Evaluation of Scientific Solutions Liquid Crystal Fabry-Perot Etalon

Testing of the etalon was done using a frequency stabilized He-Ne laser. The beam from the laser was passed through a spatial filter and collimated, producing a parallel beam. The aperture in the spatial filter was 15 microns in diameter and the collimating lens was 100 mm focal length, resulting in a beam divergence of 150 μradian. The collimated beam was passed through two polarizers. The last polarizer set the polarization for the liquid crystal etalon and the first polarizer was used as an intensity control. The etalon was adjusted in tilt so that a reflected beam from the first cavity surface coincided with the incident beam, thereby ensuring that the beam was applied normal to the etalon. After passing through the etalon, the light was focussed onto an aperture in front of a PMT. Further light reduction was provided by two thicknesses of card stock located behind the entrance aperture. This enabled us to use either the red He-Ne laser or the green Nd:YAG alignment laser, and the combination of small aperture and light reduction by the card stock protected the PMT from the possibility of room lights being turned on while the PMT was powered.

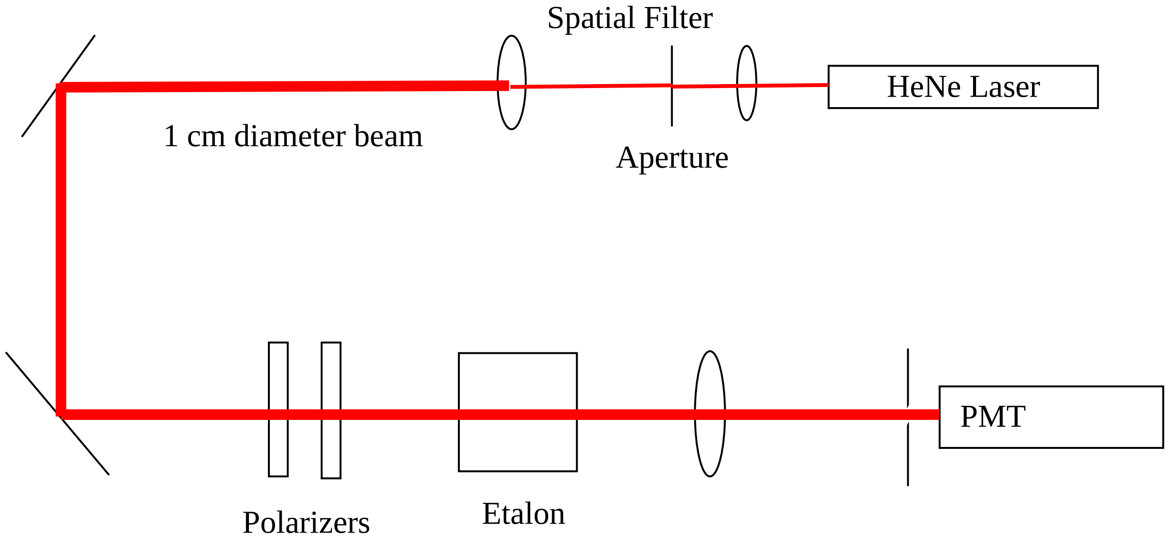
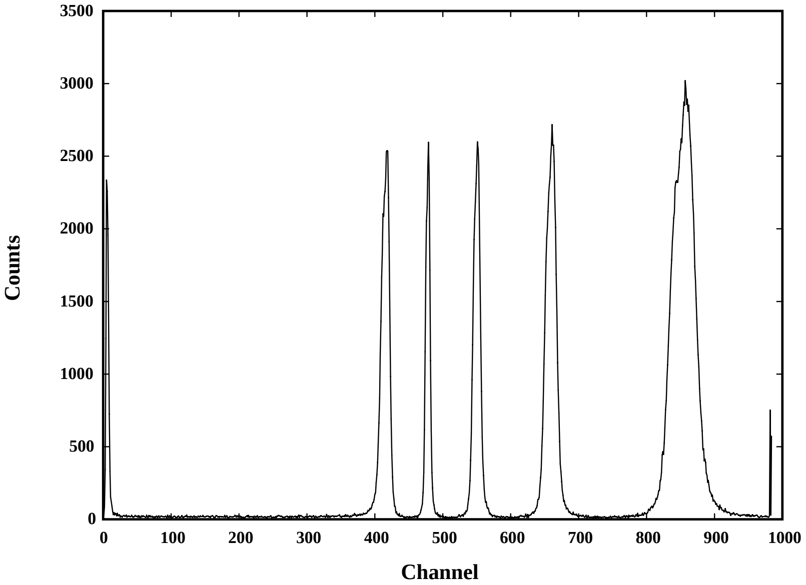


