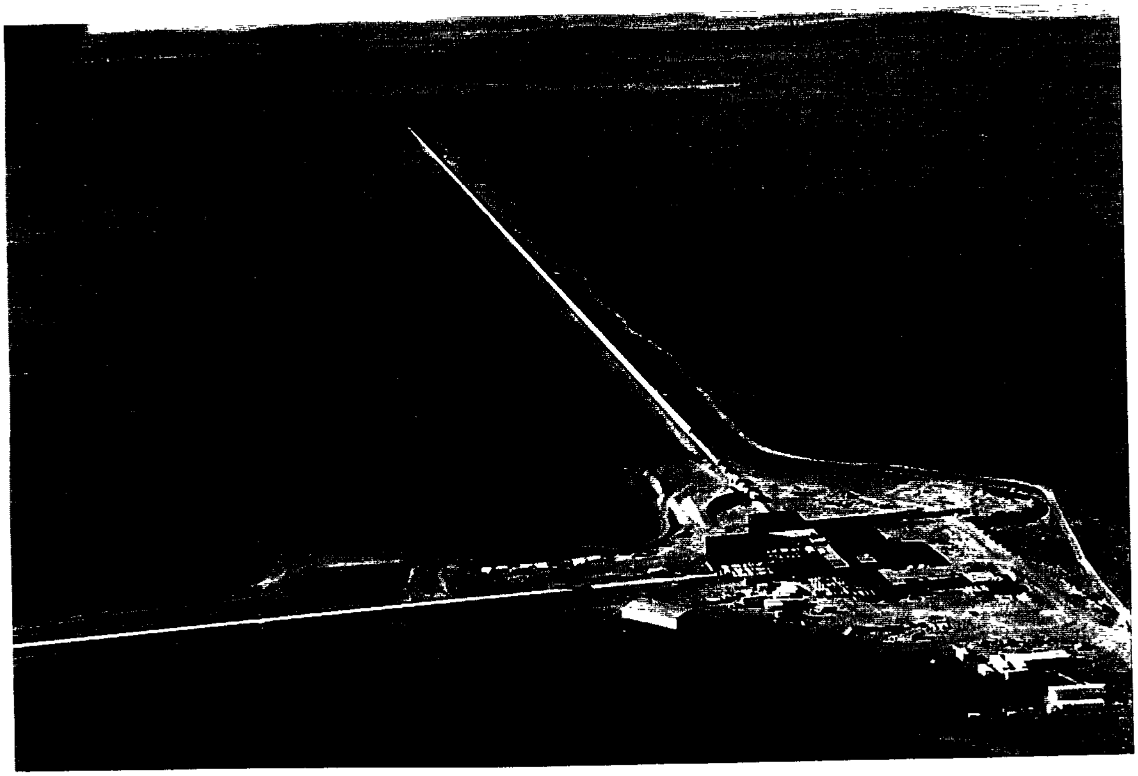
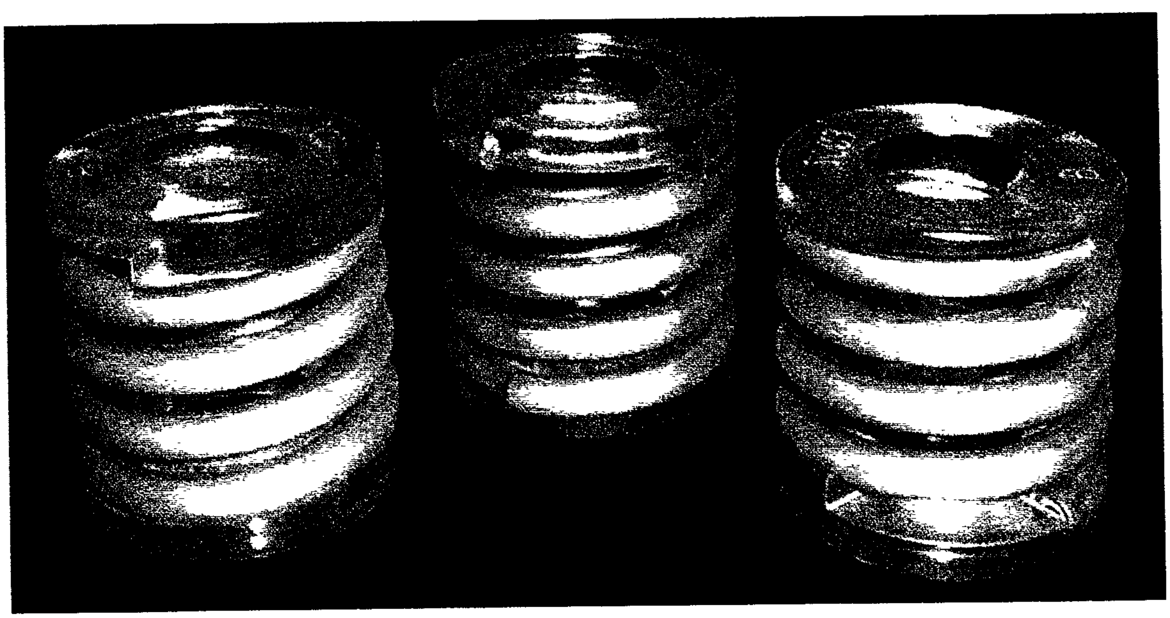
LIGO PROJECT

California Institute of Technology / Massachusetts Institute of Technology





National Science Foundation Technical Review

April 15-17, 1997 - California Institute of Technology-Pasadena, California 91125

LIGO G970089-00-M

Laser Interferometer Gravitational Wave Observatory

LIGO PROJECT

California Institute of Technology / Massachusetts Institute of Technology

NSF Technical Review - April 15-17, 1997

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NSF Review of the LIGO Project
April 15-17, 1997

Charge

Review the progress made since the last NSF review held in October 1996, particularly:

The R&D program and the detector system. This should include reports on the current status of the 40 m and the phase noise interferometers, the seismic isolation systems, the laser, the core optics and the alignment and control system.

System integration and acceptance testing. This should include the definition of methods LIGO will use in its role as general contractor to oversee and coordinate all project participants during integration, acceptance and commissioning of the subsystems. Examine the plan to bake-out the beam tube, its relationship to the acceptance of the beam tube and to the overall system integration.

New developments in data acquisition, archiving and analysis.

National Science Foundation Technical Review of the LIGO Project
California Institute of Technology
April 15-17, 1997
112-114 East Bridge

Agenda

Tuesday April 15, 1997:
8:00 am - 8:30 am: Coffee (30)

8:30 am - 9:30 am: Review Committee Executive Session (60)
1) Including Report on Hanford Site Visit

2) 9:30 am - 10:00 am: Introduction - Barish (30)

10:00 am - 10:15 am: COFFEE BREAK (15)

FACILITIES
4) 10:15 am - 10:35 am: Civil - Asiri (20)
5) 10:35 am - 10:55 am: Beam Tube - Jones (20)
6) 10:55 am - 11:10 am: Baffles - Lazzarini (15)
7) 11:10 am - 11:25 am: Bakeout - Althouse (15)
8) 11:25 am - 11:45 am: Vacuum Equipment - Worden (20)
3) 11:45 am - 12:00 pm: Integration/Acceptance - Stapfer (15)

12:00 pm - 1:00 pm: LUNCH BREAK (60)

RESEARCH AND DEVELOPMENT
9) 1:00 pm - 1:30 pm: PNI - Fritschel (30)
10) 1:30 pm - 2:00 pm: Recycling - Logan (30)

DETECTOR
11) 2:00 pm - 2:30 pm - Overview - Whitcomb (30)

2:30 pm - 2:45 pm: COFFEE BREAK (15)

Tuesday April 15, 1997 (continued)

FACILITIES
2:45 pm - 5:00 pm: Interactive Session - Engineering Conference Room (39 Bridge Annex)

DATA
12) 2:45 pm - 3:05 pm: Data Acquisition - Bork (20)
13) 3:05 pm - 3:25 pm: Data Processing - Blackburn (20)
14) 3:25 pm - 3: 45 pm: Networking - Lazzarini (20)
15) 3:45 pm - 4:05 pm: Lock Acquisition System - Sievers (20)
16) 4:05 pm - 4:25 pm: End-to-End Simulation - Yamamoto (20)
4:30 pm - 6:00 pm: Executive Session (90)
6:00 pm - 8:00 pm: LIGO-hosted Dinner at The Athenaeum

Wednesday April 16, 1997:
FACILITIES
9:00 am - 12:00 pm: Interactive Session - Science Conference Room (351 West Bridge)

DETECTOR/R&D/DATA
9:00 am - 12:00 pm: 112 - 114 East Bridge
17) 9:00 am - 9:20 am: Laser - Savage (20)
18) 9:20 am - 9:40 am: Core Optics - Camp (20)
19) 9:40 am - 10:00 am: Input Optics - Reitze (UFla) (20)

10:00 am - 10:20 am: COFFEE BREAK (20)

20) 10:20 am - 10:40 am: Seismic Isolation - Thompson (HYTEC) (20)
21) 10:40 am - 10:55 am: LSC/ASC - Zucker (20)
22) 10:55 am - 11:15 am: FMI/Alignment - Mavalvala (15)
23) 11:15 am - 11:35 am: CDS/Electronics - Heefner (20)

1:00 pm - 5:00 pm: Committee Execusive Session and Writing

Thursday April 17, 1997:
11:00 am (Tentative): NSF Review Committee Close-Out

Glossary of Acronyms and Abbreviations

1x/2x/3x	notation for single, double, and three-fold coincidence operational modes of the LIGO detector comprised of 3 IFOs
10BaseT	telephone type Ethernet cable
ADC	Analog-to-Digital Converter
AMU	Atomic Mass Unit
API	Application Programmer Interface
ARO	After Receipt of Order
AS	Alignment System
ASC	Alignment Sensing and Control
ATM	Asynchronous Transfer Mode (inter-processor communications pr
AVS	Advanced Visual Systems (graphical development software packa
BAC	Budget At Completion
BCU	Beam Control Unit
BNWL	Battelle Northwest Laboratories
BSC	Beam Splitter Chamber
BT	Beam Tube
BTD	Beam Tube Demonstration
BUDG	Budget
CA/NS	Control Area and Networking System
CACR	Center for Advanced Computing Research (Caltech)
CAM	Control Account Manager
CAP	Control Account Plan
CBI	Chicago Bridge & Iron
CCB	Change Control Board
CCD	Charge Coupled Device
CDF/HDF	Common/Hierarchical Data Format
CDR	Conceptual Design Review
CDRL	Contract Data Requirements List
CDS	Control and Data System
CDS/DAQ	Computer & Data Systems Data Acquisition System
CNTR	beam Centering Alignment System
COC	Core Optics Components
COS	Core Optics Support
COTS	Commercial Off-The-Shelf software
CPU	Central Processing Unit
CSIRO	Commonwealth Scientific & Industrial Research Organization
CSR	Center for Space Research (MIT)
DAC	Digital-to-Analog Converter
DCC	Document Control Center
DCCD	Design Configuration Control Document
DEC/SUN	Computer Manufacturers: Digital Equip.Corp/SUN Microsystems,
DMA	Direct Memory Access
DoD	Dept. of Defense
DoE	Dept. of Energy
DOF	Degree of Freedom
DRD	Data Requirement Description
DRR	Design Requirements Review
DSP	Digital Signal Processor
EAC	Estimate At Completion
EFINISH	Early Finish
EMC	Electro-magnetic Control
EMI	Electro-magnetic Interference
EMSL	Environmental Molecular Sciences Lab (Battelle)
EPICS	Experimental Physics and Industrial Control System
ESNET/DoE	Energy Sciences Network/Dept. of Energy
ESTART	Early Start
ETC	Estimate to Complete
FAB	Fabrication
FDR	Final Design Review
FFT	Fast (Discrete) Fourier Transform

FFT	Fast (Discrete) Fourier Transform
Fiber Channel	255 Mbit per second communications network
FIFO	First In, First Out Method of reading data written to dynamic
FMI	Fixed Mass Interferometer
FP	Fabry-Perot
FSSC	Frequency-Shifted Subcarrier generator
GCDS	Global CDS Functions
GEO	British/German Cooperation for Gravity Wave Experiment
GFLOPS	1000 MFLOPS
GO	General Optics (Company Name)
GPIB	General Purpose Interface Bus
GPS	Global Positioning System
GUI	Graphical User Interface
GW	Gravitational Wave
HAM	Horizontal Access Module
HDOS	Hughes Danbury Optical Systems (Company Name)
HEP	High Energy Physics
HNR	Hanford Nuclear Reservation (LIGO Site)
HR	High Reflector (mirror)
HWP	Half-Wave Plate
HYTEC	Company Name
I/O	Input/Output
IAS	Initial Alignment System
IFO	Interferometer
IFODAQ	Interferometer Data Acquisition
Internet II	Consortium of Universities (Formed Fall 1996)
IOC	Input/Output Controller
IOO	Input/Output Optics
IPAC	Image Processing & Analysis Center (Caltech)
IPS	Integration Project Schedule
IR	Infrared
ISC/ASC/LSC	Interferometer/Alignment/Length Sensing & Control Systems
JPL	Jet Propulsion Laboratory
kB/MB/GB/TB	kilo-/mega-/giga-/terabyte: 10^3/10^6/10^9/10^12 bytes
kbps	Kilobits per second
kBps	Kilobytes per second
kFLOP/MFLOP/GFLOPS	kilo/Mega/Giga Floating Point Operations per second
kpc	3 x 3^3 lightyear (kiloparsec)
LA	Louisiana
LAN	Local Area Network
LaSERnet II	Louisiana Southeast Regional net
LBL	Lawrence Berkeley National Lab
LIGO	Laser Interferometer Gravitational-Wave Observatory
LN2	Liquid Nitrogen
LNT2	Liquid Nitrogen Trap No. 2
LNS	Laboratory for Nuclear Science (MIT)
LOS	Large Optic Suspension
LRC	LIGO Research Community
LSC	Length Sensing and Control
LSU	Louisiana State University
LVDT	Linear Variable Differential Transducer
LVEA	Laser/Vacuum Equipment Area
Mbps	Megabits per second
MBps	Megabytes per second
MICS	DOE Mathematics, Information, & Computer Sciences
MIMO	Multiple Input, Multiple Output
MFLOPS	Million Floating Point Operations Per Second
MOPA	Master Oscillator, Power Amplifier
MPE	Message Passing Extensions
MPI	Message Passing Interface
MSFC	NASA Marshall Space Flight Center
NPACI	Nat'l Partnership for Advanced Computational Infrastructure
NPRO	Nonplanar Ring Oscillator
NIM	Nuclear Instrumentation Module
NIST	National Institute of Standards and Technology
NS	Neutron Star

NS	Neutron Star
NSB	National Science Board
NSF	National Science Foundation
OPI	Operator Interface
OptLev	Optical Lever Alignment System
OSEM	Integrated Optical Position Sensor/ElectroMagnetic driver
PAC	(LIGO) Program Advisory Committee
PC	Pockels Cell
PD	Photo-Detector
PDR	Preliminary Design Review
PDRR	Preliminary Design Requirements Review
PEM	Physical Environment Monitoring System
PERF	Performance
PLC	Programmable Logic Controller
PM	Project Manager
PMB	Performance Measurement Baseline
PMCS	Project Management Control System
PMDAQ	Physical Environment Monitor Data Acquisition
PNI	Phase Noise Interferometer
PNNL	Pacific Northwest Nat'l Laboratory
POSIX	established industry standard for software/hardware interface
PSI	Process Systems International
PSL	Prestabilized Laser
PZT	Piezo-electric Transducer
QT	Qualification Test
QTR	Qualification Test Review
RAID	Redundant Array of Inexpensive Disks
RAM	Responsibility Assignment Matrix
RANCOR	vessel subcontractor to PSI
RDIAG	Remote Diagnostics
REO	Research Electro-Optics (Company Name)
RF	Radio Frequency
RFP	Request for Proposal
RFPD	Radio-Frequency Photo-Detector
RGA	Residual Gas Analyzer
RMP	Ralph M. Parsons, LIGO Architect/Engineer Contractor
ROM	Relative Order of Magnitude or Read-Only Memory
s	Second
SDSC	San Diego Supercomputing Center (UCSD)
SC	Supercomputer(ing) Center(s)
SEI	Seismic Isolation
SEPSCOR	South East Partnership for Shared Computational Resources
SI	Seismic Isolation
SNR	Signal-to-Noise Ratio
SOS	Small Optic Suspension
SPARC	Scaled Processor Architecture
SS20	SunSparc 20 workstation
SUR	IBM's Sponsored University Research Grants Program
SQL	Standard Quantum Limit
SQRT	Square Root
STACIS	(Product Name)
SUP	Support Equipment
SUS	Suspension System
SYS	Systems Engineering
T	Time
T3	Telecommunications standard, 45 Mbps
TAMA	Japanese Interferometric Gravitational-Wave Detector Project
TCP/IP	Transmission Control Protocol/Internet Protocol
TEM	Transverse Electromagnetic
TF	Total Float
TFP	Thin Film Polarizer
TLA	Three-letter Acronym
TFLOPS	1000 GFLOPS
TMC	Test Mass Chamber
TWIDDLE	name of a particular modelling code within LIGO

UTC	Universal Time Code
VAC	Vacuum System Controls
vBNS	very high-speed Backbone Network Service(NSF)
VCO	Voltage Controlled Oscillator
VE	Vacuum Equipment
VEA	Vacuum Equipment Area
VFC	Vacuum Feedthroughs and Cabling
VIRGO	Italian-French Laser Interferometer Collaboration
VME	Versa Modular Eurocard (IEEE 1014)
VXI	VME eXtensions for Instrumentation
VxWorks	a real time operating system for VME based systems
WA	Washington
WAN/LAN	Wide/Local Area (Computer) Network
WBS	Work Breakdown Structure
WFS	Wavefront Sensing
WP	Work Package
WVFNT	Wavefront Alignment System
XCVR	Transmitter/Receiver

URL: http://www.ligo.caltech.edu/LIGO_web/acronyms/acronyms.html
last modified 13 Jul 95
For problems or suggestions regarding Web materials, contact webmaster@ligo.caltech.edu
For information about LIGO, contact info@ligo.caltech.edu

National Science Foundation Review of the LIGO Project
at the LIGO Hanford, WA. Site
Best Western Tower Inn
April 13-14, 1997

Agenda

Sunday April 13, 1997:
Best Western Tower Inn

MANAGEMENT REVIEW - 1:00 pm - 5:00 pm

1:00 pm - 1:45 pm: Management Overview - Sanders (45)
1:45 pm - 2:30 pm: Cost/Schedule - Lindquist (45)
2:30 pm - 3:15 pm: Detector - Fischer (45)
3:15 pm - 4:00 pm: Facilities - Stapfer (45)
4:00 pm - : Discussion

6:00 pm - 8:00 pm: LIGO-hosted Dinner

Monday April 14, 1997:

8:00 am: Depart Hotel for Site
Visit Site
LUNCH
12:00 pm: Depart Site for CBI Tube Factory
Visit CBI Tube Factory
3:00 pm: Depart CBI Tube Factory for Airport
4:00 pm: Depart for LAX

NSF Review at the LIGO Hanford Site

LIGO Cost/Schedule/Management Status

Gary Sanders

April 13 - 14, 1997

LIGO Status

- LIGO Construction is 45% complete.
- NSF has provided $265.4 million of the $292 million construction budget.
  - Funds have been provided when required by the Project schedule.
- NSF has provided initial Operations funding as requested, enabling site activities for installation.

Facility Construction Status

- All major Facility construction contracts have been placed and are in progress and 95 % of budget is spent or obligated.

  ›› No significant cost changes have been made to the large fixed-price contracts.

  ›› Contractor non-interference has been successfully managed to date.

  – Enclosure installer vs. beam tube installer, delivery "just in time" and use of road

  ›› Weather has caused modest delays.

  – Rain in Louisiana delayed grading and snow/wind in Washington has delayed foundation work.

  ›› Beam tube baffle design has been revised and retrofitting of first arm will be required.

Hanford Construction

- Hanford vacuum equipment delivery is expected to meet the required schedule.
  - Delayed gate valves have nevertheless met required schedule for CB&I.
  - Beam tube deliverables on schedule.
- Hanford beam tube fabrication is slightly ahead of schedule.
- First arm beam tube installation is essentially *complete*.
  - Installation schedule is 3 - 4 weeks late but is recovering.
- Fabrication of enclosures is essentially complete and installation is paced by CB&I.
- Buildings are 28 days late due to weather but gaining.
- Facility and Detector (CDS) staff (8 FTE) on site is growing.

Louisiana Construction

- First concrete has been poured in Livingston!
- Woodrow Wilson Construction has begun road and slab work.
  - Soil amendments are underway.
- Hensel Phelps has begun building foundation excavations.
- Alternate access road onto site completed by Louisiana.
  - This was a potential schedule driver.
- Gerry Stapfer and Allen Sibley now resident in Louisiana to manage construction.
- CB&I arrival expected earlier than schedule.

Facility Acceptance

- CB&I preparing for first 2 kilometer leak test.
- Beam tube bakeout planning and design is underway within LIGO.
  - Bill Althouse will describe this in Pasadena.
- LIGO CDS group is on schedule for Vacuum Equipment Controls needed for acceptance testing.
  - CDS staff on site in Hanford.

Detector Status

- Optics, laser and seismic isolation contracts have been awarded and are making good progress.
- Suspension prototypes have been tested.
- Recycling experiment is making good progress.
- Phase noise measurement at 514 nm completed and 1064 nm conversion is underway.
- Some subsystems are two months behind schedule, but within available slack, due to staffing shortfalls.
  - Hiring has accelerated.
  - Replan in progress to accommodate delays.

