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ISC Electrooptic Shutter: Angle and Temperature Tolerance

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Detector commissioning & ISC groups

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1 ABSTRACT

We tested a sample ISC electrooptic shutter module (used to protect sensors on the LIGO ISC tables) for tolerance to angular misalignment and for time and temperature drift in preset attenuation. We find the “OFF”-state (zero bias voltage) extinction ratio of about 6 parts in 10^4 is degraded to 1 part in 10^3 if the beam is misaligned by 2 milliradians (about 0.1 degree) and to 2 parts in 10^3 at 3.5 milliradians. With bias voltage set to give either 2% or 50% net transmission (about 350 V and 1850 V bias for the sample crystal, respectively), we find the transmitted power varied by less than 1.5% fractionally per degree Kelvin of ambient temperature change. We conclude that from the standpoint of thermal and angular stability, the EO shutters should perform adequately as controllable attenuators for dynamic range enhancement during interferometer lock acquisition.

Keywords: LSC, ISC, EOS, electrooptic, shutter, lock acquisition

2 MOTIVATION

During lock acquisition on the Hanford 2km interferometer, transient RF photocurrent signals were observed to exceed the dynamic reserve of the LSC photodectors, causing unanticipated nonlinear behavior and preventing acquisition. This was temporarily cured by attenuating the beam, but to recover adequate SNR once lock has been achieved it will eventually be necessary to bring the full quiescent power to the operational detector(s). Running a parallel detector chain which receives a small sample of the beam, and digitally handing off from this to the main detector chain after acquisition, would solve this problem. However this strategy is costly in hardware and uses precious front-end acquisition channels. As an alternative we have proposed using the EO shutters in a continuous-attenuator mode; since the shutters are already required for protection, the incremental cost is lower, and the continuously variable attenuation afforded is potentially more flexible.

This approach could be complicated if the selected attenuation is not stable. While in principle there is enough information available to actively correct for modest variations in the shutter’s transmission by adjusting the actuation voltage, this would further complicate an already complex algorithm. As a result it is useful to establish exactly how variable the shutter transmission is under two of the typical perturbations known to affect electrooptic devices, beam-crystal alignment and ambient temperature.

3 EO SHUTTER DESCRIPTION

ISC electrooptic shutters are provided to protect sensor assemblies on the LIGO interferometer sensing tables (IOT1, ISCT1, etc.) from overpowering and resultant damage during optical transients. In normal operation they are set to be as transmissive as possible (greater than 90% transmission) by applying a DC bias of approximately 3-4 kV. However, on loss of interferometer lock and while waiting to reacquire they may be commanded electrically to very low transmission, typically as low as 10^{-3}, by removing the field. Optionally, the shutters may also be set to intermediate transmission values by continuous adjustment of the bias voltage.

Each shutter comprises a commercial LaserMetrics model 3903-1064 lithium niobate ($LiNb0_3$) Q-switch module, followed by a Brewster-cut calcite polarizer. The module’s clear aperture is 8 mm in diameter. Protective windows supplied on the commercial Q-switch are removed before installation to improve optical efficiency and to reduce opportunities for spurious interference and backscattering[1].

A transverse electric field applied to the crystal rotates the polarization plane of laser light passing through the crystal. In our application, we introduce a linear polarization orthogonal to the transmissive plane of the output polarizer, such that the beam is attenuated if the EO crystal is electrically unbiased. Applying a positive or negative bias voltage rotates the polarization until it is transmitted by the output polarizer; as a result the transmission varies sinusoidally with applied voltage. The so-called “half-wave voltage” is the voltage required for full transmission.

To achieve good extinction in the “off” state and repeatable “on” state transmission, the beam must not only pass through the end apertures of the crystal housing but must also travel parallel to the crystal’s optic axis. Errors in optical path/crystal axis angular alignment cause contamination of the polarization state, leading to a second-order degradation of the transmissive extinction ratio. The proper crystal axis direction may not correspond to perfect centering in both the exit and entrance apertures, due to mounting tolerances. A simple procedure is provided by the manufacturer for aligning to the crystal axis, using scattered light from a diffuser placed at the entrance aperture. This procedure should be followed whenever a crystal is moved or the beam alignment changes significantly; we reproduce it in the Appendix for reference[2]. Note that the IR beam itself, *attenuated to low power*, can be used for alignment in lieu of the separate collinear HeNe probe beam, so long as a reasonably IR-sensitive CCD camera (Watec 902-HS or equivalent), fast lens and video monitor are available for viewing the scattered transmission pattern.

