A 4 quadrant photo detector for measuring laser pointing stability

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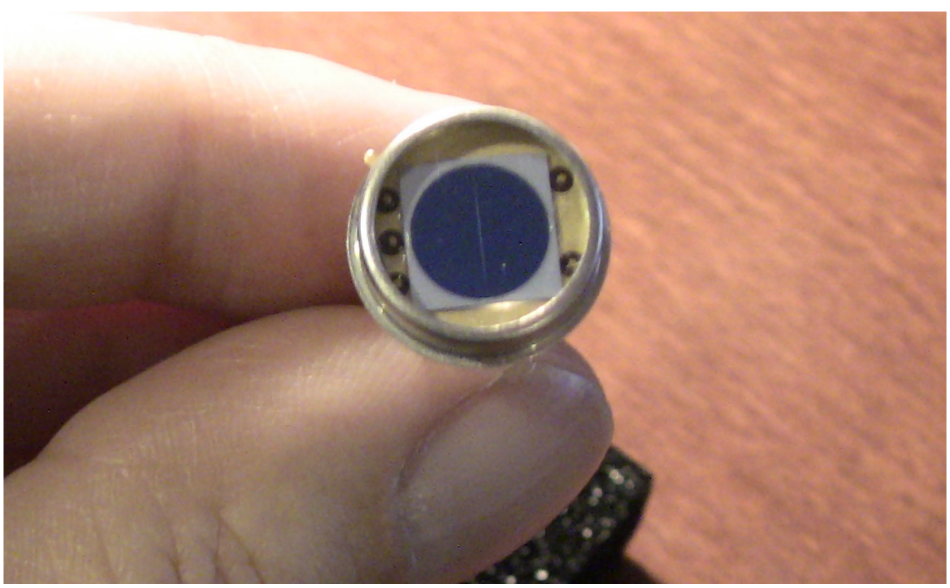
Introduction

Beam pointing stability is an important quality of a laser. Angular drift in a laser beam can be a serious concern in interferometer experiments where such drift can cause anomalous fringe shifts, skewing results. We describe herein a 4 quadrant photo detector we constructed for measuring angular beam drift in a HeNe laser system. We then examine the degree to which the exit angle of a couple of HeNe laser tubes drift over the course of hours to days, and what are the underlying causes of this drift.

The 4 Quadrant Photodiode Principle of Operation:

The photodiode unit consists of 4 separate P on N silicon photosensitive surfaces separated by a small gap, as shown in Fig. 1. In our device this gap is 42 um. The laser beam is usually pointed towards the dead center between the 4 quadrants and the beam diameter is selected to fit inside of the total quadrant area. Although light falls on all four quadrants, the difference between the left and right quadrants (X output) and top and bottom quadrants (Y output) can be adjusted to zero by centering the beam, whereas the SUM is at a maximum. The device X and Y output voltages thereby become very sensitive to slight deviations in the position of the beam from this initial centered setting. The SUM value on the other hand can be used to measure changes in the beam intensity, so this can be used to correct the X and Y output values for voltage changes that are due to intensity fluctuations rather than actual beam deviations.

Fig. 1: A 4-Quadrant Photo detector from First Sensor (formerly Pacific Silicon) QP50-6-TO8



In order to present the outputs of the 4 quadrants as X, Y and SUM, it is necessary to first amplify the individual quadrant outputs, and then combine them using a series of sum and difference amplifiers (for X and Y) or just a sum amplifier (for the SUM output). The circuit we chose is shown below:

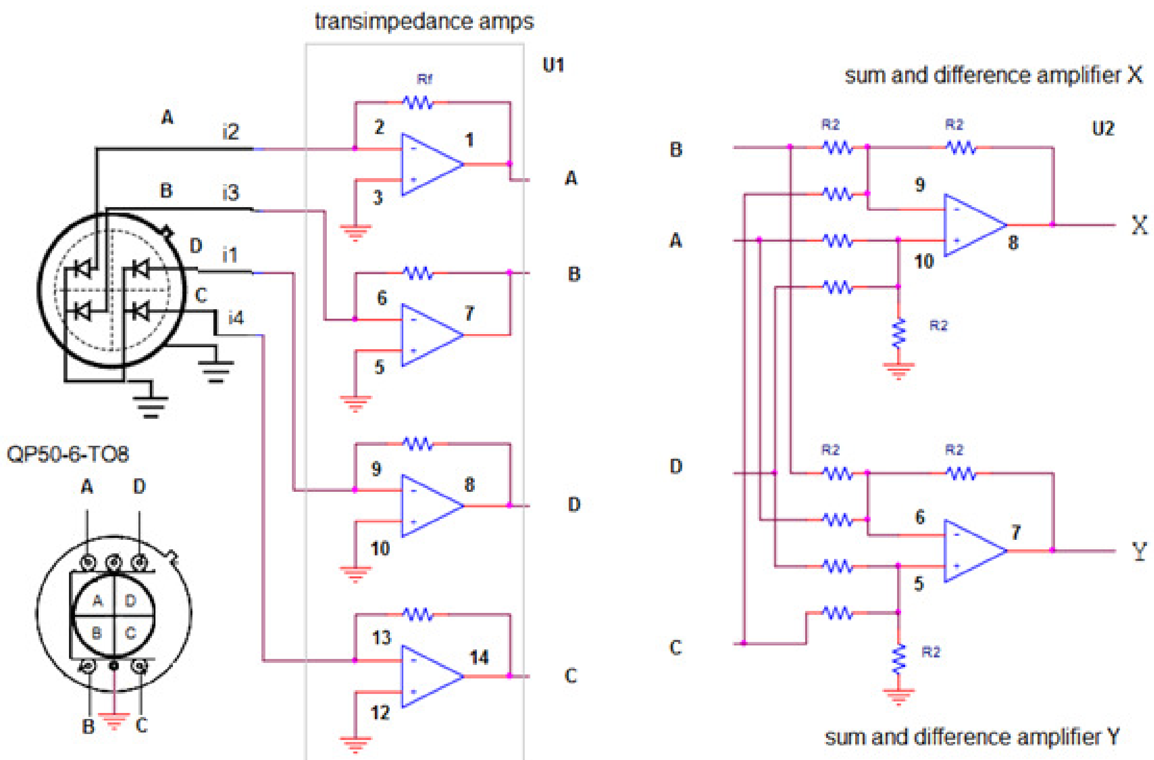
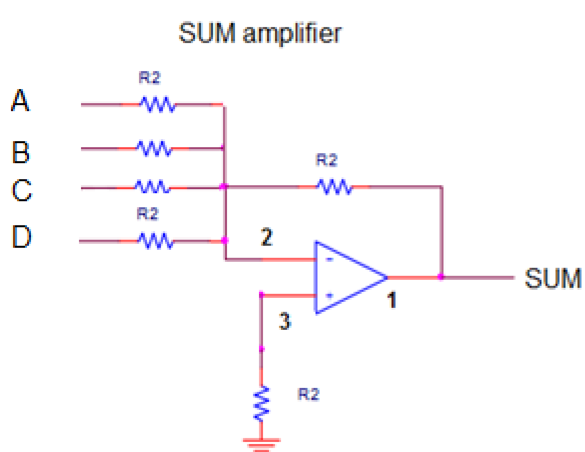