Figure 1: Test Setup

Scanning for the etalon was provided by a virtual arbitrary waveform generator in LabView. This virtual instrument was a part of the LabView example package and generated a 1000 point waveform which could be set to standard waveforms such as a square wave or a sawtooth (ramp) or any other function could be loaded from an external file. We used a ramp, which was adjustable in amplitude and offset voltage. The virtual instrument had two channels, so we used the second channel to output a pulse at the beginning of the scan to trigger the multichannel scaler which recorded the pulses from the PMT.

The first tests were simply putting a 0-5 volt ramp into the etalon and looking at the PMT output. This enables us to look at the overall linearity of the scan and allows us to choose the most nearly linear region for further study. In the figure at right, 5 orders can be seen in the scan. The peaks on the left and right edges of the figure are transients which are not a part of the etalon response. It is apparent that the wavelength response of the etalon is nonlinear. An attempt was made to fit the positions of all five peaks to a polynomial function in order to establish an algorithm to linearize the voltage scale, but this was largely unsuccessful. The first and last peaks are broadened, from which it can be seen that the response is most nonlinear at the edges of the scan. Limiting the scan to the three peaks in the center was more productive and allowed us to approximate a linearized scan more easily.



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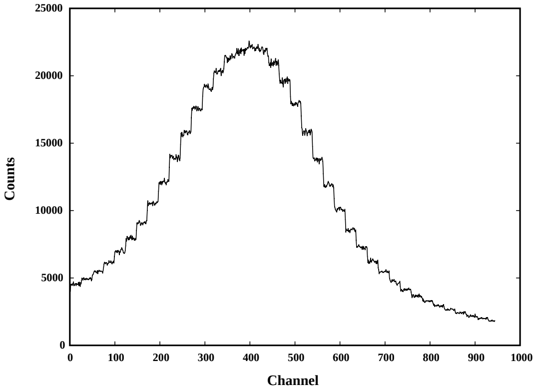
A range of voltages was found that would generate a scan of the center 3 peaks and the system was run overnight. The resulting data were analyzed for peak position and large drifts were found. On inspecting the system it was found that the temperature control was not operating. The initial solution was to replace the cable from the temperature control to the etalon housing, since the cable had been pulled off the system accidentally some time previously. This worked sporadically, but was sensitive to motion of the cable. The system was returned to SSI, where new connectors were installed on the etalon housing. This worked for a while, but the temperature control finally quit altogether. It was found that the commercial temperature control module was defective and the entire drive electronics box was replaced. This stabilized the temperature. The temperature control has an output jack where the thermal sensor voltage can be read. This voltage remains fairly constant, although the voltage can be increased (corresponding to a temperature decrease) by air motion around the etalon housing.

When we tried to do a long run using only two peaks, we got a bimodal variation of the peak position. Putting an oscilloscope on the output of the ramp generator we found that the system would occasionally break into oscillation. When oscillating, the effective scan voltage was changed, resulting in a different set of peak positions. It appeared that the coaxial cable between the ramp generator and the etalon drive electronics was too long. Placing a resistor in series with the ramp generator appeared to solve the problem, but introduced a voltage drop in the line. Finally we made a unity-gain op-amp circuit to buffer the ramp generator output.

