LIGO-T960061-00-D

FAX MESSAGE FROM

UNIVERSITY OF FLORIDA

DEPARTMENT OF PHYSICS

Gainesville, Florida 32611-8440

FAX: (352) 392-3591
Voice: (352) 392-4718
Bitnet: UFTANNER @ NERVM
Internet: uftanner @ nervm.nerdc.ufl.edu

Number of pages, including this page: 9

8 March 1996

FAX to:	Barry Barish
Number:	818-304-9834
From:	David Tanner
Subject:	Input/output optics

As we discussed on our visit, the UF group has written a short description of the Ligo input/output optics, as we understand them. We would appreciate your comments on what we've written. I have also sent a copy to Stan Whitcomb.

We remain very interested in and excited by the chance to participate in this experiment. Thanks for hosting us during our visit.

DT:dt

THE INPUT/OUTPUT OPTICS SYSTEM

The input/output optics consist of two distinct optical systems: the optics which couple the laser light to the Core Optics and the optics which direct the output from the Core Optics to the detector. The design of the input optics is better defined at the present time than the design of the output optics.

Both the input optics and the output optics operate in the same vacuum environment as the Core Optics. There are individual vacuum housings for the input optics and the output optics. The vacuum housings are not part of the input/output optics system.

1 The input optics

The input optics is responsible for receiving the laser beam (through a vacuum window), imposing modulation sidebands on the beam, assuring that the beam has the proper modal structure, expanding the beam to the proper size for the Core Optics, and directing it into the Core Optics. The next optic the light sees is the rear side of the recycling mirror. The most sensitive part of the input optics is the mode cleaner, a triangular-path Fabry-Perot interferometer, which passes only the TM_{00} mode to the Core Optics.

The input optics must return a control signal to the laser. This signal is part of the laser wavelength stabilization system.

The input optics must provide a signal which measures the power transmitted to the Core Optics, which is used in the laser power stabilization system.

The input optics must accept a signal from the Core Optics, so that the wavelength passband of the Mode Cleaner may be properly matched to the resonant cavities of the Core Optics interferometer.

The light is vertically polarized entering and leaving the input optics.

2 Input optics subsystems

There are three parts to the input optics, called "optics 1," "mode cleaner," and "optics 2."

2.1 Optics 1

Optics 1 consists of small diameter optics and is mostly concerned with applying the modulation signals to the laser light. At the beginning of optics 1, the light from the laser has entered the vacuum chamber. At the end, the light has been expanded to size proper for the mode cleaner.

Question: Can optics 1 be operated in air? It might make sense to do the modulation/isolation in ambient and then transmit into the vacuum either just before or just after the telescope which expands the beam for the mode cleaner.

Optics 1 contains the following parts, indicated on Fig. 1, below:

