OPTICS IN MOTION

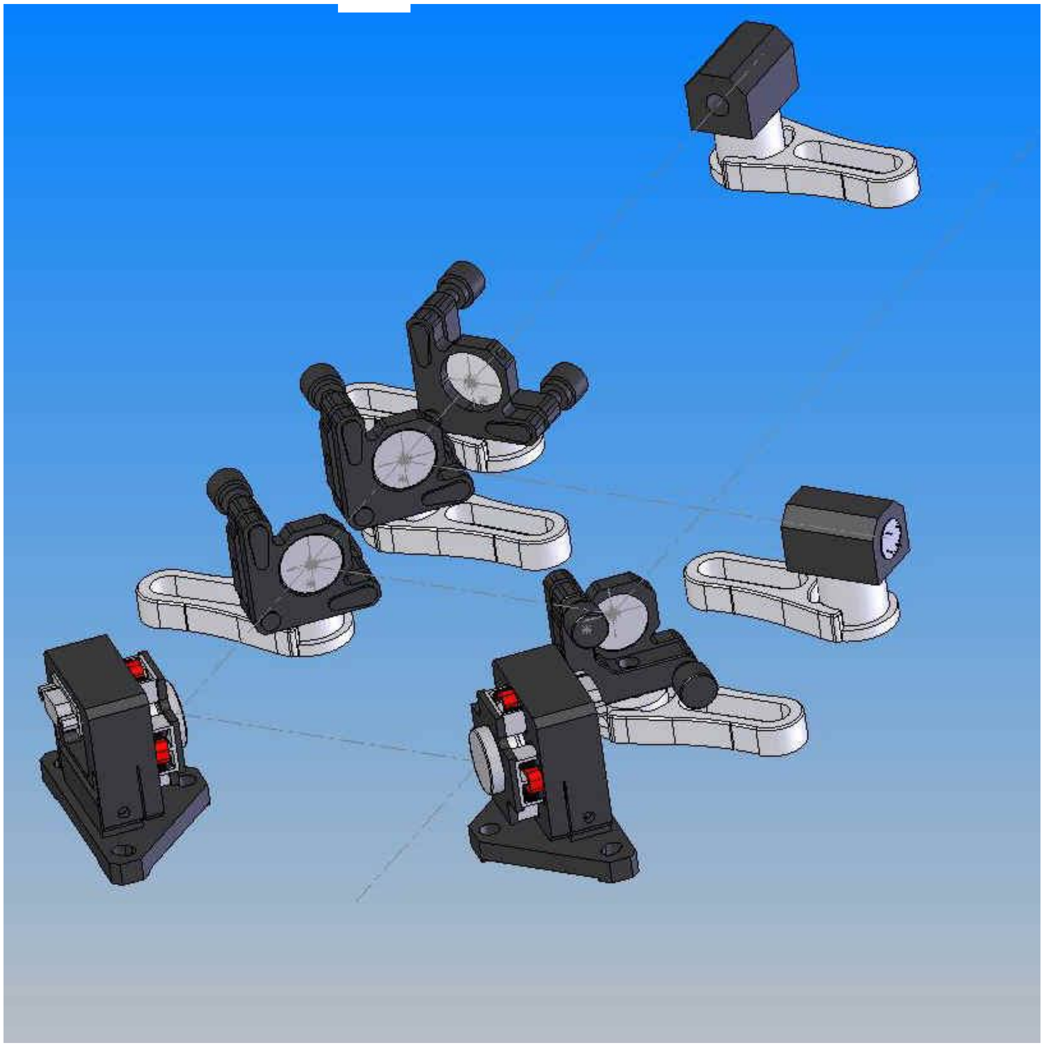
STANDARD AND CUSTOM FAST STEERING MIRRORS

Tutorial

to design and build a custom 3.5 x 5 inch, +/- 10 degree range fast steering mirror.

July 2004 - Improved standard fast steering mirror actuator design. Added performance and improved heat-sinking (allows higher peak power)

PSD Volts 1) Laser Beam Stabilization PSD Volts



Beam Stabilizer Layout, Dual Fast Steering Mirrors

Introduction:

Beam stabilizers are used to correct for dynamic laser beam pointing errors in optical systems. These pointing errors can be a combination of slow varying (thermal) and higher frequency error (mechanical vibration from fans, water pumps, etc.).