Another test was performed by generating a scan over a small voltage range covering only the region near a peak. Here we can see the digitizing noise generated by the 12-bit D/A converter which generates the scan. The effective bit count was raised by dividing the output of the D/A converter by 4 and using a larger voltage scan to compensate.



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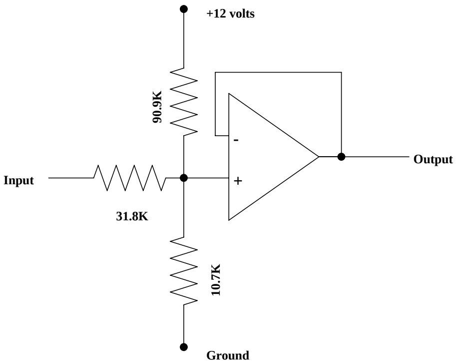
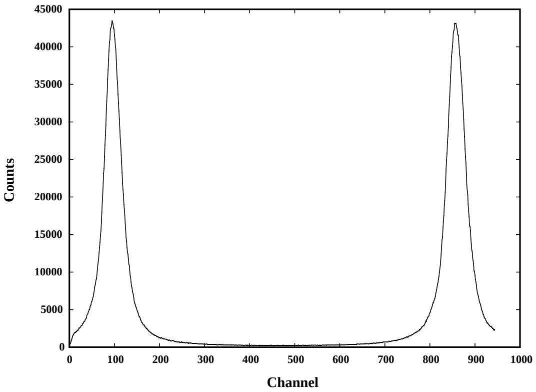


The diagram at left shows the circuit used to buffer the LabView ramp and divide the voltage by 4. It is a common resistive divider and a unity gain buffer amplifier. The 90.9K resistor to +12 volts was added to provide a DC offset to the output voltage. This was required because the drive circuit for the etalon requires a minimum of 1.5 volts before it reaches the first transmission peak, and this voltage would not be reached with a 5 volt ramp and a gain of 0.25.



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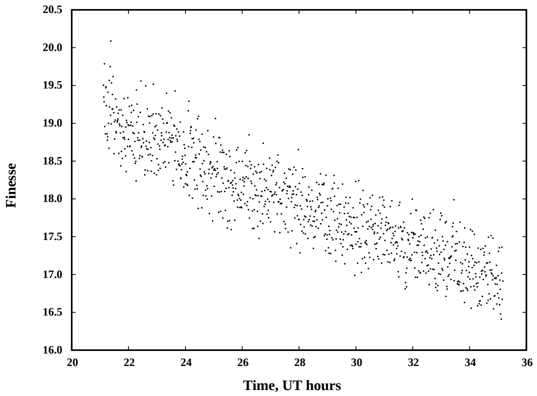
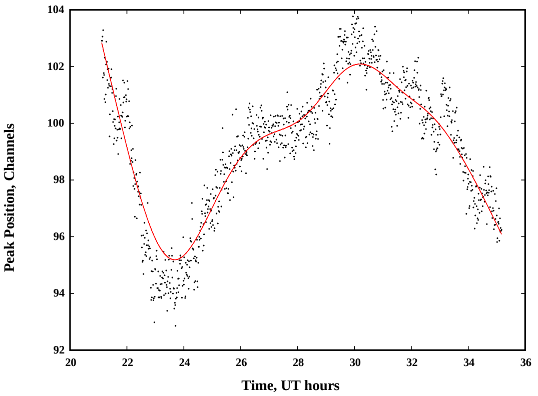
On the right is a typical scan using the frequency stabilized HeNe laser and covering two peaks. The finesse of this profile (ratio of line separation to full width at half maximum, a measure of resolution) is about 20. This is a moderately high number and is primarily caused by the small divergence of the beam passing through the etalon. The divergence of the light at the lidar receiver will be the same as the divergence of the laser output, or about 500 μradian, which is about a factor of 3 larger than the beam used in the test. Consequently, we expect the effective finesse of the final system to be smaller than that measured here. However, the higher finesse allows us to resolve smaller variations in the line position. The multichannel scaler was operated here with a 0.050 second dwell time.