4 EXTINCTION & ANGULAR TOLERANCE

Approximately 100 mW from a Lightwave 126-1064-700 Nd:YAG nonplanar ring oscillator (NPRO) laser at 1064 nm wavelength was collimated to about 2 mm beam diameter at the device position. A calcite polarizer was inserted to ensure a clean horizontal input polarization, and a second calcite polarizer (the “analyzer”) arranged vertically downstream of the EOS under test. With the second polarizer temporarily removed, the power was reduced and the crystal (serial number 2806-4) was installed and rough-aligned to bring the beam through its apertures centrally. The “isogyre” alignment procedure (Appendix 7) was then used to fine-align the crystal axis to the beam direction. A piece of white paper was used as an output screen and was imaged by a Watec 902-HS CCD video camera with 48 mm f/1.4 lens to show the scattering pattern. A short extension ring was placed between the camera and lens to allow close focusing. After fine alignment and reinstallation of the output analyzer, the net transmission of the assembly was about 6 parts in 10^4. This was measured with an Ophir Nova power meter equipped with a PDA-300-3W silicon photodiode head and calibrated attenuator.

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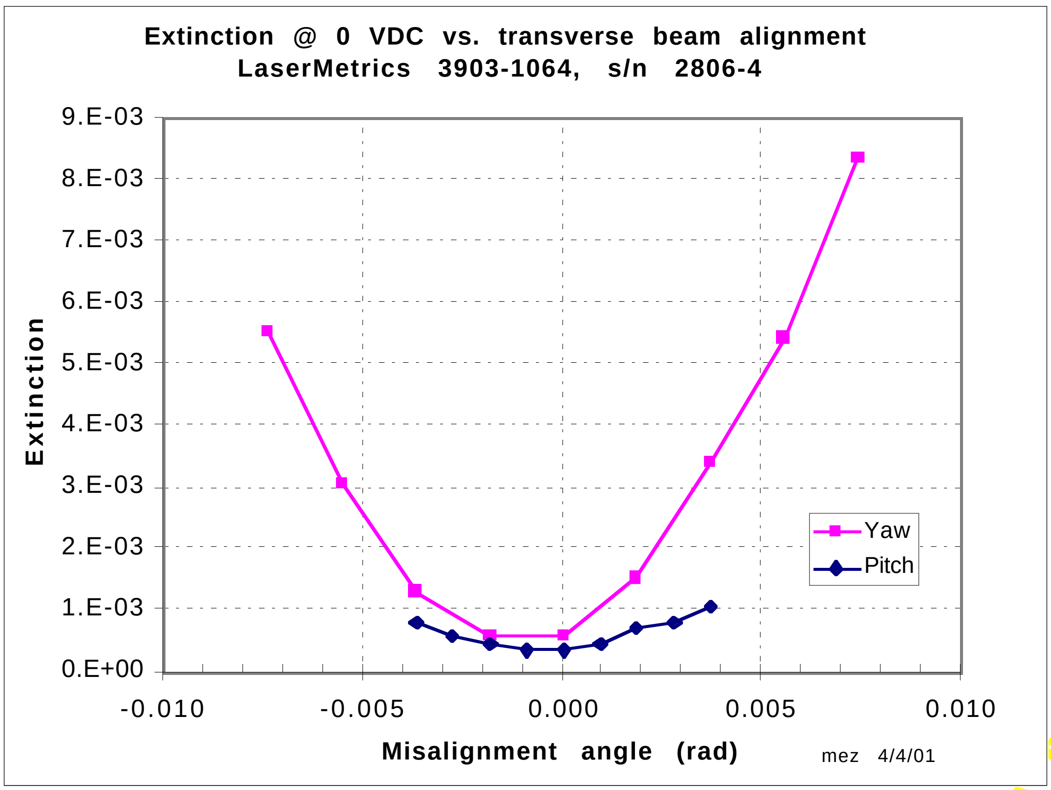
1. This leaves the crystal faces unprotected. While $LiNbo_3$ is not particularly hygroscopic, the high electric field across the cell tends to attract and concentrate dust on the crystal faces. Maintaining strict cleanroom protocol and sealing of the table enclosure is therefore essential to avoid contamination and damage.
2. For a minor misalignment, it may be sufficient to slightly tilt and yaw the crystal to minimize transmission at zero bias voltage, without starting the procedure from scratch. However it is possible to fall into a false minimum, so correct operation should be verified by electrically biasing the crystal through its full transmission range.

