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Input / Output Optics Conceptual Design

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IOO Design Review Board

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1 IOO SUBSYSTEM: OVERVIEW

1.1. Interferometer System Context

The Input / Output Optics act as a bridge between the prestabilized laser light of the PSL subsystem and the requirements of the Length and Alignment Sensing and Control subsystems. The IOO performs frequency and pointing stabilization, and also mode matches the light to the mode defined by the Core Optics. The IOO also provides for phase modulation of the light and signal extraction of the IFO reflected light.

1.2. System components

The Input / Output (IOO) subsystem layout consists of the following units, schematically shown in figure 1:

- RF modulation
- Steering and Conditioning Optics
- Mode Cleaner
- IFO Signal Extraction
- IFO mode matching and beam pointing

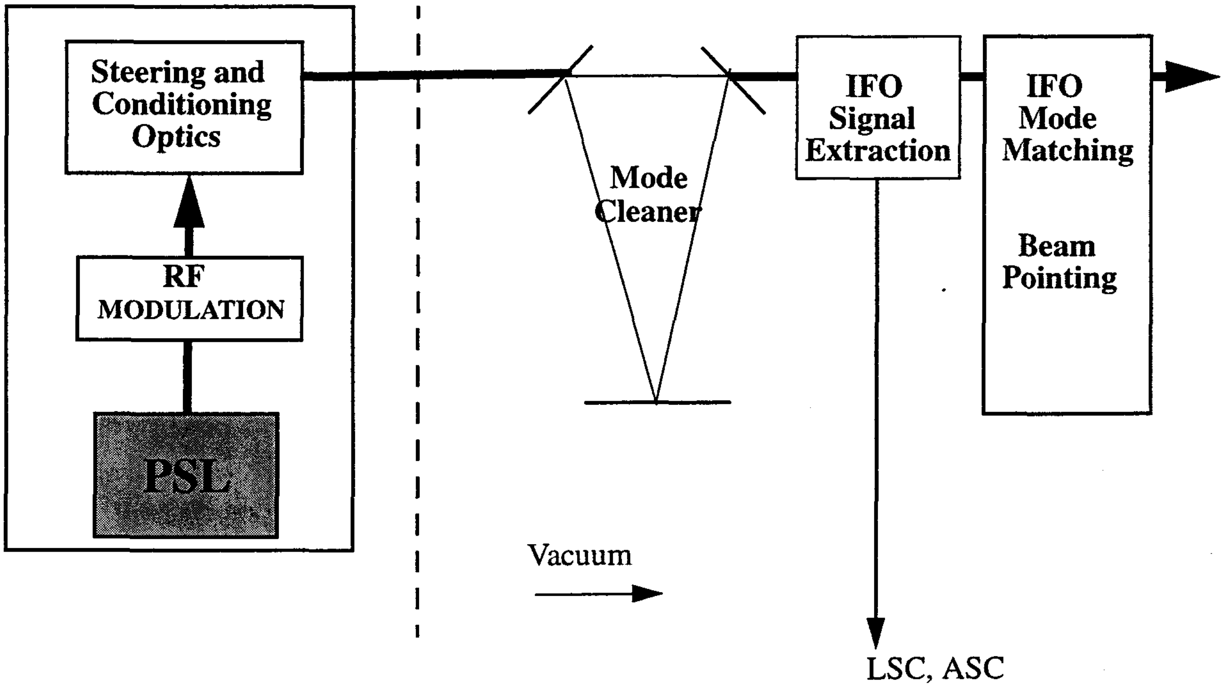

Figure 1: System Components

To minimize beam pointing variations associated with optical table drift, the in-air components of the IOO are located on the same table as the PSL output beam. A set of steering mirrors, actively controlled through feedback from a wavefront sensing signal, direct the beam to the mode cleaner. After passage through an element which provides for signal extraction of the IFO reflected light, the beam is expanded and steered to the Core Optics components.

1.3. IOO system layout

A schematic diagram of the positions of the input optics components both outside and within the vacuum chamber is shown in Figure 2. Optics not in vacuum are mounted on the same table as the PSL in a clean, enclosed environment. All optics in vacuum will be mounted on vibration isolation stacks. With the exception of the Faraday isolator, all optics in and following the mode cleaner will be suspended (shown as dashed boxes). Each HAM has an optical table 1.8 m long by 1.7 m wide. The distance between HAM 1 and HAM 2 is 11.92 m, allowing for accommodation of the mode cleaner and beam expanding telescope for the core optics mode-matching. Our design allows for additional space which can accommodate additional steering optics if the need arises. Output ports in the HAMs will be used as optical feedthroughs for sensing beams.

1.3.1. Dimensions

Relevant dimensions are given in the following table. HAM1 and HAM2 are part of the IOO system, and hold the mode cleaner, as described above and shown in Figure 2. HAM3 holds the recycling mirror and BSC3 (4 km IFO) or BSC8 (2km IFO) hold the input test masses. The separations of these chambers determine the modulation frequencies, as discussed below. We have assumed that the separation may be adjusted over a total range of 3 m for the mode cleaner and 2.4 m for the recycling cavity.[1]

[1] From a memo by M. Zucker and P. Fritschel, LIGO-T960122-00-I

Table 1: Dimensions

	4km IFO	*2km IFO*
HAM1 -- HAM2 spacing (center - center, m)	13.72	13.72
HAM1 -- HAM2 adjustment (m)	+/- 1.5	+/- 1.5
HAM3 -- BSC3/8	8.41	13.05
HAM3 -- BSC3/8 adjustment (m)	+/- 1.2	+/- 1.2