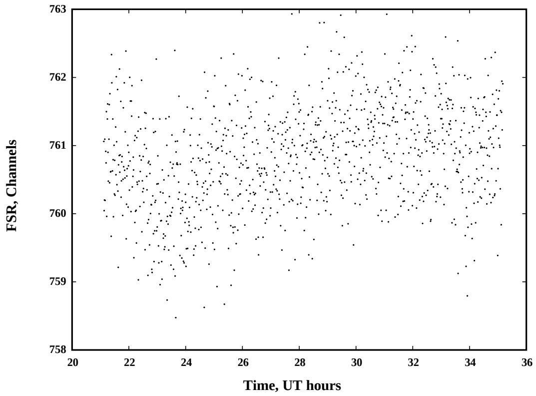


990826 Finesse



990826 Peak Position

An overnight run of the system at this point is shown here. The data were read into a program which found the peak positions and widths from the data and wrote the resulting numbers to a data file. On the left is the finesse as a function of time and on the right is the position of the first peak in the scan (third peak in the overall scan). The decrease in the finesse was traced to a gradual relaxation of one of the etalon separation pins, which were adjusted just prior to the overnight run. The etalon occasionally shows such a finesse change, but it is normally rapid, taking only an hour or two to reach equilibrium. Most of the long runs show no such change. The position plot shows some variation in the position with time. The solid line through the points is a running average with 2-hour hanning weighting. The RMS deviation of the points about a constant value is 2.45 channels, while the RMS deviations of the points about the solid line is 0.82 channels.

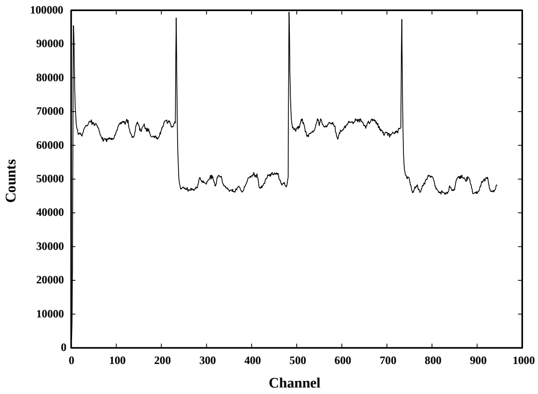


990826 Free Spectral Range

From the same run, the plot on the left shows the free spectral range of the etalon through the run. From the variations of the position and the free spectral range, we can find the stability of the system expressed in velocity units. Using light with a 532 nm wavelength and an etalon with a 1.5 cm effective gap, we have n = (2 * 1.5 cm) / 532x10^{-7} cm = 56391 as the order of interference of the FP etalon. Consequently, a free spectral range corresponds to c/n = 5320 m/sec. In the above examples, the free spectral range is 760.8±0.8 channels. A drift of 2.45 channels therefore corresponds to 5320 m/sec * 2.45 / 760.8 = 17 m/sec. This represents the long-term drift of the system. The short-term drift can be characterized by the variations about the running average, or 5320 * 0.82 / 760.8 = 5.7 m/sec.

These numbers represent the overall drift of the system, which includes the etalon, the laser and the scanning system. It is not known how much the temperature of the system affects the peak position although the fact that it does affect the position was seen by the large drifts in the early tests. The laser stability is assumed to be good. Measurements on the laser around 1989 showed line positions to be repeatable with an RMS variability on the order of 5-7 m/sec, although much of that was statistical uncertainty in the peak position calculation. The scan voltage difference between the two orders is about 0.32 volts, so a variation of 17 m/sec could be caused by a variation in the scan voltage of about 0.001 volt. It should be noted that the LabView system uses a 12 bit A/D converter running in a ±5 volt range, so the individual voltage steps are 0.0024 volts. This is divided by 4 in our buffer circuit, so the resolution of the drive system is equivalent to about 8 m/sec. Other possible sources of voltage variation include the power supplies running the buffer amplifier and the etalon driver system. The etalon driver shares a power supply with the etalon heater, so even though the power supply is a linear regulated supply, load variations could produce millivolt power changes. The buffer amplifier should be resistant to power line variations since it is a unity gain configuration with lots of negative feedback, however the DC offset from the 90.9K resistor is directly dependent on the power supply voltage.

