40m Dual Recycling Experiment Design Requirements and Conceptual Design Overview

- **Objectives and scope**
- **Trade-offs and compromises**
- **Design Requirements**
- **Conceptual design**
- **Recent achieved milestones**
- **Milestones to come**
- **Outstanding design issues**

Alan Weinstein, Caltech

People

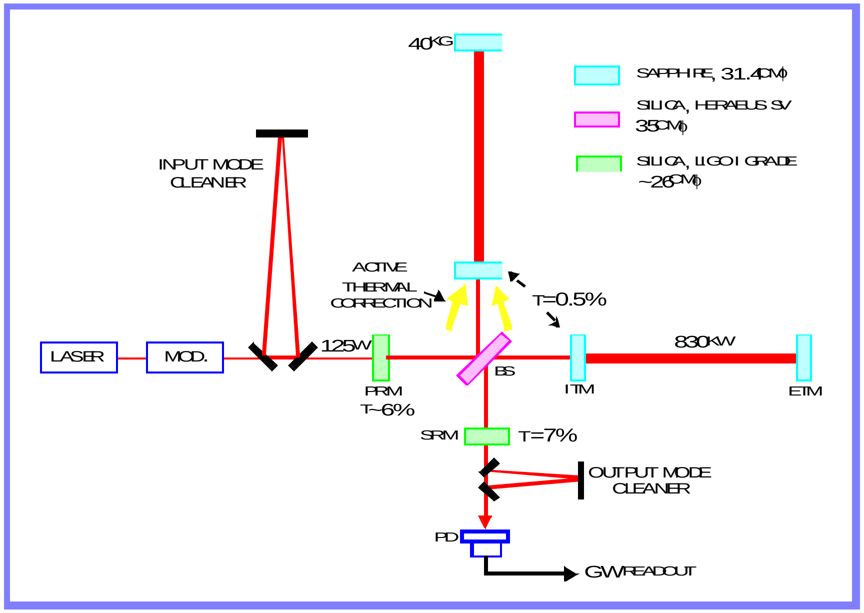
- Live & breathe 40m: Alan Weinstein, Dennis Ugolini, Steve Vass, Ben Abbott
- LIGO lab engineers playing major roles: Garilynn Billingsley, Lisa Bogue, Rolf Bork, Lee Cardenas, Dennis Coyne, Jay Heefner, Larry Jones, Rick Karwoski, Peter King, Janeen Romie, Paul Russel, Mike Smith, Larry Wallace
- Lots of SURF students (this summer – 6) and visitors.
- We'll need lots of add'l help in coming years!

40m Laboratory Upgrade - Objectives

- Primary objective: full engineering prototype of optics control scheme for a dual recycling suspended mass IFO,

  Looking as close as possible to the Advanced LIGO optical configuration and control system

Advanced LIGO optical configuration



Key features:
- Pre-stabilized laser
- Frontal modulation
- Input mode cleaner
- Power- and Signal-recycled Michelson
- High finesse Fabry-Perot arms
- Detuned signal cavity
- Output mode cleaner
- DC readout of GW signal

Timeline

- Table-top IFOs at Caltech, Florida, Australia, Japan (~ complete!)
- These lead to decision on control scheme by LSC/AIC (August 2000 LSC)
- Glasgow 10m DR prototype with multiple pendulum suspensions (2002)
- Then, full LIGO engineering prototype of ISC, CDS at 40m (2003-2004)
- First look at DR lock acquisition, response function, shot noise response (*high-f*)

Advanced LIGO technical innovations tested at 40m

- a seventh mirror for signal recycling
  - » (length control goes from 4x4 to 5x5 MIMO)
- detuned signal cavity (carrier off resonance)
- pair of phase-modulated RF sidebands
  - » frequencies made as low and as high as is practically possible
  - » unbalanced: only one sideband in a pair is used
  - » double demodulation to produce error signals
- short output mode cleaner
  - » filter out all RF sidebands and higher-order transverse modes
- offset-locked arms
  - » controlled amount of arm-filtered carrier light exits asym port of BS
- DC readout of the gravitational wave signal

Much effort to ensure high fidelity between 40m and Adv.LIGO!

Differences between AdvLIGO and 40m prototype

- **Initially, LIGO-I single pendulum suspensions will be used**
  - » **Full-scale AdvLIGO multiple pendulums will not fit in vacuum chambers**
  - » **to be tested at LASTI**
  - » **Scaled-down versions can fit, to test controls hierarchy – in 2004?**
- **Only commercial active seismic isolation**
  - » **STACIS isolators already in use on all 4 test chambers**
  - » **providing ~30 dB of isolation in 1-100 Hz range**
  - » **No room for anything like full AdvLIGO design – to be tested at LASTI**
- **LIGO-I 10-watt laser, negligible thermal effects**
  - » **Other facilities will test high-power laser: LASTI, Gingin, …**
  - » **Thermal compensation also tested elsewhere**
- **Small (5 mm) beam spot at TM's; stable arm cavities**
  - » **AdvLIGO will have 6 cm beam spots, using less stable cavities**
  - » **40m can move to less stable arm cavities if deemed useful**
- **Arm cavity finesse at 40m chosen to be = to AdvLIGO**
  - » **Storage time is x100 shorter**
  - » **significant differences in lock acquisition dynamics, in predictable ways**
- **Due to shorter PRC length, control RF sidebands are 36/180 MHz instead of 9/180 MHz; less contrast between PRC and SRC signals**

40m Laboratory Upgrade – More Objectives

- Expose shot noise curve, dip at tuned frequency
- Multiple pendulum suspensions
  - » this may be necessary, to extrapolate experience gained at 40m on control of optics, to LIGO-II
  - » For testing of mult-suspension controllers, mult-suspension mechanical prototypes, interaction with control system
  - » Not full scale. Insufficient head room in chambers.
  - » Won't replace full-scale LASTI tests.
- thermal noise measurements
  - » Mirror Brownian noise will dominate above 100 Hz.
- Facility for testing/staging small LIGO innovations
- Hands-on training of new IFO physicists!
- Public tours (SURF/REU students, DNC media, princes, etc)

Design Requirements

- **The optical configuration of the 40m IFO should be a power- and signal recycled Michelson with Fabry-Perot arms.**
- **The optical configuration should emulate, as closely as possible, that of Advanced LIGO. Any significant differences (impacting lock acquisition and control) should be well understood.**
- **The interferometer controls, diagnostics, and monitoring must be adequate to the task of bringing and keeping the interferometer in lock.**
- **The interferometer must be able to be brought into lock (including all length and angular degrees of freedom), with locking times on the order of seconds, and remain robustly in-lock for hours.**
- **The DC circulating beam power in all cavities, and in all beam frequency components, and at all stages of lock acquisition, should be within expectations from models**
- **The in-lock GW response function should be measureable, and measured to be within expectations from models**
- **The ability to control the DOFs unique to Advanced LIGO (SRC length, SRM pitch and yaw, peak in response function due to SRC detuning, offset-locking of the arms, DC readout of the L_ degree of freedom, *etc*) without degrading the control of the Initial LIGO degrees of freedom, should be demonstrated.**

More design requirements

- Sources of noise which impact the ability of the interferometer to obtain and maintain lock must be identified, and efforts must be made to eliminate them
- Best efforts must be made to reduce those sources of noise that contribute to the GW readout, especially in the high-frequency (shot-noise-limited) regime
- Systems must be in place to monitor and reduce excess noise from the usual sources: electronics, EM pickup, scattered light, vacuum pressure, seismic motion, suspensions & controllers, misalignments, mode mismatch, etc…
- Data logged to Frames for offline analysis
- The laboratory must be a safe environment in which to work

Conceptual design

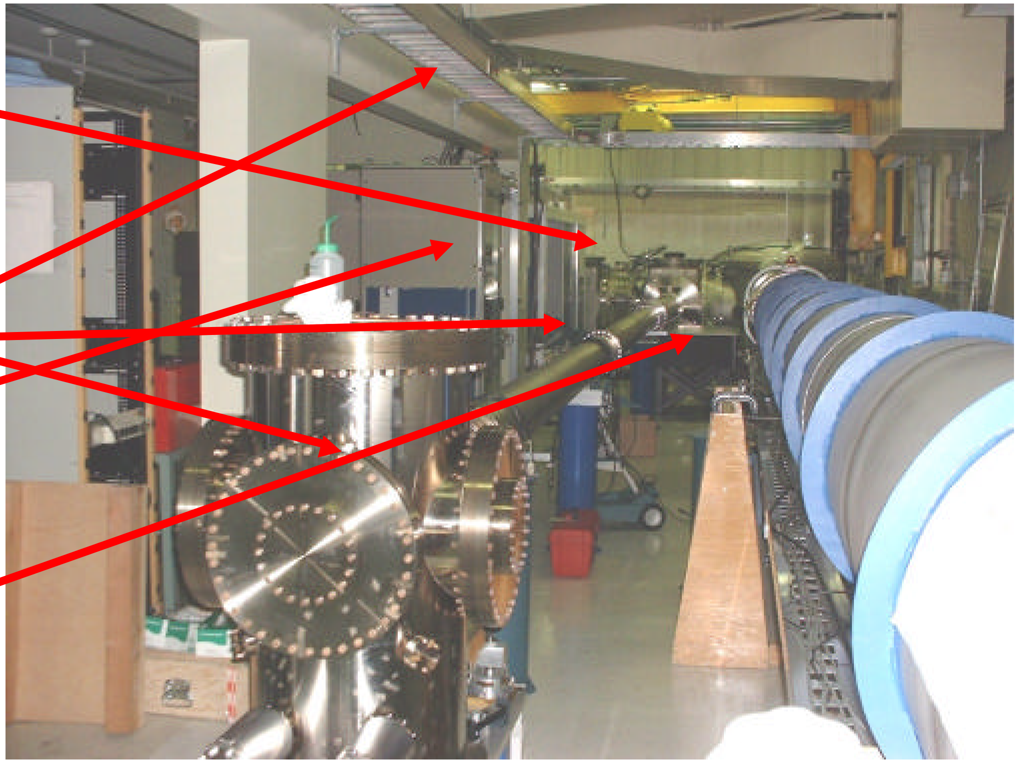
- 40m upgrade conceptual design report (T010115) is available
- Optical systems DRD and CDR (T010117) is available
- Optical topology (Dual recycled Michelson with F-P arms) (AJW)
- Infrastructure upgrade (Larry Jones)
- Suspended optics (GariLynn Billingsley)
- Suspensions (Janeen Romie)
- Suspension controllers (Ben Abbott)
- Laboratory subsystems (PSL, DAQ, PEM, Vacuum, etc) (Dennis Ugolini)
  Optical systems and sensing design (Mike Smith)
- Auxiliary optical systems, scattered light control, … (Mike Smith)
- Outstanding issues (AJW)

40m Infrastructure – substantially complete

- **Dismantling of old IFO, distribution of surplus equipment to LIGO and LSC colleagues**
- **Major building rehab:**
  - » **IFO hall enlarged for optics tables and electronics racks**
  - » **roof repaired, leaks sealed**
  - » **new electrical feeds and conditioners, 12" cable trays, etc**
  - » **new control room and physicist work/lab space**
  - » **New entrance room/changing area**
  - » **rehab of cranes, safety equipment, etc**
- **Active seismic isolation system (STACIS) procured, installed, and commissioned on all four test mass chambers**

40m Infrastructure, continued

- **New vacuum control system and vacuum equipment**
  - » **Installed and commissioned**
- **New output optic chamber, seismic stack fabricated**
  - » **Chamber installed in July, stack to be installed in fall 2001**
- **Vacuum envelope for 12 m input mode cleaner fabricated**
  - » **Chamber installed in July, stack to be installed in fall 2001**
- **All electronics racks, crates, cable trays, computers, network… procured and installed**
- **New optical tables**



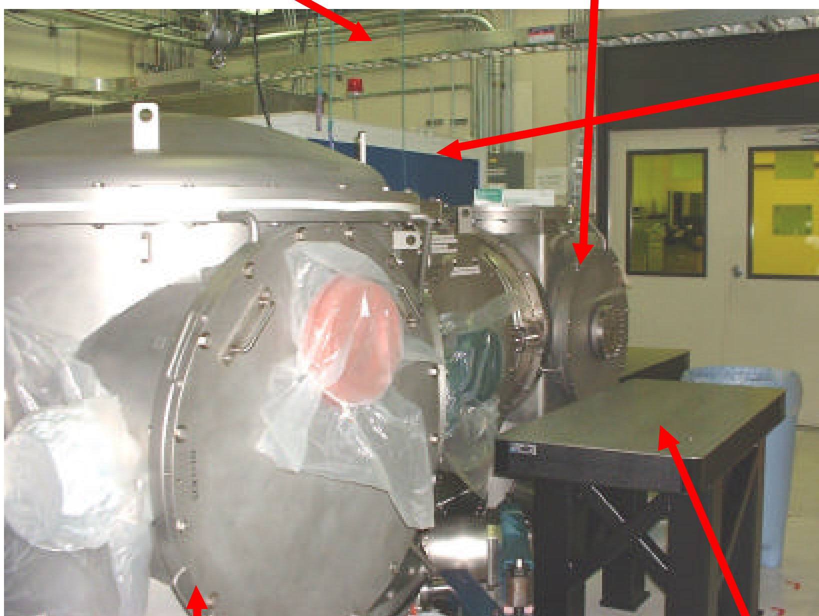
New vacuum envelope at 40m

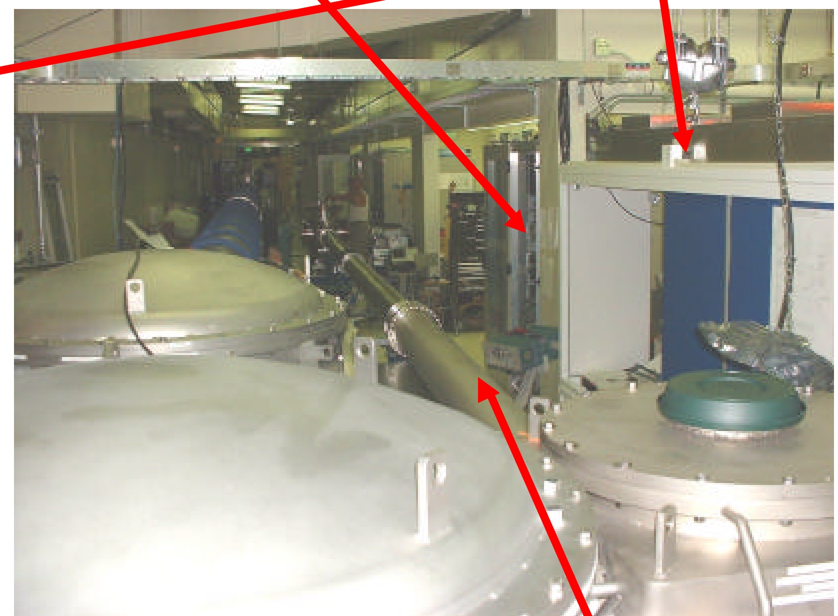
New Output Optic Chamber

Cable trays

PSL Electronics

PSL Enclosure





BS chamber

New optical tables

12m MC beamtube

Lab Infrastructure systems

- DAQS
- PEM
- PSL
- Seismic stacks
- STACIS
- Vacuum equipment and controls
- Computing, networking
- Laser Safety

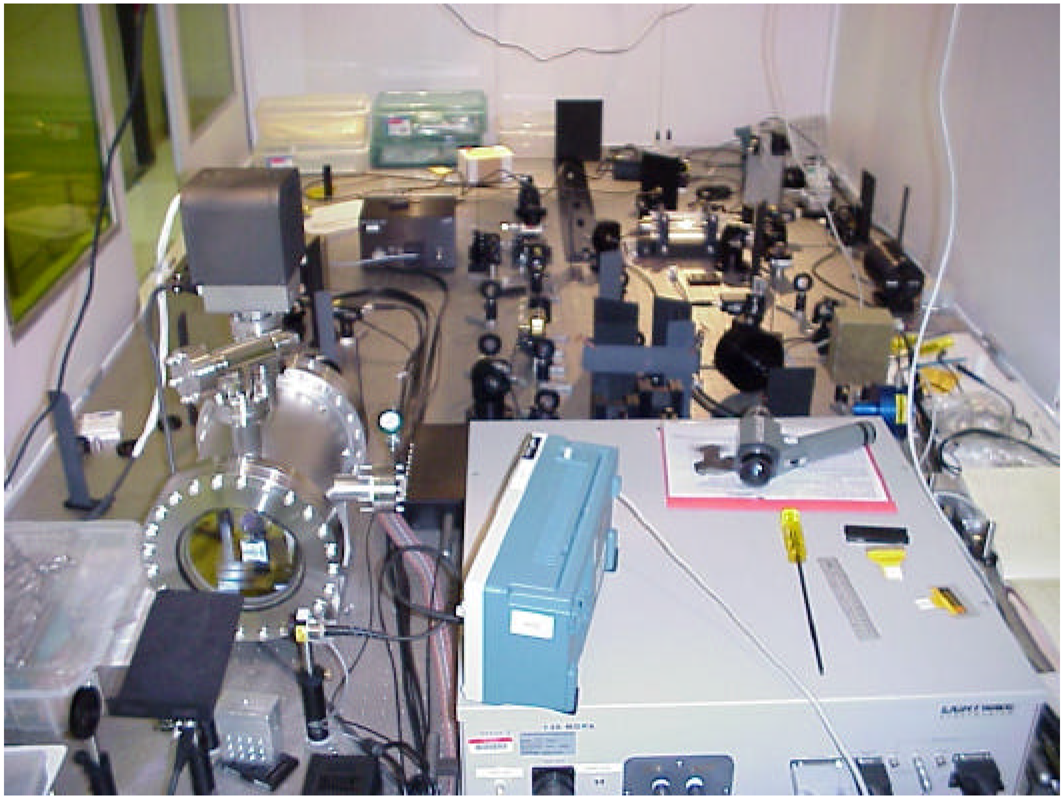
} Dennis Ugolini, Steve Vass, Ben Abbott

- In-vacuum cables
- Vacuum envelope
- Optical tables

} Larry Jones, Steve Vass

40m PSL

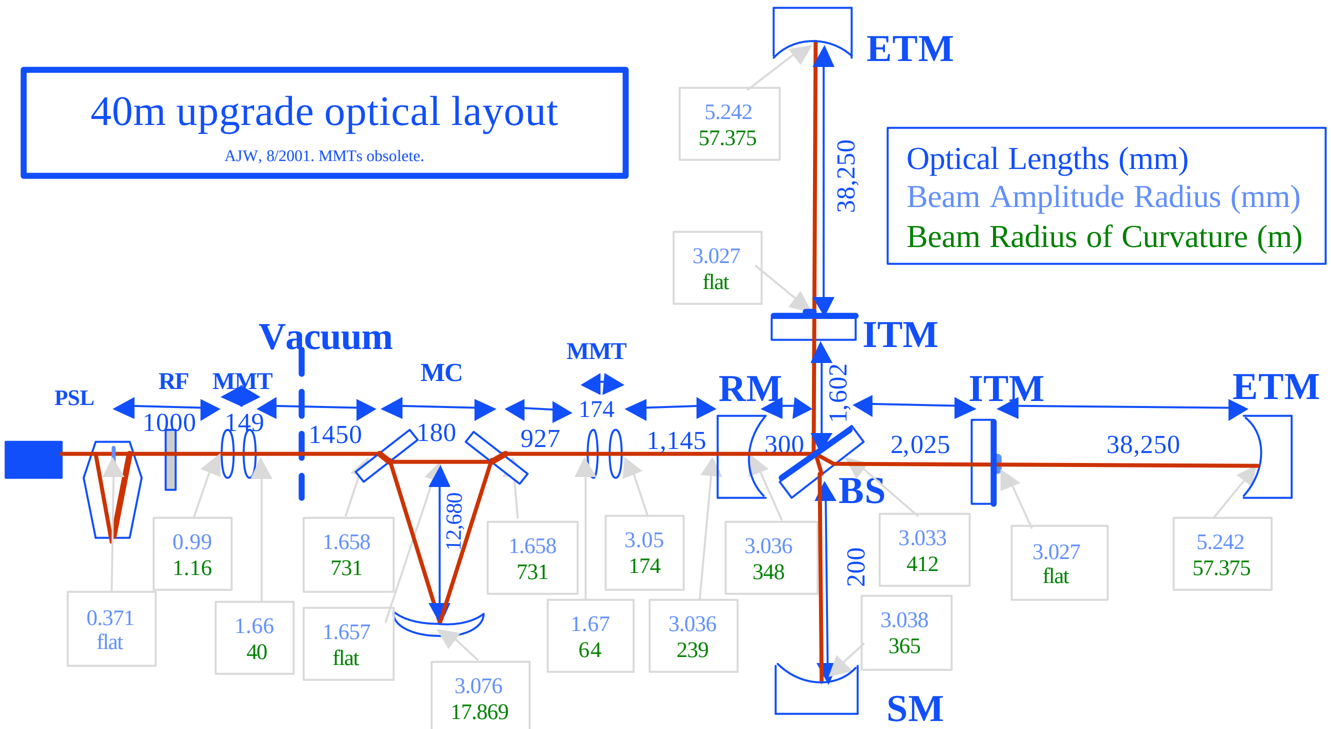
- LIGO-I PSL installed in June by Peter King, Lee Cardenas, Rick Karwoski, Paul Russell
- Spent the last month fixing birthing problems, tuning up (Ugolini, Ben Abbott, SURF students)
- All optical paths have had one round of mode matching tune-up, comparing BeamScan with model; round 2 coming up.
- Frequency stability servo (FSS) and PMC servo (PMCS) have been debugged
- Both servos now lock easily, reliably, stably
- DAQ birthing problems have been fixed; full DAQ readout of fast channels (and slow EPICS channels) logged to frames routinely
- Frequency reference cavity has visibility > 94%; PMC has visibility ~80% and transmission > 50%. More tuning required, and Peter will install less lossy curved mirror sometime soon.
- No temp stability on Freq reference cavity; Peter should have heating jacket on order.
- Full characterization of PSL in progress, first draft available within a month:
  - Frequency noise
  - Intensity noise
  - Pointing and angle jitter
  - Long-term stability of frequency, intensity, pos/angle
  - Beam size and mode matching everywhere on table.



Optical design

- **Dual recycled Michelson with F-P arms. Specified:**
  - » **12m Input Mode Cleaner design, expected performance**
  - » **Core mirror dimensions (3”x1” for all optics except for 5”x2” TMs)**
  - » **transmissivities, cavity finesses, gains, pole frequencies**
  - » **Cavity lengths, RF frequencies, resonance conditions**
  - » **Mirror ROC, beam dimensions everywhere**
  - » **SRC tune specified, transfer function determined**
  - » **DC detection scheme**
  - » **Twiddle modeling, DC fields, length sensing matrix**
  - » **ModalModel, alignment sensing matrix, WFS parameters (TBD)**
  - » **Expected noise (BENCH)**
  - » **Thermal effects – estimated to be negligible**

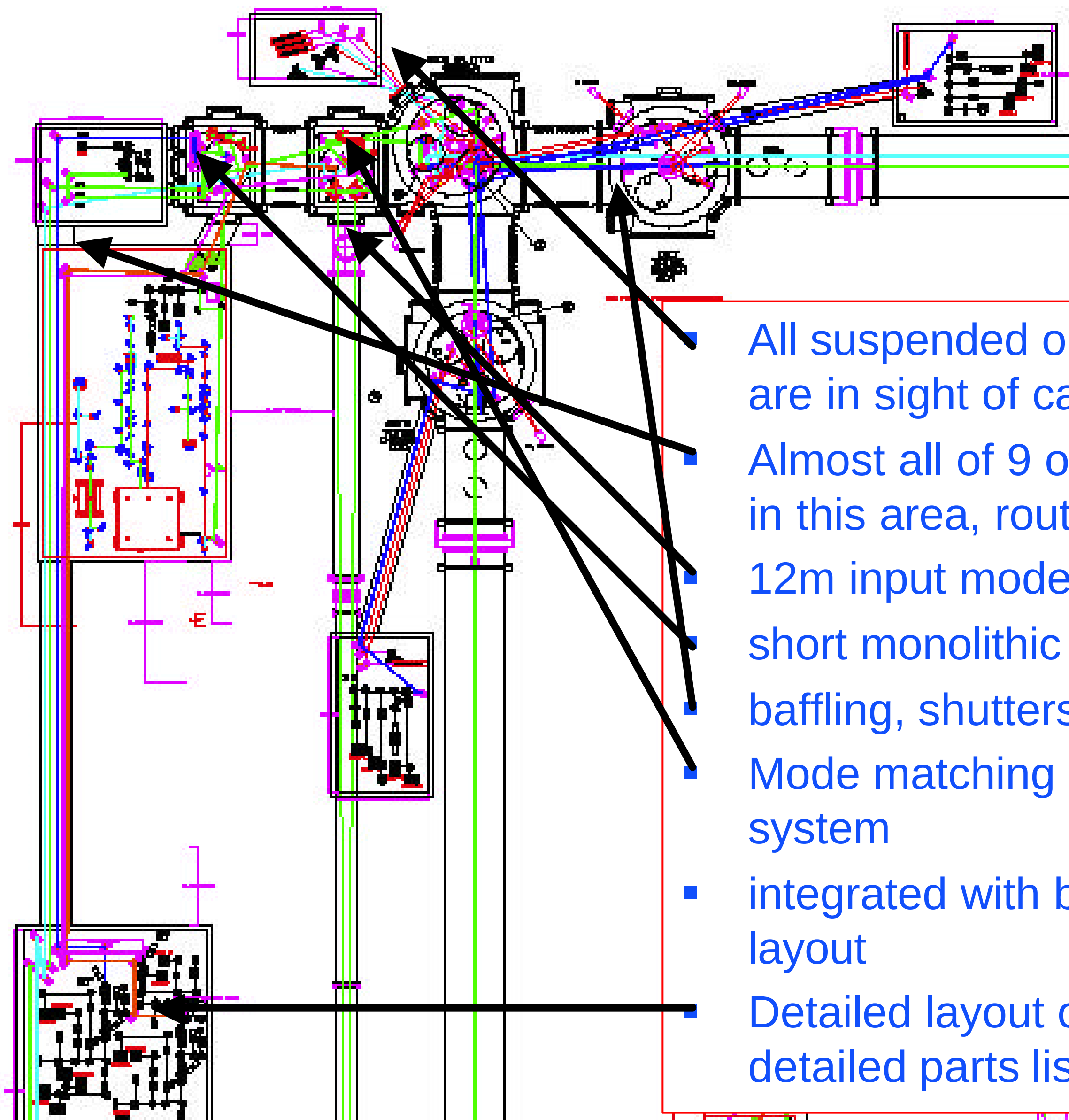
Optics parameters



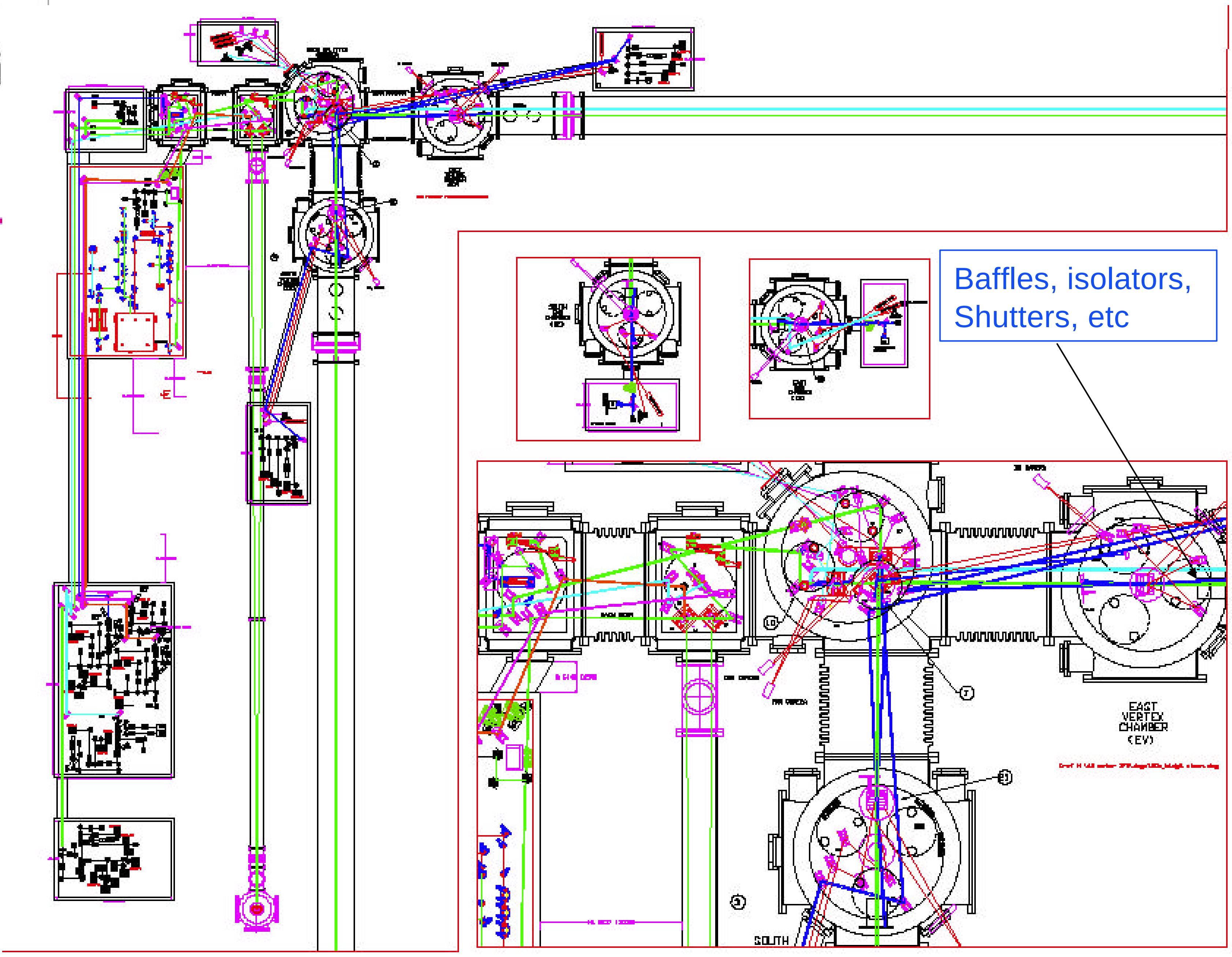
- Arms are half-symmetric, g = 1/3
- Beams are w_0 ~ 3 mm everywhere in vertex area
- IMC almost identical to Initial LIGO LLO4K
- Mode matching done in detail by M. Smith
  (PSL FRC, PSL PMC, PSL → IMC, IMC → IFO, IFO → OMC, output beams → sensors)

Optical Layout

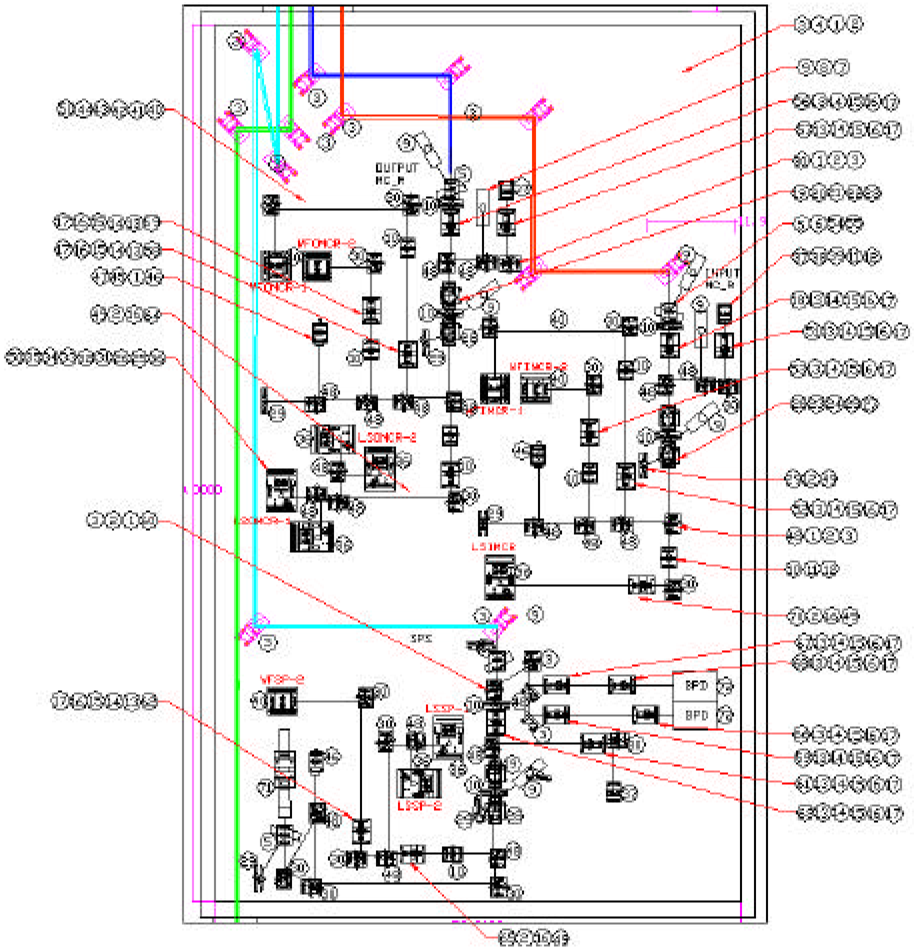
Mike Smith

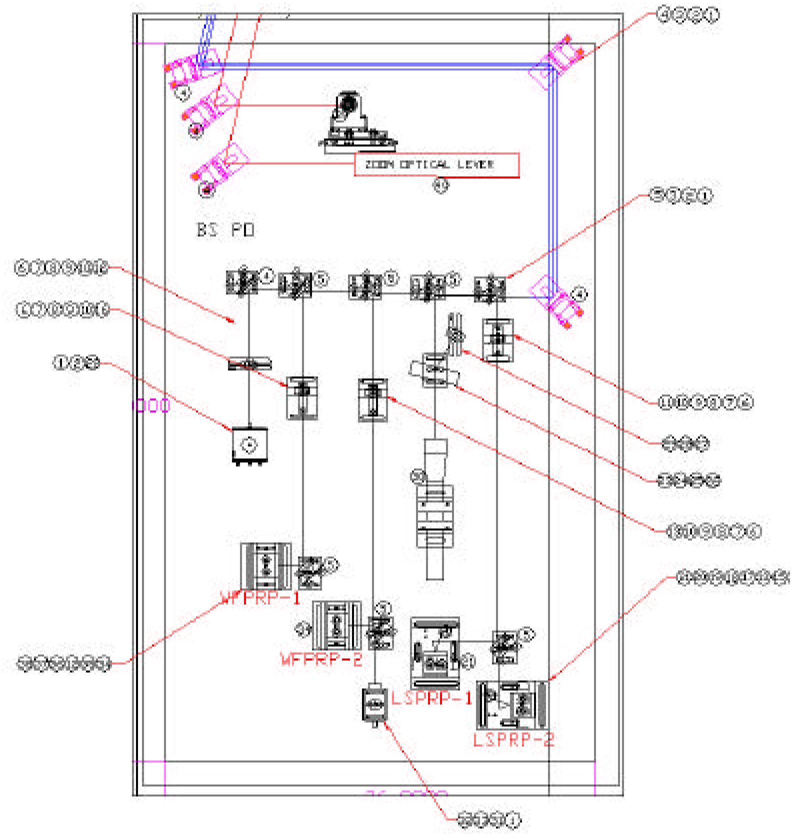


- All suspended optics have OpLevs and are in sight of cameras
- Almost all of 9 output beams come out in this area, routed to ISC tables
- 12m input mode cleaner
- short monolithic output MC
- baffling, shutters, scattered light control
- Mode matching between each optical system
- integrated with building, electrical, CDS layout
- Detailed layout of all ISC tables, with detailed parts lists


Baffles, isolators, Shutters, etc
EAST VERTEX CHAMBER (EV)
SOUTH

Detailed layouts of ISC tables, parts lists

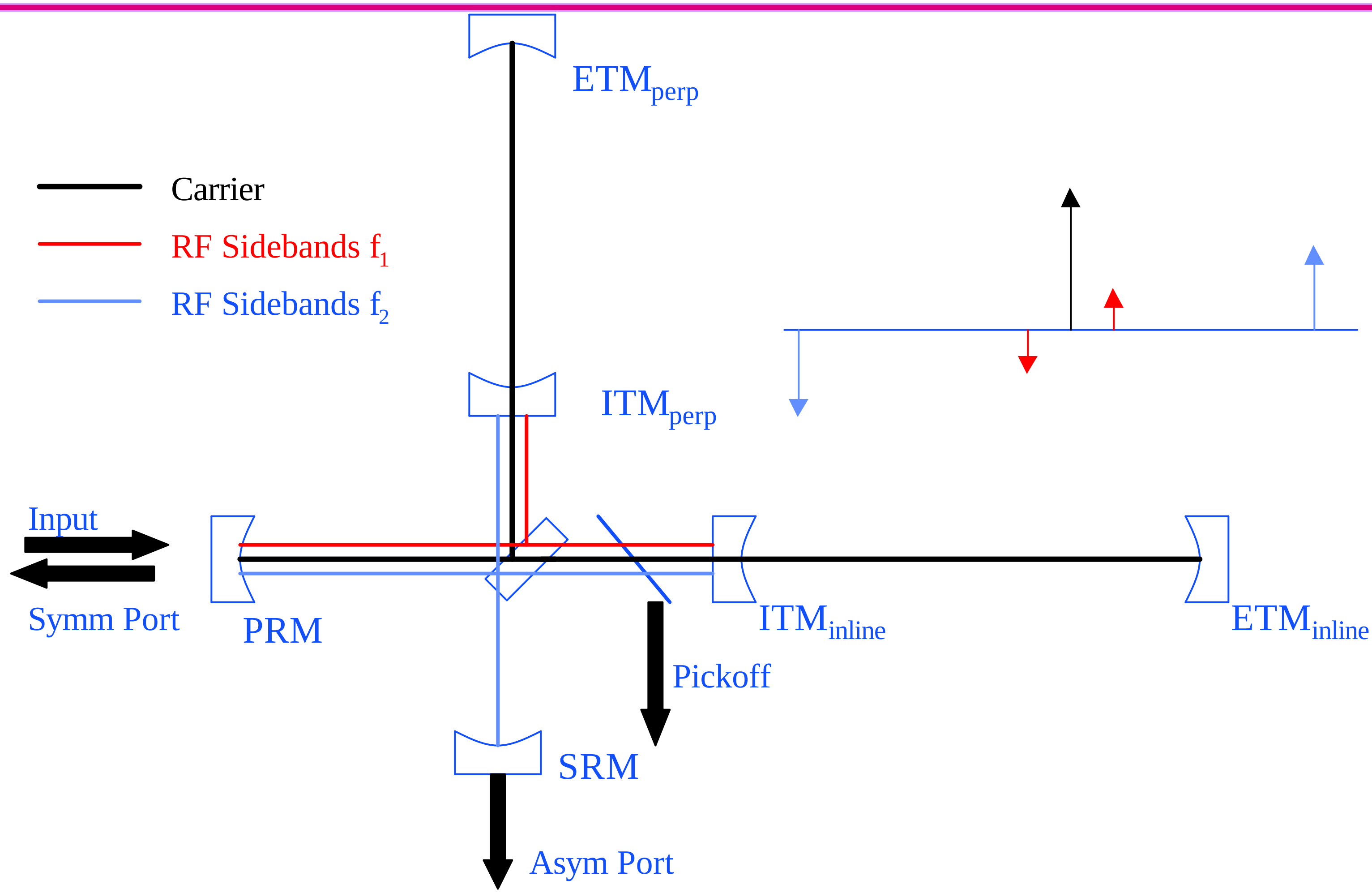




Suspended optics

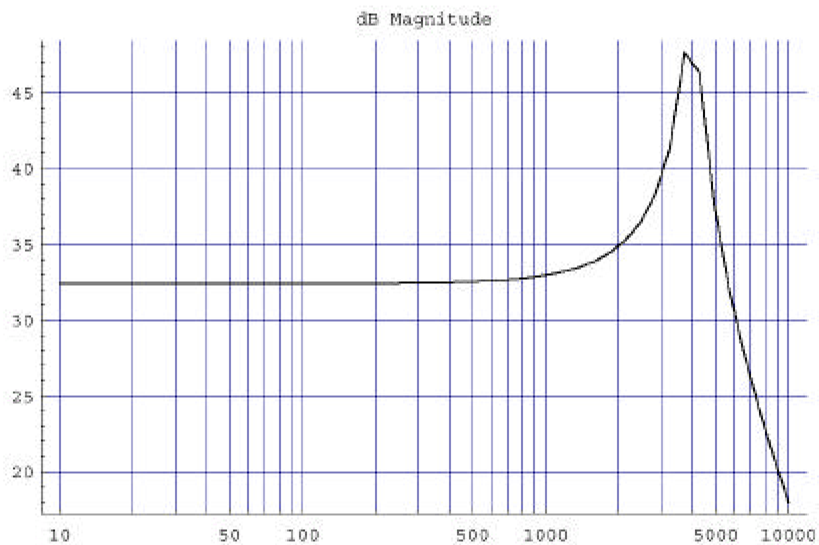
- Ten suspended optics
  - » MCF1, MCF2, MCCM, PRM, SRM, BS, ITMx, ITMy, ETMx, ETMy
- All suspended optics blanks are in hand (more spares on order)
- Polishing, coating in progress – GariLynn
- All SOS suspensions (6+spare) in hand – Janeen
- Scaled SOS suspensions for test masses under construction – Janeen
- Digital suspension controllers under design – Ben Abbott, Jay Heefner

Control topology for Advanced LIGO



GW RF, DC fields, and LSC signals – from Twiddle

GW Response Function



le 3: DC power in the 40m cavities (no arm offset). The signal cavity detuning produces asymmetric response for the sideband pairs, thus, effectively, only one sideband is used for erating error signals.

frequency	$-f_2$	$-f_1$	carrier	f_1	f_2
Modulation depth Γ	0.1	0.1		0.1	0.1
Input from Laser	0.00249	0.00249	0.99003	0.00249	0.00249
Reflected (SP)	0.00249	0.00224	0.00620	0.00199	0.00013
Asym port (AP)	0.00000	0.00013	0.00000	0.00024	0.00235
PR Cavity	0.00010	0.05836	16.3827	0.12328	0.03359
SR Cavity	0.00009	0.00174	0.00000	0.00324	0.03117
Arm Cavity	0.00000	0.00130	6338.8	0.00354	0.00008

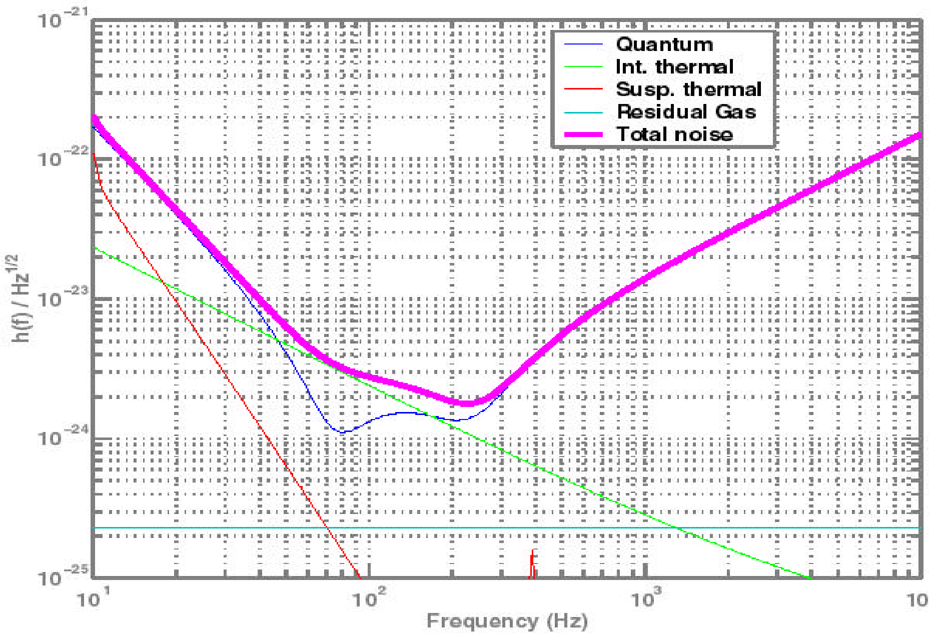
Table 4: Length sensing signals. ⊗ means double demodulation.

Signal	L_+	L_-	l_+	l_-	l_s
SP, f_1	**95.4**	0.003	-0.27	0.05	-0.007
AP, f_2	0	**-44.5**	0	-0.05	0
SP, $f_2 - f_1$	0.005	-0.001	**-0.112**	-0.024	-0.029
AP, $f_2 \otimes f_1$	-0.0007	-0.0001	0.0102	**-0.0029**	-0.0047
SP, $f_2 \otimes f_1$	-0.0036	-0.0011	0.0688	**-0.0222**	-0.0037
PO, $f_2 - f_1$	-0.16	-0.027	1.49	-0.34	**-3.26**

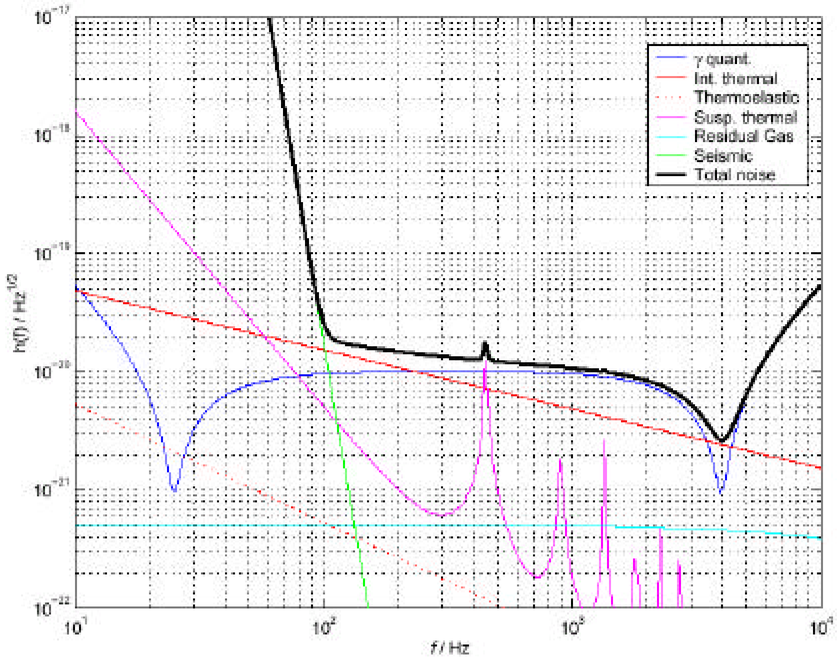
Michelson (l_-) signal is sub-dominant everywhere.

