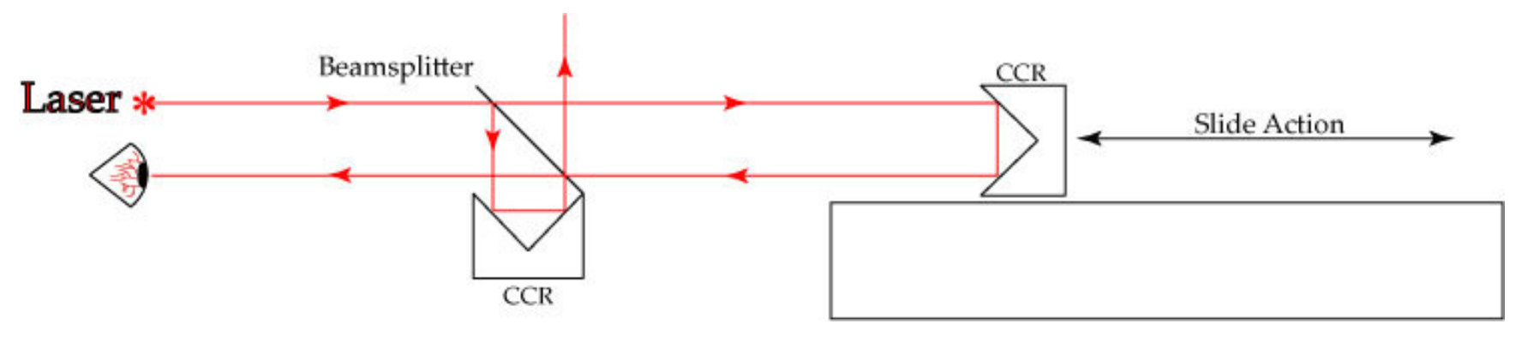


Figure 6. Experimental set-up for Phase I and Phase II OPD Tests consisting of a metrology system (laser and detector), two corner cube reflectors (CCRs), a beam splitter, and a fast switchyard slide.