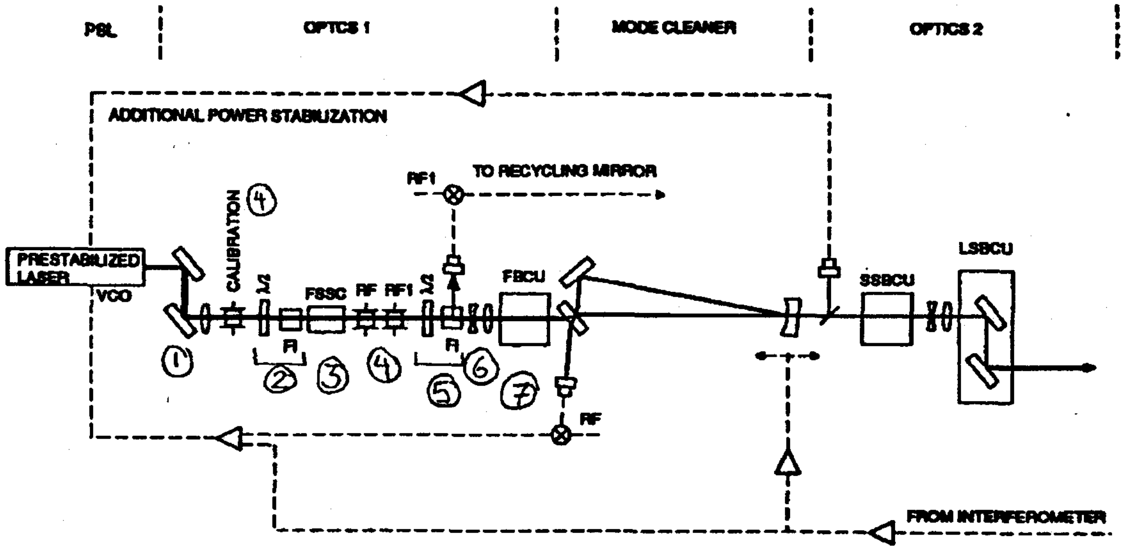


Fig. 1. Optics 1 components, ①-⑦

1. Input beam directing mirrors. These two plane mirrors steer the beam onto the centerline of the optical axis for optics 1. These mirrors are under active control to compensate for jitter and wander from the laser.
2. Optical isolator. This Faraday cell transmits the beam in the forward direction but prevents reflected light from entering the laser. The power transmission in the forward direction is ~85%; in the reverse direction less than 0.1%
3. Frequency shifted subcarrier generator (FSSC). Provides a single-sideband modulation to the laser light, for locking the laser to the Core Optics resonant wavelength. **Frequency offset? Pockels cell OK?**
4. Pockels cells. There are three of these: one for calibration; one modulated at RF1, providing a locking signal to the recycling mirror; and one modulated at RF providing initial frequency stabilization to the laser. **Frequencies?**
5. Directional coupler (Second Faraday Isolator). This cell transmits the beam in the forward direction. Reflected light from the Recycling mirror is directed to a detector, whose output is demodulated at RF1 and used to move the recycling mirror to a resonant location. (When the recycling mirror is properly positioned, the reflected

light from the Core Optics is at a minimum.)

6. Beam expanding telescope. This lens pair expands the beam to a size appropriate for the mode cleaner.
7. Fixed beam control unit (FBCU). These plane mirror optics direct the beam into the mode cleaner. Active control may be necessary to compensate for drift between optics 1 and mode cleaner optical axes. This control would be relatively slow.

2.2 Mode cleaner

The mode cleaner is medium diameter optics, with a path length of 12 m. Its purpose is to remove all components from the laser light except the TM_{00} Gaussian mode.

The mode cleaner is a triangular configuration Fabry-Perot (or perhaps more accurately, a multibeam) interferometer. Its finesse is ~2000. This is high enough to reject higher order Gaussian modes. It also rejects modulation sidebands, unless they match one of the other resonant frequencies. A 12 m optical path difference means a free spectral range of 25 MHz. A finesse of 2000 means a passband of 12.5 kHz. This needs to be checked when we know the *modulation frequencies!*

The mode cleaner has three optics. Each is a suspended optic of low loss and high optical quality. (The mode cleaner stores 20kW of power.) The choice of the suspended optic is to provide vibration isolation and to move thermally activated mechanical resonances out of the Ligo frequency band. Figure 2 identifies these three optics:

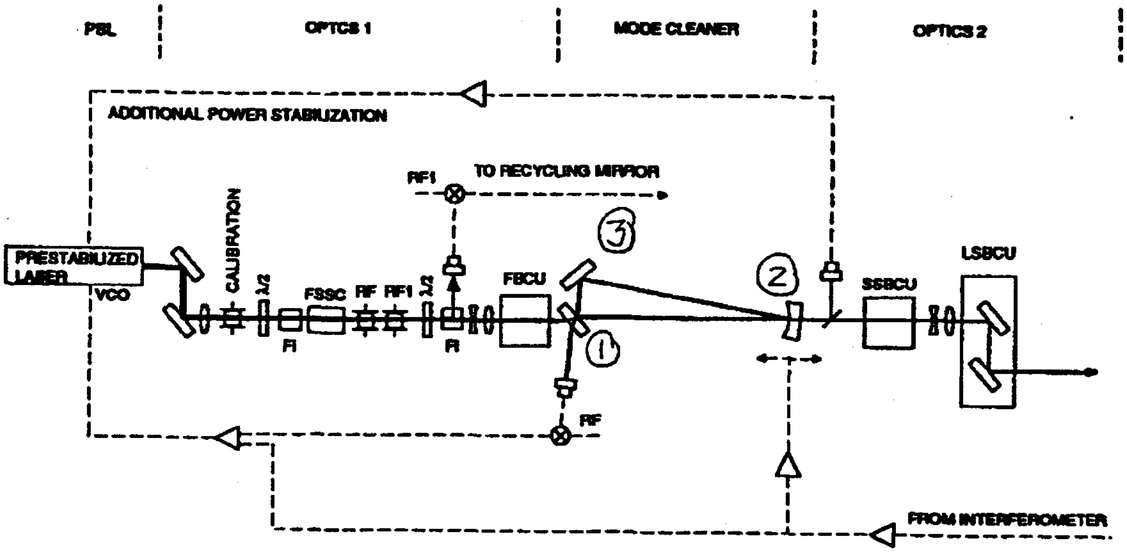


Fig. 2. Mode cleaner components, ①-③

1. The input mirror. Oriented with normal nearly 45°to the incoming beam, this plane mirror forms one reflector of the Fabry Perot. Incoming light reflected by this 45°mirror is sent to a photodetector, demodulated at RF frequency and used in the laser wavelength stabilization servo.
2. The output mirror. A spherical mirror, with radius chosen to optimize the transmission of the TM_{00} mode, this mirror is the second reflector of the Fabry Perot. It is located approximately 6 m from the input mirror. It's location may be adjusted (under active control by a signal from the main interferometer) to match its resonant wavelength to that of the main interferometer.
3. The turning mirror. Located beside the input mirror, this optic directs the beam back to the input mirror so that it interferes with the incoming light. This mirror should have $\mathscr{R} = 1$.