Rotating the fine adjustment screws on the modulator mounting stage (New Focus model 9071), and calibrating the resulting stage motions against a dial caliper, allowed us to misalign the crystal from this optimum by known increments[1]. The resulting degradation is depicted in Figure 1. Note that the extinction was much less sensitive to pitch (rotation about a horizontal axis) than it was to yaw (rotation about a vertical axis). Presumably this asymmetry arises from the selection of input polarization (in our case, the incident electric field was horizontal).

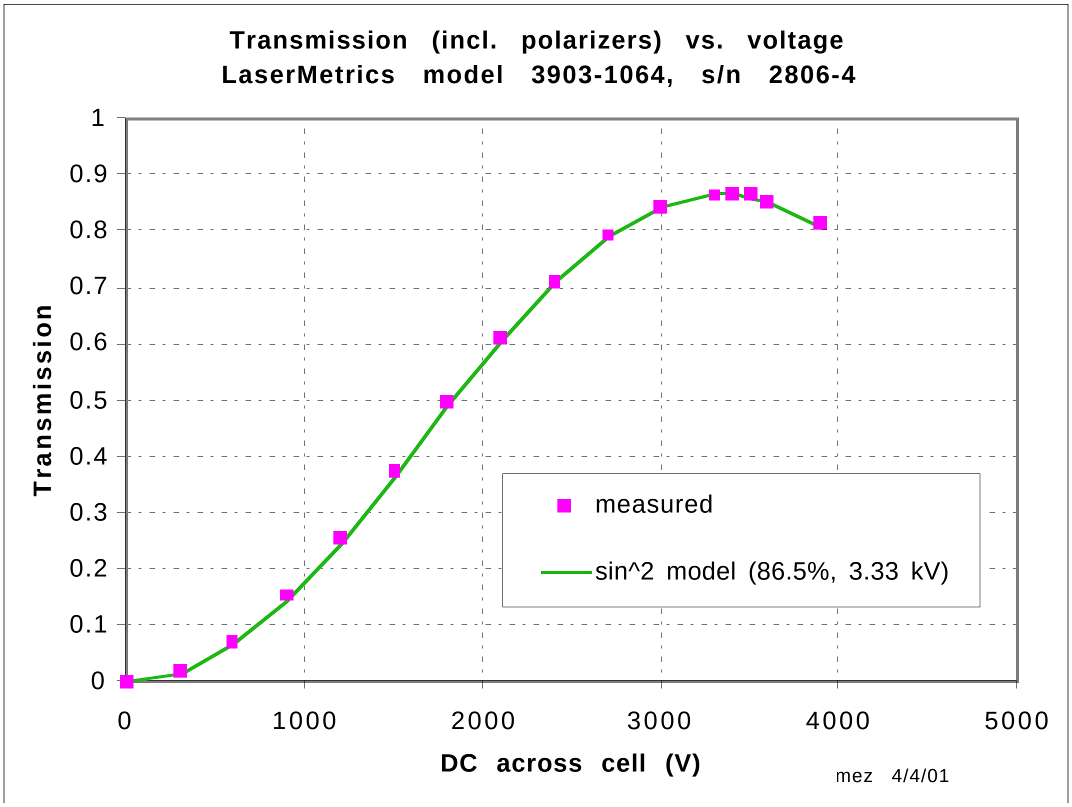
Restoring best alignment, we applied DC bias from a high-voltage supply (HP 6525A) across the cell to measure its half-wave voltage. Voltage was monitored with a Fluke 77 DVM through a precision 10 MΩ/101 kΩ resistive attenuator. The result, shown in Figure 2, gives a best fit to the measured transmission with a peak transmission of 86.5% and a half-wave voltage of 3.33 kV. Note that this transmission includes the polarizers, which were taken from lab stock and not especially transmissive (nonetheless, their mutual extinction ratio did check out at less than a part in 10^5).

Figure 1: Degradation of EO shutter extinction ratio with angular beam misalignment.



1. Contrary to the published specifications, we found the 9071 stage's vertical (pitch and elevation) adjustment screws provide about half as much motion per turn as do the horizontal (yaw and lateral translation) adjustment screws. This makes sense if you look at how the stage is designed.

