Detector Subsystems Requirements

DHS objectives for review:

- make the DSR Document **the** reference for the interferometer design
  - top-level reference for all subsystem designs
  - (much lower-level detail still to be held in DRDs)
  - all changes to require a formal action
- critical review of content of DSRD, as per charge
- bring several unresolved issues to light
- show work to be done
- outline other Ifo Systems activities

Organization of presentation:

- follow the DSRD rather closely
  - facilitates comments from text (please interrupt)
- follow with other systems activities (Dennis Coyne)

Intended Scope of complete document

How detector subsystems deliver SRD performance

- interpretation of the SRD
- translation into subsystems requirements for gaussian noise
- for non-gaussian noise
- for availability

Definition and interfaces of subsystems

- top-level conceptual design
- what is in/out of each subsystem
- detailed interfaces

Performance models

- gaussian noise model

Materials handling, reliability, and testing

- allowed materials
- cleaning methods for in-vacuum use
- contamination issues

Standards and processes

- design and construction
- documentation
- transportability, preparation for delivery
- quality assurance

Top-level Conceptual Design

Objectives:

- give a skeleton on which the requirements can be hung
- give key interface frontiers

Applicable Documents

This Detector Subsystems Requirements Document:

- based on the DRDs and other Detector Group work
- once all conflicts with existing documents resolved,
- takes precedence over all other Detector Requirements Documents
- any changes in design require a formal process

Other documents cited

- objective: to give a complete bibliography of significant documents

Assumptions and Dependencies

Vacuum Equipment

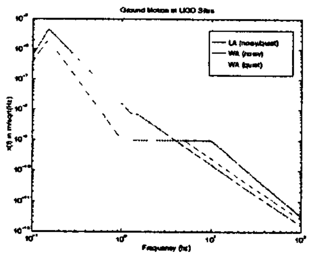
- 1 m clear aperture
- all aperture available for these interferometers

Impact of some upgrades to be considered in subsystem design

- increased input laser power, by about a factor of 10
- alternative interferometer readout configurations
- replacement of core optics components with higher-quality optical components
- changes in substrate material for lower thermal noise
- improvement of passive and/or active seismic isolation
- improvement of the suspension system (e.g., a double pendulum; electrostatic actuation)

Environment

Seismic environment



- stationary noise as characterized for the bare buildings
- quotation of requirements for building, VE performance
- non-stationary noise needs characterization
- narrow-band disturbances as required by SRD

Acoustic environment

- steady state noise as required by CC documents
- additional noise from our (CDS) equipment estimated
- non-stationary noise, rain/wind, little known

Environment

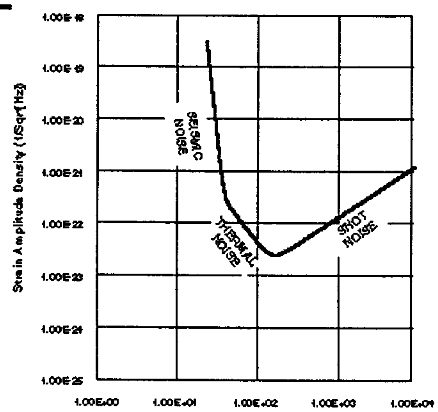
Electromagnetic environment

- measurements of the ambient man-made fields exist
- guidelines exist (EMI Control Plan)
- no real requirements for our emission, nor test procedures required

Vacuum

- requirements for BT are at a level of ~1/2 SRD
- expectation (from QT tests) are at ~1/20 SRD
- no real data on bursts, but models indicate clear signature

Requirements: The SRD



Distinctions between stationary gaussian noise types

- 'fundamental' noise
  - › those that determine the SRD, and present challenges
  - › shot, suspension thermal, stack seismic
- 'technical' noise
  - › electronics, phase noise in excess of shot
  - › thermal or seismic entering through other paths