A beam stabilizer uses active mirrors to compensate for beam pointing errors. By sampling a small percentage of the beam, the active mirrors can eliminate beam motion by using feedback from position sensing detectors.

Competing Technologies:

Active mirrors fall into the following groups:

- Piezo mirrors
- Piezo driven screw mirrors

- Actuator motor driven mirrors (steppers and dc servo motors)
- Galvometric scanning mirrors
- Voice coil actuated scan mirrors

Here is a brief overview of the various active mirror approaches.

Piezo mirrors make use of the inherent piezo effect of certain crystals and ceramics. The thickness of these materials change by applying a high voltage across a section of the material. In order to limit the magnitude of the applied voltage, most manufactures stack thin sections to form a cylinder. The range of travel of these materials is typically 15um per 20mm section. Piezo mirror have the advantage of a large pushing force over a small range. The piezo actuators push against a flexure to obtain the desired mirror tilt.

See the Physik website for information on piezo mirrors *www.physikinstrumente.de*

Note: combining piezo technology and using mechanical levers, can increase the angular range of piezo mirrors for example Physik model "*s-224 ultra-fast minature piezo tiltplatform with mirror*" has a 2.2 mrad angular range. And a company called Mirrortech has a line of mechanical advantage piezo mirrors *www.mirrortech.com* these mirror have up to a +/-20mrad angular range.

Key features: small angular range, high bandwidth, high accuracy.

Piezo driven screw mirrors, one company uses a piezo to drive a fine pitch screw thread acutator. This approach can result in very fine motion increments (company claims <30 nm of incremental motion). These units are great for laboratory mount replacements where adjustments are done very seldom. But they fall short when it comes to active control. Because of the way these actuators work, they create a large noise during motion (high pitched whine) and they have a very limited lifetime. Because the actuator relies on friction between the moving piezo actuated part and the lead screw, repetitive motion will cause the actuator to stop working. The manufacturer claims a 2500 cycle (motion of 3mm) life for these actuators. In addition the maximum speed of the acutator is 40um/second which limits the frequency/amplitude of the mirrors disturbance capability to slow drifts such as thermal changes.

For more information on these actuators see *www.newfocus.com*.

Key features: great for occasional operation and replacement of manual actuators.

Note: a similar product that has been around for years is the Burleigh Inchworm. This product uses as series of clamping piezos to slowly inch an actuator forward. See *http://documents.exfo.com/appnotes/AnoteBurleigh010-ang.pdf* for more information.

Actuator motor driven mirrors, for very slow speed applications, standard kinematic mirror mounts with motorized actuators can be used. These actuators are available as stepper motors or dc servo motors. Because most of these actuators use fine pitch threaded lead screw, wear is a consideration for repetitive usage.

Galvometric scanning mirrors, these are single axis mirrors cantilever mounted on shafts. These can scan large angular ranges +/-20degrees. Very low priced versions of these mirror are simple stepper motors with mirrors mounted to the rotary shafts. High end galvo mirrors have built in position sensors and are linear to better than 0.1%. The galvo rotary shaft is usually supported by a ball bearing, but flexure suspended shafts are available. The disadvantage of this mirror is that since it is only a single axis device, two scanners need to be mounted together get a two axis scan. In addition, when using a scanning head (f-theta lens), an additional optic is needed between the scanners to eliminate beam walk on the second mirror.

Voice coil mirrors, are two axis mirrors with flexure suspension. The voice coils are mounted in a push/pull configuration to apply torque to rotate the mirror. Most mirrors have magnets mounted to the moving mirror substrate and the voice coils mounted on the fixed base. This arrangement allows for better heat-sinking of the coils and eliminates the problems associated with moving wire connections. Proper design will result in an infinite life mirror, limited only by the electrical component lifetimes.

Beam Stabilizer Configurations:

A beam stabilizer is made up a number of the following components:

1) Fast steering mirror - in our case a flexure suspended two axis voice coil mirror.

