ISC Initial Alignment Subsystem (IAS)

Final Design Review

P. Fritschel

K. Mason

M. McInnes

M. Zucker

April 30, 1998

FDR Outline

- Introduction & committee charge (DHS)
- IAS Scope & Interfaces (MZ)
- SUS Installation Alignment Support (KM)
  - Requirements
  - Tools & instruments
  - Monuments and chain of reference
  - Procedure (sample)
  - Error budget
- Chamber Video & Illuminators (MZ)
  - Requirements; resolution, sensitivity
  - Camera, illuminator, viewports
  - Mount designs

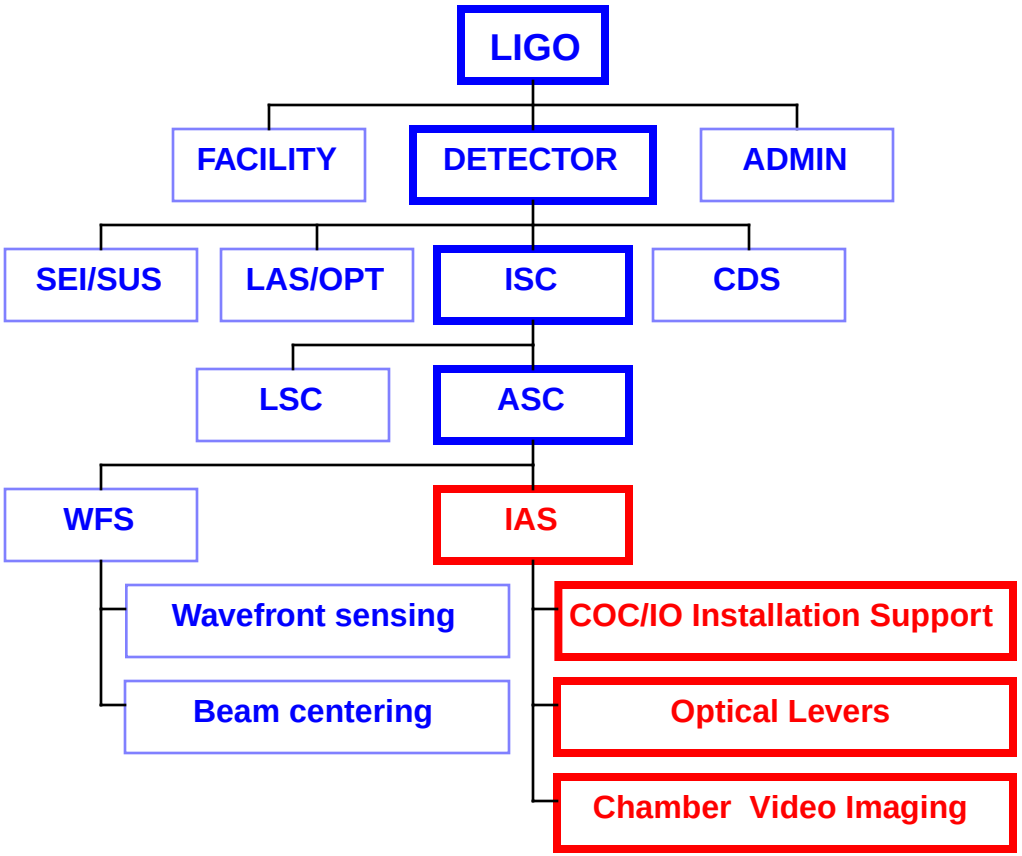
Outline (cont'd.)

- Optical Levers (KM)
  - ❑ Requirements
  - ❑ Laser, beam expander, movable mirror
  - ❑ Kinematic interface design
  - ❑ Support column design
  - ❑ Prototype test performance data & analysis
- Implementation (MZ)
  - ❑ Staffing
  - ❑ Fabrication schedule
  - ❑ Cost
- Discussion & action items (DHS)

IAS Scope

- Installation alignment support
  - ❑ Monuments & sight apertures to establish angular relation to BT axes, axial and transverse positions
  - ❑ Optical tooling & procedures for transfer to suspended optics at installation (all COC plus MMT3)
- Optical levers
  - ❑ lab-frame long term monitoring of suspended optic angle
  - ❑ diagnostic/temporary closed-loop angle control (if req'd).
- Chamber video imaging & internal illuminators
  - ❑ All "active" IO and COC chambers (1 illuminator, 1 camera per)

IAS Detector/ISC Context



Principal IAS Interfaces

- Vacuum equipment
  - viewports: all standard 10” OD CF (+ one lonely 4.5” OD CF)
  - port nozzle positions: potentially critical for optical lever beam clearances
  - manifold endcap stayclear (headers, conduit, water/air lines, cable trays, ...)
  - removable spools & SW cleanrooms (for installation alignment)
- BT, BTE and Civil Construction
  - alignment monuments
  - sight apertures through station walls
- SEI
  - BSC support pier optical lever mount brackets
- SUS
  - retroreflector prism mount on LOS cages

IAS Interfaces (cont'd)

- COC
  - ❑ Substrate dimensions and wedge angles
  - ❑ Nominal position and surface normal orientation
  - ❑ Coating reflectances (at various wavelength & incidence angles)
    - autocollimator range (normal incidence, 'front surface')
    - optical lever beam reflectance (various angles, 'front' or 'AR' surface)
- COS
  - ❑ Baffle perforations for video, illuminator, optical lever beam access
  - ❑ Manifold Brewster baffle orientation for IAS camera beam finding
- IOO
  - ❑ MMT3 ~ as for COC
  - ❑ MC and steering mirrors aligned in local chamber coordinates, net output beam aligned using MMTx and in-vac steering mirrors

IAS Interfaces (cont'd)

- Personnel Safety
  - ❑ Optical lever lasers are all Class IIIb, but:
  - ❑ IAS treats ALL NOZZLES on vacuum envelope as Class IV laser apertures, due to remote (negligible?) possibility of IR beam egress
  - ❑ All viewport penetrations fully enclosed by opaque shields
  - ❑ Shields only removable with tools (no latches or thumbscrews)
  - ❑ LASER GOGGLES STILL REQUIRED in VEA/LVEA to qualify as 'redundant means' (unless Nd:YAG power is locked/tagged out)
  - ❑ Electrical interlocks not req'd (or practical)

SUS Installation Alignment Support

- Initial alignment requirements
  - ››Establish offset centerlines
    - –Allows alignment and alignment verification with beam tubes installed and pumped down
    - –Equipment and technology developed for paper mill industry
  - ››Alignment specifications
    - –pitch angular positioning to +/- .06 mrad
    - –yaw angular positioning to +/- .08 mrad
    - –transverse position to +/- 1 mm (ITM,ETM), +/- 5 mm (RM, BS,FM), +/- 3 mm (MMT3)
    - –axial position to +/- 3 mm

SUS Installation Alignment Support

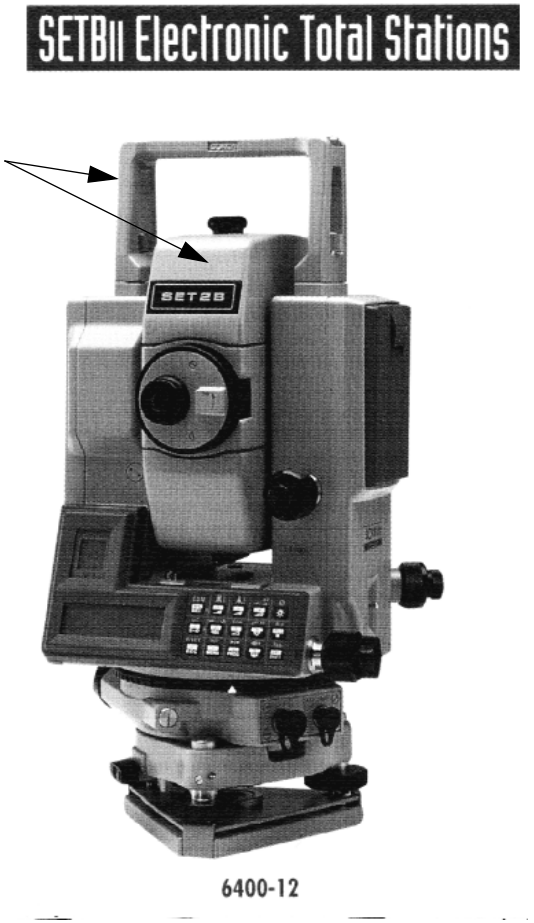
- Angular alignment requirement is 10% of the adjustment range of the suspended optic
- Aligned beam must fall within +/- 560mm tube clear aperture
- Optical Levers to detect any change in the aligned optic position

SUS Installation Alignment Support

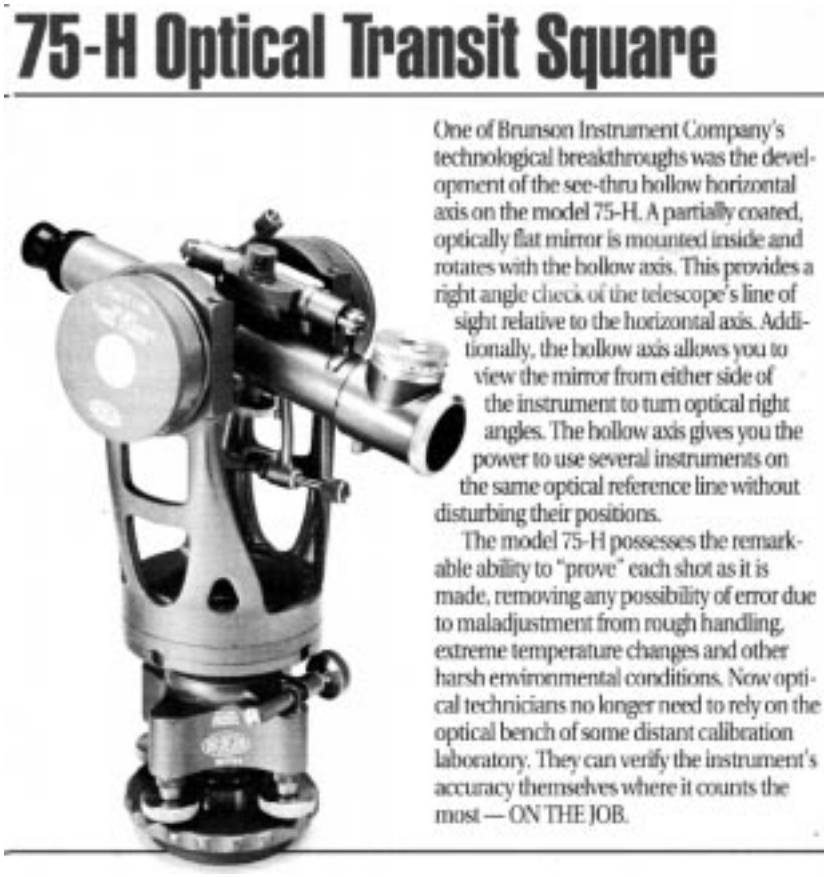
- Tools and instruments
  - ››Sokkia Total Station Theodolite Model SET2B with electronic distance measurement, autocollimating eyepiece, tripod, prism, and optical plummet
  - ››Brunson Model 75-H Optical Transit Square with autocollimating eyepiece, stand, coincidence level, and optical plummet
  - ››680 nm laser autocollimator mounted and aligned to theodolite
  - ››200 mm dia. optical flat, gimbal mount, and clamps
  - ››400 mm PLX Lateral Transfer Retroreflector with mount
  - ›› LOS Alignment Fixture per Ligo D980001-00-D
  - ››Plumb line with tripod and contrasting background
  - ››Sokkia Model AP11A prism system
  - ››Sokkia SDR33 electronic field book