Figure 2: Transmission vs. voltage at optimum alignment.



5 TRANSMISSION STABILITY

The transmission stability and temperature sensitivity of the EOS assembly were also measured by monitoring the input and transmitted power over time. A wedged uncoated piece of glass was placed before the input polarizer and the picked-off beam was directed into a ThorLabs PDA150 photodiode to monitor the input laser power. The transmitted beam through the EOS assembly was fed into a second PDA150 photodiode. An Analog Devices AD590 IC temperature transducer was placed in thermal contact with the EOS metal casing. The input light monitor, the transmitted light monitor, the temperature sensor, and the shutter voltage power supply monitor signals were fed into a National Instruments data acquisition board connected to a PC. These four channels were sampled at 1 sample per minute. The signal from the input light monitor was also used to stabilize the laser power. A fixed DC offset was subtracted and the difference was inverted and fed back into the laser's power control input. This was implemented because the laser's output power drifted significantly with temperature, complicating interpretation of the EOS transmission.

To determine thermal stability of the EOS assembly, the transmission was monitored while the ambient room temperature was varied. First, the setup was optimized for the desired transmission setting. Two different transmission settings were tested: 2% transmission (requiring an applied voltage to the EOS of ~350 V), and 50% transmission (requiring ~1850 V on the EOS). After data were taken for a while to achieve a baseline measurement, the ambient room temperature was increased or decreased by turning the room's thermostat to its maximum or minimum settings respectively. The thermostat was turned to the opposite extreme a few hours later, and then back to its nominal setting after another few hours. The voltage measured across the EOS did not vary significantly with room temperature.

The data from these measurements are presented in Figures 3 and 4 which show, for the 2% and 50% nominal transmission settings respectively, the transmission of the EOS assembly and temperature of the EOS housing as a function of time. The quantity plotted is the quotient formed by the transmitted photodetector voltage divided by the input monitor photodetector voltage, taken after subtracting off the measured dark offset of each detector (it has not been normalized to the absolute optical transmission in each case, but is proportional to it). In both instances the transmitted power changed by less than 1.5% fractionally per Kelvin, although in the 2% transmission case the correlation is not as strong.

Figure 3: EOS transmission and case temperature vs. time, 2% nominal setting (350 V bias)