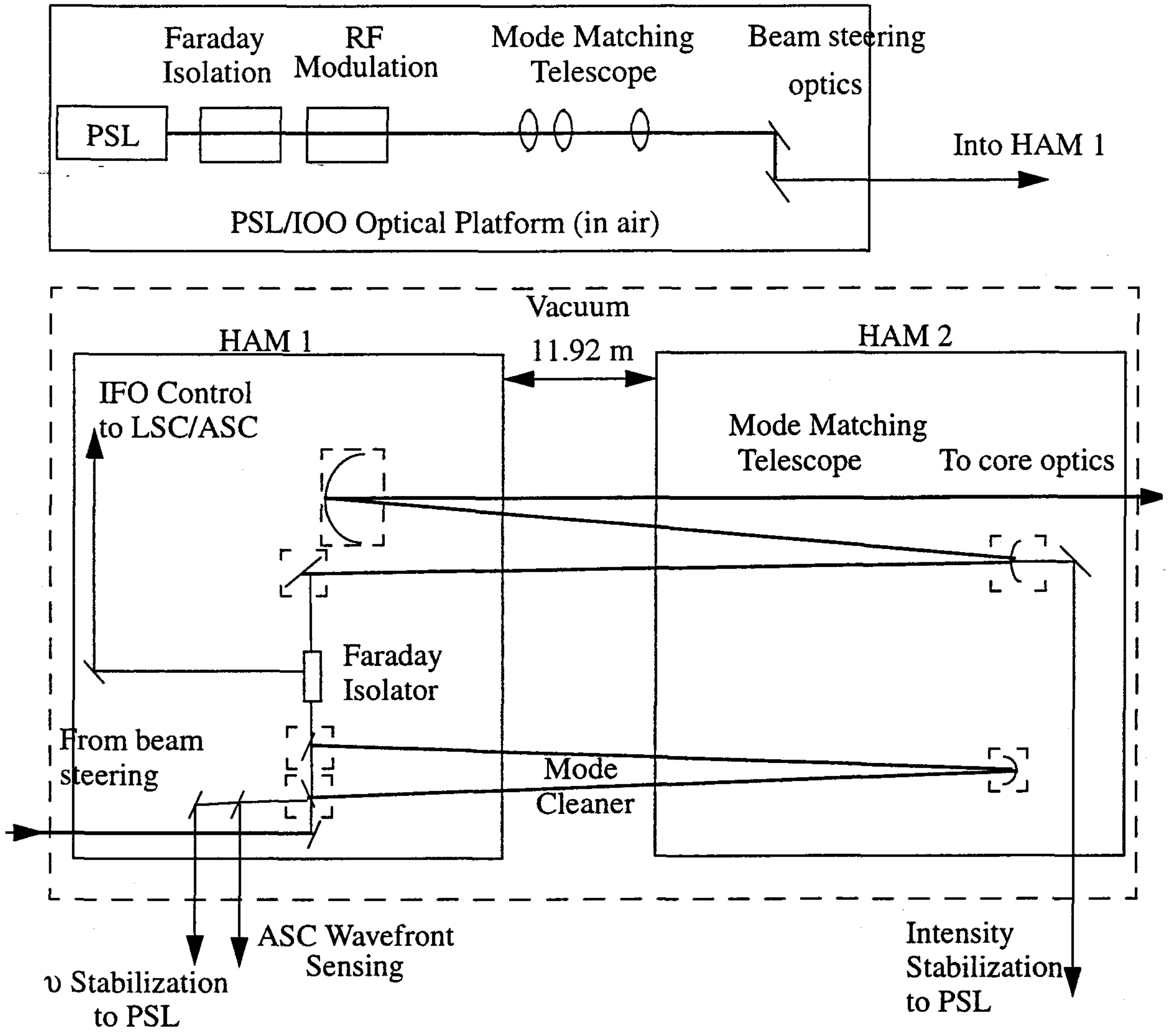

Figure 2: Overall System Layout

2 OPTICAL EFFICIENCY

The IOO must deliver 75% of the TEM_{00} light emerging from the PSL to the IFO, including all integrated losses from reflection, transmission, and absorption in the IOO optical components. The following table shows the transmission of the components of the IOO components. Numbers are rounded to 3 significant figures. For the suspended components we have assumed coatings almost (but not quite) as good as those of the core optics. (These have 25 ppm loss assumed; we have taken typical losses as 200 ppm.) The small optics are assumed to have antireflection coatings that match the Ealing narrowband multilayer coatings (0.1%). Finally we have assumed that the polarizing components of the Faraday isolators have some loss (2%) on account of beam depolarization.

Table 2: Optical efficiency of IOO system

Item	*Loss(%)*	*Transmittance*	*Accumulated Transmittance*
Faraday isolator 1	5	0.95	0.95
RF modulation unit (See section 3.1)	3.5	0.965	0.917
3 mode matching lenses	0.6	0.994	0.911
HAM1 window	0.2	0.998	0.910
3 beam steering mirrors	0.06	0.999	0.909
Mode cleaner	5	0.95	0.864
Faraday isolator 2	5	0.95	0.820
Steering mirror	0.02	1.0	0.820
Telescope negative mirror	1	0.99[a]	0.812
Telescope converging mirror	0.2	0.998	0.810

a. Includes pickoff for intensity stabilization and RFAM monitor

3 INTERFACE TO PSL

The following diagram shows a Faraday isolator between the PSL and the RF modulator. These are bolted to the optical table.

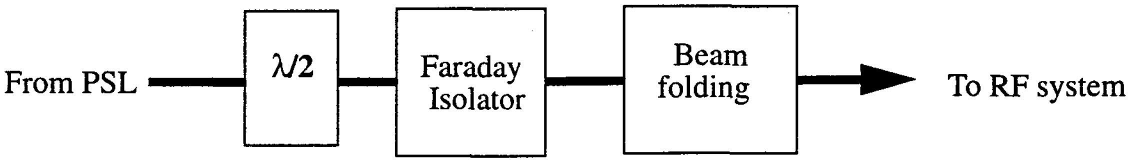

Figure 3: IOO interface to PSL

The half-wave plate will provide the required vertical polarization of the light entering the mode cleaner, with the Faraday Isolator providing ~30 dB optical isolation between back reflected light and the PSL. The beam folding optics direct the light into the RF Modulation system.