ALIGNMENT INSTRUMENTS

Removed & replaced w/mtg. bracket (by LIGO) for laser autocollimator



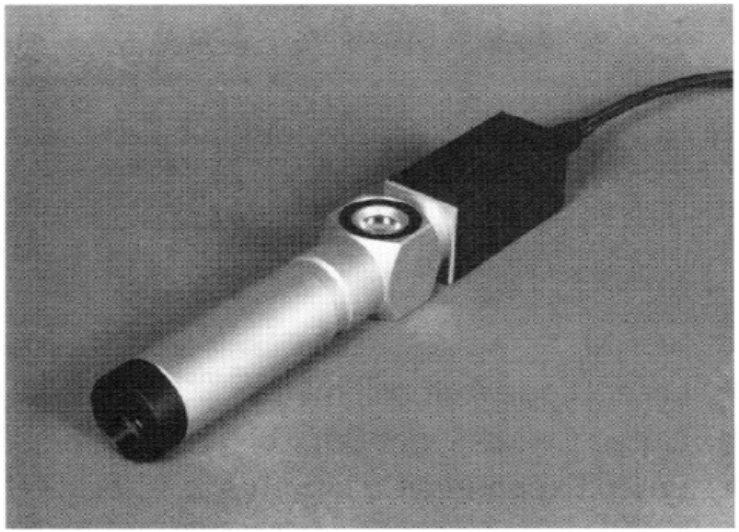
Sokkia



Brunson

LASER AUTOCOLLIMATOR

Laser Diode Autocollimator



LAE 500

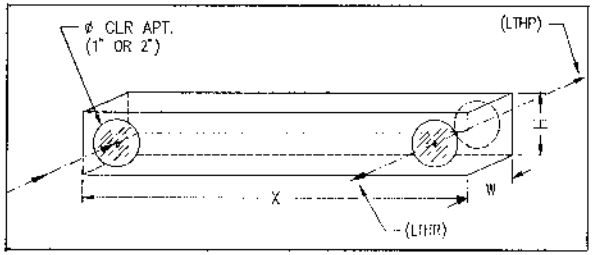
- 10X eyepiece makes coarse alignment fast and easy
- High-speed 2 kHz sampling rate captures fast angular movements
- IEEE-488 and RS-232 controller interface allow automated measurement and process control
- ±7 arcmin total angular range with 0.1 arcsec resolution

NEWPORT

LATERAL-TRANSFER RETROREFLECTORS

SPECIFICATIONS

Lateral Transfer Hollow Retroreflector (LTHR)
Lateral Transfer Hollow Periscope (LTHP)

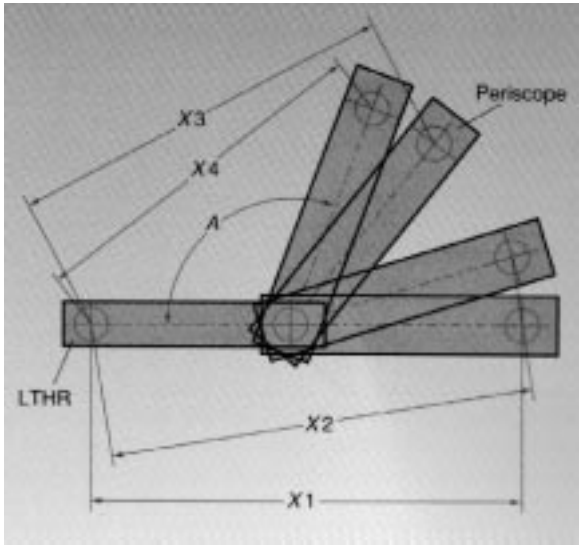


DIMENSIONS (IN./MM.)

CLEAR APERTURE	H	X	W
1.00/25.40	2.75/69.85	from 3.00/76.20 min to 30.00/762.00 max	2.75/69.85
2.00/50.80	4.00/101.60		4.50/114.30

PART NUMBERS (L=LTHR P=LTHP)				MIRROR SURFACE FLATNESS	EXITING BEAM MAX DEVIATION
1 inch Clear Aperture		2 inch Clear Aperture			
LTHR	LTHP	LTHR	LTHP		
L101	P101	L201	P201	λ/10	1.0
L102	P102	L202	P202	λ/10	2.0
L105	P105	L205	P205	λ/8	5.0
L110	P110	L210	P210	λ/4	10.0
L130	P130	L230	P230	λ/2	30.0

PLX CATALOG PAGE



EXCERPT FROM
PLX APPLICATION NOTE
(ADJUSTABLE-LENGTH
RETROREFLECTOR
IMPLEMENTATION)

SUS INSTALLATION ALIGNMENT SUPPORT

- Monuments and chain of reference
  - IAS Monuments currently being installed per LIGO D970210-00-D sheets 1thru 5 by Rogers Surveying in the LVEA corner, mid, and end stations.
  - Monument coordinates are in the LIGO Global Coordinate System
  - Compensations in theodolite level must be made for arms relative to local tangent and Earth curvature
    - -0’.57” corner station y-axis
    - +1’4” mid and end stations y-axis
    - -2’9.75” corner station x-axis
    - -1’6” mid and end stations x-axis