Facility Milestones (Hanford)

Milestone Description	Project Mgmt Plan	Baseline Dates	Current Status
Select VE Contractor	Mar-95	Complete	Complete
Accept Vacuum Equipment	Mar-98	4/6/98	4/6/98
Beam Tube Final Design Review	Apr-94	Complete	Complete
Complete BT Qual Test	Feb-95	Complete	Complete
Initiate Beam Tube Fabrication	Oct-95	Complete	Complete
Accept Tubes and Covers	Mar-98	11/6/97 *	1/5/98 *
Initiate Site Development	Aug-95	Complete	Complete
Select A&E Contractor	Nov-94	Complete	Complete
Initiate Slab Construction	Oct-95	2/14/96	2/14/96 (A)
Initiate Building Construction	Jun-96	8/8/96	8/8/96 (A)
Joint Occupancy	Sep-97	8/5/97	9/5/97
Beneficial Occupancy	Mar-98	9/2/97	10/6/97
Initiate Facility Shakedown	Mar-98	4/7/98	4/7/98

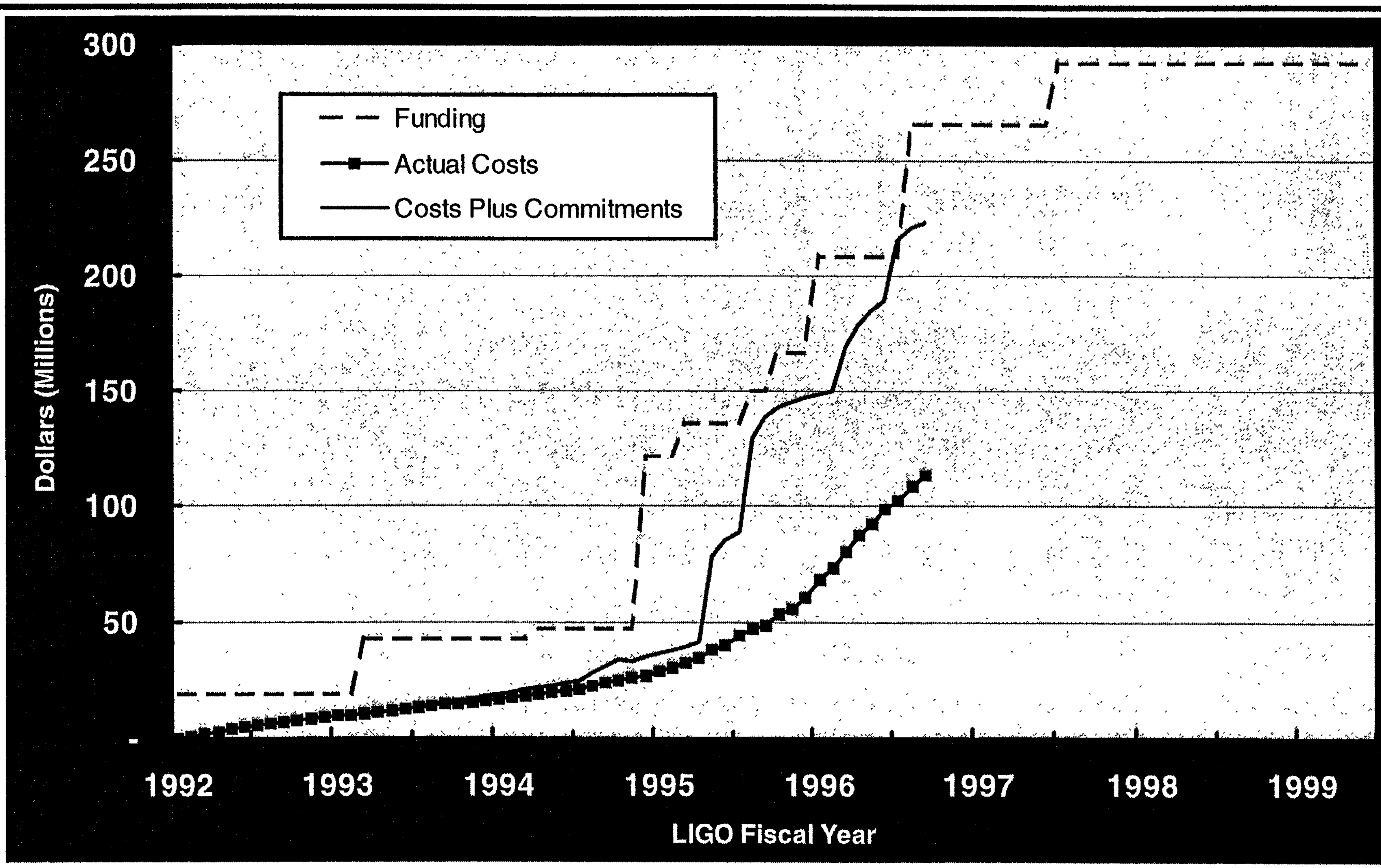
Facility Milestones (Livingston)

Milestone Description	Project Mgmt Plan	Baseline Dates	Current Status
Select VE Contractor	Nov-94	Complete	Complete
Accept Vacuum Equipment	Sep-98	10/28/98	10/28/98
Beam Tube Final Design Review	Apr-94	Complete	Complete
Complete BT Qual Test	Feb-95	Complete	Complete
Initiate Beam Tube Fabrication	Oct-95	Complete	Complete
Accept Tubes and Covers	Sep-98	12/10/98 *	12/23/98 *
Initiate Site Development	Aug-95	Complete	Complete
Select A&E Contractor	Nov-94	Complete	Complete
Initiate Slab Construction	Jan-97	1/10/97	12/17/96 (A)
Initiate Building Construction	Jan-97	10/10/96	12/12/96 (A)
Joint Occupancy	Mar-98	2/2/98	2/23/98
Beneficial Occupancy	Sep-98	4/13/98	6/9/98
Initiate Facility Shakedown	Sep-98	3/3/99	12/28/98

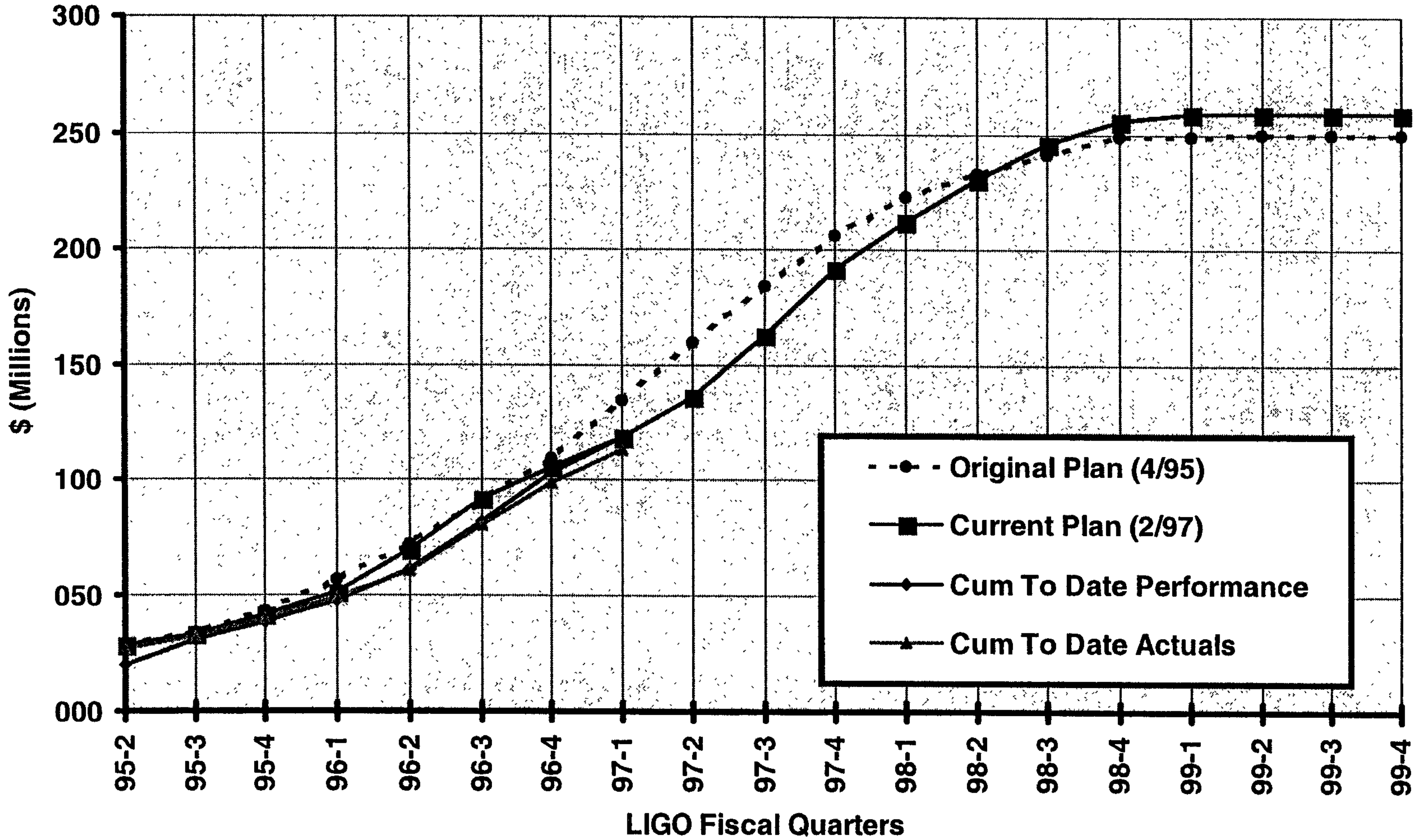
Detector PMP Milestones

Milestone Description	Project Mgmt Plan	Baseline	Current Status
Pre-Stabilized Laser FDR	8/30/98	3/6/98	7/30/98
Input/Output Optics FDR	4/30/98	2/10/98	5/19/98
Length Sensing Control FDR	5/30/98	6/17/97	12/15/97
Wavefront FDR	4/30/98	10/8/97	2/13/98
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
BSC Stack Final Design Review	7/30/97	7/30/97	9/19/97
HAM Final Design Review	7/30/97	7/30/97	9/19/97
Control Data System DAQ FDR	4/30/98	3/26/98	5/28/98
Physics Environ Monitoring FDR	6/30/98	4/28/97	8/6/97
WA Cntl Area/Net Sys Ready To Install	9/30/97	9/10/97	9/29/97
Detector System Prelim Design Review	12/30/97	12/30/97	4/3/98
Begin WA IFO Installation	7/30/98	7/30/98	7/30/98
Begin LA IFO Installation	1/30/99	1/30/99	1/30/99
Begin COINCIDENCE TEST	12/31/00	12/31/00	12/31/00

Actual Costs and Commitments
(End of February 1997 Data)



LIGO Construction Performance



NSF Review
April 13, 1997

LIGO Project Cost/Schedule Status

Phil Lindquist

NSF Review - April 13, 1997
LIGO Project Cost/Schedule Status

- Overview
- Actual Costs and Commitments
- Schedules
- Cost Schedule Status Report
- Performance Graphs
- Change Control and Contingency
- Staffing

Overview

- Facilities were replanned for the April 1996 NSF Review
- Since the last Semi Annual Review (October 1996)
  - Livingston, Louisiana construction contracts issued to Hensel-Phelps and Woodrow Wilson
  - Construction started in Livingston in January (last of the major Facilities contracts)
  - Detector in process of replanning *

* Replanning is <u>defined</u> as adjustments to the baseline to reflect

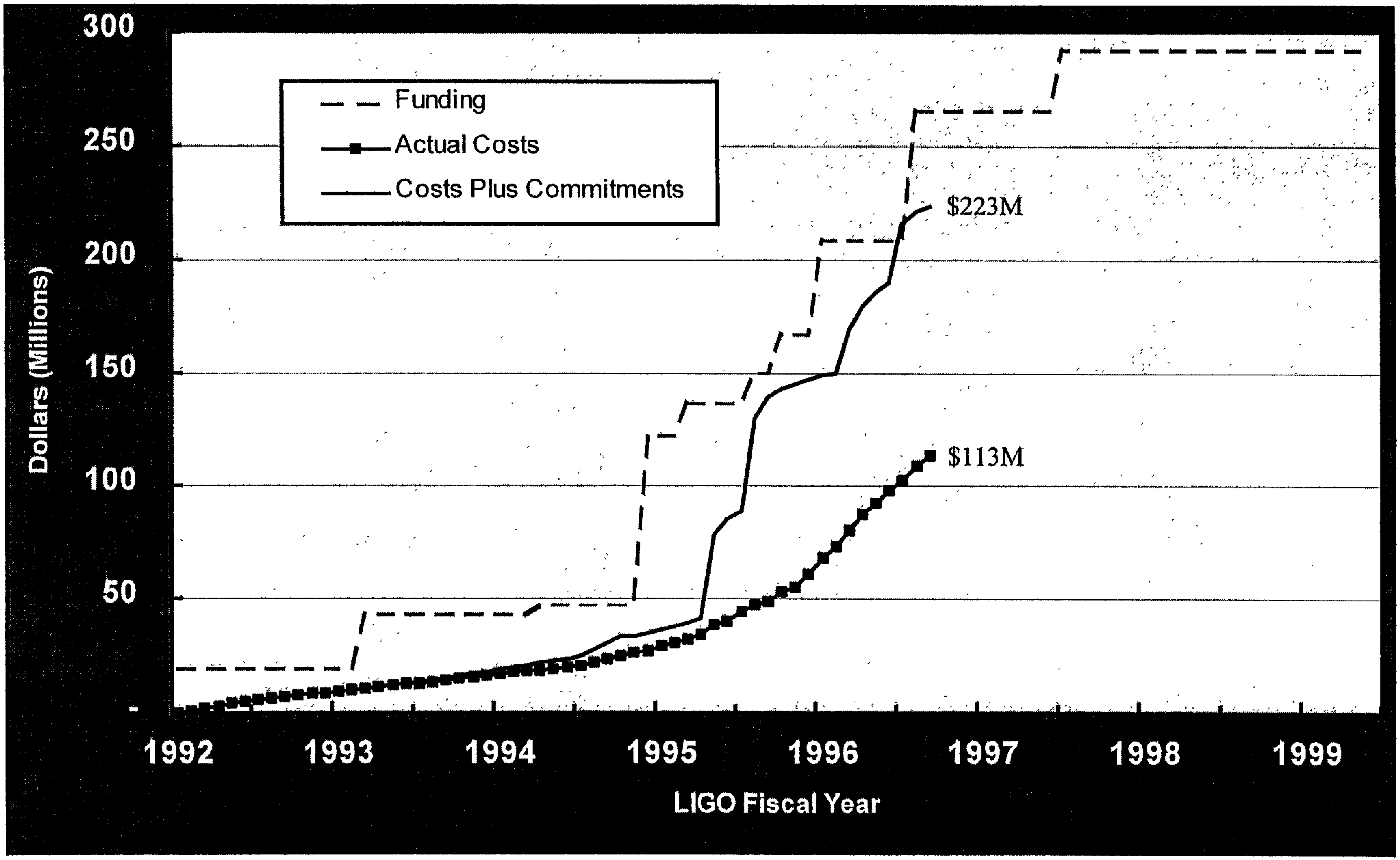
- Approved Change Requests (Change Control Board Actions)
- Time-phasing of the detailed budget to reflect subcontractor planning

Actual Costs and Commitments
(End of February 1997 Data)

- All subcontracts have been awarded for Facilities

WBS	Description	Costs Thru Nov 1996	Dec-96	Jan-97	Feb-97	Cumulative Costs	Open Commitments	Total Cost Plus Commit-ments
1.1.1	Vacuum Equipment	21,254	869	43	44	22,210	22,662	44,872
1.1.2	Beam Tube	17,262	107	3,427	1,260	22,057	35,292	57,349
1.1.3	Beam Tube Enclosure	6,237	251	459	247	7,195	12,269	19,465
1.1.4	Civil Construction	14,117	1,665	1,567	1,474	18,822	30,239	49,061
1.2	Detector	6,270	478	281	762	7,791	6,014	13,805
1.3	R&D	16,816	272	153	420	17,661	1,229	18,890
1.4	Project Management	16,288	457	411	583	17,740	1,964	19,704
	Unassigned (See Note)	2	(1)	-	1	2	131	132
	TOTAL	98,246	4,098	6,342	4,791	113,477	109,800	223,277
	Cumulative Actual Costs	98,246	102,344	108,686	113,477			
	Open Commitments	91,492	113,149	112,583	109,800			
	Total Costs Plus Commitments	189,738	215,493	221,269	223,277			
	NSF Funding	*208,468*	*208,468*	*265,389*	*265,389*			

Actual Costs and Commitments
(End of February 1997 Data)



Project Mgmt Plan Milestones
(Hanford, WA Facilities)

Milestone Description	Project Mgmt Plan	Baseline Dates	Current Status
Beam Tube Final Design Review	Apr-94	Complete	Complete
Select A&E Contractor	Nov-94	Complete	Complete
Complete BT Qual Test	Feb-95	Complete	Complete
Select VE Contractor	Mar-95	Complete	Complete
Initiate Site Development	Aug-95	Complete	Complete
Initiate Beam Tube Fabrication	Oct-95	Complete	Complete
Initiate Slab Construction	Oct-95	2/14/96	2/14/96 (A)
Initiate Building Construction	Jun-96	8/8/96	8/8/96 (A)
Joint Occupancy	Sep-97	8/5/97	9/5/97
Accept Tubes and Covers	Mar-98	11/6/97 *	1/5/98 *
Accept Vacuum Equipment	Mar-98	4/6/98	4/6/98
Beneficial Occupancy	Mar-98	9/2/97	10/6/97
Initiate Facility Shakedown	Mar-98	4/7/98	4/7/98

* Beam Tube Bake is planned after Beam Tube Acceptance

Project Mgmt Plan Milestones
(Livingston, LA Facilities)

Milestone Description	Project Mgmt Plan	Baseline Dates	Current Status
Beam Tube Final Design Review	Apr-94	Complete	Complete
Select VE Contractor	Nov-94	Complete	Complete
Select A&E Contractor	Nov-94	Complete	Complete
Complete BT Qual Test	Feb-95	Complete	Complete
Initiate Site Development	Aug-95	Complete	Complete
Initiate Beam Tube Fabrication	Oct-95	Complete	Complete
Initiate Slab Construction	Jan-97	1/10/97	12/17/96 (A)
Initiate Building Construction	Jan-97	10/10/96	12/12/96 (A)
Joint Occupancy	Mar-98	2/2/98	2/23/98
Accept Vacuum Equipment	Sep-98	10/28/98	10/28/98
Accept Tubes and Covers	Sep-98	12/10/98 *	12/23/98 *
Beneficial Occupancy	Sep-98	4/13/98	6/9/98
Initiate Facility Shakedown	Sep-98	3/3/99	12/28/98

* Beam Tube Bake is planned after Beam Tube Acceptance

PMP Milestones
(Detector)

Milestone Description	Project Mgmt Plan	Baseline	Current Status
[redacted]	[redacted]	[redacted]	[redacted]
BSC Stack Final Design Review	7/30/97	7/30/97	9/19/97
HAM Stack Final Design Review	7/30/97	7/30/97	9/19/97
WA Cntl Area/Net Sys Ready To Install	9/30/97	9/10/97	9/29/97
Detector System Prelim Design Review	12/30/97	12/30/97	4/3/98
Input/Output Optics FDR	4/30/98	2/10/98	5/19/98
Wavefront FDR	4/30/98	10/8/97	2/13/98
Control Data System DAQ FDR	4/30/98	3/26/98	5/28/98
Length Sensing Control FDR	5/30/98	6/17/97	12/15/97
Physics Environ Monitoring FDR	6/30/98	4/28/97	8/6/97
Begin WA IFO Installation	7/30/98	7/30/98	7/30/98
Pre-Stabilized Laser FDR	8/30/98	3/6/98	7/30/98
Begin LA IFO Installation	1/30/99	1/30/99	1/30/99
Begin COINCIDENCE TEST	12/31/00	12/31/00	12/31/00

Cost Schedule Status Report

(End of February 1997)

Run Date: 26MAR97	COST / SCHEDULE STATUS REPORT (CSSR)			Page 1
CONTRACTOR: Caltech LOCATION: Pasadena, CA	CONTRACT NUMBER: PHY-9210038	CONTRACT BUDGET BASELINE	REPORTING PERIOD: 31JAN97-28FEB97	PROJECT FILE NAME: LIGO Master Merged PMB - WBS 1.0

PERFORMANCE DATA (K$s)

REPORTING LEVEL	CUMULATIVE TO DATE					AT COMPLETION		
	BUDGETED COST		ACTUAL COST	VARIANCE				
MPA LEVEL	WORK SCHEDULED	WORK PERFORMED	WORK PERFORMED	SCHEDULE (2-1)	COST (2-3)	BUDGET (BAC)	ESTIMATE (EAC)	VARIANCE (6-7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.1.1 : Vacuum Equipment	23580	23423	22210	(157)	1213	42113	42113	0
1.1.2 : Beam Tubes	20527	22282	22057	1755	226	47298	47298	0
1.1.3 : Beam Tube Enclosur	8641	8151	7195	(490)	956	19384	19384	0
1.1.4 : Facility Design &	18548	19589	18822	1042	767	48311	48311	0
1.2 : Detector	10327	8928	7753	(1399)	1175	52567	53336	(769)
1.3 : Research & Developme	18429	18121	17661	(309)	460	23490	23490	0
1.4 : Project Office	17844	17844	17740	0	104	27074	27074	0
SUBTOTAL	117896	118338	113437	441	4901	260238	261007	(769)
CONTINGENCY						0	31087	(31087)
MANAGEMENT RESERVE						0	0	0
TOTAL	117896	118338	113437	441	4901	260238	292094	(31856)

$117.9M → 117896; $118.3M → 118338; $113.4M → 113437; $0.4M → 441; $4.9M → 4901

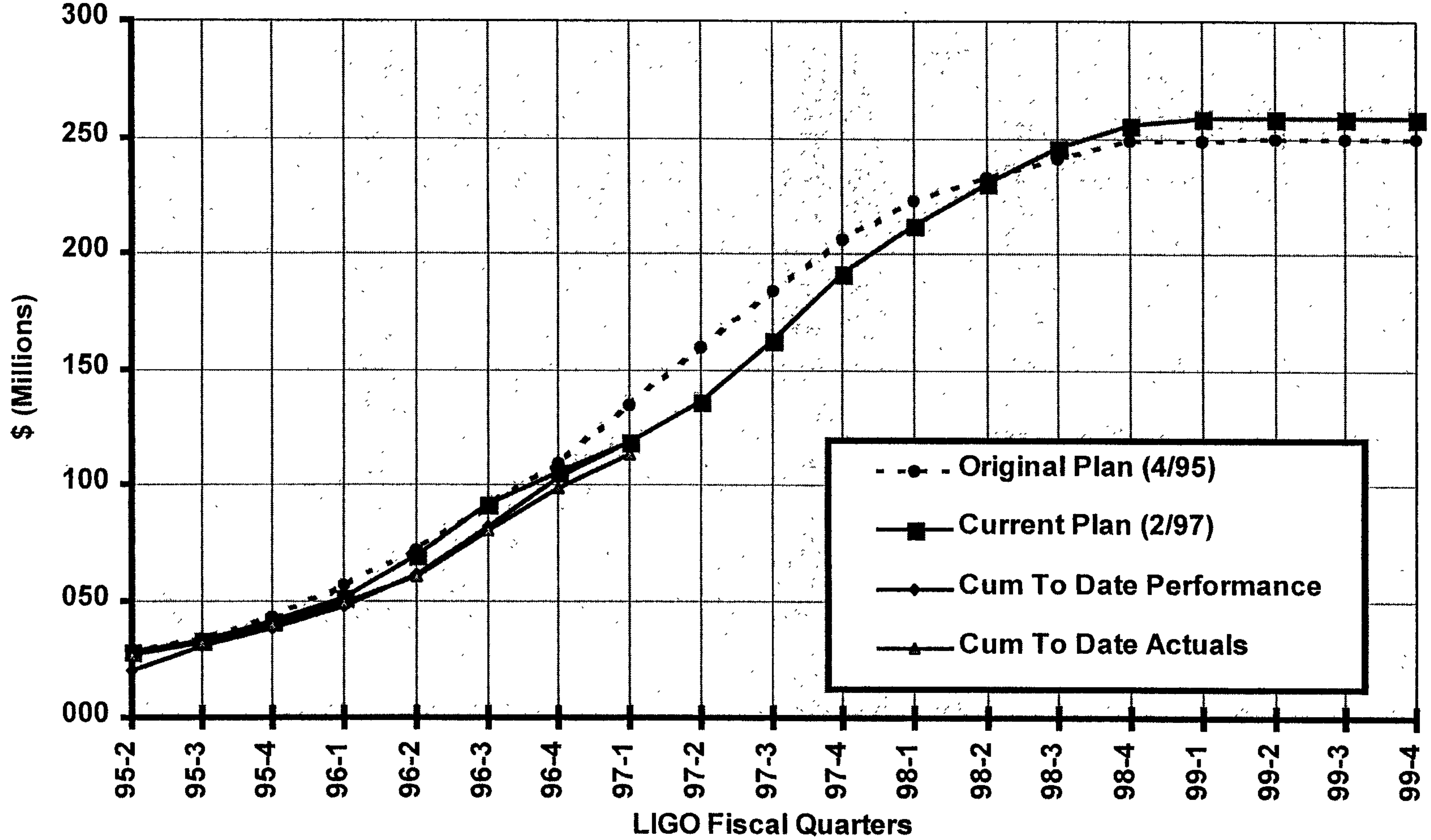
COBRA (R) by WST Corp.