Requirements for Fundamental Noise

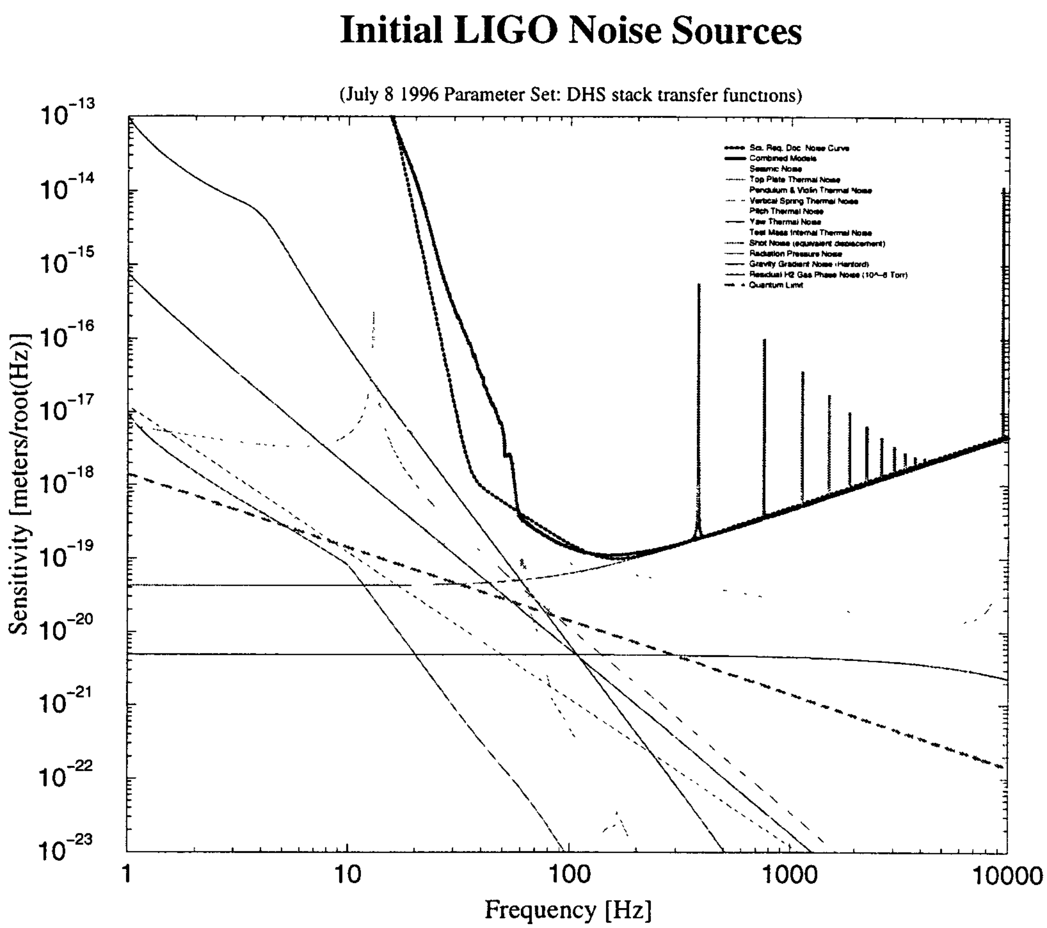
SRD sensitivity curve

- interpreted as an envelope not to be exceeded
- can make some limited choices as to composition of noise terms
  - › thermal noise region is $1/f^2$, not appropriate for internal damping
  - › arm cavity knee frequencies not prescribed
  - › actual seismic noise source not a simple power law
- no prescription for Narrow-band exceptions
  - › intend to develop both RMS (controller) and
  - › peak height/width criteria

Approach for fundamental noise sources

- express SRD as a sum of curves in seismic, thermal, shot regions
- for each region, allocate contributions
  - › use RES noise tree as one cross check
  - › use subsystem DRDs/authors as another
- often, no real choice (technical limit; e.g., thermal noise)
- assume least-squares addition of independent noises

Noise model

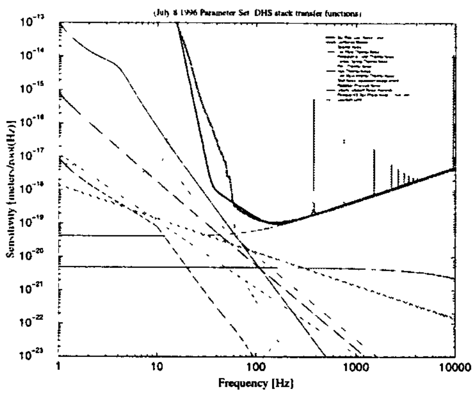


Should reflect current design

- uses noise models from design effort (in general)
- uses parameters based on experimental data when possible
- at present, includes primarily 'fundamental' sources
- (seismic curve is 'double viton'—not a present design)

Noise model

Initial LIGO Noise Sources



Should reflect current design

- uses noise models from design effort (in general)
- uses parameters based on experimental data when possible
- at present, includes primarily 'fundamental' sources
- (seismic curve is 'double viton'—not a present design)

Seismic noise

SRD requirement:

$h_{seismic} = h_{0s}\left(\frac{30\ \mathrm{Hz}}{f}\right)^{14}, h_{0s} = 3.3\times10^{-21}\frac{1}{\sqrt{\mathrm{Hz}}}, 20 < f < 60$

Drift

- require performance equal to Viton stack, with 20 days of settling time
- determines bellows design, sizing of support beam
- could reconsider if we can commit to non-Viton spring

Resonances

- solid-body motions, 1-20 Hz
- determines servocontrol design for LSC, ASC
- require $Q < 70$, consistent with Hytec designs
- higher frequency resonances not to exceed RMS values
- also, not to exceed TBD narrow-band requirements

GW band stack isolation

- requirement is to meet SRD, given suspension XF
- Viton stack is insufficient; Hytec designs meet requirement

GW band suspension isolation

- many constraints on design (violin, vertical, stress, horizontal)
- allow design priority, thus $f_p = 0.74$ Hz, $f_v = 13$ Hz

Thermal Noise

SRD Requirement:

$h_{thermal} = h_0(100/f)^2, h_0 = 3.8\times10^{-23} 1/\sqrt{\mathrm{Hz}}$, $30 < f < 160$ Hz

- slope does not match that anticipated for any one thermal noise source
- best effort for all aspects of thermal noise; drives other designs, in fact