RESULTS IMTEC FINAL REPORT LIGO C962208-00

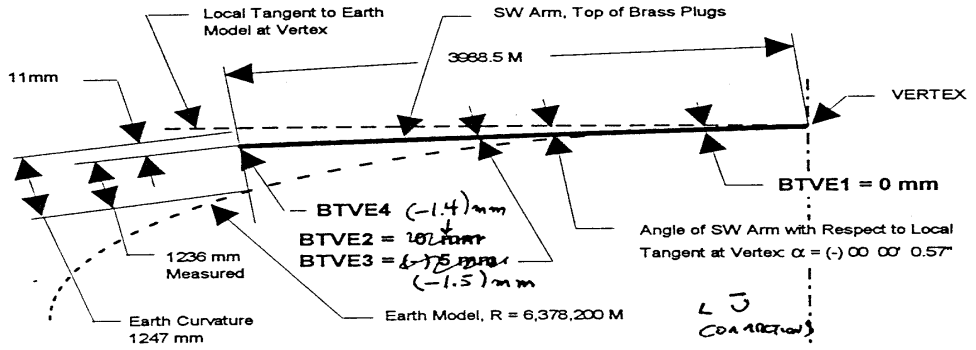


FIGURE B-LIGO 1 - SOUTHWEST ARM

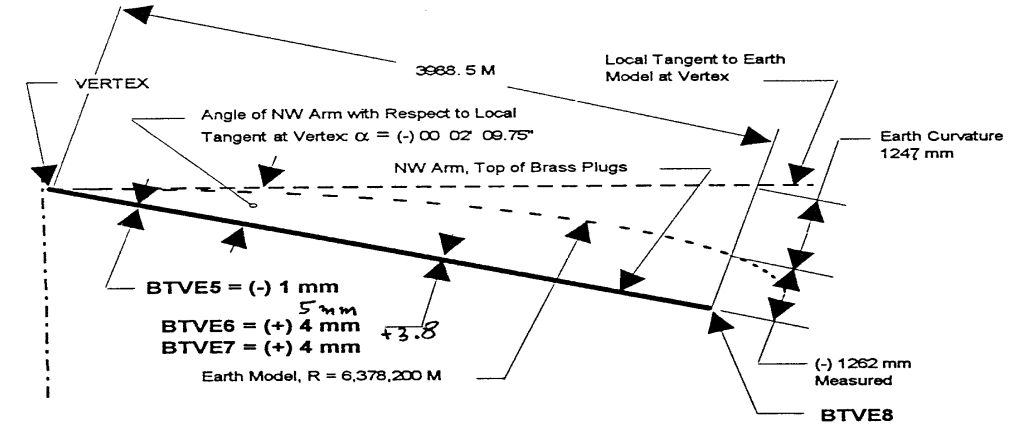


FIGURE C-LIGO 1 - NORTHWEST ARM

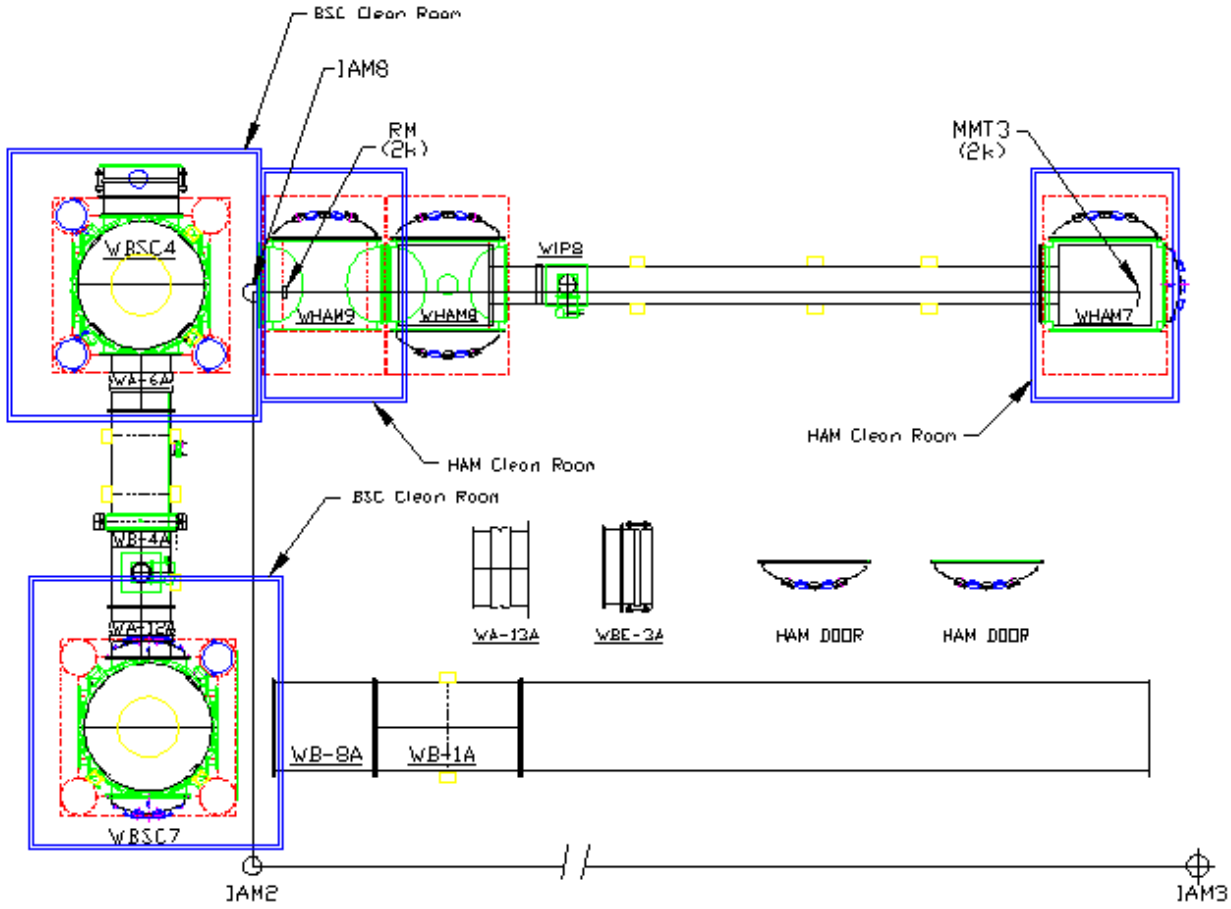
SUS Installation Alignment Support

- Procedure (2k MMT3 and RM)
  - ››BSC clean rooms placed over BSC4 and BSC7
  - ››HAM clean rooms placed over WHAM7 and WHAM9
  - ››Adapters WBE-3A and WA-13B removed for access with alignment equipment
  - ››Doors on WHAM7 and WHAM9 removed for loading of LOS assemblies
  - ››Offset centerline established between IAM2 and IAM3 at a height of 12 mm above beam tube centerline with transit square and plumb line.
  - ››Theodolite is set up over IAM8 with optical plummet and facing the transit square.
  - ››Theodolite is autocollimated to the optic within the transit square
  - ››The theodolite is rotated to setup angles for MMT3

SUS Installation Alignment Support

- Vertical and transverse settings are established by sighting on center of prism or fiducial on alignment fixture
- Axial position is set using EDM feature on theodolite and prism
- Angular positions are set using the laser autocollimator with coarse adjustments made with fixture adjustments(<.05mrad). The LOS is clamped in place and fine adjustments are made with the permanant magnets(<5 microrad)
- Optical lever is positioned and centered on the photodiode with the beam reflecting off the back surface of MMT3
- Same procedure used to align the 2k Recycling mirror
- The doors and adapters are replaced and clean rooms removed

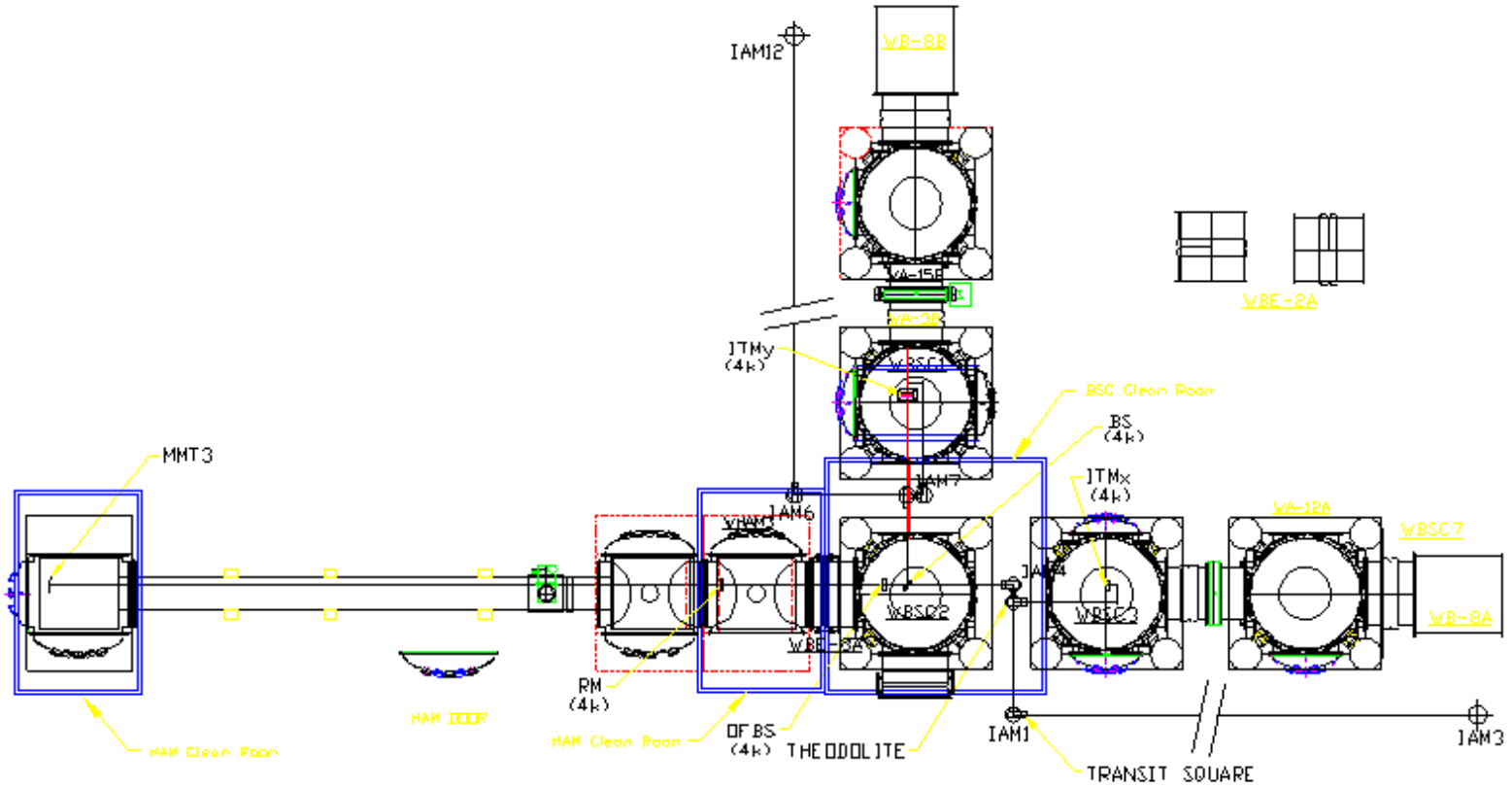
2K MMT3 AND RM ALIGNMENT



SUS Installation Alignment Support

- Special Cases: BS, ITM, ETM
- BS and FM are positioned at 45 degrees
  - ››An optical flat will be aligned in the beam path by autocollimation. The beamsplitter is then aligned by autocollimation using the back reflection from the optical flat
- A direct line of sight cannot be made to the HR surfaces of several of the ITM's and ETM's
  - ››The theodolite will be set 400 mm to the side of the optic and the PLX retroreflector will be used to transfer a parallel line to the face of the optic

4K CORNER STATION ALIGNMENT



SUS INSTALLATION ALIGNMENT SUPPORT

- Error budget - yaw

Table 1:

Positioning of monuments	.03 mrad (6 arc seconds)
Sighting of plunb markers	.02mrad (4 arc second)
90 degree autocollimation	.01 mrad (2 arc seconds)
90 degree rotation	.01 mrad (2 arc seconds)
Autocollimation of optic	.01 mrad (2 arc second)
Total	*.08 mrad (16 arc seconds)*

- Error budget - pitch

Table 2:

Positioning of monuments	.03 mrad (6 arc seconds)
Leveling of theodolites	.01mrad (2 arc second)
Angular rotation	.01 mrad (2 arc seconds)
Autocollimation of optic	.01 mrad (2 arc second)
Total	*.06 mrad (12 arc seconds)*

Chamber Video/Illuminator

- Goal: Image optic surfaces and/or chamber walls to
  - determine beam centroid location w.r.t. COC or IO optic edge bevel
  - verify resonant eigenmode shape
  - locate scattering from walls & baffles during initial startup alignment
- Spatial resolution
  - sufficient to resolve beam centering tolerance (1 mm for ETM, ITM)
  - for full 25 cm dia. optic FOV, R > (250 lines)*($N^{-1/2}$) for N pixels in “feature”
  - (trivial for standard CCD resolutions ~ 400 lines)
- Sensitivity
  - Sufficient to register scattered light from clean, superpolished optic
  - (maybe not so trivial)
- Illuminator
  - highlight reference “landmarks” like edge bevel; not too critical

Estimate of required video sensitivity

'effective scene illumination' L_{eff} at spot center (Lux)

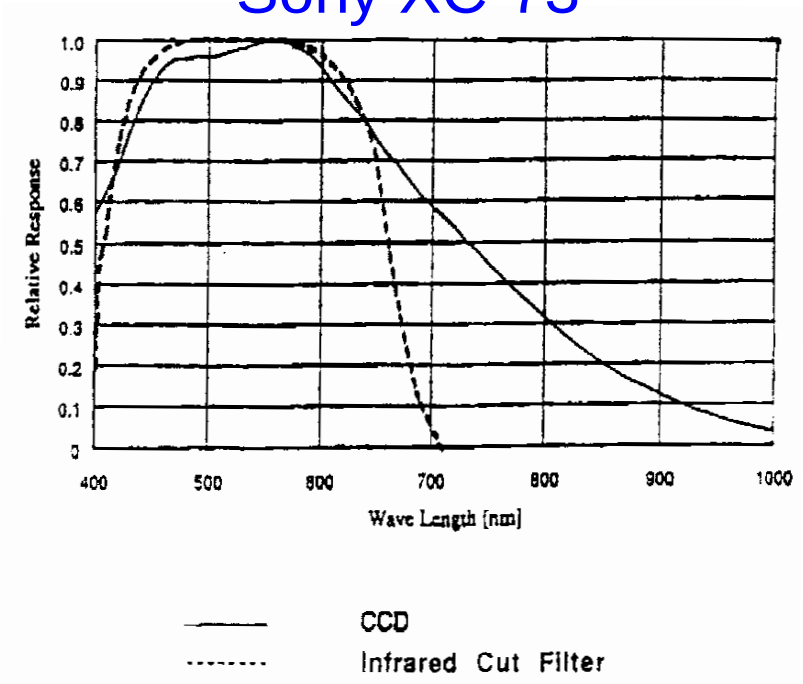
$$L_{eff} \approx \frac{BRDF(\theta)\cdot 4P_c}{w_0^2}\cdot\left(\frac{R_{1064\ nm}}{R_{555\ nm}}\right)\cdot 683\frac{lm}{W}\bigg|_{555\ nm}$$