AdvLIGO and 40m noise curves

AdvLIGO (PF, 7/01)



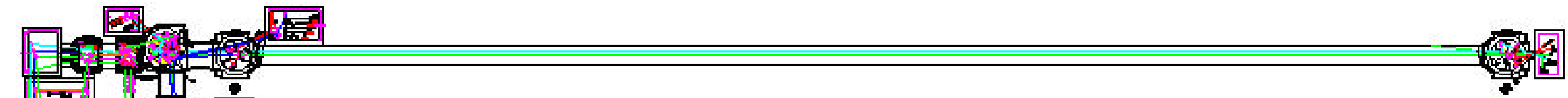
40m

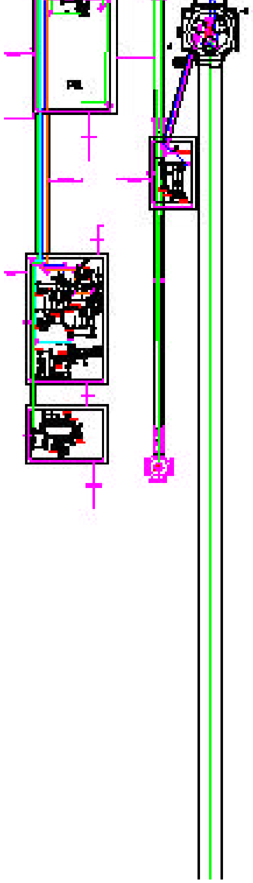


Milestones achieved so far

- Old IFO dismantled, surplus equipment distributed
- Lab infrastructure substantially complete, incl new conditioned power, new 12" cable trays, new CDS racks
- Vacuum control system complete (D. Ugolini)
- Active seismic isolation system installed, commissioned (Vass, Jones, etc)
- Vacuum envelope for 12m MC and output optic chamber installed (Vass, Jones)
- All but one optical table in place (Vass, Jones)
- Remaining on infrastructure: install seismic stacks for 12m MC and OOC; all in-vacuum cabling; and one more (big) optical table.
- DAQ system installed, logs frames continuously (R. Bork)
- PSL installed, commissioned; full tuning and characterization in progress (P. King, L. Cardenas, R. Karwoski, P. Russell, D. Ugolini, B. Abbott, SURFs)
- Many PEM devices installed, in EPICS and DAQS, and in routine use (vacuum gauges, weather station, dust monitor, STACIS, accelerometer, mics, …) (Ugolini, SURF Tsai).

More milestones achieved





- Full in-vacuum optical layout complete, incl. Mode matching and steering, optical levers, cameras (M. Smith)
- Full out-of-vacuum IFO sensing table layout complete, for 11 output beams; parts lists assembled (M. Smith)
- Scattered light control, baffling, isolators (M. Smith)
- Design of digital suspension controllers for MC and COC in progress (B.Abbott, J.Heefner)
- Computing hardware, networking, software (EPICS, Dataviewer, DMT, etc) largely in place (Bork, Ugolini, Bogue, Wallace)
- Optical glass in hand, polishing of MC glass in progress (G. Billingsley)
- Specs for polishing and coating core optics ready (G. Billingsley)
- SOS suspensions (all but TM’s) constructed (J. Romie)
- TM suspensions designed and in construction (J. Romie)
- Detailed WBS for construction, and for experiment (T. Frey)

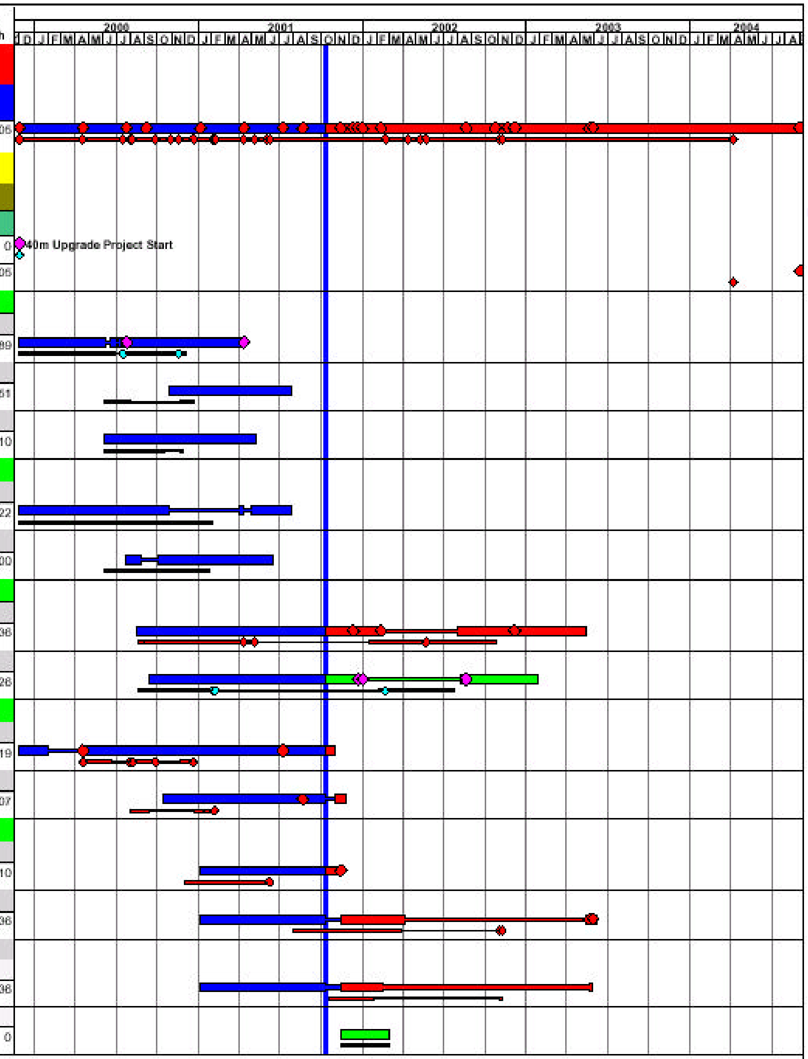
Milestones through 2002

- **4Q 2001: Infrastructure complete**
  - » **PSL, 12m MC envelope, vacuum controls, DAQS, PEM.**
  - » **Conceptual design review. Begin procurement of CDS, ISC, etc.**
- **2Q 2002:**
  - » **All in-vacuum cables, feedthroughs, viewports, seismic stacks installed.**
  - » **12m input MC optics and suspensions, and suspension controllers.**
- **3Q 2002:**
  - » **Begin commissioning of 12m input mode cleaner.**
  - » **Acquisition of most of CDS, ISC, LSC, ASC.**
- **4Q 2002:**
  - » **Core optics (early) and suspensions ready. Ten Suspension controllers. Some ISC.**
  - » **Glasgow 10m experiment informs 40m program**
  - » **Control system finalized**

Milestones through 2004

- **2Q 2003:**
  - » **Core optics (late) and suspensions ready.**
  - » **auxiliary optics, IFO sensing and control systems assembled.**
- **3Q 2003: Core subsystems commissioned, begin experiments**
  - » **Lock acquisition with all 5 length dof's, 2x6 angular dof's**
  - » **measure transfer functions, noise**
  - » **Inform CDS of required modifications**
- **3Q 2004: Next round of experiments.**
  - » **DC readout. Multiple pendulum suspensions?**
  - » **Final report to LIGO Lab.**

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp	Late Start	Late Finish	Total Float	Variance Early Finish
LIGO										
LIGO.2 LIGO Laboratory Operations										
Subtotal		1,198	728	01DEC99A	02SEP04	44	01DEC99A	12APR04	-101	-106
LIGO.2.01 Laboratory Caltech Site Operations										
LIGO.2.01.6 Campus Research Facilities (CAM)										
LIGO.2.01.6.1 40 Meter Interferometer Upgrade										
4M-M00010	40m Upgrade Project Start	0	0	01DEC99A		100	01DEC99A			0
4M-M99999	40m Project Complete	0	0		02SEP04	0		12APR04*	-101	-106
LIGO.2.01.6.1.1 FAC										
+ LIGO.2.01.6.1.1.1 Lab Expansion										
		344	0	01DEC99A	13APR01A	100	01DEC99A	13APR01A		-89
+ LIGO.2.01.6.1.1.2 Vacuum Envelope										
		187	0	27OCT00A	26JUL01A	100	27OCT00A	26JUL01A		-151
+ LIGO.2.01.6.1.1.3 Vacuum Controls										
		232	0	05JUN00A	07MAY01A	100	05JUN00A	07MAY01A		-110
LIGO.2.01.6.1.2 SEI										
+ LIGO.2.01.6.1.2.1 Output Chamber Stack										
		416	0	01DEC99A	26JUL01A	100	01DEC99A	26JUL01A		-122
+ LIGO.2.01.6.1.2.2 Cavity Optics Isolation										
		227	0	22JUL00A	15JUN01A	100	22JUL00A	15JUN01A		-100
LIGO.2.01.6.1.3 SUS										
+ LIGO.2.01.6.1.3.1 Large Optic Suspensions										
		692	398	14AUG00A	14MAY03	36	14AUG00A	04FEB03	-71	-136
+ LIGO.2.01.6.1.3.2 Small Optic Suspensions										
		598	323	11SEP00A	29JAN03	64	11SEP00A	04FEB03	4	-126
LIGO.2.01.6.1.4 PSL										
+ LIGO.2.01.6.1.4.1 Laser										
		484	14	01DEC99A	31OCT01	97	01DEC99A	31OCT01	0	-219
+ LIGO.2.01.6.1.4.2 PSL										
		283	18	13OCT00A	27NOV01	66	13OCT00A	27NOV01	0	-207
LIGO.2.01.6.1.5 Optical Systems and Sensing										
+ LIGO.2.01.6.1.5.1 Optical Systems Design										
		219	23	05JAN01A	13NOV01	82	05JAN01A	13NOV01	0	-110
+ LIGO.2.01.6.1.5.2 IFO Input Beam										
		608	390	08JAN01A	05JUN03	1	08JAN01A	28MAY03	-5	-136
LIGO.2.01.6.1.5.3 Optical Sensing Beams										
+ LIGO.2.01.6.1.5.3.1 Initial Pointing Beam										
		604	385	05JAN01A	28MAY03	6	05JAN01A	21JAN03	-91	-136
+ LIGO.2.01.6.1.5.3.2 IMC Reflected										
		71	71	15NOV01	01MAR02	0	20SEP02	06JAN03	212	0



Start Date 01DEC99
Finish Date 02SEP04
Data Date 12OCT01
Run Date 16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

L043 - 40MU

Sheet 1 of 4

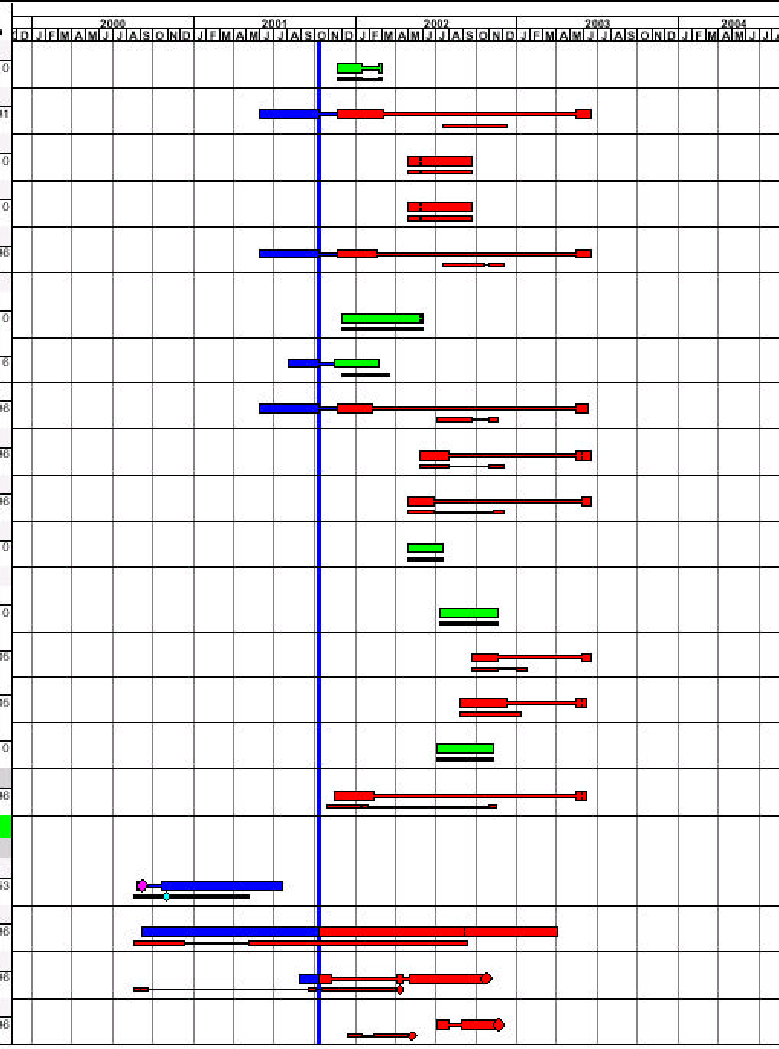
LIGO II

40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp		Late Start	Late Finish	Total Float	Variance Early Finish
+ LIGO.2.01.6.1.5.3.3 IMC Transmitted											
		66	66	22NOV01	01MAR02	0		04NOV02	06JAN03	212	0
+ LIGO.2.01.6.1.5.3.4 Symmetric Port Signal											
		516	394	01JUN01A	19JUN03	7		01JUN01A	28JAN03	-101	-131
+ LIGO.2.01.6.1.5.3.5 ITMx Pickoff Beam											
		100	100	01MAY02	20SEP02	0		01MAY02	20SEP02	0	0
+ LIGO.2.01.6.1.5.3.6 ITMy Pickoff Beam											
		100	100	01MAY02	20SEP02	0		01MAY02	20SEP02	0	0
+ LIGO.2.01.6.1.5.3.7 BS Pickoff Beam											
		516	394	01JUN01A	19JUN03	8		01JUN01A	28JAN03	-101	-136
LIGO.2.01.6.1.5.3.8 AP1 Output Beam											
+ LIGO.2.01.6.1.5.3.8.1 Output Faraday Isolator											
		127	127	03DEC01	06JUN02	0		24JUL02	28JAN03	160	0
+ LIGO.2.01.6.1.5.3.8.2 AP1 Focus Lens											
		139	67	03AUG01A	22FEB02	6		03AUG01A	28JAN03	232	16
+ LIGO.2.01.6.1.5.3.8.3 AP1 Optical Train Assy.											
		510	388	01JUN01A	11JUN03	4		01JUN01A	28JAN03	-95	-136
+ LIGO.2.01.6.1.5.3.9 OMC Reflected Beam											
		268	268	27MAY02	19JUN03	0		09OCT02	28JAN03	-101	-136
+ LIGO.2.01.6.1.5.3.A ETMx Transmission Monitor											
		286	286	01MAY02	19JUN03	0		04NOV02	28JAN03	-101	-136
+ LIGO.2.01.6.1.5.3.B ETMy Transmission Monitor											
		55	55	01MAY02	18JUL02	0		04NOV02	28JAN03	130	0
LIGO.2.01.6.1.5.3.C AP2 Output Beam											
+ LIGO.2.01.6.1.5.3.C.1 Mode Matching Telescope, OMC											
		91	91	12JUL02	18NOV02	0		13SEP02	28JAN03	44	0
+ LIGO.2.01.6.1.5.3.C.2 Beam Steering, OMC											
		185	185	24SEP02	19JUN03	0		04NOV02	28JAN03	-101	-105
+ LIGO.2.01.6.1.5.3.C.3 Output Mode Cleaner											
		195	195	26AUG02	05JUN03	0		30AUG02	28JAN03	-91	-105
+ LIGO.2.01.6.1.5.3.C.4 AP2 Optical Train Assy.											
		90	90	05JUL02	08NOV02	0		16SEP02	28JAN03	50	0
+ LIGO.2.01.6.1.5.4 View Ports											
		390	390	14NOV01	05JUN03	0		07OCT02	28JAN03	-91	-136
LIGO.2.01.6.1.6 Suspended Optics											
LIGO.2.01.6.1.6.1 COC											
+ LIGO.2.01.6.1.6.1.1 Substrates											
		227	0	25AUG00A	20JUL01A	100		25AUG00A	20JUL01A		-53
+ LIGO.2.01.6.1.6.1.2 Polishing											
		644	388	08SEP00A	02APR03	10		08SEP00A	02APR03	0	-136
+ LIGO.2.01.6.1.6.1.3 Coating											
		290	280	30AUG01A	23OCT02	0		30AUG01A	23OCT02	0	-136
+ LIGO.2.01.6.1.6.1.4 Metrology											
		100	100	02JUL02	20NOV02	0		03JUN02	20NOV02	0	-136



Start Date	01DEC99
Finish Date	02SEP04
Data Date	12OCT01
Run Date	16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

L043 - 40MU

Sheet 2 of 4

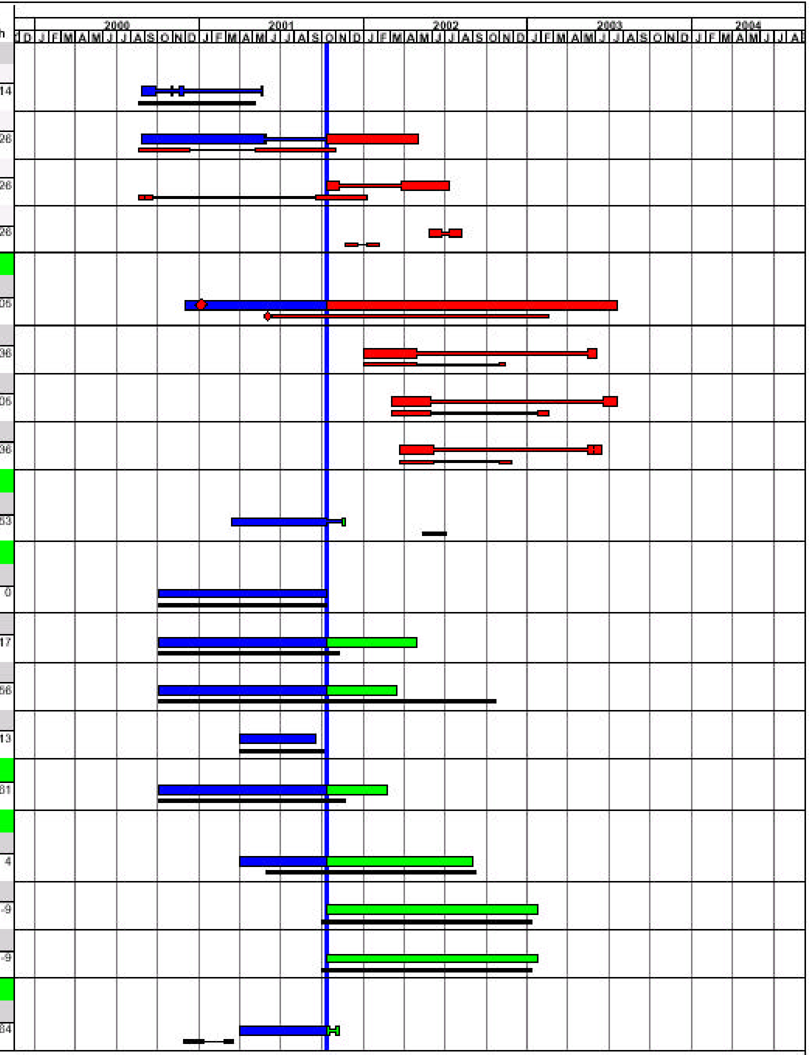
LIGO II

40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp	Late Start	Late Finish	Total Float	Variance Early Finish
LIGO.2.01.6.1.6.2 IO										
+ LIGO.2.01.6.1.6.2.1 Substrates		189	0	24AUG00A	24MAY01A	100	24AUG00A	24MAY01A		-14
+ LIGO.2.01.6.1.6.2.2 Polishing		424	140	28AUG00A	03MAY02	30	28AUG00A	03MAY02	0	-128
+ LIGO.2.01.6.1.6.2.3 Coating		185	185	12OCT01	09JUL02	0	08APR02	09JUL02	0	-128
+ LIGO.2.01.6.1.6.2.4 Metrology		50	50	27MAY02	06AUG02	0	10JUL02	06AUG02	0	-128
LIGO.2.01.6.1.7 AOS										
+ LIGO.2.01.6.1.7.1 Design		661	443	01DEC00A	18JUL03	34	01DEC00A	25FEB03	-101	-106
+ LIGO.2.01.6.1.7.2 Stray Light Control		357	357	02JAN02	02JUN03	0	06SEP02	28JAN03	-88	-136
+ LIGO.2.01.6.1.7.3 Initial Alignment System		345	345	07MAR02	18JUL03	0	07OCT02	25FEB03	-101	-106
+ LIGO.2.01.6.1.7.4 Optical Lever System		309	309	22MAR02	12JUN03	0	07OCT02	28JAN03	-96	-136
LIGO.2.01.6.1.8 ISC										
+ LIGO.2.01.6.1.8.1 ISC Design		177	6	15MAR01A	21NOV01	83	15MAR01A	10SEP02	200	153
LIGO.2.01.6.1.9 DAQ										
+ LIGO.2.01.6.1.9.1 Control & Networking		260	0	02OCT00A		100	02OCT00A			0
+ LIGO.2.01.6.1.9.2 Diagnostics - GDS		397	137	02OCT00A	30APR02	51	02OCT00A	02JUL03	296	-117
+ LIGO.2.01.6.1.9.3 DAQ		364	104	02OCT00A	14MAR02	82	02OCT00A	02JUL03	328	156
+ LIGO.2.01.6.1.9.4 PEM		130	0	02APR01A	14SEP01A	100	02APR01A	14SEP01A		13
+ LIGO.2.01.6.1.B PEM		351	91	02OCT00A	25FEB02	69	02OCT00A	02JUL03	341	-61
LIGO.2.01.6.1.C CDS										
+ LIGO.2.01.6.1.C.1 SUS Controls		359	223	02APR01A	30AUG02	32	02APR01A	04FEB03	104	4
+ LIGO.2.01.6.1.C.2 Length Sensing and Control		320	320	12OCT01	24JAN03	0	13NOV01	25FEB03	22	-9
+ LIGO.2.01.6.1.C.3 Alignment Sensing and Control		320	320	12OCT01	24JAN03	0	13NOV01	25FEB03	22	-9
LIGO.2.01.6.1.D Experiments										
+ LIGO.2.01.6.1.D.0 Vacuum Controls Sys.		154	18	02APR01A	06NOV01	89	02APR01A	29APR03	369	-164



Start Date 01DEC99
Finish Date 02SEP04
Data Date 12OCT01
Run Date 16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

L043 - 40MU

Sheet 3 of 4

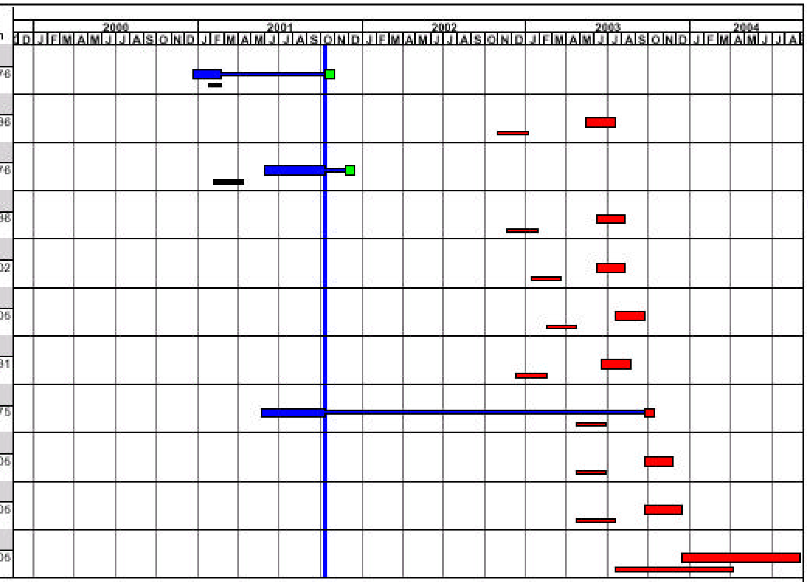
LIGO II

40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp	Late Start	Late Finish	Total Float	Variance Early Finish
LIGO.2.01.6.1.D.1 SEI										
		218	15	22DEC00A	01NOV01	50	22DEC00A	24APR03	369	-176
LIGO.2.01.6.1.D.2 SUS										
		45	45	15MAY03	18JUL03	0	05FEB03	29APR03	-56	-136
LIGO.2.01.6.1.D.3 PSL										
		139	14	01JUN01A	17DEC01	69	01JUN01A	29APR03	341	-176
LIGO.2.01.6.1.D.4 COC										
		45	45	08JUN03	08AUG03	0	26FEB03	29APR03	-71	-136
LIGO.2.01.6.1.D.5 IO										
		45	45	08JUN03	08AUG03	0	26FEB03	29APR03	-71	-102
LIGO.2.01.6.1.D.6 AOS										
		45	45	21JUL03	22SEP03	0	26FEB03	29APR03	-101	-106
LIGO.2.01.6.1.D.7 ISC										
		45	45	20JUN03	22AUG03	0	26FEB03	29APR03	-81	-131
LIGO.2.01.6.1.D.8 DAQ										
		601	15	24MAY01A	13OCT03	67	24MAY01A	24JUL03	-56	-75
LIGO.2.01.6.1.D.9 LDAS										
		45	45	23SEP03	25NOV03	0	21MAY03	24JUL03	-86	-106
LIGO.2.01.6.1.D.A Dual Re-cycled										
		60	60	23SEP03	16DEC03	0	30APR03	24JUL03	-101	-106
LIGO.2.01.6.1.D.B IFO Experiments										
		180	180	17DEC03	02SEP04	0	25JUL03	12APR04	-101	-106



Start Date	01DEC99
Finish Date	02SEP04
Data Date	12OCT01
Run Date	16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

LD43 - 40MU

Sheet 4 of 4

LIGO II

40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

(Some) outstanding issues and action items (40m, AdvLIGO)

- **Any significant changes in people's thinking re: optical configuration, controls, CDS architecture??**
- **Near term: in addition to the digital suspension controllers, need LSC and ASC for input mode cleaner, and servos for steering PSL beam into input mode cleaner and thence into IFO.**
- **Develop ASC model with ModalModel.**
- **IFO design (optics, sensing, control, etc) needs careful review by experts, double-check LSC, ASC calculations – I welcome volunteers!!**
- **180 MHz PD's for WFS, LSC. Double demodulation(180 Å 36 MHz).**
- **Design servo filters for LSC, ASC!**
- **Detailed noise model (RSENOISE, Jim Mason)**
- **Lock acquisition studies with E2E/DRLIGO. Develop lock acquisition algorithms, software.**
- **Triple-check thermal effects (Melody) – negligible?**
- **Output mode cleaner – will PSL-PMC-like device be adequate? (For 40m, for AdvLIGO). Suspended?**
- **Offset-lock arms - algorithms, software.**
- **DC GW PD – in vacuum? Suspended?**

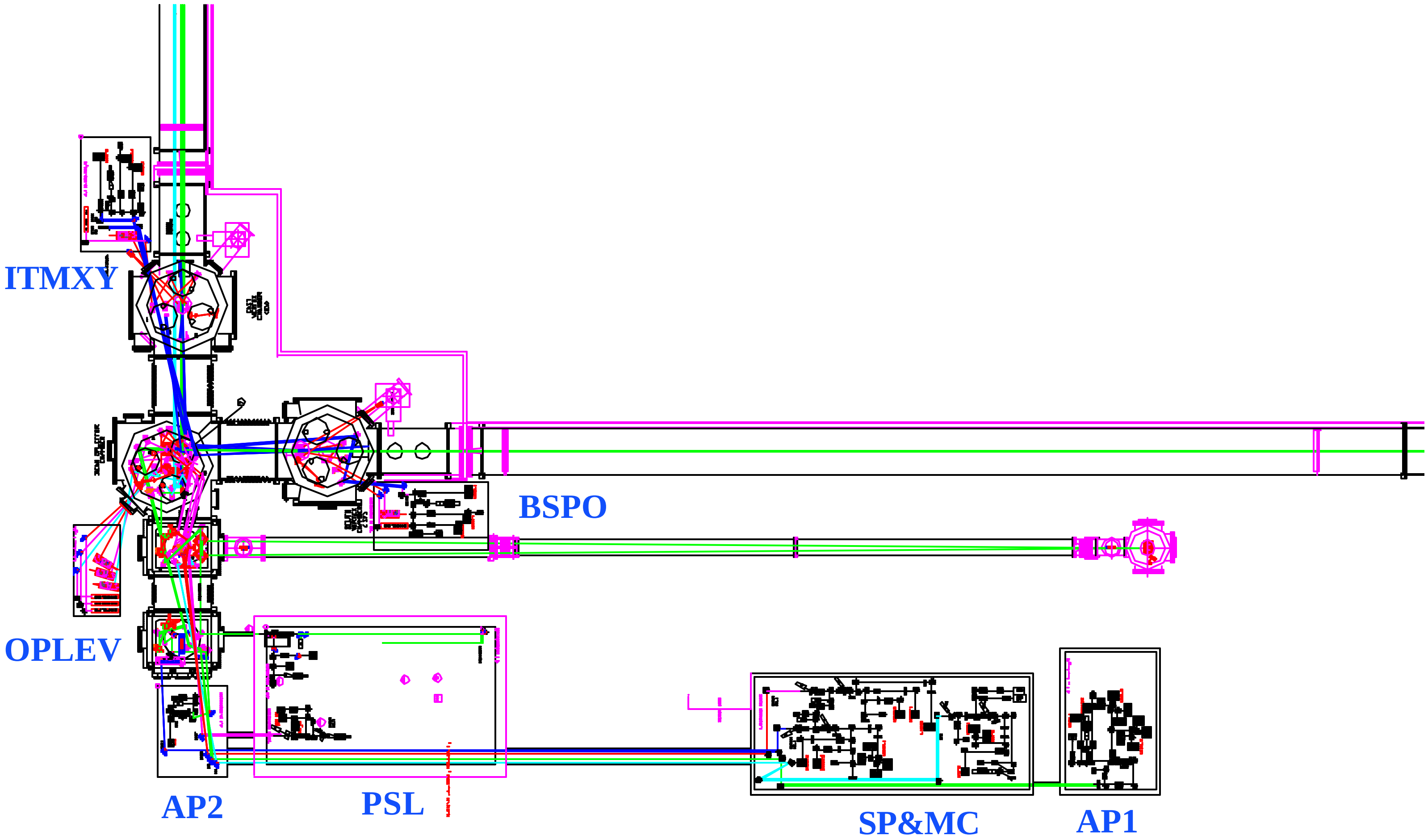
Recent Lab Infrastructure Upgrades

B. Abbott, L. Jones, M. Smith, D. Ugolini,
S. Vass, A. Weinstein

Vacuum Envelope Changes

- Output chamber has been installed, with support beam
  - » 29.5” Adjustable Bellows has been installed
  - » Seismic stack is to be installed Feb ‘02
  - » Special seal ring may be added at triple window door
- MCCM chamber has been installed, with support beams and beam tube
  - » Seismic stack is to be installed Feb ‘02
- Ion pumps have been regenerated & moved to clear STACIS units
- Machined flanges to tilt optical windows are due Jan ‘0

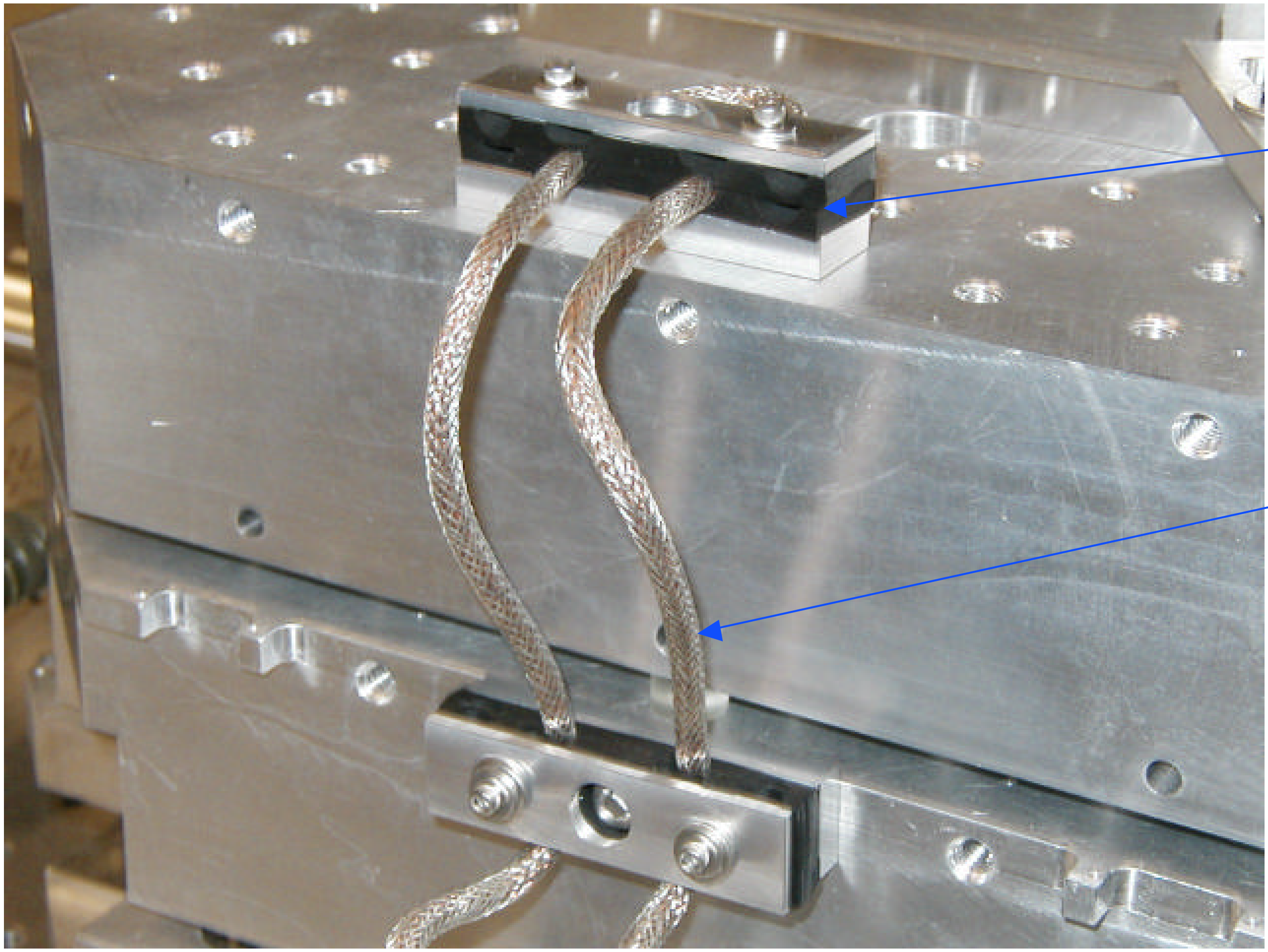
Vertex Area Layout



In-vacuum Cabling

- The Initial LIGO cable was too stiff for our small seismic stacks; also, we wanted twisted pairs with braided shield
- Designed hybrid cable: to be available Jan ‘02
  - » D25 cable connectors
  - » Flexible form, multi-strand, fine gauge, 180VDC, 5 mil FEP
  - » 12 twisted pair: 5 twists per inch, each conductor 28 ga
  - » Shielded: 90% coverage, fine gauge, braided copper shield
- Prototyped and tested for shorting seismic isolation
- Cable clamp design has been prototyped and tested
- Cost is less than the Initial LIGO design
- Coyne & Heefner on board throughout development

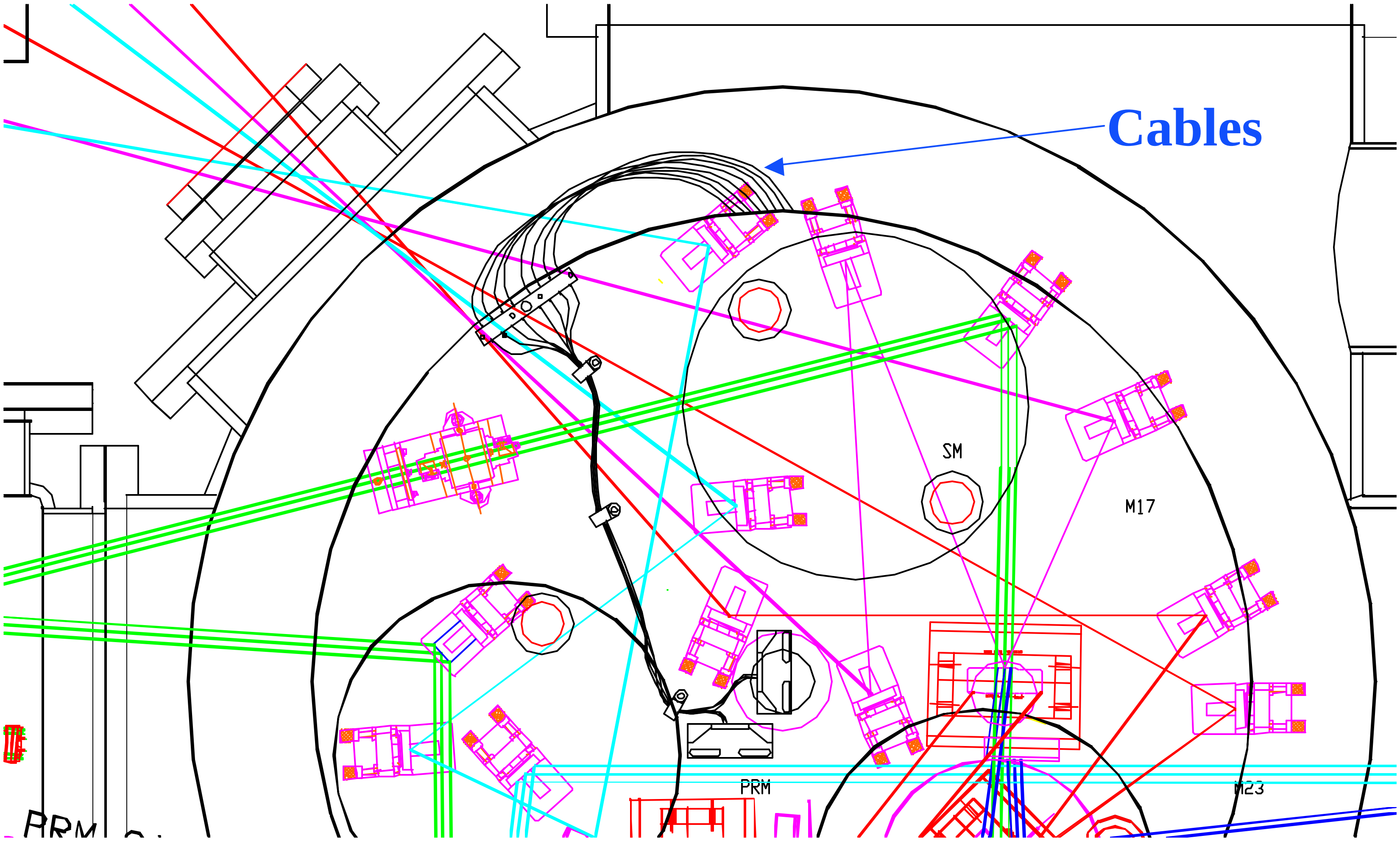
Cable Design



Fluorel Liner

Shielded Cable

BSC Cable Layout



Racks & Cable Trays

- 12 electronic racks and over 300 feet of cable tray have been installed

Active Seismic Isolation

- Three-legged STACIS systems have been installed at the SE, SV, EV, & EE chambers
- Performance testing showed 20-30 dB of seismic isolation is provided in the 1-100 Hz range

STACIS Installation

Optical Tables

- 9 optical tables are planned: 8 are in-house, 1 is due on campus next week
  - » All table support stands are of custom, rigid design; 6 are in-house, three are due for fabrication completion next week
  - » All tables will be bolted to the floor
  - » Surface area and depth vary with position
    - – (3) 2'x4'x4": ETMX, ETMY, OPLEV
    - – (1) 3'x4'x12": AP2
    - – (2) 3'x5'x12": BSPO, ITMXY
    - – (1) 4'x6'x12": AP1
    - – (1) 5'x10'x12": PSL
    - – (1) 5'x12'x24": SP&MC

Schedule

- 10/19 Order cable, clamps, liners, fixture, brackets, & hardware
- 10/26 Receive table & table stands
- 11/2 Install remaining tables & stands
- 12/21 Receive cable
- 12/28 Receive clamps, liners, fixture, brackets & flanges
- 1/11 Terminate & test cables
- 1/11 Ship cables, clamps, liners, fixture, & hardware for cleaning
- 2/1 Cleaning complete, RGA scan approved
- 2/8 Cleaned parts received at 40M lab
- 2/11 Open vacuum system & start installing seismic stacks (MC and Output chambers), cables, clamps, liners, brackets, hardware & flanges (includes cable continuity tests)
- 3/1 Cables & stacks installation complete

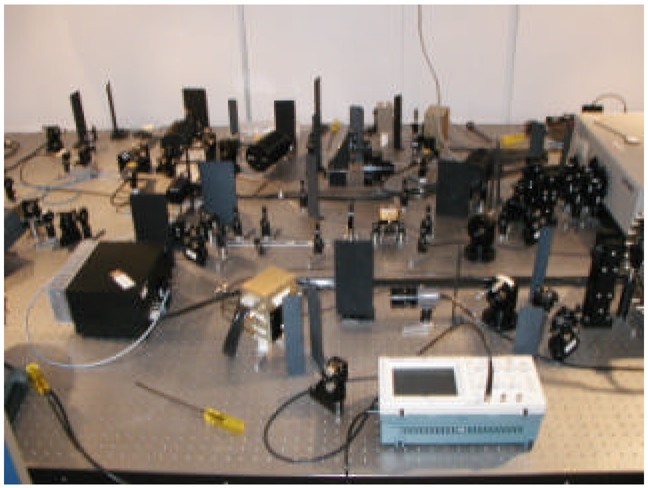
Gotchas

- What are we forgetting?

40-Meter Subsystems: "As LIGO-Like as Possible"

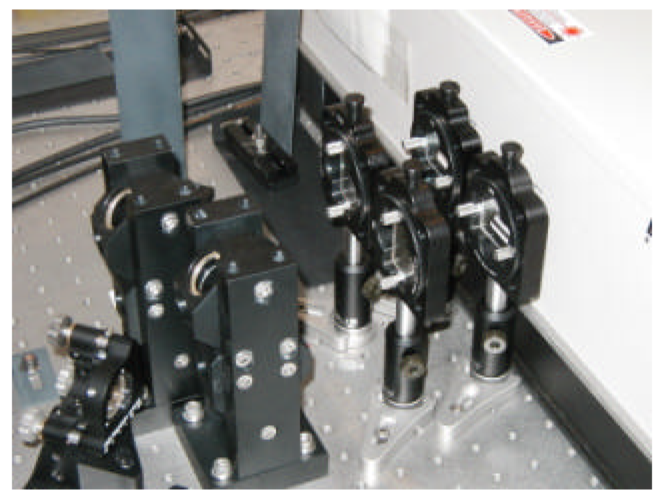
- PSL
  - » Commissioning
  - » Noise performance
- Vacuum
  - » Operating pressure goal
  - » EPICS control system
- PEM
  - » Weather, seismic monitoring
  - » Cable flexibility testing
  - » STACIS
- Computing
  - » Networking goals
  - » DAQ, DMT installation

PSL Overview

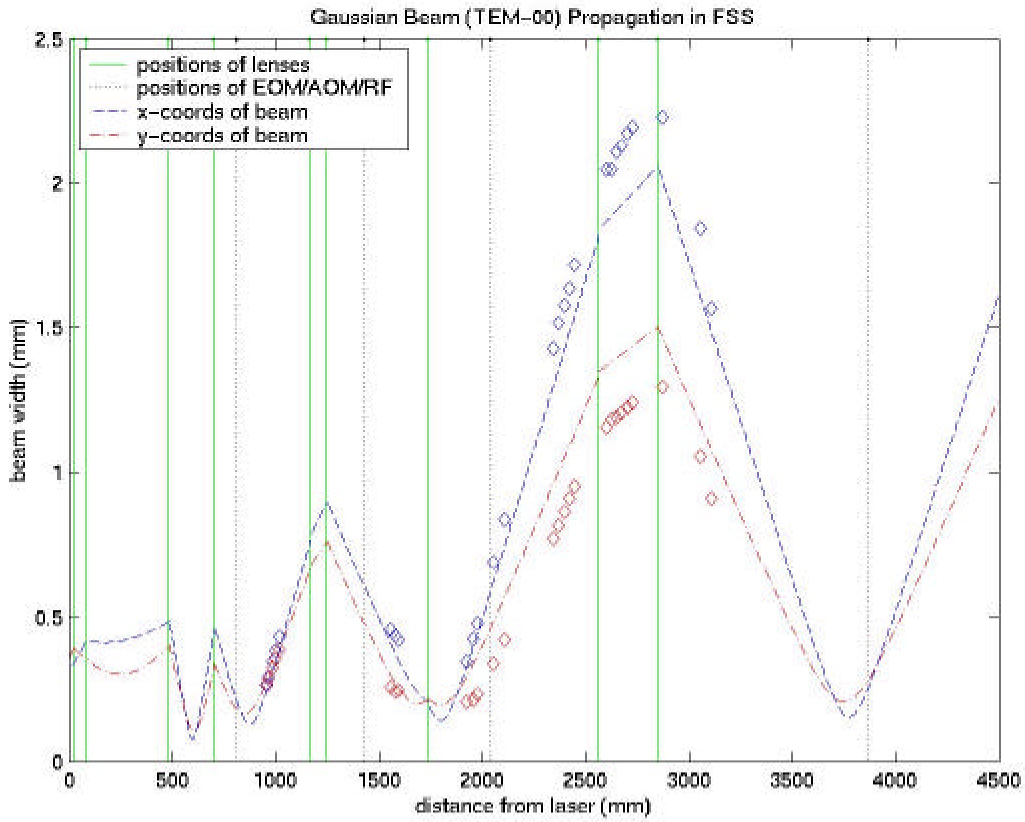


We use the same 10-watt Nd:YAG Lightwave 1064μm laser as the main LIGO sites, except that our master oscillator runs at 1 watt.

Currently both output ports of the laser are in use, requiring two sets of cylindrical lenses to correct its astigmatism. We need to pickoff the low-power beam after the periscope, and rethink the circularity and mode-matching.