These three mirrors are adjusted so the mode cleaner optical path is an integer number of laser wavelengths. On resonance, the mode cleaner transmits nearly all the incident light in the TM_{00} mode to the optics 2 portion of the input optics. Off resonance, most of the incoming light is reflected away from the optical axis. (The fact that the triangular Fabry-Perot does not reflect towards the laser is the motivation for its choice over the simple two-mirror Fabry Perot.)

2.3 Optics 2

Optics 2 comprises large diameter optics, of a quality nearly equal to that in the Core Optics interferometer. There are four main components, shown in Fig. 3:

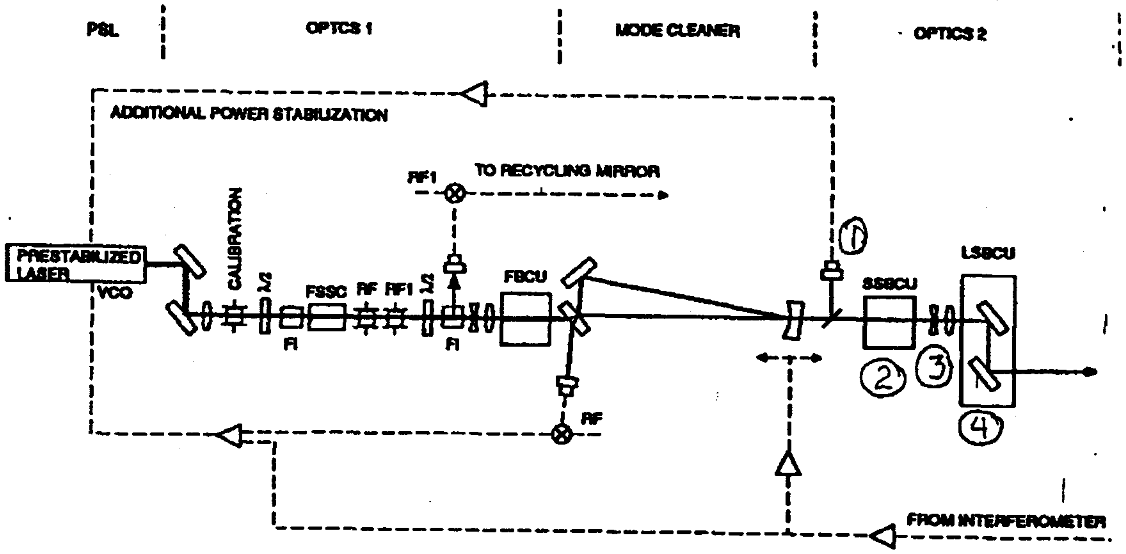


Fig. 3. Optics 2 components, ①–④

1. Power meter. A small amount of the light from the mode cleaner is diverted to a detector. The detected signal is used for power stabilization of the laser.
2. Small suspended-beam control unit (SSBCU). This optic matches the output of the mode cleaner to the final beam expansion telescope.
3. Beam expansion telescope. This refractive system expands the beam to approximately 5 cm diameter, suitable for the Core Optics.
4. Large suspended-beam control unit (LSBCU). This optic matches the output of the telescope to the Core Optics. It consists of two plane mirrors which are actively controlled to align the beam to the optical axis of the Core Optics.

3 The output optics

The output optics resembles a stripped-down version of the input optics. Light enters the output optics from the Core Optics beam splitter. The light is demagnified by a refractive telescope, transmitted through an output mode cleaner, and imaged on the detector. (This detector is the main output for gravitational wave signals.)