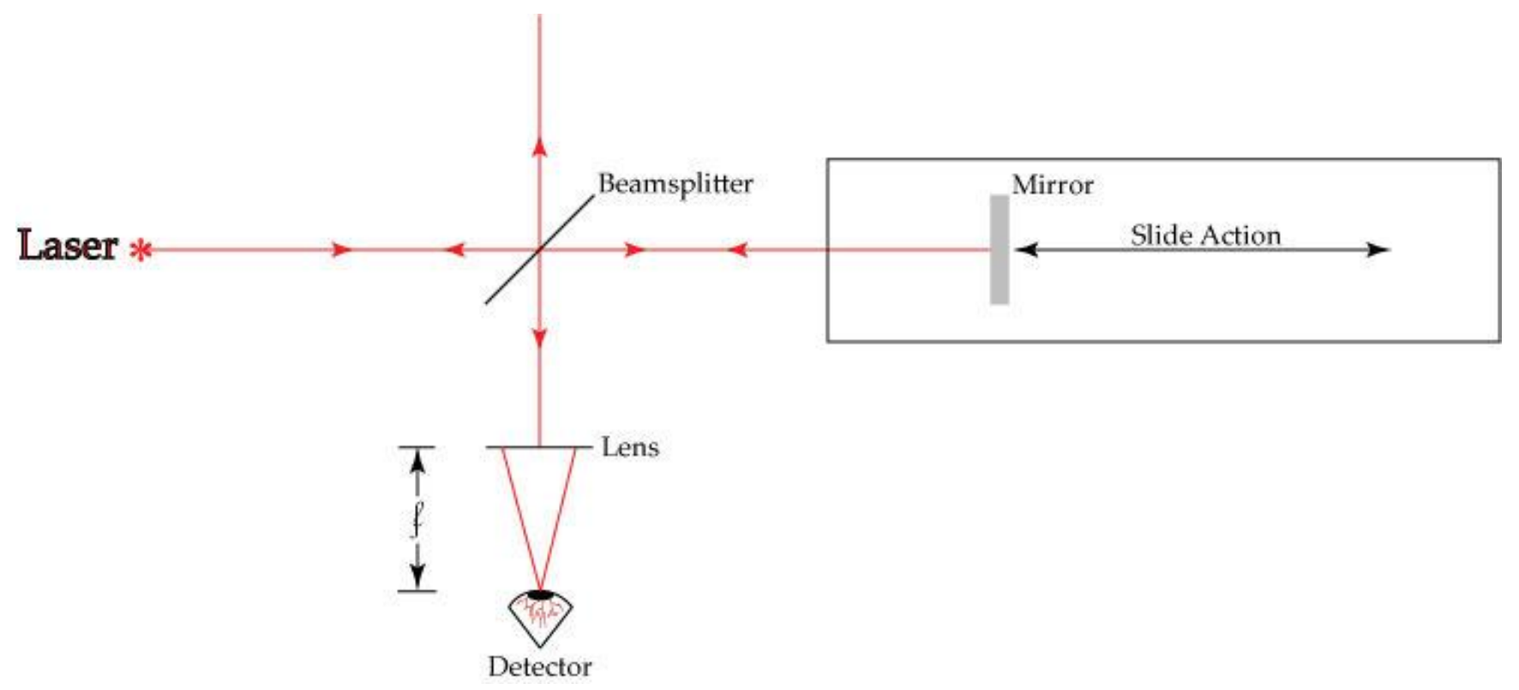


Figure 7. Experimental set-up for Phase I and Phase II Pitch and Yaw Tests. A series of absorption filters were used to cut down the light intensity of the 7mm beam before reaching the high-sensitivity CCD detector.

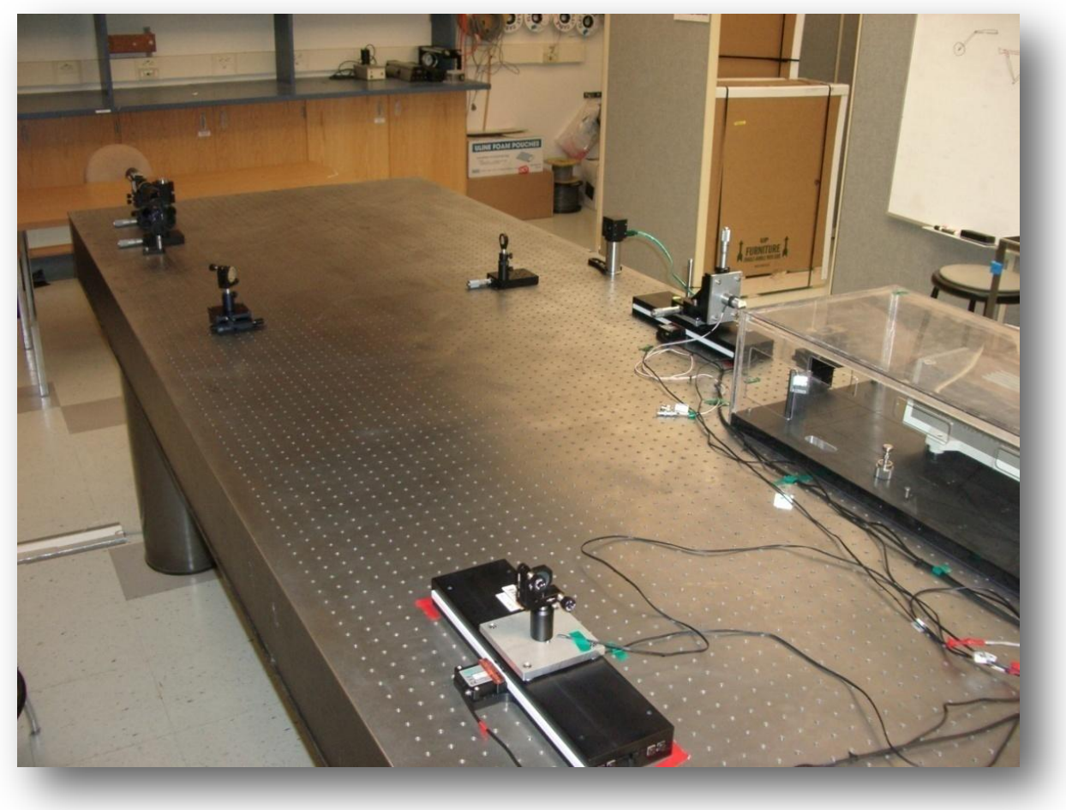


Figure 8. A photograph the experimental set-up for Phase I and Phase II slide tests. On the left is the Pitch and Yaw set-up and on the right it the OPD set-up with the metrology system that is on loan from IOTA.