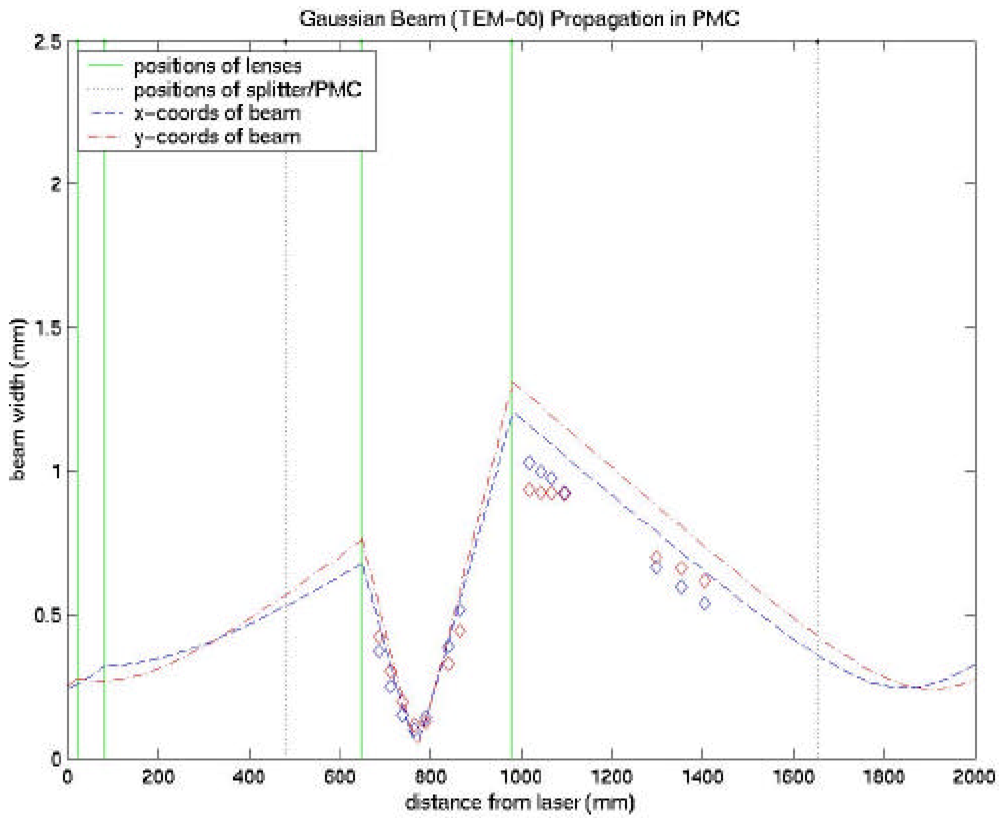


Mode Matching in FSS Path



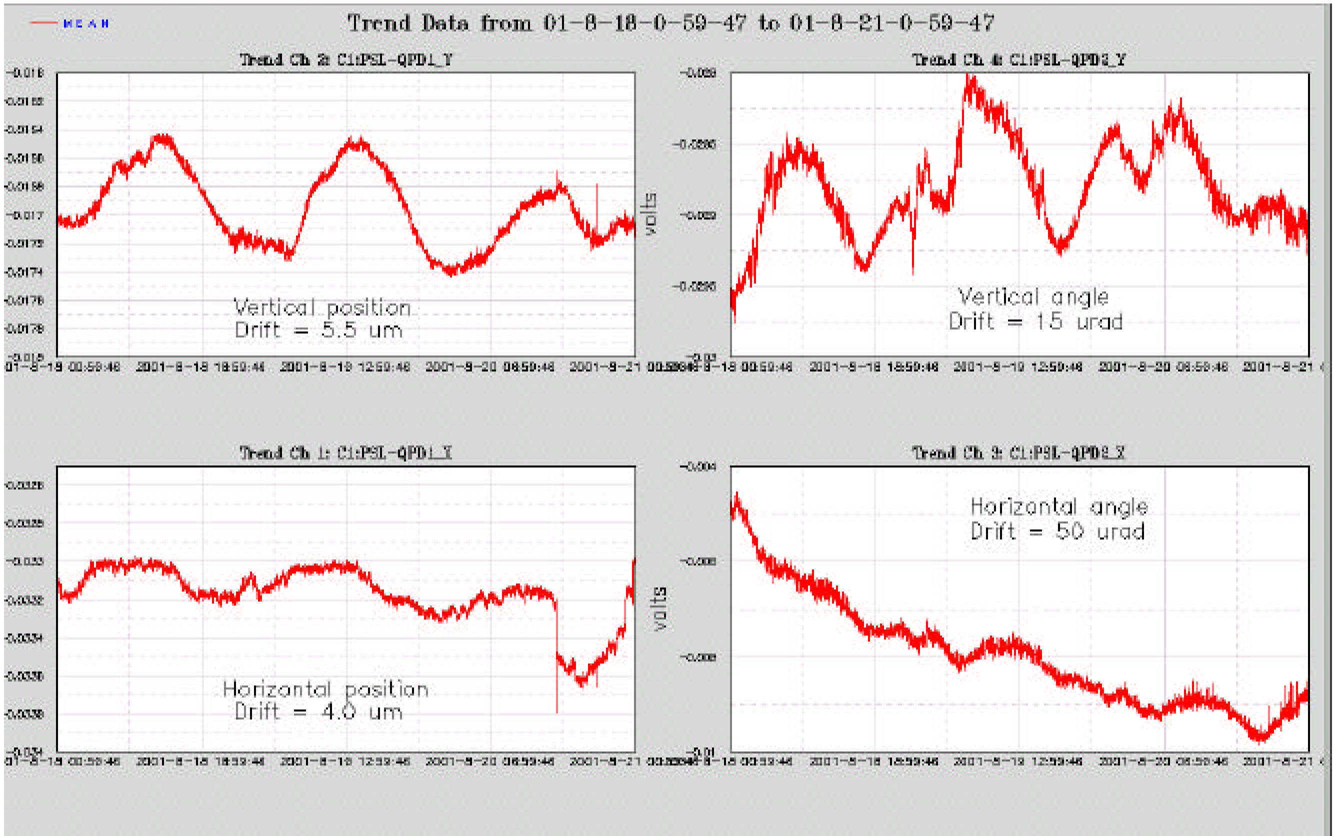
Reference cavity visibility = 93%   Transmitted power = 5 mW

Mode Matching in PMC Path



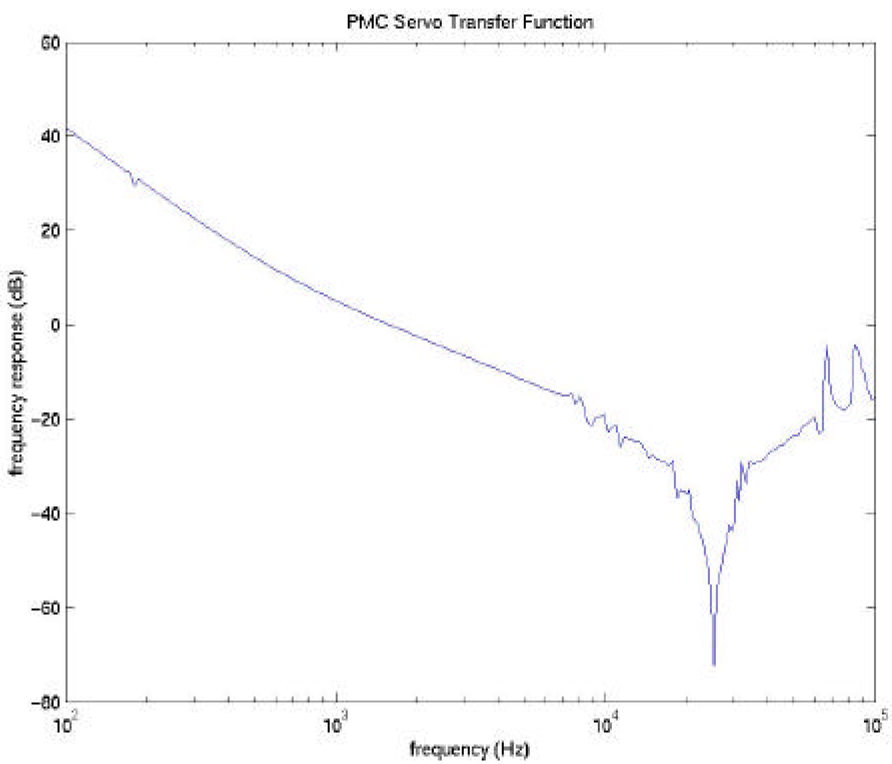
PMC cavity visibility = 64% Transmitted power = 5.2 W

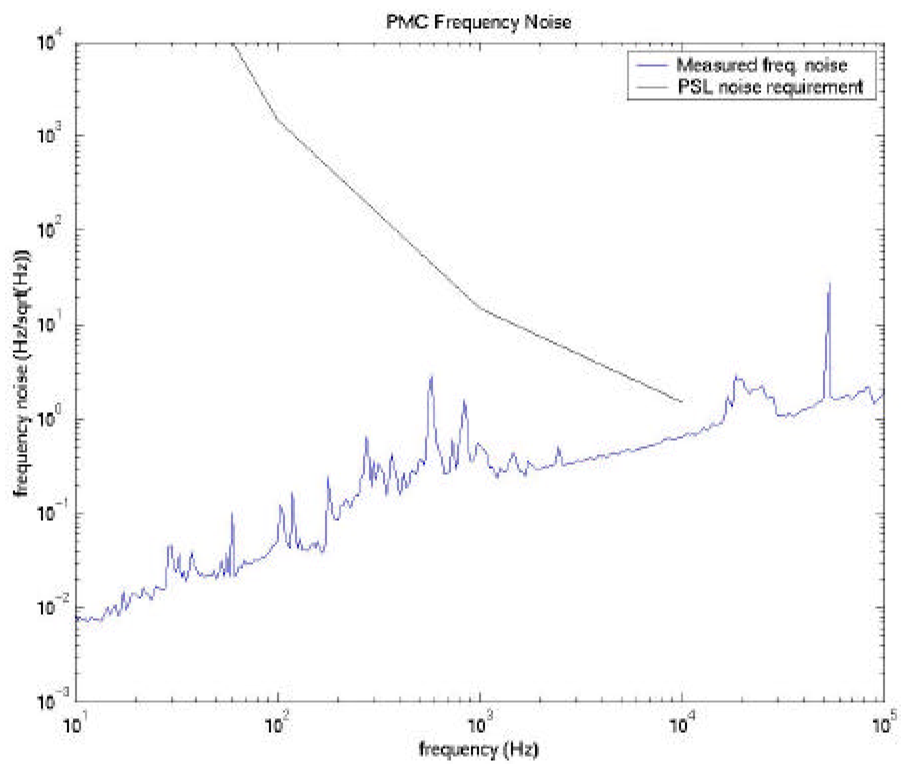
Positional/Angular Stability



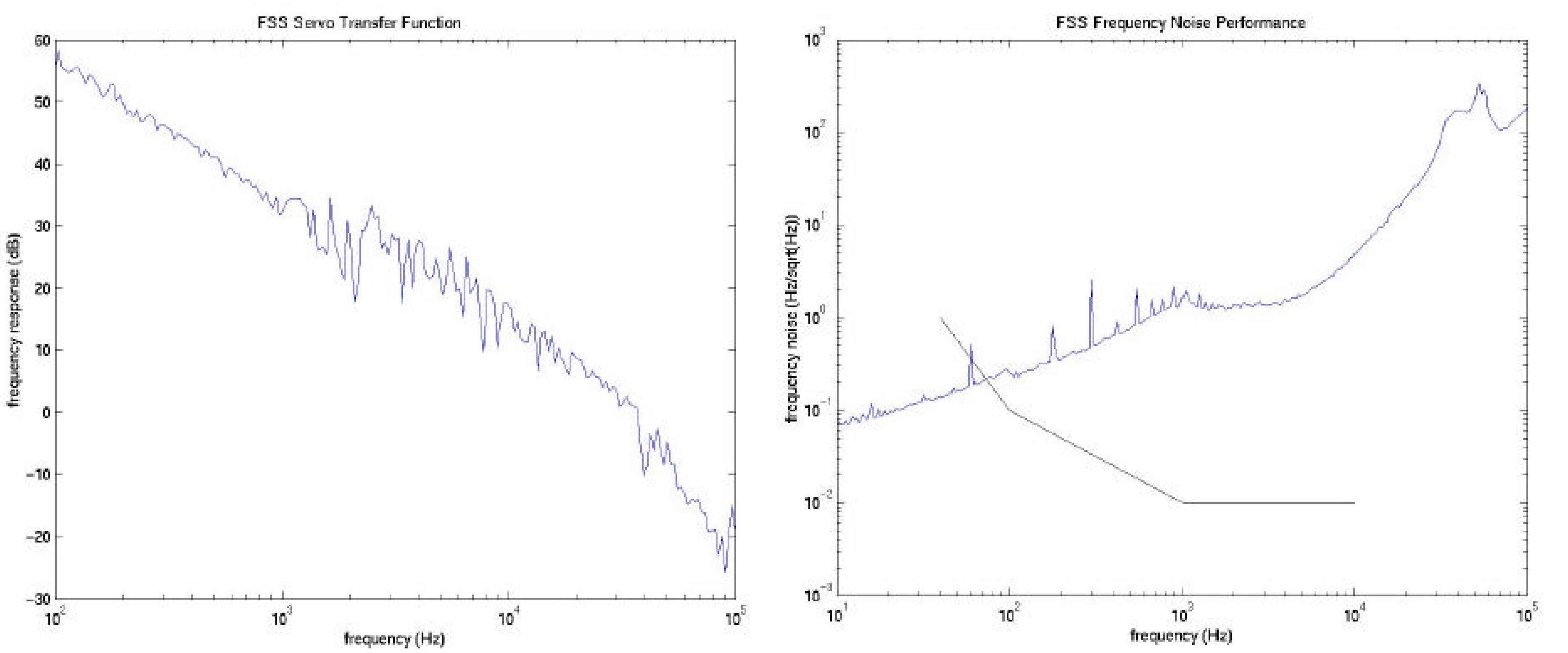
QPD measurements taken over 72 hours, 8/17/01-8/20/01

PMC Servo Noise Performance



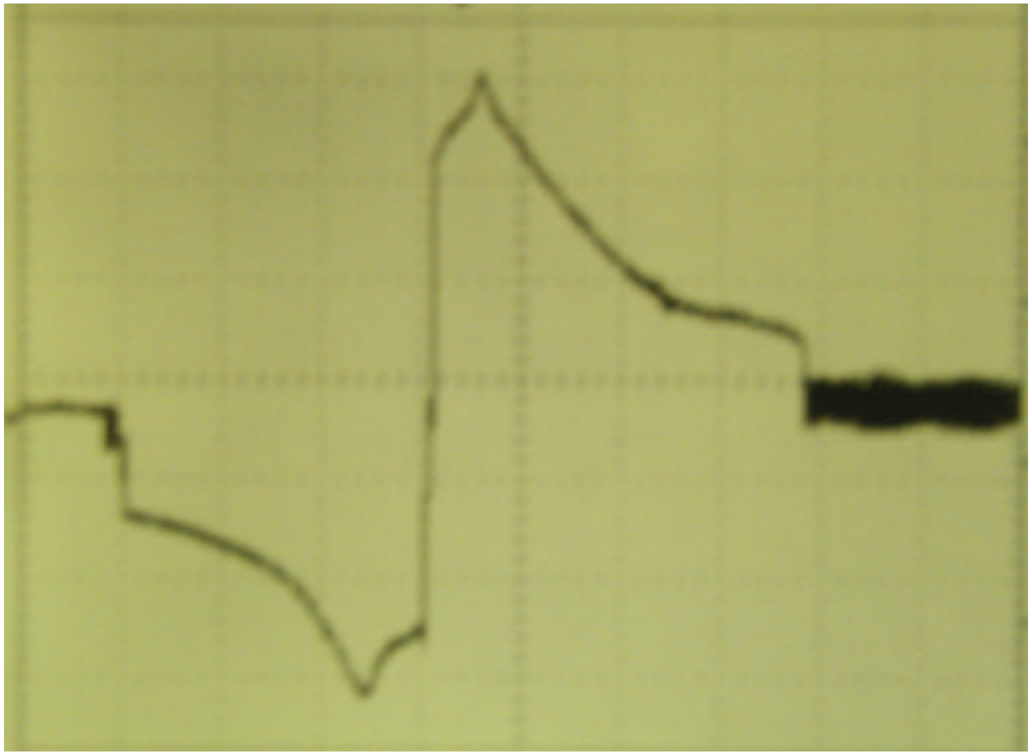


FSS Servo Noise Performance



What's Wrong With the FSS?

- Photo at right shows the FSS error signal.
  - » 7 MHz oscillation in tail
  - » "Zigzag" at zero crossing
- What's causing this?
  - » Bad servo/mixer? Swapped out with no change
  - » LO signal too small? 5 Vpp from FSS reference card
  - » RFPD signal too small? 2 mW of light at resonance

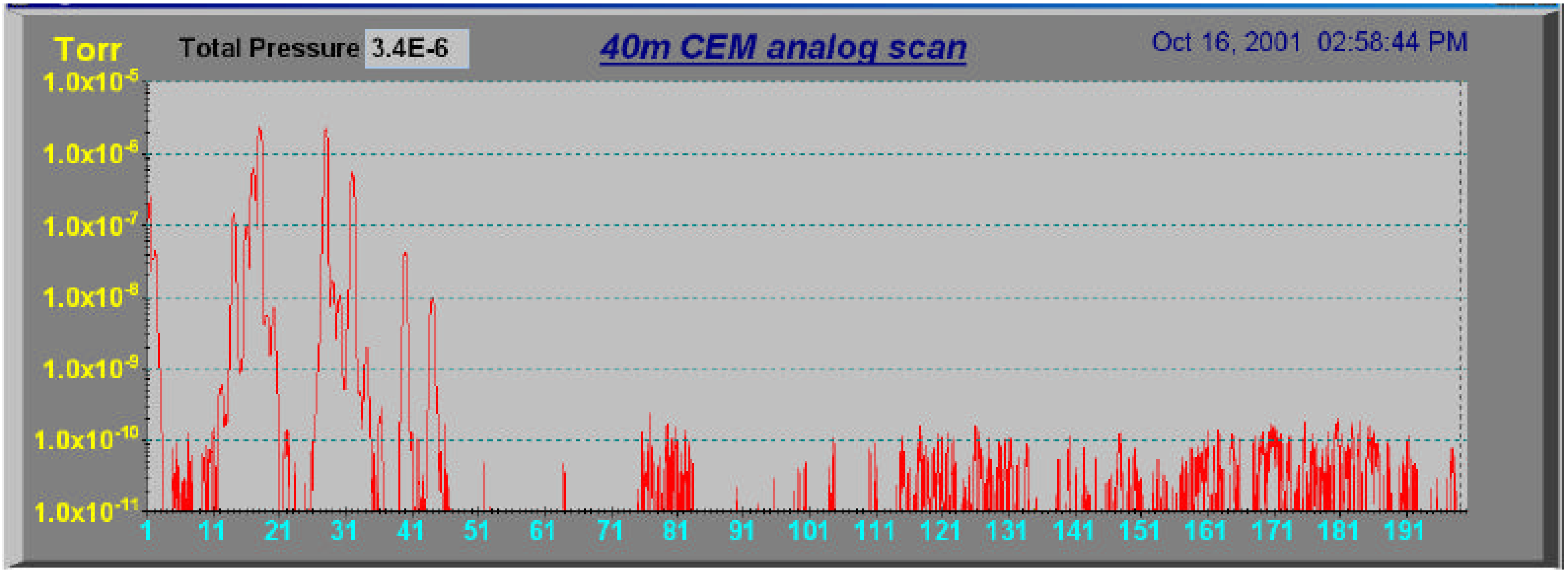


Future PSL Work

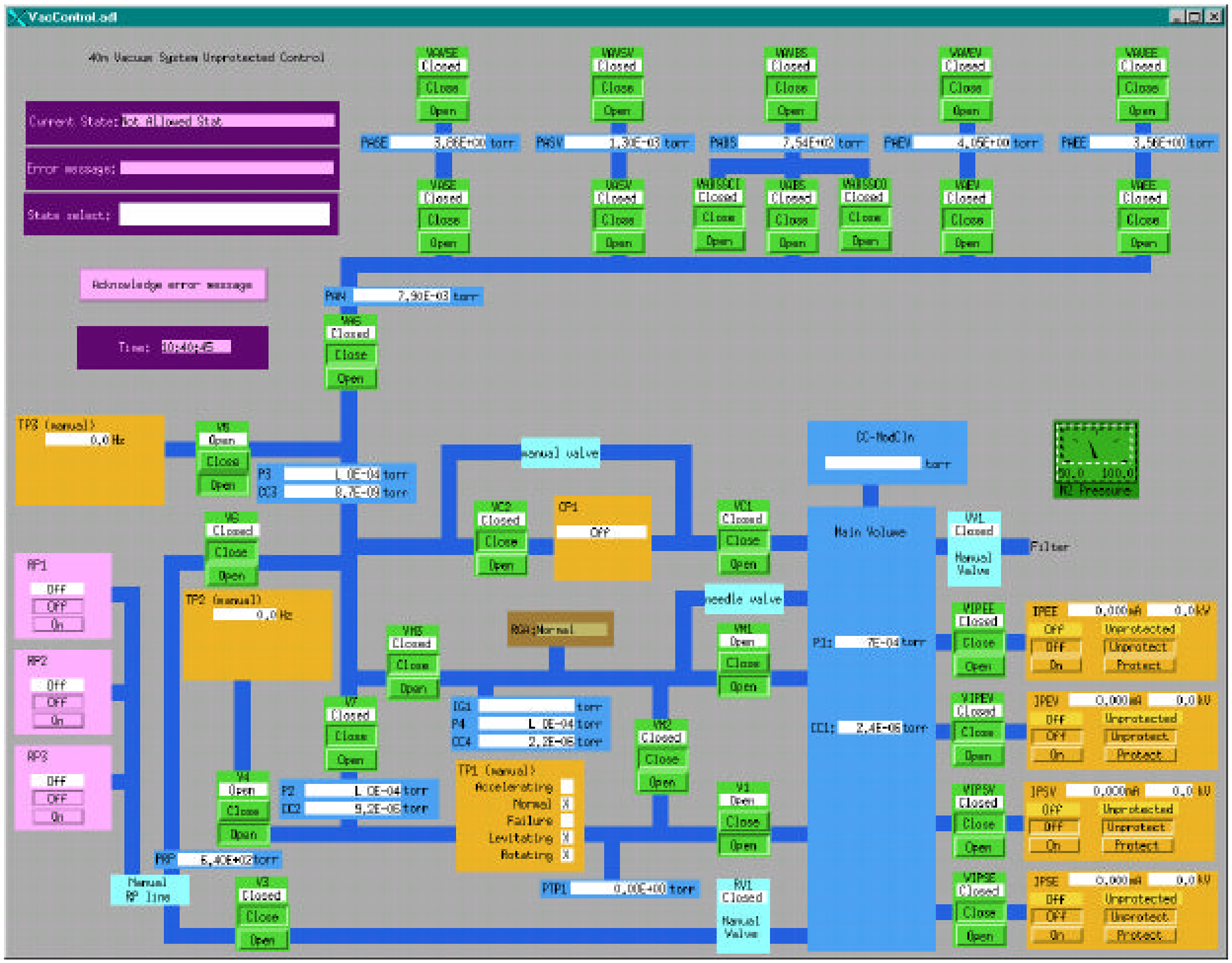
- Review optical layout
  - » Pick off low-power beam after periscope
  - » Select new cylindrical lenses for better circularity
  - » New mode-matching scheme in both paths by M. Smith
- Diagnose excess FSS noise
- Install EOMs, relocate QPDs to final position
- PSL ready for arrival of MC optics in January

Vacuum System Overview

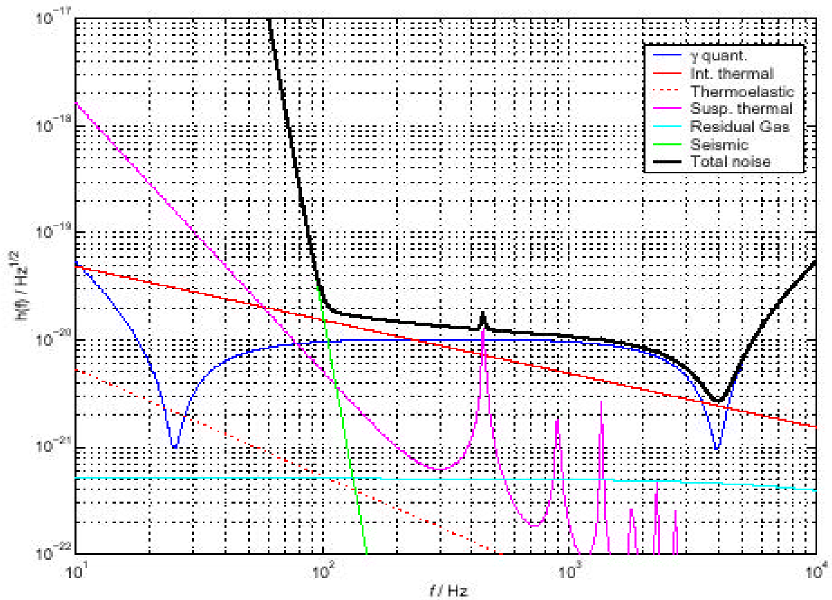
- Expanded envelope -- MC, OOC chambers added
- Regenerated, reinstalled ion pumps
- Contaminant level unchanged; opted for no bake-out



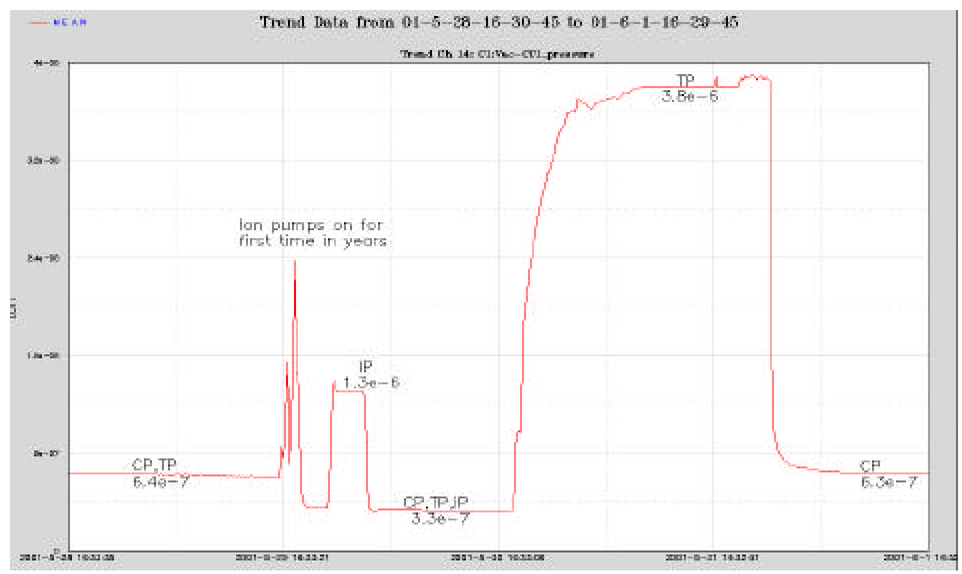
EPICS-based Control System



Residual Gas Noise Requirement



The plot at left includes the residual gas noise for a vacuum of 10^{-6} torr, dominated by water and nitrogen. At higher pressures the noise becomes significant at the tuned frequency.

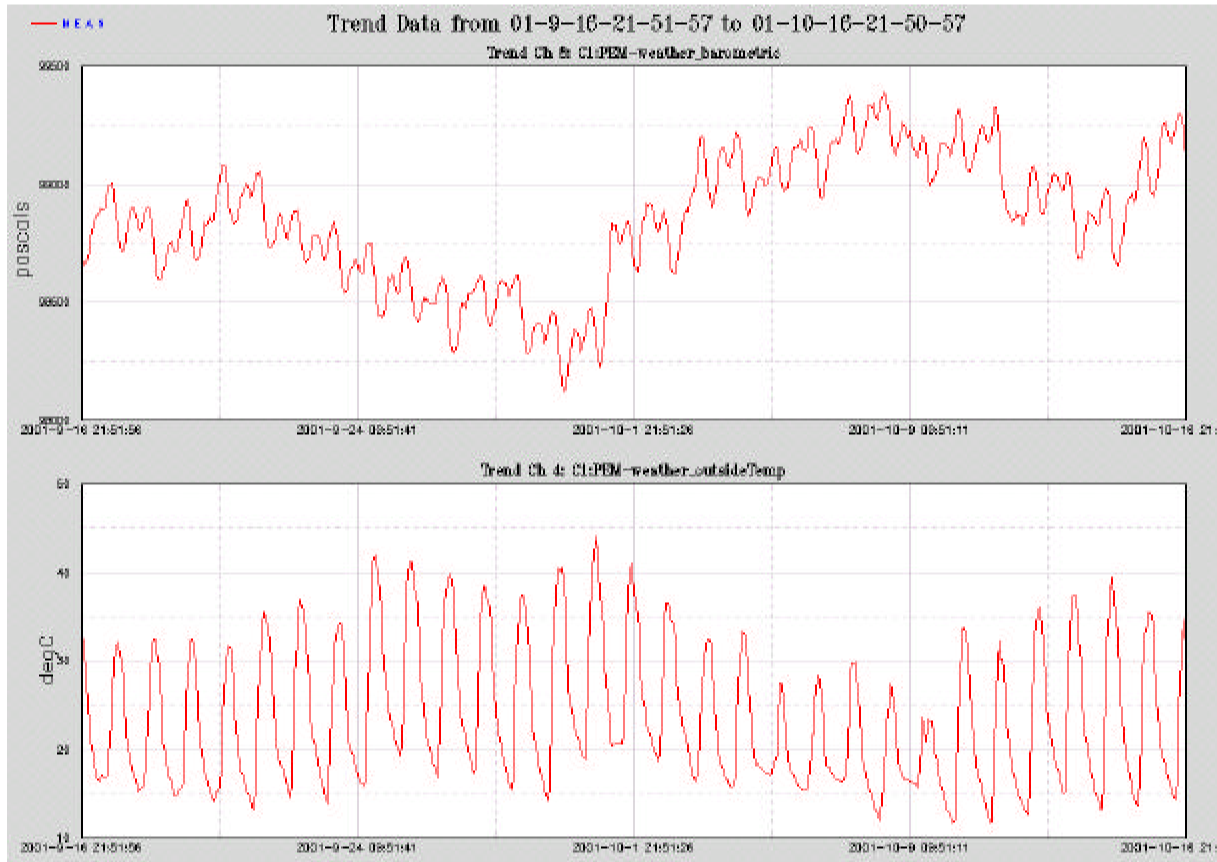


The 40m vacuum system can run as low as $3*10^{-7}$ torr, and has a pressure of $1.3*10^{-6}$ torr in low-vibration mode (ion pumps only).

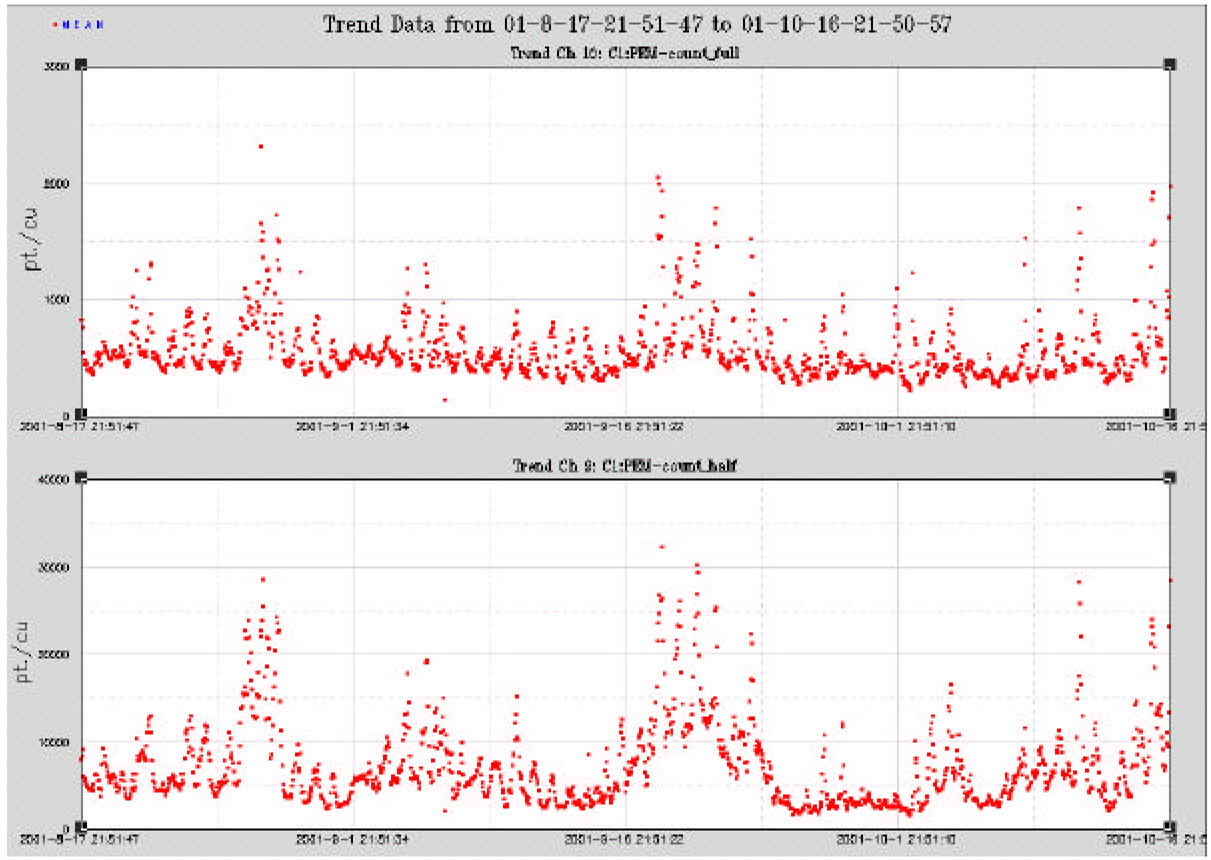
Future Vacuum System Work

- Hardware installation nearly complete
  - » Still need to install new filter at vent valve
  - » Single O-ring at OOC; permeation only significant at 10^{-8} torr
  - » Turbopumps obsolete by next year; should they be replaced?
- Improvements to EPICS control system
  - » Ion pump voltage, current, status readout (crash problem)
  - » Turbopump status, rotation speed readout (no response)
  - » Read out RGA alarm status
  - » Recognition of system state
  - » Automated state changes
- Begin logging RGA scans, system status

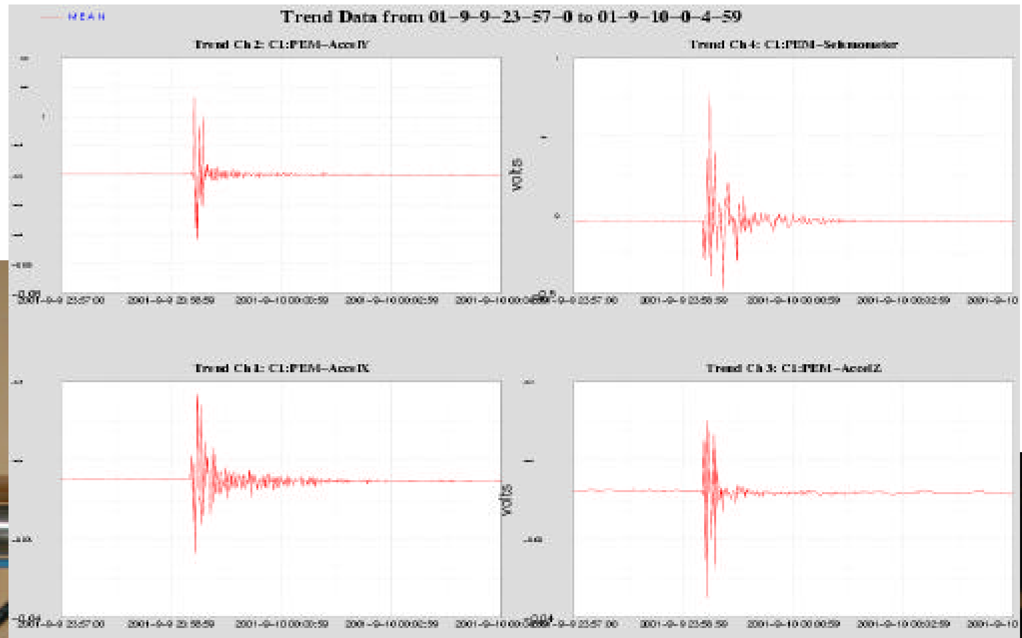
PEM: Weather Station

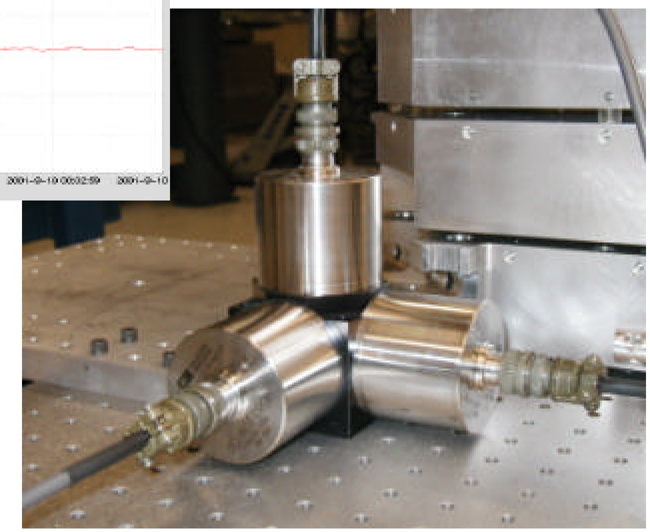


PEM: Particle Counter



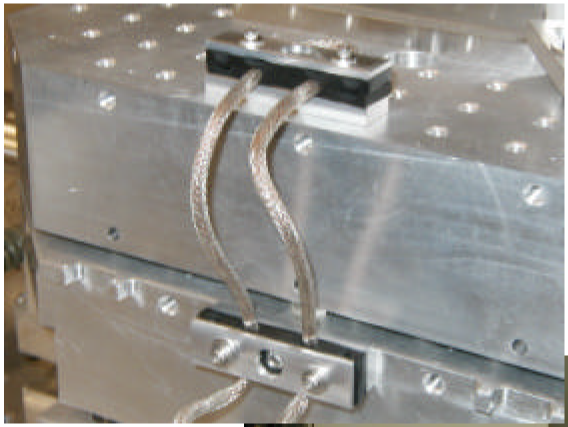
PEM: Seismic Monitoring



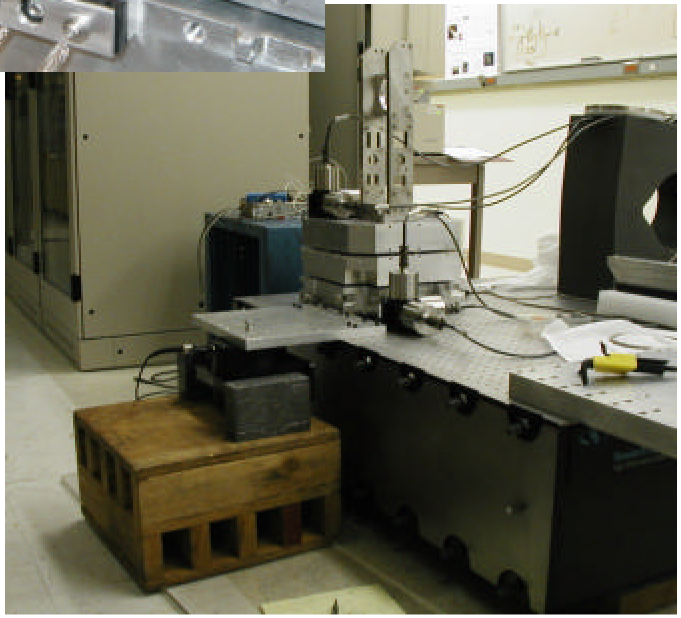


Cable Flexibility Testing

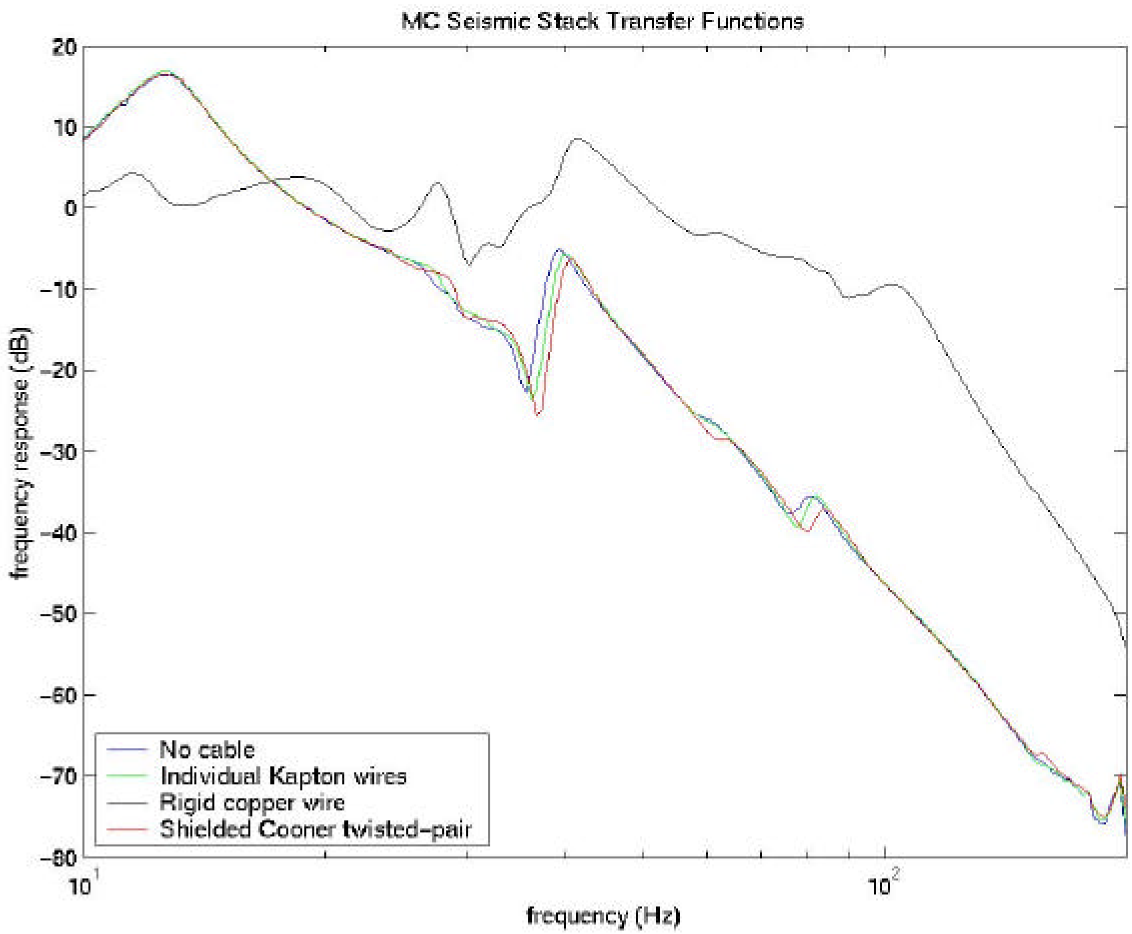
There has been concern that the in-vacuum cables used at the sites are too stiff, and would short out the 40m seismic stacks.



Larry Jones has been acquiring cable prototypes, which are tested with the apparatus shown here. The cables are clamped to the MC end chamber seismic stack, which is then vertically shaken. Wilcoxon accelerometers are used to measure the transfer function.



Flexibility Testing Results



STACIS Active Seismic Isolation

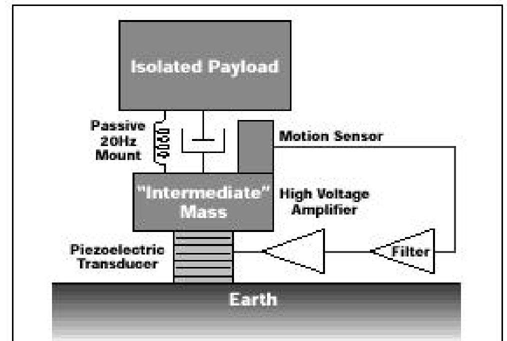
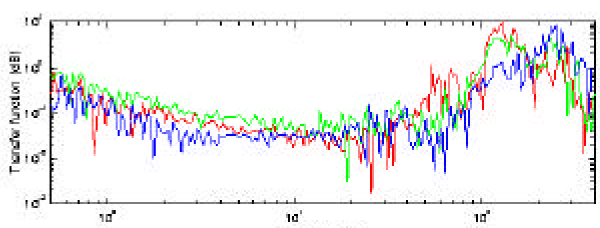
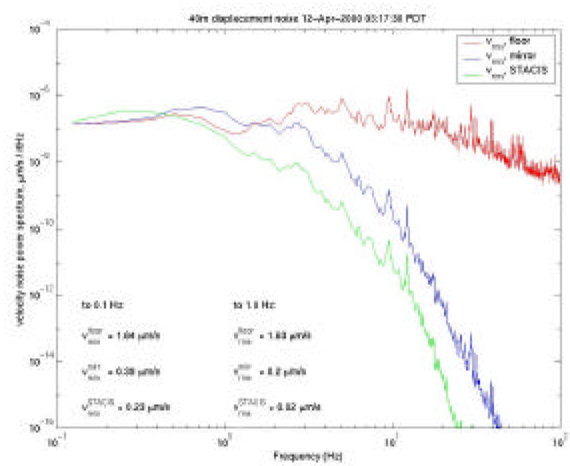


Figure 18

- One set of 3 for each of 4 test chambers
- 6-dof stiff PZT stack
- Active bandwidth of 0.3-100 Hz,
- 20-30dB of isolation
- passive isolation above 15 Hz.