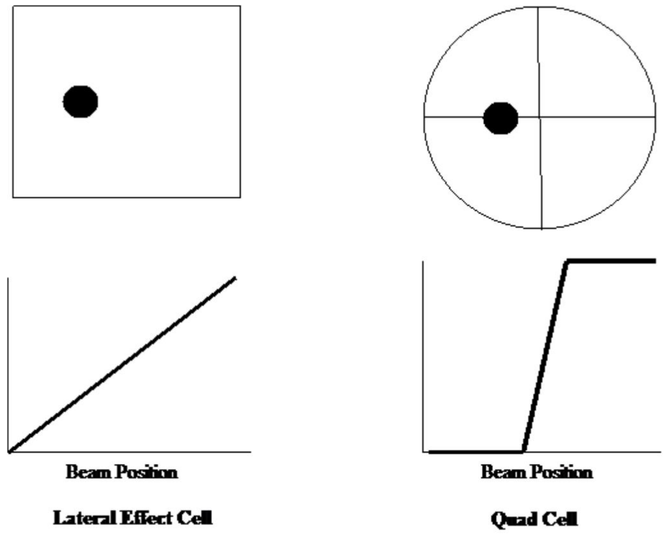
2) Optical Beam-splitter - a half silvered flat mirror that reflects some percentage of a laser beam while also transmitting a percentage.

3) Position Sensing Detector - either a lateral effect cell that outputs a voltage proportional to beam placement, or a quad cell that splits up the detector into 4 quadrants.

4) Imaging or focusing lenses – used either to transform angular error into displacement or to re-image an angular source.

Why would you use a lateral effect cell instead of a quad cell? A lateral effect cell measures the power centroid of a beam regardless of the beam size. A quad cell only measures position when the beam is split up into the quadrants of the cell. If the beam is fully on one quadrant the output will rail (either positive or negative)

If a lateral effect cell is used, the angular gain of the beam stabilizer mirror loop is dependent on the detector size and the distance of the mirror to the detector. If a quad cell is used, the angular gain is dependent on the detector size, the distance from the mirror to detector, and the beam size. See the graphs bellow to see how beam size effects the mirror angular gain.



Note: *Changes in beam size do not affect the lateral effect cell scale factor but they do affect the quad cell scale factor. (in volts/beam position)*

There are other advantages for using a quad cell in a beam stabilizer system. The first is that the quad cell is less likely to drift center position with aging. The other advantage is that for the same size detectors the quad cell has a lower capacitance and lower noise.

Single FSM Stabilizers

It is possible to configure a beam stabilizer with a single FSM however there are drawbacks to this approach. In order to eliminate beam motion 4 degrees of freedom are necessary (to compensate for two displacements, and two tilts). A single FSM allows only 2 degrees of freedom, so proper placement of the error sources must be considered.

The simplest implementation of a beam stabilizer consists of a FSM, a beam-splitter, and a position sensing detector. The laser is reflected off the FSM and then passes through a beam-splitter. The majority of the energy is reflected and a small percentage is passed through the beam-splitter. The energy that passes through the beam-splitter is directed onto a quad cell.

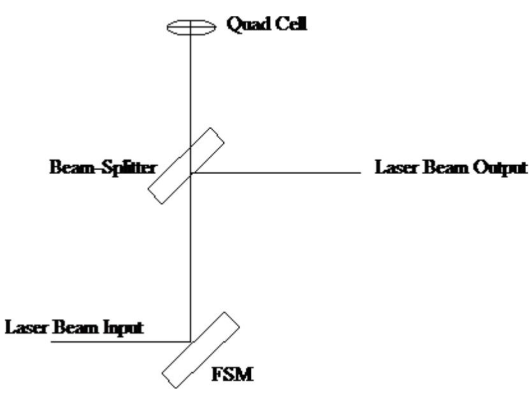


Figure 1. Simple Single FSM Stabilizer

As the laser beam drifts, the spot on the quad cell moves off center. Feedback from the quad cell causes the FSM to correct this motion and move the beam back to the center of the quad cell. The result of this correction is that the beam is held fixed at a point in space (the center of the quad cell). This may be an acceptable condition, but the beam angle is not controlled. In fact depending on the distance from the FSM of the angular error source compared to the distance from the quad to the FSM, the angular error may even be magnified. For example, if you wanted the angular error to be reduced by a factor of 100, then the distance from the FSM to the quad cell must be 100 times greater than the distance from the error source (usually the laser) to the FSM.