Results of Phase I and Phase II Slide Tests

OPD Results for Phase I & II

Results of Slide 3 are presented below:

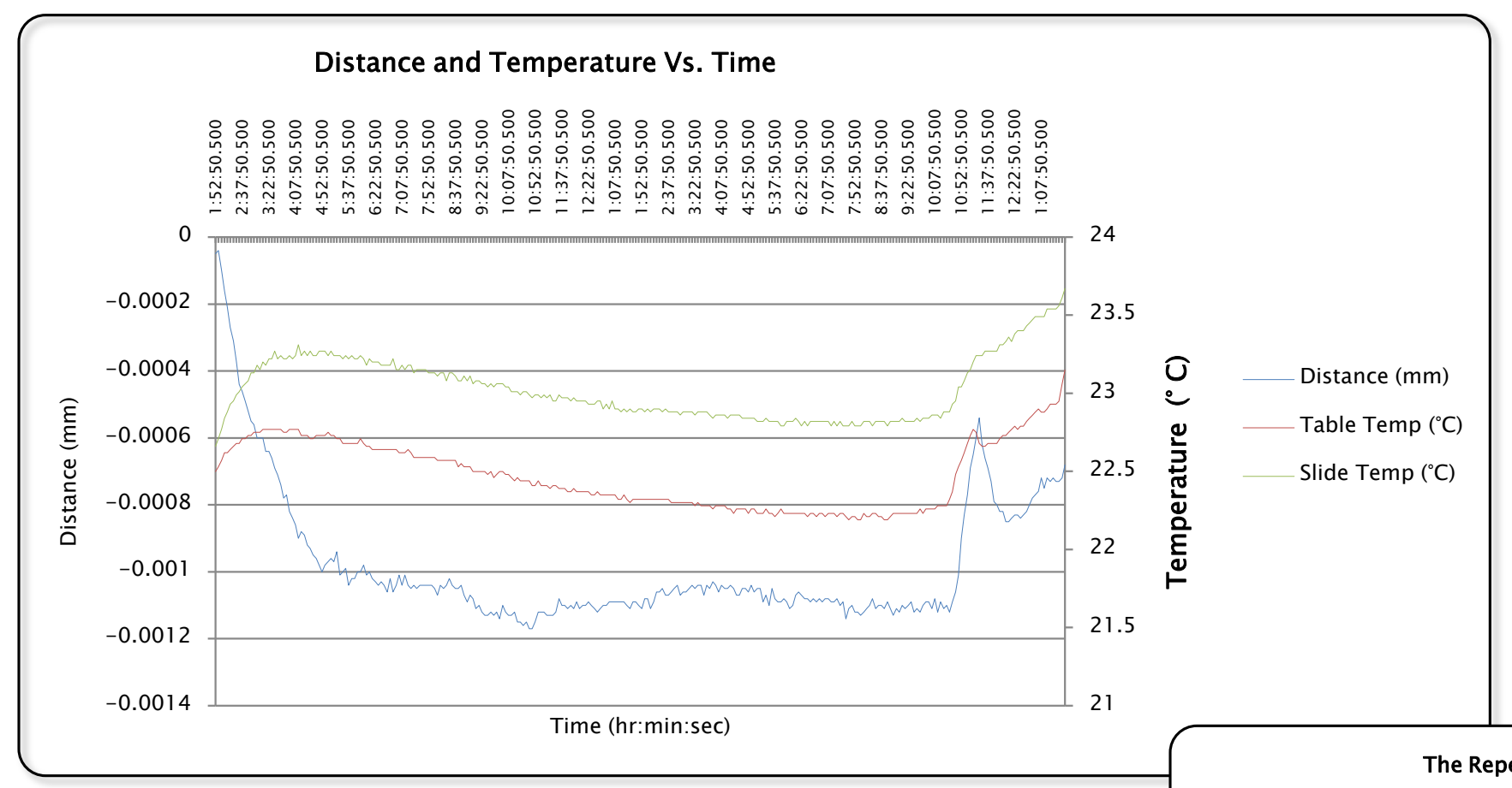
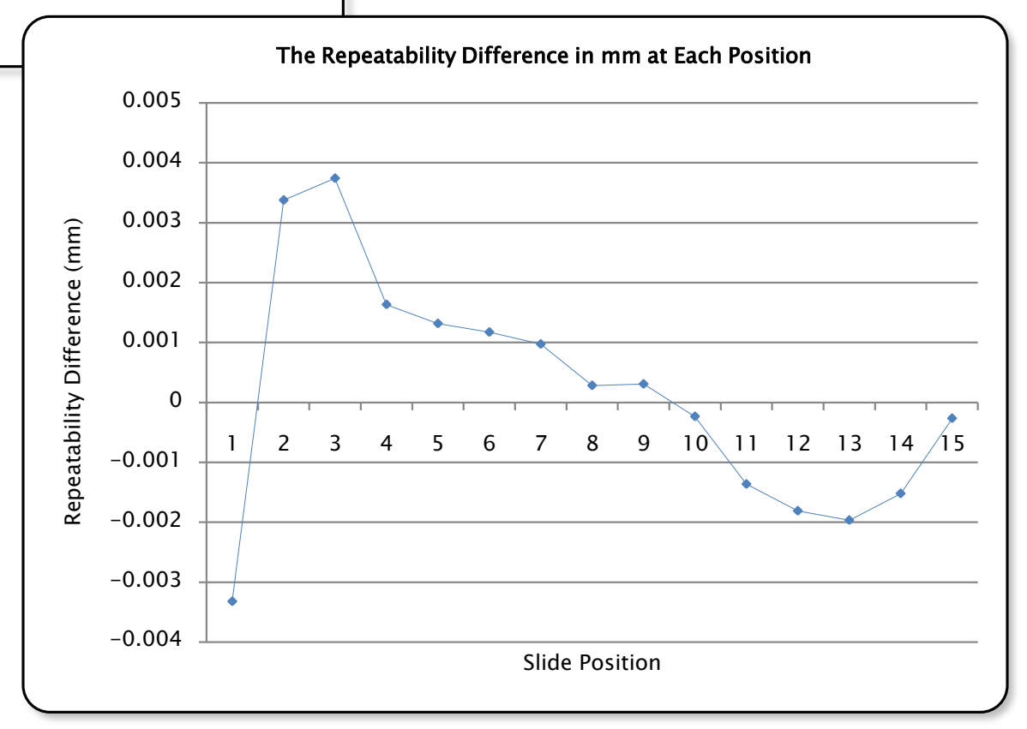