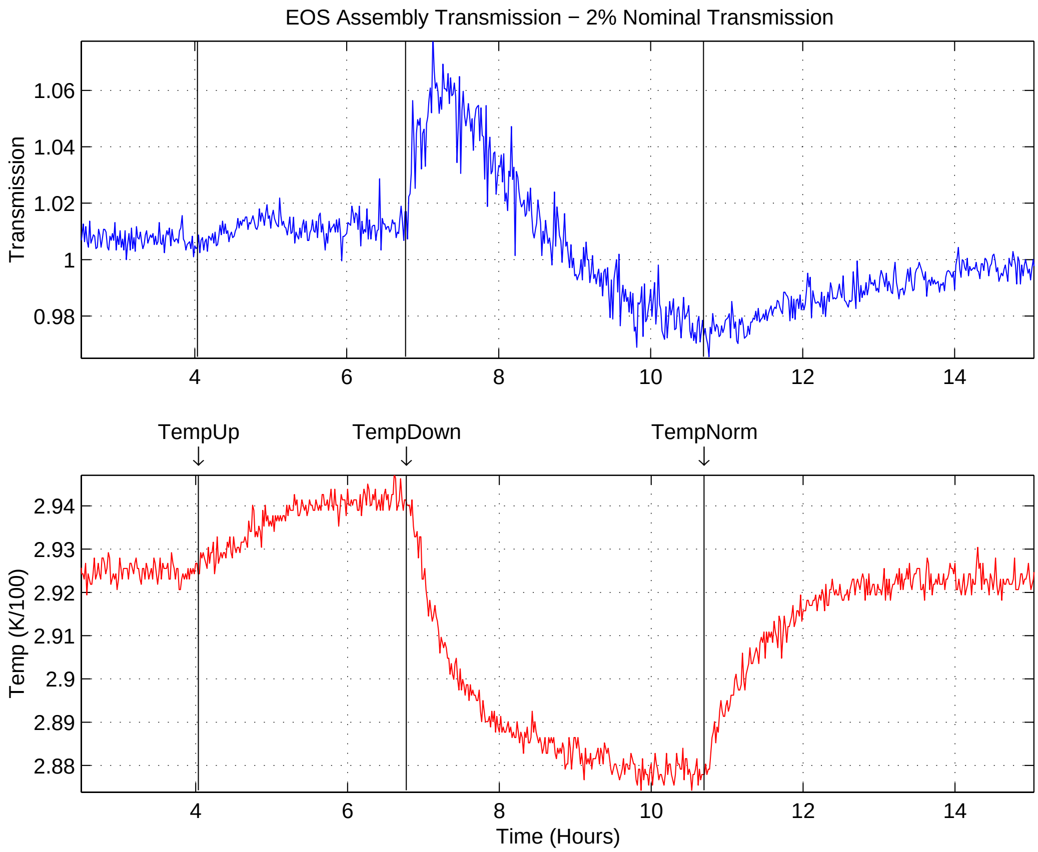
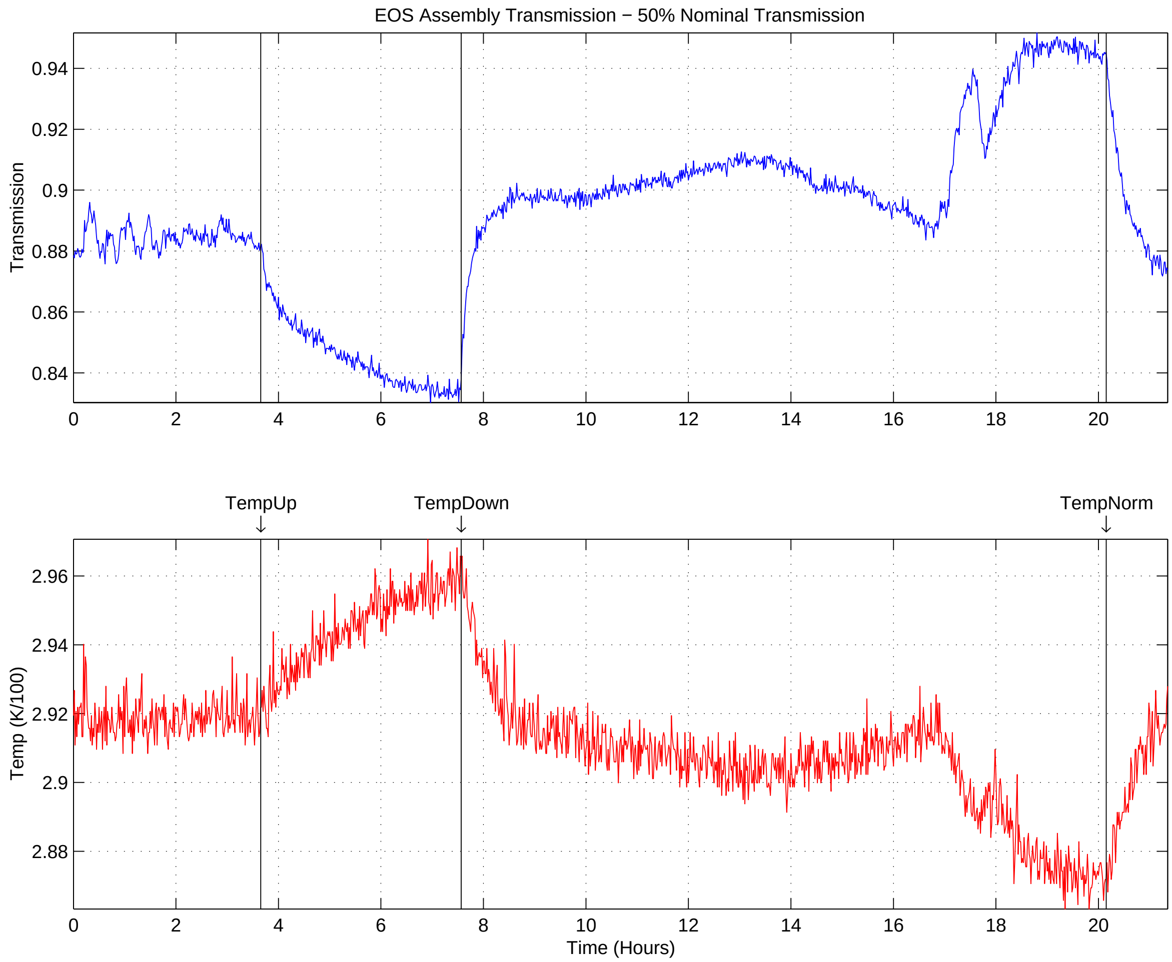