Cost Schedule Status Report

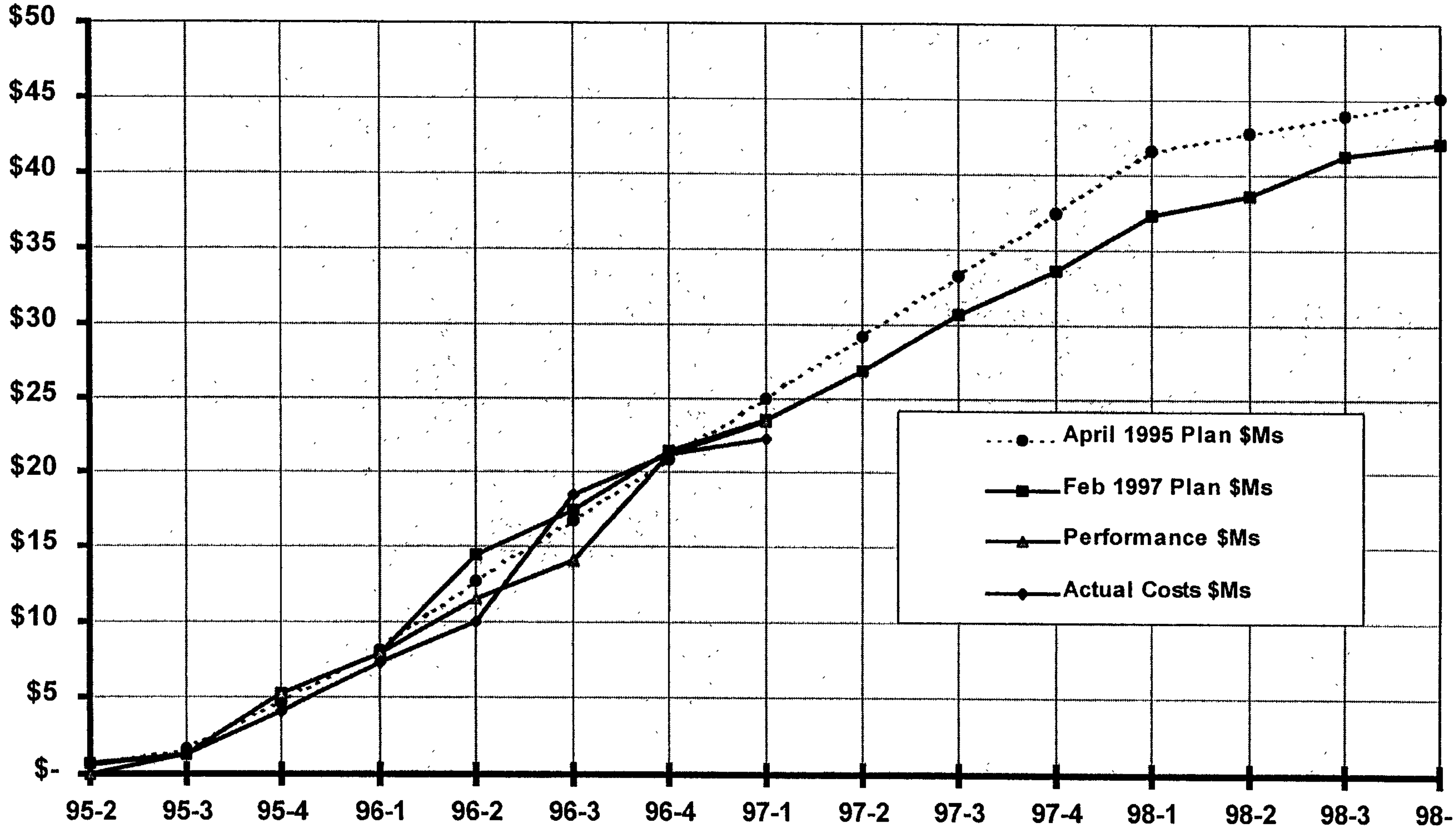
(End of February 1997)

Work Breakdown Structure	Cumulative to Date						
	Budgeted Cost		Actual Cost	Schedule Variance		Cost Variance	
	Work Scheduled	Work Performed	Work Performed	$Ks	%	$Ks	%
1.1.1 - Vacuum Equipment	$ 23,580	$ 23,423	$ 22,210	$ (157)	(1%)	$ 1,213	5%
1.1.2 - Beam Tubes	$ 20,527	$ 22,282	$ 22,057	$ 1,755	9%	$ 226	1%
1.1.3 - BT Enclosures	$ 8,641	$ 8,151	$ 7,195	$ (490)	(6%)	$ 956	12%
1.1.4 - Facility Design & Construction	$ 18,548	$ 19,589	$ 18,822	$ 1,042	6%	$ 767	4%
1.2 - Detector	$ 10,327	$ 8,928	$ 7,753	$ (1,399)	(14%)	$ 1,175	13%
1.3 - Research & Development	$ 18,429	$ 18,121	$ 17,661	$ (309)	(2%)	$ 460	3%
1.4 - Project Office	$ 17,844	$ 17,844	$ 17,740	$ -	0%	$ 104	1%
TOTAL	$ 117,896	$ 118,338	$ 113,437	$ 441	0%	$ 4,901	4%

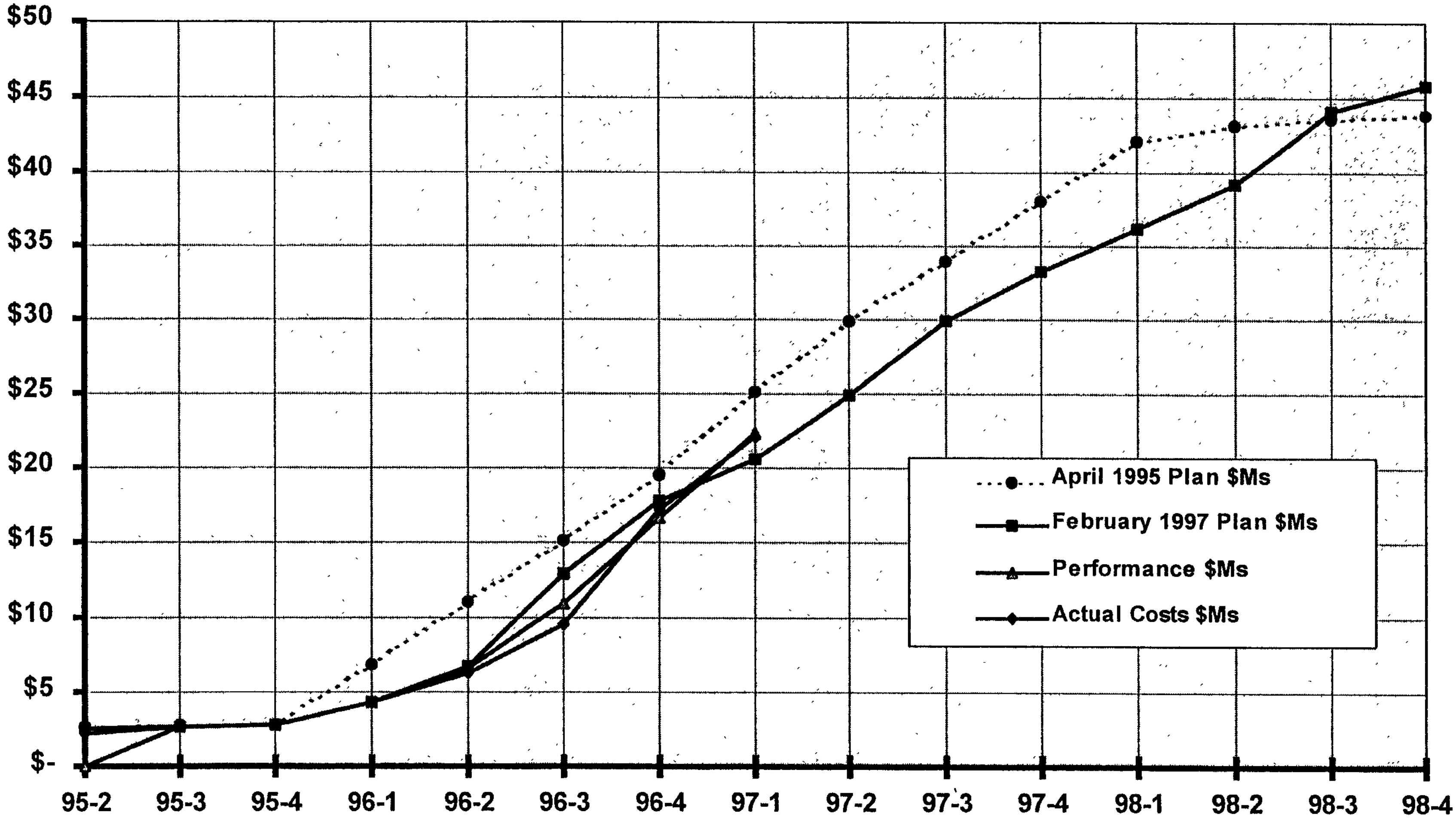
Performance Graphs
(LIGO Construction Project Total)



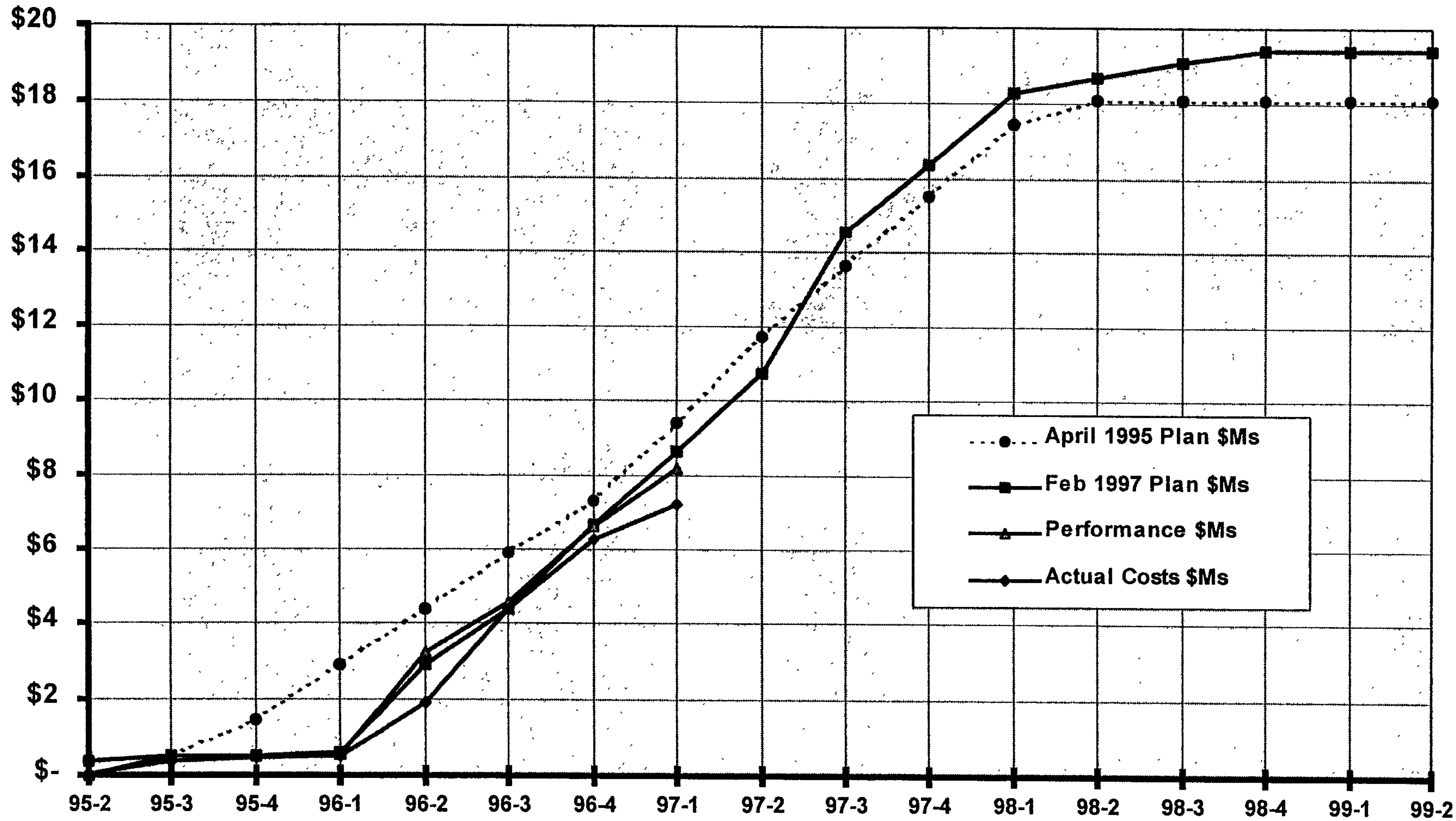
Performance Graphs
(WBS 1.1.1 - Vacuum Equipment)



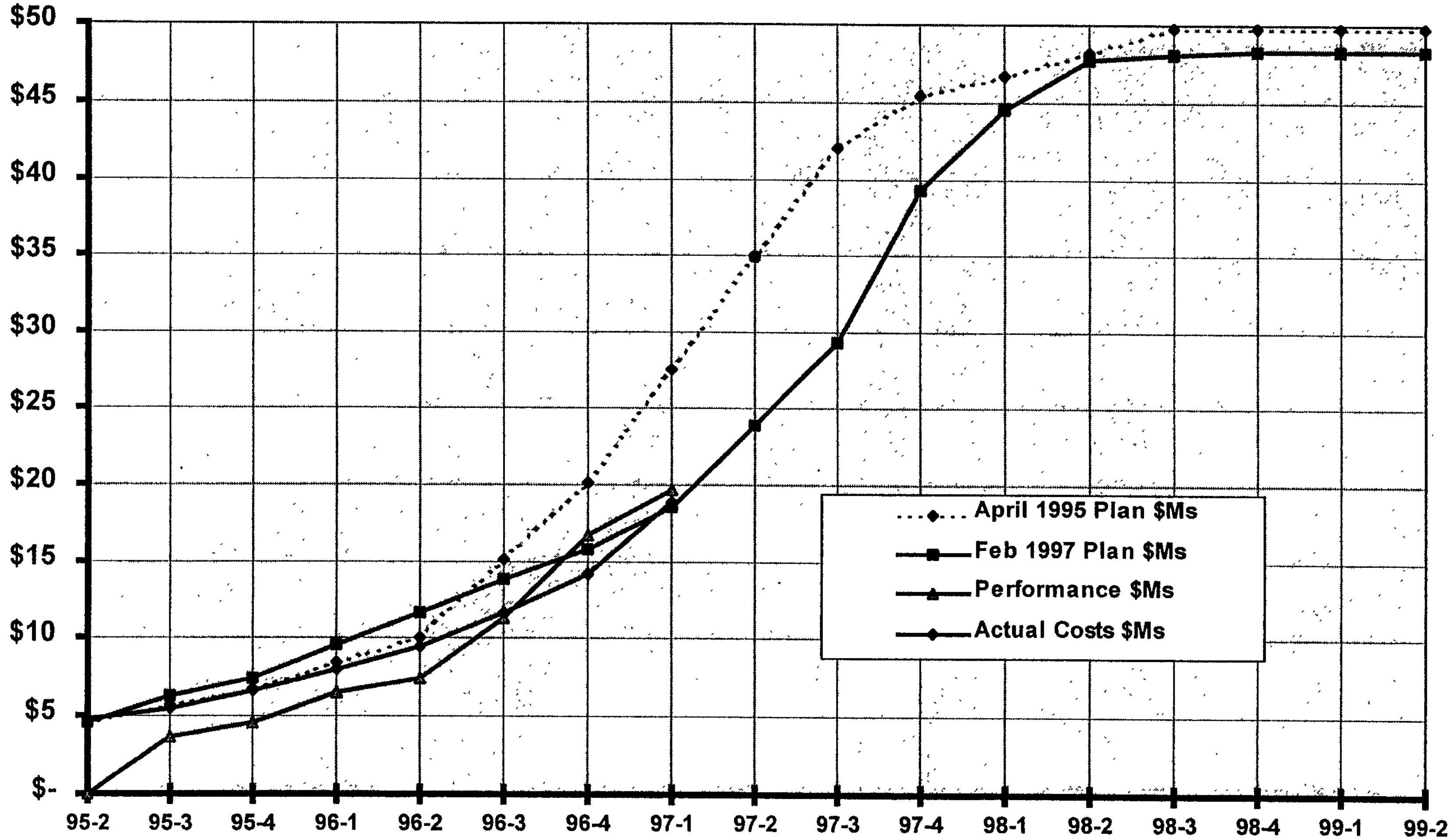
Performance Graphs
(WBS 1.1.2 - Beam Tube)



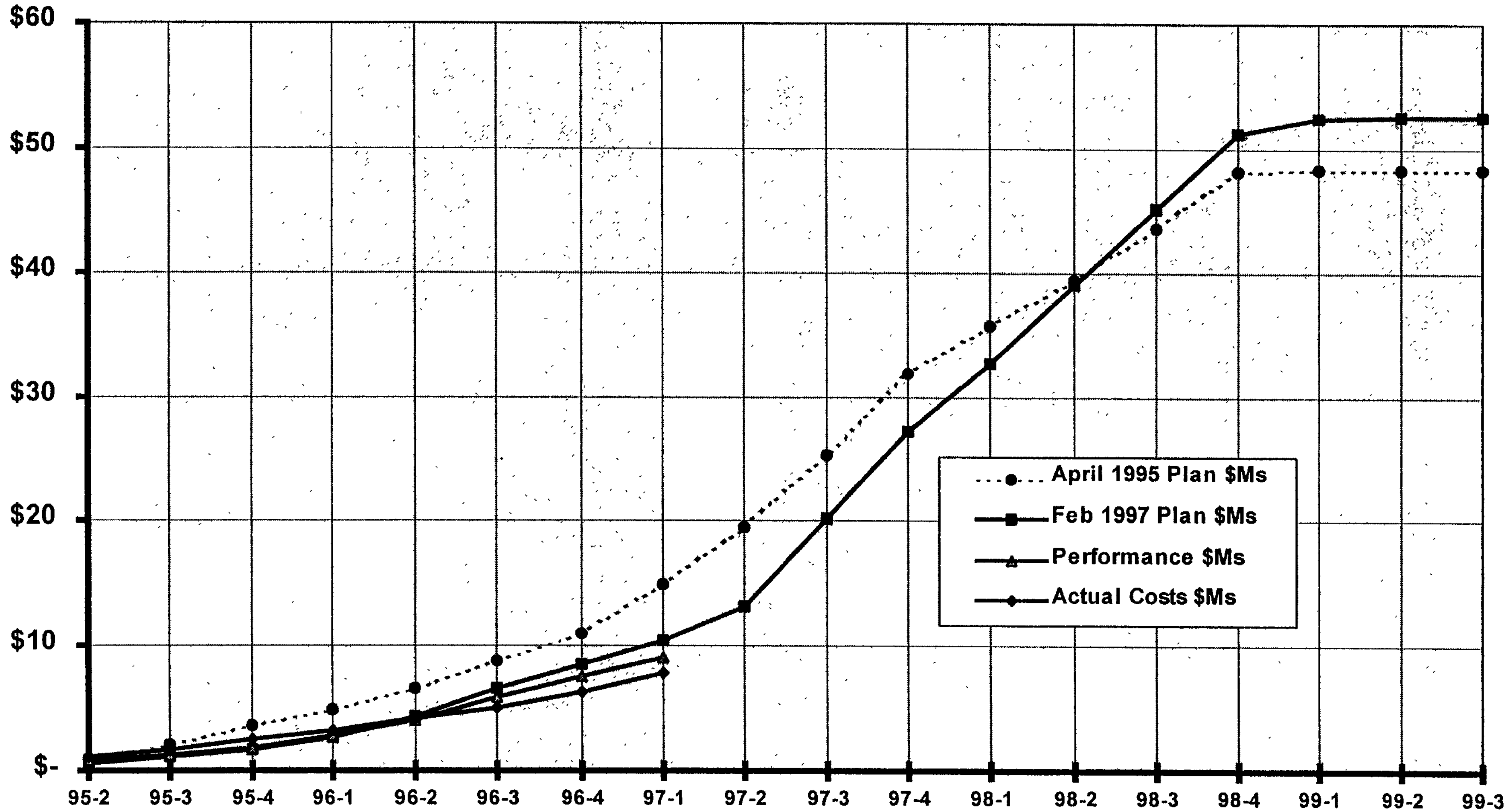
Performance Graphs
(WBS 1.1.3 - Beam Tube Enclosure)



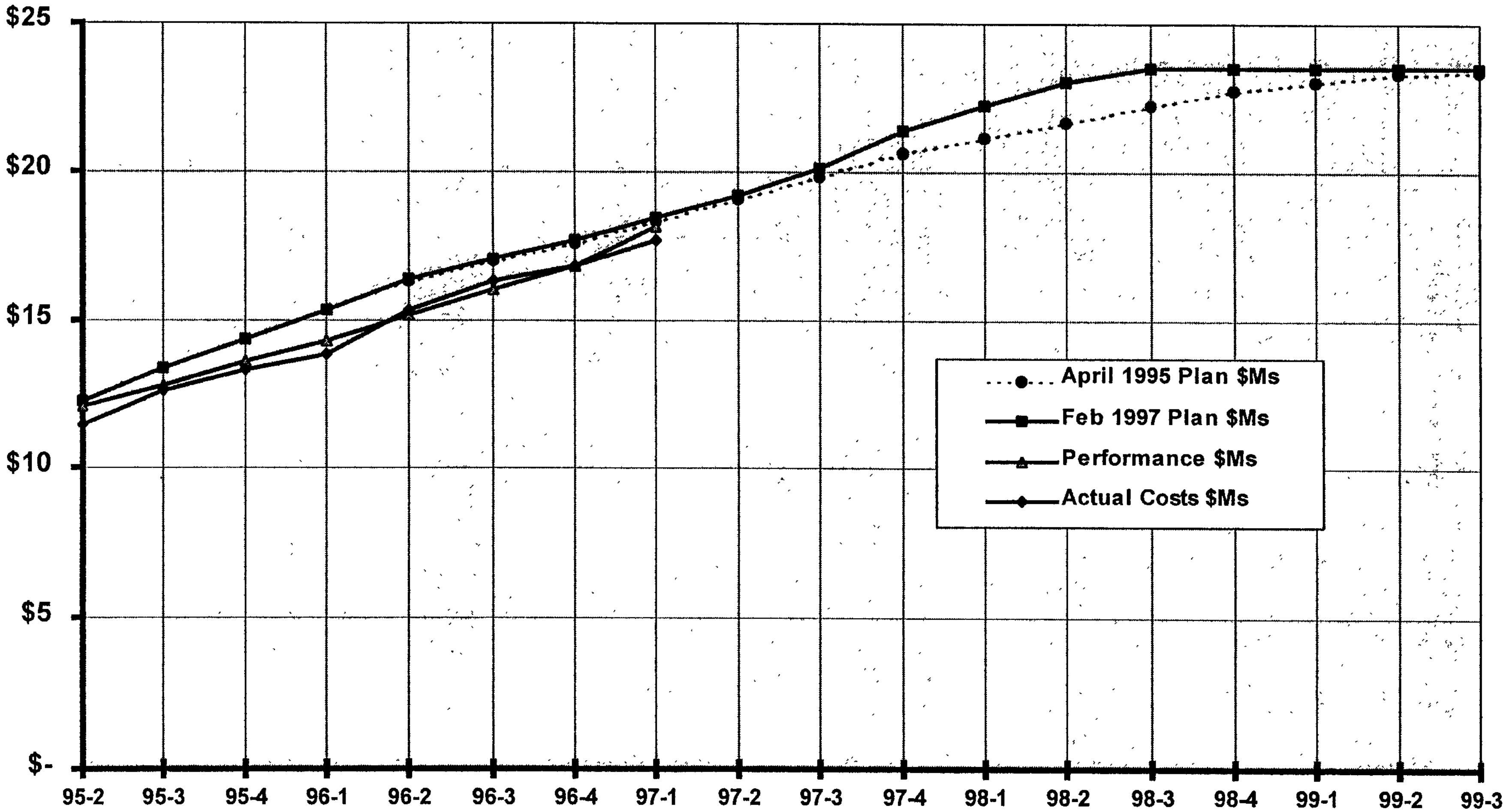
Performance Graphs
(WBS 1.1.4 - Civil Construction)