Figure 9. (left) This test was to get a quick estimate of the behavior of the slides while enabled and left for an extended period of time in the same position. The test was performed while the slide was enabled and in its middle position. Samples were taken by a metrology system every 5 minutes over the course of 24 hours. It was found that if the slide was not enabled, it significantly wandered (Phase I tests).

Figure 10. (right) Hysteresis measurements: this is the differential between a series of original and return positions. There were a total of 30 positions separated by 20 mm increments (1-15 moving forwards (280 mm) and 16-30 moving backwards (280 mm)). The initial zero position and end position (before the return trip) were both 10 mm in from the ends of the slide travel to avoid "oscillation points" discovered in earlier tests. The slides have a total travel of 300 mm.



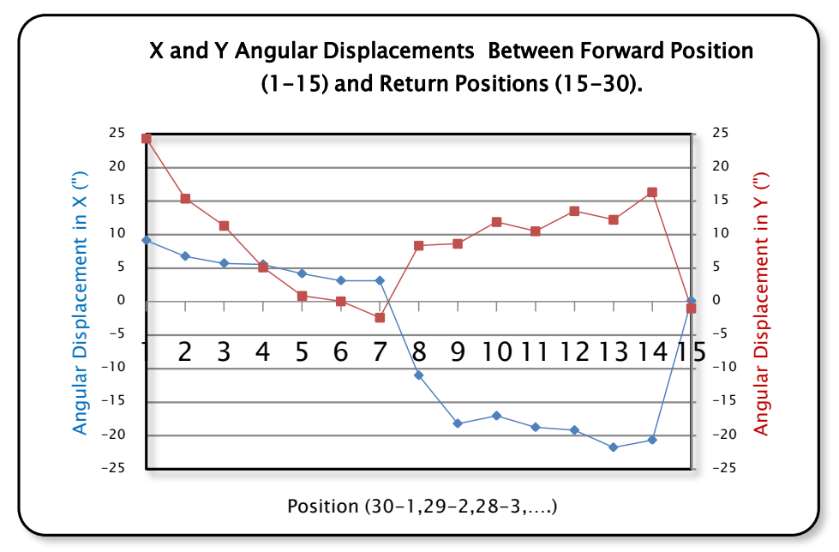


Figure 11. (above) Hysteresis plot of angular deferential between forward and backward movement with single 20 millimeter increments (a total of 30). The red line refers to the angular displacement in Y and the blue line refers to angular displacement in X. (E.g. Position 30-Position 1, Position 29-Position 2.)