Core Optics

- 'require' $<2\times10^{-7}$ loss per mode (as extrapolated from measurements)

Suspensions: internal modes of TMs

- require $<8\times10^{-20}(100\ \mathrm{Hz}/f)^{1/2}\ \mathrm{m}/\sqrt{\mathrm{Hz}}$ net contribution
- puts constraints on magnets, attachments, suspension techniques

Suspensions: pendulum mode

- require $1\times10^{-19}(100\ \mathrm{Hz}/f)^{5/2}\ \mathrm{m}/\sqrt{\mathrm{Hz}}$ net contribution, $30 < f < 160$ Hz
- also, violin resonances $\Delta f/f_0 < 10^{-5}$ and less than 2% variation in freq.
- puts constraints on wire, wire tension, clamping techniques

Shot noise

SRD Requirement:

$h_{shot} = h_0\sqrt{1+\left(\frac{f}{f_0}\right)^2}, h_0 = 1.13\times10^{-23}\frac{1}{\sqrt{\mathrm{Hz}}}, f_0 = 90\ \mathrm{Hz}, 130 < f < 10^4\ \mathrm{Hz}$

- pole frequency not explicit in SRD, choose 90 Hz

Degradation factor '(0.005)'

- designed to give tolerances to parameters affecting shot noise
- distinct from (but equal degradation from) additional noises @ 1/10 SRD

Calibration

- precision to come from System Engineering
- LSC to provide practical constraints

Shot noise

Useful light power

- 6 W required coupled into Recycling Cavity (allows SRD to be realized)
- distributed as follows; power is for carrier and GW-sensing SB:3

Property	*Requirement*
PSL output power	8.5 W
IOO optical efficiency	0.75
IOO coupling efficiency to COC	0.95
Coupling from COC to ASC/LSC (COS)	0.99
ASC/LSC Symmetric port splitter	0.05/0.95
ASC/LSC Antisymmetric port splitter	0.01/0.99
GW antisymmetric port photodiode quantum efficiency	0.8

Notes on Power:

- IOO coupling to ifo will be expressed in allowed higher order modes
- these values to be maintained for optics tolerances (initial, thermal focussing)
- output beams (COS) to be flat to $\lambda/10$

Shot noise

Configuration

Property	*Requirement*
Recycling cavity optical length (physical length shorter due to substrate index)	9.38 m (4km) 11.67 m (2km)
Mode cleaner optical length	12.55 m (4km) 14 75 m (2km)
Schnupp optical length asymmetry (4 km)	$l_1 - l_2$ = 31 cm nominal; -1 to +50 cm range
GW readout modulation frequency (4 km)	24.0 MHz
GW readout modulation depth (4 km) at recycling cavity input	Γ=0.45 nominal; range TBD $0 < \Gamma < 1.0$
ASC non-resonant sideband frequency	TBD
ASC non-resonant sideband modulation depth	TBD

Deviations from optimal lengths

- here, to maintain shot noise (power circulating); '(0.005)'
- as technical noise source (e.g., coupling to frequency noise) elsewhere
- sum of the Arm lengths $L_+ < 2.5\times10^{-12}$ m RMS
- sum of the two inside ifo arms $l_+ < 1\times10^{-10}$ m RMS

Shot noise

Angular alignment of core optics

- COC shall be held within 1×10^{-8} rad rms of the optimal alignment
- reflects power coupling efficiency
- also, determines coupling to beam jitter (tech noise)
  - coupling to beam jitter means actual value needed
  - in fact, varying sensitivity per mirror; criterion should be '(0.005)'

Centering of beams

- TMs: such that <0.1ppm additional loss (tech req dominates)
- BS, RC: such that <100ppm additional loss (trivial)

Optics Requirements

- trades of thermal noise, fabrication ease, diffraction loss
- not truly optimized, but mostly slow functions, broad maxima
- optical efficiency, contrast quality, frequency response principal drivers
- 2km optics not yet called out, but now possible
- overcoupling of recycling cavity active question
  - determines s/n for reflected signals
  - sensitive to optics degradation

Shot noise

Property	*Requirement*
Optic Sizes	TM, RM: 25 cm dia., 10 cm thick
	BS: 25 cm dia., 4 cm thick
Coated surface	24 cm dia.
Beam Sizes	ITM: 3.6343 cm w_0, ETM: 4.5655 w_0, BS: 3.6359 w_0, RM: 3.6377 w_0
Radii of Curvature (tolerances to maintain strain sensitivity to 0.95 nominal)	ITM: 14571 m; -0.07< $\Delta R_{ITM}/R_0$ <0.01
	ETM: 7400.0 m; $\Delta R/R_0$ of 0.03
	BS: flat/flat, tolerance TBD
	RM: 9998.33m; -0 01< $\Delta R_{RM}/R_0$ < 0.05
Surface figure	equivalent to '1.5 × Calflat'
Mirror transmissions	ITM: 0.030±0.00015
	ETM: 10<T<20 ppm
	BS: 0.50±0.01 TBD
	RM: Overcoupled, 0.1 E field reflected
AR Coatings:	ITM, RM: 600±300 ppm
	BS, ETM: 200±100 ppm
Mirror losses:	50 ppm scatter+absorption
Substrate index	1.44963 (Heraeus), 1.44968 (Corning)
Substrate OPD for BS, ITM, RM	5×10^{-7} p-v, λ = 632 8 nm, cntr 150 mm 2.5×10^{-6} p-v, λ = 632.8 nm, cntr 225 mm
Substrate absorption	<2 ppm/cm
Substrate scatter	<5 ppm/cm