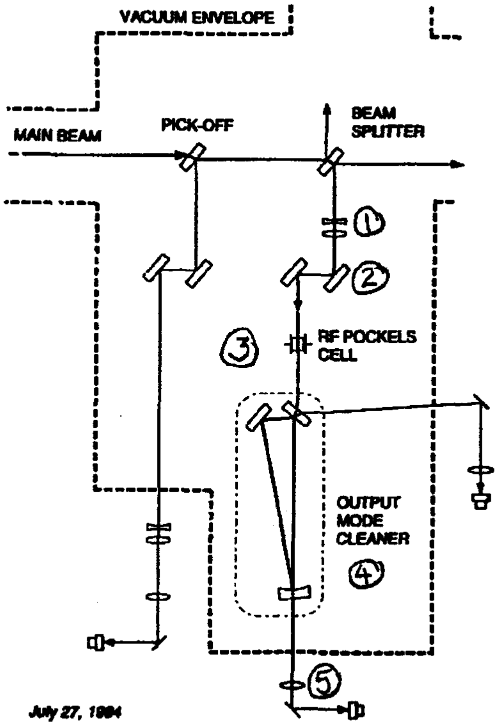
There is also a second output optics train which samples the light returned to the recycling mirror from the Core Optics beam splitter. This output beam is deflected from the main input axis by a pick-off mirror.

I assume the pick-off mirror is part of the Core Optics, since it lies between the recycling mirror and the beamsplitter.

4 The output optics components

4.1 The dark fringe of the Core Optics interferometer

The principal components are marked on Fig. 4.



July 27, 1994

Fig. 4. Output optics components, ①–⑤

1. Beam compression telescope. This refractive system reduces the beam from the approximately 5 cm diameter used in the Core Optics to a size suitable for the output mode cleaner.
2. Steering mirrors. Two plane mirrors, under active control, steer the output beam onto the axis of the output optics.
3. There is a pockels cell to apply RF modulation to the beam. I am not sure what the purpose of this is.

4. Output mode cleaner. The main purpose is to reject scattered and stray light and to pass the TM_{00} mode to the detector. Because the Core Optics interferometer is operated with a dark fringe in the output arm, the stored power here is 1–2 orders smaller than in the input mode cleaner. This can be a more modest unit than the input mode cleaner, but the optical layout is essentially the same.
5. Further beam diameter reduction. This lens images the light on the detector.

The detector can be in the vacuum chamber, although thermal issues may prefer it outside.

4.2 The output from the pick-off mirror

Light returning from the beamsplitter to the recycling mirror is picked and sent to a detector.

The principal components are shown on Fig. 5

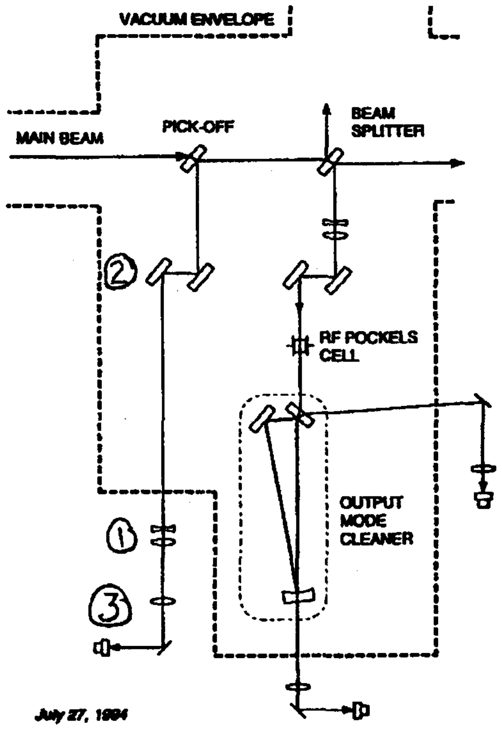


Fig. 5. Pickoff components, ①–③

1. Beam compression telescope. This refractive system reduces the beam from the approximately 5 cm diameter used in the Core Optics to a small size.
2. Steering mirrors. Two plane mirrors, under active control, steer the output beam onto the axis of the pick-off optics.

3. Imaging system. This lens images the light on a detector. The signal is used in the beamsplitter positioning servo, to ensure that the output arm is in a dark fringe.

5 Other aspects of the input/output optics

There are three features that have not been fully addressed here. First, the servo system in the input/output optics interacts with other control servos in the laser and the Core Optics systems. The Ligo control systems group will need to be involved with both design and construction of these servos.

Second, for initial alignment and for recovery from upsets, optical lever systems are needed on several of the input/output optics components. We envision that these optical levers would be similar to those used on the Core Optics components. They have not been mentioned above, but at a minimum we would put them on the mirrors of the input and output mode cleaners, probably on the large suspended beam control unit, and perhaps on the small suspended beam control unit. Are there other places where optical levers or other alignment tools are needed?

Third, there are suspended-mirror mounts which need to be designed and constructed. This is an area which will need to be discussed further; our machine shop can manufacture complex parts with very high quality and precision but we would want the Ligo group involved with the design. We discussed this some during our visit, I remember.