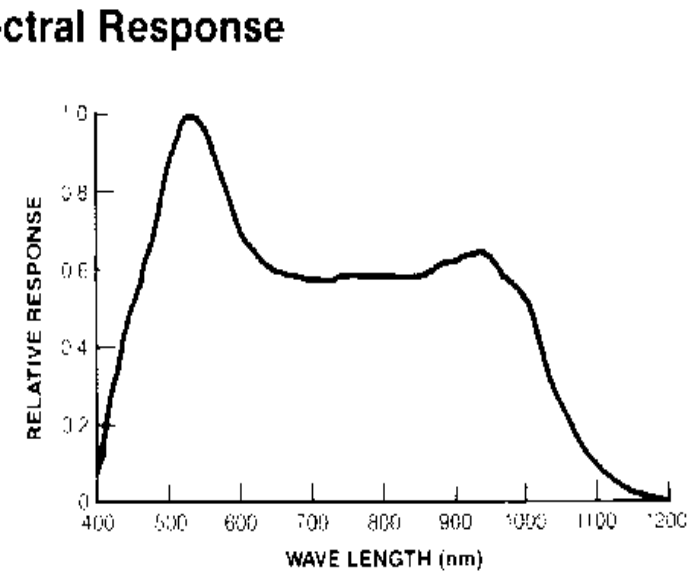
$$\approx 1\ \text{Lux}\cdot\left(\frac{P_c}{300\ \text{W}}\right)\cdot\left(\frac{36\text{mm}}{w_0}\right)^2\cdot\left(\frac{BRDF(\theta)}{10^{-8}\text{sr}^{-1}}\right)\cdot\left(\frac{R_{1064\ nm}}{R_{555\ nm}}/0.2\right)$$

Optic	P_c (W)	$P_c/(2\pi w_0^2)$ (W/m^2)
ITM, ETM	15,000	2M
RM, BS	300	37k
MMT3	6	0.7k
MC1-3	6,000	600M

CCD spectral responsivity curves

Sony XC-73





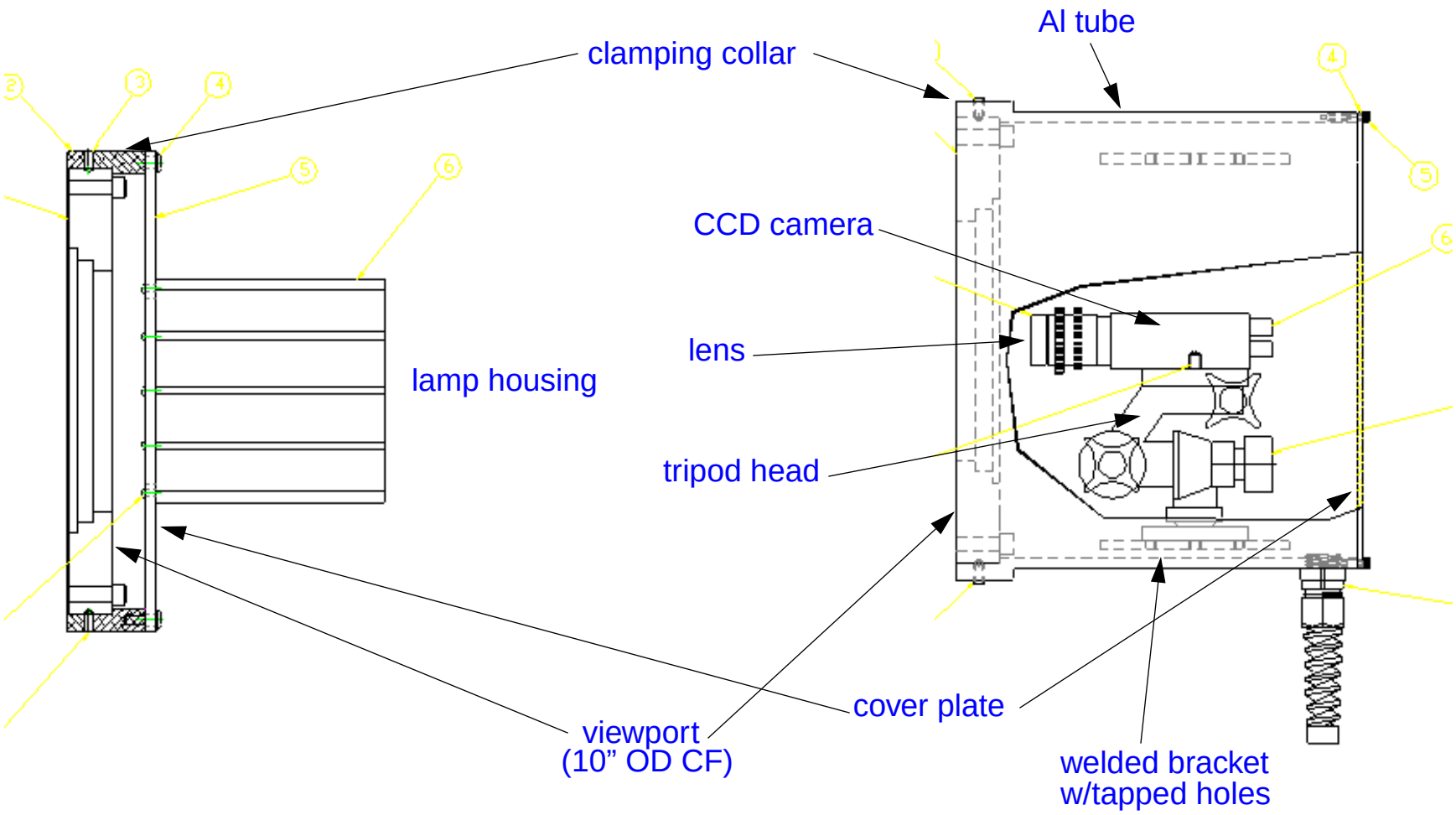
Pulnix TM540

mfg. spec	Sony XC-73	Pulnix TM 540
'min. illum.' (lux @ f/1.4)	3	2
$R_{1064nm}/R_{555\ nm}$	.03	.2
SNR	53 dB	50 dB

CCD tests & selection

- Tested XC-73 and TM540 using f/1.2 lens on bench
  - ❑ played NPRO spot (500 mW, w_0 ~ 1.5 mm => peak irradiance ~ 40 kW/m^2) on surplus PNI mirror (REO superpolished HR at 1064nm, 'clean'...?)
  - ❑ Near normal incidence, both cameras picked up scatter from spot
  - ❑ At 45^o incidence (more typ. for installation) only Pulnix showed beam (~ factor of 5 above threshold)
  - ❑ Suspect BRDF is very small at 45^o (MIT meas. upper limit is < 10^{-5} sr^{-1}, literature indicates ~ 10^{-8} -10^{-7} sr^{-1} plausible)
- => use XC-73 for ITM, ETM and MC imaging; TM540 for BS, RM; TBD (intensifier, surveillance camera) for MMT3
- Additional tests planned on PNI next week (~ 3 MW/m^2)

Camera/Illuminator mounting

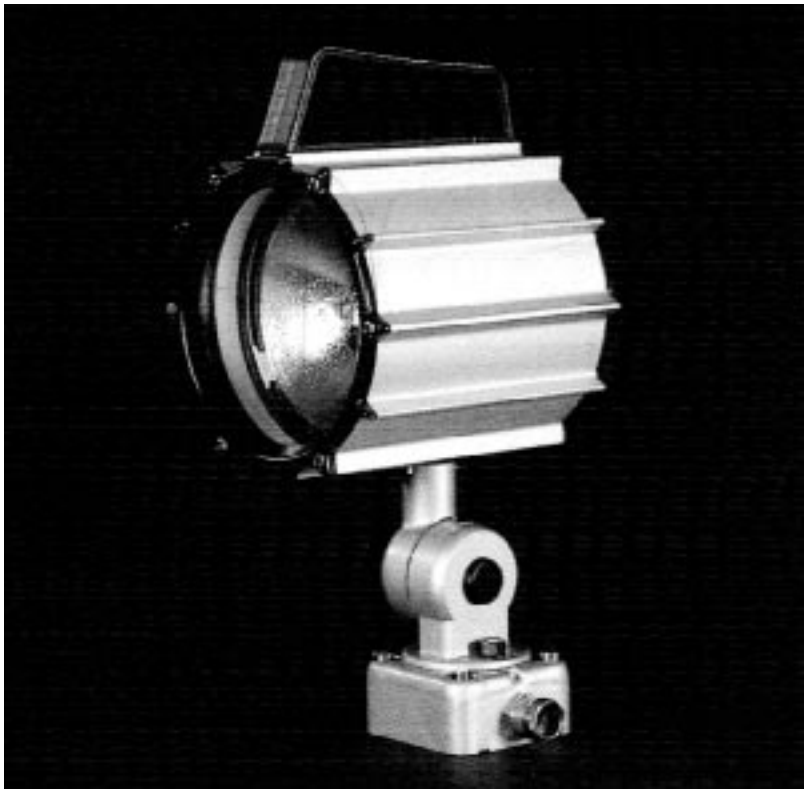


Chamber video camera selections

Sony XC-73
44w x 29h x 71l (mm, w/o lens)

Pulnix TM-540
42w x 32h x 120l (mm, w/o lens)

Chamber illuminator lamp



Waldman HGKW-70-24V
70 W 24 V halogen floodlamp
sealed extruded aluminum housing
(bezel, handle & mount deleted)

Viewports

- Video
  - 1064 nm AR to minimize ghost beams
  - 5.38” clear aperture, 7056 glass
- Optical lever
  - 635 nm or 1064 nm AR (OK for 980 nm laser) to improve transmission, reduce ghost beams
  - 5.38” clear aperture 7056 glass most places
  - 7.75” clear aperture fused quartz in tight clearance spots
  - 2.5” aperture on 4.5” OD CF for one place (WBSC8)
- Illuminator
  - Uncoated
  - 5.38” clear aperture, 7056 glass
- ~ 1/3 of viewports currently on order (ISI/MDC)