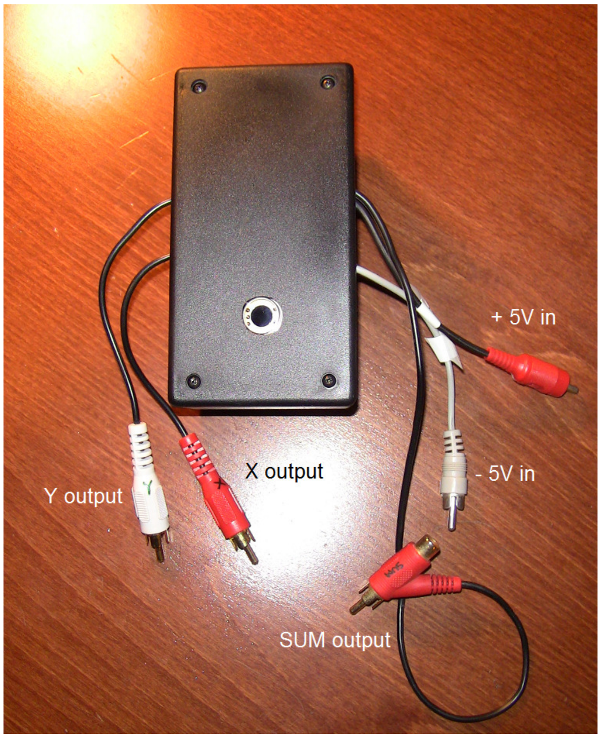
Fig. 2. Signal readout electrical circuit of the quadrant detector.

Rf = 10K, all others = 20K. The op-amps used were the TLC2264 quad type at +/-5VDC operating voltage. The X and Y amplifiers are shown above and connect to the outputs of the transimpedance amplifiers. The SUM amplifier is shown below and also connects to the outputs of the transimpedance amplifiers (A,B,C,D).



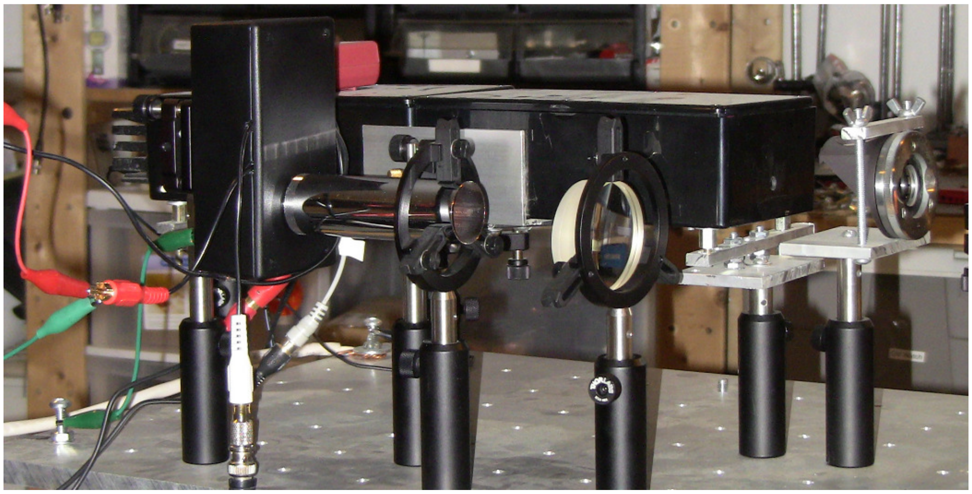
The circuit was assembled and put into a project box as shown in Fig. 3. The back of the box was fitted with threaded screw holes to allow mounting on a Thorlabs KM100B kinematic mount.