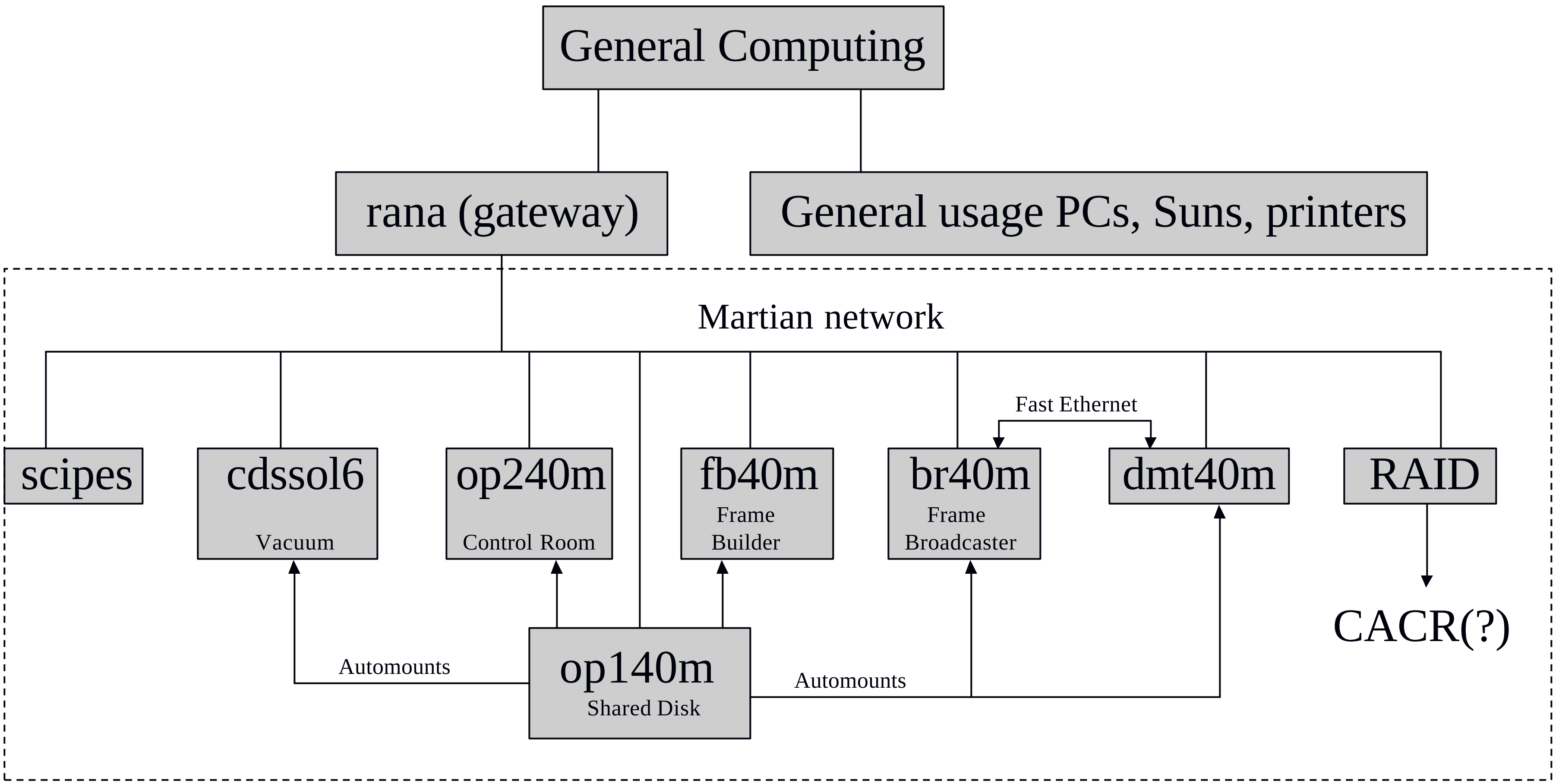




Future PEM Work

- Fix, understand current devices
  - » Outside humidity stuck at 128%
  - » Weather station, particle counter do not agree
- Add more sensors (microphone, line monitor, etc.)
- Read STACIS information into EPICS, DAQ
  - » “Black box” software, must reverse-engineer
- Start looking for correlations with IFO performance

40m Network Diagram



Data Acquisition System

- The 40m DAQ is essentially the same as the sites:
  - » ADCU with two ICS-110B modules (64 fast channels)
  - » EDCU for reading values from EPICS (currently 79 slow channels)
  - » RAID array with hundreds of GB of frame storage space:
    - – Full data for 48 hours
    - – Second trend frames for one month
    - – Longer trend frames “forever”
  - » Frame broadcaster for use with DMT (still being installed)
  - » Connection to CACR for permanent data storage?

Future Computing Work

- Populate op140m shared disk
  - » Move state code, medm screens, DAQ code, etc.
  - » Point all VME crates to boot from op140m
- Finish DMT installation
  - » J. Zweizig has just installed software on dmt40m; we're still learning how it all works
  - » R. Bork, A. Ivanov are preparing br40m
- Send EPICS screens, values to web server

Summary

- The 40m PSL is up and running, but needs further commissioning work to increase its power output and reduce the frequency noise in the FSS
- The vacuum system meets the goal of operating vibration-free at ~10-6 torr
- Several PEM components are in place (weather & seismic monitoring) and more are being added
- The DAQ is functioning, and DMT is being installed
- These systems should be ready for the arrival of MC optics in January!

40M RSE Core Optics

LIGO Lab

October 18, 2001

Specifications

Material

- BS and ITM are Heraeus Low absorption fused silica (aka. SV)
- All others are Corning 7980 fused silica

Polishing

- Radii of curvature range 57m - flat.
- ROC tolerance ± 20 nm sag over 30 mm diameter
- Arm cavity surfaces < 2nm rms residual, < 0.1 nm microroughness
- Recycling cavity surfaces < 5nm rms residual, < 0.2 nm microroughness

Coating

- Same as Ad LIGO plan (E000487) except PRM HR=7% nominal

Polishing Spec Summary

#	Name	Spec	Drawing	Size	Wedge degrees	ROC S1	ROC S2	Residual error S1	Residual error S2	Micro-roughness S1
2	PRM	E010099	D010101	75mm ± 0.5 x 25mm+0, -0.5	2.5 asymmetric	348 ± 23m	Flat >5625m	< 5 nm	< 5 nm	< 2 Å
2	SRM	E010100	D010102	75mm ± 0.5 x 25mm+0, -0.5	2.5 asymmetric	365 ± 25m	Flat >5625m	< 5 nm	< 5 nm	< 2 Å
2	BS	E010101	D010103	75mm ± 0.5 x 25mm+0, -0.5	1 symmetric	Flat >5625m	Flat >5625m	< 5 nm	< 5 nm	< 2 Å
3	ITM	E010102	D010104	125mm +0, -1 x 50mm+0, -0.5	1 asymmetric	Flat >5625m	Flat >5625m	< 2 nm	< 5 nm	< 1 Å
3	ETM	E010103	D010105	125mm +0, -1 x 50mm+0, -0.5	2.5 asymmetric	57.37 ± 0.6m	Flat >5625m	< 2 nm	No Spec	< 1 Å

Polishing Specs continued…

Wedge: All wedge tolerances are ±5’

Defects: Same for all substrates; none in the central 10mm diameter, total in the central 30mm not to exceed 500 square micrometers, total in central 30mm not to exceed 5000 square micrometers. Defects smaller than 5 micrometers are disregarded.

Coating Spec Summary

	Side 1 Transmission (%)	Side 2 Reflection (ppm)
PRM	7.0 ± 0.7	1000
SRM	7.0 ± 0.7	< 100
BS	50 ± 1.0	< 100
ITM	0.5 ± 0.05	600 ± 100
ETM	< 20 ppm	< 300

Coating absorption <1ppm   Uniformity .1%   Scatter < 15ppm

LIGO

Status

IO blanks being polished at Wave Precision

- MC flats are due now
- MC Curves are due by Mid Nov.
- Have not been able to get an update on delivery dates.

COC blanks at Caltech

- Bid received from CSIRO
- Probable no-bid from Wave Precision

Additional blanks on order

Schedule: slip ~ 80 days

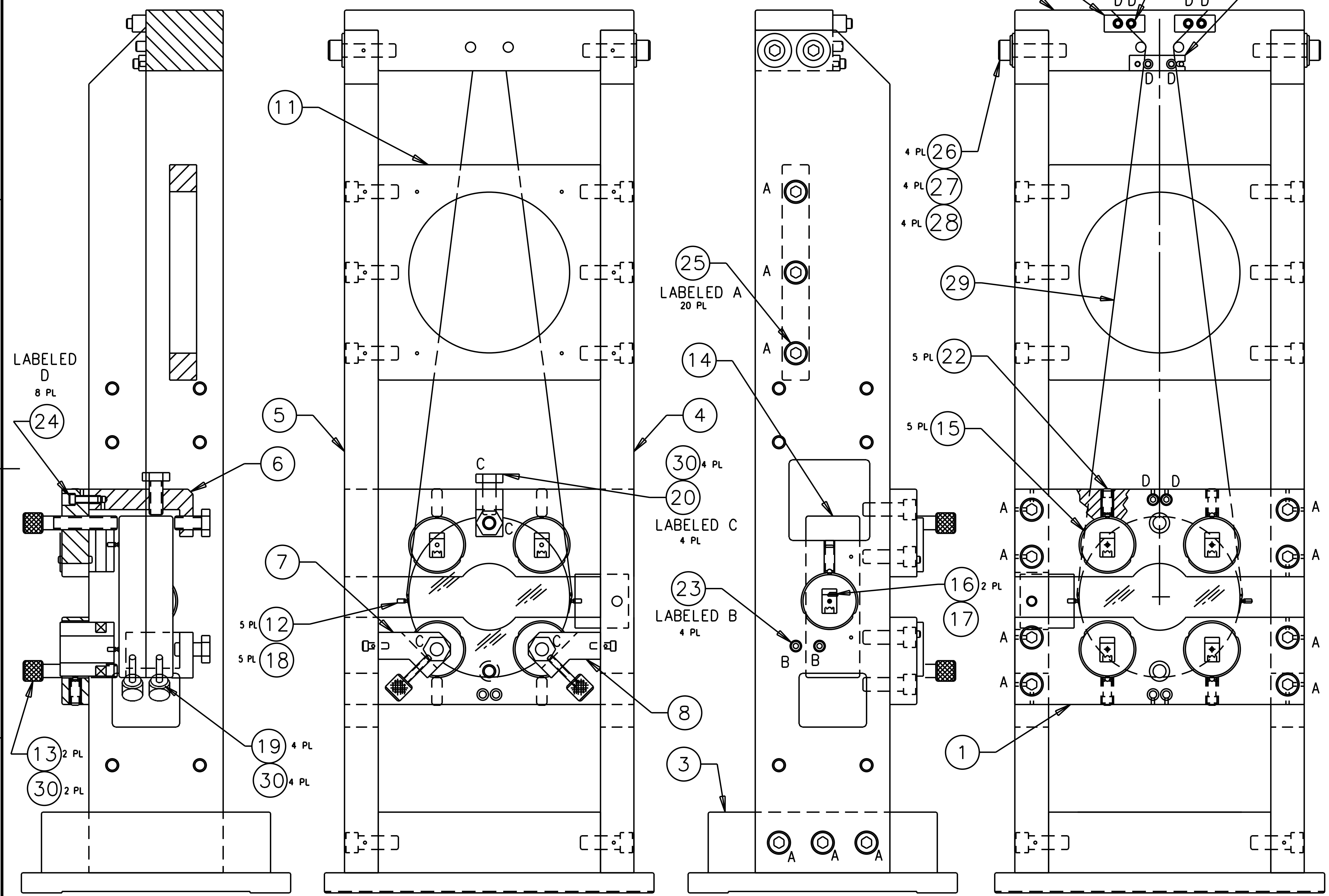
- If Vendors are responsive we should be able to start IO delivery in Feb ’02 and COC delivery in June ‘02

40m SUSPENSIONS

- Two suspension types for 40m IFO;
  - LIGO 1 SOSs for 75mm dia. X 25mm thick optics:
    - BS, PRM, SRM, MCC, MCF1 and MCF2
    - Quantity 6, plus one spare, possibly for output mode cleaner.
  - Redesigned 40m TM Suspensions for 125mm dia. X 50mm optics:
    - ETMs and ITMs.
    - Quantity 4, plus one spare
- Both suspension types will use the redesigned LIGO I sensor/actuator heads ("osems")

40m SUSPENSIONS SCHEDULE

- SOSs – all machined parts and fixtures are fabricated and stored in the So. Annex. They are ready for cleaning and baking – approx. 1 month.
- TM SUSs – CES is estimating fabrication completion of all parts and all but one fixture by Feb. 2002. Subcontractor for guide rod fixture should deliver the fixture by Nov. 2001. Cleaning and baking (~1 month) after.
- Optic cleaning, suspending and balancing to start as soon as the optics are available after metrology ~ tentative March '02 for small optics and June '02 for TMs.
- Each suspension should take approx. 1 week to suspend, 1 week to bake optic and 1 day to rehang and test. Suspensions may be done in groups.
- Assembly specifications need to be written for the TM suspensions. SOSs will use LIGO I assembly and balancing specifications.



REV	DATE	DRAWN BY	CHECKED	DCC	DCN/DESCRIPTION
A	7-28-97	J.Hazel			E970121/INITIAL RELEASE
B	11-7-00	J. Romie			E980221/UPDATE HARDWARE

10	LEE SPRING C012X250PBBR	PHOSPHOR BRONZE SPRING	30
AR		ϕ.0017"±.0001" STEEL MUSIC WIRE	29
4	1/4	SST WASHER, REDUCED OD	28
4	1/4	SST LOCK WASHER	27
4	UC COMPONENTS C-2020-NA	1/4-20x1.25L Ag PLATED SHCS	26
20	UC COMPONENTS C-2012-NA	1/4-20 X.75L Ag PLATED SHCS	25
8	UC COMPONENTS C-408-NA	4-40 X.50 LG Ag PLATED SHCS	24
4	UC COMPONENTS C-406-NA	4-40 X.38 LG Ag PLATED SHCS	23
5	84985A999	SST SPRING PLUNGER, 10-32	22
		.75-2.5 LBS, McMASTER P/N	
4	D970311	SAFETY STOP, CONDUCTIVE	20
4	D970312	SAFETY STOP, CONDUCTIVE, SMALL	19
6	D960501	MAGNET	18
1	D970188	GUIDE ROD	17
2	D970187	WIRE STANDOFF	16
5	D960011	SENSOR/ACTUATOR ASSEMBLY	15
1		OPTIC	14
2	D970313	SAFETY STOP, CONDUCTIVE, LONG	13
6	D970075	DUMBBELL STANDOFF	12
1	D960009	STIFFENER PLATE	11
2	D960134	CLAMP, SUSPENSION BLOCK	10
1	1205308-1	WIRE CLAMP	9
1	D960008-2	LOWER CLAMP, OPPOSITE	8
1	D960008-1	LOWER CLAMP	7
1	D960007	UPPER MIRROR CLAMP	6
1	D960006	LEFT SIDE PLATE	5
1	D960005	RIGHT SIDE PLATE	4
1	D960004	TOWER BASE	3
1	D960003	SUSPENSION BLOCK	2
2	D960002	SENSOR/ACTUATOR PLATE	1
QNTY	PART NUMBER	DISCRIPTION	ITEM NO.

DRWN J. Hazel 12-29-95
CHK

LIGO PROJECT

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SMALL OPTIC SUSPENSION ASSEMBLY

SCALE: 1/2
DRAWING NUMBER D960001-B-D
SHEET 1 OF 2

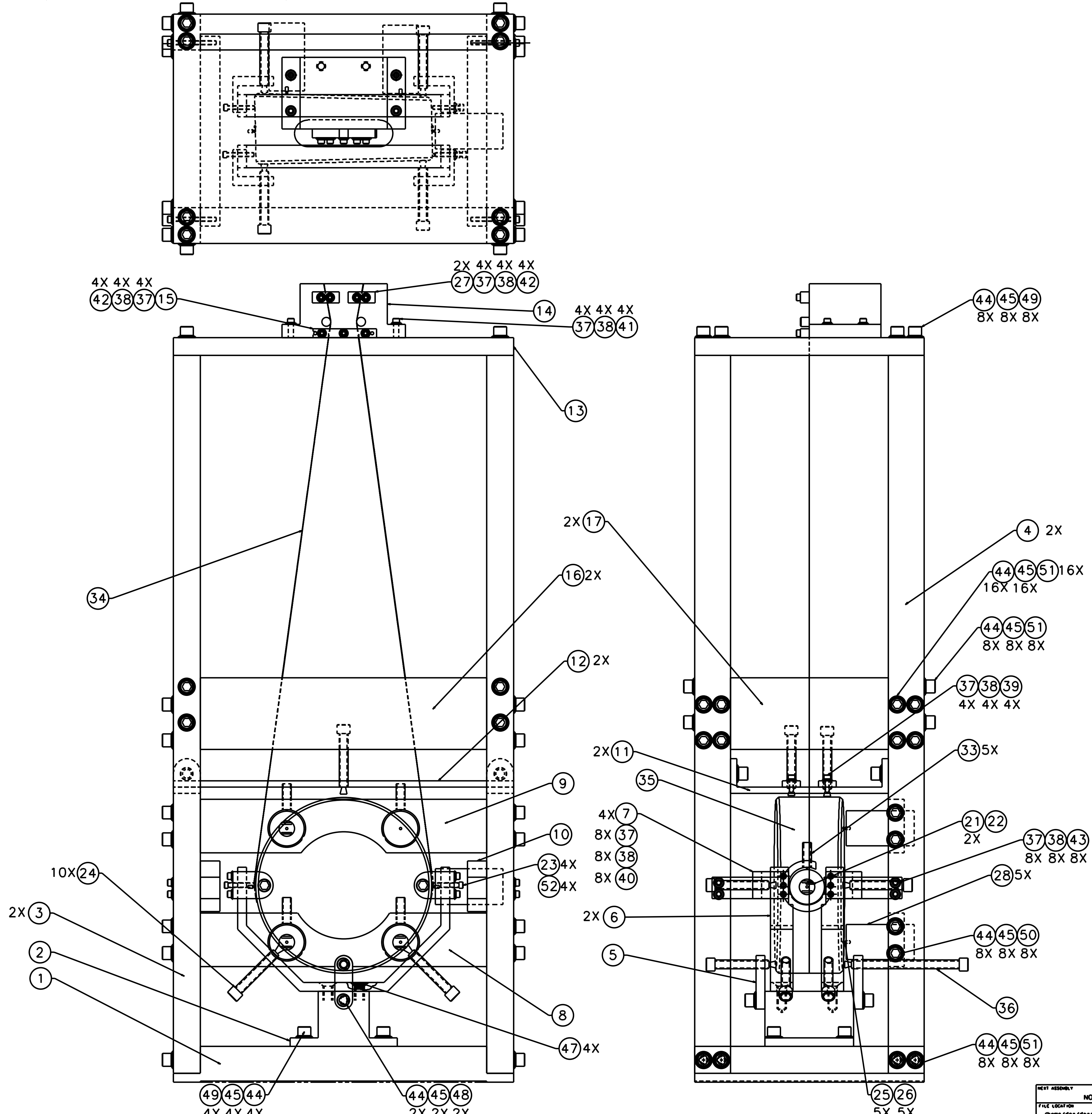
LIGO-G010385-00-R

/home/dcc/docs/D960001.pdf

LIGO-G010385-00-R

NOTES: (UNLESS OTHERWISE SPECIFIED)
1.

REV	DATE	BY	DESCRIPTION
A	8-30-01	J. Romie	D010163/INITIAL RELEASE



QTY REQD	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO
4	LEE P/N C012X250PHBR	COMPRESSION SPRING	PHOSPHOR BRONZE	52
32		1/4-20 x 1.50 SHCS	STAINLESS	51
8	U-C COMP C-2016-NA	1/4-20 x 1.00 SHCS	Ag PLATED SST	50
12		1/4-20 x 1.00 SHCS	STAINLESS	49
2		1/4-20 x .75 SHCS	STAINLESS	48
4		1/4-20 x .50 100* CSINK	STAINLESS	47
4		1/4-20 x .50 SHCS	STAINLESS	46
62	MS35338-139/EQUIV.	1/4 LOCK WASHER	STAINLESS	45
62	MS15795-810/EQUIV.	1/4 FLAT WASHER	STAINLESS	44
8	U-C COMP C-416-NA	4-40 x 1.00 SHCS	Ag PLATED SST	43
7	U-C COMP C-412-NA	4-40 x .75 SHCS	Ag PLATED SST	42
4		4-40 x .75 SHCS	STAINLESS	41
8	U-C COMP C-406-NA	4-40 x .375 SHCS	Ag PLATED SST	40
4		4-40 x .375 SHCS	STAINLESS	39
27	MS35338-135/EQUIV.	#4 LOCK WASHER	STAINLESS	38
27	MS15795-803/EQUIV.	#4 FLAT WASHER	STAINLESS	37
1	D010214	BEAMSPLITTER CHAMFER STOP		36
REF		40m TEST MASS OPTIC		35
A/R		ø.0036" DIA STEEL MUSIC WIRE		34
5	D010085	SPRING PLUNGER		33
REF	D970180	WINCH FIXTURE		32
REF	D000035	MAGNET&DUMBBELL SANDING FIXTURE		31
REF	D961412	SET SCREW TOOL		30
REF	D000036	MAGNET-TO-DUMBBELL ASSY FIXTURE		29
5	D000069	SENSOR ACTUATOR HEAD, LONG, SMD		28
2	D960134	LOS CLAMP, SUSPENSION BLOCK		27
6	D970075	DUMBBELL STANDOFF		26
6	D960501	MAGNET		25
9	D010213	BEAMSPLITTER SAFETY STOP		24
4	D970312	SAFETY STOP, CONDUCTIVE, SMALL		23
1	D010185	40m TM GUIDE ROD		22
2	D010184	40m TM WIRE STANDOFF		21
REF	1010183	40m TM GUIDE ROD FIXTURE		20
REF	D010182	40m TM RING ASSEMBLY		19
REF	D010181	40m TM RING FIXTURE		18
2	D010180	40m TM SIDE STIFFENER PLATE		17
2	D010179	40m TM FRONT STIFFENER PLATE		16
1	D010178	40m TM WIRE CLAMP		15
1	D010177	40m TM SUSPENSION BLOCK		14
1	D010176	40m TM TOP PLATE		13
2	D010175	40m TM SAFETY BAR		12
2	D010174	40m TM BRACE		11
2	D010173	40m TM HEAD HOLDER, SIDE		10
1	D010172	40m TM HEAD HOLDER, TOP		9
1	D010171	40m TM HEAD HOLDER, BOTTOM		8
4	D010170	40m TM CORNER BRACKET		7
2	D010169	40m TM CRADLE		6
2	D010168	40m TM FACE BRACKET		5
2	D010167	40m TM LEG, BACK		4
2	D010166	40m TM LEG, FRONT		3
1	D010165	40m TM SAFETY CAGE BASE		2
1	D010164	40m TM BASE PLATE		1

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX= .03 .XXX= .005 ANGLES ± .5°
DO NOT SCALE DRAWING

APPROVALS		DATE
DRAWN	J. Romie	8/01
CHECKED		

LIGO CALIFORNIA INSTITUTE OF TECHNOLOGY / MASSACHUSETTS INSTITUTE OF TECHNOLOGY

TITLE: 40m TEST MASS SUSPENSION

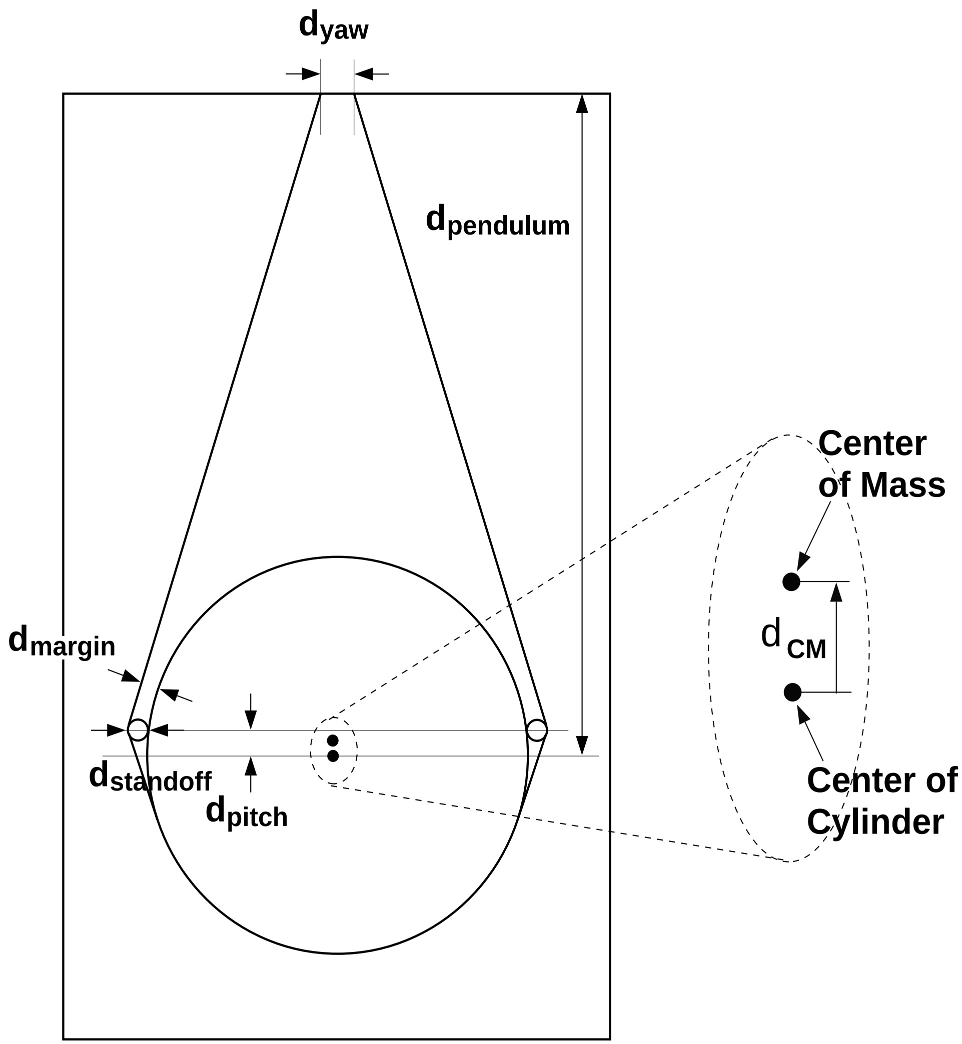
SIZE E — D010163 — REV A

SCALE 1/1 — SHEET 1 OF 1

NEXT ASSEMBLY: NONE

FILE LOCATION: /home/dcc/docs/D010163.pdf

40m SUSPENSION DESIGN



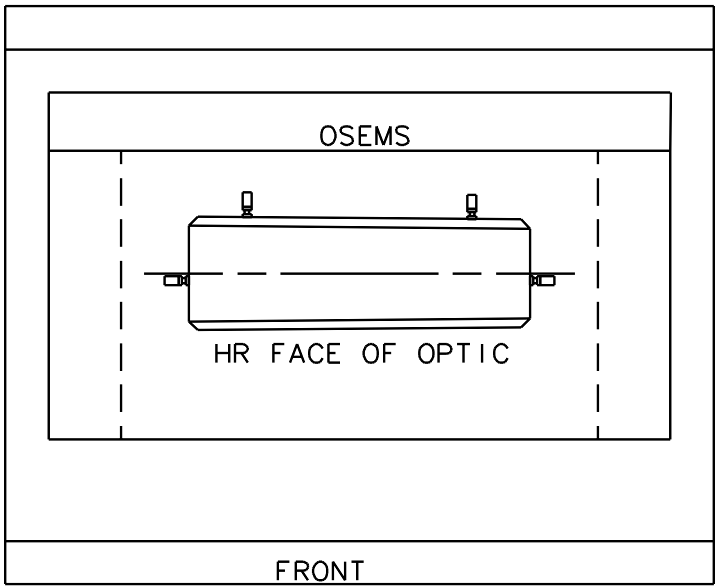
40m SUSPENSION DESIGN PARAMETERS

Parameter	ETM	ITM	BS	SRM/PRM	MCC/MCF
Pendulum freq., Hz	.800	.800	1.000	1.000	1.000
Pitch freq., Hz	.500	.500	.744	.744	.744
Yaw freq., Hz	.600	.600	.856	.856	.856
Violin freq., Hz	451	459	641	628	645
Vertical freq., Hz	11.79	11.59	16.23	16.57	16.12
$d_{pendulum,}$ cm	38.80	38.80	24.80	24.8	24.80
$d_{pitch,}$ cm	.1195	.1195	.09	.09	.09
$d_{yaw,}$ cm	2.13	2.13	1.57	1.57	1.57
$d_{standoff,}$ mm	1.00	1.00	1.00	1.00	1.00
$d_{margin,}$mm	.577	.577	.818	.818	.818
mass, kg	1.276	1.320	.235	.225	.238
wire dia, in	.0036	.0036	.0017	.0017	.0017

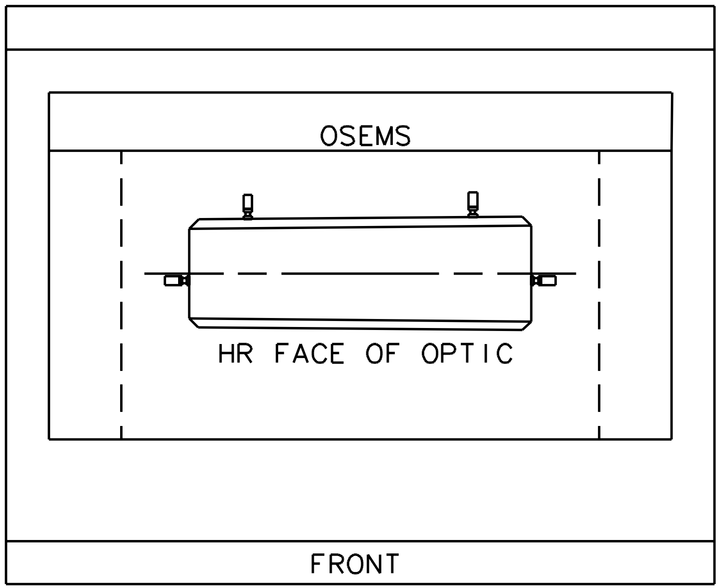
Table 1: 40m Optics

Optic	Material Size	Finish Size	Wedge	Orientation
ETM	128mm dia x 53mm 5.039” dia x 2.087”	125mm dia x 50mm (thickest) 4.921” dia x 1.969	2.5 deg	left
ITM	128mm dia x 53mm 5.039” dia x 2.087”	125mm dia x 50mm (thickest) 4.921” dia x 1.969	1 deg	right
BS	78mm dia x 28mm 3.071 x 1.102	75mm dia x 25mm (thickest) 2.953” dia x .984	1 deg symm.	right
PRM	78mm dia x 28mm 3.071 x 1.102	75mm dia x 25mm (thickest) 2.953” dia x .984	2.5 deg	right
SRM	78mm dia x 28mm 3.071 x 1.102	75mm dia x 25mm (thickest) 2.953” dia x .984	2.5 deg	left
MCC	78mm dia x 28mm 3.071 x 1.102	75mm dia x 25mm (thickest) 2.953” dia x .984	30 min.	left
MCF1	78mm dia x 28mm 3.071 x 1.102	75mm dia x 25mm (thickest) 2.953” dia x .984	30 min. symm.	right
MCF2	78mm dia x 28mm 3.071 x 1.102	75mm dia x 25mm (thickest) 2.953” dia x .984	30 min symm.	left

TOP VIEW OF 40M SMALL OPTIC SUSPENSIONS



LEFT ORIENTATION
(THICK SIDE ON THE LEFT)



RIGHT ORIENTATION
(THICK SIDE ON THE RIGHT)

40m SUSPENSIONS DESIGN CONSIDERATIONS

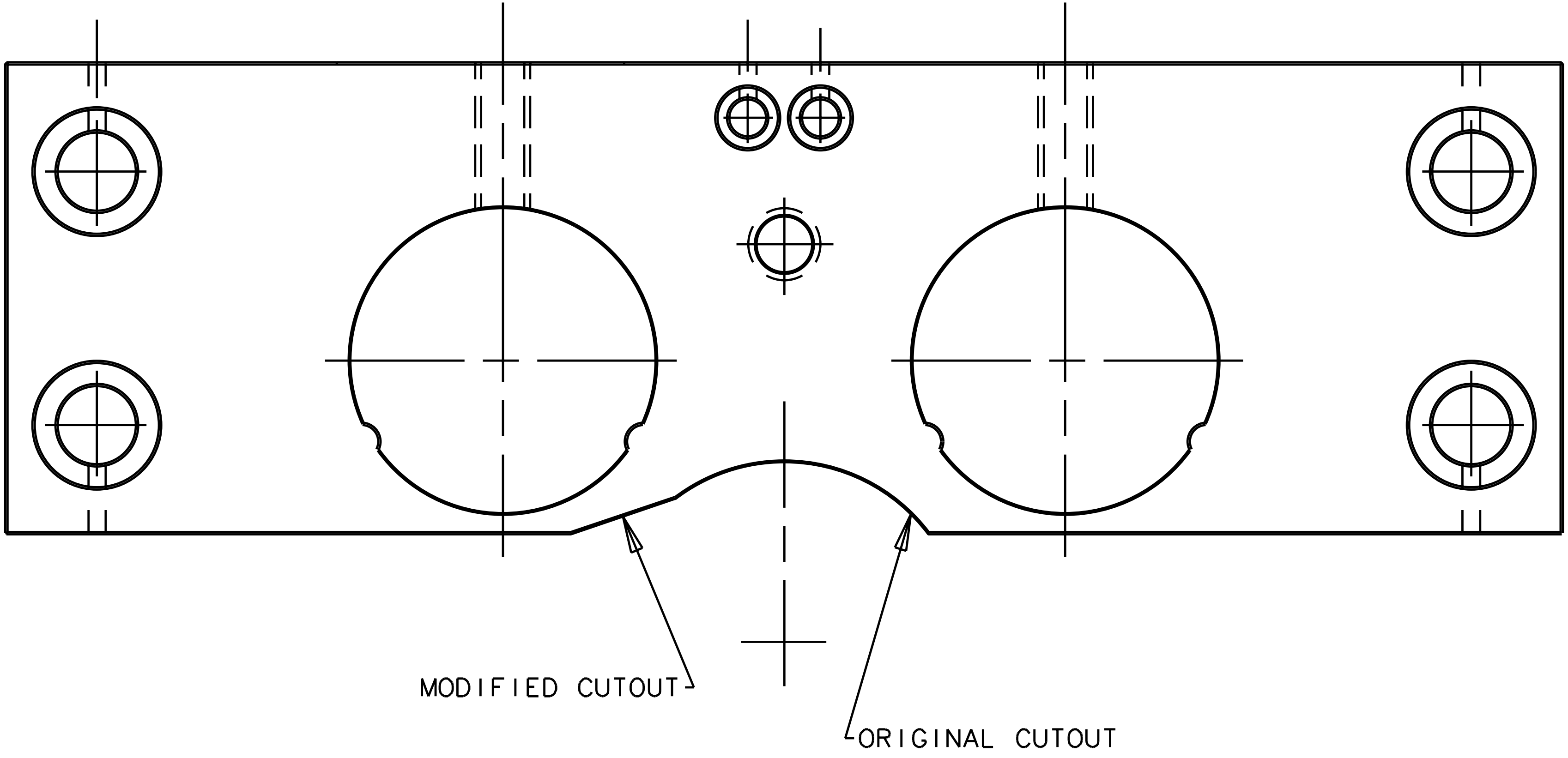
- FIXTURES
  - SOS guide rod fixture design, D000335, will work for the 40m SOSs eventhough LIGO I SOSs have a .5 deg max wedge and the 40m SOSs have a 2.5 deg max horizontal wedge (for the PRM and SRM.)
  - 40m SOSs required a redesigned magnet gluing fixture, D010131, with separate ears for the different wedges of the optics.
  - TM guide rod fixture, D010183, is scaled up from the SOS design. It is designed and will be fabricated by KineOptics in Slidell, LA.
  - TM magnet gluing fixture, D010181, also has separate ears because of the different wedges of the test mass optics.

40m SUSPENSIONS DESIGN CONSIDERATIONS

- 40m TM suspensions, for a 5” dia. X 2” optic, are scaled up from the prototype 40m TM suspension whose optic was 4” dia. X 3.5” thick. It has the same optic centerline to beam centerline distance as the SOSs -> 13.97cm = 5.5”
- Prototype 40m TM drawings were modified to include a new name and part number, to include an identification requirement, to remove “machine all over” requirement and radius all corners note. Also, included note on vacuum compatible machining fluids requirement.

40m SUSPENSIONS DESIGN CONSIDERATIONS

- BS suspension was to have had sensor/actuator heads at the 60 deg position wrt horizontal. But, the nominal position of 45 deg to the horizontal was sufficient as 1ppm dia. is 15.94mm and the open aperture is 31.75mm.
- Material has been removed from the sensor/actuator brackets to increase the size of the aperture on all small optic suspensions.


MODIFIED CUTOUT
ORIGINAL CUTOUT

LIGO

40m Suspension Electronics

Benjamin Abbott
California Institute of Technology

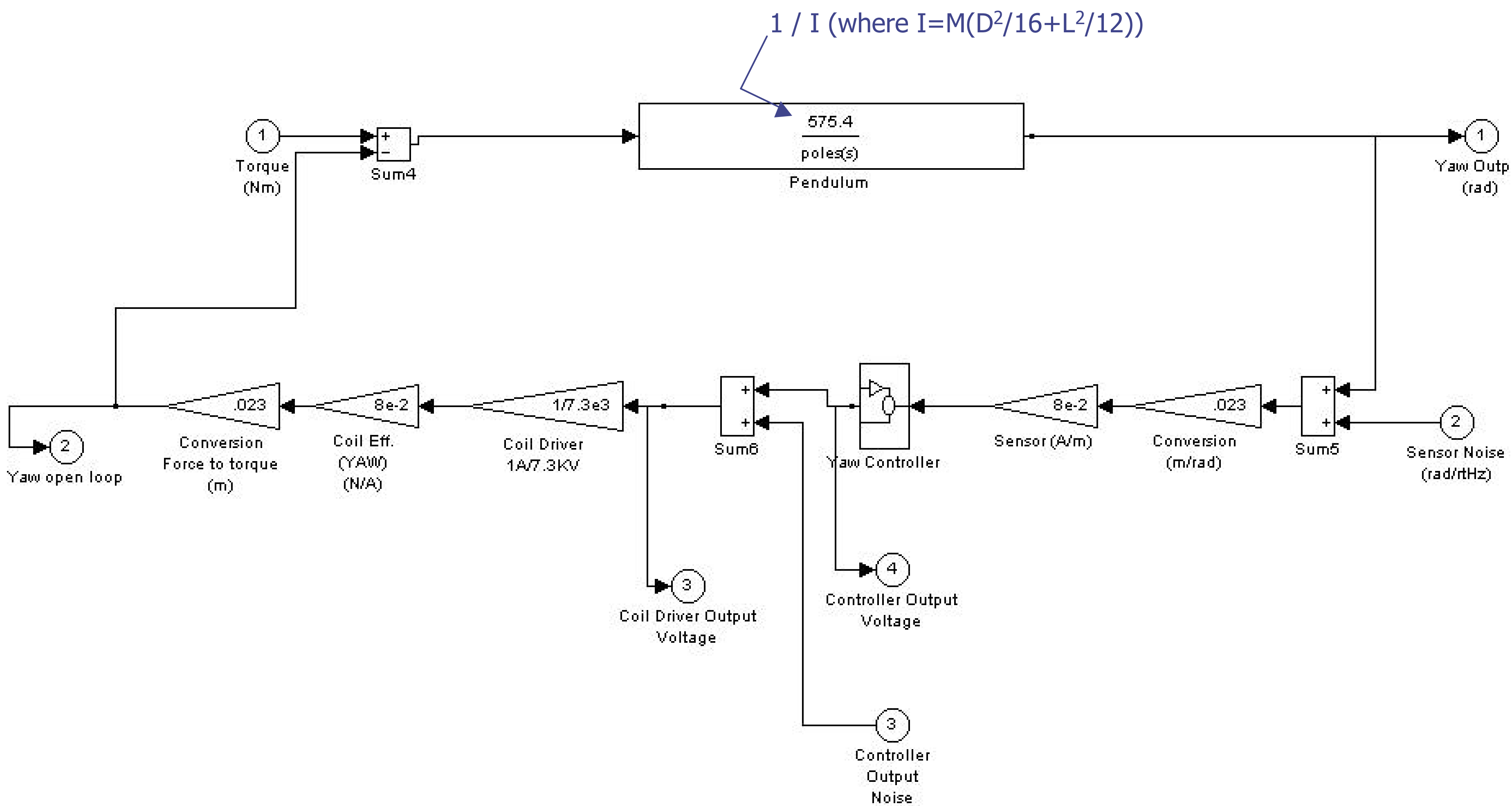
Requirements

- Digital Suspension should be as Advanced LIGO-like as possible.
- Coil Drivers should be sufficient to move the 1.3Kg optics with a dynamic range on order 30μm p-p in length, and 1.5mrad p-p in angle.
- Filtering should meet 10^{-20} m/$\sqrt{}$Hz noise requirement.

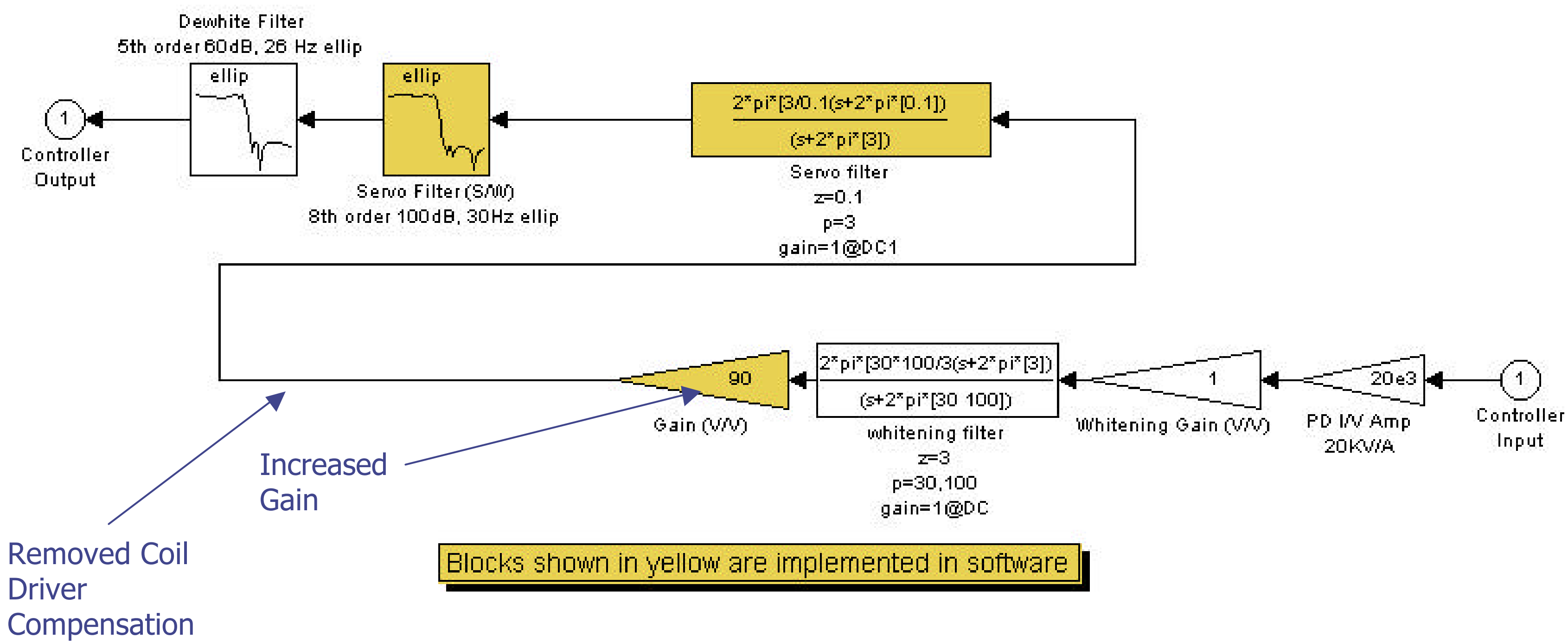
Modeling

- Modeling done in Simulink
- Intended to prove that small optic controllers are sufficient for 40m core optics.
- Noise suppression was evaluated.