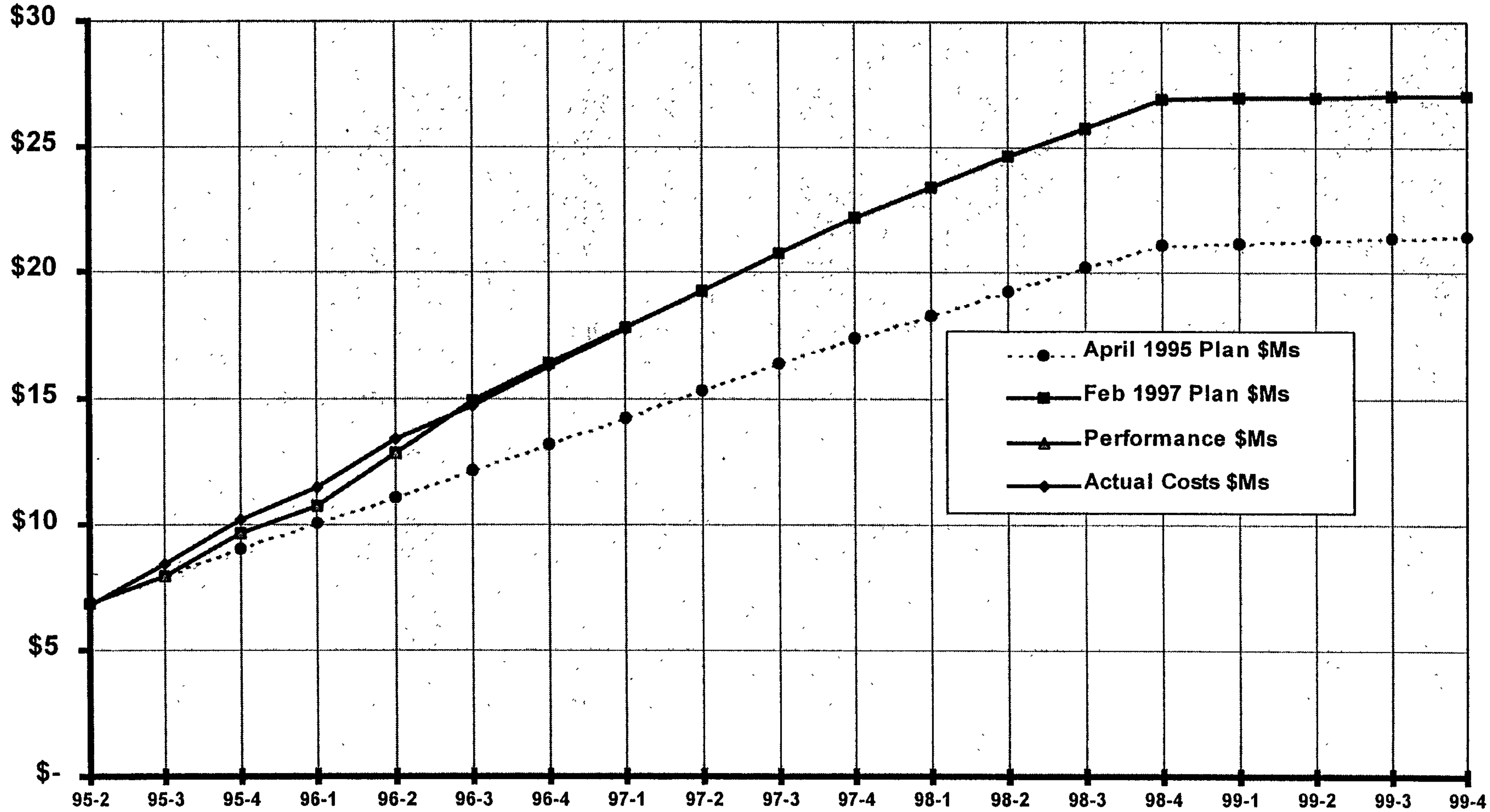
Performance Graphs
(WBS 1.2 - Detector)



Performance Graphs
(WBS 1.3 - Research and Development)



Performance Graphs
(WBS 1.4 - Project Office)



Change Control Log
(Since last NSF Review)

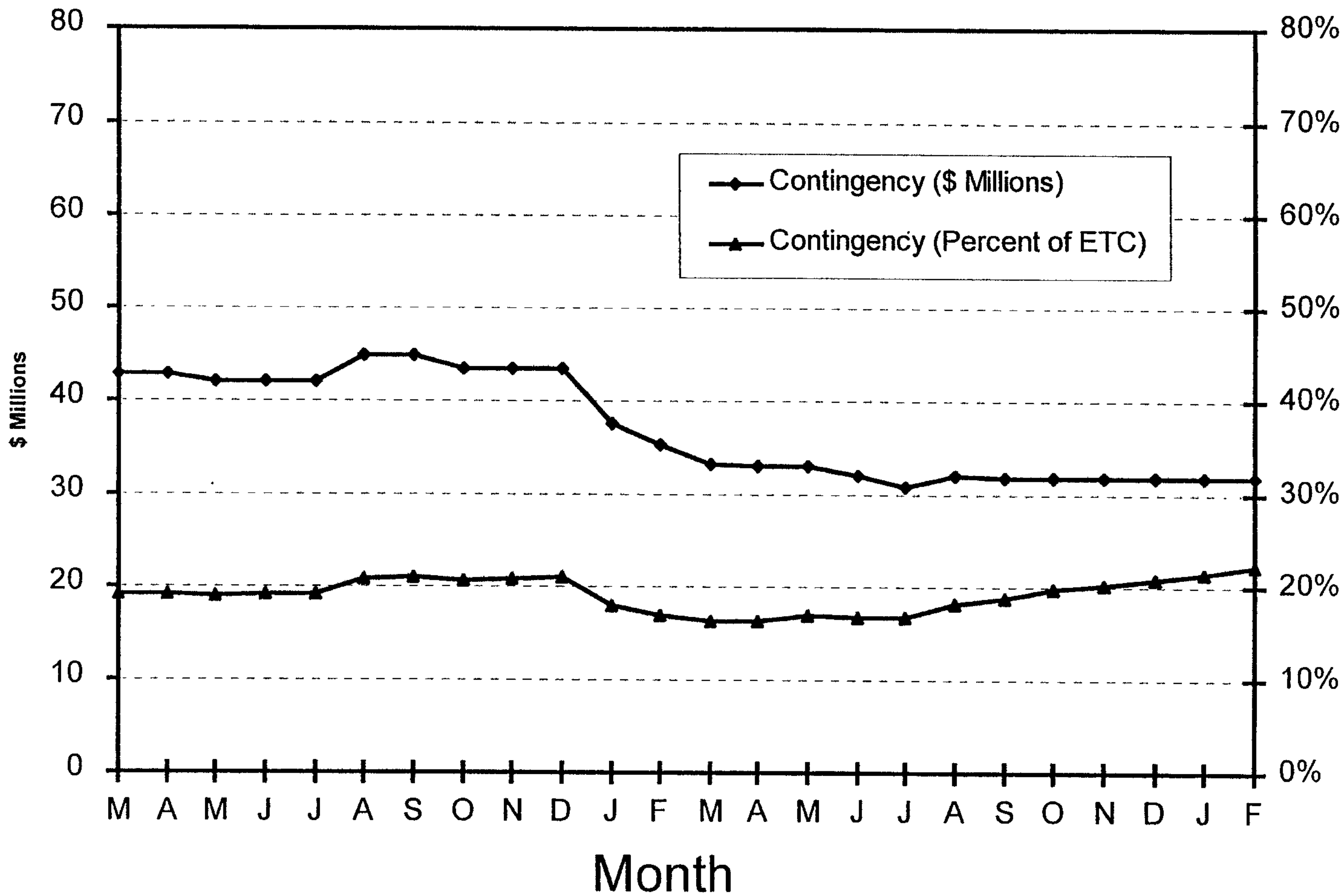
Change Request No.	Description	Submitted By	Submittal Date	Current Status	Disposition Date
CR-970001	WBS 1.1.1 Vacuum Equipment - Replacement of one BSC with proto-type	J. Worden 372-1788	February 7, 1997	Not Approved	March 25, 1997
CR-970002	WBS 1.1.1 Vacuum Equipment - Metal Seal Test	J. Worden 372-1788	February 7, 1997	Approved $21,000	Information only
CR-970003	WBS 1.1.4 Facilities - Air Handling Ducts cleaning procedures and specifications	O. Matherny 372-1788	February 12, 1997	Approved $150,000 NTE	February 13 1996
CR-970004	WBS 1.1.2 - Beam Tube, Transformers	L. Jones	March 12, 1995	Approved ($44,110)	March 25, 1997
CR-970005	WBS 1.1.2 - Beam Tube Miscellaneous	L. Jones	March 12, 1995	Approved $51,200	March 25, 1997

Change Control Log - continued

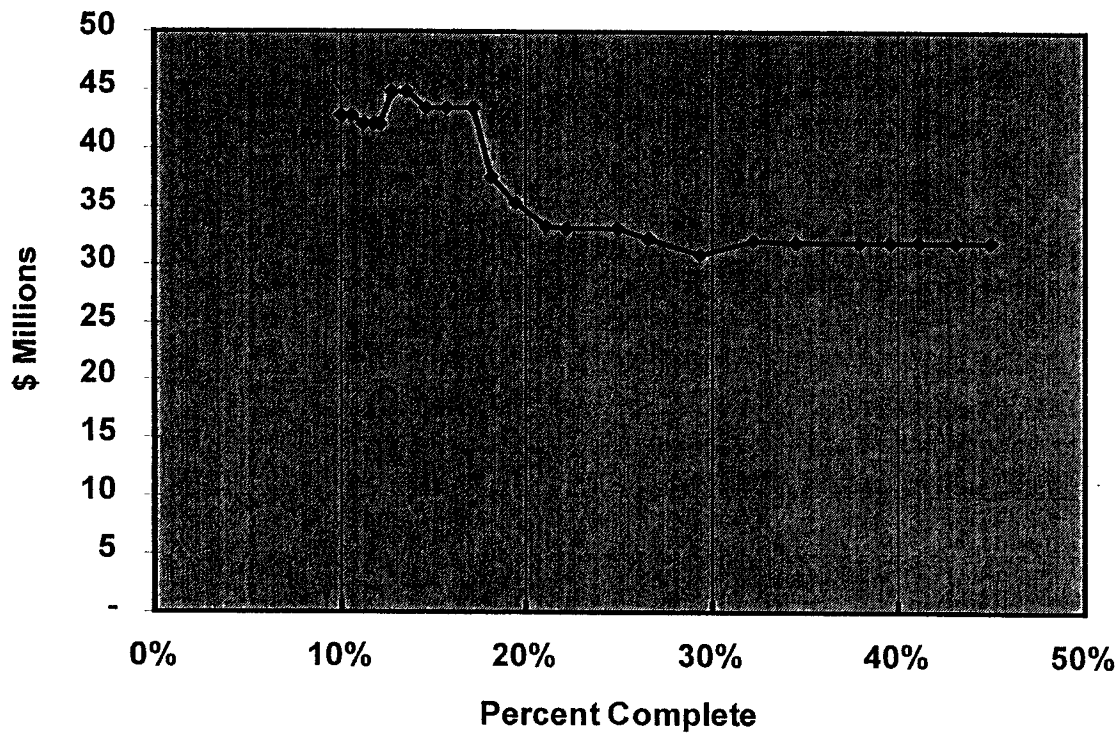
(Since last NSF Review)

Change Request No.	Description	Submitted By	Submittal Date	Current Status	Disposition Date
CR-970006	WBS 1.1.2 - Beam Tube, BDF Air Monitoring	L. Jones	March 12, 1995	Approved $46,130	March 25, 1997
CR-970007	WBS 1.1.2 - Beam Tube, Hanford Labor Rates	L. Jones	March 19, 1995	Approved $61,316	March 25, 1997
CR-970008	WBS 1.1.4 - Cement Treatment of Berm, Livingston, Louisiana Site	F. Asiri	March 21, 1997	Approved Pending Additional Information $900,000	March 25, 1997
CR-970009	WBS 1.2 - Core Optics Components, Reduced Quantity/Unit Price	G. Billings-ley	March 20, 1997	Approved ($881,636)	March 25, 1997
CR-970010	WBS 1.2 - Input/Output Optics, Delete Output Mode Cleaners	J. Camp	March 21, 1997	Approved ($471,000)	March 25, 1997

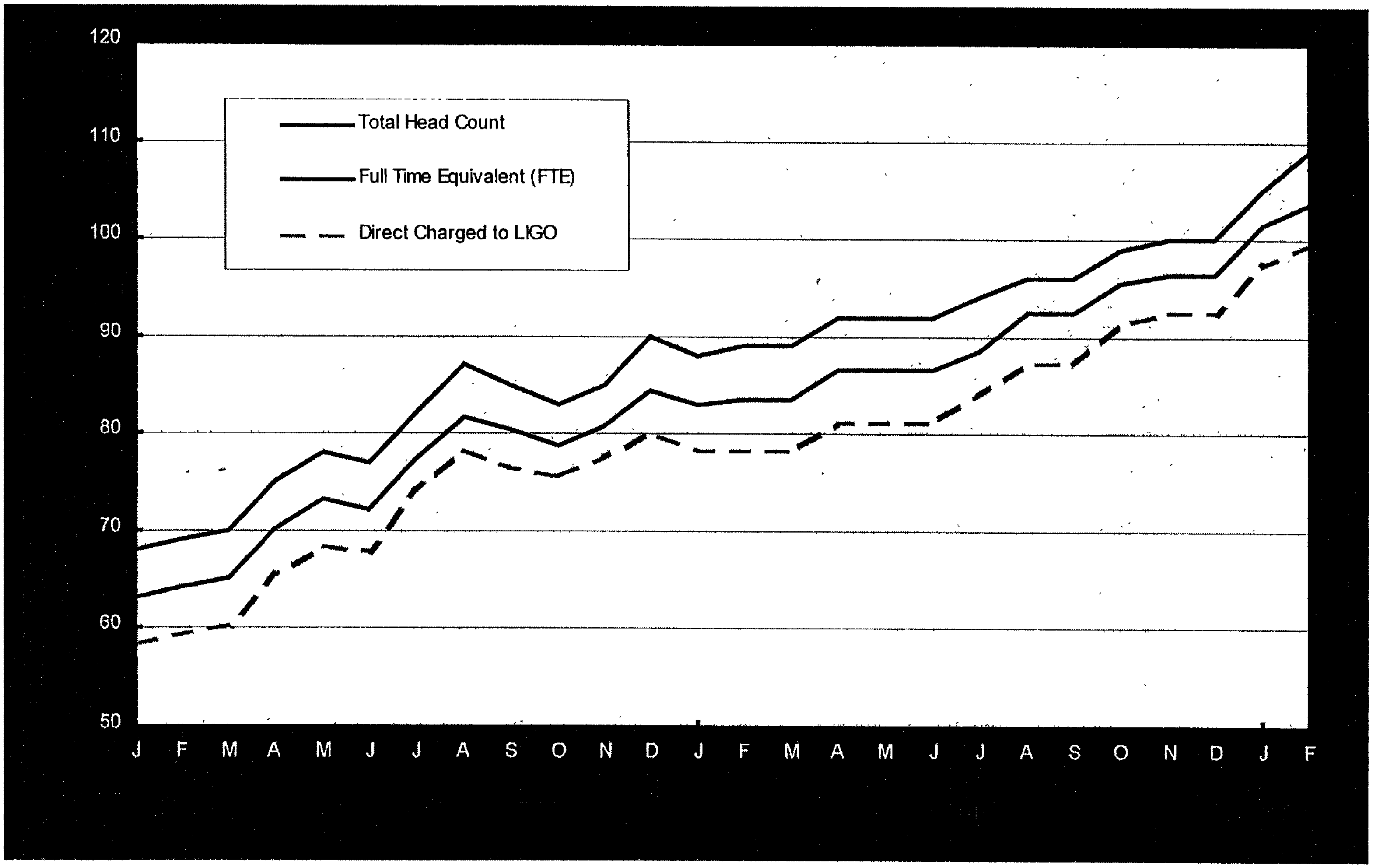
Project Contingency
(As a function of Time)



Project Contingency
(As a function of Percent Complete)



LIGO Staffing History
(Since January 1995)



Detector Cost/Schedule Status

NSF Presentation
April 13, 1997

Richard L. Fischer

Ic

Detector Cost/Schedule Status
Outline

I. Current Detector Organization

II. Current Cost/Schedule Status & Accomplishments

- Detector Cost/Schedule Status
- Schedule Milestones
- Task Group Accomplishments

III. Replanned Detector Schedule

- Beginning Detector Installation Schedule
- Detector Critical Path(s)
- Key Milestone Comparisons

IV. Anticipated Detector Budget

- Anticipated Budget Changes

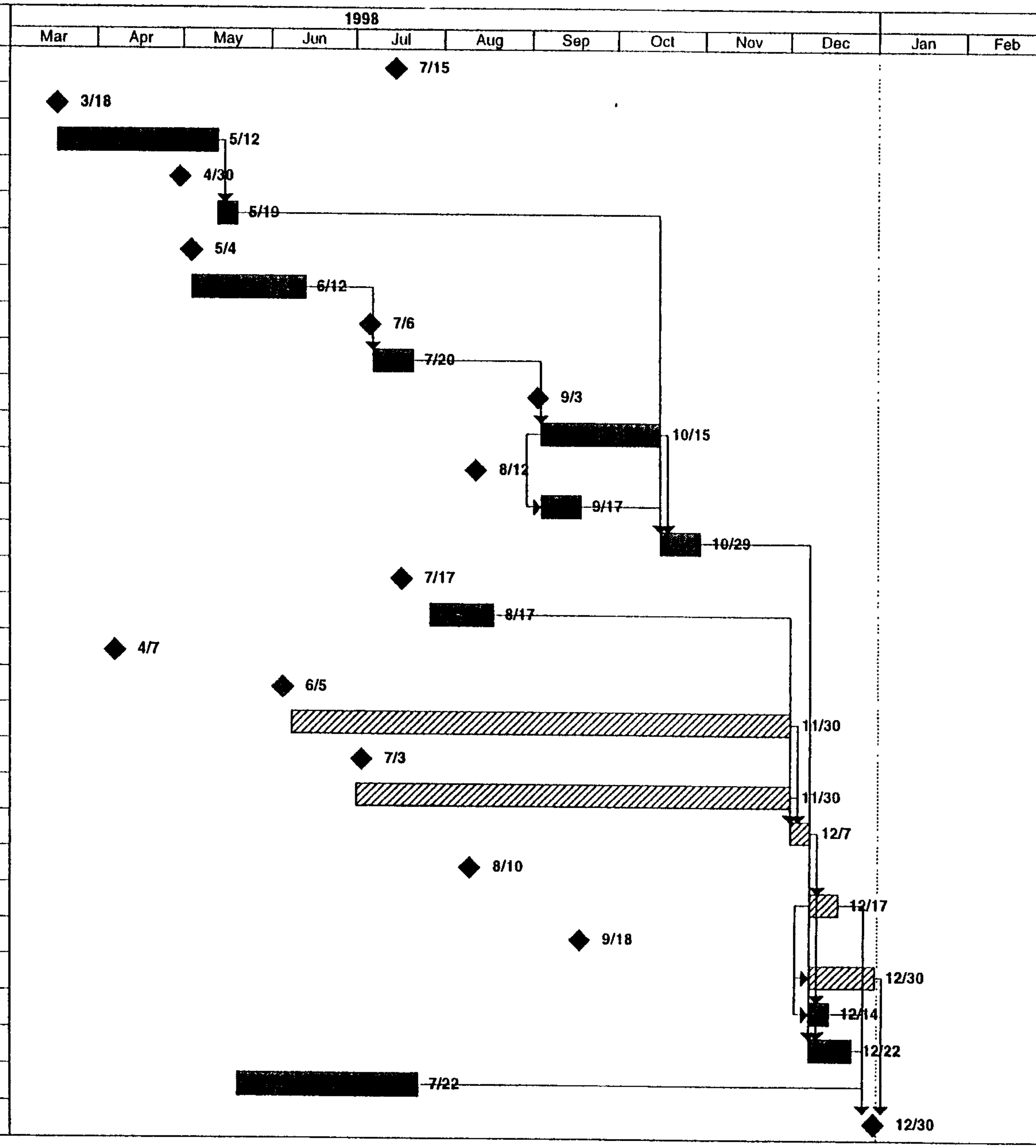
V. Conclusions

Conclusions

1. The Detector Subsystems are Completing Preliminary Design or are in Final Design.
2. Over the Last 12 Months the Detector has Accomplished most of its Milestones.
3. The Detector is Roughly Two Months Behind Schedule and is $1M Under Budget.
4. The Detector is Staffing up - 8 new people in the last 3 months and 13 new people within the last 6 months.
5. The Seismic Stacks and Core Optics Continue to Pace Interferometer Installation as the Critical Path Items.