Figure 12. (right) A program was written in IDL to calculate the x and y centroids of the beam on the CCD detector for pitch and yaw measurements. This is a plot of the mean x and mean y values for every position in both directions of slide travel. Points along the forward moving position (towards the beam splitter) are shown in black; the points during the return trip (moving backwards away from the beam splitter) are shown in red.

Pitch Yaw Results for Phase II

Results of Slide 3 are presented below:

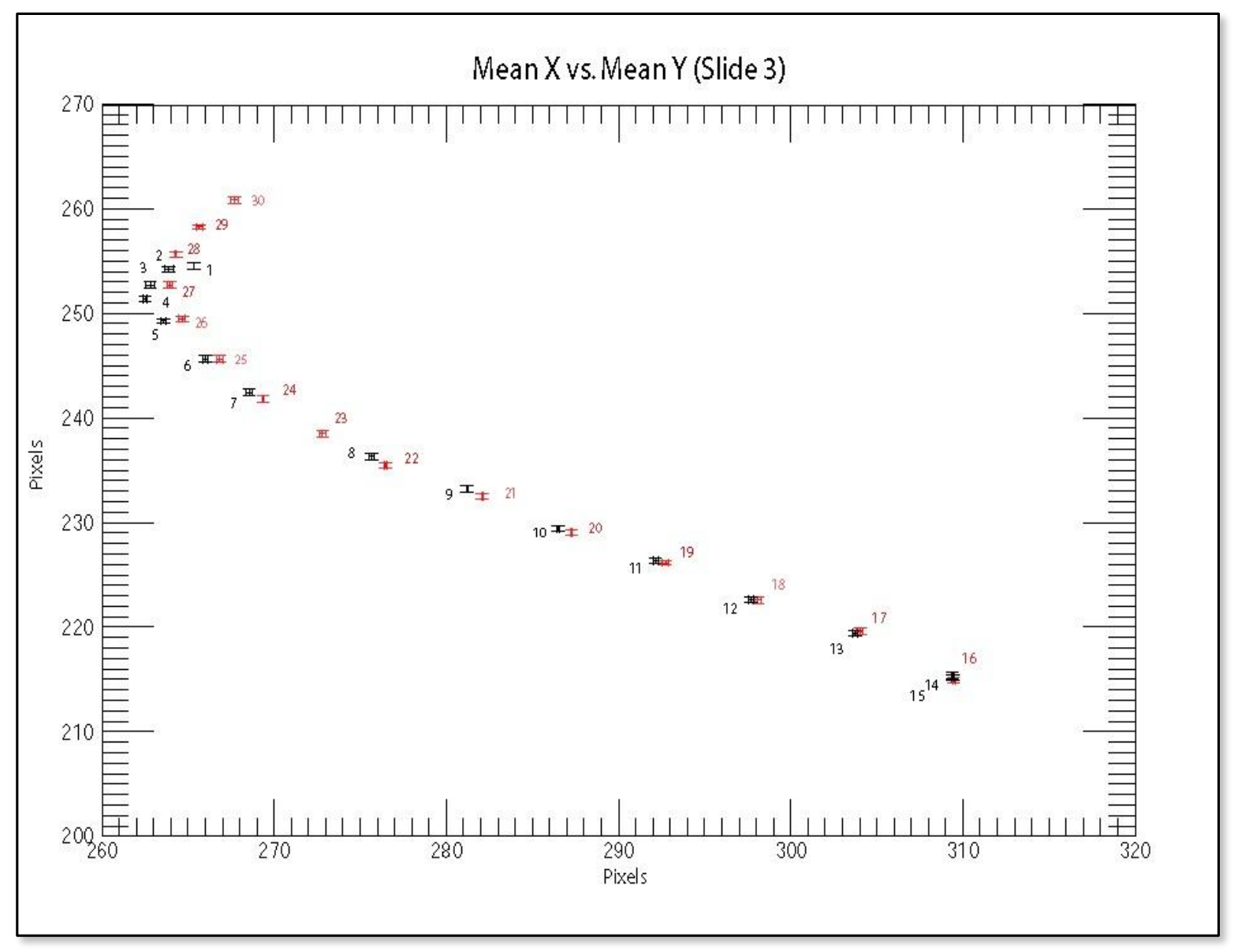
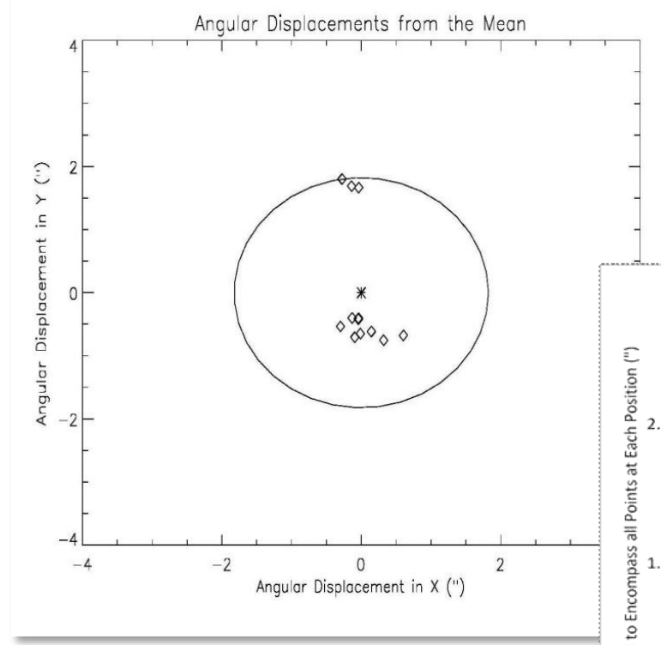