4 RF MODULATION

4.1. Baseline Design

The IOO RF modulation must produce both the resonant and non-resonant sidebands required by the ISC subsystem. The modulation is applied in such a way that cross products of the two frequencies do not occur. The layout is shown in figure 4.

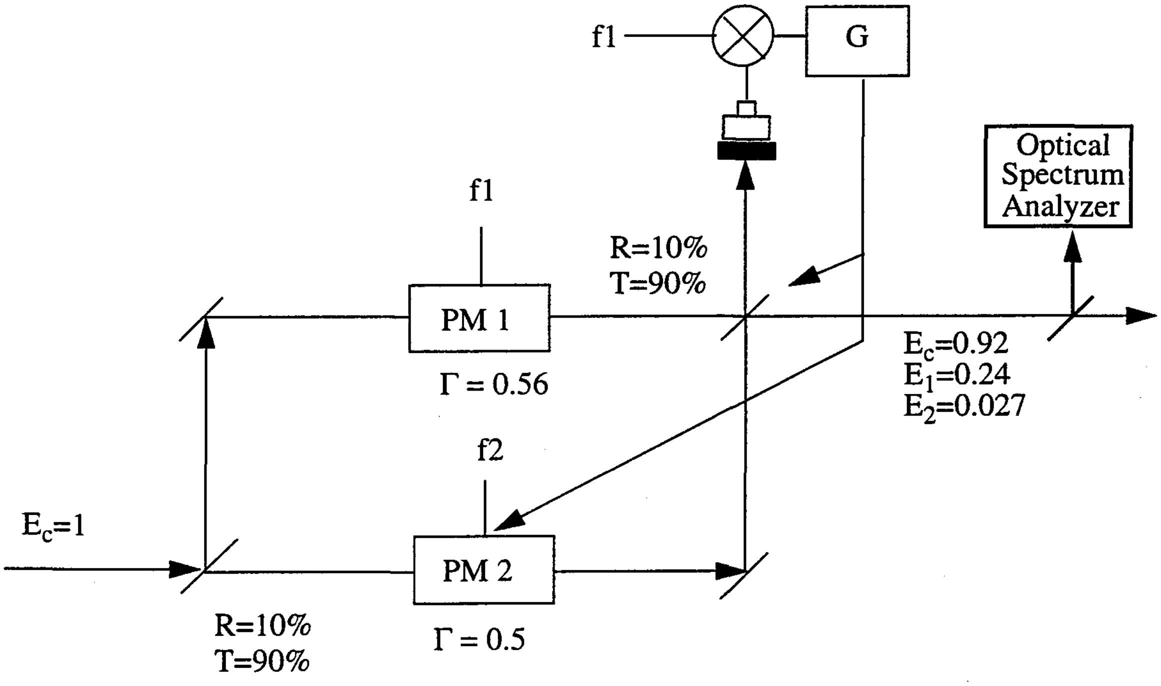

Figure 4: RF modulation system

A control system will hold the recombined beams in phase lock by using the sidebands at frequency f1 as a reference for the carrier in the split path. The feedback signal may be applied either at the recombining beamsplitter or at phase modulator 2. The role of the feedback is to ensure that the two arms of this Mach-Zender interferometer combine the carrier in phase at the combining beam splitter.

We expect the following performance:

- Optical efficiency: given a 5% match in the reflectivity of the two beam splitters (coating variations and losses), ~ 96 % of the input light is transmitted.
- Fringe lock: control of the fringe to the level of 10^{-8} m is adequate to ensure the above optical efficiency. In-band control at the level of 10^{-10} m/rHz will maintain the PSL intensity noise level.
- Frequency noise: In-band variations of the split path length will produce phase noise in the recombined beam. To avoid compromising the frequency stability achieved with the PSL reference cavity (~10^{-2} Hz / rHz @ 1 kHz) the length control must be of order 10^{-12} m / rHz.
- Shot noise: ~4 % of the incident power will appear at the photodetector, mainly at the sideband frequencies. With a 1% attenuator, shot noise induced frequency noise is ~ 10^{-6} Hz / rHz, well below the required level.

The expected disturbance level to the above system is of order angstroms at 100 Hz, induced by acoustic noise[1]. Thus the demands on the control system are modest.

An optical spectrum analyzer will be included to monitor the sidebands.

Finally, the IFO resonant sideband will also be used to lock the mode cleaner, using a deliberate mode mismatch to give ~ 1% sideband reflected power at the length control photodiode. The shot noise in the mode cleaner length control in this arrangement is ~5 x 10^{-6} Hz / $Hz^{1/2}$, meeting the IOO requirement.[2]

4.2. Modulation Frequencies

There are two modulation frequencies that will be applied:

- Sidebands that are resonant in the recycling cavity but not resonant in the interferometer arm cavities. These are used for locking the arm cavity mirrors and the beam splitter.
- Sidebands that are not resonant in the recycling cavity. These are used for locking the recycling mirror.

The values of these frequencies are set by the lengths of the respective cavities, which are listed in Table 1. Values on the lower end of the range have been chosen for the mode cleaner, especially in the 4 km interferometer. The lengths and modulation frequencies are related by

$$f_{mc} = n\, c / 2L_{mc}$$

where n is an integer (1,2,3 ...) and L_{mc} the mode cleaner length. For the resonant sidebands (not resonant in the arm cavities) the frequencies are given by

$$f_{res} = (k + 1/2)\, c / 2L_{rc}$$

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[1] Estimate based on work of M. Regehr and F. Raab (private communication.)