Begin WA 4K Installation

ID	Task Name	Days	Start	Finish
1	NSF Level 1 - Begin WA Install	0d	7/15/98	7/15/98
2	Receive PSL Prototype	0d	3/18/98	3/18/98
3	Install PSL Prototype	40d	3/18/98	5/12/98
4	Receive PSL Proto Electronics	0d	4/30/98	4/30/98
5	Install PSL Proto Electronics	5d	5/13/98	5/19/98
6	Receive 3 Ham Stacks + 1 HAM	0d	5/4/98	5/4/98
7	Install 3 HAM Stacks + 1 HAM	30d	5/4/98	6/12/98
8	Receive ASC/LSC Hardware	0d	7/6/98	7/6/98
9	Install ASC/LSC Hardware	10d	7/7/98	7/20/98
10	Receive IOO	0d	9/3/98	9/3/98
11	Install 2 IOO	30d	9/4/98	10/15/98
12	Receive IOO Electronics	0d	8/12/98	8/12/98
13	Install IOO Electronics (SOS)	10d	9/4/98	9/17/98
14	Align IOO	10d	10/16/98	10/29/98
15	Receive LOS Electronics	0d	7/17/98	7/17/98
16	Install Suspension Electronics - (LOS)	16d	7/27/98	8/17/98
17	Receive Core Optics	0d	4/7/98	4/7/98
18	Receive LOS Suspensions	0d	6/5/98	6/5/98
19	Assemble 3 COC into Suspension	126d	6/8/98	11/30/98
20	Receive BSC Stacks	0d	7/3/98	7/3/98
21	Install 3 BSC Stacks	109d	7/1/98	11/30/98
22	Install last of 3 COC Susp Assbmly	5d	12/1/98	12/7/98
23	Receive Wave Front Sensing	0d	8/10/98	8/10/98
24	Install 3rd Wavefront Sensing	8d	12/8/98	12/17/98
25	Receive ASC/LSC Electronics	0d	9/18/98	9/18/98
26	Install ASC/LSC Electronics	17d	12/8/98	12/30/98
27	Install last of 3 COS	5d	12/8/98	12/14/98
28	Align COC	11d	12/8/98	12/22/98
29	Install Remote Diagnostics	46d	5/20/98	7/22/98
30	Lock Vertex Michelson	0d	12/30/98	12/30/98



LIGO Detect[illegible] Organization

DETECTOR GROUP

Leader: *S. Whitcomb*

Deputy: *D. Shoemaker*

Lead Engineer: *D. Coyne*

Programmatics: *R. Fischer*

Implementation / Ops / 40m
F. Raab / M. Coles / R. Spero

- *Denise Durance*
- *Stephen Vass*
- *Karthik Naidu **

Lasers and Optics Task Leader: *J. Camp*

COC
- *Gari Billingsley*
- *Bill Kells*
- *Doug Jungwirth*
- *Steve Elieson*
- *William Lee **
- *Alex Golovister*

PSL
- *Rick Savage*
- *Stefan Seel **
- *Lee Cardenas **
- *Peter King **

COS
- *Mike Smith **
- *Dennis Rose **
- *Paul Kabot **

IOO
- *Florida (4 FTEs)**

Suspension and Isolation Task Leader: *M. Fine **

SUSPENSION
- *Janeen Hazel*
- *Seiji Kawamura*
- *Mark B[illegible]ton **

SEISMIC
- *HYTEC (6 FTEs)*

IFO Sensing & Control Task Leader: *M. Zucker*

LSC
- *Lisa Sievers*
- *Nergis Mavalvala*
- *Alex Marin **
- *Peter Csatorday (Grad)*

ASC
- *Peter Fritschel*
- *Daniel Sigg*
- *Ken Mason **

R&D
- *Jennifer Logan (40m)*
- *Brent Ware (40m)*
- *Gabriela Gonzales (PNI)*
- *Haishing Rong (PNI)*
- *Brian Lantz (Grad)*
- *Ralph Burgess (PNI)*
- *Edward Kruzel (PNI)*

Control & Data Systems Task Leader: *R. Bork*

SOFTWARE
- *David Barker*
- *Christine Patton **
- *Tryon Mitchel **

ELECTRONICS
- *Rich Abbott*
- *Jay Heefner*
- *Sander Liu*
- *Oliver McCullough*
- *Paul Russell*
- *Tony Terranova*
- *Dale Ouimette*

* = New Staff since October 1996

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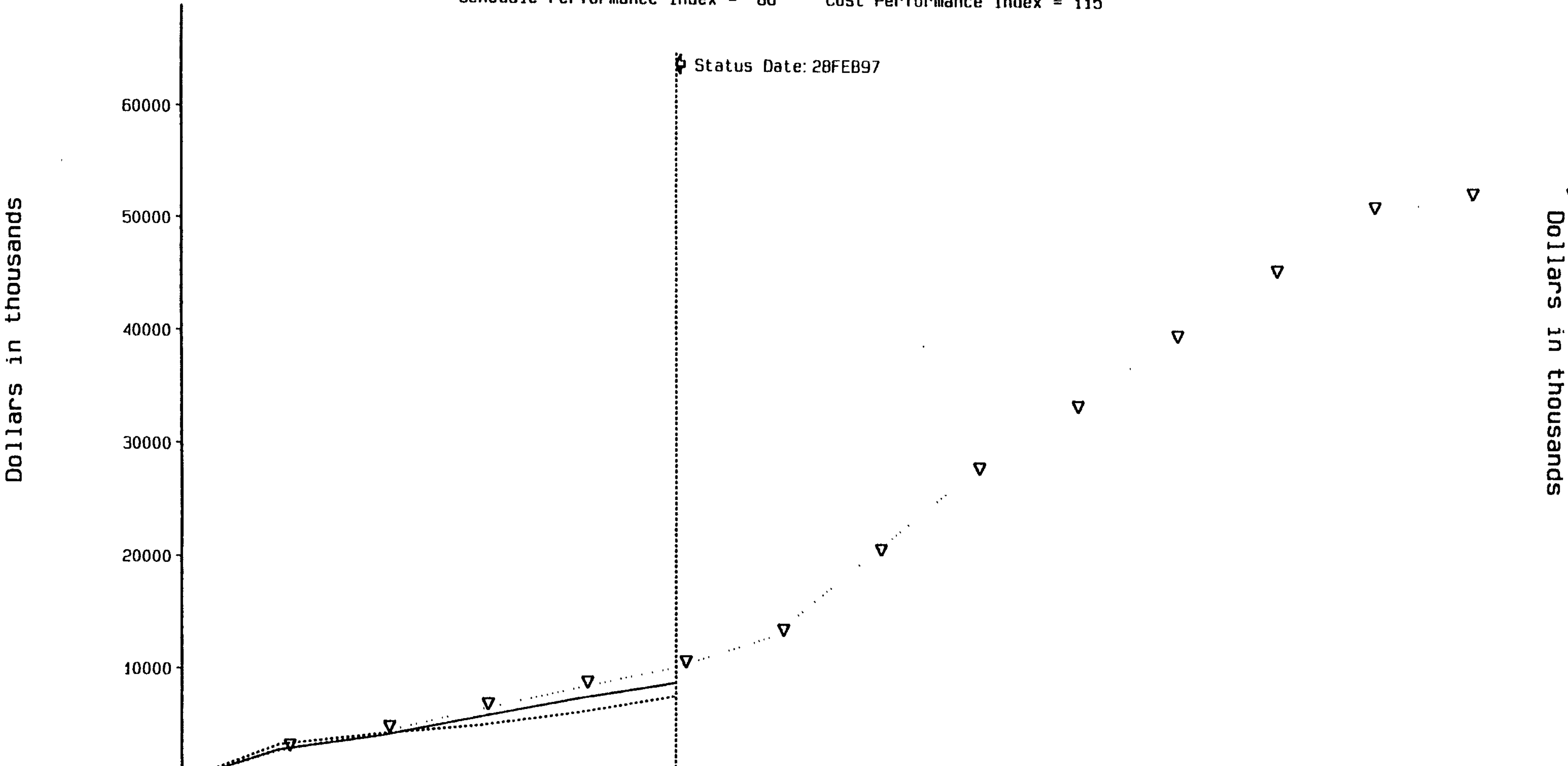
LIGO PROJECT
1.2 Detector

Date: 11APR97
Program. LIGOPMB2
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 86 Cost Performance Index = 115



	FEB96	MAY96	AUG96	NOV96	FEB97	MAY97	AUG97	NOV97	FEB98	MAY98	AUG98	NOV98	FEB99	MAY99
Planned Budget	2,610	4,314	6,421	8,396	10,327	13,178	20,410	27,690	33,257	39,561	45,377	51,165	52,459	52,559
Performance	2,759	4,013	5,780	7,486	8,928									
Actuals	3,218	4,199	5,011	6,231	7,752									
Schedule Variance	149	- 301	- 641	- 910	-1,399									
Cost Variance	- 459	- 186	769	1,255	1,176									

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

Key Near Term Detector Activities-----Month End February 1997

4/11/97

Activity Identification	Milestone Description	Plan Dates	Current Month End Status FEB-1997	Schedule Change (DAYS)
12009100	Award Contract for Nd:YAG Laser Development	Jun-96	May-96	Complete
12045020	PDR for Optics Suspension System	Jun-96	Jun-96	Complete
12033425	DRR II Alignment Sensing Control	Jun-96	Aug-96	Complete
12003020	Test of new Suspension Design on 40m	Jul-96	Aug-96	Complete
12039058	Award Contract for Core Optics Polishing	Dec-96	Oct-96	Complete
12085065	PDR for Global CDS	Jul-96	Sep-96	Complete
12039122	Demonstration of Coating Uniformity	Dec-96	Dec-96	Complete
13220442	Completion of PNI recycling experiments (with AR Laser)	Aug-96	Dec-96	Complete
12009020	Completion of Nd: YAG Master Oscillator Stabilization	Aug-96	Jan-97	Complete
12057020	PDR for Seismic Isolation Stacks	Jan-97	Feb-97	Complete
12033445	PDR for Alignment Sensing Control	Oct-96	Feb-97	Complete
12024075	PDR for Length Sensing Control	Oct-96	May-97	-153
13221935	First Operation of 40m with Recycling Mirror	Apr-97	May-97	-20
12012120	Nd:YAG LASER PDR	Apr-97	Apr-97	0
12062035	PDR for Data Acquisition System	Mar-97	May-97	-45

Level 1 DETECTOR Milestone's - FEB 1997

4/11/97

Milestone Description	Project Mgmt Plan Dates	Current Month End Status Feb-1997	PMP vs Current Month End (Days)
Pre-Stabilized Laser FDR	8/30/98	7/30/98	22
Input/Output Optics FDR	4/30/98	5/19/98	-15
Length Sensing Control FDR	5/30/98	12/15/97	110
Wavefront FDR	4/30/98	2/13/98	56
Core Optics Components FDR	7/30/97	10/27/97	-66
Core Optics Support FDR	4/30/97	12/9/97	-181
BSC Stack Final Design Review	7/30/97	8/21/97	-16
HAM Stack Final Design Review	7/30/97	8/21/97	-16
Control Data System DAQ FDR	4/30/98	5/28/98	-22
Physics Environ Monitoring FDR	6/30/98	8/6/97	-22
WA Cntl Area/Net Sys Ready To Install	9/30/97	9/29/97	0
Detector System Prelim Design Review	12/30/97	4/3/98	-88
Begin WA IFO Installation	7/30/98	7/30/98	0
Begin LA IFO Installation	1/30/99	1/30/99	0
Begin COINCIDENCE TEST	12/31/00	12/31/00	0

Laser/Optics
Schedule Accomplishment

A. Core Optics Accomplishments

1. Awarded Glass Contracts with Heraus and Corning - Oct '96
   - Corning - expect 17 of 21 pieces delivered by 1 May '97
   - Heraeus - expect first deliveries in June '97
2. Awarded Polishing Contracts with CSIRO, G.O. - Dec '96
   - CSIRO, 4 of 4 FMs in polishing; 2 of 4 ETMs in Figuring
   - G.O. , 4 of 8 ETMs in final polishing
3. Achieved Coating Uniformity Consistent with LIGO Reqs.- Dec '96
4. Added new optical engineer, William Lee

B. Input Optics (IOO) Accomplishments

1. Awarded University of Florida contact - Summer '96
2. Held Input Optics Requirement Review - Oct '96
3. Input Optics Preliminary Design Review scheduled for June '97

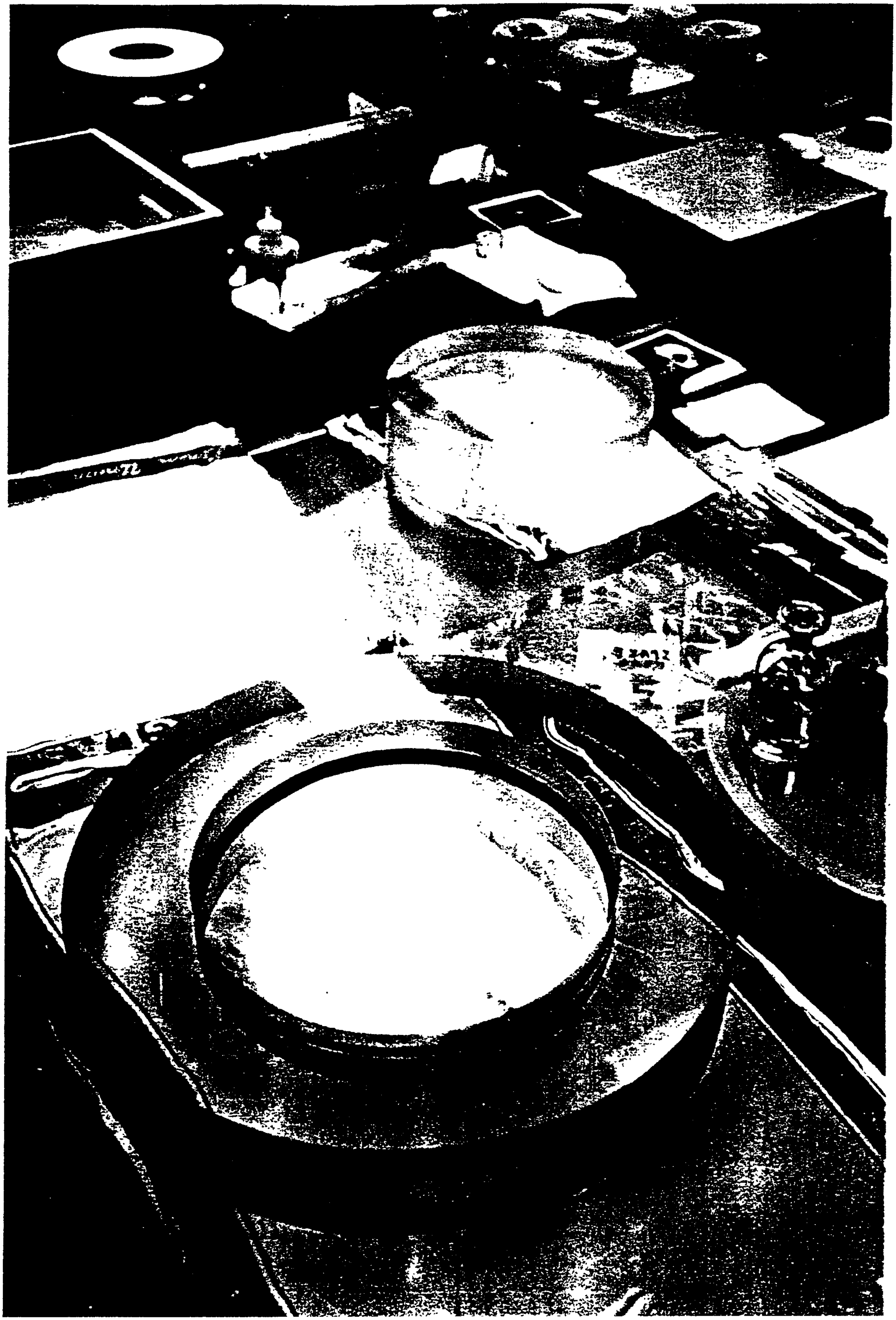
Laser/Optics
Schedule Accomplishment - continued

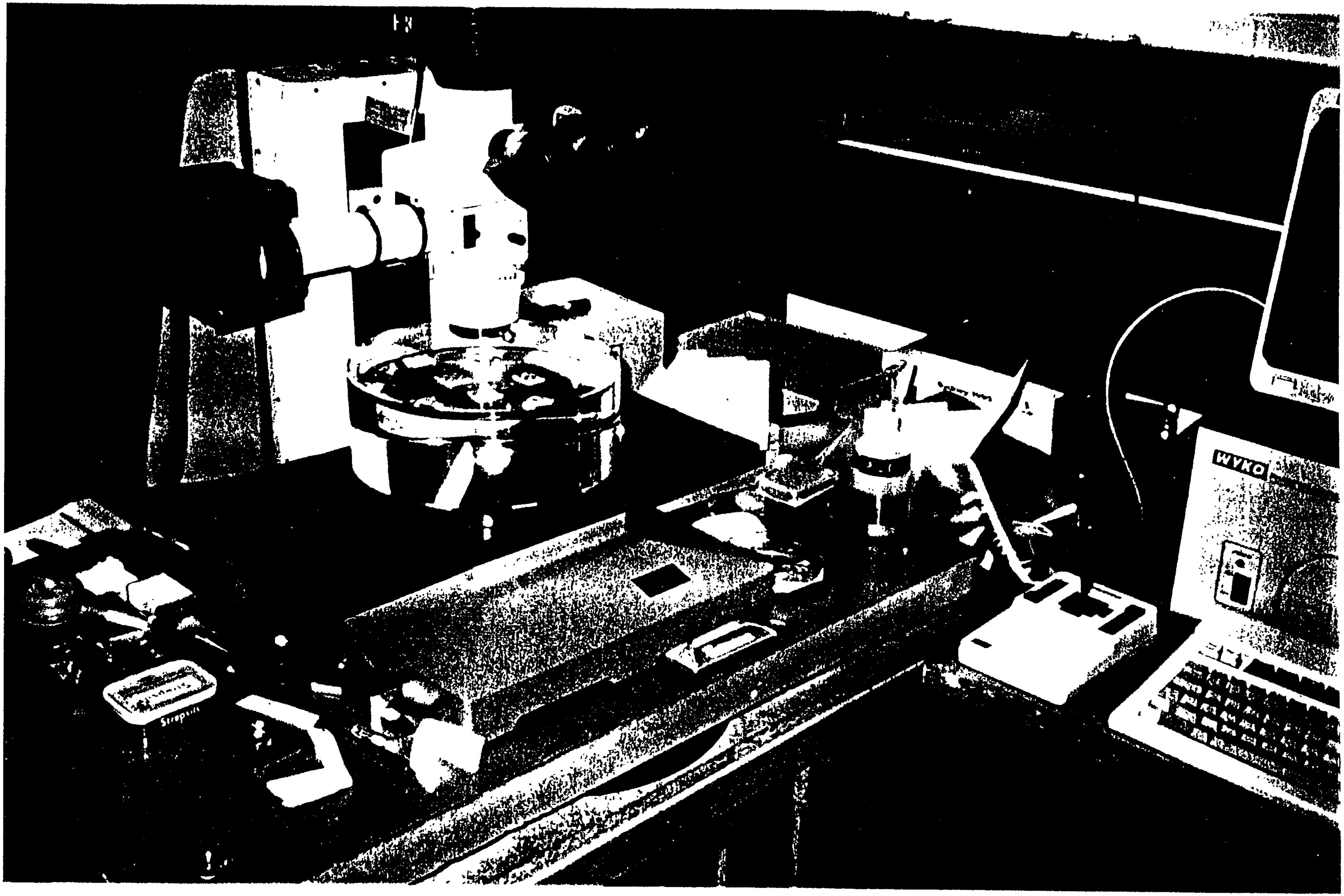
C. Pre-Stabilized Laser

1. Awarded Lightwave contract - Jun '96
2. Held YAG Laser Conceptual Design Review - Dec '96
3. Hired two laser scientist and a junior engineer - King, Seel, Cardinas - Mar '97
4. Laser Preliminary Design Review scheduled for the April 25th (>10w)
5. PSL Requirements Review is scheduled for May '97

D. Core Optics Support

1. Hired New Physicist, Mike Smith, - Nov '96
2. Held COS Requirements Review - April '97
3. Hired Optical Designer, Dennis Rose - Apr '97
4. Started Preliminary Design and mock-up
5. Preliminary Design Review Scheduled for July '97

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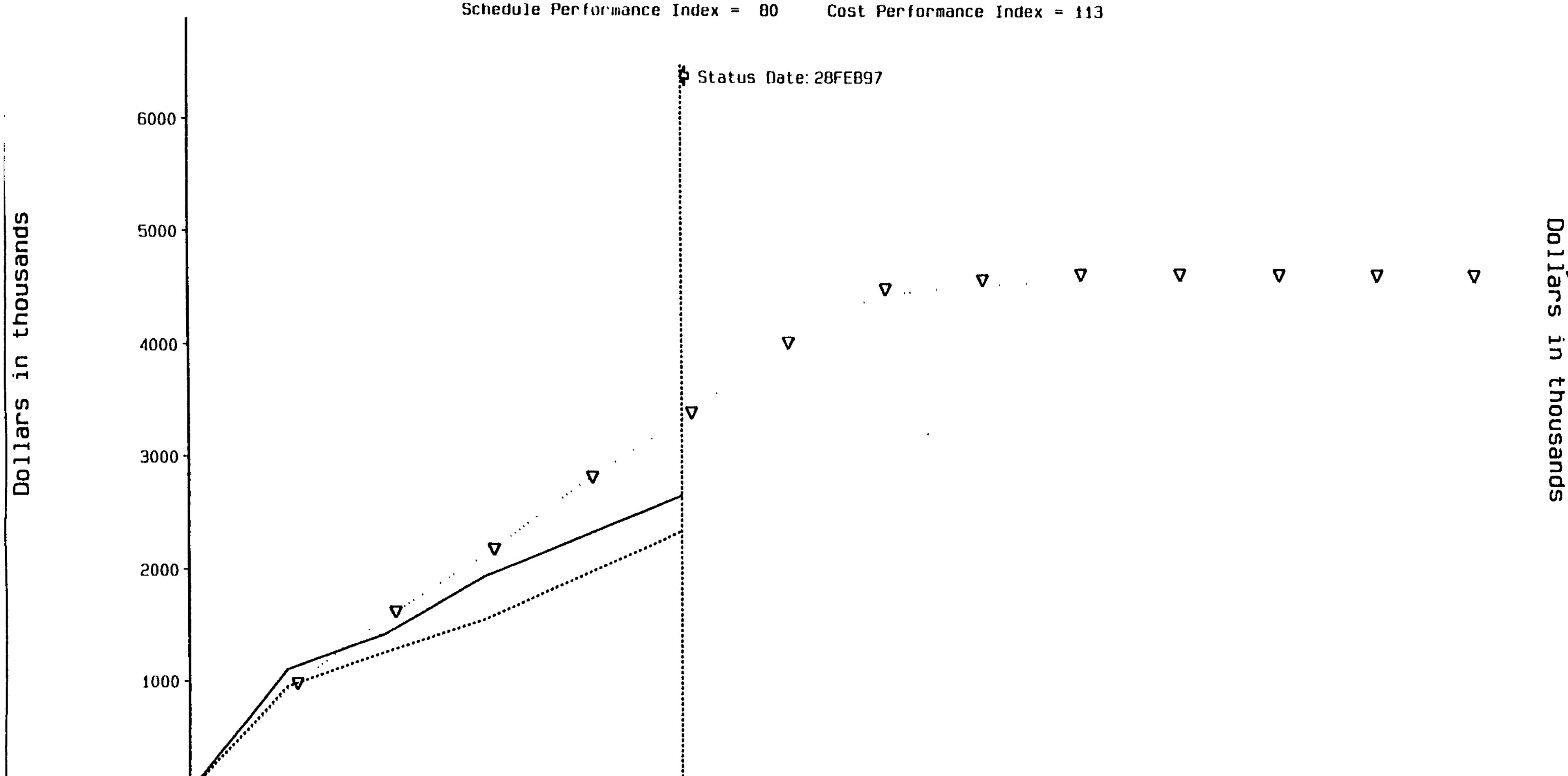
LIGO PROJECT
LASER / OPTICS (5E512, 5E513, 5E514, 5E515)

Date: 11APR97
Program. LIGOPMB2
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 80 Cost Performance Index = 113



	FEB96	MAY96	AUG96	NOV96	FEB97	MAY97	AUG97	NOV97	FEB98	MAY98	AUG98	NOV98	FEB99	MAY99
Planned Budget	921	1,565	2,134	2,768	3,348	3,974	4,445	4,529	4,580	4,586	4,586	4,586	4,586	4,586
Performance	1,103	1,421	1,940	2,305	2,663									
Actuals	953	1,257	1,552	1,949	2,354									
Schedule Variance	182	- 144	- 194	- 463	- 685									
Cost Variance	150	164	388	356	309									

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

Seismic/Suspension Schedule Accomplishments

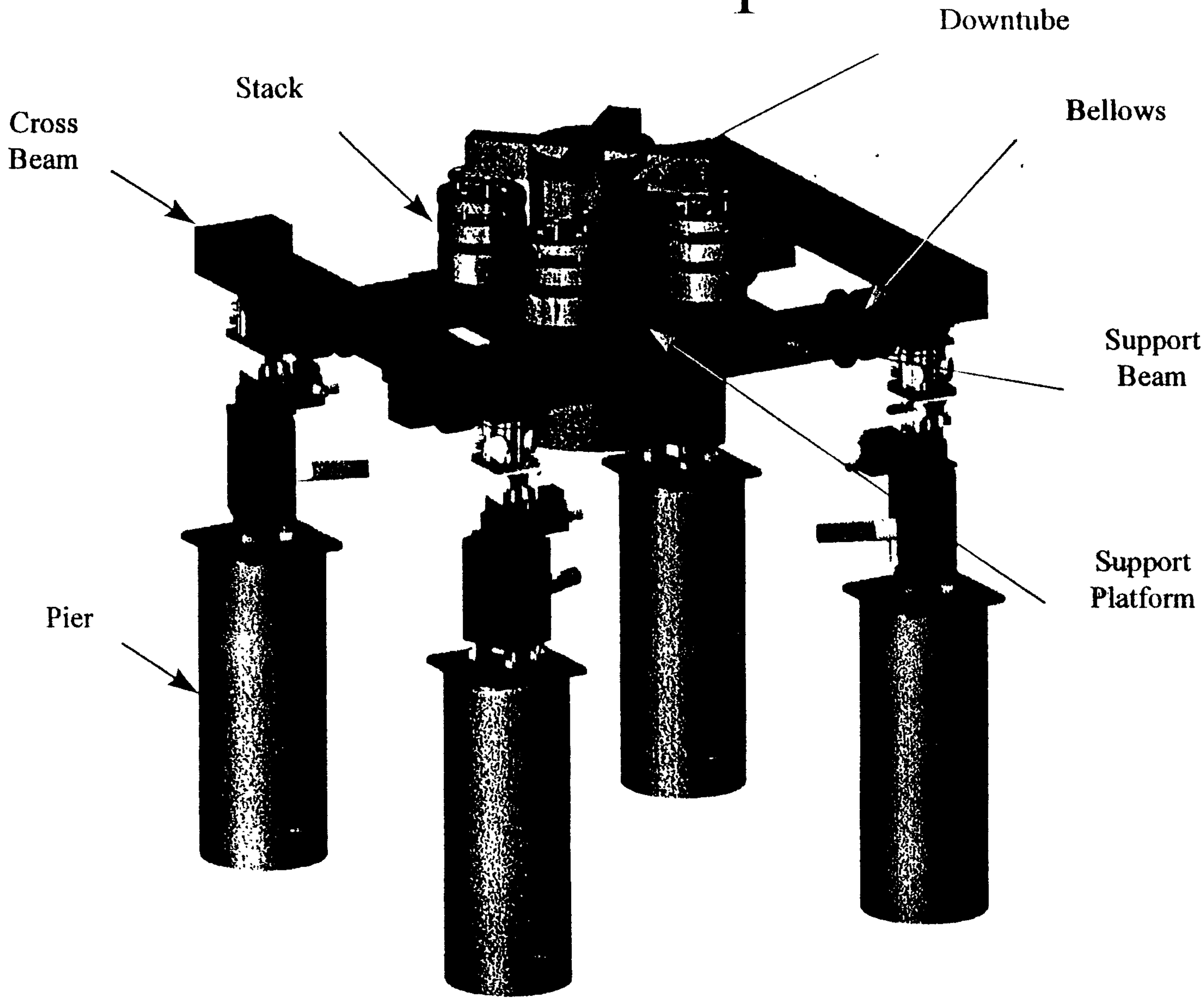
A. Seismic Isolation System

1. Hired New Task Leader, Mike Fine, - Oct '96
2. Held BSC/HAM Stack Preliminary Design Review with HYTEC - Mar '97
3. Developed two spring designs for prototype testing, Decision June '97
4. Completed Replan to allow for 1st Article testing before production
5. 1st Article Readiness Review June '97
6. Place 1st Article Hardware contracts June '97