Technical gaussian noise sources

Allocation of 1/10 SRD (called '10%' in DSR)

- addition in quadrature, so each makes s/n 1.005 worse
- different frequency regimes
  - thermal (< 150 Hz), or with a slope
  - shot (>150 Hz), or flat/rising
- order of 10 of each, leading to ~5-10% degradation above SRD

Mechanical technical noise

Thermal noise

- stack final stages (1/10)
- suspension pitch and yaw (1/10)
  - enters through mis-centering of beams on optics
  - thus, both thermal noise requirement $5\times10^{-18}\times(100\ \mathrm{Hz}/f)^{5/2}(\mathrm{rad}/\sqrt{\mathrm{Hz}})$
  - and centering: within 1.0 mm of center of rotation of test masses

SEI operational stack actuator (1/10)

- 1/10 SRD $f > 20$ Hz
- 1/10 ambient seismic environment $f < 20$ Hz

SEI internal noise generation (1/10)

- creaking - groaning (non-stationary?)

SUS

- coil drivers, longitudinal motion (1/10)
- displacement to angle coupling (1/10)
  - ASC noise input< $2.5\times10^{-18}(100/f)^{2.5}\ \mathrm{rad}/\sqrt{\mathrm{Hz}}, 40 < f < 150$ Hz; $1\times10^{-18}\mathrm{rad}/\sqrt{\mathrm{Hz}},\ f > 150$ Hz
  - SUS controller orthogonality 10^{-2}
- angle to displacement: intrinsic coupling in suspension 10^{-2}
  - leads to gain requirements for ASC, no net noise increase

Mechanical technical noise

Radiometer effect (1/10)

- laser intensity noise requirement very tight (see below), so:
- calculated to be negligible for any reasonable BS match

SUS response to magnetic fields (1/10)

- easy to require, hard to know if we will achieve
- requires $B < 10^{-12}\mathrm{T}/(\sqrt{\mathrm{Hz}})$, or $A < 50\mu\mathrm{A}/\sqrt{\mathrm{Hz}}$ at 1 m

SUS response to electrostatic forces (1/10)

- easy to require, hard to know if we will achieve

Excess PhaseSensing Technical Noise

Light intensity fluctuations (1/10)

- LSC: differential length requirements
  - $L_1 - L_2 < 1\times10^{-12}$ m RMS
  - $l_1 - l_2 < 1.3\times10^{-10}$ m RMS
- PSL: responsible for entire intensity servocontrol, so
- at input to the IOO: $\delta I(f)/I < 10^{-6}\ 1/\sqrt{\mathrm{Hz}},\ 40 < f < 10000$
- at input to the COC: $\delta I(f)/I < 10^{-8}\ 1/\sqrt{\mathrm{Hz}}$
- IOO: responsible to deliver a sample of light to PSL

Light frequency fluctuations (1/10)

- COC: arm storage times to be matched to $(\tau_1 - \tau_2)/\tau_{ave} < 0.01$
- PSL: frequency sensing system to have
  - $\delta\nu(f) < 10^{-1}\ \mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at 100 Hz, falling at f^{-1} to 1 kHz
  - rising no faster than $f^{-2.5}$ $f < 100$ Hz
- IOO: frequency sensing system to have
  - $1\times10^{-4}\ \mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at 100 Hz with $f^{-0.5}$ above 100 Hz
  - $f^{-2.5}$ frequency dependence below 100 Hz
  - limited by thermal noise in MC mirrors/suspension

Excess Sensing Technical Noise

Light beam geometry fluctuations (1/10)

- ASC: requirement set above to meet SRD shot noise requirement
- IOO: couples with the RMS misalignment, giving requirements of
  - $\alpha(f > 150\ \mathrm{Hz}) = 3\times10^{-14}(\mathrm{rad/Hz^{1/2}})$ and may rise as $1/f^2, (X < f < 150)$
  - $x(f > 150\ \mathrm{Hz}) = 1\times10^{-10}(\mathrm{m/Hz^{1/2}})$ and may rise as $1/f^2, (X < f < 150)$
- PSL:
  - $\alpha(f > 150\ \mathrm{Hz}) = 3\times10^{-11}(\mathrm{rad/Hz^{1/2}})$ and may rise as $1/f^2, (X < f < 150)$
  - $x(f > 150\ \mathrm{Hz}) = 1\times10^{-7}(\mathrm{m/Hz^{1/2}})$ and may rise as $1/f^2, (X < f < 150)$
  - do not have much data on YAG lasers, but believe to be workable using a passive filter cavity

RF modulation source (1/10)

- couples through the modulation system, and asymmetries
- AM noise <-160 dBc / $Hz^{1/2}$ at f >100Hz
- Phase noise < -70 dBc / $Hz^{1/2}$ at 100 Hz, <-120 dBc / $Hz^{1/2}$ at 10 kHz