Figure 4: Transmission vs. time and temperature, 50% nominal setting (1850 V bias)



6 CONCLUSIONS

In the absence of major disturbances and “interventions”, arm cavity alignments in the Hanford 2k and Livingston 4k interferometers are generally observed to vary by less than 20 microradians (about 8 cm spot displacement in 4 km) over periods of weeks to months. Depending on the origin of the drift, compensating adjustments could at worst be expected to change the output beam angle at the EOS position by about 20 times this amount, or 400 microradians, due to the demagnification of the beam diameter (and corresponding magnification of angle) at this location with respect to the arm cavities. Judging by Figure 1, this level of alignment drift would not be expected to degrade the EOS extinction to exceed a part in 10^3, and so should be negligible. Of course, at the current stage of commissioning there are typically a few radical interventions in the ISC table alignment each week, so the EOS will probably still need frequent attention until the configuration stabilizes.

We anticipate the LSC lock acquisition protocol should be relatively insensitive to 10%-scale variations in the relative calibrations of the sensing photodetectors. From Figure 3, we conservatively surmise a temperature variation of ±2K in the LVEA will cause less than ±6% fractional variation in effective transmission when the EOS voltage has been fixed to provide 50:1 nominal attenuation. We therefore expect the EOS attenuator can be employed for lock acquisition by simply programming a preset bias, without need for active monitoring or correction of the resulting transmission.

7 APPENDIX: EO CRYSTAL ALIGNMENT

The following procedure is excerpted from *User's Guide for KD*P and Lithium Niobate Q-Switches and Modulators for Q-Switching, Chopping and Pulse Extraction,* rev. 26 January 1998 by LaserMetrics Division of Fastpulse Technology Inc. (www.lasermetrics.com).

2.0 EOM SETUP AND ALIGNMENT

CAUTION: Protective laser goggles should be worn during alignment procedures.

Lasermetrics Modulators and Q-switches are supplied with a marker on one of the stainless steel aperture plates or on the outer housing to indicate the preferred plane of polarization of the incoming beam. The plane of polarization must be aligned with the marker (or rotated 90° from it) for correct operation. If the marker is missing, the appropriate directions must be inferred from the crystal geometry by viewing the sides of the crystal through the clear aperture. In general, for KD*P LFMs, the input polarization plane must be

parallel to a line which was drawn on the circumference of the crystal during fabrication (X crystallographic direction). For lithium niobate the polarization plane must be perpendicular to any one crystal side. For ADP and KD*P TFMs, the polarization plane must be at 45° to any crystal side

It is strongly recommended that initial alignment of be done with a low power (0.5 to 2 milliwatts) He-Ne laser to assist in visualizing beam position. If alignment must be done with only an IR laser, the power of this laser must not exceed 5 milliwatts. At higher power levels, it is possible to damage the device if the beam strikes the internal electrodes thereby causing thermal damage. Unless there are strict constraints on space and positioning devices, the device should be mounted in a gimbal that provides accurate and stable pitch and azimuth adjustments. Some means for obtaining horizontal and vertical translation is usually necessary to center the device on the input laser beam.

If the device is being used in a laser cavity, it is recommended that the alignment be done with a He-Ne laser having its beam centered on and coaxial with the laser rod. If convenient and safe, the coaxial condition should be ascertained by operating the laser with the He-Ne to confirm that the beams are indeed coaxial. If this cannot be done safely, then the He-Ne beam should be retro-reflected off the nearest laser rod surface back onto itself using a pin hole in front of the He-Ne. It is essential that the laser beam pass through the EOM entrance and exit apertures without vignetting. The beam should be centered in both apertures with at least 0.5 mm clearance all around.

The following procedure has been shown to be most reliable for obtaining optimum alignment. The object is to center the laser beam in the device apertures and then generate an optical pattern which accurately locates the optical axis of the crystal with respect to the laser beam. This will probably require several adjustments of pitch, azimuth and translation to optimize the alignment but it will provide positive, visual confirmation of the alignment. The procedure requires two linear polarizers. If the alignment is to be done inside a laser cavity incorporating only a single polarizer, then an additional polarizer (used only for alignment) may be of the Polaroid type -- typically HN-32 or HN-38.