Fig. 3: The completed 4–Quadrant Photodetector showing the amplifier output leads



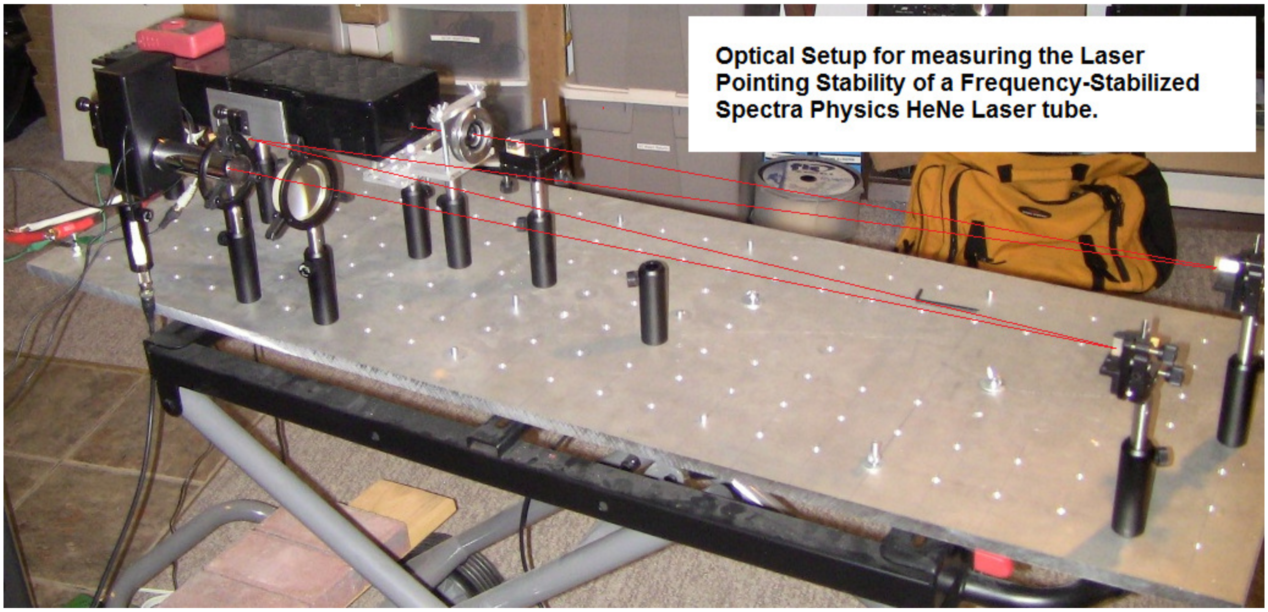
Once completed, the device was screwed onto its kinematic mount and placed on an optical breadboard as shown in Fig. 4. A metal shroud was mounted in front of the detector window in order to shield it from the room lights. A lens was also used to focus the laser beam from the HeNe source to a suitable size to fit inside of the quadrant area.

Fig. 4: Close-up of the detector on the optical breadboard.



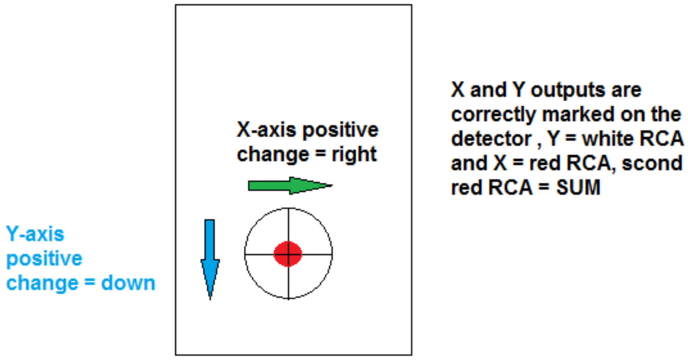
In order to make the drift angle as obvious as possible, the path length from the laser to the quadrant photodiode was made around 2.5 meters long by bouncing the beam between a series of mirrors. This is shown below in Fig. 5. A polarizing beam splitter was used at the beginning to select out a single polarization of the beam for study.

Fig. 5:



Finally, a 3 channel voltage data logger was used to sample the photodiode outputs every minute and to send these data samples directly to an Excel spreadsheet for later plotting. This data logger is similar to the one described in the article here. Briefly, it uses a PIC16F777 microcontroller and three A/D channels to collect the X, Y, and SUM data, which are converted to ASCII voltage values and sent directly to an Excel spreadsheet using the Parallax freeware program PLX-DAQ. The convention for the drift direction and the polarity of the data output is shown below:

Fig. 6: Arrows show how to interpret the X and Y voltages as a beam drift direction.



Part 2: Measuring Actual Beam Drift in HeNe Laser Tubes

Before presenting the data collected using the quadrant detector, let's first establish some conventions about how these specific lasers operate. We are using two custom built HeNe lasers that are frequency-stabilized using a heating coil wrapped around the laser tubes that is controlled based on the intensities of the two modes in the waste beam. The lasers are described in detail here. In brief, the lasers are interfaced to an electronic circuit which attempts to lock the position of the two laser modes, one vertical and one horizontal, at some position along their gain curve. The laser circuit is controlled by a potentiometer which can be adjusted to increase or decrease the amount of heat applied to the tube, and thereby move the modes up and down the gain curve. This process is monitored on a voltmeter mounted on the laser enclosure that can be adjusted using the potentiometer from +5VDC to -5VDC. At +5VDC, the vertical polarization mode is at the center of the gain curve (maximum output), and the horizontal mode is pushed to the far side (minimum output). At -5VDC the situation is reversed – the horizontal mode is near the center of the gain curve and the vertical mode is pushed to the side. This operation can be shown graphically below: **Fig.7:**