To eliminate this angular error, we can add a focusing lens in front of the quad cell. This lens is located one focal length away from the quad cell. This lens has the effect of eliminating beam translation errors from the quad cell output. Only beam angle change causes the spot to move on the quad cell. In addition, the spot on the quad cell is now focused, this has several affects on the beam stabilizer which will be covered in the setting gain section of this tutorial.

Now this simple beam stabilizer will correct for beam angle errors. However, beam translation errors will not be corrected. The magnitude of the translation error depends on the distance from the error source to the FSM. Another benefit of this design is that the distance from the FSM to the focusing lens can be a small as possible, larger distance does not improve the angular resolution of the stabilizer. The angular range and resolution is set by the choice of the quad cell and the focusing lens.

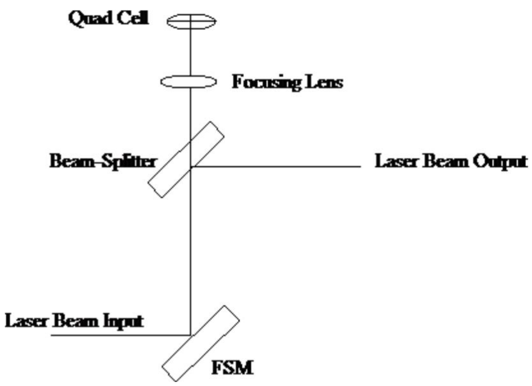


Figure 2. Single FSM Stabilizer with Focus Lens

In order to eliminate the translation effect, we need to insure that the angular error is relayed onto the surface of the FSM. If desired, the focusing optic can be eliminated and the stabilizer range and resolution will be a function of the distance from the FSM to the quad cell. This method works if there is no beam translation of the laser source, only angular errors.

Since the angular error occurs at the laser head, we need to add a set of relay optics that image the error source onto the face of the FSM.

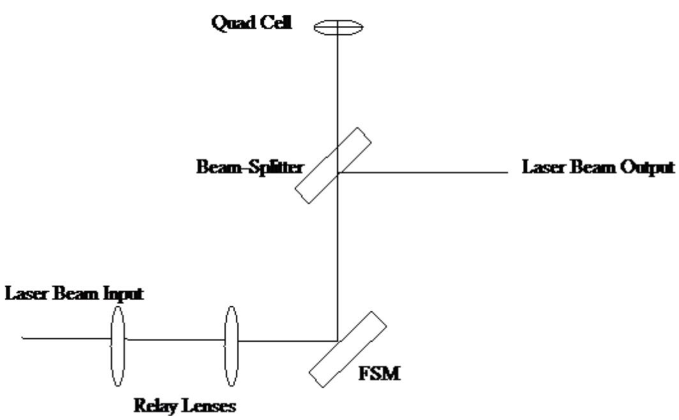


Figure 3. Single FSM Stabilizer with Relay Lenses

The distance from the first relay optic to the laser error source is one focal length of the relay lens. The relay lenses are spaced 2 focal lengths apart, and the FSM is one focal length from the second relay lens. Any angular errors at the laser source are relayed onto the face of the FSM at a single point. The laser beam then reflects off the FSM and through the beam-splitter and onto the quad cell. Since the spot on the face of the FSM is fixed, the quad cell reads only angular error which is fed back to the FSM to correct the error.

A simple test can be run to determine the effectiveness of this beam stabilizer configuration. By installing a relay lens set and placing a position sensing detector at the location of the FSM face, the resultant motion sensed by the PSD should be from any beam translation. If the magnitude of this translation is acceptable then this approach should work. Remember the resultant translation divided by the distance to the quad cell will be the resultant angular error in the system.

Dual FSM Stabilizer

A dual FSM stabilizer is more versatile than the single FSM stabilizers. This lends itself to simpler implementation. Systems can be built which act as a black box, with a laser beam input and a compensated laser beam output. Correction of both angle and displacement will be handed by the stabilizer without adding additional constraints to the optical system.

Two steering mirrors are needed to correct angular errors originating from a point at any distance from the front of the beam stabilizer unit. FSM1 corrects for errors in displacement of the beam from the reference line. FSM2 corrects for errors in angle of the beam from the reference line.