[2] Mode Cleaner Noise Sources, LIGO-T0164-00-D

[3] M. Zucker and P. Fritschel, LIGO-T960122-00-I

where (k = 0,1,2 ...) and L_{rc} is the recycling cavity length. These frequencies must equal each other because the sidebands are resonant simultaneously in both the mode cleaner and the recycling cavity. Also, the non resonant sidebands are chosen as far as possible from the recycling cavity resonances but equal to one of the mode cleaner resonances. A final consideration in choice of the modulation frequencies is that they must miss all the harmonics of the 37.5 kHz (75 kHz) 4 km (2 km) arm free spectral range.[3]

Table 3 gives nominal values for the relevant quantities. We assumed an additional 0.3 m for the base leg of the triangular mode cleaner in both cases.

Table 3: Modulation frequencies

	4k IFO	*2k IFO*
Mode cleaner length (m)	12.55	14.75
Free spectral range (MHz)	11.95	10.17
Resonant modulation frequency (MHz)	23.90	30.51
Recycling cavity length (m)	9.41	12.29
Indices n, k	2,1	3,2
Non-resonant modulation frequency (MHz)	35.86	20.34
Index n	3	2
Offset from closest RC cavity resonance (MHz)	3.99	2.03

5 CONDITIONING AND STEERING OPTICS

The following diagram shows the set of conditioning and steering optics downstream of the RF modulation. These are the last optics encountered before the light enters the vacuum, and are bolted to the optical table.

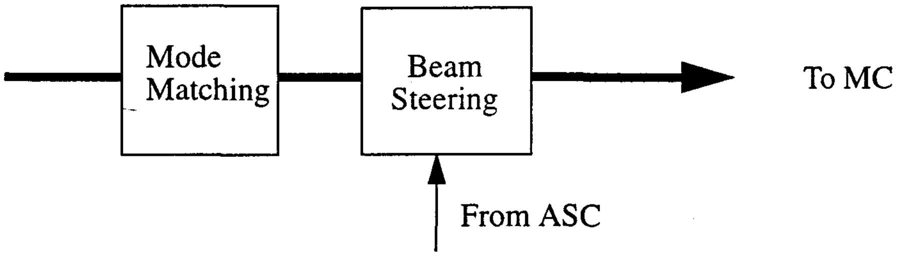

Figure 5: IOO Conditioning and Steering Optics

The beam steering optics are low-bandwidth (<1 kHz) PZT driven mirrors which use an ASC wavefront error signal to actively align the light with the mode cleaner optical axis to ~10^{-7} rad, allowing the IO requirements on power throughput and frequency stability to be met.

6 MODE MATCHING INTO MODE CLEANER

The mode-matching optics indicated in Figure 6 is a three-lens arrangement which allows the waist of the PSL to be matched to the Gaussian parameters of the mode cleaner. Using 3 lenses, it is possible to control independently the waist position and the waist size.

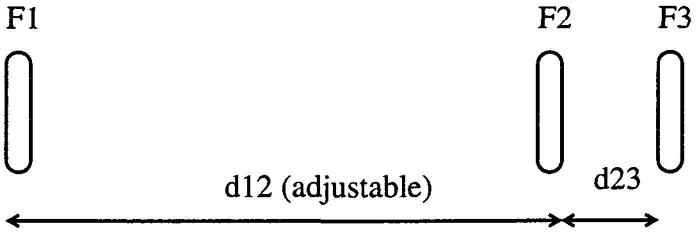

Figure 6: Mode Matching into Mode Cleaner

A three lens design allows for separate adjustment of waist position while maintaining constant waist size. Table 4 lists the mode matching parameters.

Table 4: Mode Cleaner Mode-Matching

Component	
F1 focal length (cm)	+ 150
F3 focal length (cm)	+ 5.02
F2 focal length (cm)	+17.5
d23 (cm)	22.52
PSL waist - F1 distance (cm)	297.5
nominal F3 - MC waist distance (cm)	300.0

7 MODE CLEANER

The suspended mode cleaner of the IOO serves the following functions in stabilizing the laser light.

- In-band active frequency stabilization.
- Rejection of laser output that is not in the TEM_{00} mode. (Beam Jitter suppression.)
- Passive frequency stabilization.

7.1. In-band active frequency stabilization

- Mode Cleaner frequency stability set by mirror vibrational thermal noise[1]
  - 10^{-4} Hz / rHz f = 100 Hz
  - 10^{-5} Hz / rHz f = 10 kHz

7.1.1. Mode Cleaner Servo Topology

The following diagram shows the feedback paths to the IOO (from the LSC L+ sensor) and the paths from the IOO to the PSL.

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[1] Mode Cleaner Noise Sources, LIGO-T0164-00-D