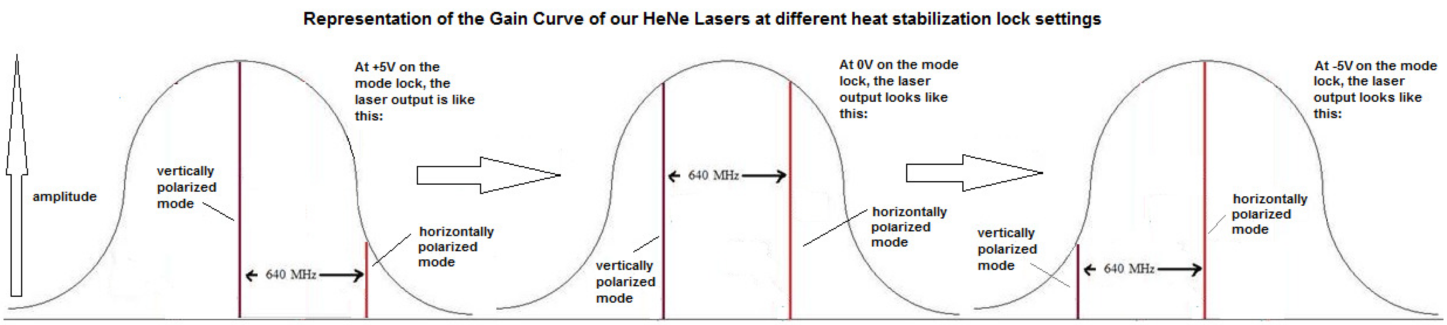
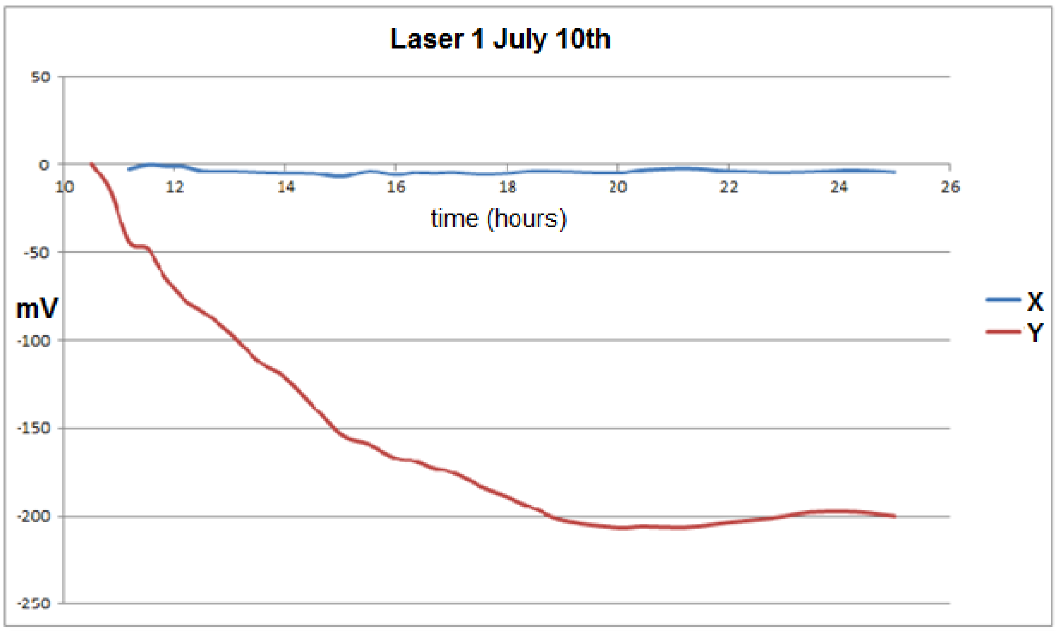


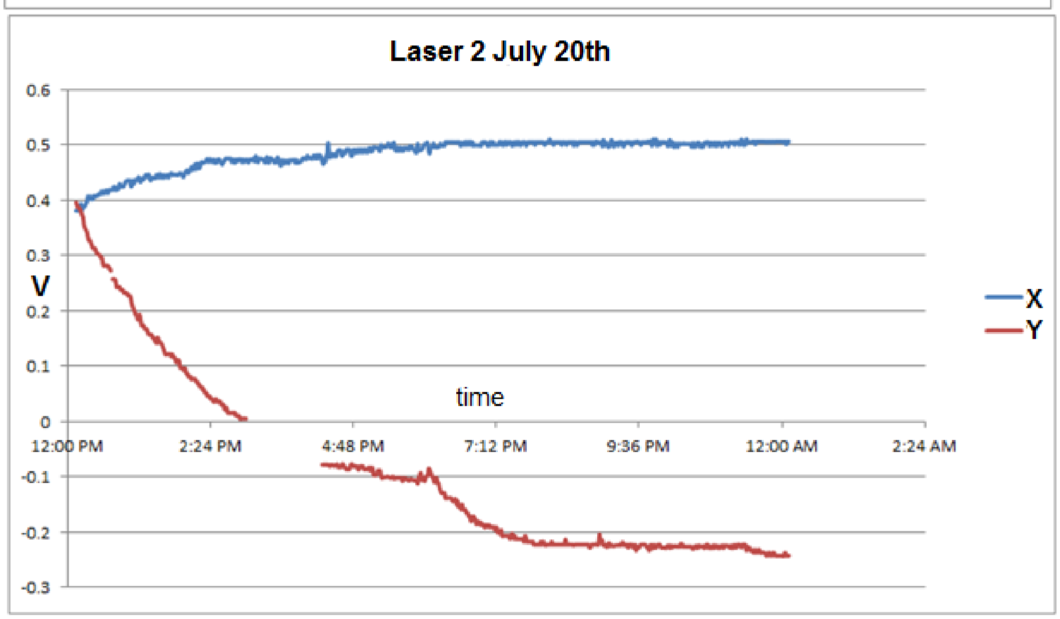
Fig. 8: Picture of the laser potentiometer control and the voltmeter on the enclosure.

Example Drift Data from the Frequency Stabilized Spectra Physics HeNe Tubes

Some data examples are shown below for two different Spectra Physics HeNe tubes (herein referred to as 1 & 2) – both lasers exhibited similar deviations of the X and Y axis alignment over the first 12 hours after cold start-up. Lasers were turned on at 9 and 10 AM respectively, allowed 90–120 minutes to warm up, put on mode lock, and then the drift measurements were initiated. In both cases horizontally polarized laser light alone was measured at the detector and the lasers were locked with the horizontal mode at less than the amplitude of the vertical mode at ~+1v setting on the lock voltage - see description above.