1. Remove any polarizers used to polarize the beam entering the device. If the laser is already polarized it does not effect this procedure. Position the EOM in the He-Ne laser beam to center the through the apertures without touching the aperture edges.

2. Place a light colored card in the path of the beam at a distance of about 8 to 12 inches from the exit aperture of the EOM. If the EOM is located within a laser cavity, the card should be placed against the laser rod holder and a small hole made in the card to locate the rod aperture. Mark the beam location on the card with a circle or dot and leave the card in place.

3. Place the input polarizer in the beam with its polarizing axis aligned to the mark on the device. It is assumed that the polarizer does not angularly deviate the beam. Locate the output polarizer (analyzer) at the output side of the device and insure that its polarizing axis is rotated 90° from that of the input polarizer.

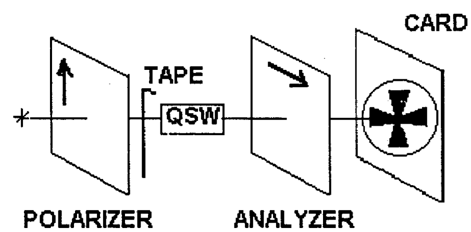


Figure 1: Setup for alignment of optical axis to laser beam

4. Place a strip of frosted adhesive tape (Scotch Magic Mending Tape or similar material) over the device entrance aperture. Gently press the tape in place. A lightly frosted glass plate will provide the same scattering but must be nearly in contact with the entrance aperture. A pattern, or some part of it, will be projected on the card. This is called an isogyre pattern as illustrated in Figure 2 below. <u>When the tape is in place, the laser beam may become so diffused that the central spot may not be visible on the card.</u> <u>Do not move the card</u>. If is usually safe to assume that the spot is really there, in its original position..

The isogyre is a representation of direction through the crystal, not position on a surface. The beam will form incomplete, distorted isogyre patterns if the beam direction is not parallel (within a few degrees) to the optic axis. If the beam is parallel to the optic axis, the pattern of Figure 2 will result.

This alignment procedure works with all devices utilizing uniaxial crystals such as KDP, KD*P, ADP, lithium niobate and tantalate, etc.

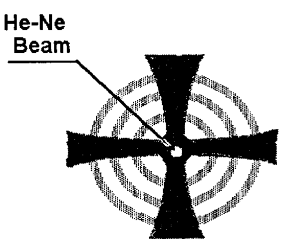


Figure 2: Isogyre pattern with beam centered

NOTE: These measurements are usually made in a darkened room after basic alignment and adjustments are completed. In most instances, the pattern to be viewed will be difficult to see in normal room lighting. For improved resolution and visualization, a ≤150 mm focal length lens can be used to collect light exiting the analyzer and project the beam onto the card. <u>Do not focus the beam to a fine spot.</u> The lens should be positioned to produce a conveniently sized image on the card for viewing. If a lens is used, insure that the laser beam is centered and is not deviated from its original path. It is difficult sometimes to tell exactly which part of the pattern is being displayed when the beam axis is not closely parallel to the crystal optic axis. When this occurs, the modulator pitch and/or azimuth position must be varied until some identifiable portion of the pattern is visible. The alignment process can then be completed as in the following steps:

If the optical axis of the crystal is not parallel to the path of the laser beam, the isogyre pattern will be off-center and the device must be moved in pitch and azimuth. When the isogyre is centered over the circle or dot or hole in the card, this indicates that the device is well aligned , i.e., the crystal optic axis is parallel to the laser beam. After making any positional adjustments, the beam position relative to the device aperture stops must be re-confirmed. The beam must still pass through both apertures without vignetting and with adequate clearance. If it does not, employ horizontal and vertical translation until clearance is confirmed.

If the figure is not in the form of a cross, then the polarizers are not rotationally aligned to the faceplate mark or at 90° to each other.

After the cross of the isogyre is centered, the polarizers can be rotated slightly to maximize the darkness of the center of the cross. Once this is done, the device is not only aligned with the laser beam, it is also nulled with respect to the crossed polarizers for best contrast ratio and is ready for operation. When the modulator is in actual use, very fine adjustments of the pitch and azimuth controls can further optimize performance.