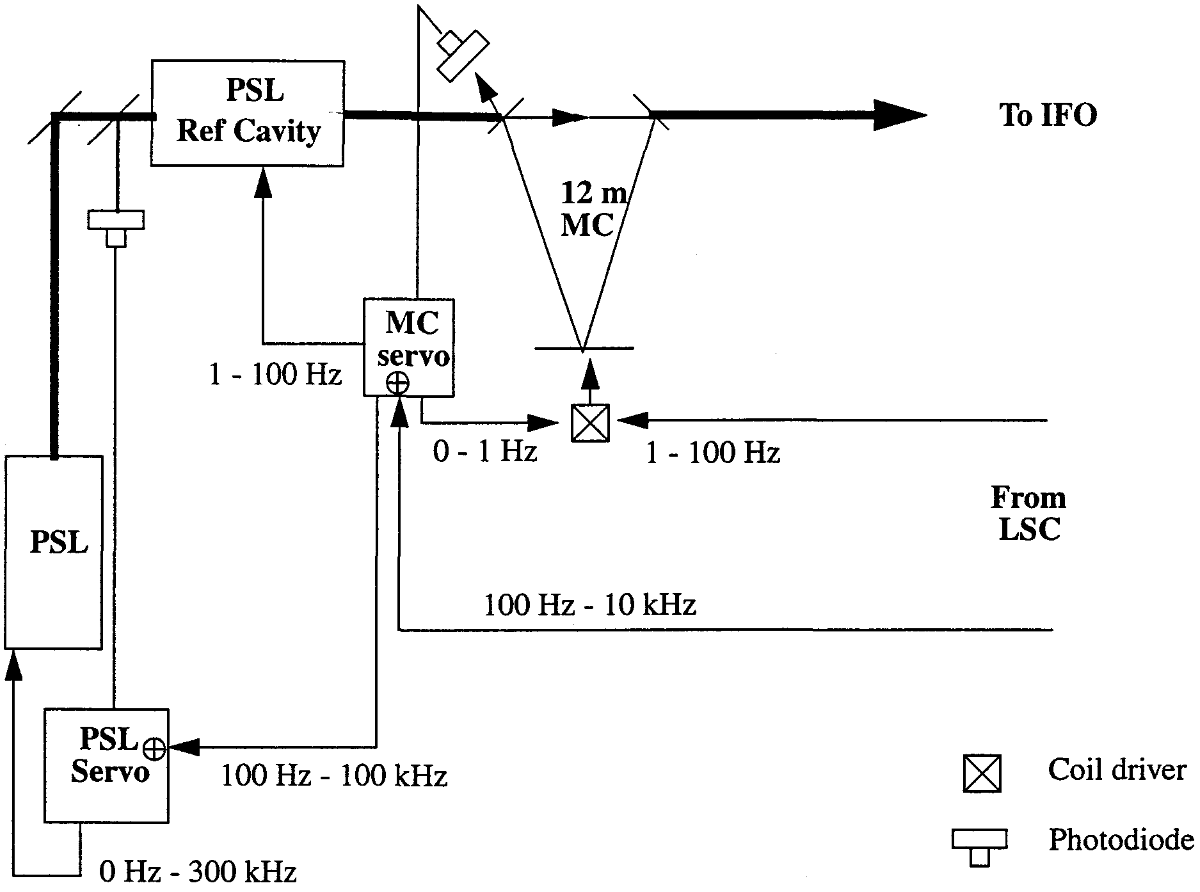

Figure 7: Mode Cleaner ν Stabilization Topology

The above topology yields the following features:

- Mode cleaner coil path for lock acquisition to PSL.
- Mode cleaner free spectral range stability of ~10^{-2} Hz by locking at low frequency to quieter PSL and arm cavities.
- Mode Cleaner servo gains, together with the LSC L+ loop gains, meet the LIGO frequency stability requirement: 10^{-7} Hz / rHz at f = 100 Hz.

7.2. Beam Jitter Suppression

The mode cleaner jitter suppression must be adequate to bridge the gap between the LIGO requirements and the PSL output beam performance. This is achieved with the optical specifications in the following table.

Table 5: Mode cleaner optical parameters.

	4k IFO	*2k IFO*
Optics diameter (mm)	75	75
Optics thickness (mm)	25	25
Cavity length (m)	12.55	14.75
Free spectral range (MHz)	11.95	10.17
Radius of curvature of converging mirror (m)	18.15	21.34
waist size (mm)	1.685	1.827
Rayleigh range (m)	8.38	9.86
Cavity stability product g	0.309	0.309
Beam radius at curved mirror (mm)	3.03	3.29
Beam radius at flat mirrors (mm)	1.68	1.83
Flat mirror transmittance (%)	0.2	0.2
Mirror absorption/scattering loss (ppm)	30	30
Intensity at curved mirror (kW/cm^2)	14	12
Intensity at flat mirror (kW/cm^2)	45	38
Circulating power (kW)	4.0	4.0

The cavity optical parameters were chosen to maximize the frequency offset of higher order TEM_{mn} mode resonances when the mode cleaner is resonant at the TEM_{00} frequencies. With the stability factor of 0.309 for both cavities, all of the first 15 modes are at least 750 kHz (640 kHz) away from resonance for the 4 km (2 km) interferometer.

Together these specifications result in an amplitude suppression of the 1st higher order mode by a factor of ~700 in electric field strength. Higher order mode suppression is shown in Table 6. The highest transmission is for the TEM_{12} and TEM_{21} modes. If 10% of the PSL power is in these modes, then the relative power in these modes leaving the mode cleaner will be about 3 ppm.

The mode cleaner stored intensity, ~ 50 kW / cm^2, is not expected to induce losses or cause thermal distortion. (A linear fixed cavity mode cleaner operating at a similar intensity level has been operating for several years at the 40 m laboratory.)

Table 6: Mode Cleaner Amplitude Suppression

Mode N=n+m	*4k IFO MC Suppression*	*2k IFO MC Suppression*
1	0.0014	0.0014
2	0.0012	0.0012
3	0.0058	0.0058
4	0.0016	0.0016
5	0.0011	0.0011
6	0.0029	0.0029
7	0.0020	0.0020
8	0.0011	0.0011
9	0.0020	0.0020
10	0.0029	0.0029

7.3. Passive frequency Stabilization

The mode cleaner acts as a passive low pass filter cavity with a pole frequency determined by the mirror transmission and cavity length. For the above parameters, we obtain a pole at ~ 4 kHz. This value meets the requirements for the LSC while keeping the mode cleaner intensity at the above mentioned "safe" level.

8 SIGNAL EXTRACTION

The Faraday Isolator rejects back-reflected light from the COC and directs the light to LSC/ASC photodetectors for length and alignment sensing. A schematic layout is shown in Figure 8.