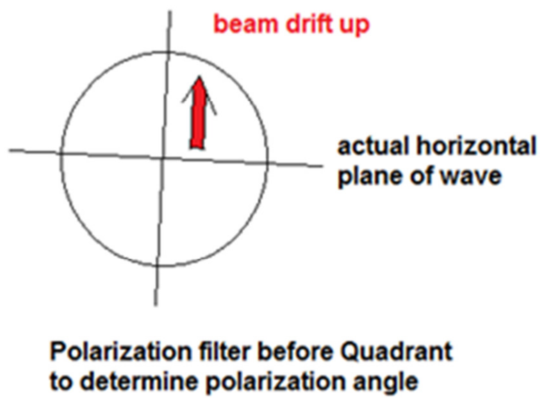
Fig. 9: Drift of the horizontal mode from HeNe Laser 1 and 2 over 14 hours:





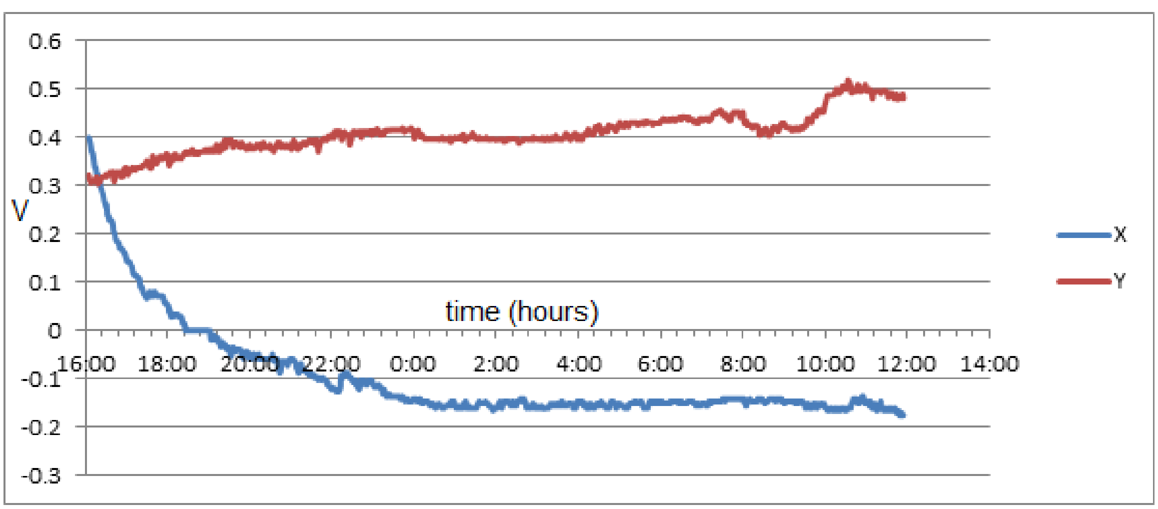
To determine the polarization sense and angle, a polarization filter was placed in the path to the quadrant detector and adjusted until the SUM went to zero. This showed that in the case of laser 2, for example, the horizontally polarized beam was slightly off the exactly parallel to earth horizontal. The beam drift appeared to be predominantly vertical and normal to the plane of polarization – however, due to this slight misalignment to earth horizontal, the data for laser 2 also showed a drift slightly to the right (X-axis positive drift) and predominantly up (Y-axis negative drift) as can be seen in the lower part of Fig. 9. This is shown diagrammatically below.

Fig. 10:



This process appeared to be a long term stabilization pattern for these Spectra Physics HeNe tubes which usually stretched over 8 hours or more. This often ended in a lessening of the drift, but in some cases then developed into more chaotic patterns of smaller amplitude. When the vertical polarization mode was selected instead, the pattern of X and Y change was reversed. This is shown below in Fig. 11. Again, most of the drift occurs in the first 8-10 hours after starting up the laser. Lock voltage was ~+1v.

Fig. 11: Drift of the vertical mode from HeNe laser 2 following cold start-up over 20 hours.



The vertical mode of the beam appeared to drift normal to its plane of polarization as shown below, which was off slightly from the earth vertical and predominantly to the left:

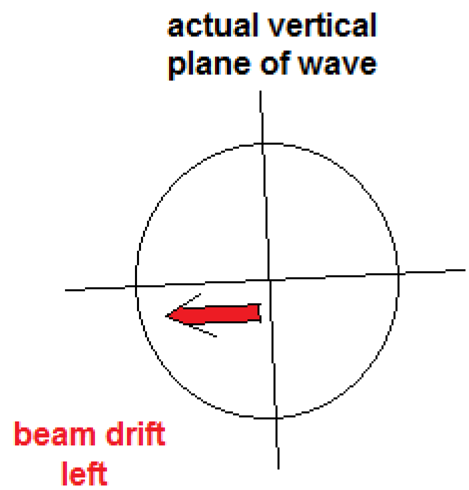
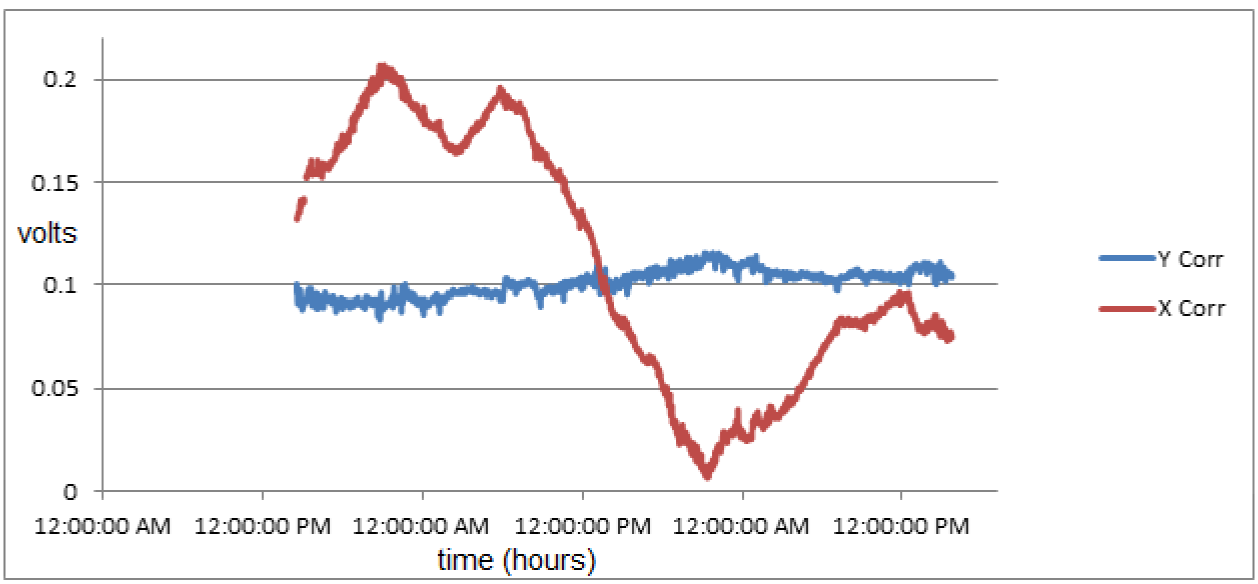