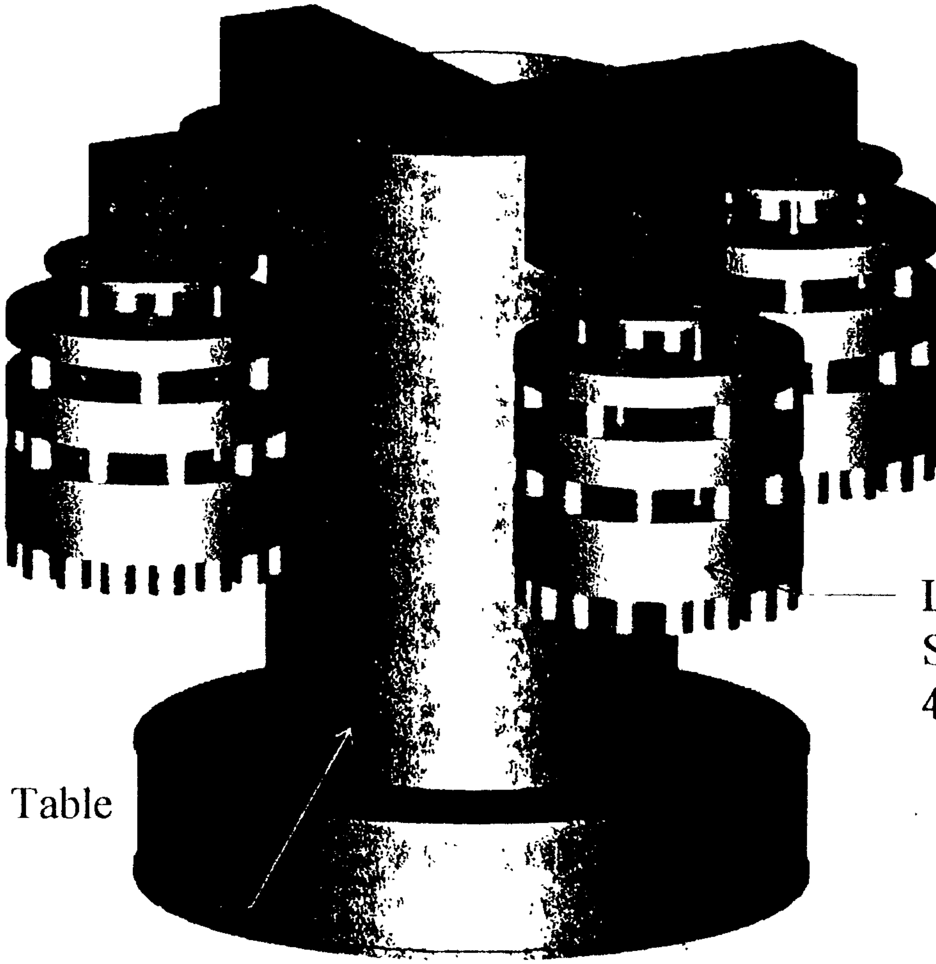
B. Suspension Systems

1. Held Suspension Prelim Design Review June '96
2. Have Built a Large Optic and a Small Optic Suspension prototype
3. Suspension Final Design Review is scheduled for June '97
4. New suspension scientist, Mark Barton, to start July '97

BSC SEI Components



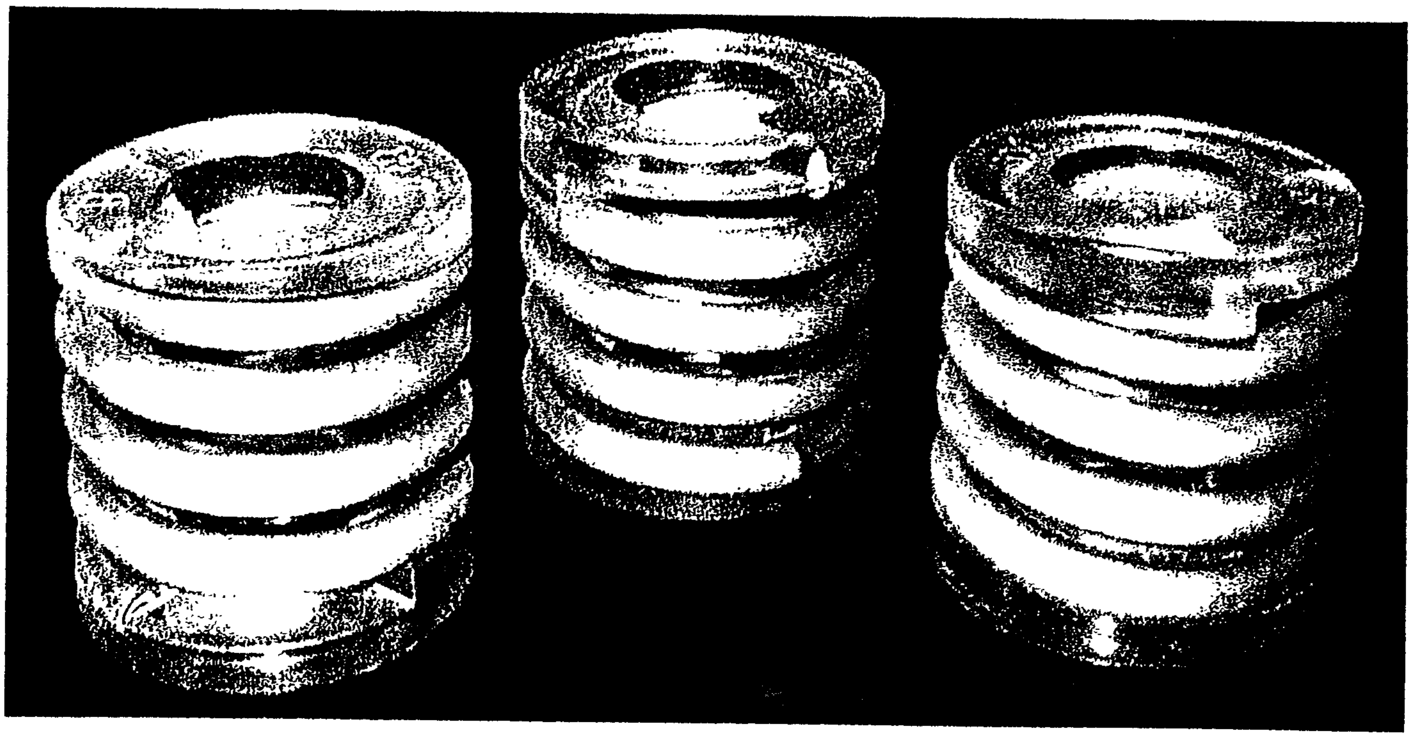
Isolation Stack Assembly



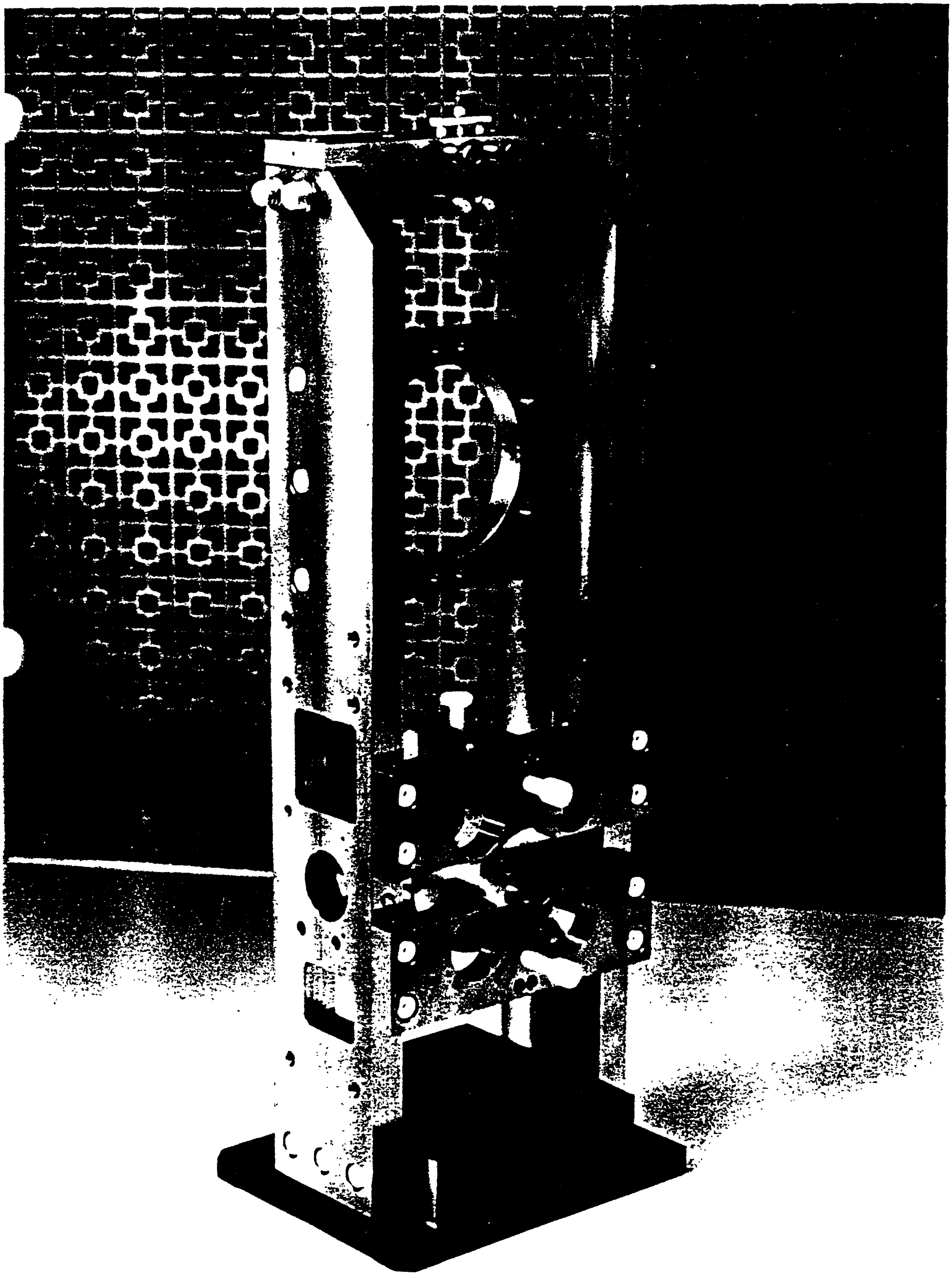
Legs: 4x 3 elements
Stainless Steel
4 x 578 kg (1272 lb)

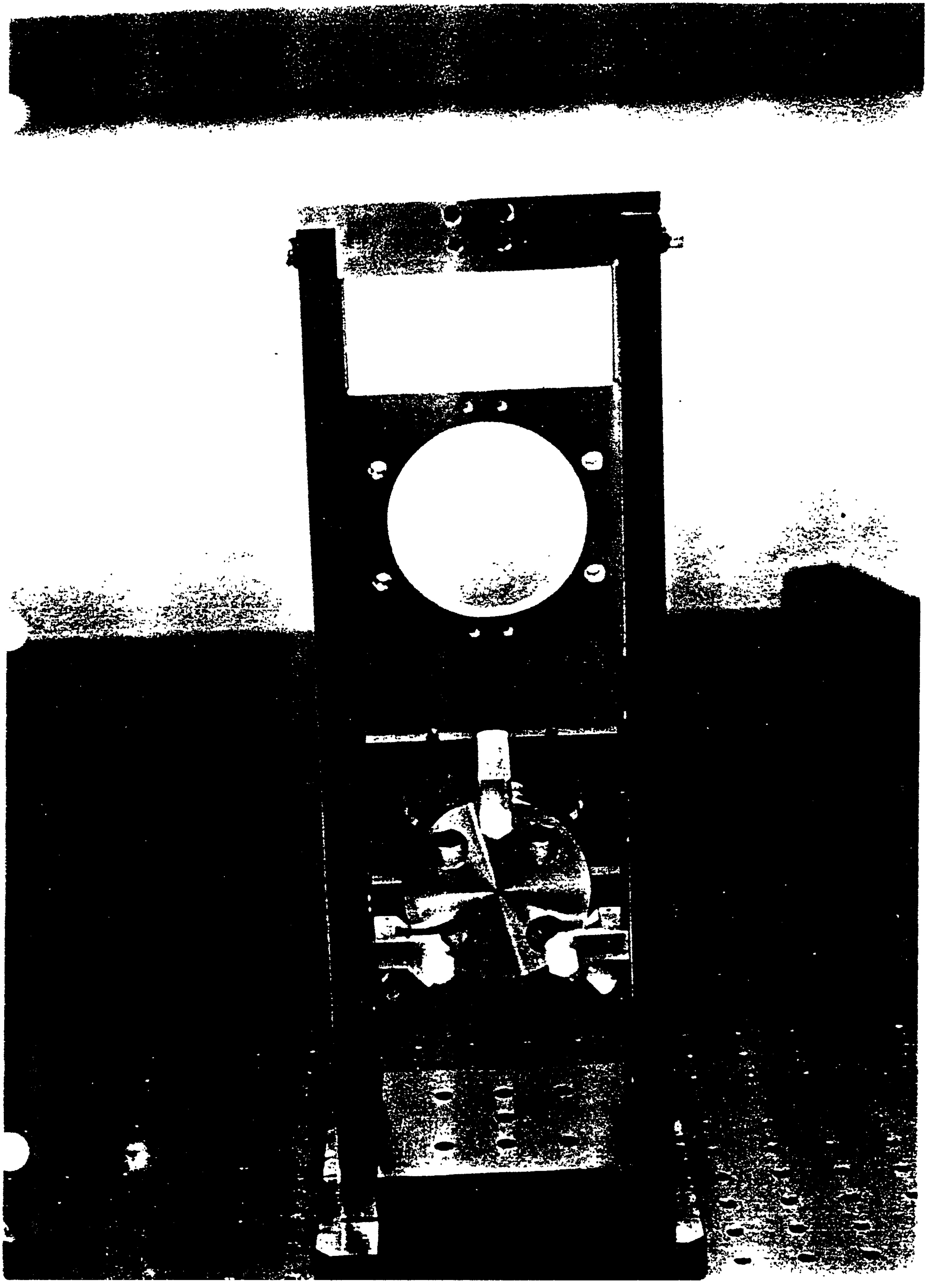
Downtube/Optics Table
Aluminum
424 kg (935 lb)

Total Weight = 2733 (6025 lb)



LIGO-G970069-06-D





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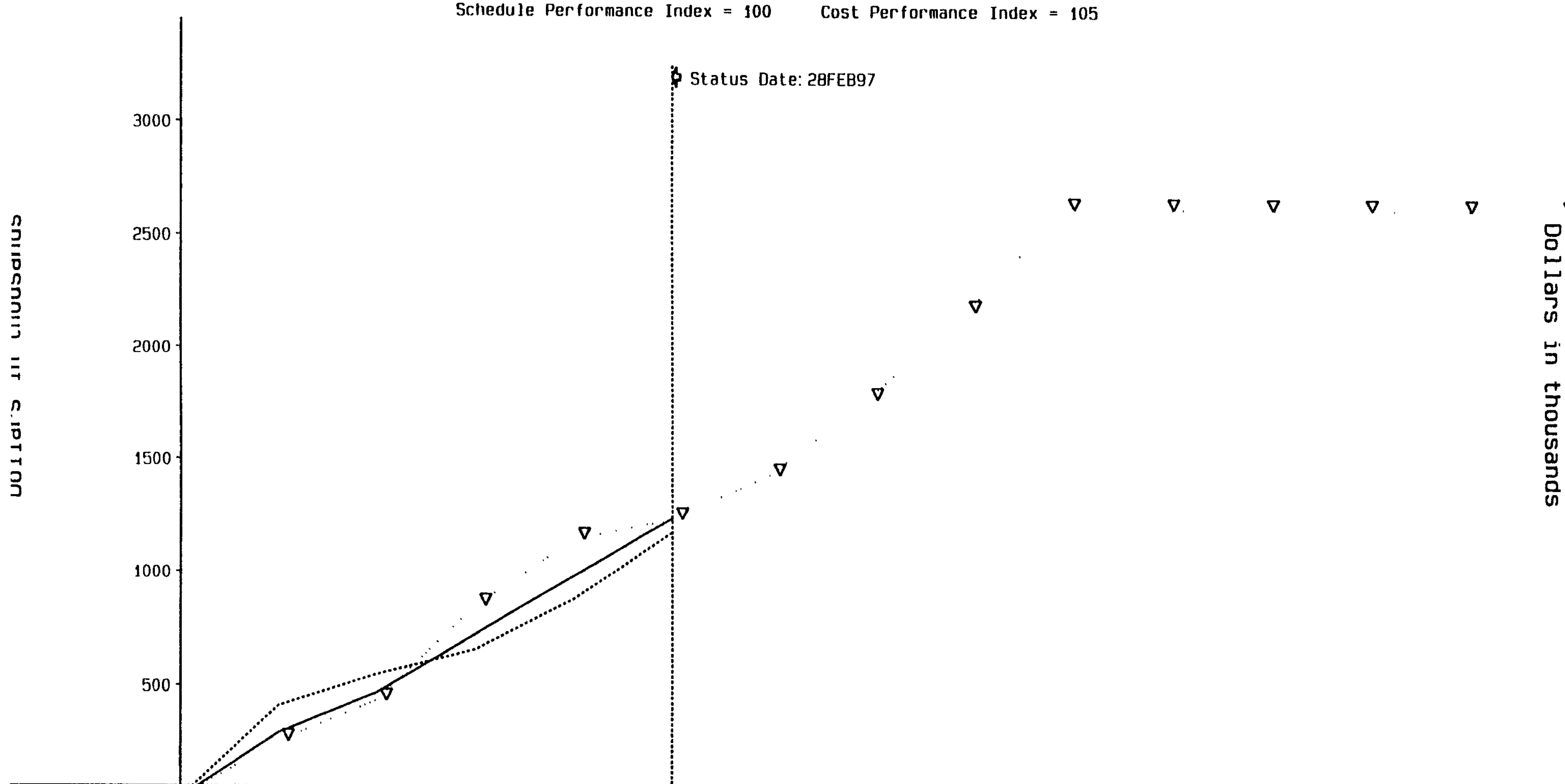
LIGO PROJECT
VIBRATION ISOLATION (5E511, 5E518)

Date: 11APR97
Program: LIGOPMB2
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 100 Cost Performance Index = 105



	FEB96	MAY96	AUG96	NOV96	FEB97	MAY97	AUG97	NOV97	FEB98	MAY98	AUG98	NOV98	FEB99	MAY99
Planned Budget	253	433	849	1,145	1,237	1,434	1,773	2,171	2,623	2,623	2,623	2,623	2,623	2,623
Performance	290	467	725	984	1,241									
Actuals	409	548	658	880	1,178									
Schedule Variance	37	34	- 124	- 161	4									
Cost Variance	- 119	-81	67	104	63									

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

Interferometer Sensing and Control (ISC) Schedule Accomplishments

A. Alignment Sensing and Control (ASC)

1. Completed simulation software for Interferometer Lock Acquisition - Sept '96
2. Completed FMI experiment validating Modal Alignment Model - Nov '96
3. Successfully tested the Wavefront Sensing Alignment Control concept - Nov '96
4. Held ASC Requirements Review - Aug '96
5. Held ASC Preliminary Design Review - Feb '97

B. Length Sensing and Control

1. Hired New Engineer, Ken Mason, for ASC/LSC design and fab - Jan '97
2. Held LSC Requirements Review - April '96
3. LSC Preliminary Design Review is scheduled for May '97

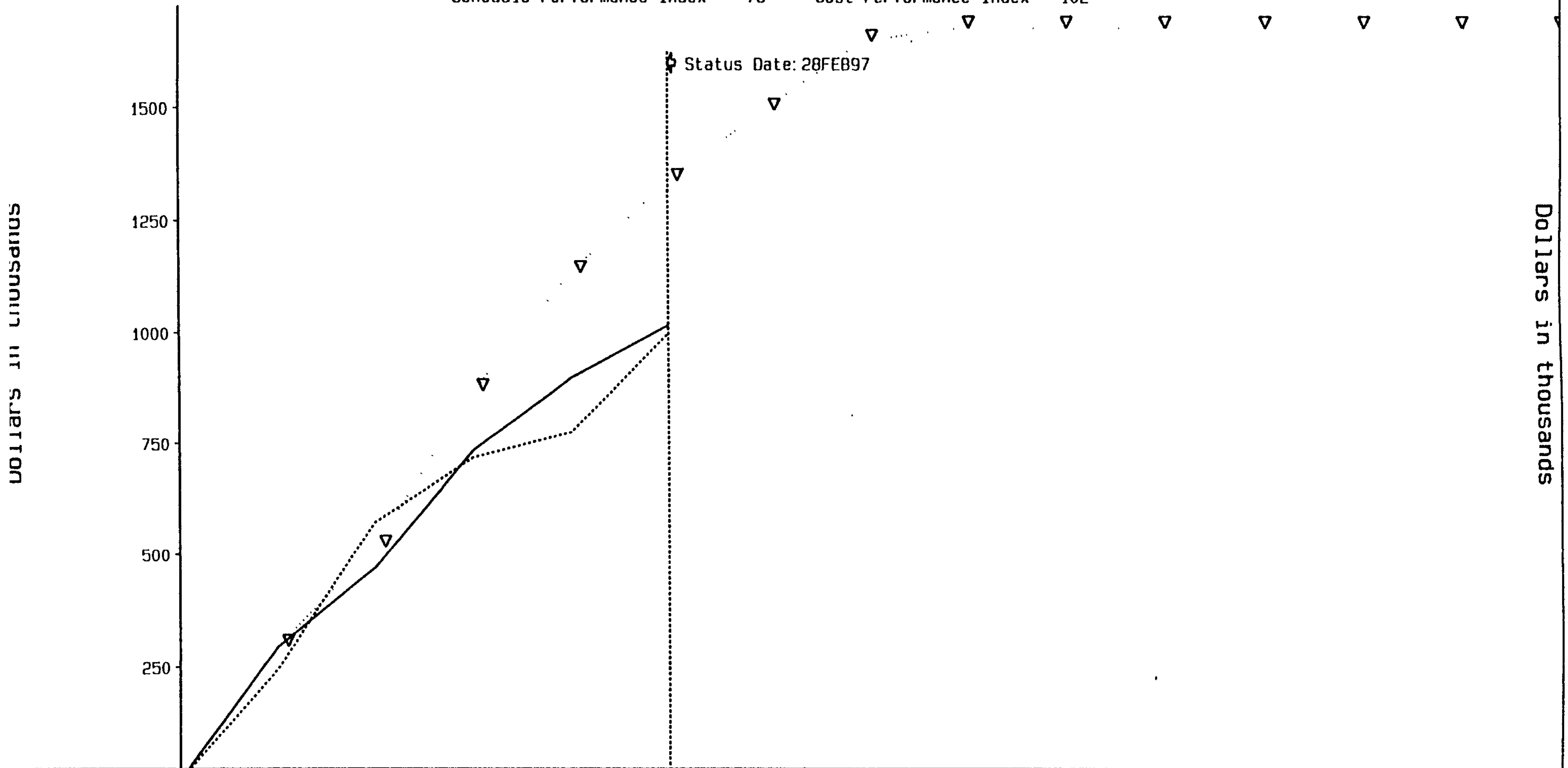
LEGEND	
Bud	▽ ▽ ▽
Per	——
Act	········

LIGO PROJECT
INTERFEROMETER SENSING CONTROL (5E516, 5E517)