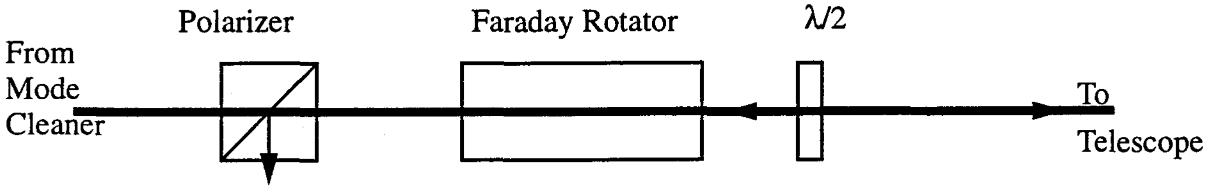

Figure 8: IFO LSC Signal Extraction

Table 7: Signal Extraction Components

Component	*Properties*	
Polarizer	Type:	Glan Laser
	Clear Aperture (cm):	1.0
	Extinction Ratio:	100000:1
Faraday Rotator	Material:	TGG
	Clear Aperture (cm):	1.0
Waveplate	Material:	Quartz
	Clear Aperture (cm):	1.0

All components need be compatible with SYS specifications for vacuum qualification. Permissible leakage magnetic field from the Faraday Isolator is TBD.

9 MODE MATCHING TO IFO

9.1. Telescope design

The Input Optics provides a beam to the IFO with mode characteristics determined by the fundamental (Gaussian) mode parameters of the Fabry-Perot cavity arms. The telescope must provide a beam that is 95% TEM_{00} in the FP cavities. The reflective telescope layout is shown in Figure 9 and Table 8.

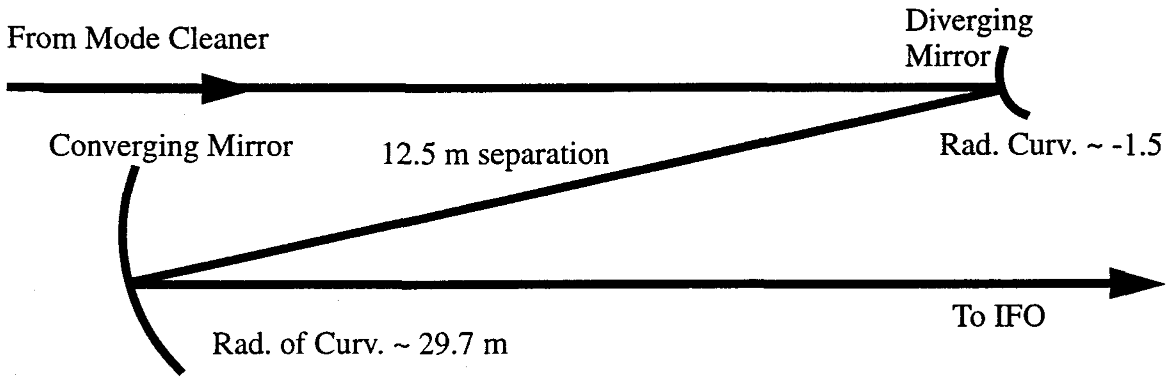

Figure 9: Mode Matching Telescope

Table 8: Proposed Telescope Geometry

Mirror	Radius of Curvature	Diameter	Thickness	Spot size	Incident angle	Surface figure
Input	-1.5 m	5 cm	2.5 cm	0.18 cm	8 mrad	λ / 20 (TBR)
Output	29.7	25 cm	10 cm	3.7 cm	8 mrad	λ / 20 (TBR)

The telescope optics are suspended to preserve the beam jitter and drift consistent with SYS specifications for in-band noise. We have chosen a reflective telescope design over a refractive telescope design primarily for two reasons. First, surface reflections from lenses can feedback into the IFO, while modal analysis codes show that slightly tilting the lenses to steer the back-reflected light off-axis results in unacceptable higher order mode amplitudes in the transmitted beams. In addition, reflective telescope optics provide steering capability into the IFO without the use of additional large suspended beam steering optics.

10 INPUT OPTICS ALIGNMENT

We consider a conceptual design for the alignment of the Input Optics consistent with the IO requirements on the mode cleaner and mode matching telescope.

10.1. Disturbances in IO components

The sources of noise to the IO components are slow stack translational and angular drift[1], stack low frequency displacement and in-band tilt[2], and residual angular fluctuation of suspended components.[3]

• Stack angular drift	10^{-5} rad / day
• Stack translational drift	10^{-5} m / day
• Stack displacement (f = 1.5 Hz)	3×10^{-7} m / $\mathrm{Hz}^{1/2}$
• Stack in-band tilt	10^{-16} rad / $\mathrm{Hz}^{1/2}$
• Suspended component in-band tilt (100 Hz)	10^{-18} rad / $\mathrm{Hz}^{1/2}$
• RMS angle of suspended components (f > 0.1 Hz)	5×10^{-7} rad

10.2. Mode Cleaner Alignment Requirements

The alignment requirements for the mode cleaner, listed in the IOO DRD, are summarized here.

• Low frequency alignment stability (with respect to incident light)	
• Frequency stability requirement	$\theta_{rms} < 3 \times 10^{-7}$ rad
• In-band alignment stability	
• Jitter rejection	$\theta < 10^{-12}$ rad / $\mathrm{Hz}^{1/2}$

10.3. Mode Matching Telescope Alignment Requirements

The mode matching telescope must be sufficiently aligned so that the following modal requirements are satisfied:

- IFO acquisition: > 85% power TEM_{00}
- IFO detection: > 95% power TEM_{00}
  $< 10^{-3}$ amplitude TEM_{03} (TBR)