Fig 11B: Temperature-related drift in the beam angle.

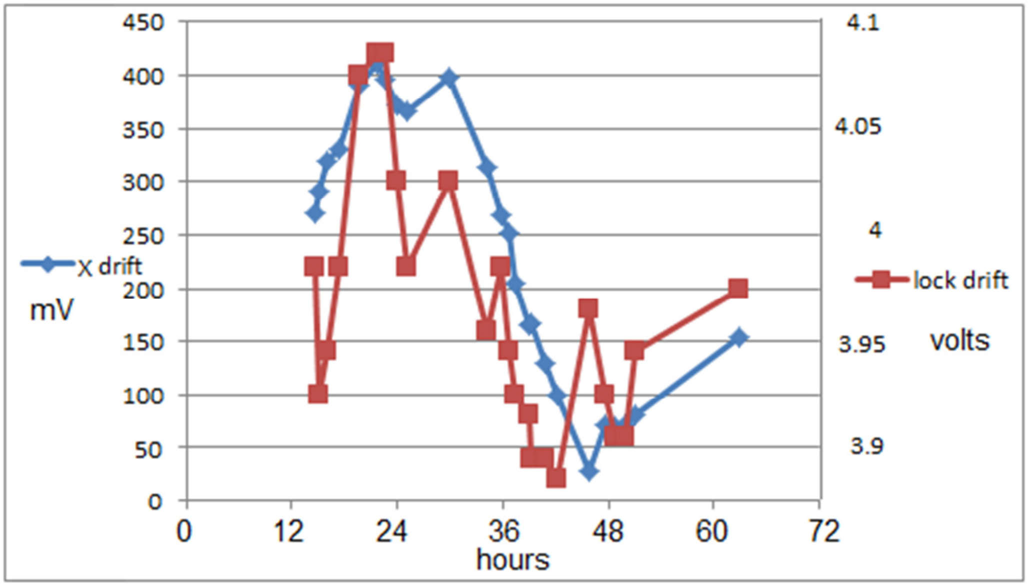
It was observed on at least one occasion that long after the initial warm up stabilization period of 10 hours, smaller amplitude drift patterns would emerge such as shown below in Fig. 12.

Fig. 12: Small amplitude drift after initial stabilization of the tube.



It was observed that this drift followed a similar pattern to the spontaneous drift of the mode lock voltage on the laser, as is shown in Fig. 13 below. This was after correcting for intensity changes by normalizing to the SUM values of each reading. Since the mode lock voltage is a composite of the combined waste beam intensities of the two modes, if the mode lock voltage is drifting then this means that the modes are also drifting along the laser gain curve, and it is this change which appears to be causing the laser beam to change its output angle by a small degree.

Fig. 13: Comparison of long term X-axis beam angle drift to laser lock voltage drift



The ultimate cause appears to be long term changes in room temperature affecting the length of the HeNe tube. Although the HeNe laser tubes are temperature stabilized, this stabilization is floating with respect to the ambient temperature in the room, and any significant change in room temperature then puts pressure on the stabilization system to move to a new lock level, which subsequently leads to a new position of the two modes along the gain curve of the laser. This move along the gain curve then results in a change in the exit angle of the beam, which is detected in our 4-quadrant photodetector data. In order to attempt to prove that the movement of the modes along the gain curve actually affects the beam output angle, we initiated a series of tests using a 4 channel data logger to monitor the changes in the X, Y and Sum values on the quadrant detector, concurrently with changes in the lock voltage. Sampling was performed 35 times per second on each channel. In these tests the laser LOCK switch was left off, and the laser was started from cold and the modes were allowed to drift back and forth along the gain curve, which they normally do in the first hour or more after cold start. This is shown below in Fig. 14. The freely swinging voltage on the voltmeter is displayed in green, showing the swing of the modes. The blue data is the drift along the X-axis (after correcting for the intensity changes using the Sum values) and the red data is the drift along the Y-axis after applying a similar correction. The resultant data appears to imply that the laser beam is in fact drifting repeatedly in both the X and Y directions as the modes sweep along the laser gain curve, the greatest change occurring for the horizontal mode when it is farthest from the center of the gain curve. This is seen as spikes down from the blue and red lines in Fig. 14 that line up with +5V on the voltmeter. A similar pattern is seen when the sampling is longer as shown in Fig. 15 – the beam pointing oscillation is then modulated by a longer range drift pattern, possibly due to room temperature changes.