Date: 11APR97
Program LIGOPMB2
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 76 Cost Performance Index = 102



	FEB96	MAY96	AUG96	NOV96	FEB97	MAY97	AUG97	NOV97	FEB98	MAY98	AUG98	NOV98	FEB99	MAY99
Planned Budget	296	517	871	1,135	1,339	1,496	1,648	1,678	1,678	1,678	1,678	1,678	1,678	1,678
Performance	295	470	735	900	1,018									
Actuals	245	573	719	776	999									
Schedule Variance	-1	-47	-136	-235	-321									
Cost Variance	50	-103	16	124	19									

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

Control and Data Systems (CDS) Schedule Accomplishments

A. General CDS

1. Established CDS at Hanford with 3 software engineers including two new staff hires - Mar '97
2. Procured first 20 Racks and VME Crates to Hanford

B. Vacuum Controls

1. Completed Vac Controls Prelim and Final Design Reviews
2. Vac Control System and Software in fabrication
3. First Vac Control Hardware Ready on Schedule - Aug '97

C. ASC - CDS

1. Completed conceptual design and held Requirements Review
2. Prototype hardware is on order

D. NPRO PSL Controls

1. Designed, fabricated, tested and shipped one NPRO Laser Controls System to MIT for use in the PNI

LEGEND
Bud ▽ ▽ ▽
Per ————
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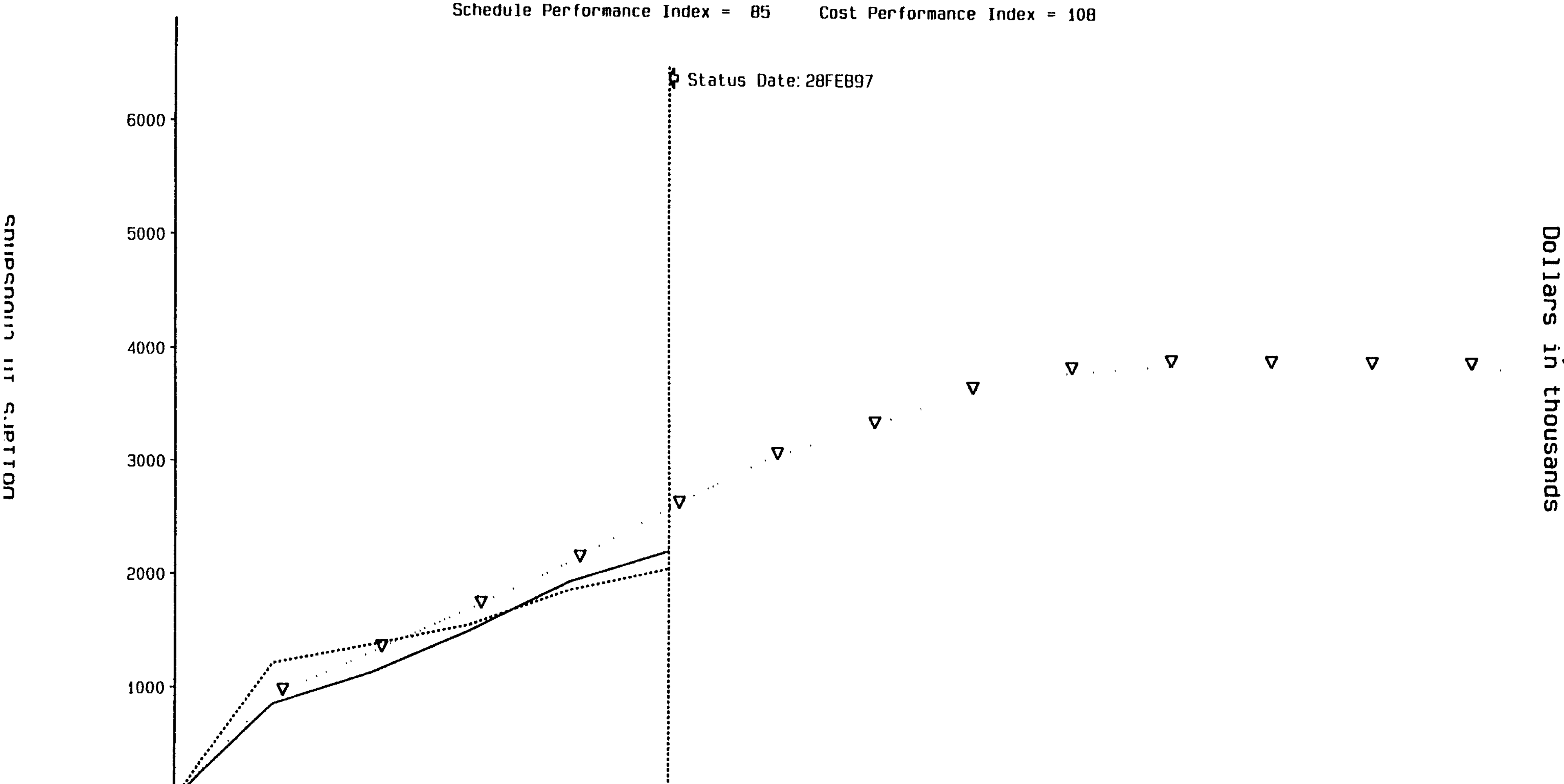
LIGO PROJECT
CDS DESIGN

Date: 11APR97
Program: LIGOPMB2
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 85 Cost Performance Index = 108



	FEB96	MAY96	AUG96	NOV96	FEB97	MAY97	AUG97	NOV97	FEB98	MAY98	AUG98	NOV98	FEB99	MAY99
Planned Budget	932	1,317	1,706	2,124	2,608	3,047	3,332	3,641	3,821	3,892	3,892	3,892	3,892	3,892
Performance	856	1,143	1,516	1,952	2,226									
Actuals	1,221	1,383	1,566	1,875	2,068									
Schedule Variance	-76	-174	-190	-172	-382									
Cost Variance	-365	-240	-50	77	158									

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

R & D
Schedule Accomplishments

A. 40 Meter

1. Completed vacuum envelope reconfiguration For Recycling
2. Installed New Beam Splitter with Small Optics Suspension Prototype
3. Locked Recombined Interferometer with High Transmission Test Masses

B. PNI

1. Started Reconfigure of the PNI with YAG laser
2. Completed PNI measurements Argon Laser, achieving the highest recorded phase sensitivity

C. FMI

1. Confirmed Validity of Model for Wavefront Sensing
2. Demonstrated Closed Loop Operation of Recycled Interferometer Using Wavefront Sensing

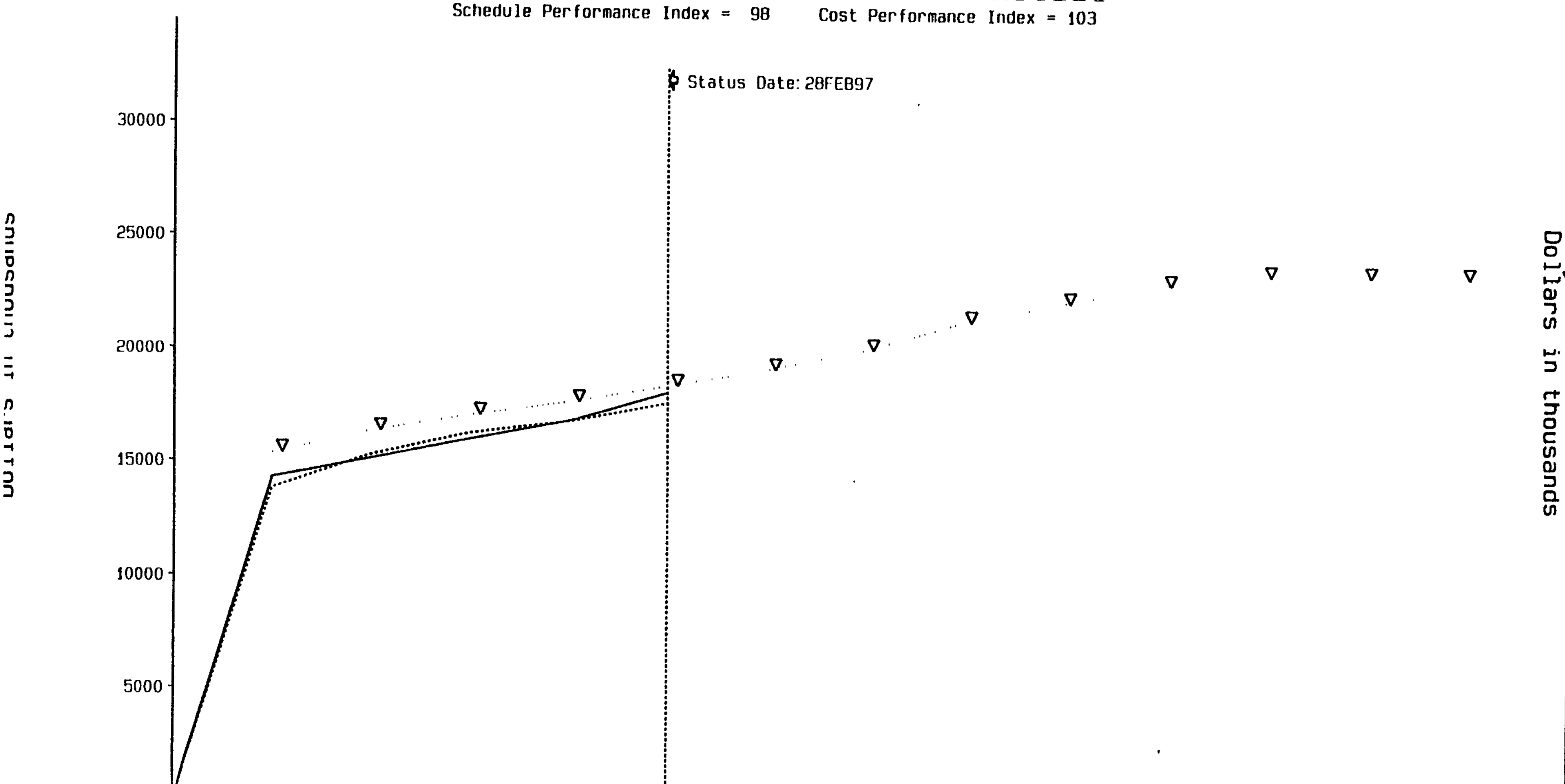
LEGEND	
Bud	▽ ▽ ▽
Per	———
Act	···········

LIGO PROJECT
1.3 Research & Development

Date: 11APR97
Program: LIGOPMB3
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

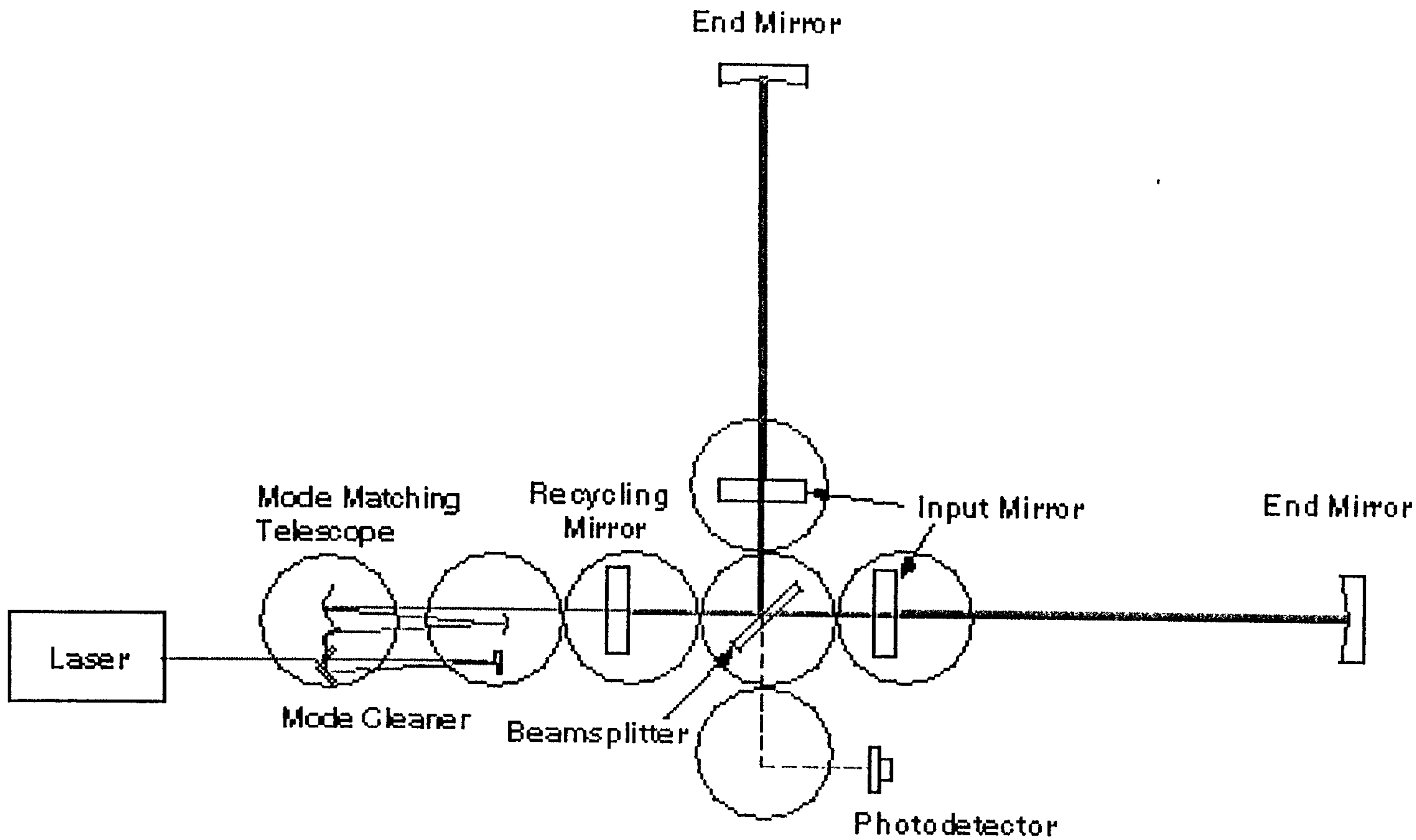
Schedule Performance Index = 98 Cost Performance Index = 103



	FEB96	MAY96	AUG96	NOV96	FEB97	MAY97	AUG97	NOV97	FEB98	MAY98	AUG98	NOV98	FEB99	MAY99
Planned Budget	15,346	16,334	17,069	17,680	18,429	19,182	20,110	21,356	22,211	23,030	23,490	23,490	23,490	23,490
Performance	14,298	15,135	16,011	16,840	18,121									
Actuals	13,839	15,294	16,284	16,815	17,661									
Schedule Variance	-1,048	-1,199	-1,058	- 840	- 308									
Cost Variance	459	- 159	- 273	25	460									

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

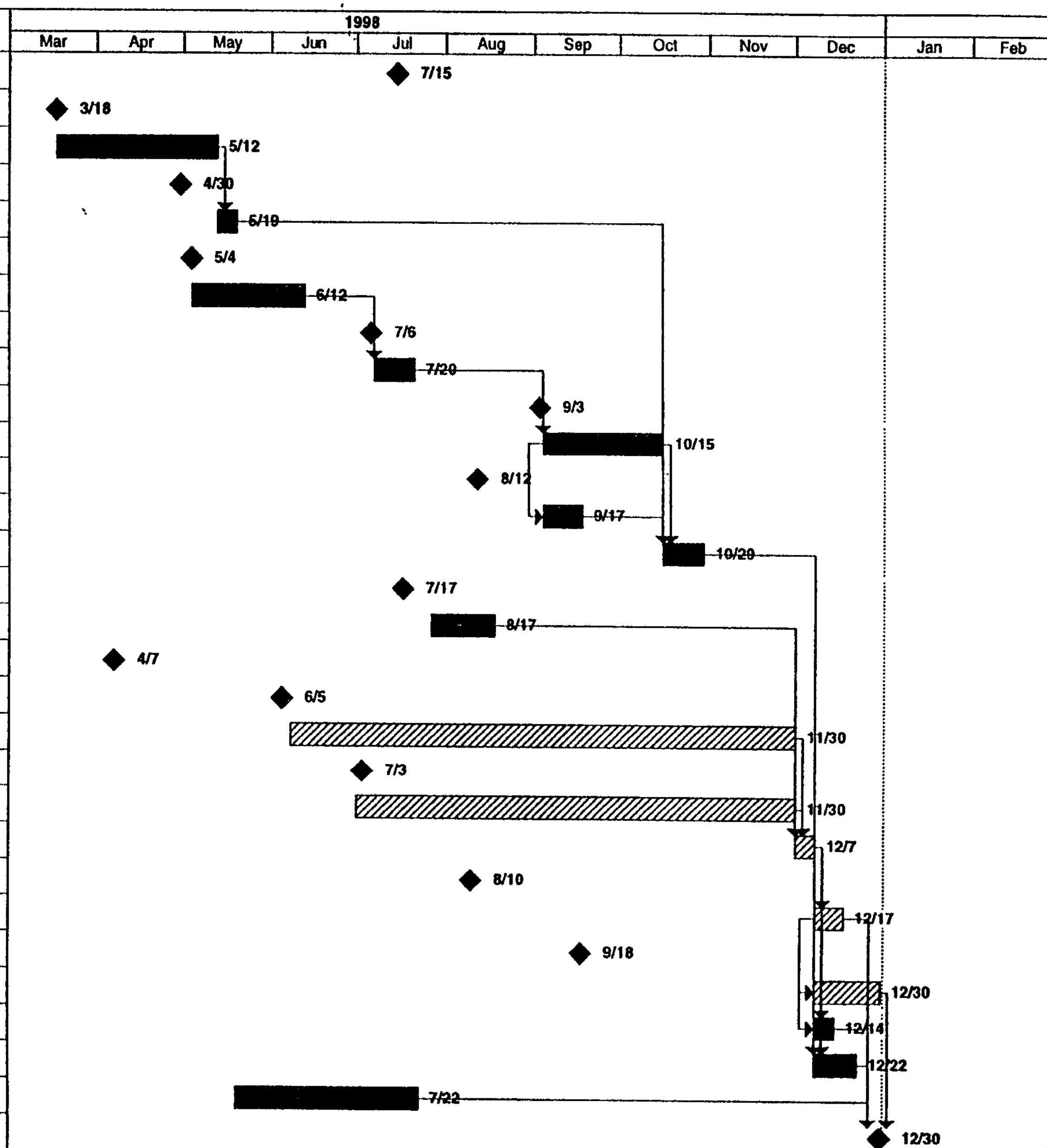
WA 4K Vertex Michelson



LIGO

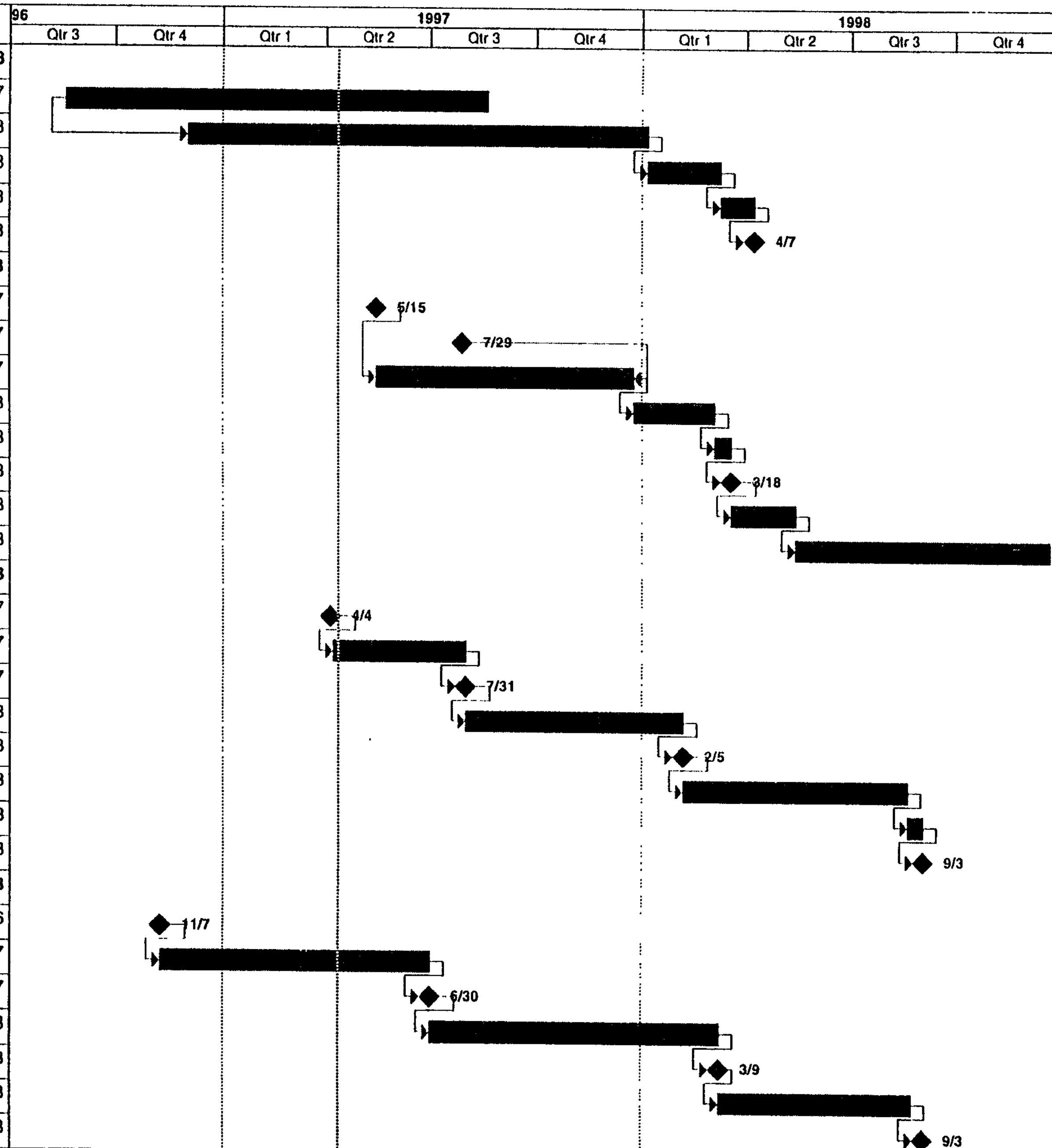
Begin WA 4K Installation

ID	Task Name	Days	Start	Finish
1	NSF Level 1 - Begin WA Install	0d	7/15/98	7/15/98
2	Receive PSL Prototype	0d	3/18/98	3/18/98
3	Install PSL Prototype	40d	3/18/98	5/12/98
4	Receive PSL Proto Electronics	0d	4/30/98	4/30/98
5	Install PSL Proto Electronics	5d	5/13/98	5/19/98
6	Receive 3 Ham Stacks + 1 HAM	0d	5/4/98	5/4/98
7	Install 3 HAM Stacks + 1 HAM	30d	5/4/98	6/12/98
8	Receive ASC/LSC Hardware	0d	7/6/98	7/6/98
9	Install ASC/LSC Hardware	10d	7/7/98	7/20/98
10	Receive IOO	0d	9/3/98	9/3/98
11	Install 2 IOO	30d	9/4/98	10/15/98
12	Receive IOO Electronics	0d	8/12/98	8/12/98
13	Install IOO Electronics (SOS)	10d	9/4/98	9/17/98
14	Align IOO	10d	10/16/98	10/29/98
15	Receive LOS Electronics	0d	7/17/98	7/17/98
16	Install Suspension Electronics - (LOS)	16d	7/27/98	8/17/98
17	Receive Core Optics	0d	4/7/98	4/7/98
18	Receive LOS Suspensions	0d	6/5/98	6/5/98
19	Assemble 3 COC into Suspension	126d	6/8/98	11/30/98
20	Receive BSC Stacks	0d	7/3/98	7/3/98
21	Install 3 BSC Stacks	109d	7/1/98	11/30/98
22	Install last of 3 COC Susp Assbmly	5d	12/1/98	12/7/98
23	Receive Wave Front Sensing	0d	8/10/98	8/10/98
24	Install 3rd Wavefront Sensing	8d	12/8/98	12/17/98
25	Receive ASC/LSC Electronics	0d	9/18/98	9/18/98
26	Install ASC/LSC Electronics	17d	12/8/98	12/30/98
27	Install last of 3 COS	5d	12/8/98	12/14/98
28	Align COC	11d	12/8/98	12/22/98
29	Install Remote Diagnostics	46d	5/20/98	7/22/98
30	Lock Vertex Michelson	0d	12/30/98	12/30/98