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[1] F. Raab, SEI DRD

[2] G. Gonzales, ASC: Environmental Input to Alignment Noise, LIGO-T960103

[3] Ibid

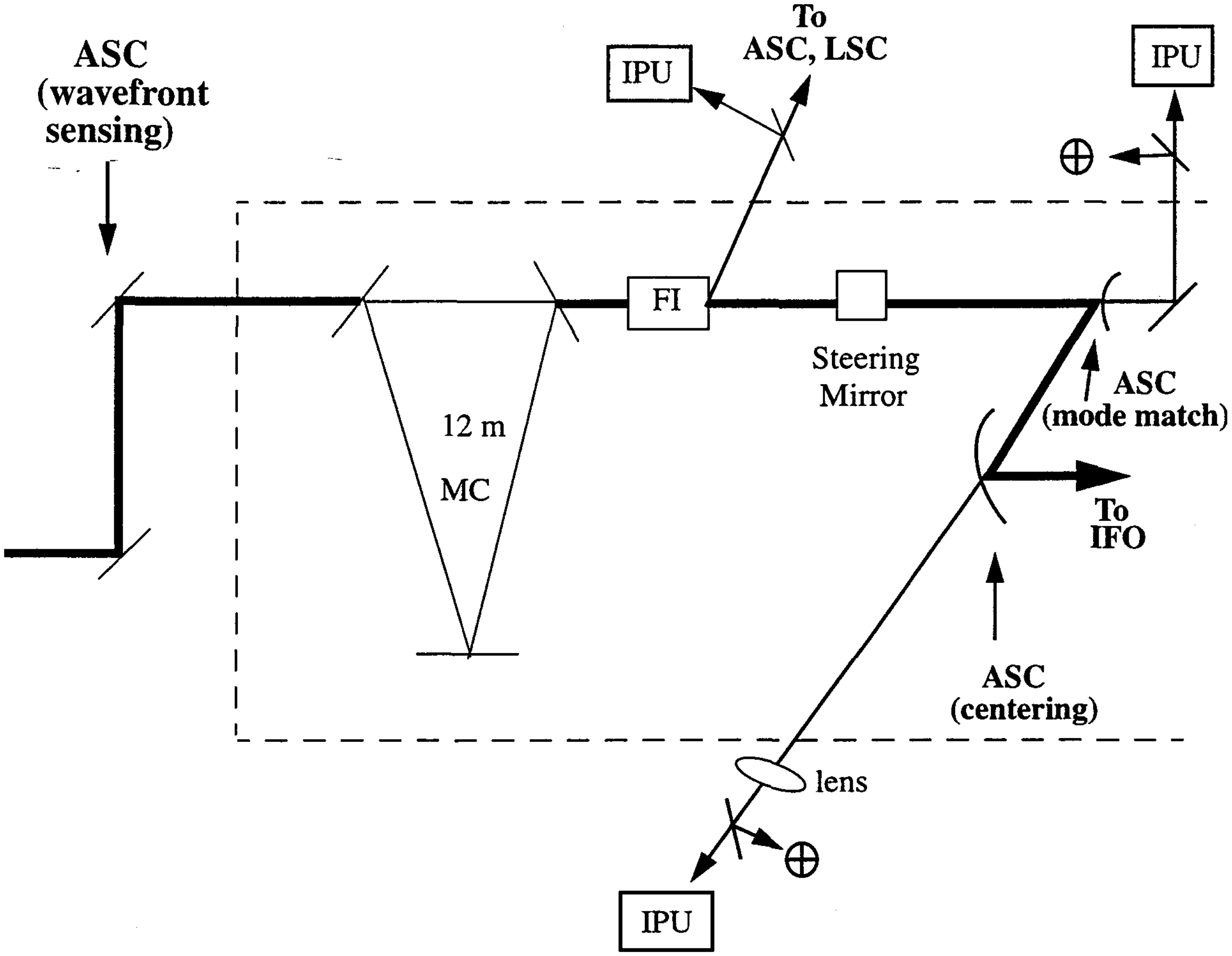

Figure 10: IOO alignment concept

The alignment requirements are met in the following layout (discussed below). The alignment of the IOO is accomplished with WFS alignment feedback to the mode cleaner input steering mirrors to align the beam into the mode cleaner and ETM centering feedback to the output telescope optic to align the beam pointing out of the IOO. The use of video cameras and quad photodiodes will keep the mode cleaner output beam centered on and aligned to the telescope. A diagnostic from the ASC indicating the mode matching efficiency[1] will also be used to fine tune the telescope alignment with respect to the input beam.

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[1] ASC Conceptual Design, LIGO-T960134-00, sec. 5.3

10.4. Conceptual Design: Beam Centering

10.4.1. Mode Cleaner Centering

The mode cleaner centering requirements, ~ 3 mm[1], will be satisfied during the initial alignment procedures and are not expected to be exceeded in normal operation.

10.4.2. Faraday Isolator Centering

With a nominal aperture of 1 cm, the spot should be centered to ~ 1 mm on the Faraday Isolator to prevent clipping. The centering will be monitored by an Image Processing Unit (IPU) of the type described in the ASC conceptual design and is expected to be stable during normal operation.

10.4.3. Mode Matching Telescope Centering

The mode matching telescope centering requirements are of order mm's on the input and output mirrors and will be determined during the preliminary design phase. The centering on both optics is monitored with an IPU.

10.5. Conceptual Design: Alignment

10.5.1. Mode Cleaner Alignment

The light into the mode cleaner must be aligned to the mode cleaner optical axis to within ~ 10^{-7} rad to satisfy the requirement that jitter induced frequency noise is kept below the intrinsic mode cleaner frequency noise. This is done with wavefront sensing fed back to steering mirrors at the input to the IO vacuum optical port.

10.5.2. Faraday Isolator Alignment

We propose to bolt the Faraday Isolator directly to the optical table to keep the number of suspended components to a minimum. We consider the effects of imposed beam jitter and upconverted phase noise from this transmissive optic.