The only way we have to check to see if the laser was the source of any of the drift was to use a different laser. We did this, although the alternative laser was of the same make and model. No difference in the drift was apparent.



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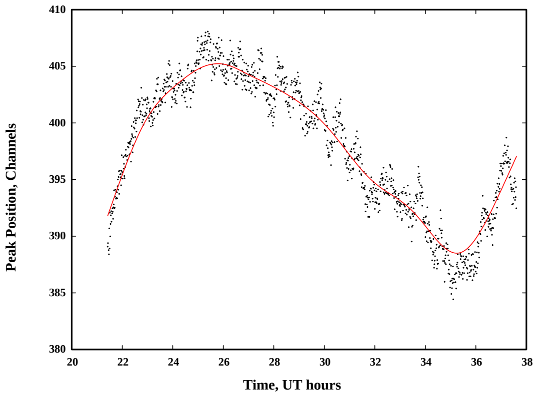
Another test was run using a two-point scan rather than the ramp. In this test the LabView function generator was set to a square wave with the amplitude and offset voltages adjusted so that the two points straddled a peak. The variations observed in this test were similar to those observed in the prior test. However, the system showed very short term variations during individual scans while the drive voltage was (supposed to be) constant. The figure on the left shows a typical scan within this data run. Two cycles of the square wave were applied to the scan drive. The transients seen here between voltages are caused by the finite time response of the etalon to a change in voltage and show that there is a peak between the two voltage levels. The small variation at constant voltage level is about 3000 counts RMS. This compares to a 10^5 count level at the transmission peak of the etalon, or 3%. Approximating the transmission profile by a gaussian, we can calculate an effective velocity corresponding to this counting variability. Assuming the form of the gaussian is $y = A\exp\left[-\ln(2)\left(\frac{(x-x_0)}{\delta x}\right)^2\right]$ where δx is the half width at half maximum, x0 is the center of the profile and A is the peak height, the variation of the response with velocity is given by the difference in the derivatives at the two half power points. If we assume that the two points are chosen to be equidistant from the center of the line so that the derivatives differ only in sign (by symmetry), the count variation will be given by $\Delta y = \frac{dy}{dx}\Delta x = -2\frac{(x-x_0)\ln(2)}{\delta x}A\exp\left[-\ln(2)\left(\frac{(x-x_0)}{\delta x}\right)^2\right]\Delta x$.

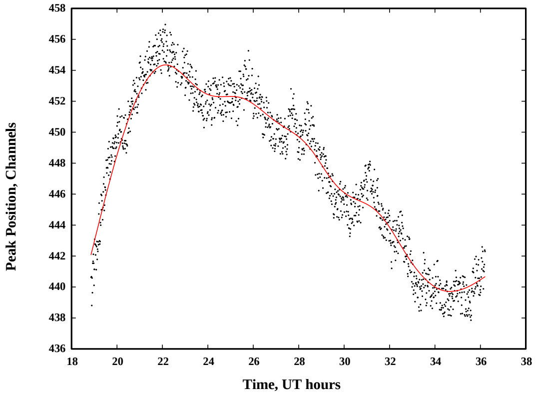
Evaluating this expression for the above case gives about 7 m/sec equivalent for the variation of 3000 counts seen in the figure.



990830 Peak Position

In discussion with SSI personnel, several suggestions were made to try to isolate the source of the variability. First, we changed the voltage divider on the scan buffer amplifier to a factor of 8 instead of 4, and increased the scan voltage accordingly. We also decreased the sample rate to a dwell time of 0.025 seconds and increased the scan length to 1950 channels. The results of an overnight run under these conditions is shown in the figure on the left. The RMS variation of the peak position about a constant is 6 channels and 1.5 channels about the smoothed line. The free spectral range here is 1009.8±0.8 channels, so in terms of velocity the long term variability is about 30 m/sec and the short term variability is about 8 m/sec, similar to the previous test.