LSC control system

- L_- control system, including photodetector noise, linearity (1/10)
- L_+, l_+, l_- control systems: shot noise and other effects (1/10)

ASC control system

- all sources, not considered as fundamental contributors (1/10)

Excess Sensing Technical Noise

Parasitic interferometers (1/10)

- accidental interferometers due to scatter within Rayleigh angle
  - direct contributions due to motion (or phase jitter) in GW band
  - upconversion due to reflectors with large velocities $\dot{x} < 40\mathrm{Hz}\cdot\lambda/4\pi$
- SUS: constraints on the damping of the BS and RM ('reference masses')
- COC: requirement that wedges be sufficient to avoid accidental ifos
- IOO: requirement of $<10^{-8}$ in power as viewed from the COC,
  - and $\dot{x} < 40\mathrm{Hz}\cdot\lambda/4\pi$ (Faraday...)
- PSL: relative velocities of all components of $x < 40\mathrm{Hz}\cdot\lambda/4\pi$
  - may involve active isolation of the PSL table and/or servos
- needs work

Scattered light (1/10)

- accidental interferometers outside of Rayleigh angle
- COC: principal source;
  - substrate scatter <5ppm/cm; superpolished substrates
- COS
- SUS
- IOO
- PSL
- LSC: photodiode uniformity

Excess Sensing Technical Noise

Mirror Heating

- impact on performance during operations (availability later)
- COC: BS shall split evenly to better than 49.5/50.5
  - bulk and initial surface absorption assumed symmetric
  - imbalance in power between arms causes defocussing
  - should be in fundamental sources!

Availability

SRD Requirement:

- 40 hours continuous operation of each individual interferometer
- annually integrated availability of 90%
- short loss of lock allowed within this window

Detector requires:

- all subsystems designs to be capable of >40 hours continuous operation without loss of lock (even for short times)
  - requires actuators to have >24 h dynamic range
- SUS: actuator displacement range of $\geq \pm 20\mu\mathrm{m}$
- SEI: fine actuator displacement resolution of $\leq 2\mu\mathrm{m}$. pole at 0.15 Hz
- PSL: no mode hops >40 hours
- LSC re-acquisition time: 180 sec (after no more than 300 sec unlocked)
- IOO re-acquisition time: 20 sec
- PSL re-acquisition time: TBD
- needed: some requirements on reliability to be consistent with availability

Commissioning

Staged approach to final configuration

- detector subsystems must allow partial implementations of the optics for initial operation (and later troubleshooting)
- needs work with Systems Integration

Initial Alignment

- PSL: modulation requirements
  - chopping at 50% intensity, 2 Hz, slew time of 0.05 sec
  - calibrated attenuator, full power to 10 mW, factors of 3 in power with servos in operation (although at reduced performance TBD)
- ASC: will provide means to place components in angle and transverse to beam
- Detector Systems: will provide means to place components along optical axis

Timing accuracy

- The strain data acquired from the detector shall have an absolute time-stamp accuracy of less than 10 μsec TBD as implemented through the CDS Data Acquisition system
- maybe this should be SystemsIntegration

Cleanliness

Allowed in-vacuum materials

- as specified in LIGO-E960022-02-E, Vacuum Compatibility

Cleaning procedures

- as specified in LIGO-E960022-02-E, Vacuum Compatibility

Performance requirement

- degradation of not worse than $h_{\text{one year}} < 1.10 \times h_0$ TBD
- no present knowledge to allow this to lead to materials selection/ processes - setting up measurement task
- scary numbers from models: 1ppm absorption makes 25% change in ITM radius of curvature

Non-gaussian noise

'Needs considerable development.'

- characterization of environment
- characterization of suspension stress-release
- characterization of laser source
- could make requirement of 'PEM should do its job'

'Boilerplate'

Will refine and make useful the sections on

- Transportability
- Design and construction
- Documentation
- Test plans and procedures
- Logistics
- Preparation for Delivery

Quality Assurance

- should be organized by existing LIGO QA plan and staff

Optical Layout, Interface Documentation

To be addressed by Dennis Coyne

- top level information to be incorporated in DSR

Optical Layout: Background

- By its very nature the layout must be an integrated design effort

  ››The task can be segmented into optical design/layout separately for the PSL, Input Optics, Output Optics and (to an extent) the ASC optlev & WFS tables

  ››the Core Optics, Core Optics Support (pick-off beams & beam transport to viewports, beam dumps, baffling) are of necessity integrated layout efforts

  ››Detector Systems Task

- Integrated layout effort must be done in-house with the tools and personnel trained in the use of the codes in-house.