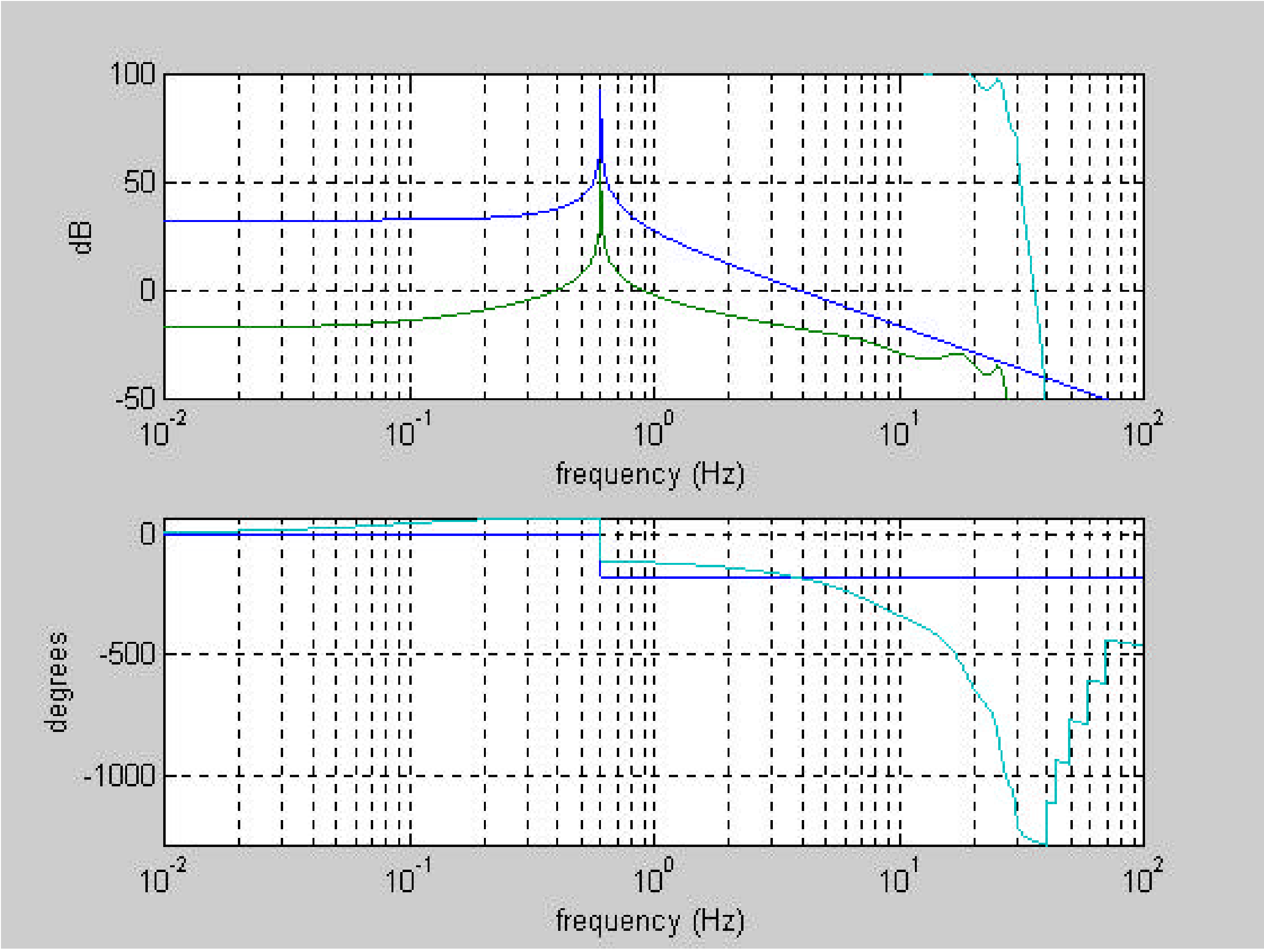
Simulink Yaw Model



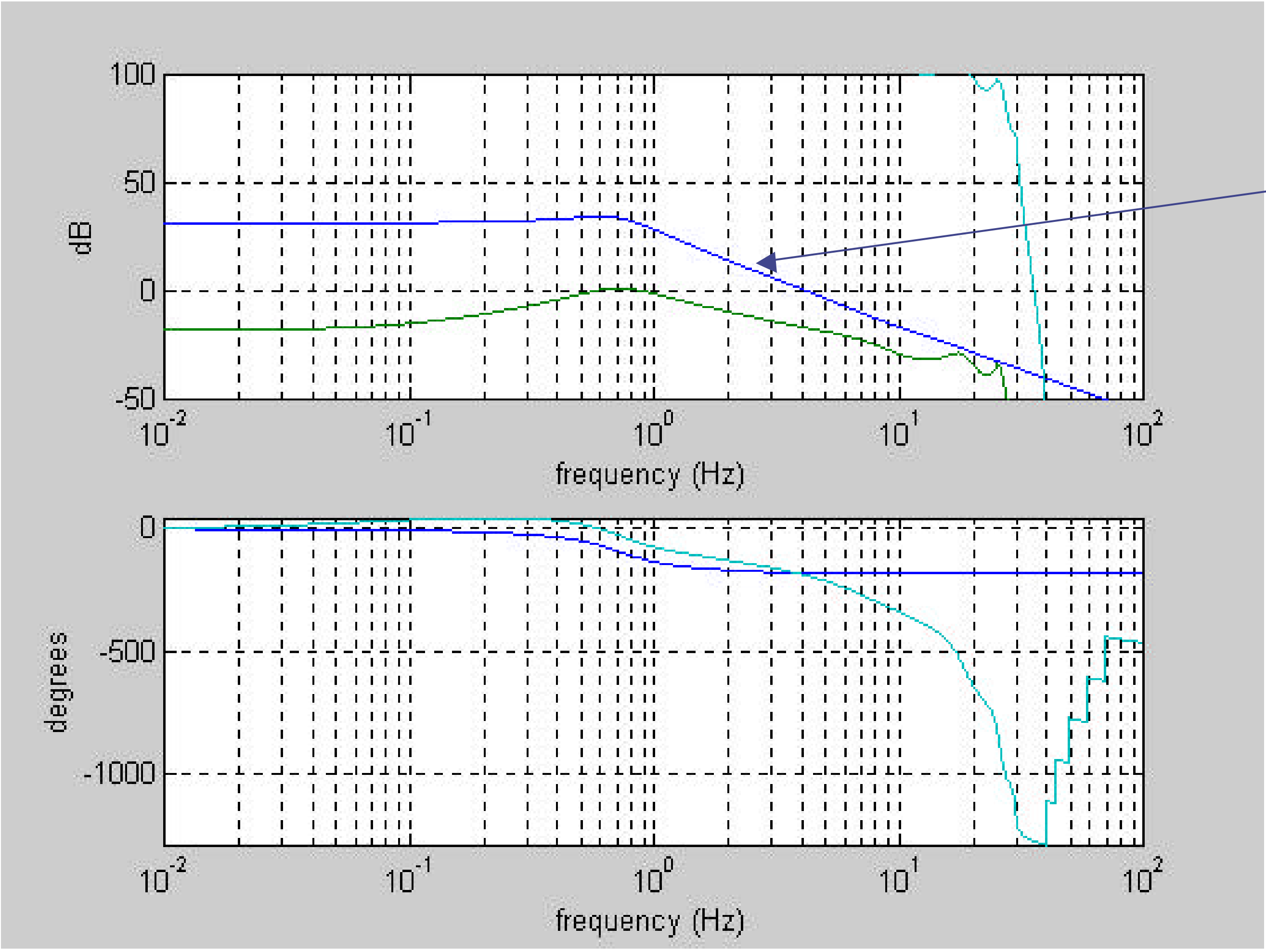
Yaw Controller Model



Open Loop Yaw Response

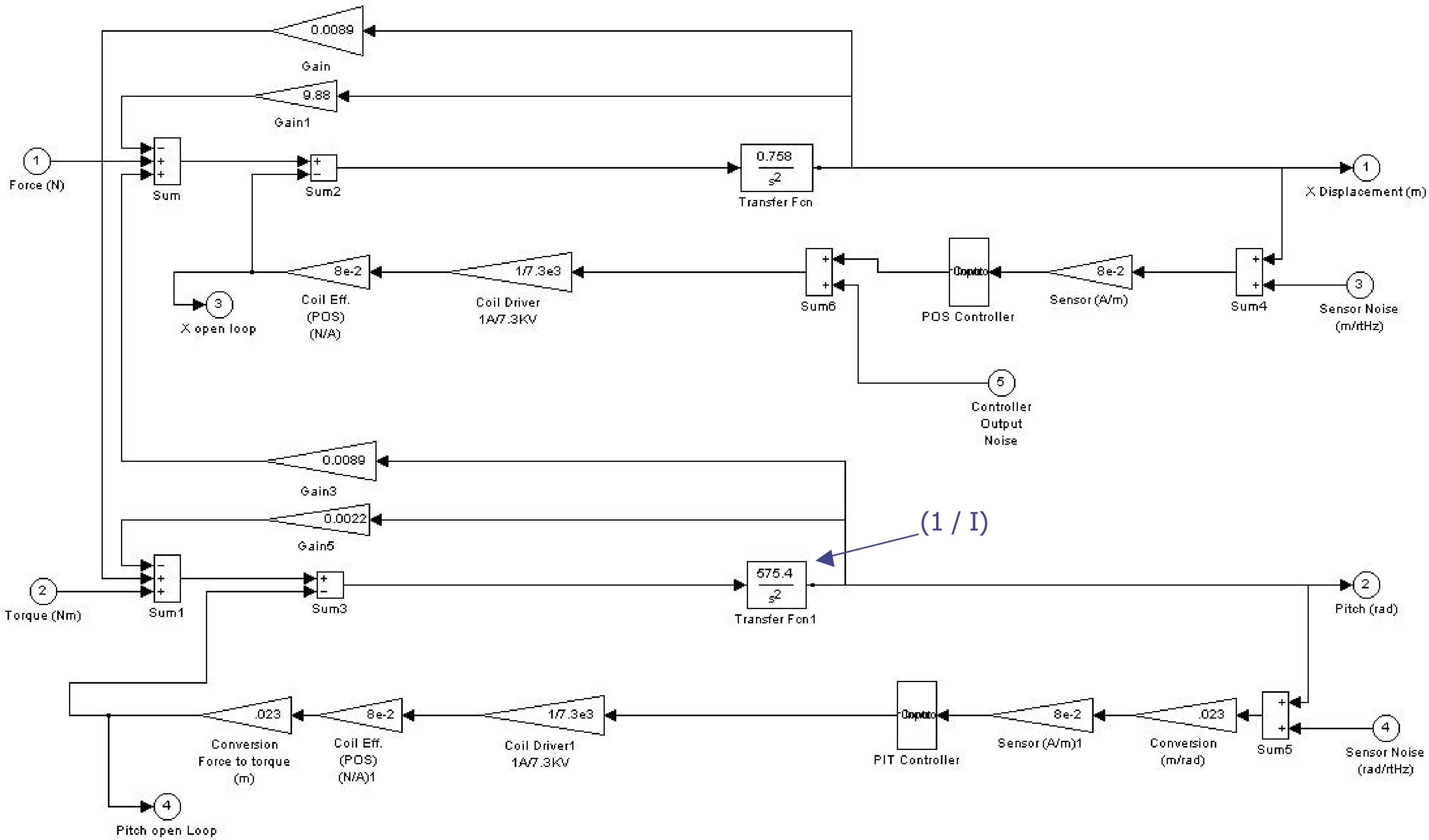


Closed Loop Yaw Response

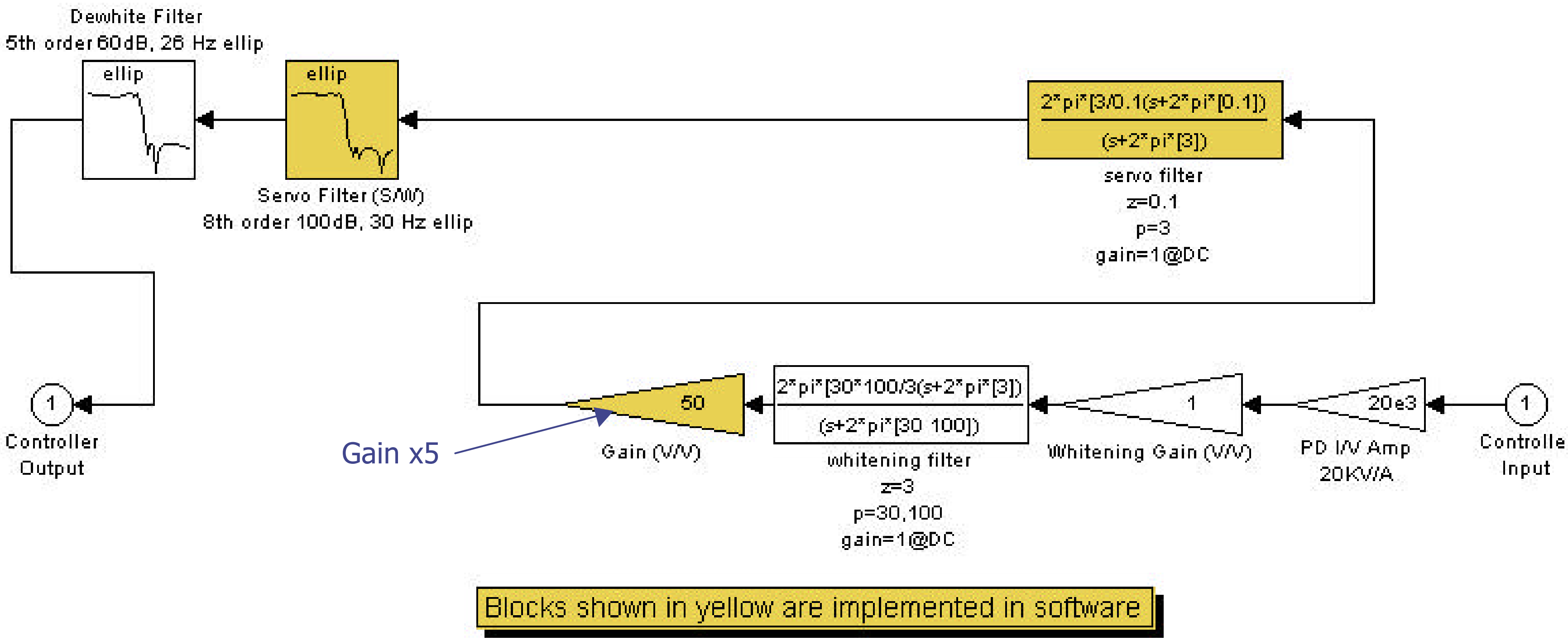


Pseudo-critically damped response

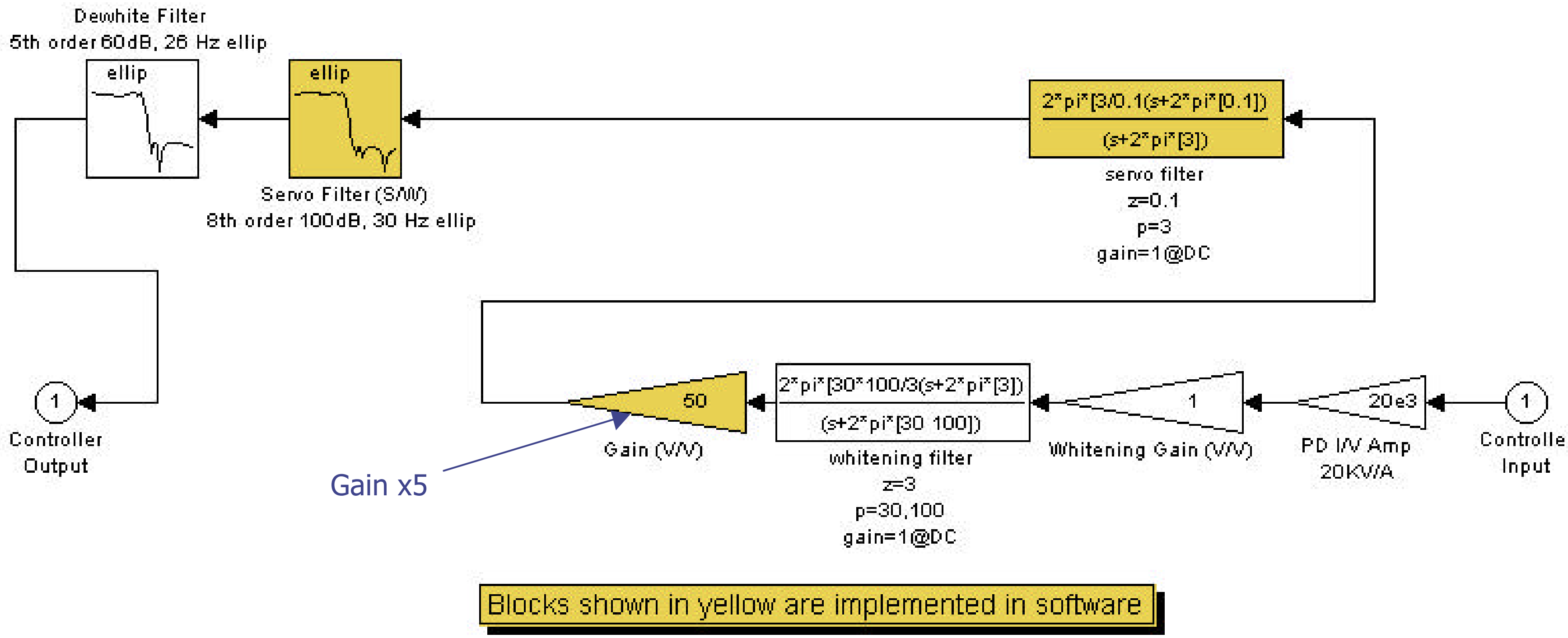
Simulink Position & Pitch Model



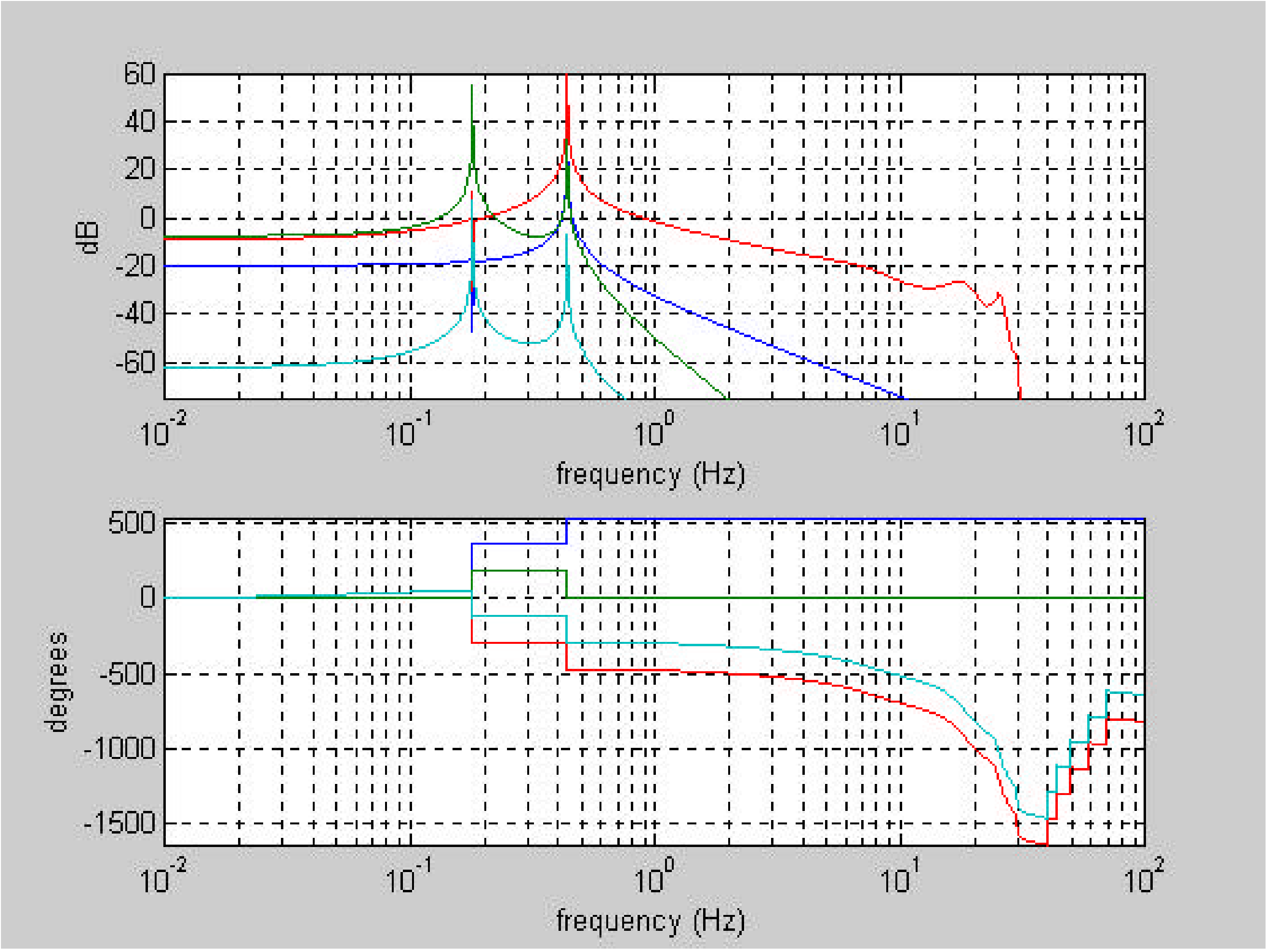
Position controller



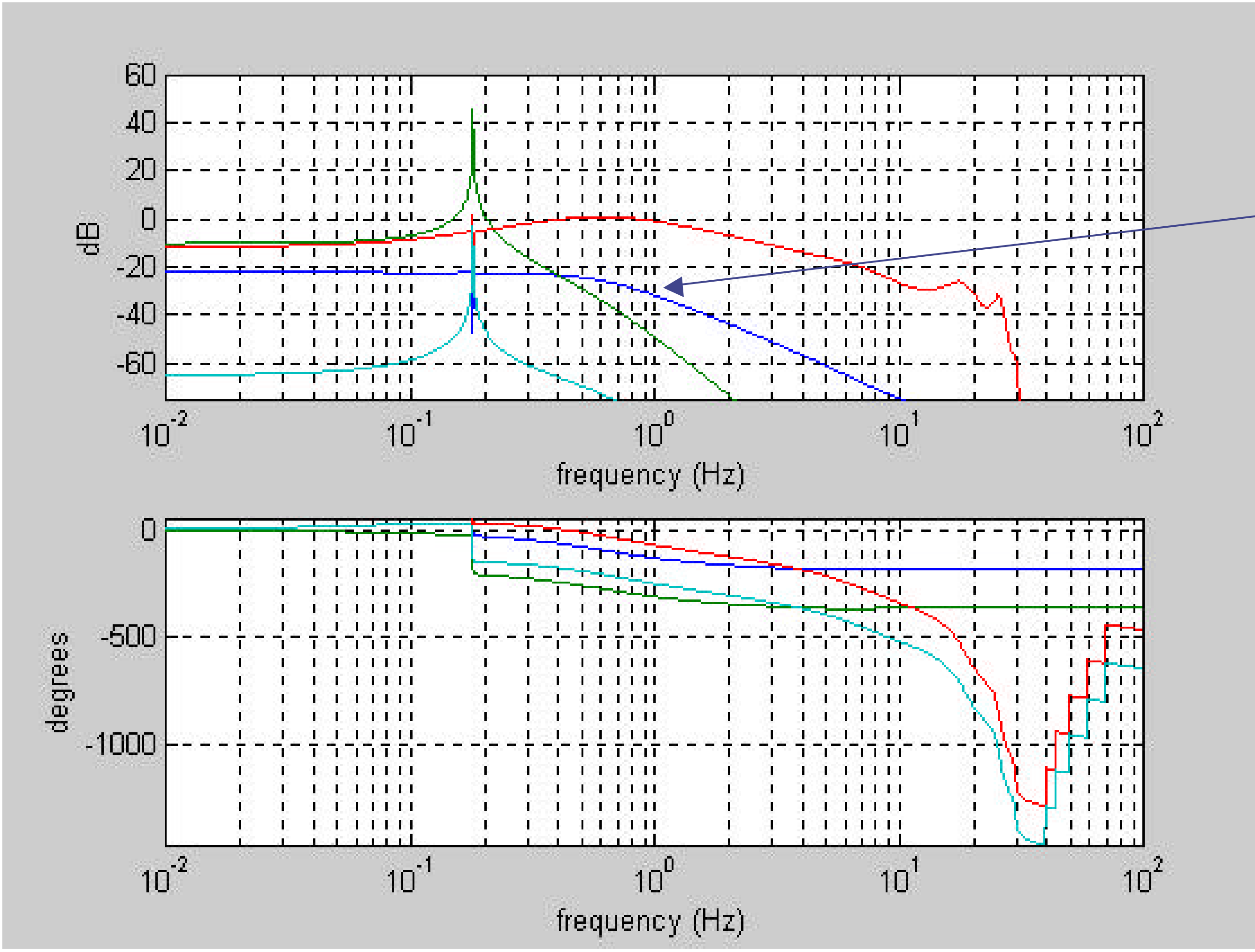
Pitch Controller



Open Loop Position Response

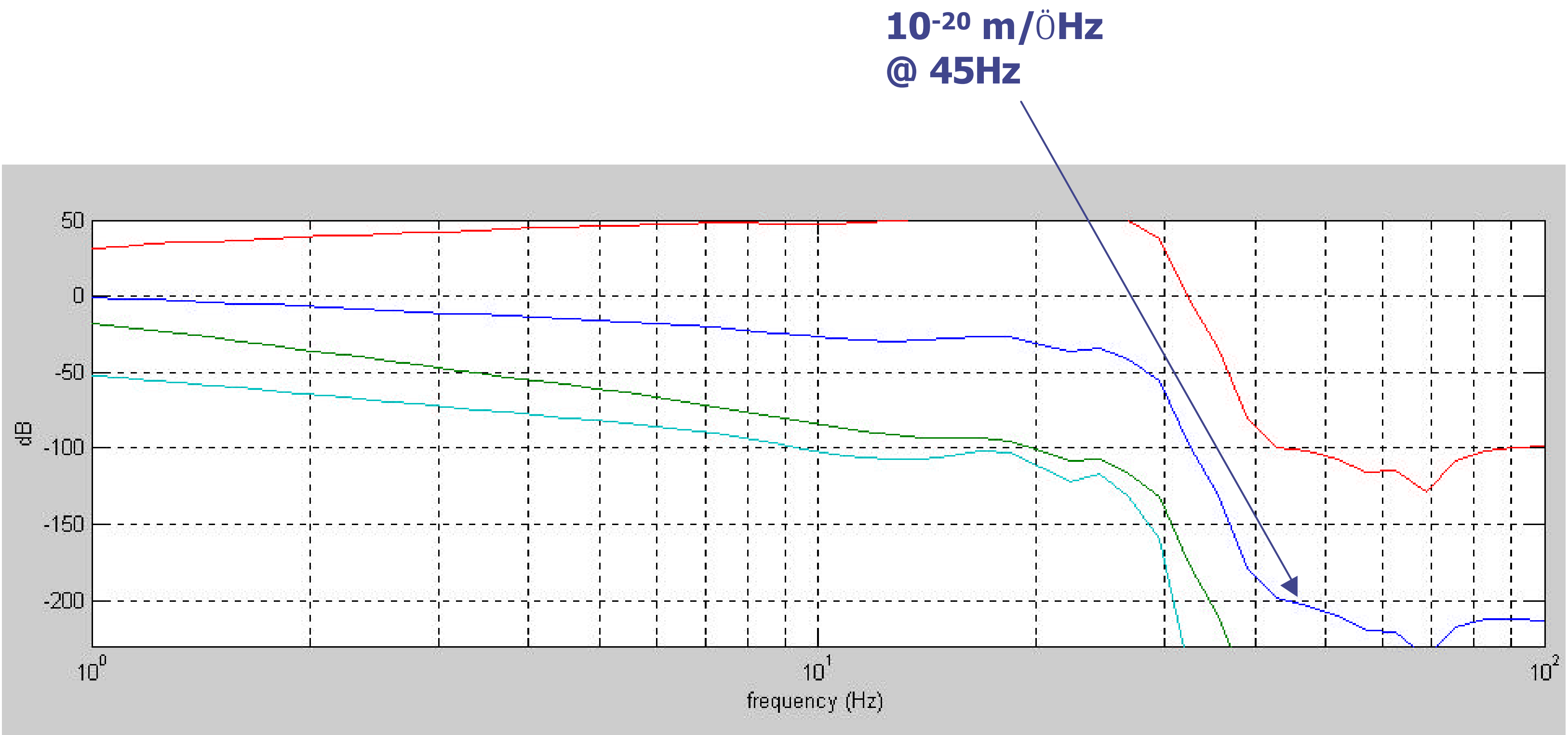


Closed Loop Position Response

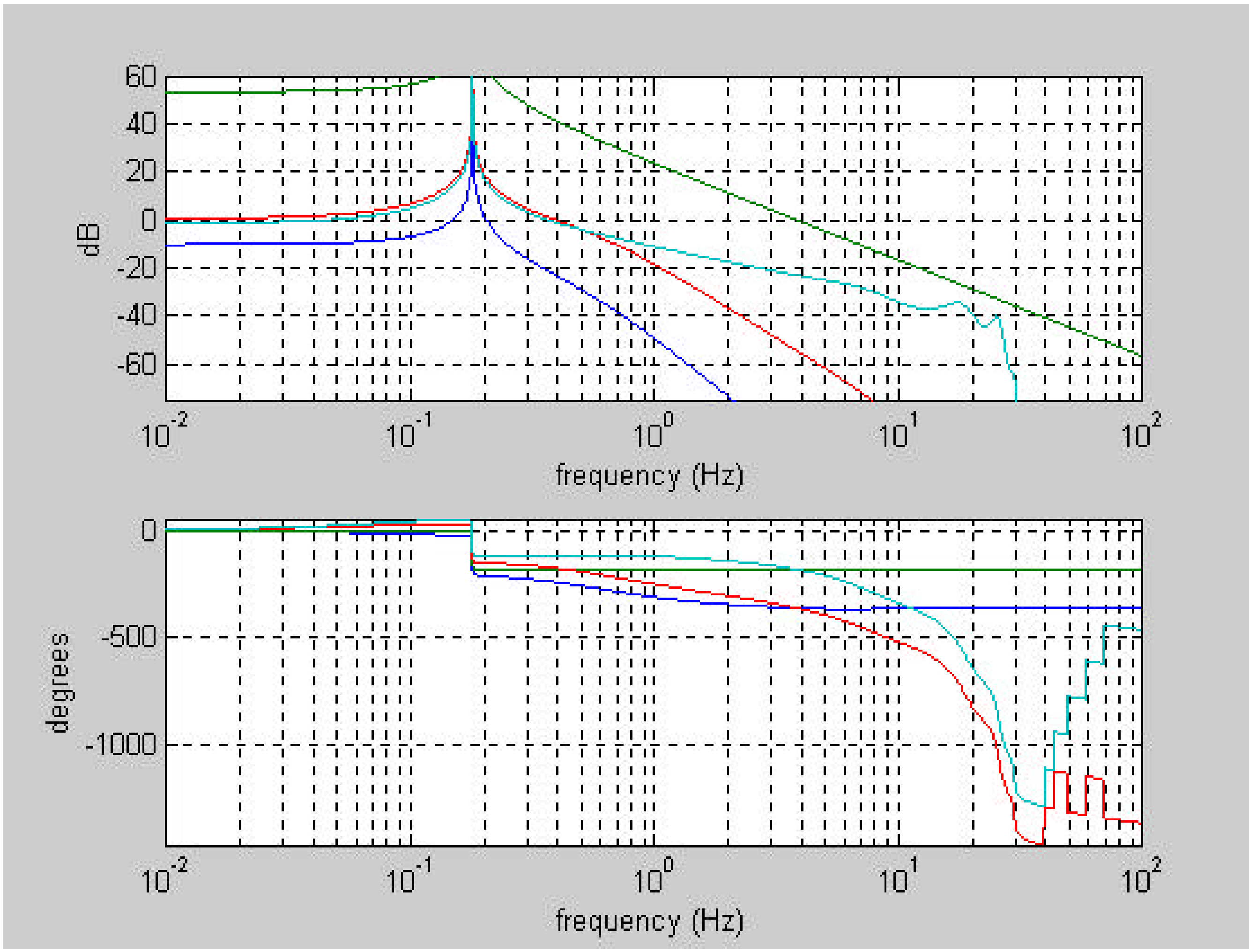


Pseudo-critically damped position response

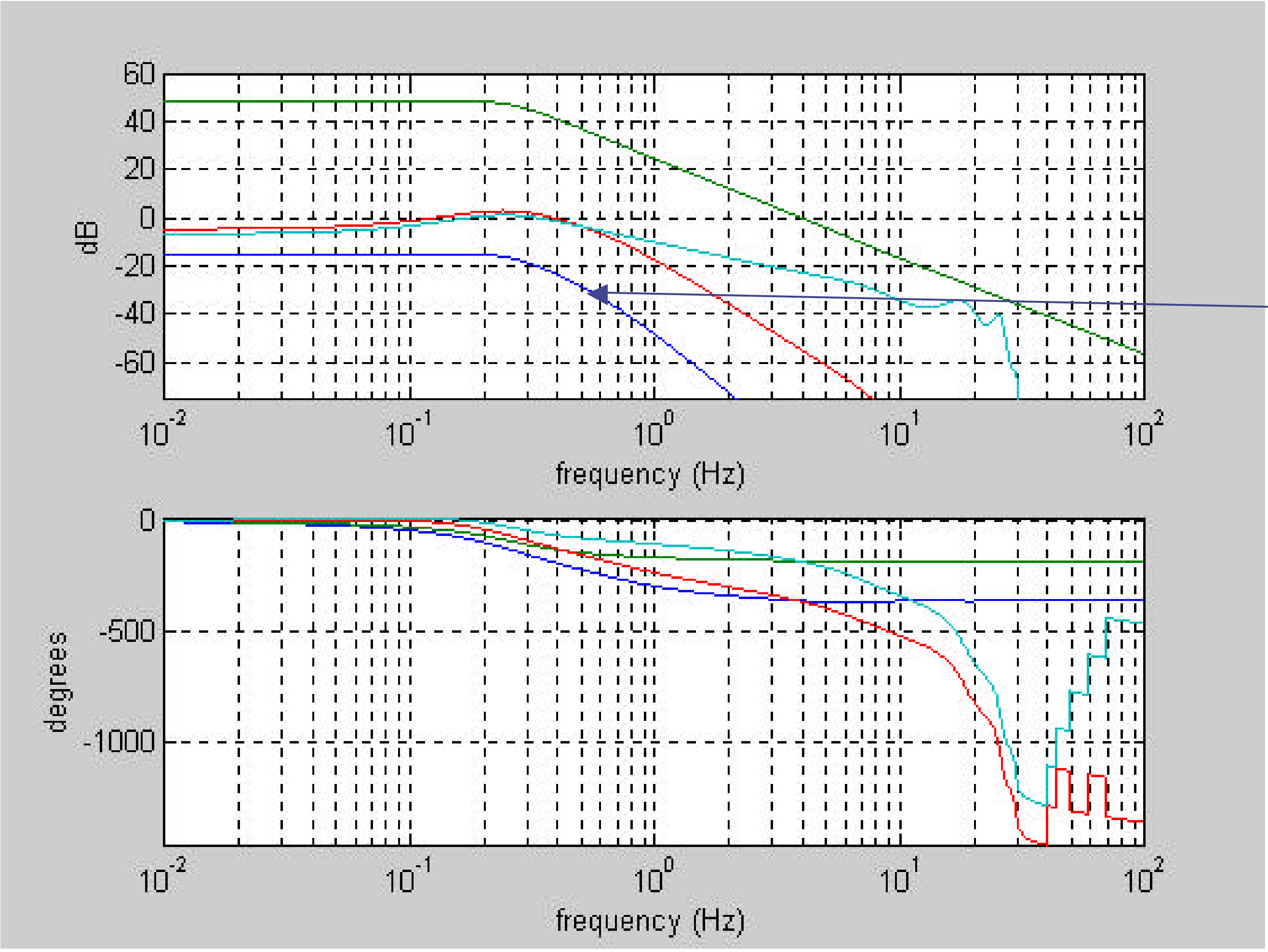
Position Noise Spectrum



Open Loop Pitch Response

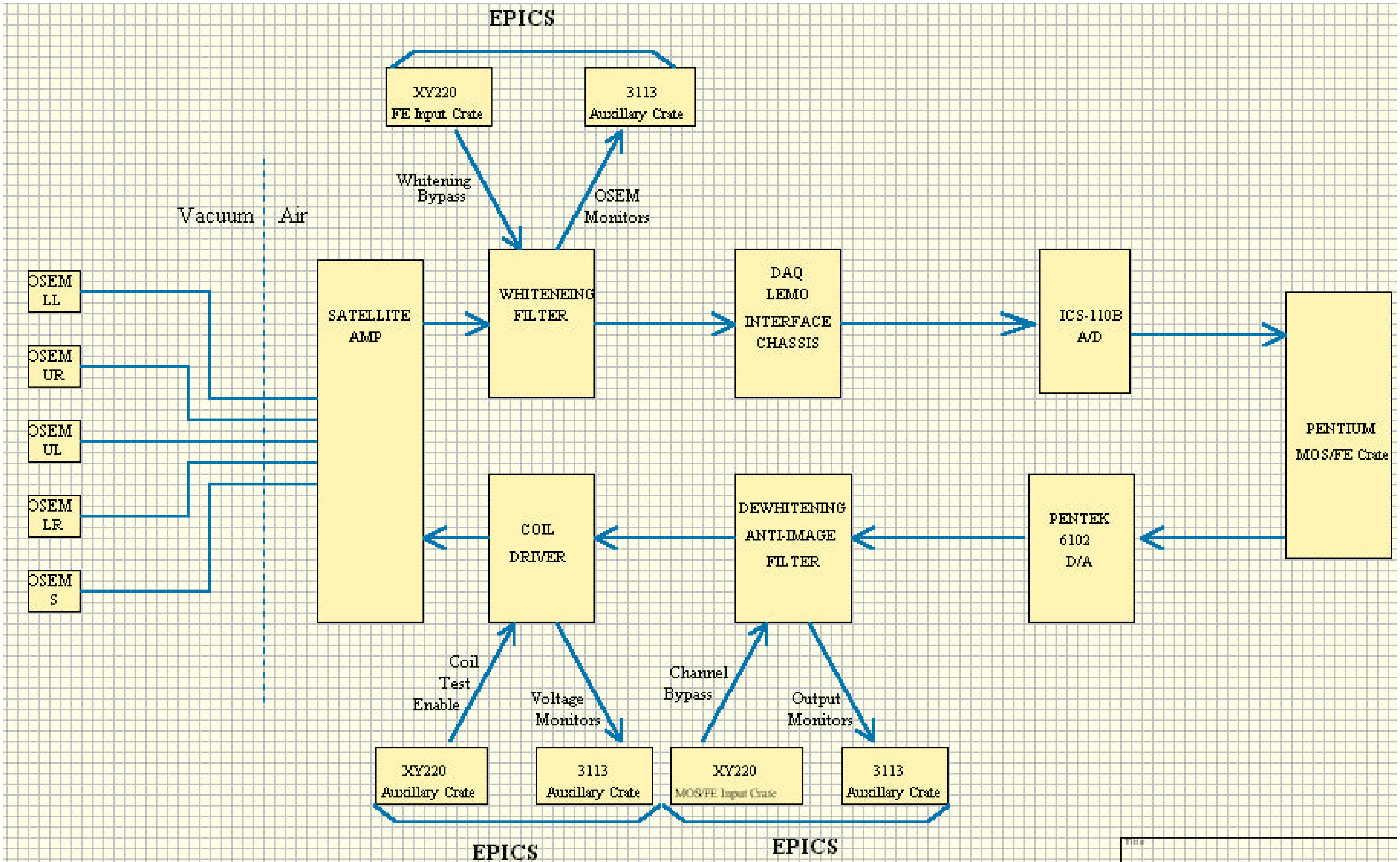


Closed Loop Pitch Response

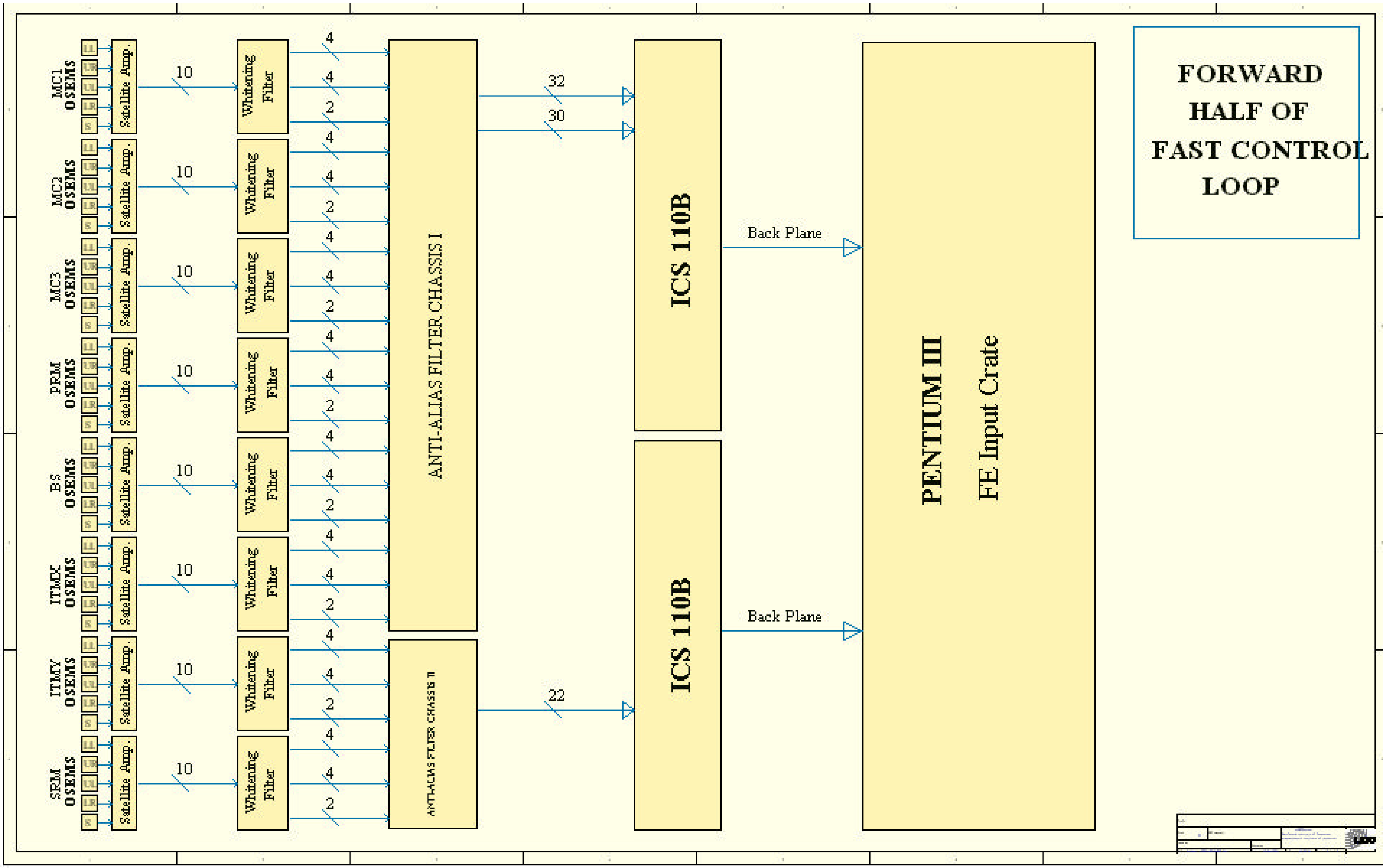


Pseudo-critically damped position response

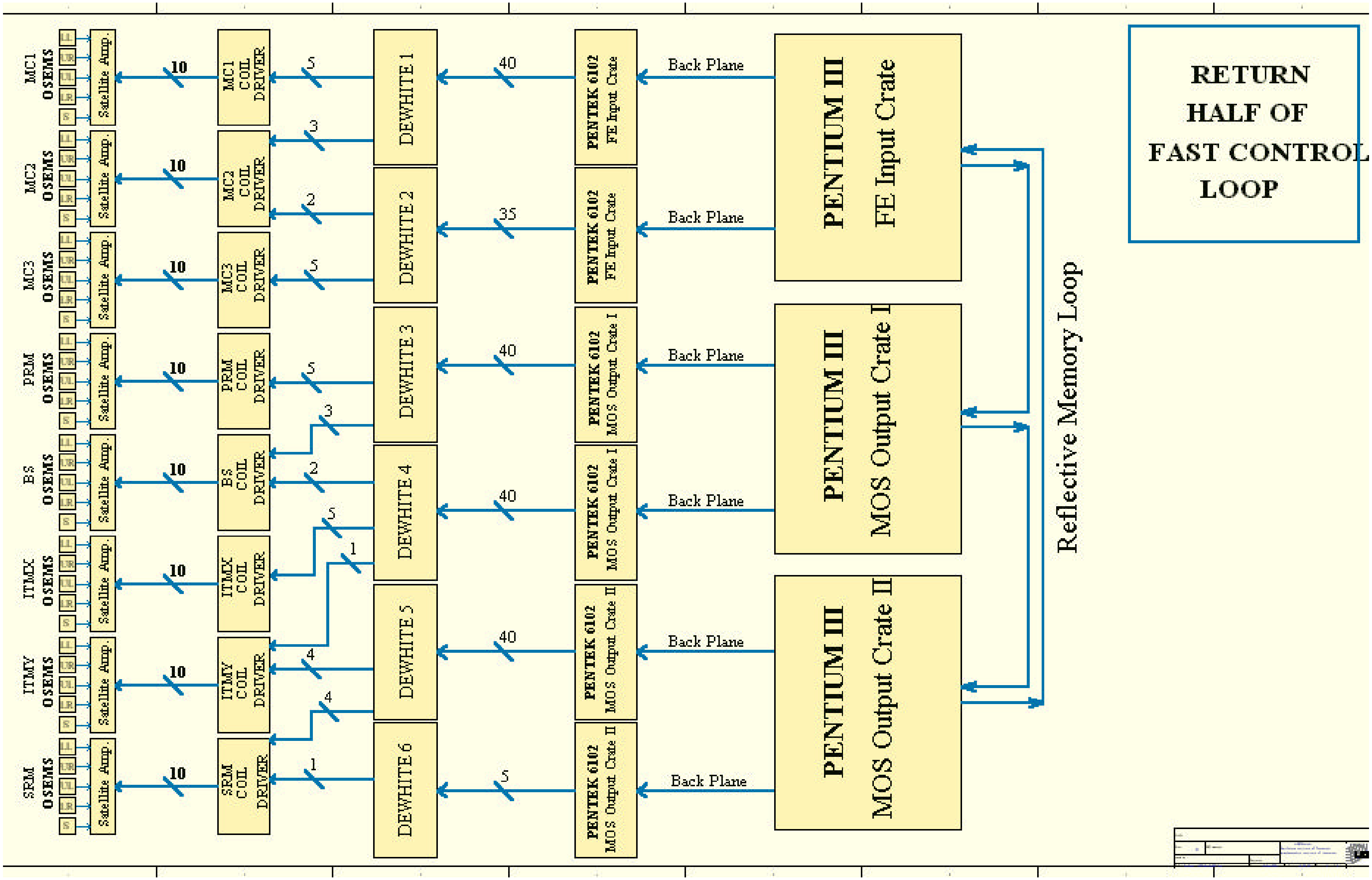
Signal Path for One Optic



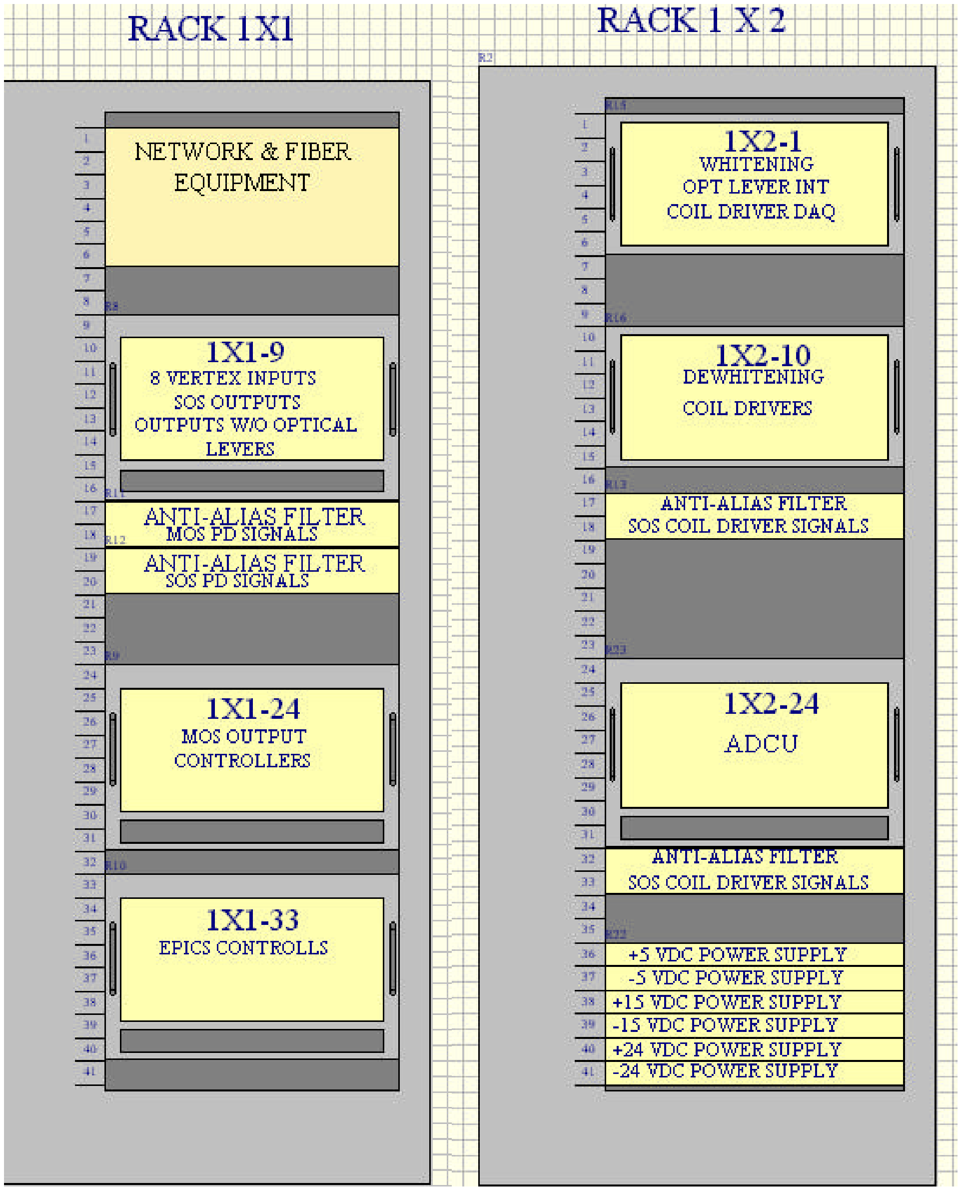
Forward Path for all Vertex Optics



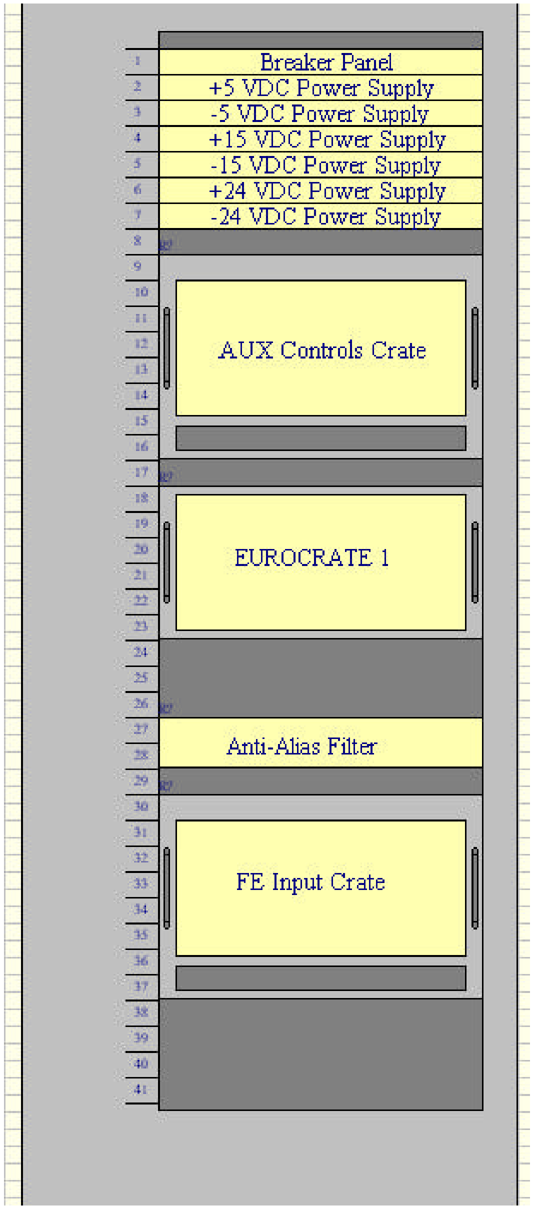
Return Path for all Vertex Optics



Vertex Rack Layout



End Rack Layouts



Future Work

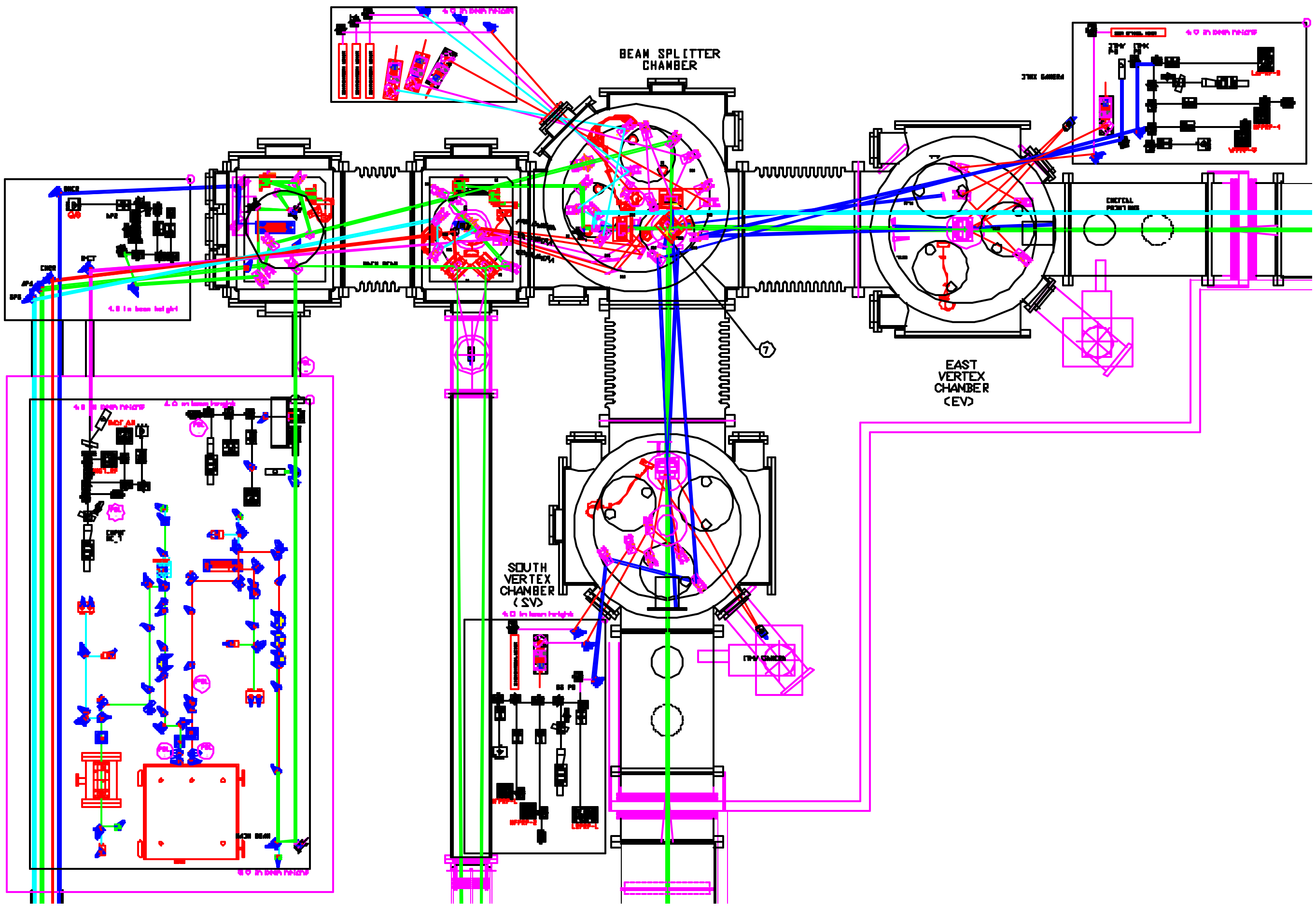
- Finish controls wiring for end stations.
- Order Penteks, LEMO connectors and other long lead items.
- Request production of custom boards.
- Install modules, make and run cables.
- Commission suspension electronics.