A schematic of a standard beam stabilization module layout is shown in figure 1. The heart of the system is the two FSMs and two position detectors. The position detectors are silicon quadrant detectors, which give feedback to the FSM's controller to keep the beam locked at the center. The beam input is at the bottom of the figure. Two 90 degree bends reproduce the beam's original direction with an offset. FSM1 corrects for angle due to the feedback it receives from Quad Cell1. FSM2 corrects for position due to the feedback it receives for Quad Cell 2. The beam position on Quad Cell 2 is an image of the spot on the front of FSM1. This is done by the lens which has a focal length of f/2 where f is the distance between FSM1 and the lens and also the distance between the lens and Quad Cell 2. This arrangement creates a relay lens which produces a spot on the detector that follows the spot on the front of FSM1. Since the two

FSMs are operating independently they simultaneously correct for angle and position. The beam sampler takes a small percentage of the output beam (usually 1% to 5%).

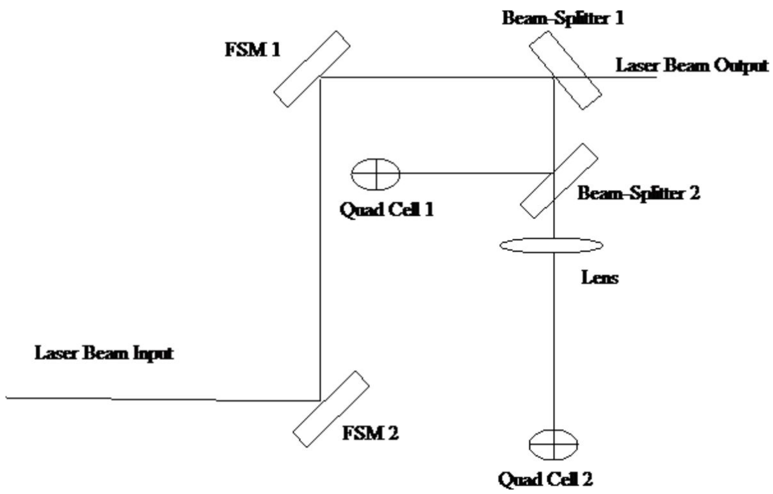


Figure 4. Dual FSM Beam Stabilizer

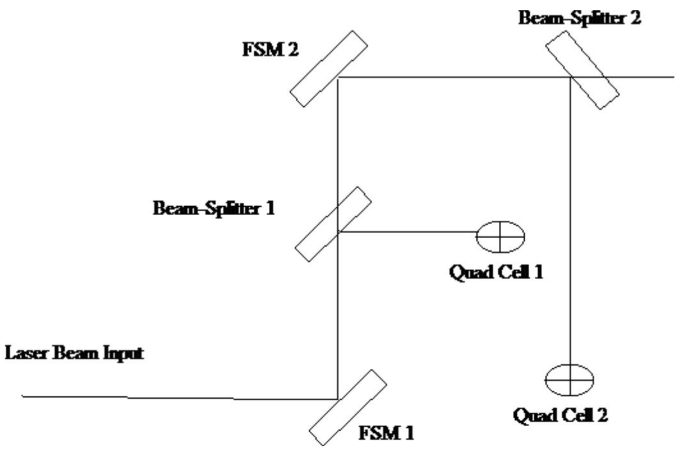


Figure 5: Alternate Dual FSM layout

The alternate dual FSM beam stabilizer shown in figure 5 uses two beam-splitters, and two quad cells. The distance from FSM 1 to FSM 2 is equal to the distance from FSM 1 to Quad Cell 1. This insures that the beam is stationary on the surface of FSM 2. An additional beam-splitter samples the beam and sends it to Quad Cell 2. FSM 2 removes the angular beam error. The advantage of this layout is that it does not need a lens, but the main beam has to pass through two beam-splitters.

Beam Stabilizer Performance Analysis:

(under construction)

Example:

If the PSD were a lateral effect cell, assume a UDT

Quad cell size is 2 mm, focusing lens is 500 mm.

The angular range is 2/500 or 4mrad. (or +/- 2mrad).

If the beam moves outside the angular range of the quad cell the stabilizer will become open loop and will not function.

The angular resolution is more difficult. First, it depends on the spot size on the quad cell. The other factors are the detector noise, and the electronic noise in the quad cell electronics.

See the "Beam Stabilizer Users Manual" for more information and getting started notes.

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