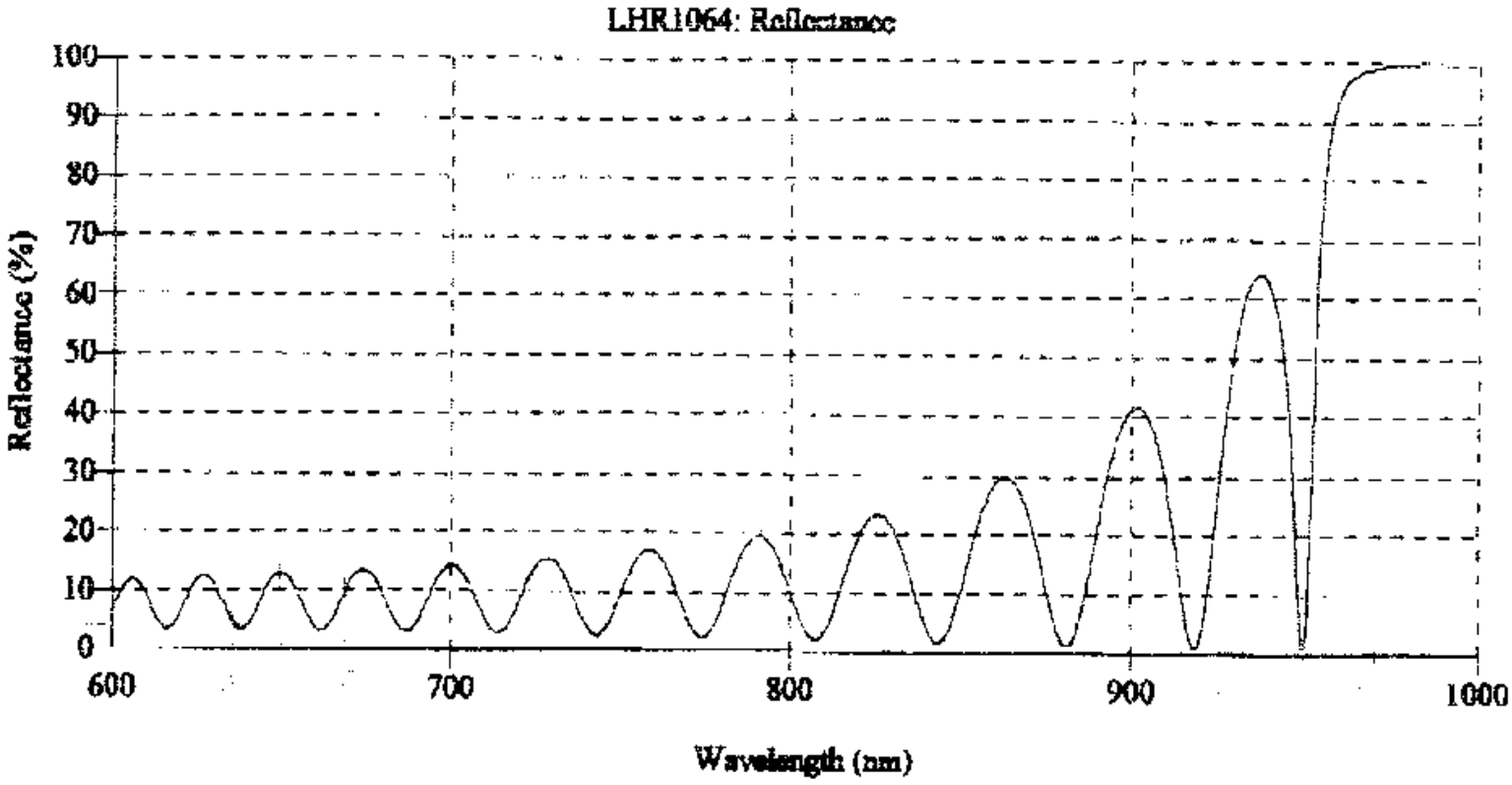
OPTICAL LEVERS

- Optical lever requirements
  - ››Provides angular readout of pitch (about horizontal axis) and Yaw (about vertical axis) angles of prealigned optics
    - –Monitors optic position during pumpdown, seismic isolation stack drift, and strain relaxation in suspension componants
    - –Allows rapid replacement or adjustment of damaged or displaced optics
    - –Augments or provides temporary replacement to wavefront sensor based alignment error signals
  - ››Stability of optical levers over extended periods of time is within initial alignment error budgets of .08 mrad (yaw) and .06 mrad (pitch)
  - ››All optical levers provide a direct reflection of the optic with no internal steering mirrors or periscopeoptical levers

OPTICAL LEVERS (CONT'D.)

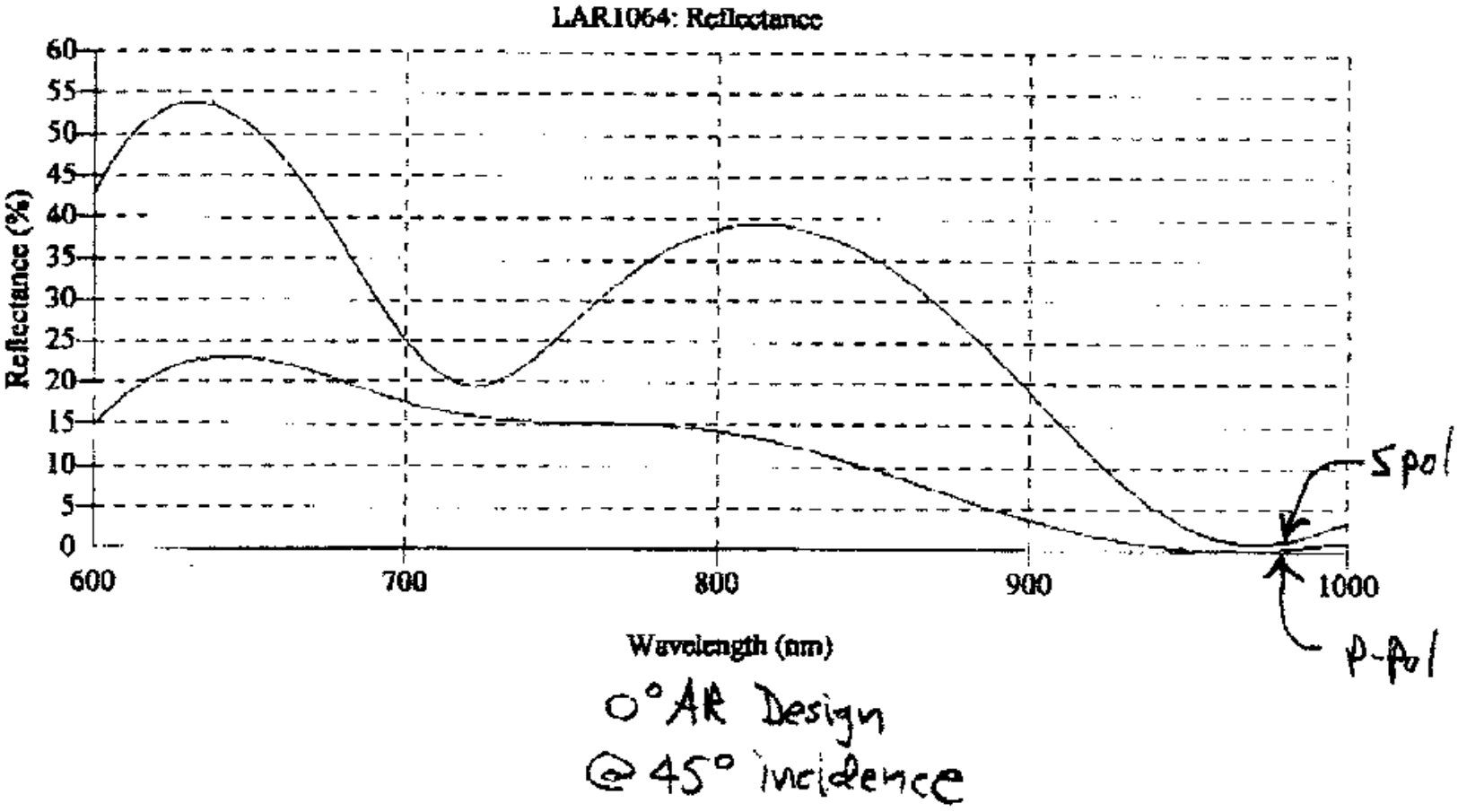
- Two wavelength options are used with the same laser package
  - ITM/ETM use 980 nm laser reflecting directly off the HR surface
  - All others use 635 nm laser reflecting off AR surface
  - Two wavelenght options are used with the same laser package
- Column support structure is mounted on kinematic base plates to be easily removable and repeatable