40m Optical Systems and Sensing Design Requirements Document & Conceptual Design

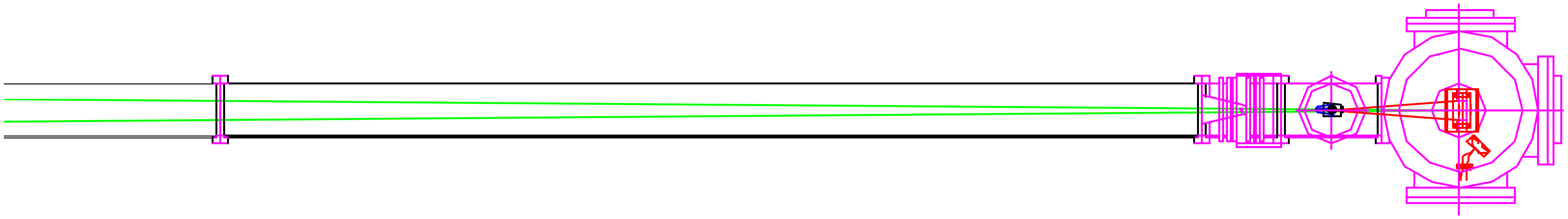
Michael Smith
10/18/01

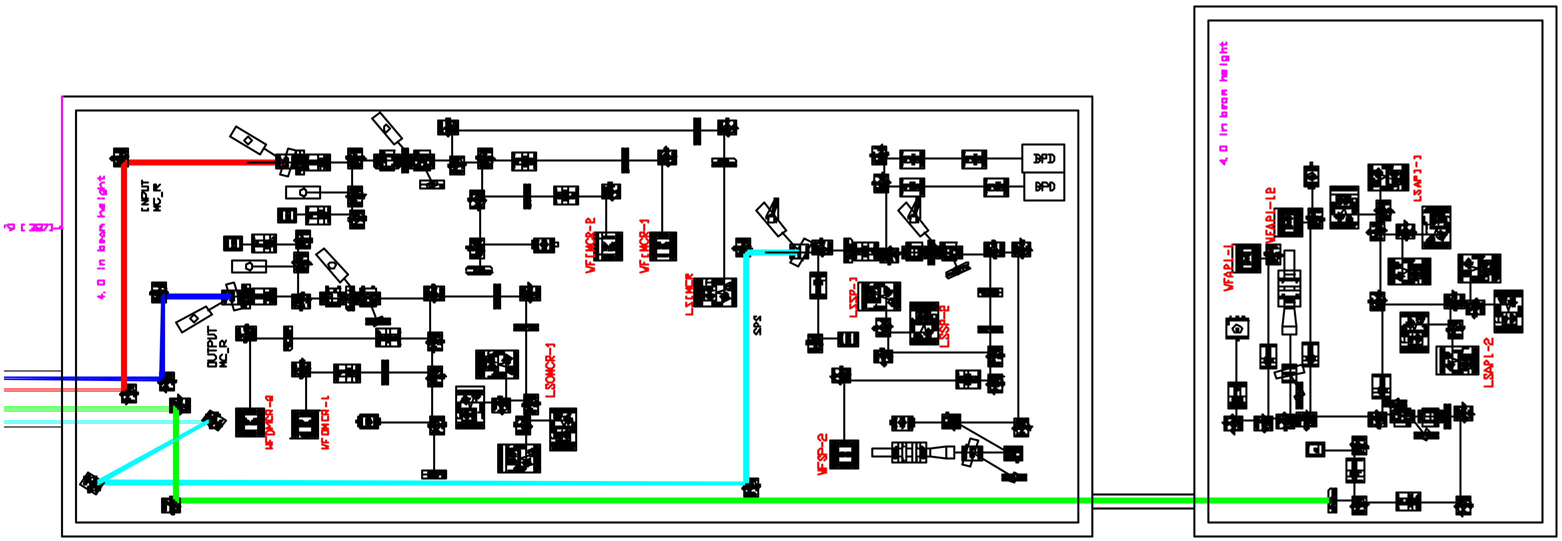
- Interferometer Input Beam
- Optical Sensing Beams
- Viewports

40 m IFO Vertex Section

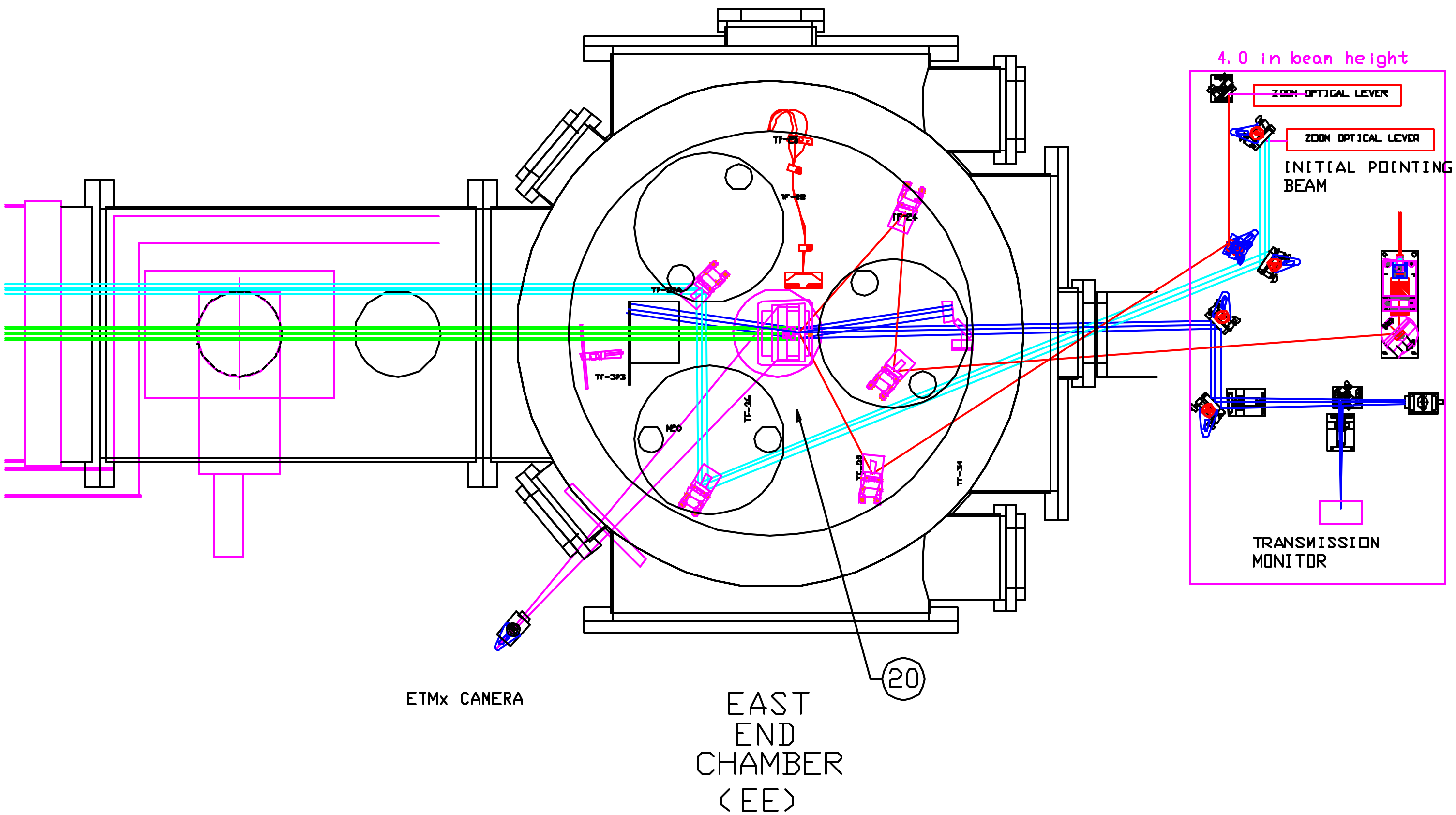


40 m IFO IMC Section





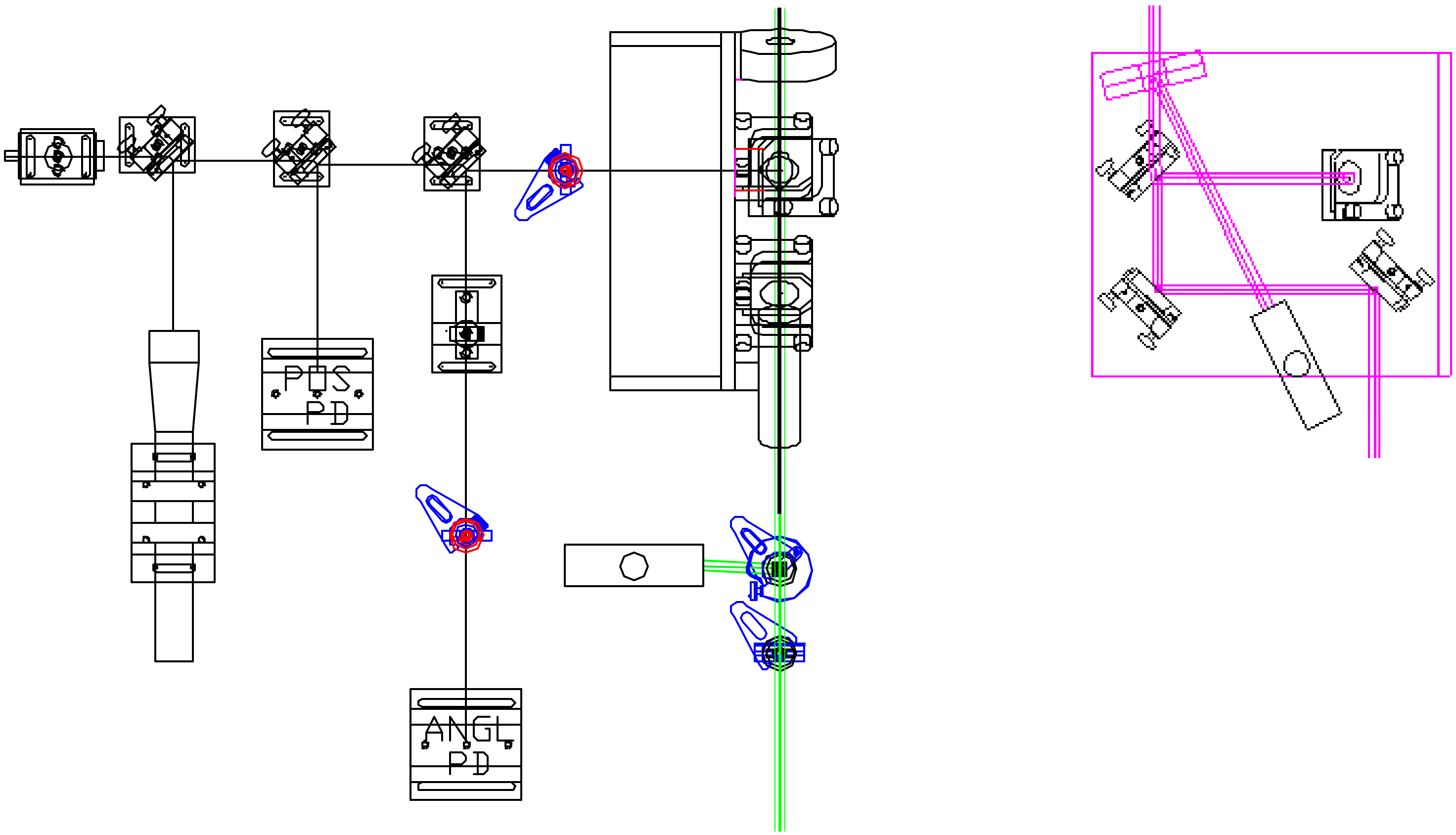
40 m IFO End Section



Core Optics Parameters

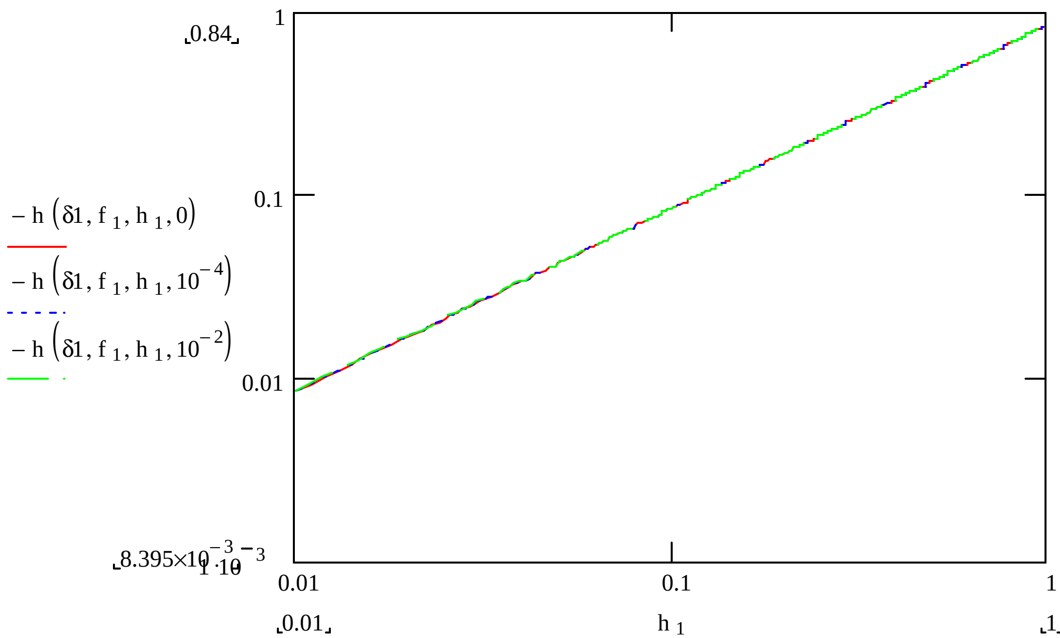
Physical Quantity	PRM	SRM	BS	ITM	ETM
AR coating @ 1060 nm	<0.0005	<0.0005	0.0006	0.0006	<0.0005
AR coating @ 940 nm	>0.4	>0.4	>0.4	>0.4	NA
Substrate thickness, mm	28	28	28	50	50
Mirror power loss fraction	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004
Mirror reflectivity @ 1060 nm	0.93	0.93	0.5	0.995	0.9999625
Mirror reflectivity @ 940 nm	>0.4	>0.4	>0.4	>0.4	>0.4
Mirror reflectivity @ 670 nm	>0.04	>0.04	>0.04	>0.04	>0.04
Refractive index @ 1064 nm	1.44963	1.44963	1.44963	1.44963	1.44963
Beam waist, mm	3.04	3.04	3.03	3.03	5.24
1ppm power contour radius, mm	7.97	7.98	7.97	7.96	13.8
Mirror diameter, mm	75	75	75	125	125
Mirror thickness, mm	25	25	25	50	50

Input Monitor



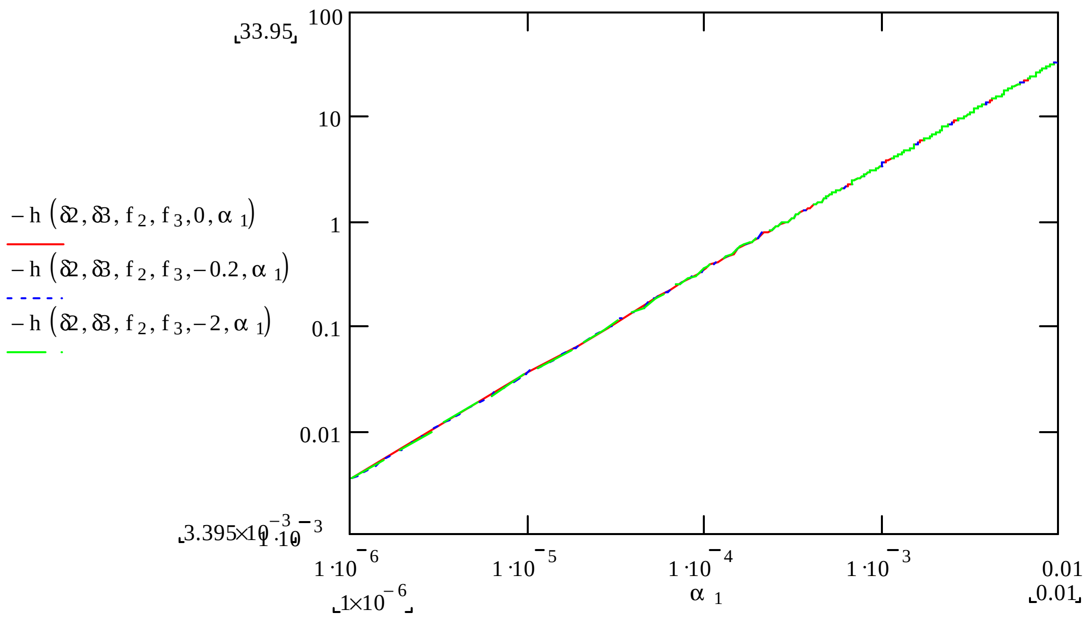
Position Sensor Response

Parameter	Requirement	Actual
position ratio, mm/mm		-0.84
Cross coupling, mm/rad		-1.07E-13
Beam displacement resolution, mm	< 0.16	0.02
Beam sample fraction	< 1%	1% sample

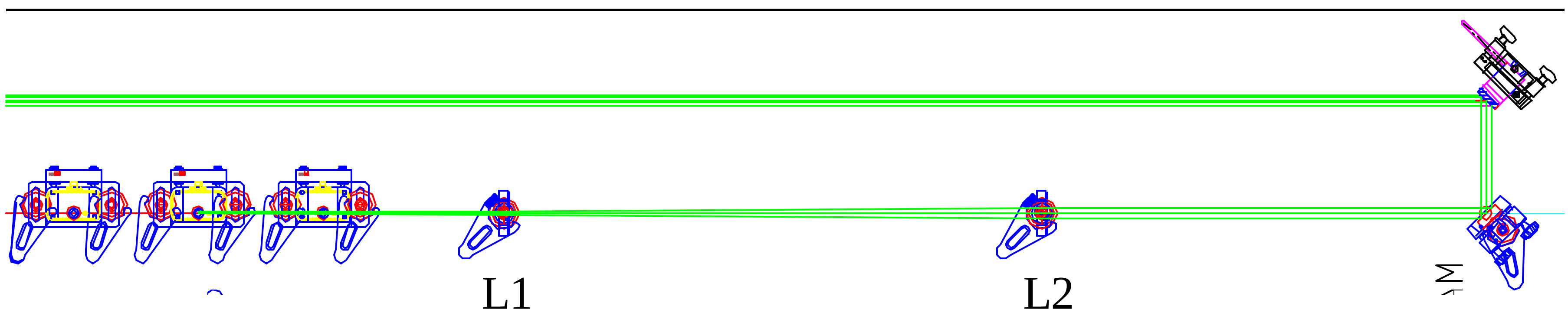


Angle Sensor Response

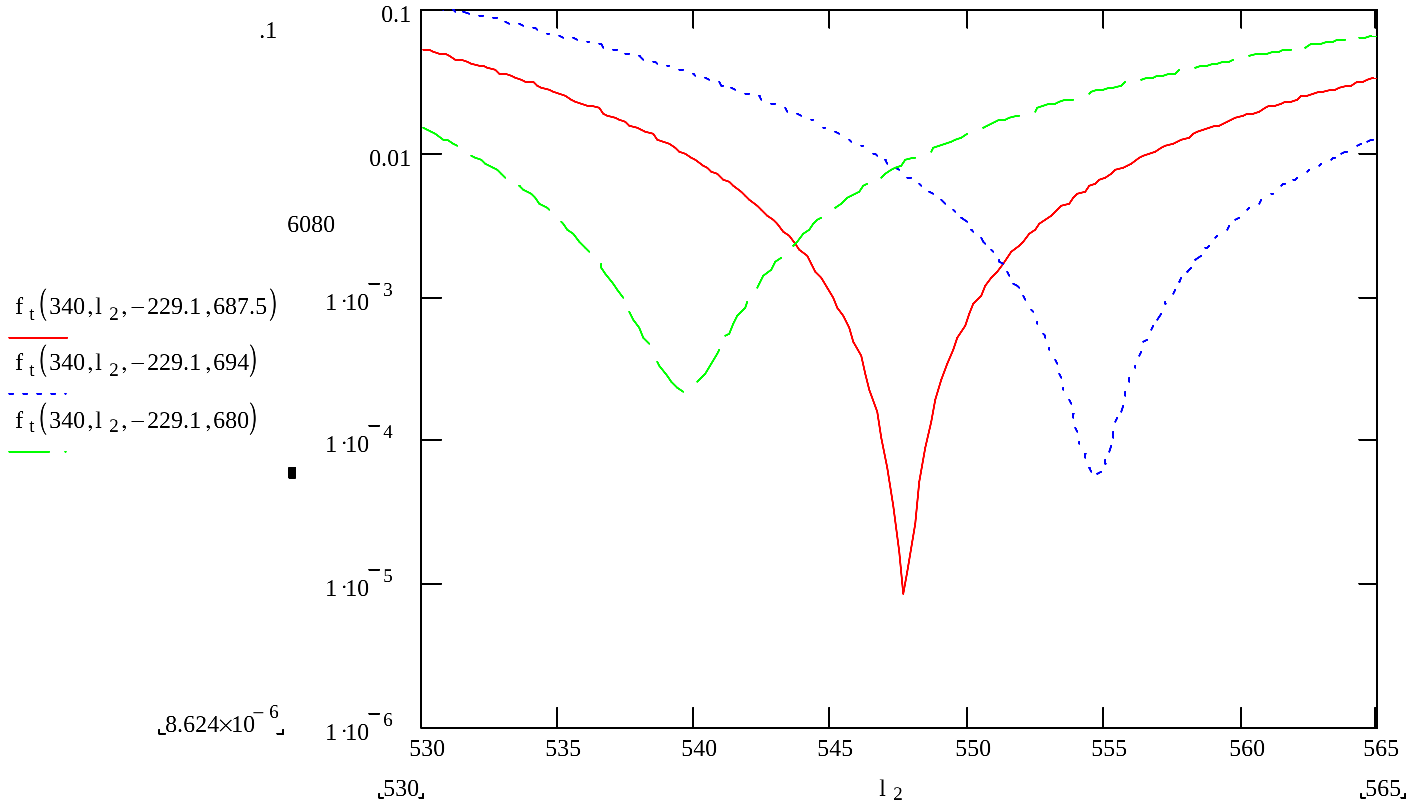
Parameter	Requirement	Actual
Transfer ratio, mm/rad		-3400
Cross coupling, rad/mm		0
Beam angular pointing resolution, rad	2E-5	3E-6
Beam sample fraction	< 1%	1% sample



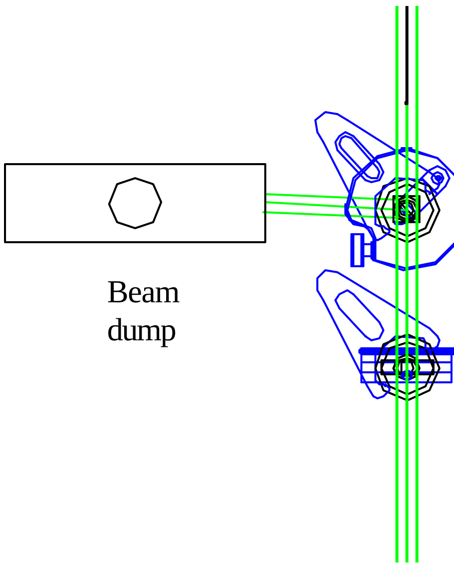
IMC Mode-matching Lenses



Power Coupling Error into IMC



Input Beam Power Control

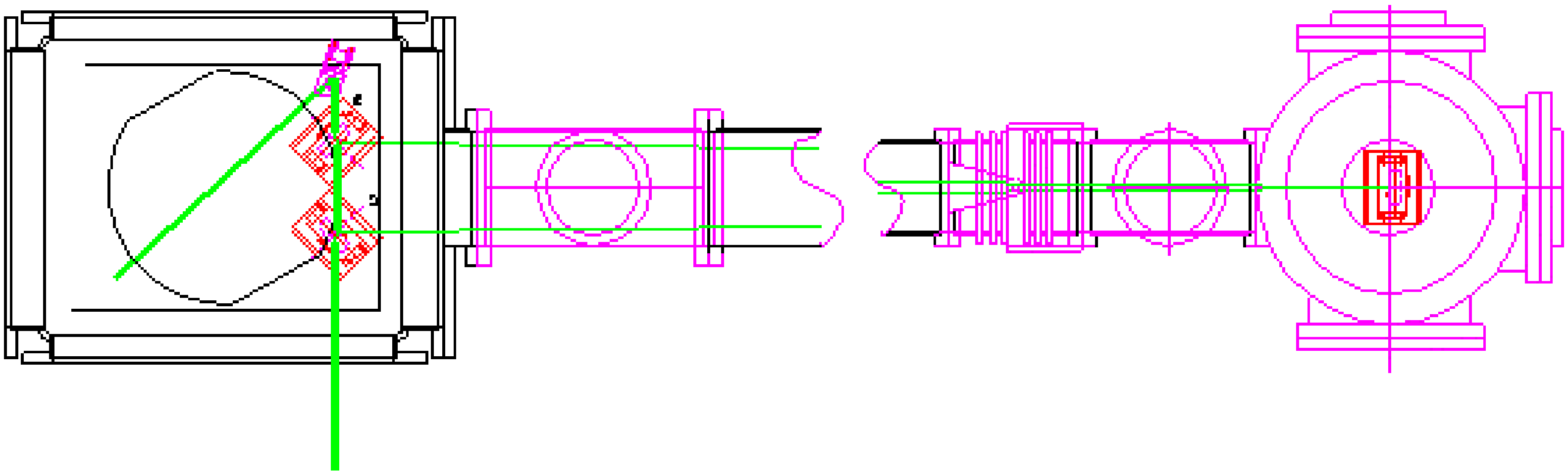


Parameter	Requirement	Actual
Wavelength	1064 nm	1064 nm
Polarizing beam splitter		
Extinction ratio	> 100:1	> 1000:1
Transmissivity	> 97%	> 98%
Half-wave plate		
Type		Zero order
Retardation tolerance		< 1% ellipticity
Transmissivity		> 99.7%

Summary of IMC Beam Steering Performance Characteristics

Parameter	Requirement	Actual
Spot size @ IMC	1.6 mm	
Lateral displacement @ IMC	+/- 1.6 mm	+/- 2.9 mm
Divergence angle of IMC	0.21 mrad	
Angular tilt	+/- 0.21 mrad	+/- 1.0 mrad
Angular slew rate	TBD	TBD

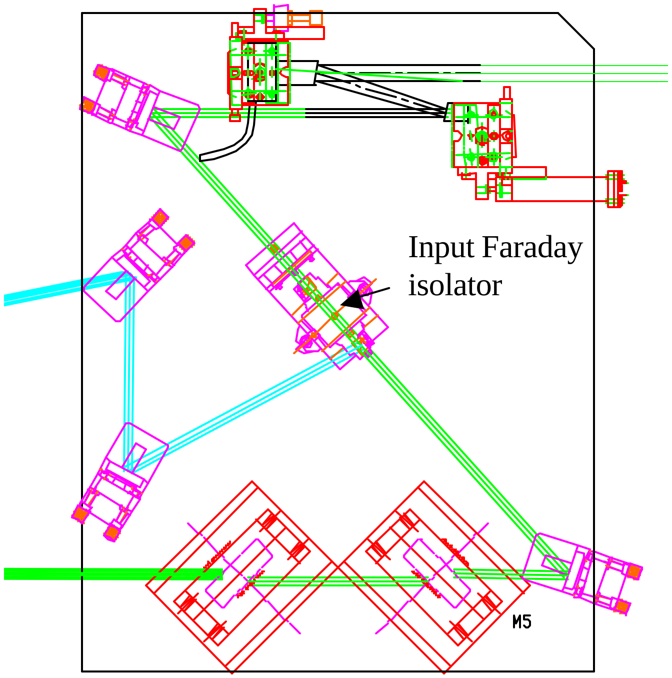
Input Mode Cleaner



IMC Performance Characteristics

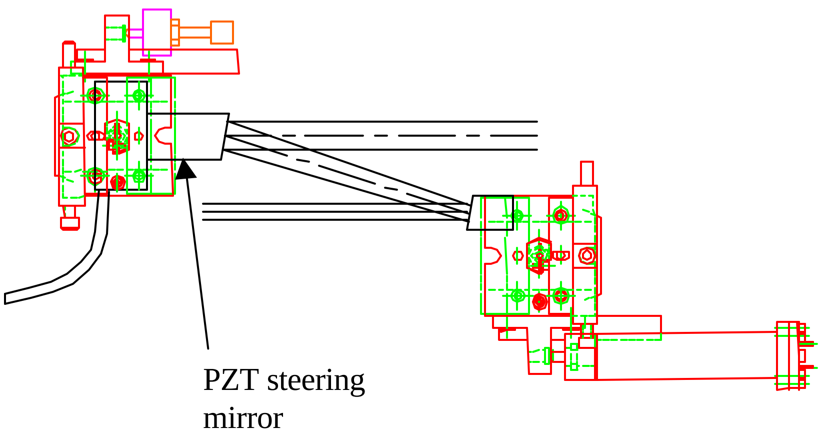
Parameter	Requirement	Actual
Plane mirror transmittance	0.002	0.002
Plane mirror reflectance	0.998	0.998
Curved mirror transmittance	$< 1 \times 10^{-5}$	$< 1 \times 10^{-5}$
AR coating reflectivity	< 0.2 %	< 0.2 %
Mirror power loss	< 0.00010	< 0.00010
Finesse	1550	1550
Free spectral range	11.83 MHz	11.83 MHz
Power build-up factor	450	450
Transmissivity of IMC	> 85 %	> 85 %
Cavity bandwidth width/half max	7.56 kHz	7.56 kHz
Cavity optical half-length	12680 mm	12680 mm
G = 1-L/R	0.29	0.29
Waist size	1.657	1.657
1ppm diameter, curved mirror	16.17	16.17
Length control, dynamic range	27 micron pk-pk	27 micron pk-pk
Angle control, dynamic range	1.5 mrad pk-pk	1.5 mrad pk-pk
Length noise density	3×10^{-18} m/rtHz	3×10^{-18} m/rtHz

Input Faraday Isolator



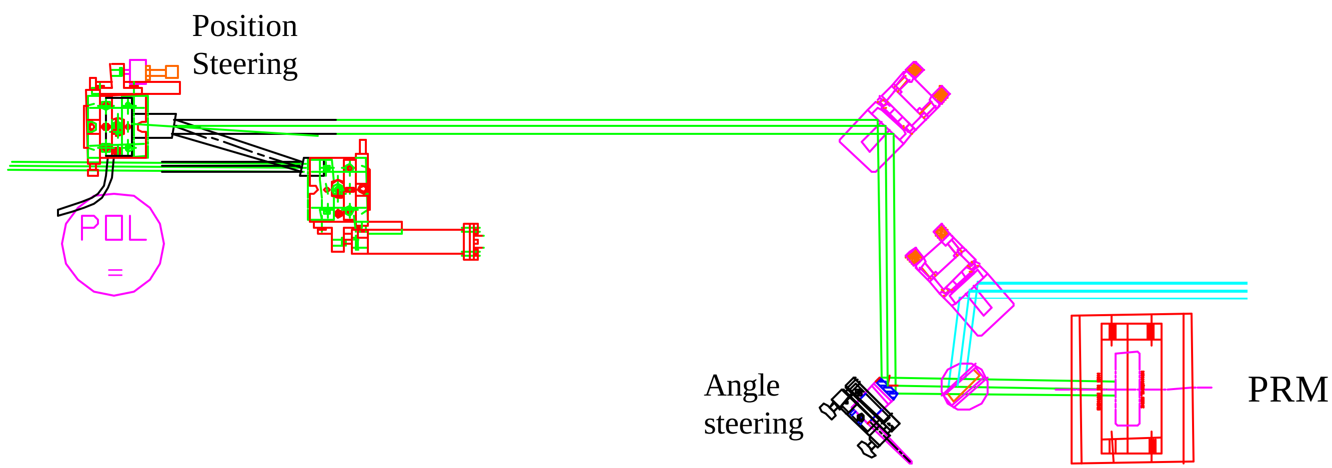
Parameter	Requirement	Actual
Wavelength	1064 nm	
Transmissivity across clear aperture		> 95%
Input polarization		Perpendicular to optical table
Output polarization		Parallel to optical table
Attenuation factor	1000:1	1000:1

IFO Mode Matching Telescope Performance Characteristics



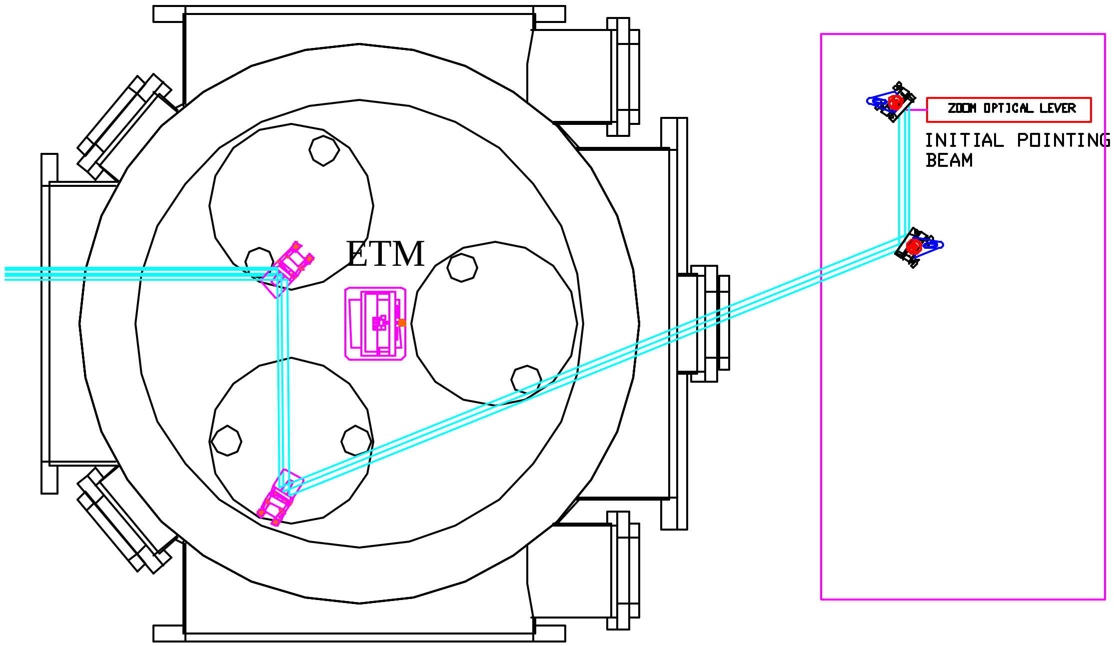
Parameter	Requirement	Actual
Clear aperture M1, mm	8.8	19
Clear aperture M2, mm	16.1	25
Input beam waist radius, mm	1.66	1.66
Output beam waist radius, mm	3.027	3.029
Power coupling error	<0.05	< 0.001
Wavefront distortion		<0.2
Transmissivity across clear aperture		> 99.8%, ion beam coating
Magnification	1.8	1.8

IFO Beam Steering Performance Characteristics



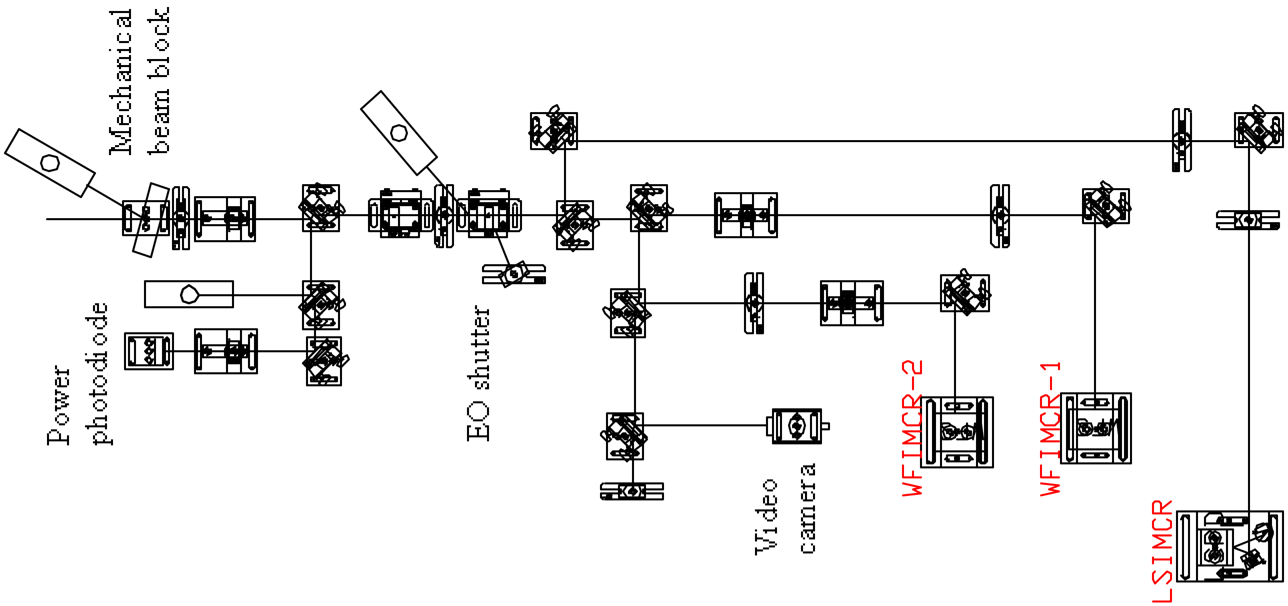
Parameter	Requirement	Actual
Spot size of IFO beam	3.03 mm	
Position steering	+/-3.03 mm	+/- 4 mm
Divergence angle of IFO beam	0.00011 rad	
Angular steering	0.00011 rad	+/- 0.004 rad
Resonant frequency		3500 Hz
Angle sensing		Internal strain gage

Initial Pointing Beam Angle Sensor



Parameter	Requirement	Actual
Pointing angle	Same as IFO beam	Same as IFO beam
Angle resolution	0.00001 rad	< 0.00001 rad
Sensor bandwidth		> 100 kHz
Main beam sample fraction	< 1 %	0.25 %