Fig. 14: Apparent oscillation of beam position in X and Y due to mode cycling (5 minute sample):

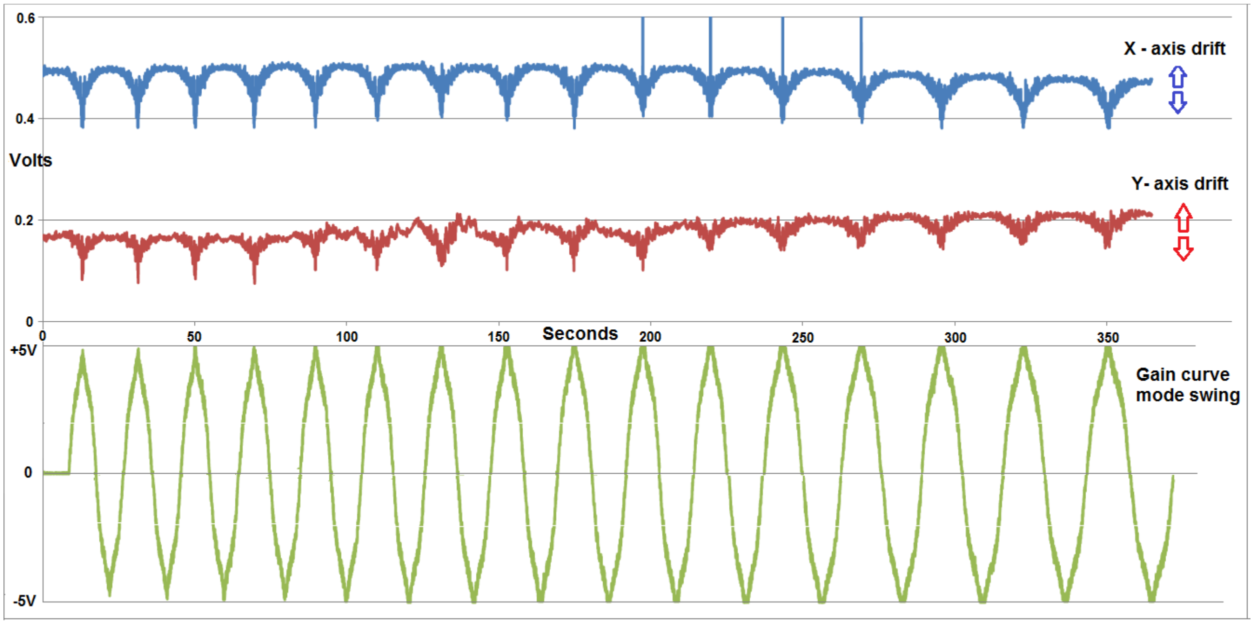
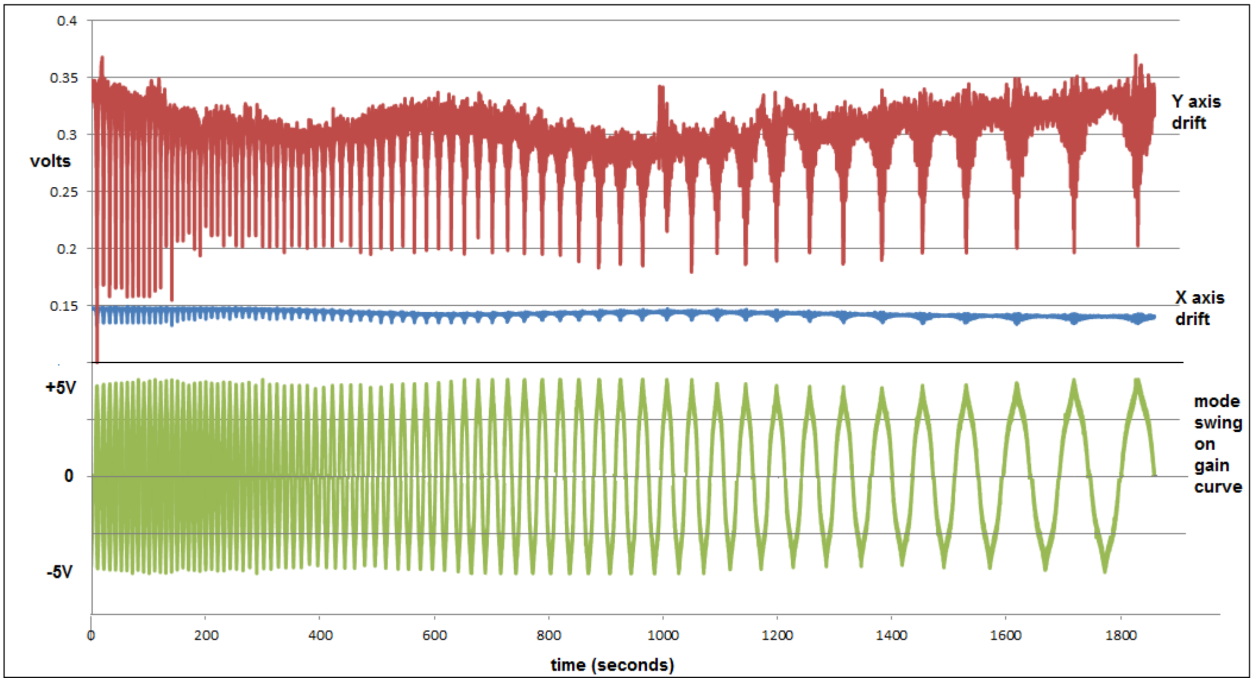
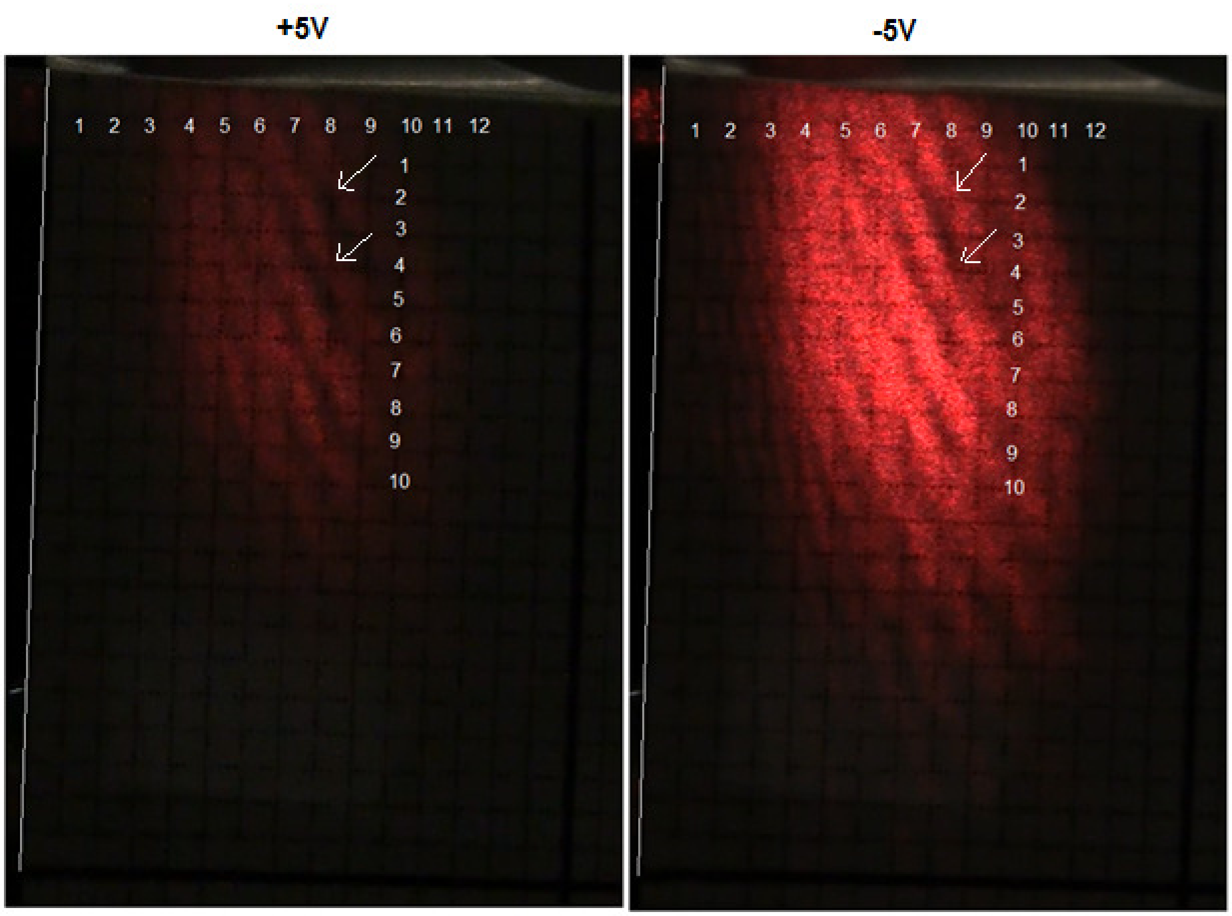