HR COATING REFLECTIVITY



0° HR Design
@ 0° incidence

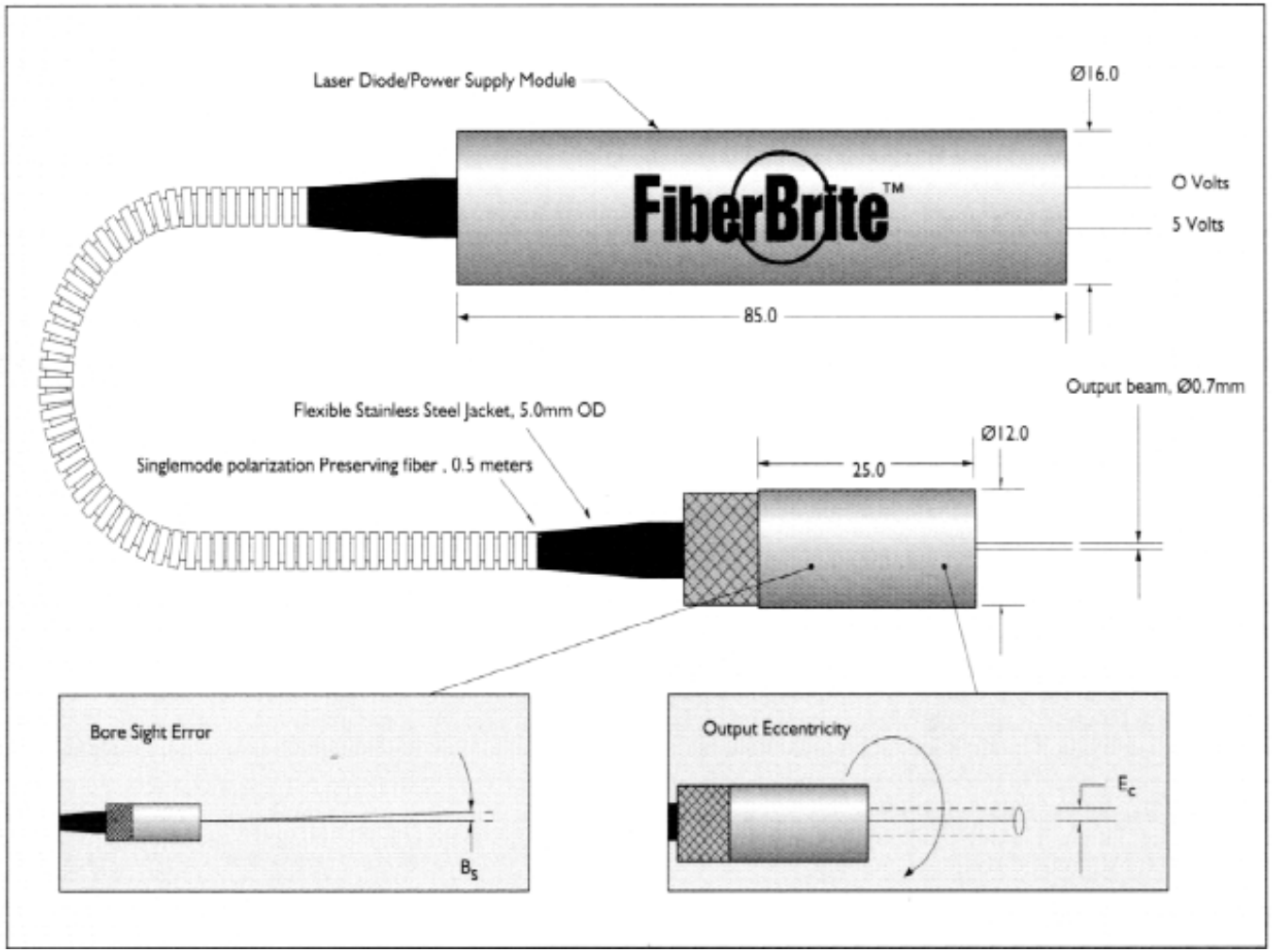
AR COATING REFLECTIVITY



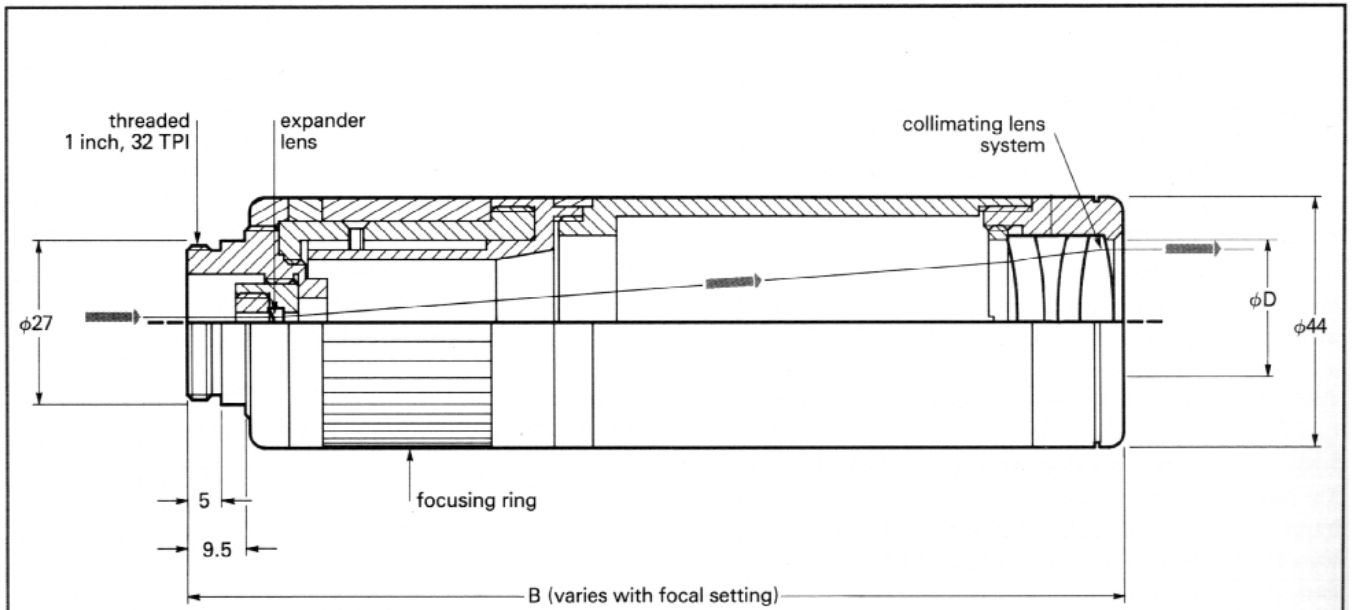
OPTICAL LEVERS

- Principal components
  - ››Blue Sky Research “Fiberbrite” FBC019-635 and FBC019-980 laser diode system
  - ››Melles Griot 10X and 30X beam expanders Model 09LBM013 (10X) and 09LBM107 (30X)
  - ››New Focus 8853 motorized mirrors with Picomotor drives
  - ››Centro Vision QD 100-0, 100mm^2 Si PIN quadrant diode

FIBER-COUPLED DIODE LASER



BEAM EXPANDER

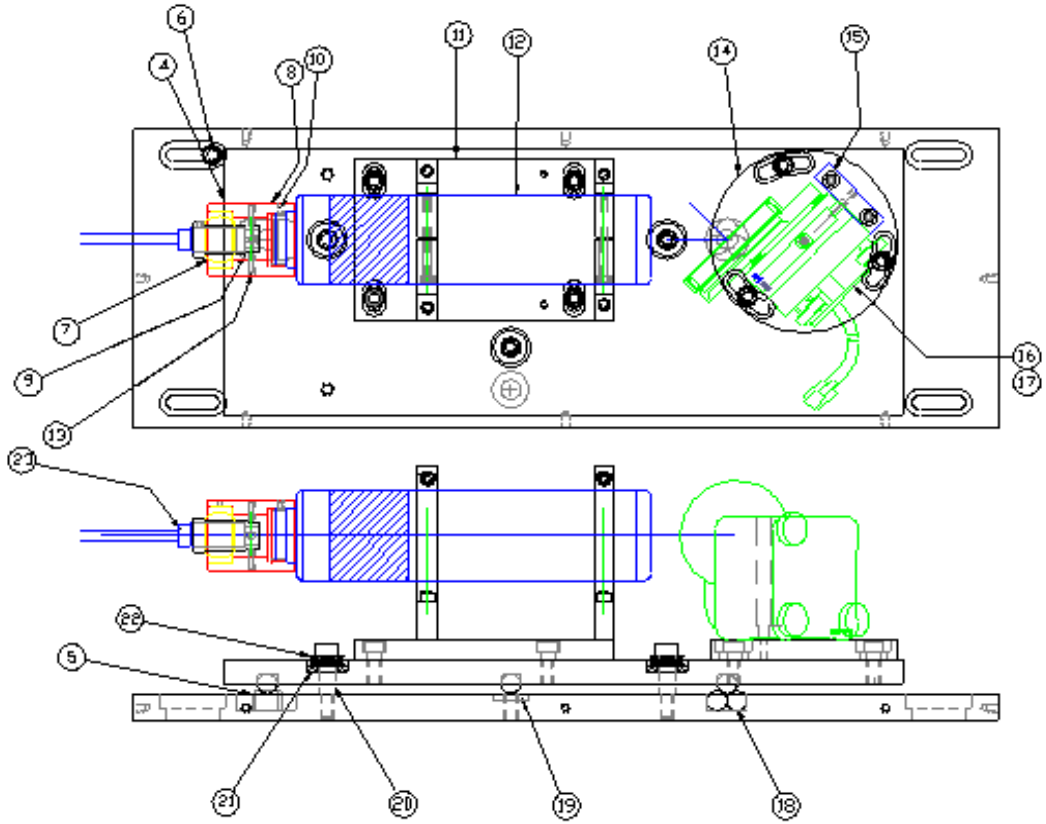


PRODUCT NUMBER	B min	B max	ϕD
09 LBM 011	75.0	82	10
09 LBM 013	92.0	99	10
09 LBM 015	117.5	124	20
09 LBM 017	162.5	169	30

OPTICAL LEVER

- Kinematic interface design
  - ››Provides stress free differential expansion along beam path
  - ››3 points provide ability to remove and place in same position
  - ››Shoulder screws guarantee equal loading on each contact
  - ››Belleville Washers provide high spring load (65#) in small area
  - ››Balls and flat made of SiC and WC
  - ››Brewe & Hamrock contact point deformation
    - – .00017” on single point contact (13 microrad)
    - –.0001” on 2 pt contact (15 microrad)
    - –.00008 on 3 pt contact (12 microrad)

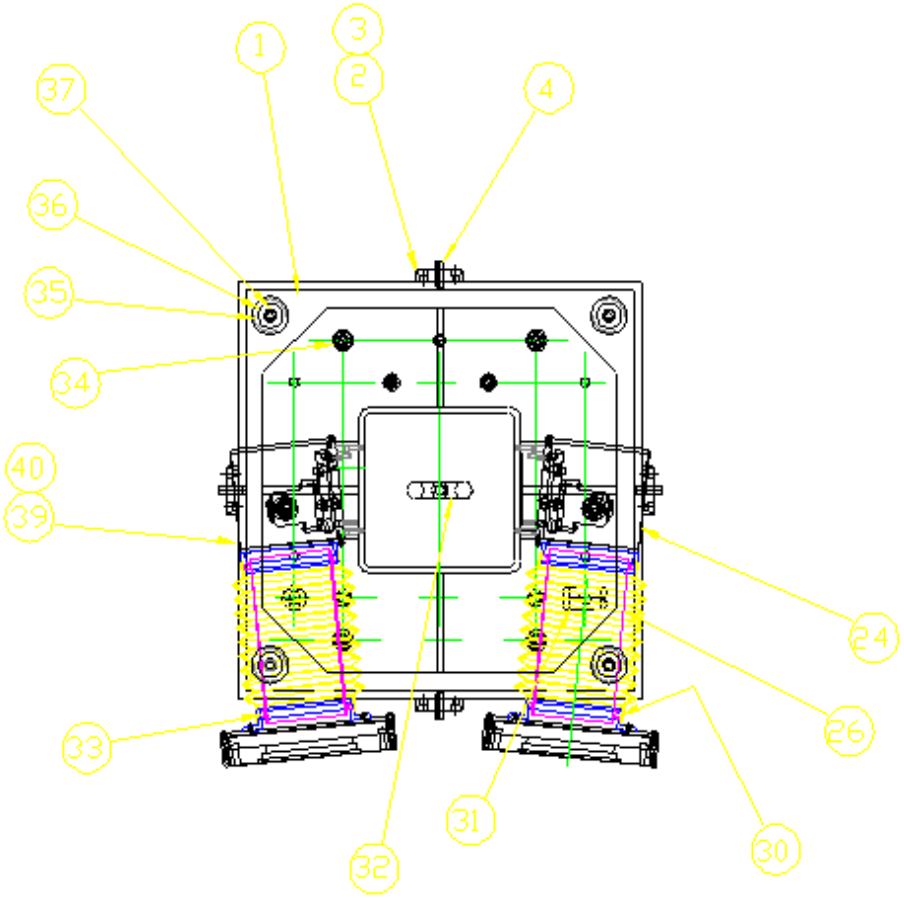
LASER SOURCE ASSEMBLY



OPTICAL LEVER

- Support column design
  - ››Kinematic mounted base for removal without losing alignment reference
  - ››10” x 10” gussetted square tube weldment, carbon steel
  - ››Resonant frequency - 338 hz
  - ››Fully enclosed laser, detector, and beam tube assemblies
  - ›› Several instances where laser and detector assemblies are mounted to SEI columns