Since the thermal control showed some variations with air motion, the etalon was wrapped in bubble plastic, leaving a tunnel for the light to pass through to enter the etalon. Another overnight run was performed and the results are shown on the right. Here the RMS variation of the peak position about a constant is 5.2 channels, and 1.1 channels about the smoothed line, for a long term variability of about 27 m/sec and a short term variability of about 5.3 m/sec.



990831 Peak Position

At this writing (990901), the only tests not yet performed are (1) to use a different power supply on the etalon drive electronics in order to check the possibility of the temperature control producing a variation in the power supply voltage, which could then be transferred to the drive voltage; (2) to record the temperature sensor voltage along with the peak positions to see if the variability is thermally driven.

In the course of measuring the peak position drift, a couple of tests were performed to measure the transmission of the etalon. The first test was simply to record some profiles with the laser, after which the etalon was simply removed from the beam path and another profile was acquired under the same conditions as if it were a scan. Using the frequency stabilized HeNe laser, we measured a transmission of 49% of the polarized light. Since the transmission is likely to be a function of wavelength, the test was repeated using the Nd lasers. We first attempted to perform the test using the small diode pumped 3 mW Nd:YIG laser. This was not successful because the light from the laser consisted of a large number of lines which were changing rapidly in intensity (on the order of seconds). We then put the 5 mW Nd:YAG laser into the system. This laser has at least 3 components in its emission, but after only a few minutes of warmup the various elements were fairly stable in intensity, allowing us to obtain a good profile. Using the same technique, a transmission of 78% was measured.

At this point I feel that we have characterized the etalon about as well as it is likely to be characterized. There are now two important questions. First, is this variability small enough to use? Second, is it likely that another system will do any better? The first question depends on the source of the variability observed in these tests: if the source is known, mitigation of the variability could be possible.

The uncertainty in the determination of the peak position is calculated by $\delta P = \frac{\sum_i y_i \left(x_i - x_0\right)^2}{\left(\sum_i y_i\right)^2}$ [Hernandez, *Fabry-Perot Interferometers*, p 57] where δP is the uncertainty in the position, y_i are the counts in channel i, x_i

are the channels and x_0 is the peak position. For the tests performed above, δP is less than 0.05 channel, negligible when compared to the 0.8 channel short term variations observed. Thus the signal levels were high enough that counting statistics are not a factor in the variability. The other possible factors are (1) variations in the laser frequency; (2) variations in the voltage driving the etalon; and (3) variations in the etalon temperature. As mentioned above, previous measurements on the laser did not have sufficient precision to determine the variability to better than about 7 m/sec. The voltage supplied to the etalon driver may be varying with temperature since the same power supply is used for both the drive electronics and the thermal controller. The etalon temperature may be varying somewhat, but this is considered unlikely to be the problem since the variations appear to be less than about 0.02°C. Separating the temperature controller from the etalon driver might be feasible, so we could test that possibility. At this point we should also point out that we don't know the stability of the Nd:YAG laser used in the lidar, so we will have to monitor the variability of that source as well as the etalon. If the variability is comparable or larger, then the observed variations in the etalon are unimportant, and the drifts in the overall system will have to be monitored. If we monitor the laser output with the SSI etalon, this will give us the correction term we will need.

The tough question is whether we can do better. The specifications for the Queensgate etalon are better than the measurements presented above, but between the specs and the performance there are frequently gaps. Without a Queensgate instrument to compare in the same tests, it's a gamble whether or not we could achieve better performance given the same driving sources.

The funding for this etalon is derived from the NSF MRI program, which is designed to fund programs with relatively high risk. The risk in this case is that we have to come up with a system that can monitor the overall drift of the laser/etalon system in such a way that a correction term can be applied.