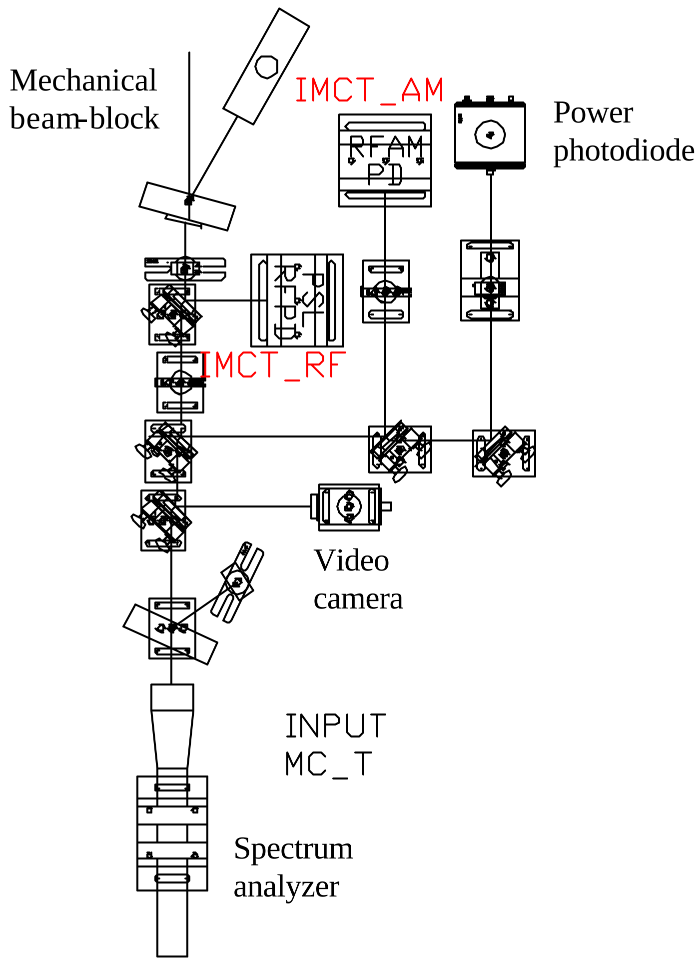
IMC Reflected Beam System



IMC Reflected Beam Performance Characteristics

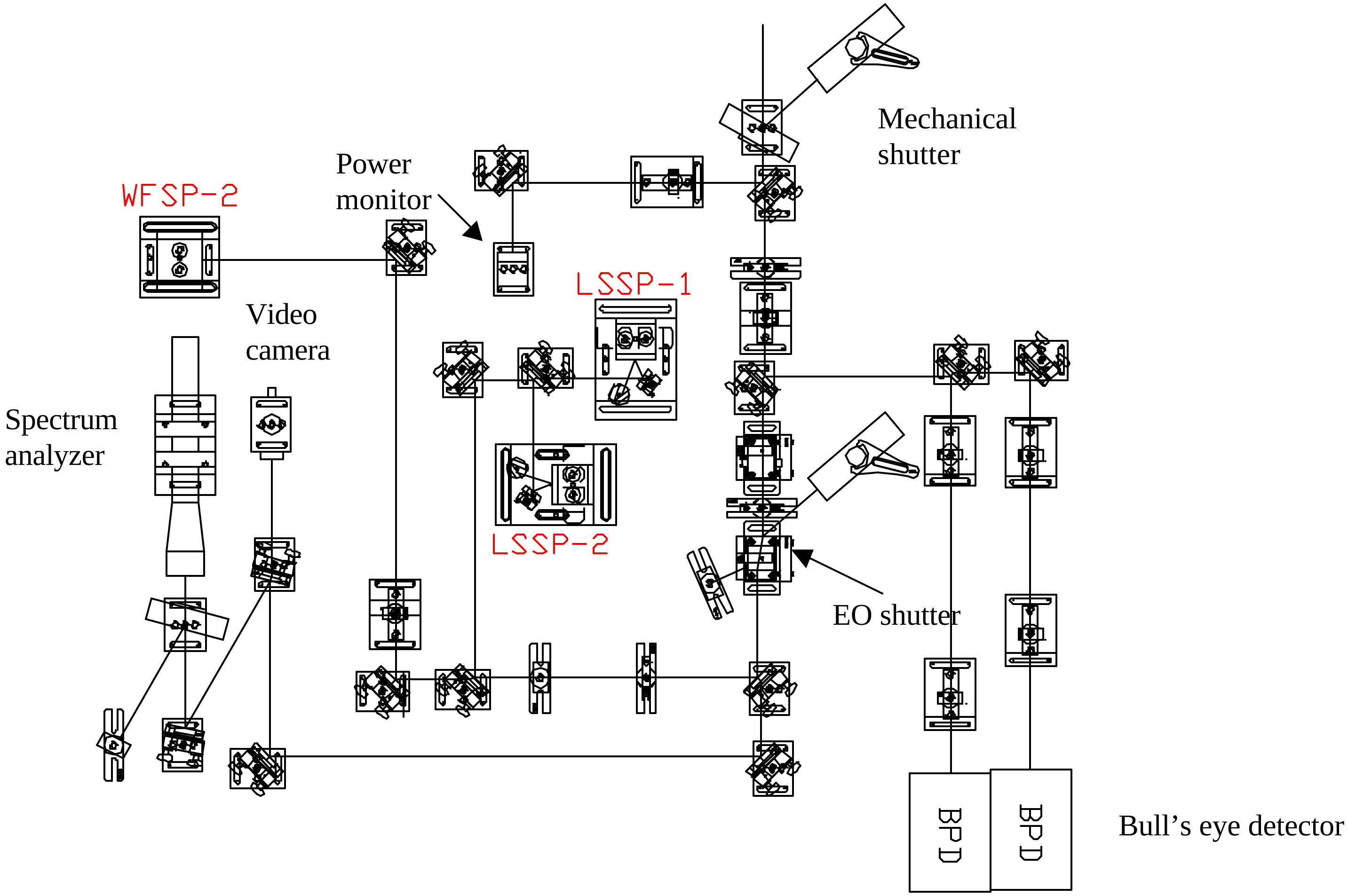
Parameter	Requirement	Actual
Wavefront distortion	< 1 wave @ 1064 nm	< 0.5 wave @ 1064 nm
Main beam sample fraction		0.6 %
WFS1, Guoy phase 1	Quad photodiode, 29.5 MHz	Quad photodiode, 29.5 MHz
WFS2, Guoy phase 2	Quad photodiode, 29.5 MHz	Quad photodiode, 29.5 MHz
LS, RF photodiode	29.5 MHz	29.5 MHz
Fast beam shutter	Yes	EO shutter
Mechanical beam block	Yes	Uniblitz
Video camera	Yes	Watek
Reflected power monitor	Yes	

IMC Transmitted Beam Performance Characteristics



Parameter	Requirement	Actual
Wavefront distortion	< 1 wave @ 1064 nm	< 0.5 wave @ 1064 nm
Main beam sample fraction	0.6 %	0.6 %
RFAM RF photodetector	TBD	TBD
PSL intensity stabilization, RF photodetector	TBD	TBD
Transmitted power photodetector	Yes	
Optical Spectrum analyzer	Yes	Coherent
Fast beam shutter	Yes	EO shutter
Mechanical beam block	Yes	Uniblitz
Video camera	yes	Watek

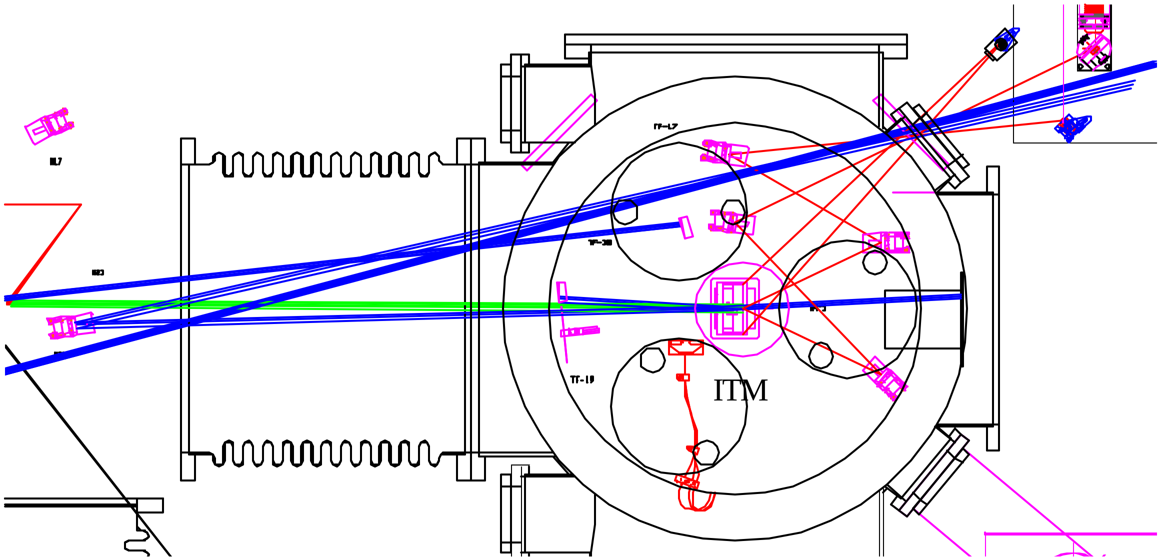
SPS Sensing System



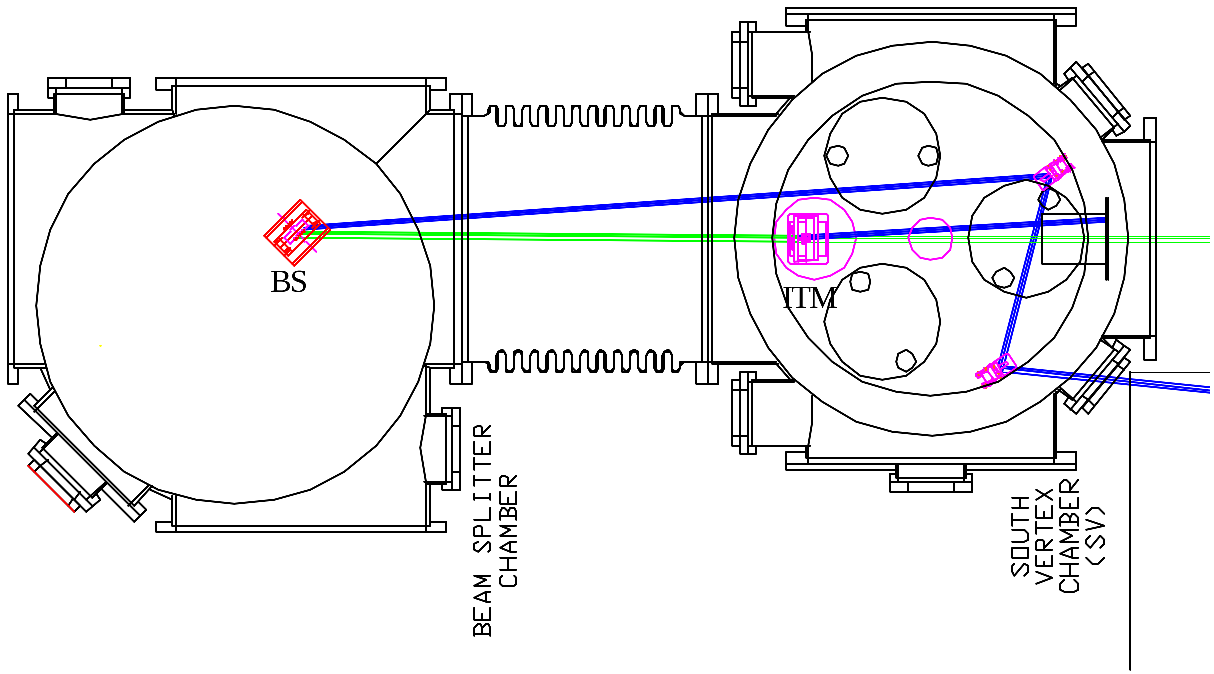
Symmetric Port Signal Performance Characteristics

Parameter	Requirement	Actual
Wavefront distortion	< 1 wave @ 1064 nm	< 0.3 wave @ 1064 nm
Symmetric port power ratio	0.01	0.01
WFSP-2 , frequency	Quad photodiode, TBD MHz	Quad photodiode, TBD MHz
LSSP-1, frequency	35.5 MHz	35.5 MHz
LSSP-2, frequency	141.9 MHz	141.9 MHz
Bull's eye photodetector		TBD
Fast beam shutter	Yes	EO shutter
Mechanical beam block	Yes	Uniblitz

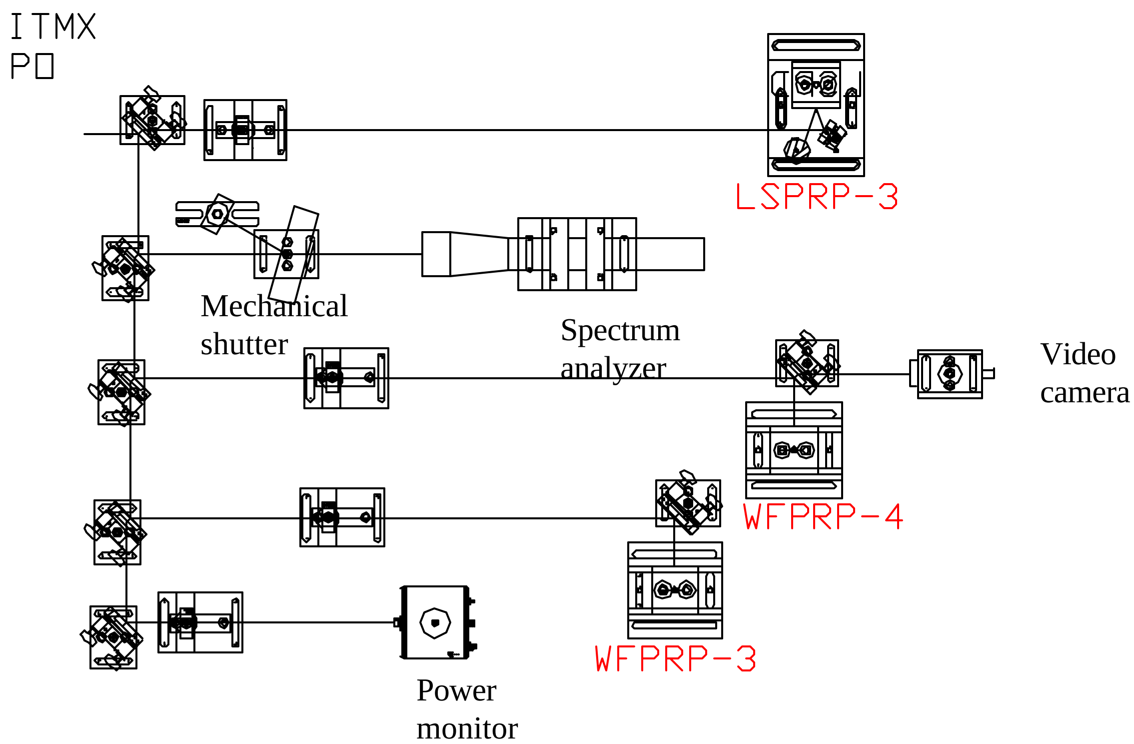
ITMx, ITMy pick-off beam



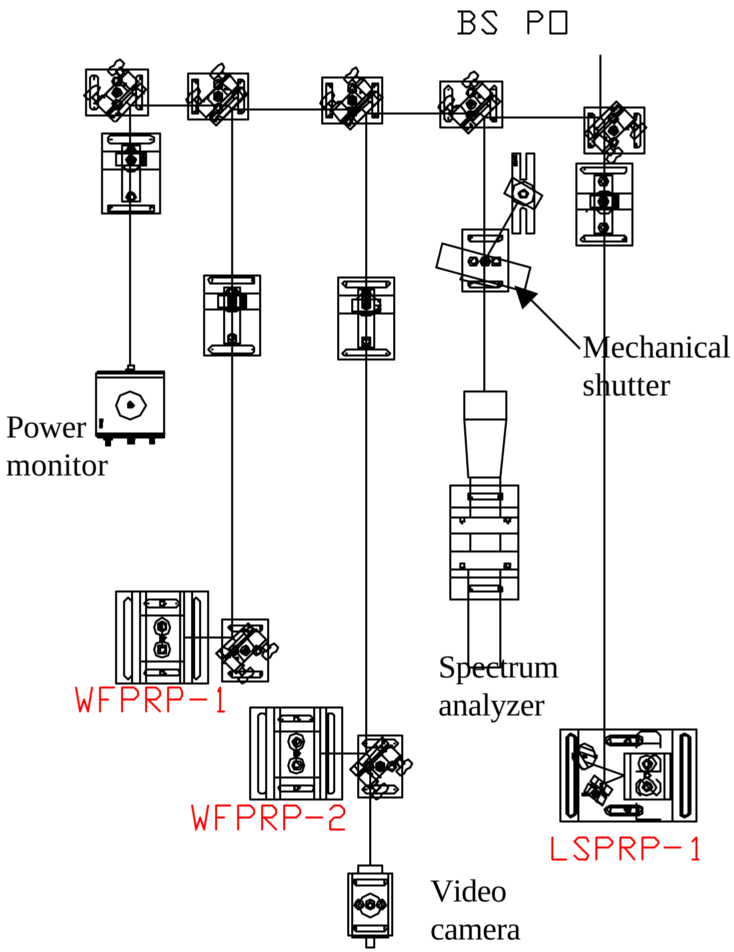
BS Pick-off Beam



ITM Pick-off Beam Sensing System

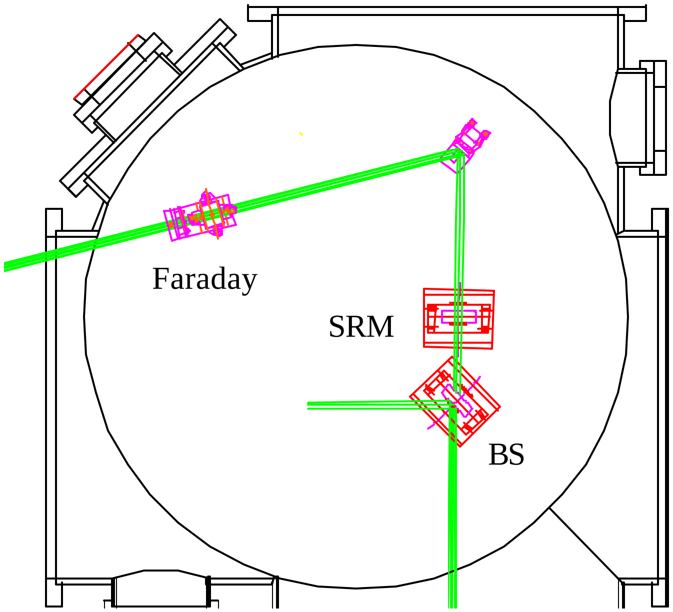


BS Pick-off Beam Sensing System



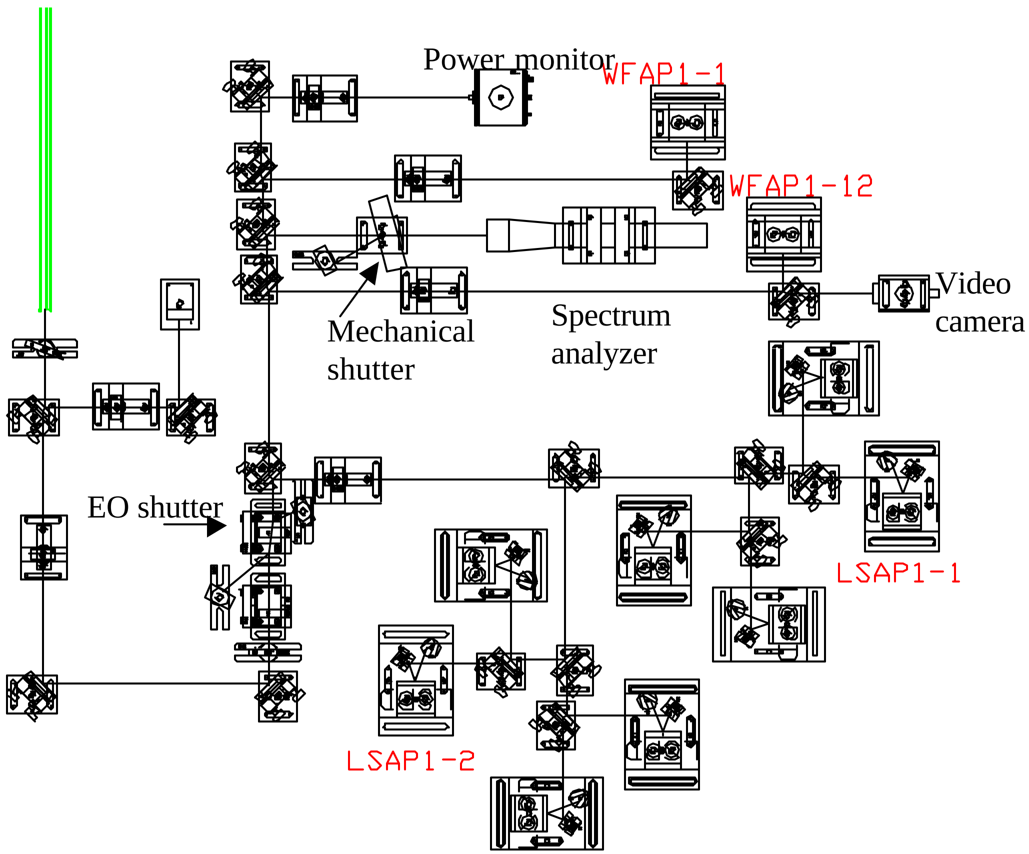
Parameter	Requirement	Actual
Wavefront distortion	< 1 wave @ 1064 nm	< 0.3 wave @ 1064 nm
Pick-off power ratio	0.0005	0.0005
WFSPPR, Guoy phase 1	Quad photodiode, 141.9 MHz	Quad photodiode, 141.9 MHz
WFSPPR, Guoy phase 2	Quad photodiode, 141.9 MHz	Quad photodiode, 141.9 MHz
LSSPRP-1, frequency	141.9 MHz	141.9 MHz

Output Faraday Isolator Characteristics



Parameter	Requirement	Actual
Wavelength	1064 nm	
Transmissivity across clear aperture		> 95%
Extinction ratio	1000:1	1000:1
Clear aperture	13 mm	20 mm
Faraday material		TGG

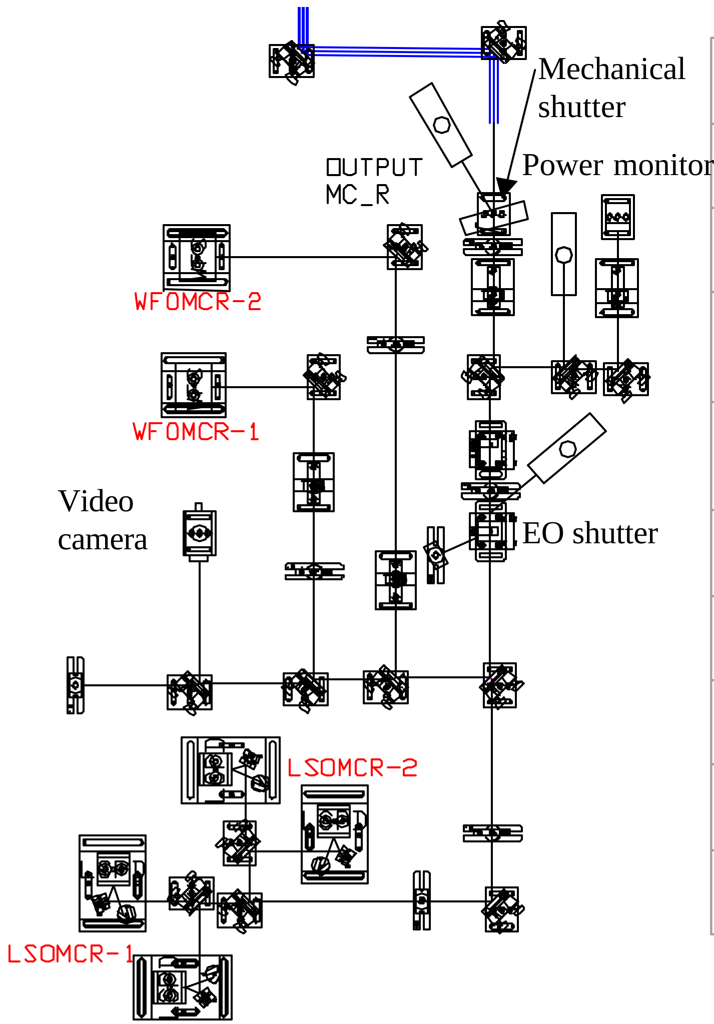
AP1 ISC System



AP1 ISC System Performance Characteristics

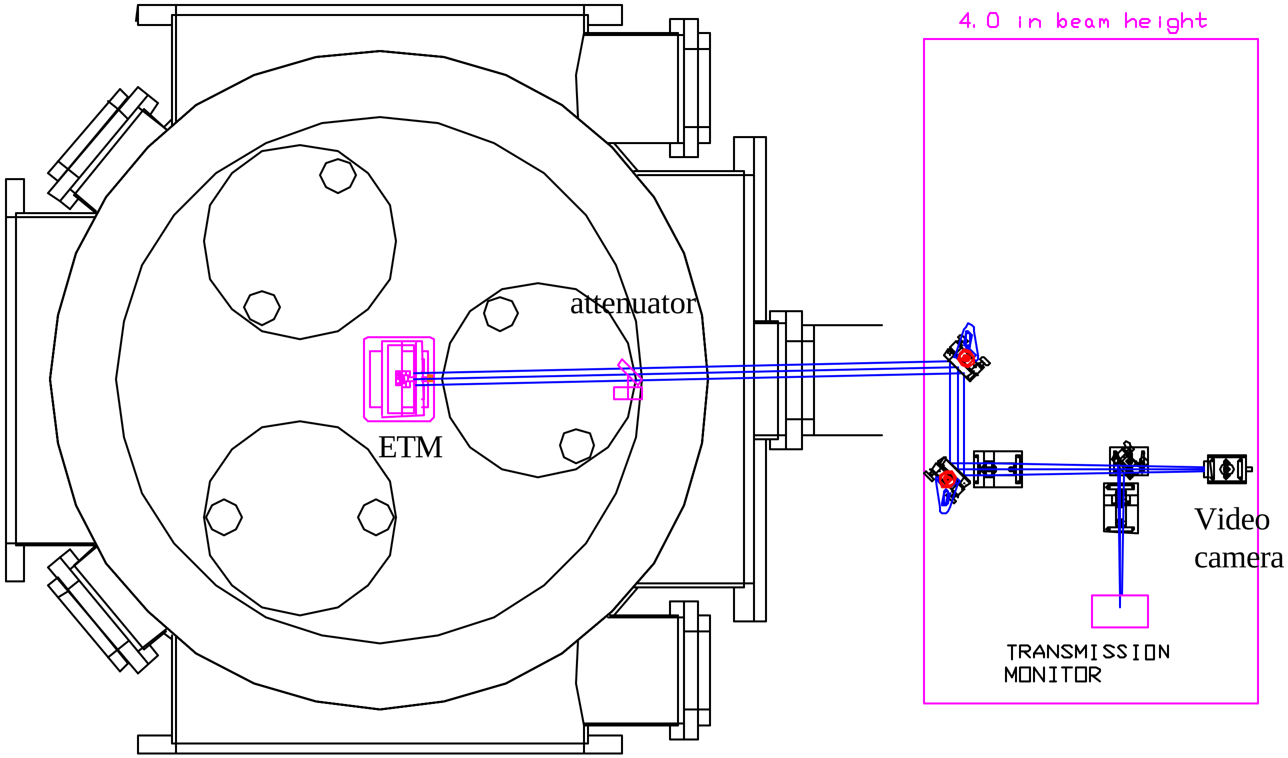
Parameter	Requirement	Actual
Wavefront distortion	< 1 wave @ 1064 nm	< 0.3 wave @ 1064 nm
Output power ratio	0.01	0.01
WFAP-1, Guoy phase 1	Quad photodiode, TBD MHz	Quad photodiode, TBD MHz
WFAP-2, Guoy phase 2	Quad photodiode, TBD MHz	Quad photodiode, TBD MHz
LSAP-1, frequency	177.3 MHz	177.3 MHz
LSAP-2, double demodulation	141.9 MHz, 212.8 MHz	35.5 MHz
Fast beam shutter	yes	EO shutter
Mechanical beam block	yes	Uniblitz
Video camera	yes	Watek
Optical spectrum analyzer	yes	Coherent

OMC Reflected Beam Sensing System



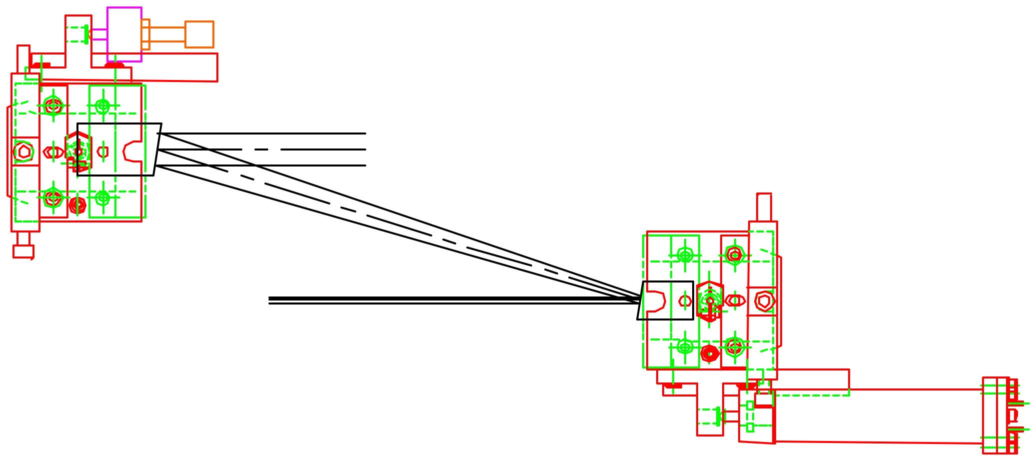
Parameter	Requirement	Actual
Wavefront distortion	< 1 wave @ 1064 nm	< 0.3 wave @ 1064 nm
Main beam sample fraction	0.01	0.01
WFS1, Guoy phase 1	Quad photodiode, 177.3 MHz	QPD, 177.3 MHz
WFS2, Guoy phase 2	Quad photodiode, 177.3 MHz	QPD, 177.3 MHz
LS, RF photodiode	177.3 MHz	177.3 MHz
Fast beam shutter	Yes	EO shutter
Mechanical beam block	Yes	Uniblitz
Video camera	Yes	Watek
Reflected power monitor photodiode	yes	

ETM Transmission Monitor



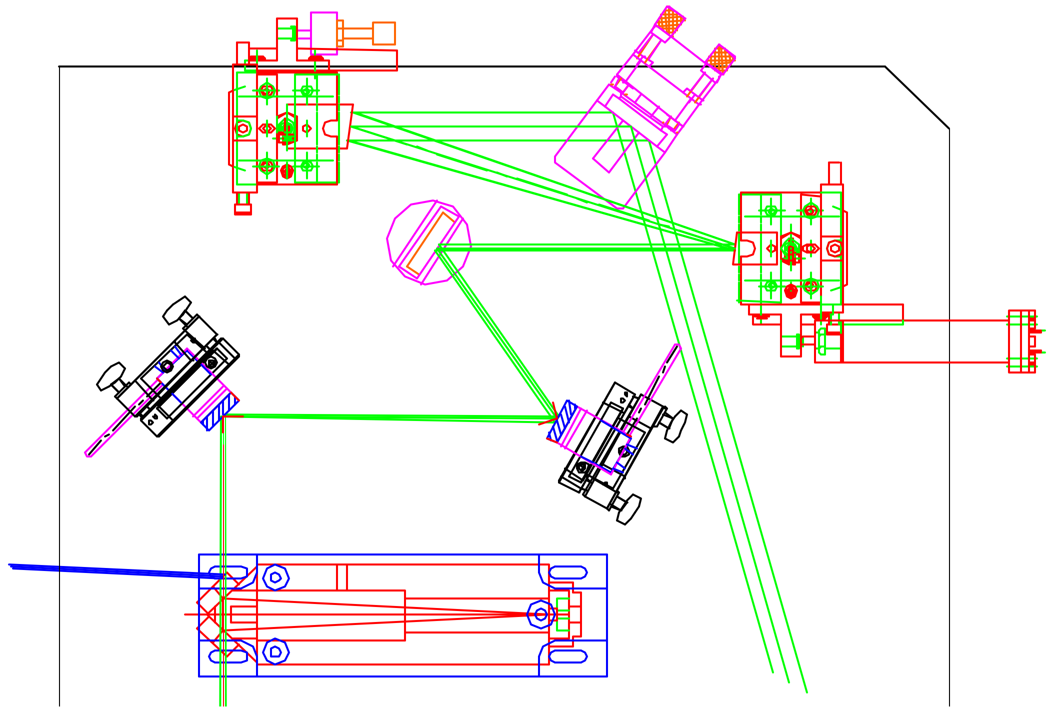
Parameter	Requirement	Actual
Output power ratio	0.01	0.01
Position transfer ratio, mm/mm		-0.18
Beam position pointing resolution, mm	0.52	0.055
Beam splitter attenuation ratio	0.1	0.1

OMC Mode Matching Telescope



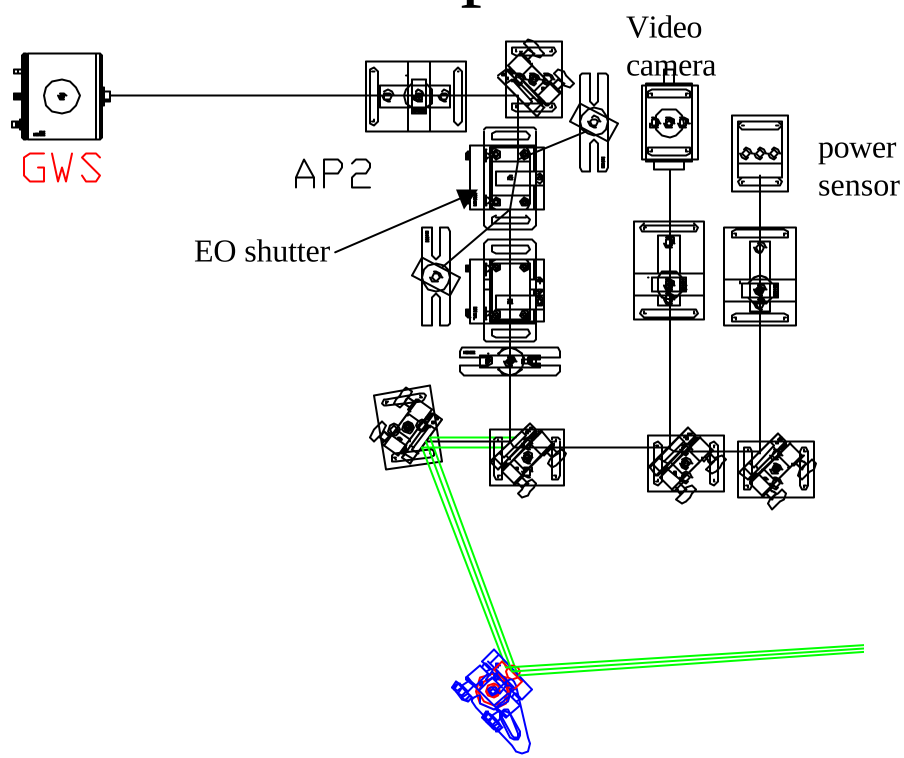
Parameter	Requirement	Actual
Clear aperture M1, mm	13	25
Clear aperture M2, mm	3	19
Input beam waist radius, mm	3.027	3.027
Output beam waist radius, mm	0.37	0.369
Power coupling error	<0.05	< 0.0001
Wavefront distortion		<0.2
Transmissivity across clear aperture		> 99.8%, ion beam coating
Magnification	0.23	0.23

OMC Beam Steering



Parameter	Requirement	Actual
Spot size of OMC beam	0.37 mm	
Position steering	+/-0.37 mm	+/- 0.8 mm
Divergence angle of OMC beam	0.00092 rad	
Angular steering	0.00092 rad	+/- 0.004 rad
Resonant frequency		3500 Hz
Angle sensing		Internal strain gage

AP2 ISC Optical Train

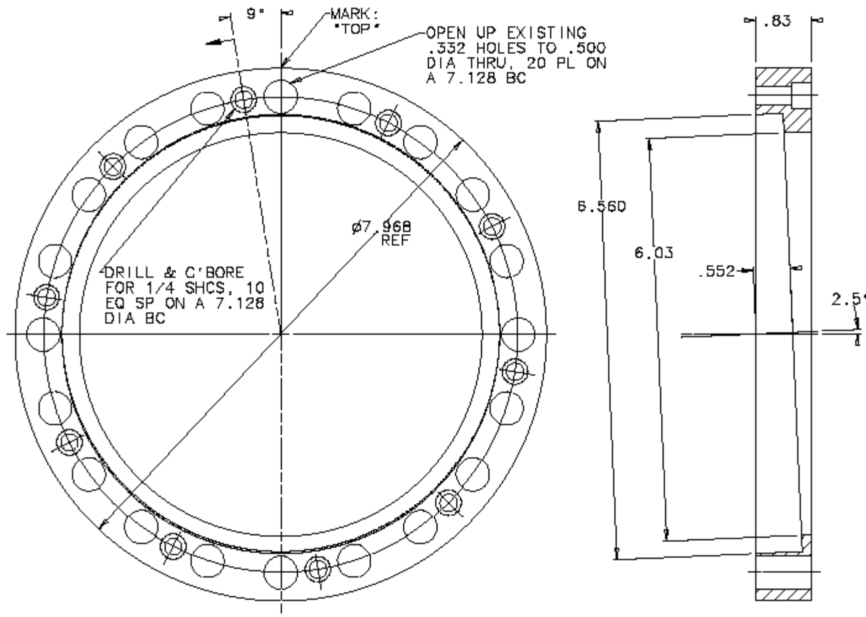


Parameter	Requirement	Actual
AP2 power ratio	0.005	0.005
GWS photodetector frequency response	DC - 10 KHz	DC - 10 KHz
Seismic velocity of GWS photodetector	TBD	TBD

Viewports, Types and Locations

Location	Type
Ouput-chamber, 1	Optical quality, type 1
Ouput-chamber, 2	Optical quality, type 1
Ouput-chamber, 3	Optical quality, type 1
Input chamber, “T”	Camera
Input chamber, top	Camera
Mode cleaner chamber	Camera
BS chamber	Optical quality, type 2
East vertex chamber, mid	Optical quality, type 2
East vertex chamber, upper	Camera
South vertex chamber, mid	Optical quality, type 2
South vertex chamber, upper	Camera
East end chamber, mid	Optical quality, type 2
East end chamber, upper	Camera
South end chamber, mid	Optical quality, type 2
South end chamber, upper	Camera

Tilted Viewport



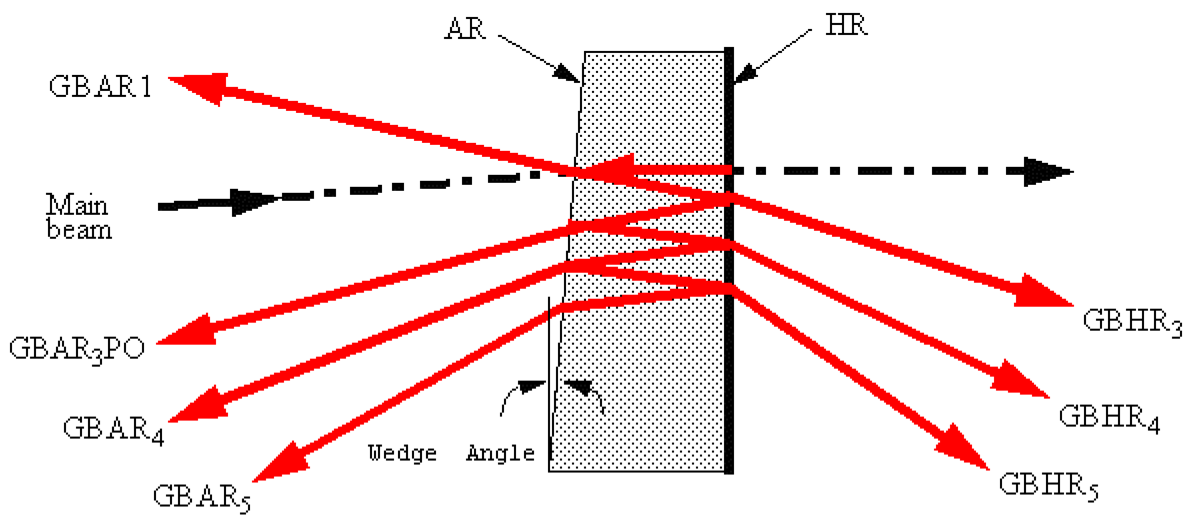
Parameter	Requirement	Actual
Tilt angle	2.5 deg	2.5 deg
Scattering BRDF, sr^{-1}	< 0.04	TBD
Reflectivity 1 @ 1064 nm, normal incidence		< 0.1 %
Reflectivity 2 @ 630 - 1064 nm, normal incidence		< 0.75 %

40m Auxiliary Optics Support Design Requirements Document & Conceptual Design

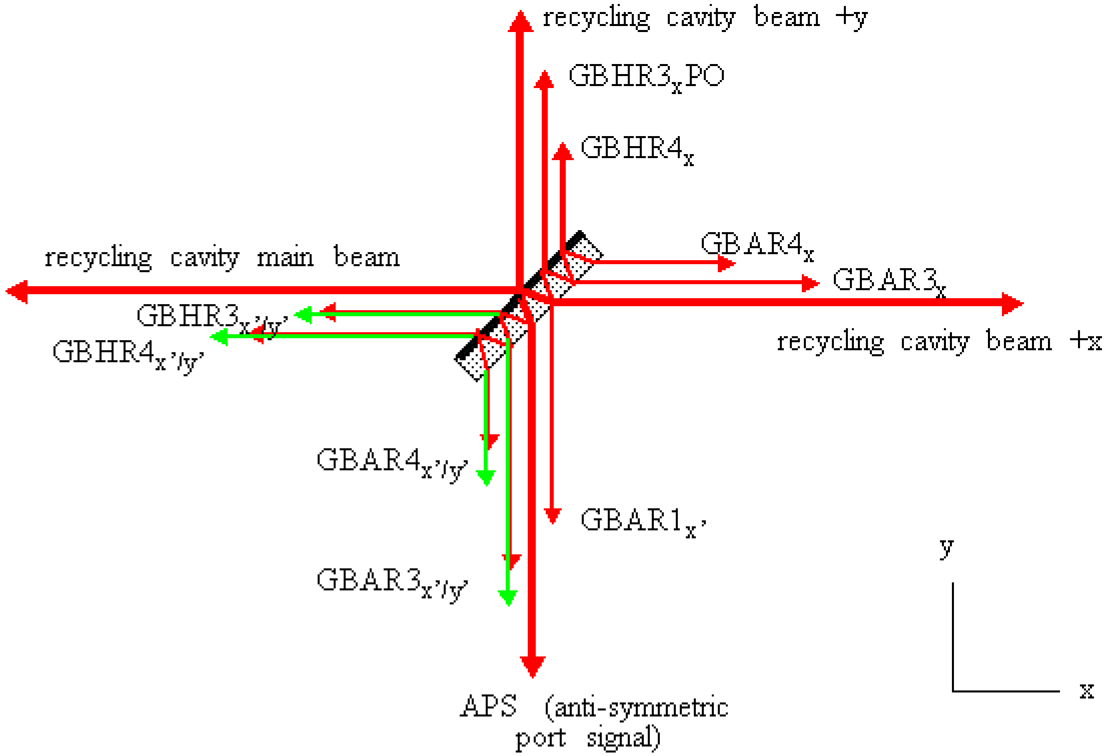
Michael Smith
10/18/01

- Stray Light Control
- Initial Alignment System
- Optical Lever System
- Video Monitoring System

Ghost Beam Naming Convention 1



Ghost Beam Naming Convention 2



Scattered Light Requirements

Source	Scattered power allocation factor	Scattered power into IFO, watt	Requirement per source, Ps, watt 100 Hz	300 Hz	1000 Hz	Incident power, Pi, watt
AP1	0.0762	1.46E-11	1.46E-11	1.27E-10	5.25E-09	0.030
AP2	0.0652	1.25E-11	1.25E-11	1.08E-10	4.49E-09	0.028
ETMX GBAR2 PO, window scatter	0.0490	3.85E-10	3.85E-10	3.44E-09	1.92E-07	0.327
ETMY GBAR2 PO, window scatter	0.0490	3.85E-10	3.85E-10	3.44E-09	1.92E-07	0.327
ETMX GBAR2 PO	0.0203	1.59E-10	1.59E-10	1.42E-09	7.94E-08	0.327
ETMY GBAR2 PO	0.0203	1.59E-10	1.59E-10	1.42E-09	7.94E-08	0.327
Glint from AP1 lens	0.0153	2.95E-04	2.95E-04	2.55E+01	1.06E+07	0.030

Beam Dump/Baffle Optical Requirements

Table 4: SEI-mounted Beam Dump Optical Requirements

Parameter	Required Value	Measured Value
Reflectivity	< 1	0.035
Material		DESAG OG 14 filter glass
BRDF	<1E-2 sr^{-1}	<1.4E-4 sr^{-1}

Arm Cavity Baffle Optical Requirements

Parameter	Required Value	Measured Value
Reflectivity	< 0.3	9E-4
Material		DESAG OG 14 filter glass
BRDF	<1E-2 sr^{-1}	<1.4E-4 sr^{-1}

Table 6: Mode Cleaner Baffle Optical Requirements

Parameter	Required Value	Measured Value
Reflectivity	Not specified	0.035
Material		DESAG OG 14 filter glass
BRDF	Not specified	<1.4E-4 sr^{-1}

Initial Alignment System Requirements

•Angular positioning +/- 0.1 mrad (ITM, ETM, BS, PRM, SRM)

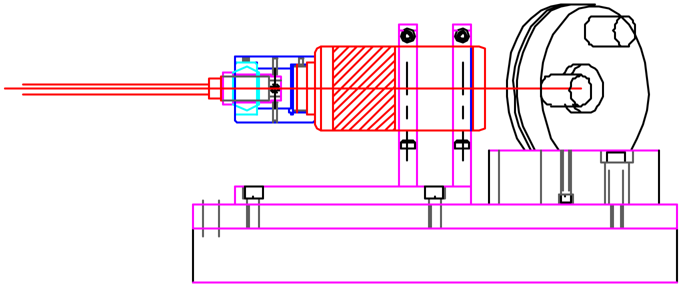
•Transverse positioning +/- 2 mm (ITM, ETM) +/- 2 mm (BS, RM, SRM)

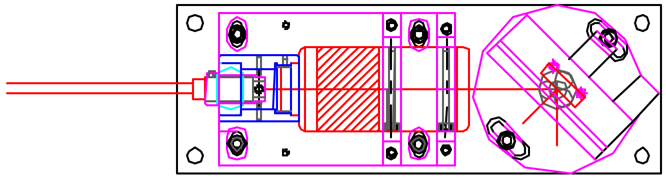
•Axial positioning +/- 3 mm (ITM, ETM, BS, RM, FM)

Initial Alignment System Physical Characteristics

- Theodolite / 3-D Coordinate Measuring System
- Transit Square
- Laser Autocollimator
- COS Autocollimator

Optical Lever Projector

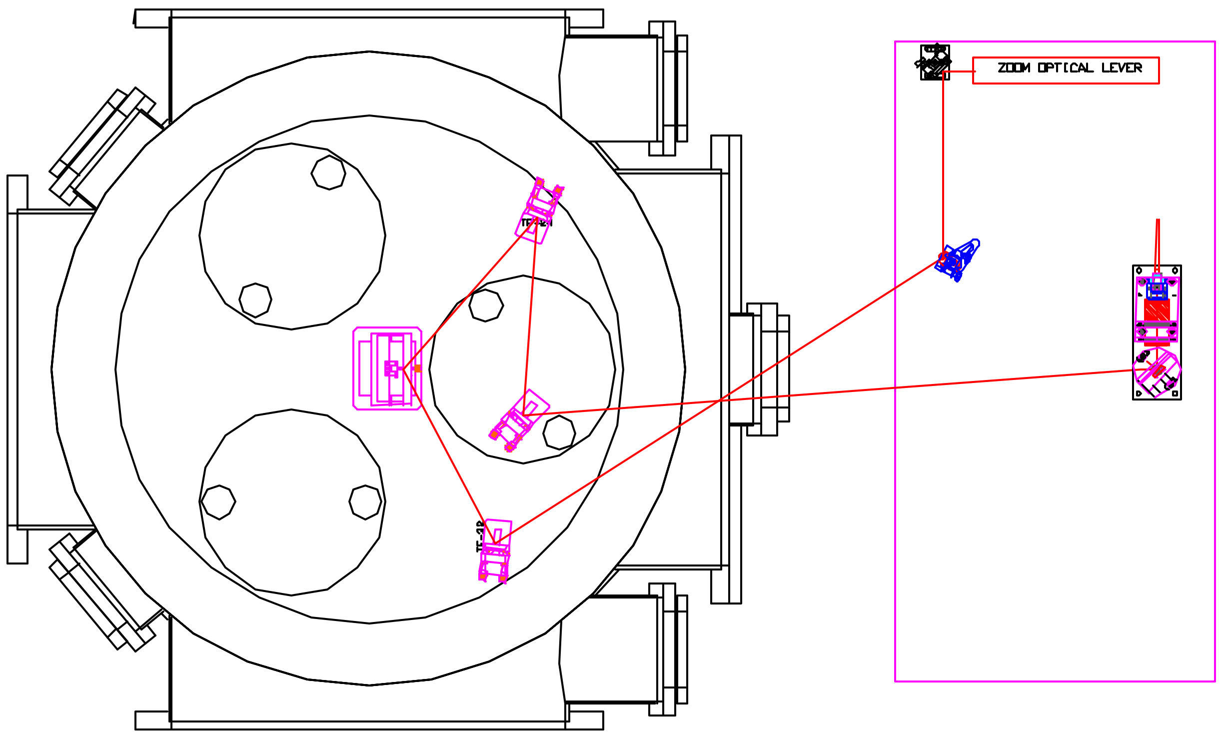




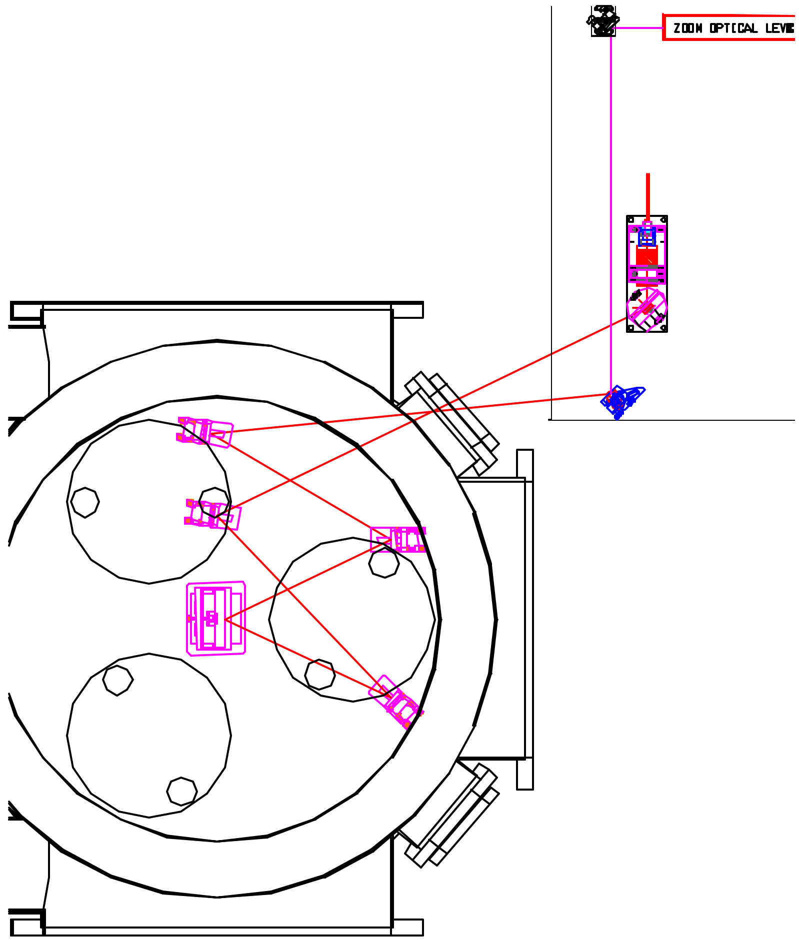
Angle Sensitivity, Zoom Optical Lever Sensor