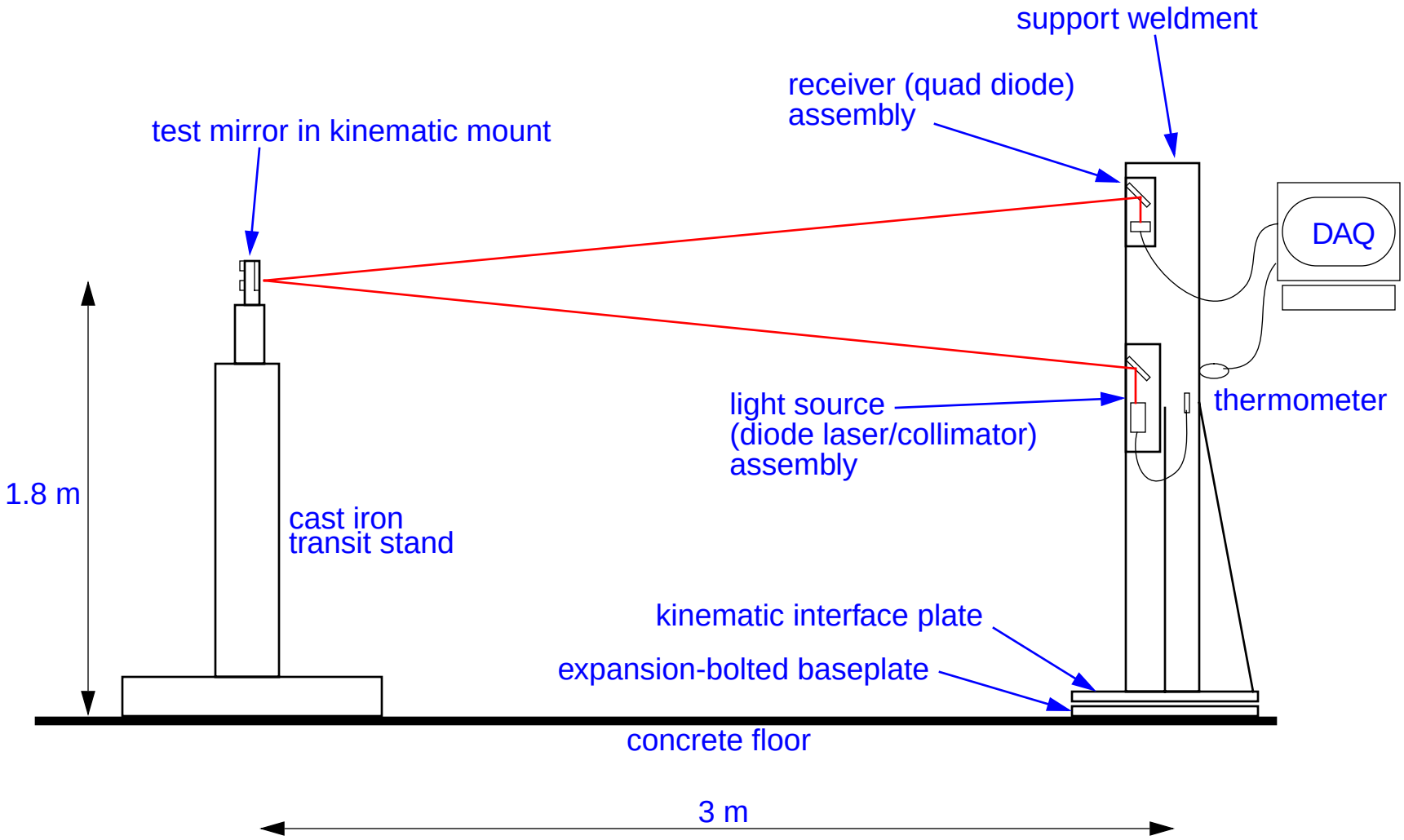
MMT3 Optical Lever Support Column (top view)



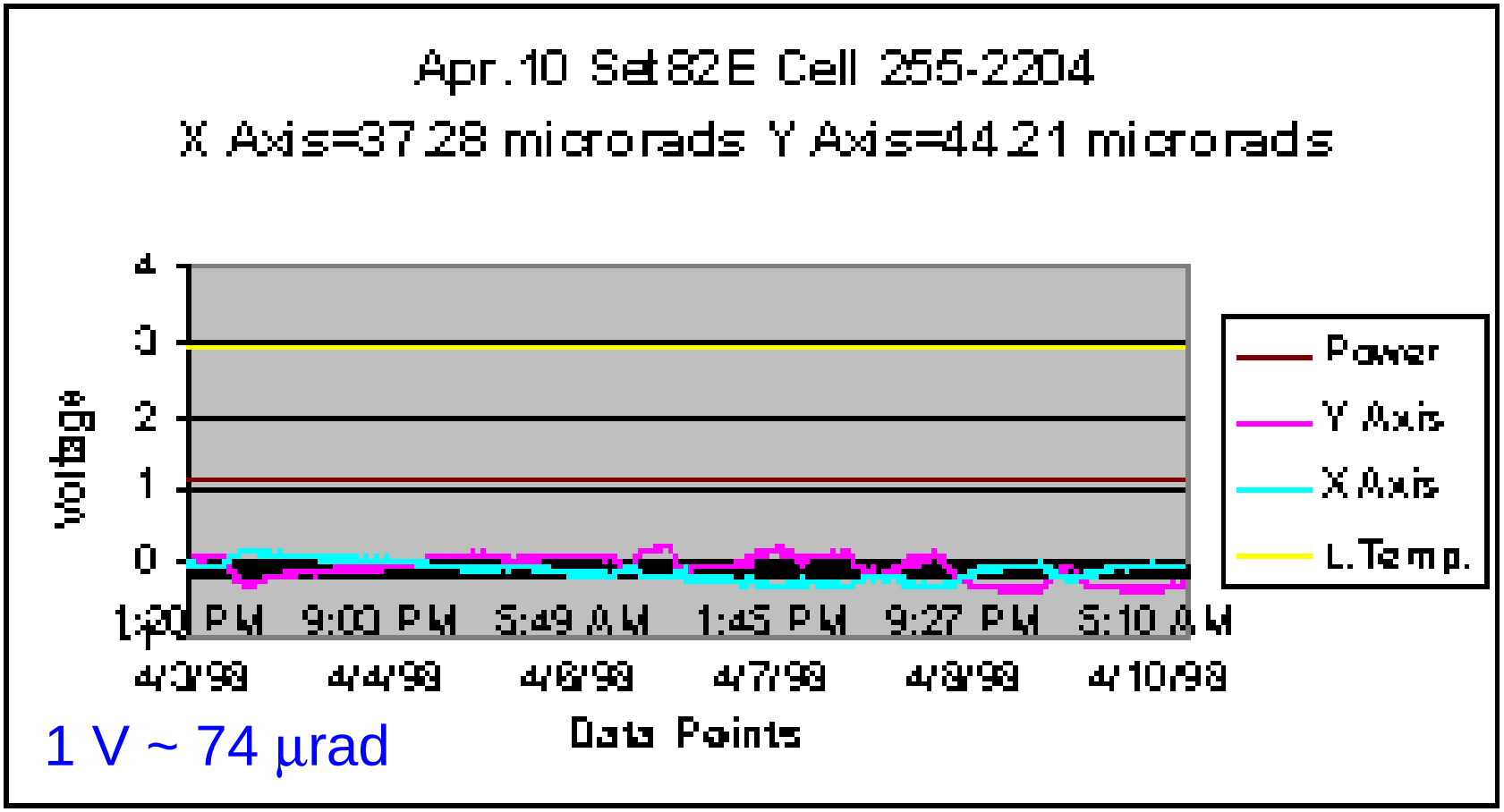
OPTICAL LEVER TEST

- Prototype test performance
  - ››Prototype based on obsolete design which was to cantilever between SEI column and the BSC chamber
  - ››Best long term stability with Klinger optical mount Model SL50
  - ››Plan is to retrofit with New Focus Picomotors
  - ›› Last calibrated March 3,1998
    - 13.6 mv/microradian (x)
    - 13.5 mv/microradian (y)
  - ››Test results are for 1 week period 4/3/98 thru 4/10/98
    - 37.28 microradians pk/pk (x)
    - 44.21 microradians pk/pk (y)

OPTICAL LEVER PROTOTYPE TEST CONFIGURATION



OPTICAL LEVER PROTOTYPE RESULTS



Staff

- Engineering
  - K. Mason, lead engineer
  - M. Smith (P/T), design & interface control
  - R. Burgess (P/T), EE support
- Procurement & manufacturing supervision
  - M. Smith (P/T)
  - M. McInnes
- Assembly/test
  - M. McInnes
  - E. Kruzel (P/T)
- Schedule/budget
  - M. Zucker

Schedule

- Top-level constraints
  - ❑ Viewport need dates paced by vacuum envelope release
  - ❑ Chamber Video need dates paced by SEI installation
  - ❑ Optical Lever and IAS survey need dates paced by core/IO optic availability (+ corresponding SEI, SUS, etc.)
  - ❑ MIT assembly work starts at occupancy of new lab (~ 6/22)
- 'Simultaneous' (interwoven) activity threads:
  - ❑ IAS fab/test (@MIT: optical lever Tx/Rx, camera & lamp mounts, autocollimator modifications & surveying accessories)
  - ❑ ASC/WFS and LSC fab/test (at MIT: IOT7, ISCT1-10)
  - ❑ IO/COC installation surveys (IAS)
  - ❑ Site installation (IAS)
  - ❑ Site installation (WFS/LSC)