  ››Due to the intimate coupling of the optical layout and mechanical design/layout

  ››Need for revision of the optical layout will exist through integration

Optical Layout: Background continued

- We have a considerable investment in the development of a LIGO model by ORA using their LightTools program

  ››comprehensive, integrated 3D model of the entire LIGO system (PSL, IOO, ASC/LSC, COS and COC) with 3D surface representation of the vacuum chambers and manifolds

- The model was developed a bit prematurely in the program with the result that:

  ››- the PSL is based on an Ar-Ion laser and must be changed substantially for the Nd-YAG system

  ››- the Input Optics layout is somewhat different from the Univ. of Florida conceptual design

  ››- the recycling cavity and mode cleaner lengths are different

  ››- the alignment approach is entirely different

- As a consequence, we are not wedded to LightTools

Optical Layout: Requirements

- Optical Layout

  ››sequential, geometric ray-tracing (non-sequential ray-tracing is not necessary)

  ››include standard optical elements, in particular wedged beamsplitters, mirrors, beam dumps, wedged windows, etc.)

  ››capable of tracing multiple internal reflections

  ››able to handle on the order of 500 elements

  ››import/export through IGES (3D) for coordination with mechanical CAD

  ››sensitivity analysis (temperature, vibration, misalignment, etc.)

  ››tool used principally by detector systems engin. for coordination/integration of design

- Lens Design

  ››for use in beam reducing telescope designs

  ››should be easy to use and available to ASC, IOO, COS, PSL designers

Optical Layout: Requirements continued

- Gaussian Beam Propagation

  ››principally for use by U. of Fl. for the Input Optics mode matching telescope design

  ››LIGO developed codes are used for analysis/design of the resonant cavities (FFT, Twiddle, SMAC, etc.)

- Scattered Light Analysis

  ››Chamber and vacuum manifold baffling and beam dumps are designed using "back of the envelope" analysis

  ››scattered light computation used to confirm and better quantify expected performance

  ››complex analysis & code -- maybe expedient to use an outside expert

Optical Layout: Tool Considerations

- Some of the better options -- not a complete listing/survey:

		Optical Layout	Lens Design	Gaussian Beam Prop.	Scattered Light	Ease of Use	Cost	Comments
LightTools	ORA	X	X			?	$4500/yr[a]	CAD environment
Code V	ORA	X	X	X	X	Hard	$0[b] or $100 or $2500	"premier" tool; somewhat more difficult to use than ZEMAX
ZEMAX	Focus SW	X	X	X		Easy	$2400 + $350/yr	afordable & easy-to-use; gaussian beam propagation is new; not clear if it can handle ~ 500 elements for optical layout
OptiCad	OptiCad	X	X			?	$3490 + $500/yr	?
TracePro	Lambda	X	X			?	?	?
SYNOPSIS	BRO	X	X			Mod	$2500	better than or equal to Code V
ASAP	BRO	X	X	X	X	Hard	$8400/yr or $15800 to $23000	hybrid FFT/modal based code; maybe a better option for stray light analysis than APART

		Optical Layout	Lens Design	Gaussian Beam Prop.	Scattered Light	Ease of Use	Cost	Comments
APART	BRO				X	Hard	$15000 add to JPL seats	the "standard" for telescope stray light analysis
GLAD				X		?	$5200	physical opics code
Paraxia				X		Mod	?	physical optics code (MIT/LIGO has a copy)

a. includes educational discount

b. No cost if LIGO uses one of the Astronomy Dept. licences, otherwise $100 for an additional PC copy
A stand-alone single licence (which Univ of Florida might need) would cost $2500.

Optical Layout: Tool Recommendations

- Optical Layout & Lens Design:
  - ››Ease of use and personnel familiarity outweigh technical considerations -- all of the reasonable options should be able to handle the geometrical ray-tracing problem
  - ››recommend ZEMAX for trial application
    - —will surely work for lens design
    - —if not adequate for optical layout in coordination with IDEAS CAD, then we could switch to another code, such as CODE V
- Gaussian Beam Propagation
  - ››MIT experience with Paraxia suggests another code would be desirable
  - ››ZEMAX has a gaussian beam propagation capability (new and untested by LIGO)
  - ››recommend trying ZEMAX and if it is not adequate, use CODE V (with contractor expert or ORA support if/as needed)

Optical Layout: Tool Recommendations continued

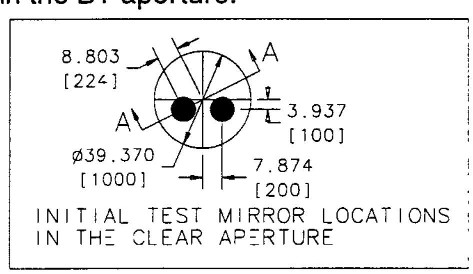
- Scattered Light Analysis
  - ››Use either APART or ASAP from BRO
  - ››hire contractor expert or BRO

Optical Layout: Approach

- Hire optical design engineer (preferably familiar with CODE-V, ZEMAX and APART as contractor)
- Develop "corporate knowledge" by assigning LIGO permanent staff to oversee optical layout effort
  - ››LIGO assigned person carries the knowledge/capability forward into the integration stage

Optical Layout: Basic Requirements

- The IFO optical layout is basically the combination of IOO, COC and COS (which in turn supports LSC and ASC requirements)
  - ››PSL and ASC optical layouts can be treated separately
- The initial IFO beams are located as follows within the BT aperture:



Optical Layout: Basic Requirements (continued)

- COC wedges:

  ››ETM, ITM, BS and FM with thick end of the wedge up

  ››RM with thick end of the wedge down

  ››Use the RM wedge to compensate for tilt deviation due to ITM and BS wedges (minimize angular compensation by the IOO mode matching telescope)

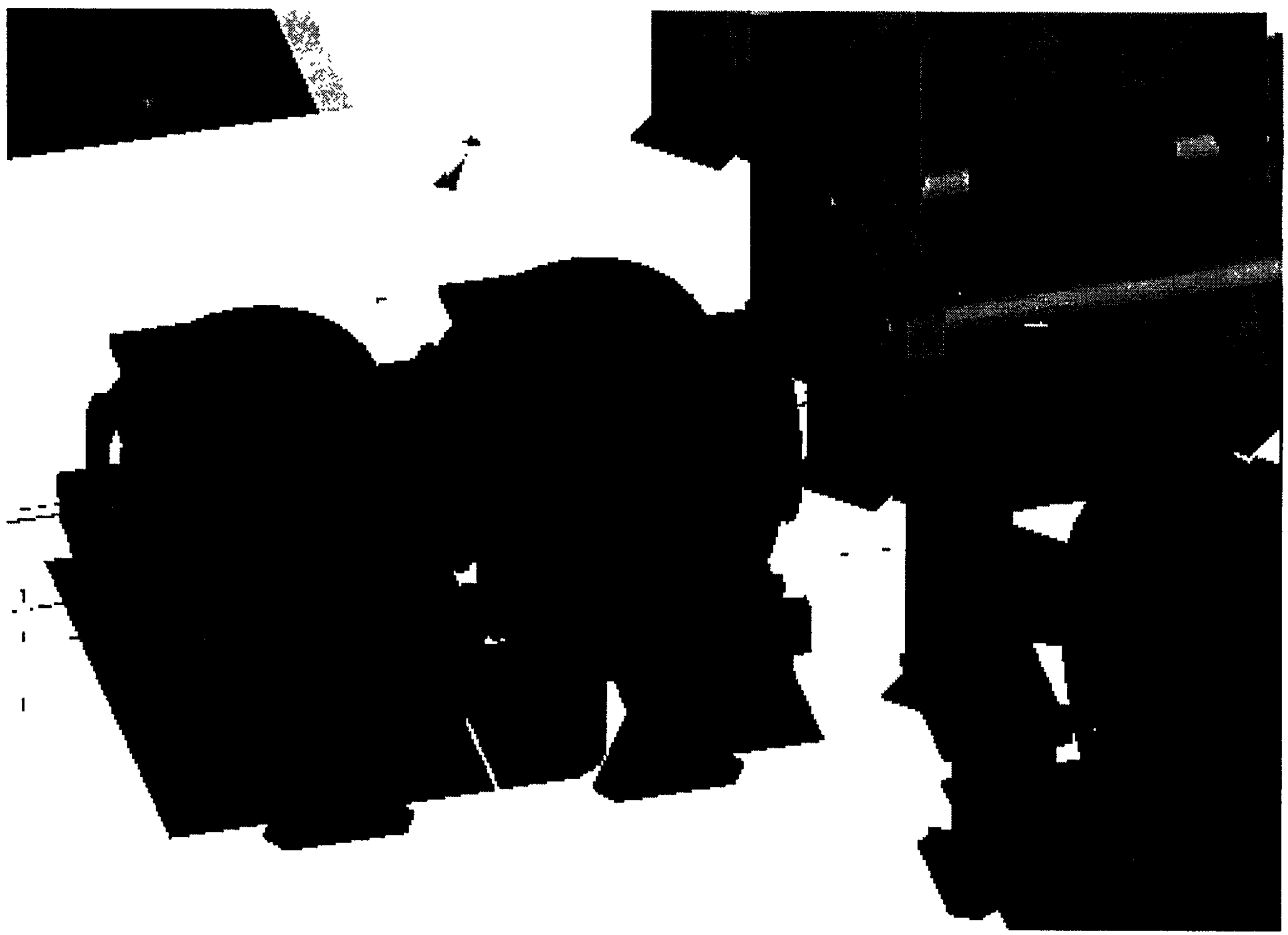
  ››Wedge angles dictated by COS requirement to obtain LSC and ASC beam samples (first reflection) separated at the 1ppm level (TBR) from the main beam at the next chamber/SEI location