The in-band tilt of the table, $\sim 10^{-16}$ rad / $\mathrm{Hz}^{1/2}$ at 100 Hz, will cause a displacement of the transmitted light of order 10^{-17} m /$\mathrm{Hz}^{1/2}$, giving a 1st higher order mode to fundamental mode ratio of $\sim 10^{-14}$ / $\mathrm{Hz}^{1/2}$. This number is well below the ASC requirement ($\sim 10^{-9}$ / $\mathrm{Hz}^{1/2}$).

Another concern is upconversion of backscattered light from IFO reflected light incident on the downstream polarizer antireflection coating. Using the LIGO standard seismic spectrum and a HYTEC type leaf spring stack (Q = 30), we find the up-converted cut-off frequency $f_c = (v_{rms} / \lambda) \sim 1$ at f = 1.5 Hz (1st stack resonance). This is well outside the LIGO signal band.

We conclude that bolting the isolator to the table will not degrade the IFO sensitivity.

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[1] ASC DRD, LIGO T952007-03-I

10.5.3. Telescope Alignment

In table 9 we list the effect of a telescope misalignment on the output mode structure for the 2 regimes of IFO acquisition and alignment. This table, obtained by calculating the modal contamination suffered in reflection from the misaligned telescope mirrors[1] (which also expand the gaussian beam through paraxial ray propagation) assumes a perfectly spherical surface figure; inclusion of a realistic figure will be undertaken in the preliminary design phase. In the calculation it was assumed that any output TEM 1 component could be removed by the alignment of the IFO optical axis to the beam; the higher modal components induced by the IFO alignment were added to the output beam corresponding modes in absolute value (worst case). During the preliminary design phase the mode matching of the IFO to the telescope alignment will be exactly determined.

Table 9: Modal Contamination from Telescope Misalignment

Input Mirror Misalignment	Output Beam Modal Composition (amplitude)		
	TEM 0	TEM 2	TEM 3
50 urad (IFO acquisition)[a]	0.93 (TBR)	0.34	0.12
1 urad (IFO detection)	0.999	0.01	0

a. The output mirror is aligned to 0.1 µrad of IFO axis through ETM centering

10.5.3.1 IFO acquisition mode

10.5.3.1.1 Pointing

Before the IFO is locked the ASC will not be able to provide the mode matching error signal to tune the telescope alignment, with the result that the telescope output mode composition will not be optimal. The IOO initial alignment must however be sufficient for IFO locking.

The initial alignment is achieved in the following way. We assume the availability of a pilot beam setup of the type described in the ASC conceptual design[2], sec. 2.1.2, which provides a line of sight within 10^{-4} rad of the interferometer optical axis. The beam will be directed *upstream* from the recycling mirror chamber to illuminate the output telescope mirror, which will be aligned to retroreflect the beam. After locking an optical lever reflection from the mirror to a fixed reference, the mirror will be rotated 8 mrad, the required off-axis alignment. Continuing upstream, the input mirror will aligned in a similar way, followed by the steering mirror which will direct the beam to the center of the mode cleaner output mirror. The mode cleaner will then be aligned by simultaneously centering and superimposing the light as its weak reflections traverse the cavity. The pilot beam will then be removed while a low power PSL beam is aligned to the mode cleaner with the input steering mirrors, brought through the locked cavity, centered on the telescope mirrors, and directed to the recycling mirror. Retroreflection of the beam will allow the initial alignment of the

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[1] see Principles of Calculating Alignment Signals in Complex Resonant Optical Interferometers, LIGO-T960005-00-R

[2] ASC Conceptual Design, LIGO-T960134-00-D, sec. 2.1.1

ASC to proceed as described in the ASC conceptual design, section 2.1.4 and following. The resultant initial ASC and IOO alignment will produce a telescope alignment at the level of 10^{-4} rad. The factor of 2 difference between this value and that of Table 9 will be resolved in the preliminary design.

10.5.3.1.2- Mirror Separation

Deviations from the nominal mirror separation result in higher order cylindrical modal contamination in the IFO. From ray tracing modeling of the waist position and size, deviations in the separation of Δd_{12} = +/-1.2 cm results in an degradation of optimal mode matching to ~98 % of the light in the TEM_{00} mode. Positioning the mirrors within this tolerance will be achieved by mounting the diverging telescope mirror on a vacuum compatible motor driven stepper stage.

Determination of the nominal telescope separation will be accomplished using the w_{ETM}, the size of the spot on the end test mass. The following table shows how the modal content and ETM spot size vary with mirror separation. $U_1(r)$ is the amplitude of the first higher order cylindrical mode.

Table 10: Modal Contamination and ETM Spot Size Due to Deviations in Telescope Mirror Separation

$\Delta\ d_{12}$ (cm)	$U_1(r)$	w_{ETM} (cm)
0	0.000	4.564
-1.2	0.112	5.071
+1.2	0.112	4.165

Measurements of variations in spot size shown in Table 10 are easily accomplished using commercially available beam profiling systems, such as Spiricon.

10.5.3.2 IFO detection mode

10.5.3.2.1 Pointing

In the interferometer detection mode, we assume that the ASC has aligned the interferometer about the beam through wavefront sensing and we also assume that an ASC mode matching diagnostic has been used to manually adjust the pointing of the light into the telescope to achieve the optimal output mode structure. In table 9 we list the effect of a ~1 μrad fluctuation of the mode cleaner output pointing with respect to the telescope, the nominal variation, on the output mode structure. The effect is seen to be negligible.

Finally, we observe that the in-band modal composition of the light is not affected by the telescope low frequency alignment fluctuation, and that the (suspended) telescope is sufficiently isolated from seismic noise that imposed jitter on the light is negligible.

10.5.3.2.2 Mirror Separation

Deviations in Δd_{12} of - 4 mm from nominal separation result in spot size on the ETM which no longer meets the 1 ppm aperture criterion. The stepper stage will be used to tune the mirror separation at this level.