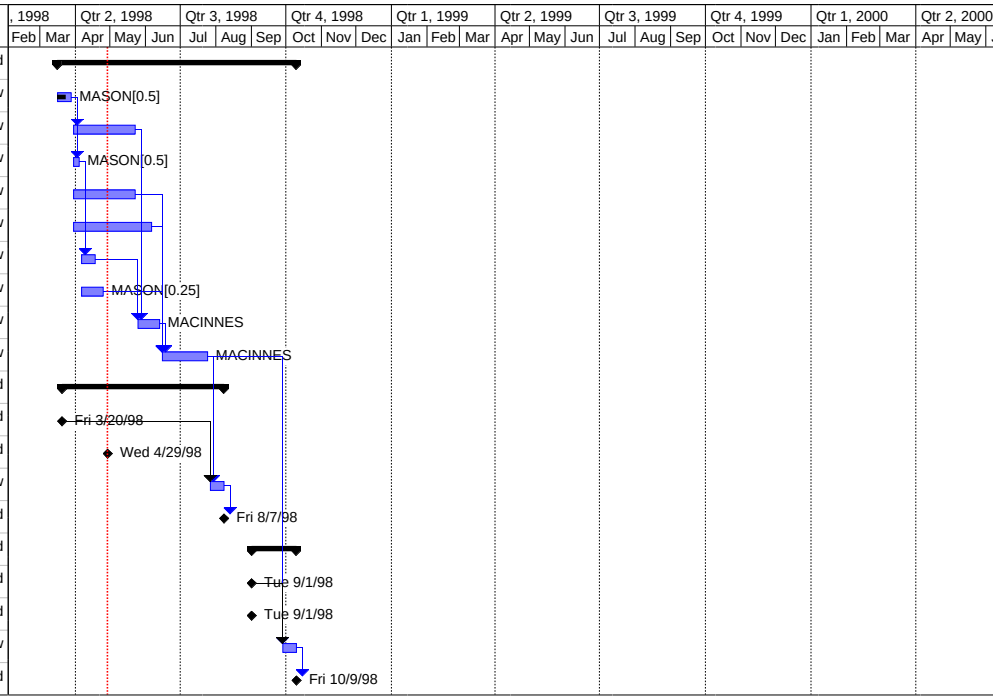
COC/IO installation support

MEZ Wed 4/29/98 12:34

ISC Fabrication and Delivery

Macintosh HD:Z Docs:Detector:ISC_FAB_MAF

ID	Task Name	Start	Finish	DUR
55	**IAS COC/IO Installation support**	Mon 3/16/98	Fri 10/9/98	150d
56	spec, RFQ, bid autocollimator	Mon 3/16/98	Fri 3/27/98	2w
57	procure autocollimator	Mon 3/30/98	Fri 5/22/98	8w
58	design theodolite mods	Mon 3/30/98	Fri 4/3/98	1w
59	procure ref. flat	Mon 3/30/98	Fri 5/22/98	8w
60	procure lateral transfer retroreflector	Mon 3/30/98	Fri 6/5/98	10w
61	fab theodolite mods	Mon 4/6/98	Fri 4/17/98	2w
62	design/fab mounts & tooling	Mon 4/6/98	Fri 4/24/98	3w
63	integrate/test theodolite/autocollimator	Mon 5/25/98	Fri 6/12/98	3w
64	test equipment at MIT	Mon 6/15/98	Fri 7/24/98	6w
65	WA site survey work	Fri 3/20/98	Fri 8/7/98	101d
66	LVEA wall access holes prepared, WA	Fri 3/20/98	Fri 3/20/98	0d
67	end/mid wall access holes prepared,WA	Wed 4/29/98	Wed 4/29/98	0d
68	dry run, long shots at WA site	Mon 7/27/98	Fri 8/7/98	2w
69	ready for IO/COC installation, WA	Fri 8/7/98	Fri 8/7/98	0d
70	LA site survey work	Tue 9/1/98	Fri 10/9/98	29d
71	LVEA wall access holes prepared, LA	Tue 9/1/98	Tue 9/1/98	0d
72	end wall access holes prepared, LA	Tue 9/1/98	Tue 9/1/98	0d
73	dry run, long shots at LA site	Mon 9/28/98	Fri 10/9/98	2w
74	ready for IO/COC installation, LA	Fri 10/9/98	Fri 10/9/98	0d



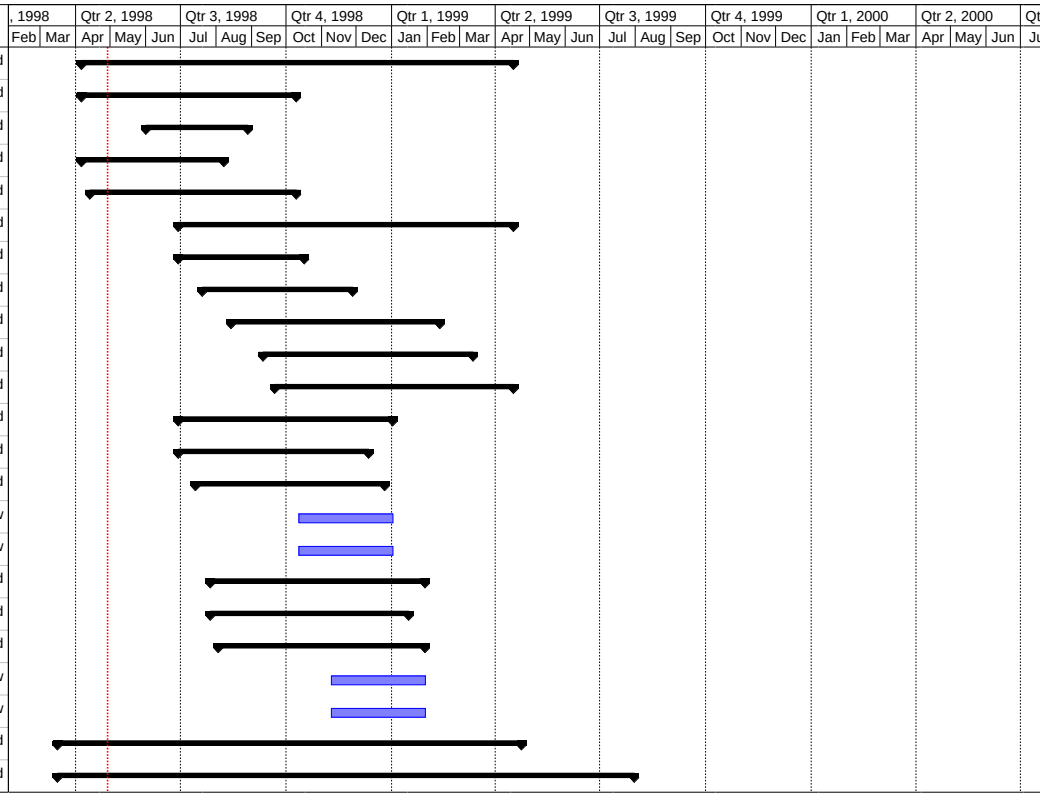
IAS hardware deliverables

MEZ Wed 4/29/98 12:40

ISC Fabrication and Delivery

Macintosh HD:Z Docs:Detector:ISC_FAB_MAR98:ISC

ID	Task Name	Start	Finish	DUR
90	**WA 2k ISC (by function group)**	Mon 4/6/98	Fri 4/16/99	270d
91	WA 2k IO DELIVERABLES	Mon 4/6/98	Fri 10/9/98	135d
92	Video & illuminator	Mon 6/1/98	Fri 8/28/98	65d
99	Optical lever	Mon 4/6/98	Fri 8/7/98	90d
111	IOT7	Mon 4/13/98	Fri 10/9/98	130d
129	WA 2k CO DELIVERABLES (Corner Sta)	Mon 6/29/98	Fri 4/16/99	210d
130	Video & illuminator	Mon 6/29/98	Fri 10/16/98	80d
136	Optical levers	Mon 7/20/98	Fri 11/27/98	95d
146	ISCT7	Fri 8/14/98	Thu 2/11/99	130d
162	ISCT9	Fri 9/11/98	Fri 3/12/99	131d
178	ISCT10	Mon 9/21/98	Fri 4/16/99	150d
194	WA 2k CO DELIVERABLES (Left Mid)	Mon 6/29/98	Fri 1/1/99	135d
195	Video & illuminator	Mon 6/29/98	Fri 12/11/98	120d
201	Optical levers	Tue 7/14/98	Fri 12/25/98	119d
211	ETM Transmission QPD	Mon 10/12/98	Fri 1/1/99	12w
212	Photon Calibrator	Mon 10/12/98	Fri 1/1/99	12w
213	WA 2k CO DELIVERABLES (Right Mid)	Mon 7/27/98	Fri 1/29/99	135d
214	Video & illuminator	Mon 7/27/98	Fri 1/15/99	125d
220	Optical levers	Mon 8/3/98	Fri 1/29/99	130d
230	ETM Transmission QPD	Mon 11/9/98	Fri 1/29/99	12w
231	Photon Calibrator	Mon 11/9/98	Fri 1/29/99	12w
233	**LA 4k ISC**	Mon 3/16/98	Fri 4/23/99	290d
394	**WA 4k ISC**	Mon 3/16/98	Fri 7/30/99	360d



Est. @completion vs. budget[1] (all ISC)

Item	Budget ($k)	EAC ($k)	Δ ($k)
LSC personnel	1,076	1,498	(422)
LSC hardware	609	247	362
ASC personnel	1,385	2,281	(896)
ASC hardware	3,419	1,832	1,587
total	**6,489**	**5,858**	**631**

1. LIGO Construction (WBS 1.x) only; does not include installation (LIGO Ops, WBS 2.x)

EAC (IAS hardware)

ASC;IAS

TOTAL ALIGNMENT SENSING/CONTROL ETC (5E516-5H516):							$2,726,751
ASC (5E516-5H516): Initial Alignment Subsystem							$1,118,065
Group	Equipment	Wa2k	Wa4k	La4k	total	Cost (ea)	Total
inst support	laser autocollimator	1			1	$30,000	$30,000
inst support	PLX retroreflector	1		1	2	$12,000	$24,000
inst support	retroreflector mount	1		1	2	$1,200	$2,400
inst support	autocollimator mount	1			1	$2,000	$2,000
inst support	optical flats	3	1	1	5	$300	$1,500
inst support	optical flat mounts	3	1	1	5	$1,500	$7,500
inst support	pipe ramps	3	2	2	7	$800	$5,600
inst support	machinist level	1		1	2	$500	$1,000
inst support	200 mm optical flat	1		1	2	$1,600	$3,200
inst support	200 mm gimbal mount	1		1	2	$1,600	$3,200
inst support	alignment monuments	12	4	6	22	$500	$11,000
inst support	theodolite			1	1	$28,000	$28,000
inst support	hollow stand, xy lateral	1			1	$3,485	$3,485
inst support	Z fine adjust	1			1	$1,220	$1,220
inst support	fixtures & spares	1	1	1	3	$5,600	$16,800
inst support	special crates	6			6	$350	$2,100
inst support	shipping	1	1	1	3	$4,000	$12,000
video	camera w/lens	20	20	20	60	$1,100	$66,000
video	camera mount/enclosure	20	20	20	60	$400	$24,000
video	illuminator	12	12	12	36	$200	$7,200
video	lamp mount/enclosure	12	12	12	36	$300	$10,800
video	hardware	32	32	32	96	$150	$14,400
video	spares	1	1	1	3	$2,400	$7,200
video	test monitors	1		1	2	$730	$1,460
video	shipping	1	1	1	3	$1,500	$4,500
viewports	5.75 dia viewport (coated)	43	39	39	121	$1,100	$133,100

EAC (hardware, cont'd.)

ASC;IAS

viewports	7.75 dia viewport (coated)	12	12	12	36	$2,900	$104,400	
viewports	port hardware	55	51	51	157	$160	$25,120	
viewports	shipping containers	55	51	51	157	$50	$7,850	
viewports	5.75 spares	6	6	6	18	$1,100	$19,800	
viewports	7.75 spares	3	3	3	9	$2,900	$26,100	
viewports	shipping	1	1	1	3	$2,500	$7,500	
opt. lever	diode laser, supply, fiber	9	7	7	23	$1,800	$41,400	
opt. lever	beam expander	9	7	7	23	$1,600	$36,800	
opt. lever	remote mirrors	18	14	14	46	$1,850	$85,100	
opt. lever	multiaxis driver	4	4	4	12	$4,000	$48,000	
opt. lever	kinematic mount	9	7	7	23	$2,800	$64,400	
opt. lever	beam enclosure tubes	9	7	7	23	$600	$13,800	
opt. lever	BSC pillar mount	8	2	2	12	$350	$4,200	
opt. lever	floor mount	12	10	12	34	$3,400	$115,600	
opt. lever	mounting hardware	9	7	7	23	$100	$2,300	
opt. lever	PIN quad (bare)	9	7	7	23	$110	$2,530	
opt. lever	spares	1	1	1	3	$18,000	$54,000	
opt. lever	special crates	18	14	14	46	$250	$11,500	
opt. lever	shipping	1	1	1	3	$8,000	$24,000	