- COS

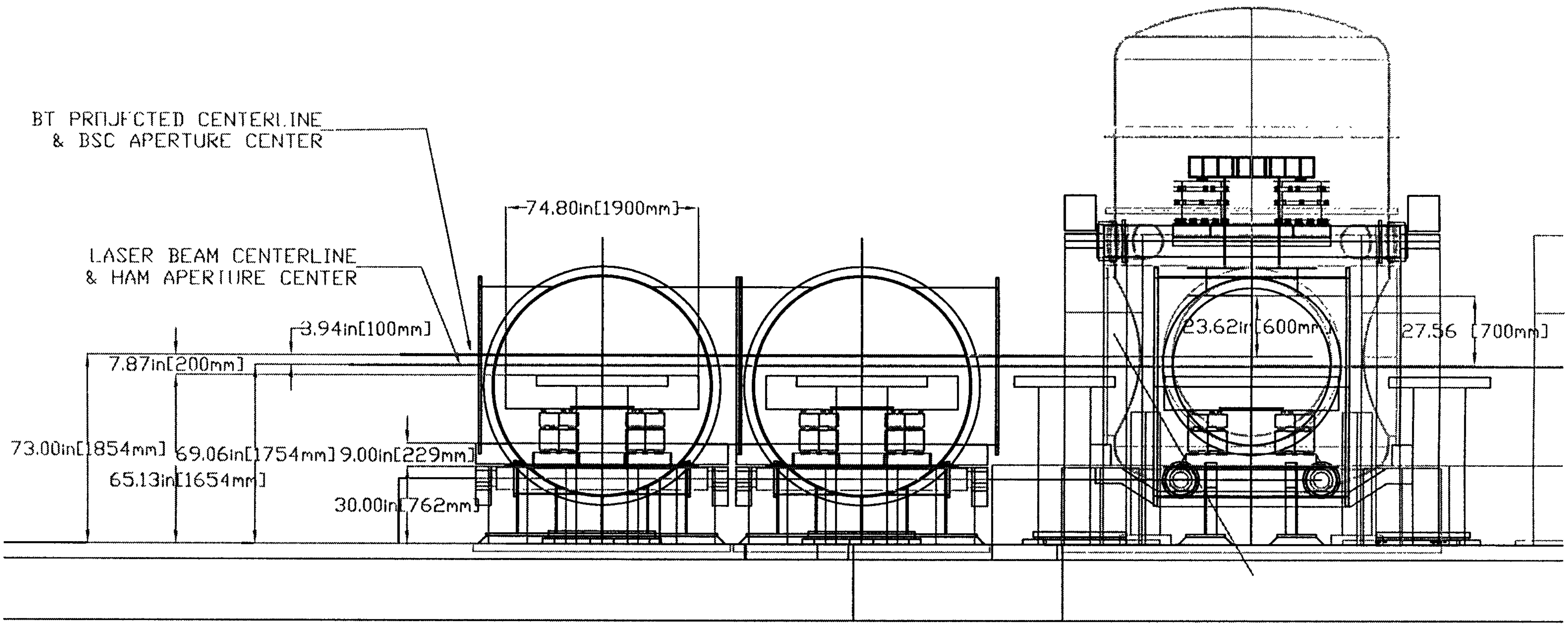
  ››COS provides the transport optics for beam sampling and alignment beams as well as baffling and beam dumping for ghost beams and stray light

  ››The optical layout basically serves to verify physical placement/compatibility of all of the optical elements

Physical Layout
Isometric View



Nominal Beam Elevation

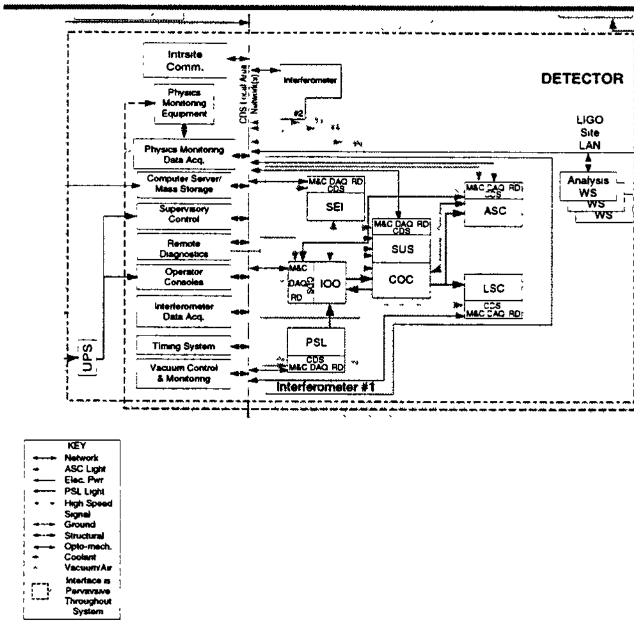


LIGO

Interface Definition

- External Interface Definition
  - ››Detector - VE ICD
  - ››Detector - Civil Construction ICD
- Internal Interface Definition
  - ››Interface definition organized by subsystem (i.e. unlike the Detector SysRD)
  - ››Propose a single Detector Internal Interface Control Document (IICD) (with change bars & change record)
    - —multiple documents (pairwise couplings) leads to too many documents with associated "overhead" in development & maintenance
  - ››Details in specifications and drawings are incorporated by reference only (not duplicated)
  - ››Integrated by Lead Engineer with input from subsystem task leaders

Internal Interfaces



Interface Definition

- Recommend "minimal" CDS interface definition since all of the following are within the CDS group scope:
  - ››All physical layout of racks, cross-connection panels and cables
  - ››All electrical connector specification
  - ››All electrical signal level, EMI shielding, grounding, etc.

Interface Control

- Oversight by Lead Engineer
- Managed with tools:
  - ››Integrated Physical Layout
  - ››Optical Layout
  - ››Drawing Review/Check preceeding PDR, FDR and Fabrication Readiness Review

Example IICD Contents