Figure 13. (left) This is a scatter plot of angular displacements of the twelve exposures taken at 1 of the 30 slide positions (in this case the scatter plot for Position 15 is displayed) with mean x and mean y centered at the origin. Scatter plots were generated for every position for both slides and a circle was inscribed about all points on the plot as a means of categorizing beam drift.



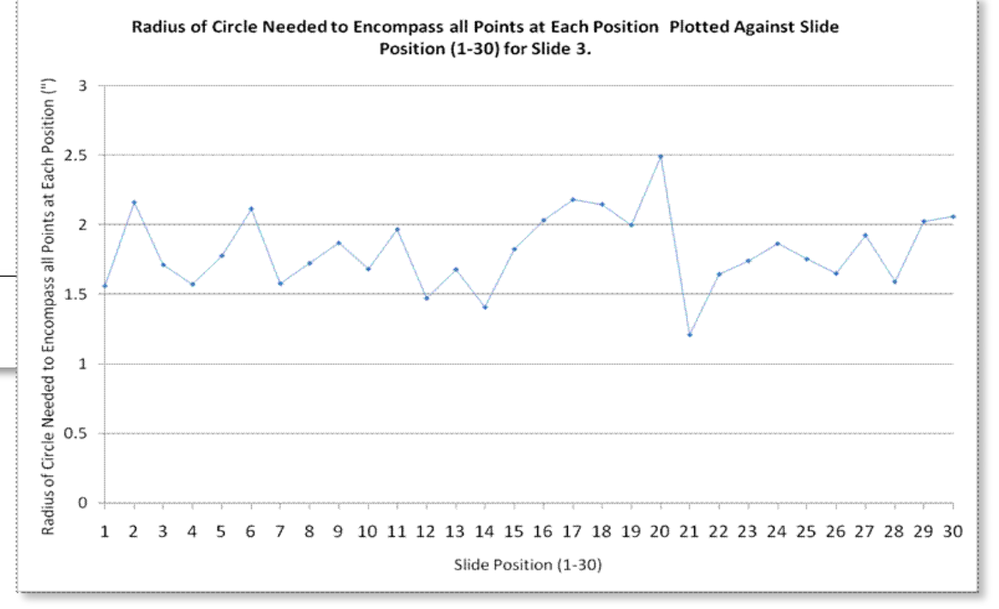


Figure 14. (left) This is a plot of the radius required in each scatter plot (1-30) to encompass all the points within each slide position.

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