Parameter	Requirement	Actual
Wavelength, nm		633
Local		
Minimum beam angle, rad	10×10^{-6}	10×10^{-6}
Maximum beam angle, rad	2500×10^{-6}	2500×10^{-6}
Global		
Minimum beam angle, rad	1×10^{-6}	1×10^{-6}
Maximum beam angle, rad	250×10^{-6}	250×10^{-6}
Cross coupling, rad/mm		0
Long term drift, rad	$<50 \times 10^{-6}$	TBD

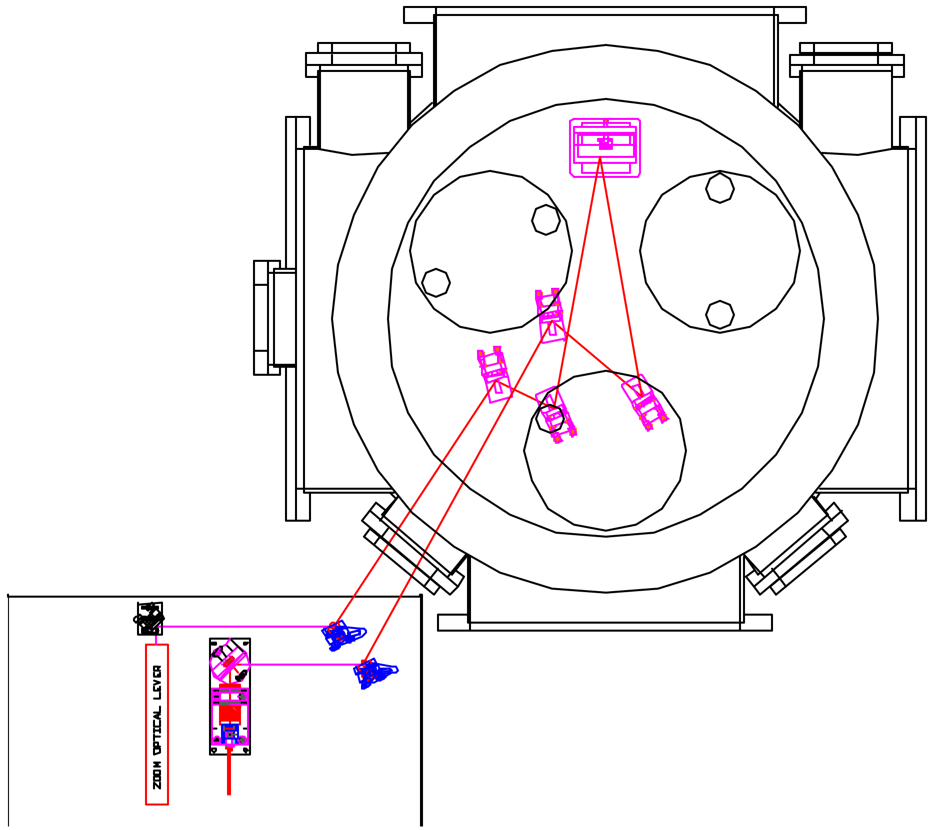
Optical Lever, Etmx



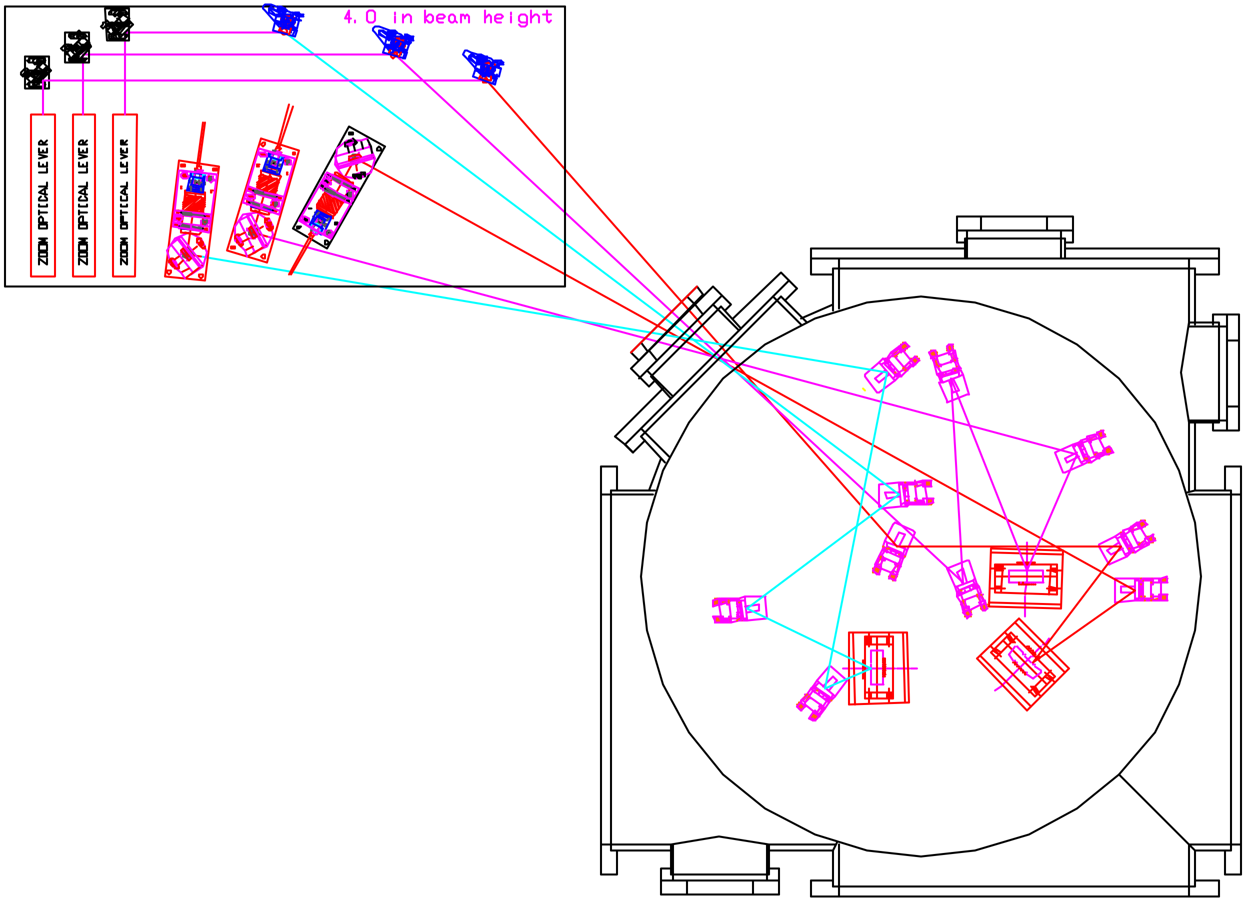
Optical Lever, ITMx



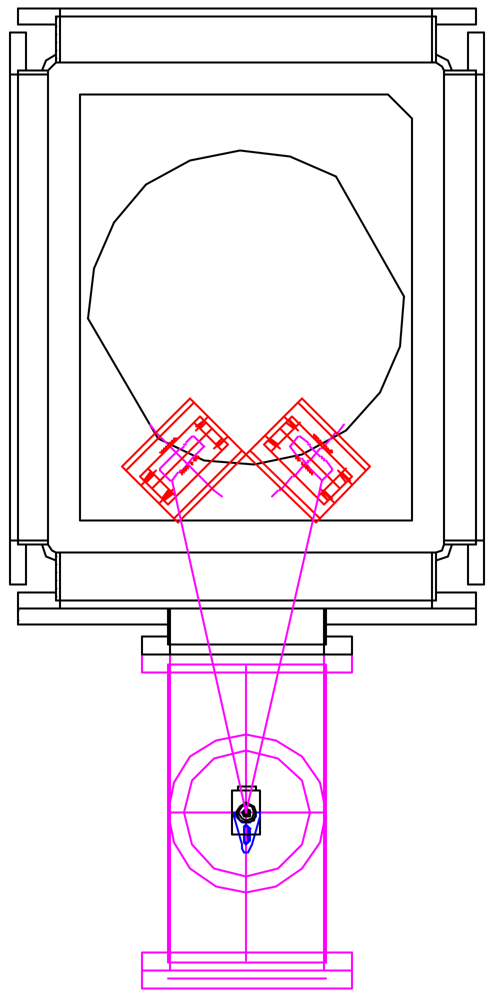
Optical Lever, ITMy



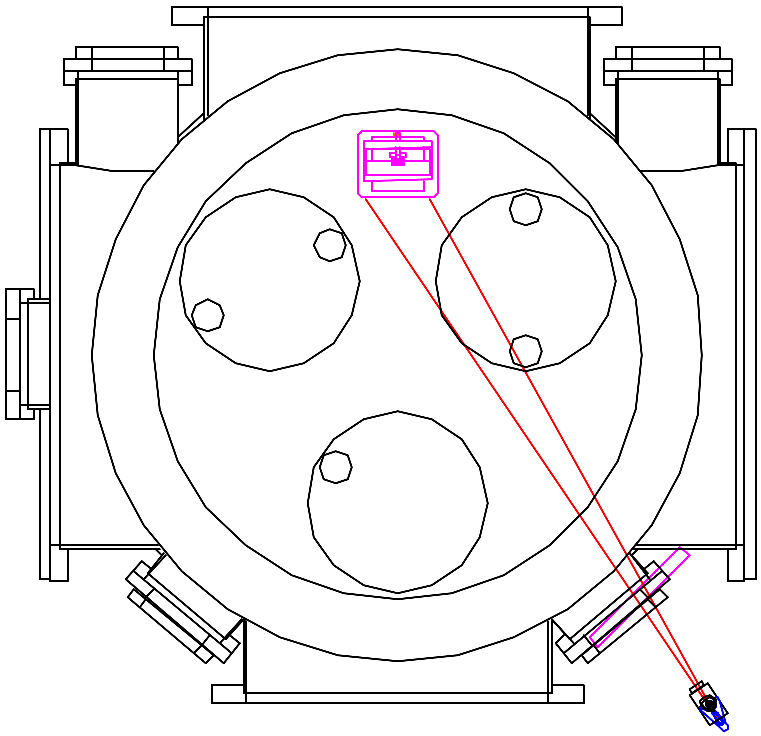
Optical Lever, PRM, BS, SRM



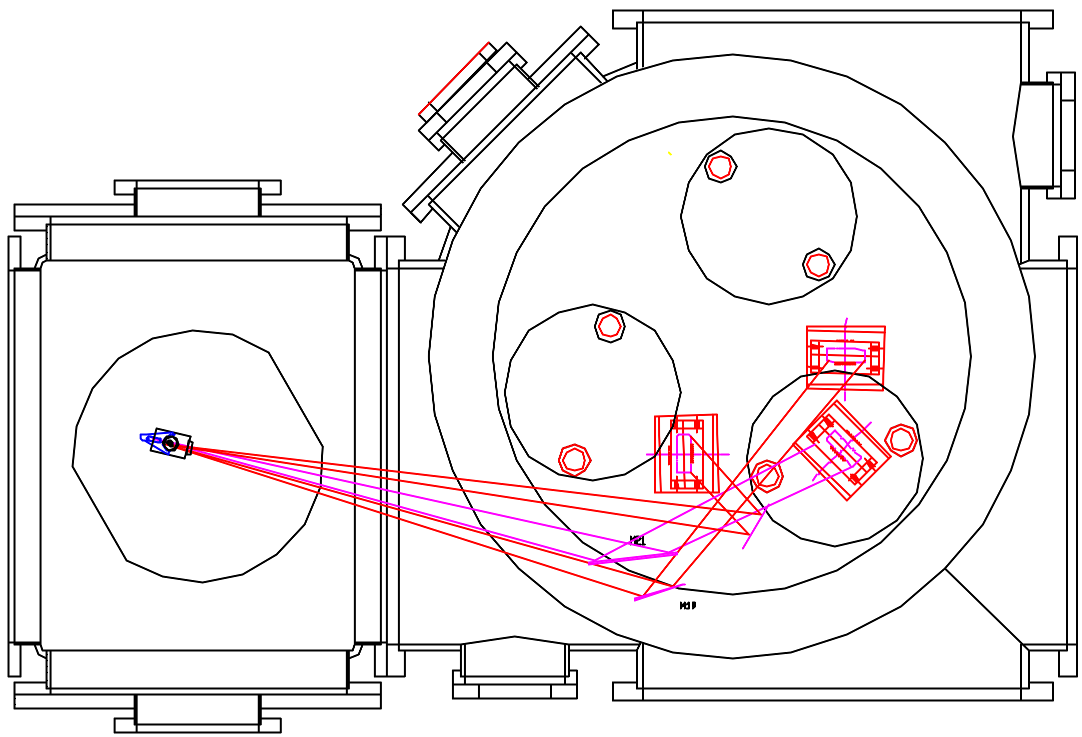
Video Monitor for IMC Flat Mirrors



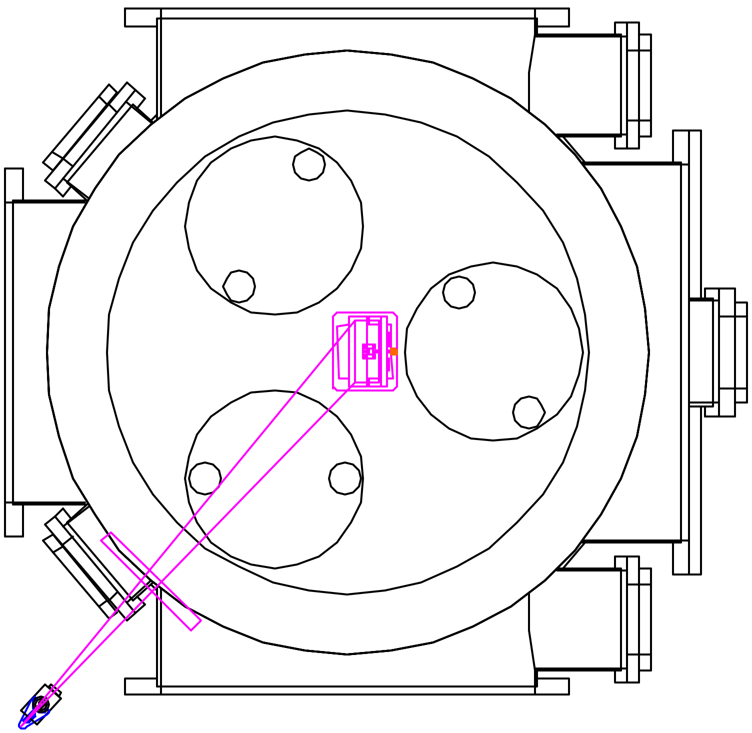
Video Monitor for Itmy



Video Monitor for PRM, BS, SRM



Video Monitor for Etmx



Scattered Light Noise Theory

- Noise/signal ratio

$$\frac{d\tilde{h}_{si}}{\tilde{h}_g} = K_i \sqrt{\frac{P_{si}}{P_0}}$$

- Scattered light criteria

$$\frac{d\tilde{h}_s}{\tilde{h}_g} = \sqrt{\sum_i (K_i)^2 \frac{P_{si}}{P_0}} \le \frac{1}{10}$$

- Allocation factor

$$F_i = \frac{(K_i)^2 \left(\frac{P_{si}}{P_0}\right)_{REQ}}{\left(\frac{1}{10}\right)^2}$$

- Requirement

$$\left(\frac{P_{si}}{P_0}\right)_{REQ} \le \frac{F_i}{(K_i)^2}\left(\frac{1}{10}\right)^2$$

Parameters for the K Values

Parameter	Value
Recycling cavity gain	14
Arm cavity power gain	778
Reflection coefficient of PRM	0.95603
Transmission coefficient of PRM	0.26458
ITM reflection coefficient	0.99748
ITM transmission coefficient	0.07071
ETM reflection coefficient	0.99998
ETM transmission coefficient	0.00316
Reflection coefficient of FP @ resonance	-0.98907
Asymmetry coeff. Michelson arms	0.003
Scattering loss from ITM and ETM mirrors	2.75E-05

K Values, Seismic Surfaces

K values, seismic surfaces	Frequency 100 Hz	300 Hz	1000 Hz
K-ITM	1.77E+04	6.01E+03	9.33E+02
K-APS	1.77E+04	6.01E+03	9.33E+02
K-ETM	2.76E+03	9.25E+02	1.24E+02
K-SPS	5.67E+01	1.93E+01	2.99E+00
K-RM	5.67E+01	1.93E+01	2.99E+00
K-SM	0.00E+00	0.00E+00	0.00E+00
K-ARM	8.74E+05	2.92E+05	3.91E+04
40 M seismic spectral density, m/Hz^0.5	2.75E-11	4.96E-12	7.58E-13
40 M strain sensitivity, 1/Hz^0.5	1.30E-20	7.00E-21	8.00E-21

APS Photodetector Scatter

- Scattered light $$P_s = P_i BRDF_{PHOTO} \Delta\Omega \left(\frac{w_0}{w_{APSPHOTO}} \right)^2 T_{APS}$$

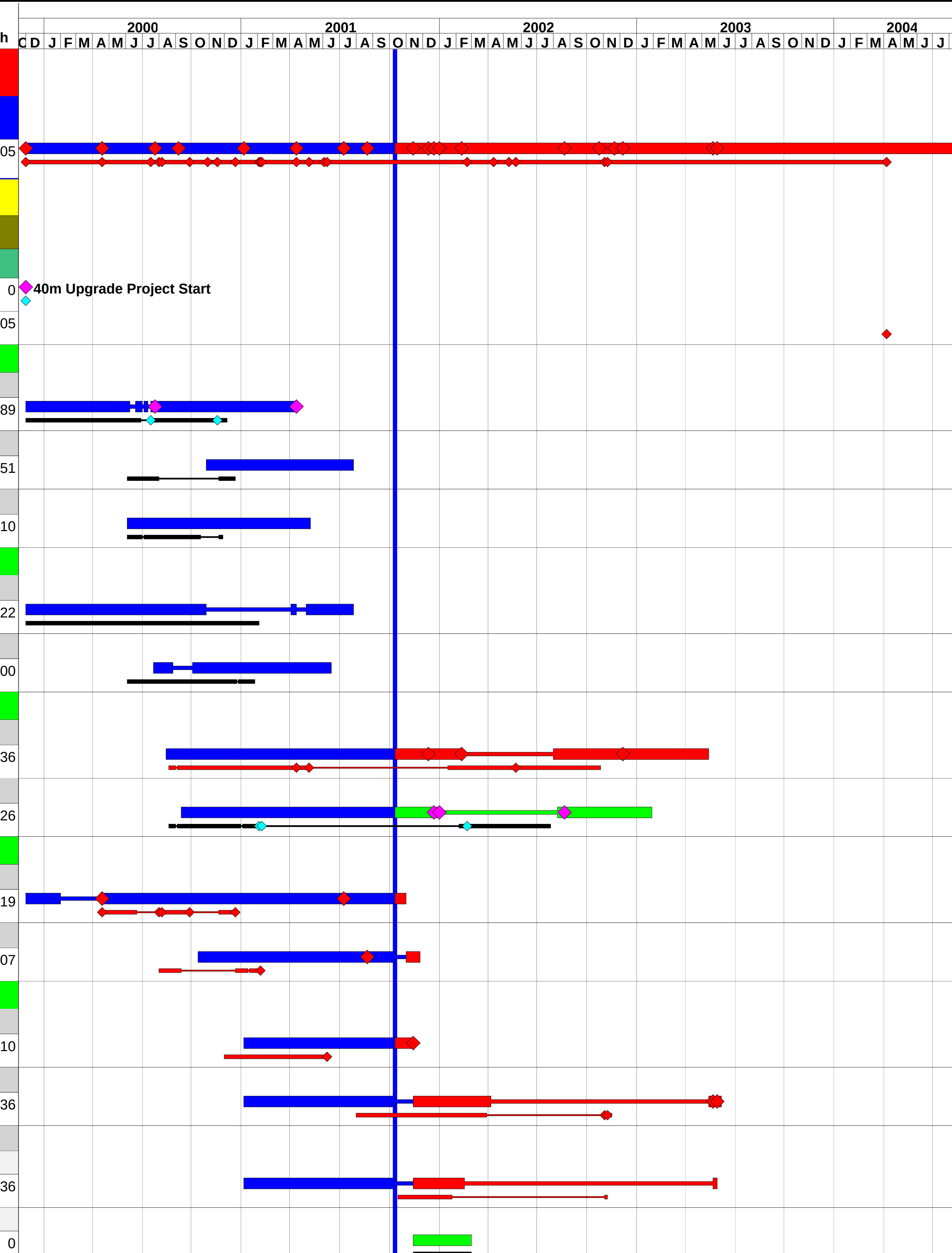
- Incident power $$P_i = P_0 F_{DPSR}$$

Beam Glint

- Glint power $$P_g = P_i R \eta$$

Parameter	Value
Glint efficiency, AP1 lens	0.00982
Glint efficiency, OMCR lens 1	0.000079
Glint efficiency, OMCR lens 2	1.2E-06
Glint efficiency, output Faraday (@ 1.25E-3 rad tilt)	2.68E-06
AR reflectivity, lens	0.0020

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp		Late Start	Late Finish	Total Float	Variance Early Finish
LIGO											
LIGO.2 LIGO Laboratory Operations											
Subtotal		1,198	728	01DEC99A	02SEP04	44		01DEC99A	12APR04	-101	-105
LIGO.2.01 Laboratory Caltech Site Operations											
LIGO.2.01.6 Campus Research Facilities (CAM)											
LIGO.2.01.6.1 40 Meter Interferometer Upgrade											
4M-M00010	40m Upgrade Project Start	0	0	01DEC99A		100		01DEC99A			0
4M-M99999	40m Project Complete	0	0		02SEP04	0			12APR04*	-101	-105
LIGO.2.01.6.1.1 FAC											
+ LIGO.2.01.6.1.1.1 Lab Expansion											
		344	0	01DEC99A	13APR01A	100		01DEC99A	13APR01A		-89
+ LIGO.2.01.6.1.1.2 Vacuum Envelope											
		187	0	27OCT00A	26JUL01A	100		27OCT00A	26JUL01A		-151
+ LIGO.2.01.6.1.1.3 Vacuum Controls											
		232	0	05JUN00A	07MAY01A	100		05JUN00A	07MAY01A		-110
LIGO.2.01.6.1.2 SEI											
+ LIGO.2.01.6.1.2.1 Output Chamber Stack											
		416	0	01DEC99A	26JUL01A	100		01DEC99A	26JUL01A		-122
+ LIGO.2.01.6.1.2.2 Cavity Optics Isolation											
		227	0	22JUL00A	15JUN01A	100		22JUL00A	15JUN01A		-100
LIGO.2.01.6.1.3 SUS											
+ LIGO.2.01.6.1.3.1 Large Optic Suspensions											
		692	398	14AUG00A	14MAY03	36		14AUG00A	04FEB03	-71	-136
+ LIGO.2.01.6.1.3.2 Small Optic Suspensions											
		598	323	11SEP00A	29JAN03	64		11SEP00A	04FEB03	4	-126
LIGO.2.01.6.1.4 PSL											
+ LIGO.2.01.6.1.4.1 Laser											
		484	14	01DEC99A	31OCT01	97		01DEC99A	31OCT01	0	-219
+ LIGO.2.01.6.1.4.2 PSL											
		283	18	13OCT00A	27NOV01	66		13OCT00A	27NOV01	0	-207
LIGO.2.01.6.1.5 Optical Systems and Sensing											
+ LIGO.2.01.6.1.5.1 Optical Systems Design											
		219	23	05JAN01A	13NOV01	82		05JAN01A	13NOV01	0	-110
+ LIGO.2.01.6.1.5.2 IFO Input Beam											
		608	390	06JAN01A	05JUN03	1		06JAN01A	28MAY03	-5	-136
LIGO.2.01.6.1.5.3 Optical Sensing Beams											
+ LIGO.2.01.6.1.5.3.1 Initial Pointing Beam											
		604	385	05JAN01A	28MAY03	6		05JAN01A	21JAN03	-91	-136
+ LIGO.2.01.6.1.5.3.2 IMC Reflected											
		71	71	15NOV01	01MAR02	0		20SEP02	06JAN03	212	0



Start Date	01DEC99
Finish Date	02SEP04
Data Date	12OCT01
Run Date	16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

L043 - 40MU

Sheet 1 of 4

LIGO II

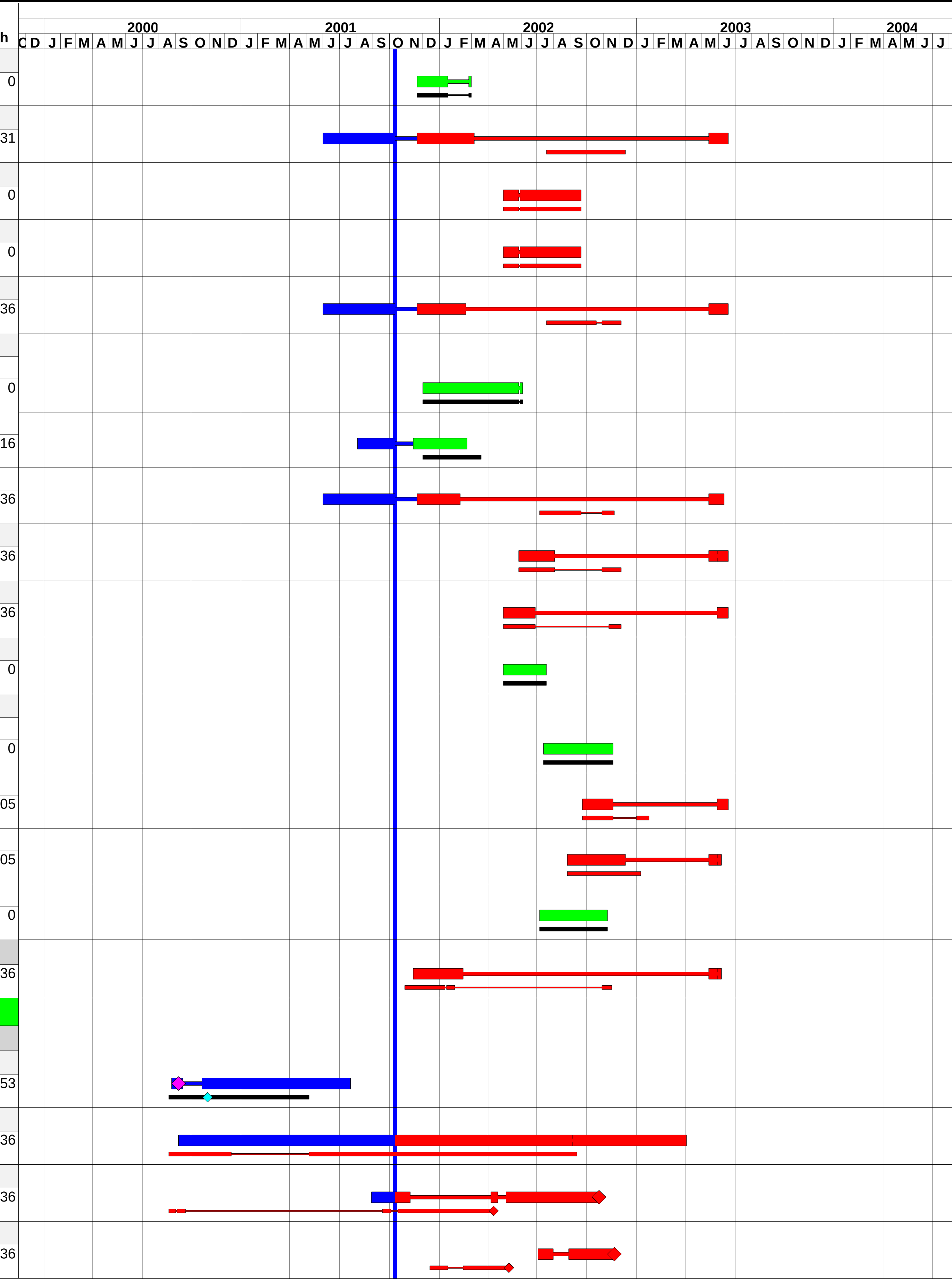
40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

LIGO

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp		Late Start	Late Finish	Total Float	Variance Early Finish
+ LIGO.2.01.6.1.5.3.3 IMC Transmitted											
		66	66	22NOV01	01MAR02	0		04NOV02	06JAN03	212	0
+ LIGO.2.01.6.1.5.3.4 Symmetric Port Signal											
		516	394	01JUN01A	19JUN03	7		01JUN01A	28JAN03	-101	-131
+ LIGO.2.01.6.1.5.3.5 ITMx Pickoff Beam											
		100	100	01MAY02	20SEP02	0		01MAY02	20SEP02	0	0
+ LIGO.2.01.6.1.5.3.6 ITMy Pickoff Beam											
		100	100	01MAY02	20SEP02	0		01MAY02	20SEP02	0	0
+ LIGO.2.01.6.1.5.3.7 BS Pickoff Beam											
		516	394	01JUN01A	19JUN03	8		01JUN01A	28JAN03	-101	-136
LIGO.2.01.6.1.5.3.8 AP1 Output Beam											
+ LIGO.2.01.6.1.5.3.8.1 Output Faraday Isolator											
		127	127	03DEC01	05JUN02	0		24JUL02	28JAN03	160	0
+ LIGO.2.01.6.1.5.3.8.2 AP1 Focus Lens											
		139	67	03AUG01A	22FEB02	6		03AUG01A	28JAN03	232	16
+ LIGO.2.01.6.1.5.3.8.3 AP1 Optical Train Assy.											
		510	388	01JUN01A	11JUN03	4		01JUN01A	28JAN03	-95	-136
+ LIGO.2.01.6.1.5.3.9 OMC Reflected Beam											
		268	268	27MAY02	19JUN03	0		09OCT02	28JAN03	-101	-136
+ LIGO.2.01.6.1.5.3.A ETMx Transmission Monitor											
		286	286	01MAY02	19JUN03	0		04NOV02	28JAN03	-101	-136
+ LIGO.2.01.6.1.5.3.B ETMy Transmission Monitor											
		55	55	01MAY02	18JUL02	0		04NOV02	28JAN03	130	0
LIGO.2.01.6.1.5.3.C AP2 Output Beam											
+ LIGO.2.01.6.1.5.3.C.1 Mode Matching Telescope, OMC											
		91	91	12JUL02	18NOV02	0		13SEP02	28JAN03	44	0
+ LIGO.2.01.6.1.5.3.C.2 Beam Steering, OMC											
		185	185	24SEP02	19JUN03	0		04NOV02	28JAN03	-101	-105
+ LIGO.2.01.6.1.5.3.C.3 Output Mode Cleaner											
		195	195	26AUG02	05JUN03	0		30AUG02	28JAN03	-91	-105
+ LIGO.2.01.6.1.5.3.C.4 AP2 Optical Train Assy.											
		90	90	05JUL02	08NOV02	0		16SEP02	28JAN03	50	0
+ LIGO.2.01.6.1.5.4 View Ports											
		390	390	14NOV01	05JUN03	0		07OCT02	28JAN03	-91	-136
LIGO.2.01.6.1.6 Suspended Optics											
LIGO.2.01.6.1.6.1 COC											
+ LIGO.2.01.6.1.6.1.1 Substrates											
		227	0	25AUG00A	20JUL01A	100		25AUG00A	20JUL01A		-53
+ LIGO.2.01.6.1.6.1.2 Polishing											
		644	368	08SEP00A	02APR03	10		08SEP00A	02APR03	0	-136
+ LIGO.2.01.6.1.6.1.3 Coating											
		290	260	30AUG01A	23OCT02	0		30AUG01A	23OCT02	0	-136
+ LIGO.2.01.6.1.6.1.4 Metrology											
		100	100	02JUL02	20NOV02	0		03JUN02	20NOV02	0	-136



Start Date	01DEC99
Finish Date	02SEP04
Data Date	12OCT01
Run Date	16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

L043 - 40MU

Sheet 2 of 4

LIGO II

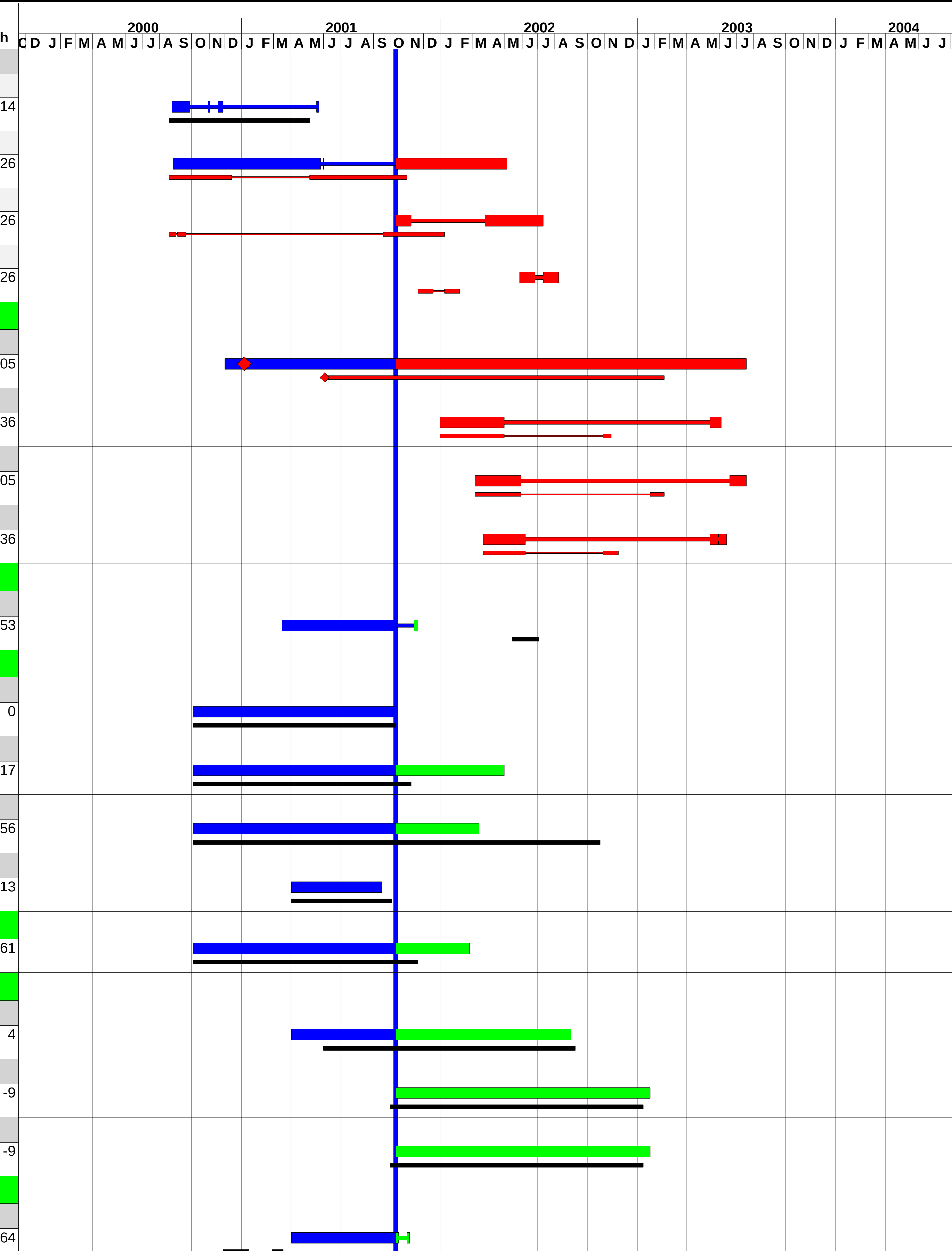
40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

LIGO

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp		Late Start	Late Finish	Total Float	Variance Early Finish
LIGO.2.01.6.1.6.2 IO											
+ LIGO.2.01.6.1.6.2.1 Substrates											
		189	0	24AUG00A	24MAY01A	100		24AUG00A	24MAY01A		-14
+ LIGO.2.01.6.1.6.2.2 Polishing											
		424	140	28AUG00A	03MAY02	30		28AUG00A	03MAY02	0	-126
+ LIGO.2.01.6.1.6.2.3 Coating											
		185	185	12OCT01	09JUL02	0		08APR02	09JUL02	0	-126
+ LIGO.2.01.6.1.6.2.4 Metrology											
		50	50	27MAY02	06AUG02	0		10JUL02	06AUG02	0	-126
LIGO.2.01.6.1.7 AOS											
+ LIGO.2.01.6.1.7.1 Design											
		661	443	01DEC00A	18JUL03	34		01DEC00A	25FEB03	-101	-105
+ LIGO.2.01.6.1.7.2 Stray Light Control											
		357	357	02JAN02	02JUN03	0		06SEP02	28JAN03	-88	-136
+ LIGO.2.01.6.1.7.3 Initial Alignment System											
		345	345	07MAR02	18JUL03	0		07OCT02	25FEB03	-101	-105
+ LIGO.2.01.6.1.7.4 Optical Lever System											
		309	309	22MAR02	12JUN03	0		07OCT02	28JAN03	-96	-136
LIGO.2.01.6.1.8 ISC											
+ LIGO.2.01.6.1.8.1 ISC Design											
		177	6	15MAR01A	21NOV01	83		15MAR01A	10SEP02	200	153
LIGO.2.01.6.1.9 DAQ											
+ LIGO.2.01.6.1.9.1 Control & Networking											
		260	0	02OCT00A		100		02OCT00A			0
+ LIGO.2.01.6.1.9.2 Diagnostics - GDS											
		397	137	02OCT00A	30APR02	51		02OCT00A	02JUL03	295	-117
+ LIGO.2.01.6.1.9.3 DAQ											
		364	104	02OCT00A	14MAR02	82		02OCT00A	02JUL03	328	156
+ LIGO.2.01.6.1.9.4 PEM											
		130	0	02APR01A	14SEP01A	100		02APR01A	14SEP01A		13
+ LIGO.2.01.6.1.B PEM											
		351	91	02OCT00A	25FEB02	69		02OCT00A	02JUL03	341	-61
LIGO.2.01.6.1.C CDS											
+ LIGO.2.01.6.1.C.1 SUS Controls											
		359	223	02APR01A	30AUG02	32		02APR01A	04FEB03	104	4
+ LIGO.2.01.6.1.C.2 Length Sensing and Control											
		320	320	12OCT01	24JAN03	0		13NOV01	25FEB03	22	-9
+ LIGO.2.01.6.1.C.3 Alignment Sensing and Control											
		320	320	12OCT01	24JAN03	0		13NOV01	25FEB03	22	-9
LIGO.2.01.6.1.D Experiments											
+ LIGO.2.01.6.1.D.0 Vacuum Controls Sys.											
		154	18	02APR01A	06NOV01	89		02APR01A	29APR03	369	-164



Start Date	01DEC99
Finish Date	02SEP04
Data Date	12OCT01
Run Date	16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

L043 - 40MU

Sheet 3 of 4

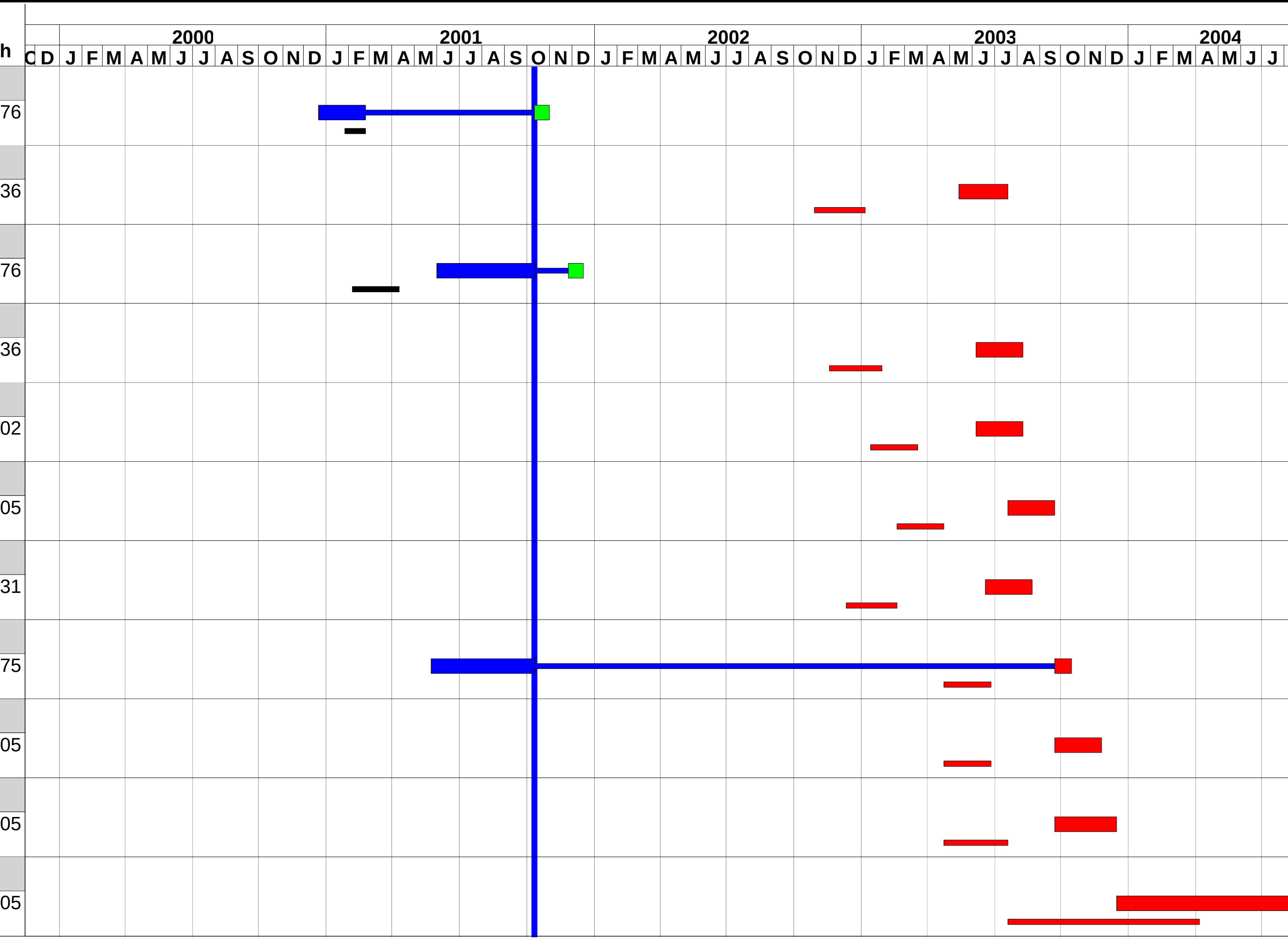
LIGO II

40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	% Comp		Late Start	Late Finish	Total Float	Variance Early Finish
+ LIGO.2.01.6.1.D.1 SEI											
		218	15	22DEC00A	01NOV01	50		22DEC00A	24APR03	369	-176
+ LIGO.2.01.6.1.D.2 SUS											
		45	45	15MAY03	18JUL03	0		05FEB03	29APR03	-56	-136
+ LIGO.2.01.6.1.D.3 PSL											
		139	14	01JUN01A	17DEC01	69		01JUN01A	29APR03	341	-176
+ LIGO.2.01.6.1.D.4 COC											
		45	45	06JUN03	08AUG03	0		26FEB03	29APR03	-71	-136
+ LIGO.2.01.6.1.D.5 IO											
		45	45	06JUN03	08AUG03	0		26FEB03	29APR03	-71	-102
+ LIGO.2.01.6.1.D.6 AOS											
		45	45	21JUL03	22SEP03	0		26FEB03	29APR03	-101	-105
+ LIGO.2.01.6.1.D.7 ISC											
		45	45	20JUN03	22AUG03	0		26FEB03	29APR03	-81	-131
+ LIGO.2.01.6.1.D.8 DAQ											
		601	15	24MAY01A	13OCT03	67		24MAY01A	24JUL03	-56	-75
+ LIGO.2.01.6.1.D.9 LDAS											
		45	45	23SEP03	25NOV03	0		21MAY03	24JUL03	-86	-105
+ LIGO.2.01.6.1.D.A Dual Re-cycled											
		60	60	23SEP03	16DEC03	0		30APR03	24JUL03	-101	-105
+ LIGO.2.01.6.1.D.B IFO Experiments											
		180	180	17DEC03	02SEP04	0		25JUL03	12APR04	-101	-105



Start Date	01DEC99
Finish Date	02SEP04
Data Date	12OCT01
Run Date	16OCT01 19:23

Early Bar
Baseline Bar
Progress Bar
Critical Activity

L043 - 40MU

Sheet 4 of 4

LIGO II

40 Meter Upgrade

Summary Schedule Layout - 40-Meter (AW)

Date	Revision	Checked	Approved

LIGO