Fig. 15: Same oscillation of beam position, now over 35 minutes:



To further verify that mode cycling actually causes the beam to oscillate in its output angle slightly, a final experiment was performed to attempt to capture this phenomenon on video. Shown below is an excerpt from this video showing the HeNe laser beam (horizontal polarization) projected onto a screen after following a 2.5 m path with a number of mirror reflections. Due to the multiple reflections along the path, the beam is quite expanded and has some static interference lines in it which can be used as a reference for the movement of the beam during mode cycling. As can be seen from the figure below, at +5V on the voltmeter (left hand image), the horizontal mode is weakest and it is at the side of the gain curve, so the beam intensity is low. At -5V (right hand image) it is strongest in intensity due to it being near the center of the gain curve. By examining the interference intensity at the arrows in (left vs. right) it is clear that the interference lines have moved from one state to the other by around ¾ of a fringe – in the video, this shift occurs once per mode cycle.

Fig. 16 – Excerpt from video showing beam drift during mode cycling.



So all of this evidence (Fig. 13 – 16) seems to support the idea that as our HeNe laser modes travel along their gain curve, that the output beam angle also changes slightly. The video evidence would suggest that the beam drift is on the order of a fraction of a mm at 2.5 meters from the laser tube.

Summation

We have sought in this article to describe the construction of a 4 quadrant photodetector circuit and apply it to examining the patterns of beam angle drift in two frequency-stabilized HeNe lasers that we had on hand. Surprisingly, the lasers do drift noticeably as readily detected in the changes in the X and Y axis voltages on the detector. The primary source of the drift appears to be a mechanical relationship of the beam angle with the position of the laser modes along the laser gain curve. As the modes move along the gain curve, generally due to a change in temperature and thereby a change in the length and/or shape of the laser tube, each mode component of the beam drifts in its exit angle. The amount of drift and direction is somewhat variable and depends on the conditions under test, but is generally on the order of a fraction of a mm at 2.5 meters out from the laser for a full mode sweep along the gain curve. Further, the amount of angle change of the exiting mode component of the beam appears to be highest when the mode is at one or the other far side of the gain curve. Applying frequency stabilization to the laser by using a heating coil wrapped around the tube appears to only dampen this drift, and this is likely because the temperature control of the tube is floating with respect to room temperature. A proposed remedy for stabilizing the beam angle would thereby be to further enclose the lasers inside of a second enclosure that regulates the air temperature to a very narrow range. Combined with the primary stabilization heating coil, this method should insure that the laser maintains a constant beam angle at all times and that the laser lock voltage remains fixed to its original set value.