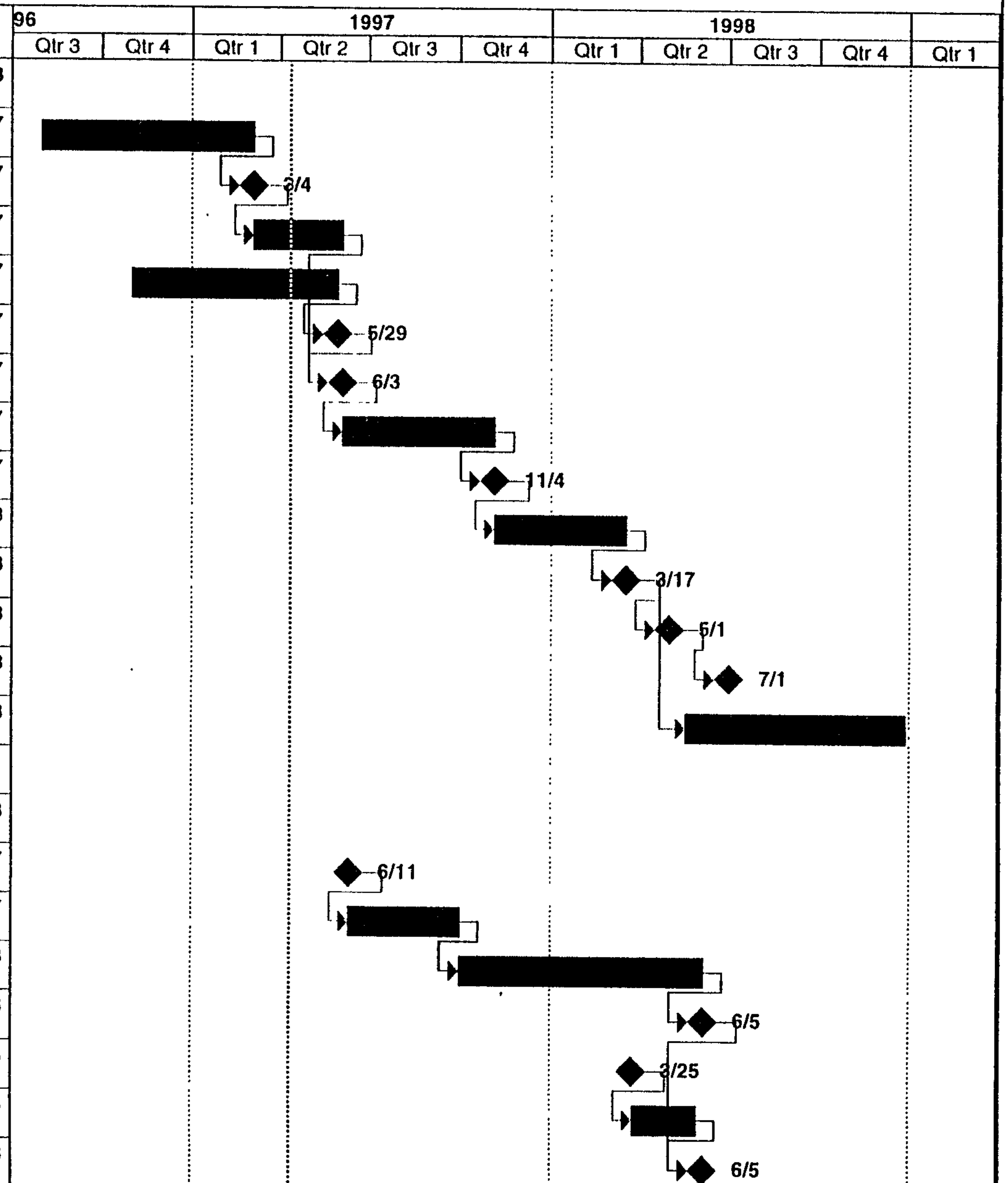
LASER/OPTICS SCHEDULE

ID	Task Name	Days	Start	Finish
1	**Core Optics**	**427d**	**8/19/96**	**4/7/98**
2	Procure Glass Substrates	262d	8/19/96	8/19/97
3	Polish Glass Substrates	286d	12/2/96	1/5/98
4	Coat 1st Lot of Core Optics	45d	1/6/98	3/9/98
5	Receive and Measure Core Optics	21d	3/10/98	4/7/98
6	Deliver Core Optics to Suspensions	0d	4/7/98	4/7/98
7	**PreStabilized Laser**	**420d**	**5/15/97**	**12/23/98**
8	Complete PSL DRR	0d	5/15/97	5/15/97
9	Receive 1st Light Wave 10W Laser	0d	7/29/97	7/29/97
10	Component test/ Build Prototype	160d	5/15/97	12/24/97
11	Integrated Prototype System Test	50d	12/25/97	3/4/98
12	Package/ Ship Prototype to Hanforc	10d	3/5/98	3/18/98
13	PSL Prototype Ready for Install	0d	3/18/98	3/18/98
14	Complete Final Design	40d	3/19/98	5/13/98
15	Fabricate Additional PSLs	160d	5/14/98	12/23/98
16	**Core Optics Support (COS)**	**369d**	**4/4/97**	**9/3/98**
17	Complete DRR	0d	4/4/97	4/4/97
18	Mock-up and Prelim Design	84d	4/7/97	7/31/97
19	Complete PDR	0d	7/31/97	7/31/97
20	Prototype and Final Design	135d	8/1/97	2/5/98
21	Complete FDR	0d	2/5/98	2/5/98
22	Fabricate COS	140d	2/6/98	8/20/98
23	Acceptance test	10d	8/21/98	9/3/98
24	COS Delivered for Install	0d	9/3/98	9/3/98
25	**Input Output Optics**	**475d**	**11/7/96**	**9/3/98**
26	IOO DRR	0d	11/7/96	11/7/96
27	Preliminary Design	167d	11/8/96	6/30/97
28	Complete IOO PDR	0d	6/30/97	6/30/97
29	Final Design and Prototype	180d	7/1/97	3/9/98
30	Complete IOO FDR	0d	3/9/98	3/9/98
31	Fabricate IOO	120d	3/10/98	8/24/98
32	IOO Deliver for Install	0d	9/3/98	9/3/98



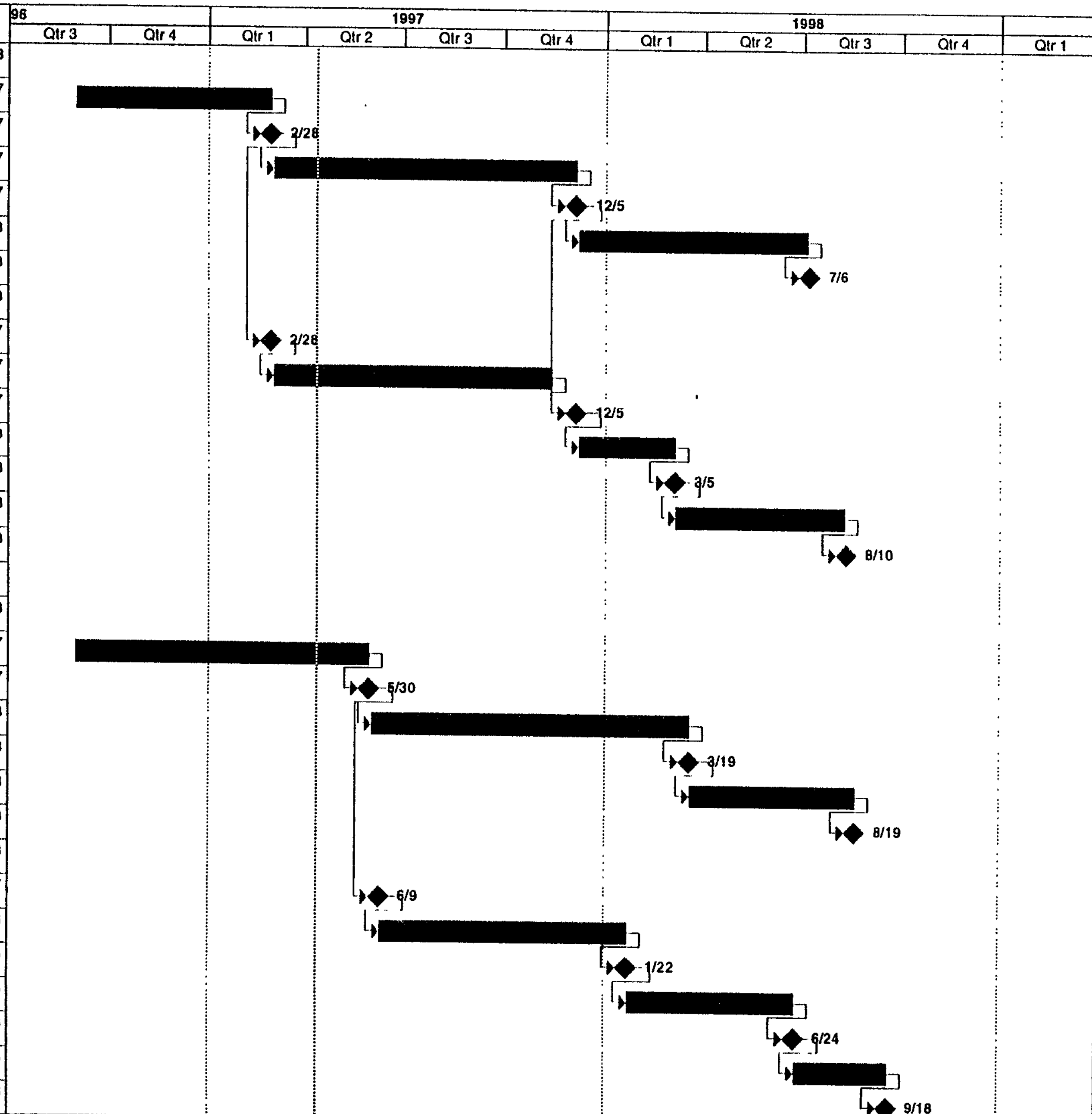
SEISMIC/SUSPENSION SCHEDULE

ID	Task Name	Days	Start	Finish
1	**Seismic Isolation**	627d	8/1/96	12/27/98
2	BSC/HAM Prelim Design	154d	8/1/96	3/4/97
3	BSC/HAM PDR	0d	3/4/97	3/4/97
4	BSC/HAM Final 1st Article Design	65d	3/5/97	6/3/97
5	Spring Prototype testing	150d	11/1/96	5/29/97
6	Make Spring Decision	0d	5/29/97	5/29/97
7	1st Article FDR/ Proc. Review	0d	6/3/97	6/3/97
8	Fabricate 1st Article BSC/HAM	110d	6/4/97	11/4/97
9	Deliver 1st Article BSC/HAM	0d	11/4/97	11/4/97
10	Perform end-to-end test	95d	11/5/97	3/17/98
11	BSC/HAM FDR	0d	3/17/98	3/17/98
12	Deliver 3 - 1st Art/PreProd Hams	0d	5/1/98	5/1/98
13	Deliver 1st Art. BSC	0d	7/1/98	7/1/98
14	Fabricate Production BSC/HAMs	160d	5/18/98	12/27/98
15				
16	**Suspensions**	258d	6/11/97	6/5/98
17	Suspension FDR	0d	6/11/97	6/11/97
18	Prepare, Compete, Award Procuremer	80d	6/11/97	9/30/97
19	Fabricate 1st lot SUS for Handford	178d	10/1/97	6/5/98
20	Suspensions Delivered for Install	0d	6/5/98	6/5/98
21	Receive Core Optics	0d	3/25/98	3/25/98
22	Prepare Optics for Suspension	47d	3/26/98	5/29/98
23	Suspended Optic Ready for Install	0d	6/5/98	6/5/98



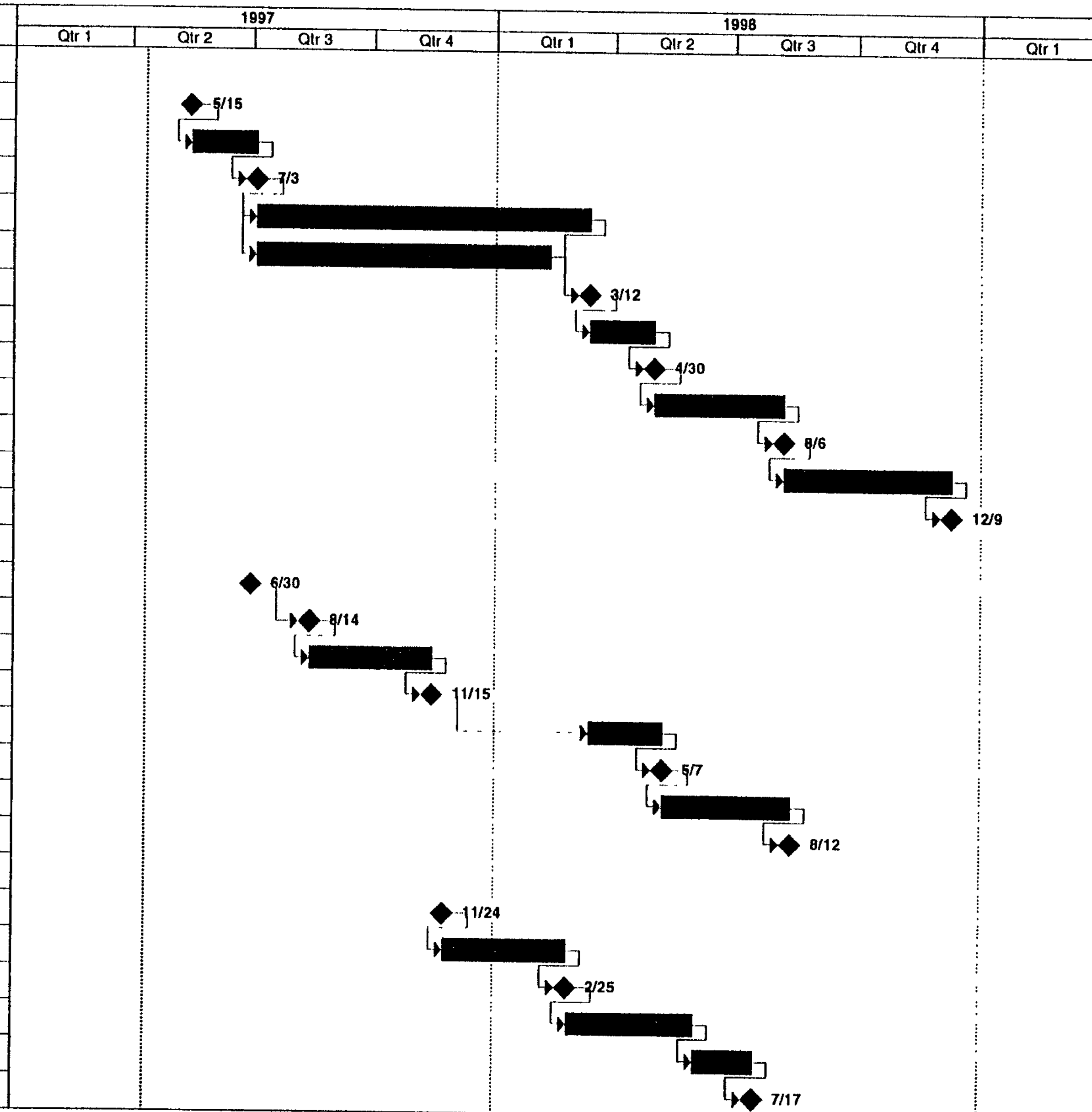
Interferometer Sensing and Control

ID	Task Name	Days	Start	Finish
1	**Alignment Sensing and Control**	481d	9/1/96	7/6/98
2	ASC Prelim Design	130d	9/1/96	2/27/97
3	ASC PDR	0d	2/28/97	2/28/97
4	ASC Final Design	199d	3/3/97	12/4/97
5	ASC FDR	0d	12/5/97	12/5/97
6	ASC Fab/Assembly/Test	150d	12/8/97	7/3/98
7	ASC Ready for Install WA 4K	0d	7/6/98	7/6/98
8	**ASC Electronics (CDS)**	376d	2/28/97	8/10/98
9	ASC CDS DRR	0d	2/28/97	2/28/97
10	ASC CDS Prelim Design	183d	3/3/97	11/12/97
11	ASC CDS PDR	0d	12/5/97	12/5/97
12	ASC CDS Final Design	63d	12/8/97	3/4/98
13	ASC CDS FDR	0d	3/5/98	3/5/98
14	ASC CDS Fabrication	111d	3/6/98	8/7/98
15	ASC CDS Ready for Install WA 4K	0d	8/10/98	8/10/98
16				
17	**Length Sensing and Control**	513d	9/1/96	8/19/98
18	LSC Prelim Design	195d	9/1/96	5/29/97
19	LSC PDR	0d	5/30/97	5/30/97
20	LSC Final Design	208d	6/2/97	3/18/98
21	LSC FDR	0d	3/19/98	3/19/98
22	LSC Fab/Assembly/Test	108d	3/20/98	8/18/98
23	LSC Ready for Install WA 4K	0d	8/19/98	8/19/98
24	**LSC Electronics**	335d	6/9/97	9/18/98
25	LSC CDS DRR	0d	6/9/97	6/9/97
26	LSC CDS Prelim Design	162d	6/10/97	1/21/98
27	LSC CDS PDR	0d	1/22/98	1/22/98
28	LSC CDS Final Design	108d	1/23/98	6/23/98
29	LSC CDS FDR	0d	6/24/98	6/24/98
30	LSC CDS Fabrication	62d	6/25/98	9/18/98
31	LSC CDS Ready for Install	0d	9/18/98	9/18/98



CDS Schedule

ID	Task Name	Days	Start	Finish
1	**Pre-Stabilized Laser**	1d	1/7/97	1/7/97
2	PSL DRR	0d	5/15/97	5/15/97
3	PSL CDS Conceptual Design	35d	5/16/97	7/3/97
4	PSL CDS DRR	0d	7/3/97	7/3/97
5	PSL CDS Proto Fab/Test	180d	7/4/97	3/12/98
6	PSL CDS Prelim Design	158d	7/4/97	2/10/98
7	PSL CDS PDR	0d	3/12/98	3/12/98
8	PSL CDS Proto Ship/ Reassemble	35d	3/13/98	4/30/98
9	PSL CDS Prototype ready for Install	0d	4/30/98	4/30/98
10	PSL CDS Final Design	70d	5/1/98	8/6/98
11	PSL CDS FDR	0d	8/6/98	8/6/98
12	PSL CDS Fab/Assemble/Test	89d	8/7/98	12/9/98
13	PSL Electreonics Ready for Install	0d	12/9/98	12/9/98
14	**Input Output Optics**	1d	1/7/97	1/7/97
15	IOO PDR	0d	6/30/97	6/30/97
16	IOO CDS DRR	0d	8/14/97	8/14/97
17	IOO CDS Prelim Design	67d	8/14/97	11/14/97
18	IOO CDS PDR	0d	11/15/97	11/15/97
19	IOO CDS Final Design	40d	3/13/98	5/7/98
20	IOO CDS FDR	0d	5/7/98	5/7/98
21	IOO CDS Fabrication	69d	5/8/98	8/12/98
22	IOO CDS Ready for Install	0d	8/12/98	8/12/98
23	**Suspension Electronics**	1d	1/7/97	1/7/97
24	SUS CDS PDR	0d	11/24/97	11/24/97
25	SUS CDS Final Design	66d	11/25/97	2/24/98
26	SUS CDS FDR	0d	2/25/98	2/25/98
27	SUS CDS Fabrication	68d	2/26/98	6/1/98
28	SUS CDS Testing	33d	6/2/98	7/16/98
29	SUS CDS Ready for Install WA 4K	0d	7/17/98	7/17/98



Project:
Date: 4/11/97

Task — Progress — Milestone — Summary — Rolled Up Task — Rolled Up Milestone — Rolled Up Progress

Level 1 DETECTOR Milestone's - FEB 1997

4/11/97

Milestone Description	Current Month End Status Feb-1997	Project Mgmt Plan Dates	REPLAN Feb-1997	PMP vs REPLAN (Days)
Pre-Stabilized Laser FDR	7/30/98	8/30/98	4/28/98	88
Input/Output Optics FDR	5/19/98	4/30/98	12/31/97	88
Length Sensing Control FDR	12/15/97	5/30/98	3/19/98	32
Wavefront FDR	2/13/98	4/30/98	12/5/97	97
Core Optics Components FDR	10/27/97	7/30/97	12/19/97	-103
Core Optics Support FDR	12/9/97	4/30/97	2/20/98	-242
BSC Stack Final Design Review	8/21/97	7/30/97	4/6/98	-182
HAM Stack Final Design Review	8/21/97	7/30/97	4/6/98	-182
Control Data System DAQ FDR	5/28/98	4/30/98	5/28/98	-22
Physics Environ Monitoring FDR	8/6/97	6/30/98	8/6/97	286
WA Cntl Area/Net Sys Ready To Install	9/29/97	9/30/97	11/3/97	-27
Detector System Prelim Design Review	4/3/98	12/30/97	12/31/97	0
Begin WA IFO Installation	7/30/98	7/30/98	7/30/98	0
Begin LA IFO Installation	1/30/99	1/30/99	1/30/99	0
Begin COINCIDENCE TEST	12/31/00	12/31/00	12/31/00	0

Anticipated Detector Replan Budget

Detector Baseline Budget (as of last October '96 Review)	$52,567,000
Cost Reductions:	
1. CR-970009 COC Savings	- 881,636
2. CR-970010 Output Mode Cleaner Savings	- 471,000
Anticipated Cost Reduction:	
1. PEM Descope Savings	- 650,000
Anticipated Cost Increases:	
1. Seismic Stack 1st Article Scope	+ 1,500,000
2. Increase Staffing Requirements	+ 2,200,000
Anticipated Detector Replan Budget	$54,264,364
Delta Increase of 3.2%	$ 1,697,364

- Original Detector Budget w/YAG Laser Requirements $51,728,000.

Conclusions

1. The Detector Subsystems are Completing Preliminary Design or are in Final Design.
2. Over the Last 12 Months the Detector has Accomplished most of its Milestones.
3. The Detector is Roughly Two Months Behind Schedule and is $1M Under Budget.
4. The Detector is Staffing up - 8 new people in the last 3 months and 13 new people within the last 6 months.
5. The Seismic Stacks and Core Optics Continue to Pace Interferometer Installation as the Critical Path Items.

FACILITIES
COST AND SCHEDULE

NSF REVIEW

APRIL 13, 1997

GERRY STAPFER

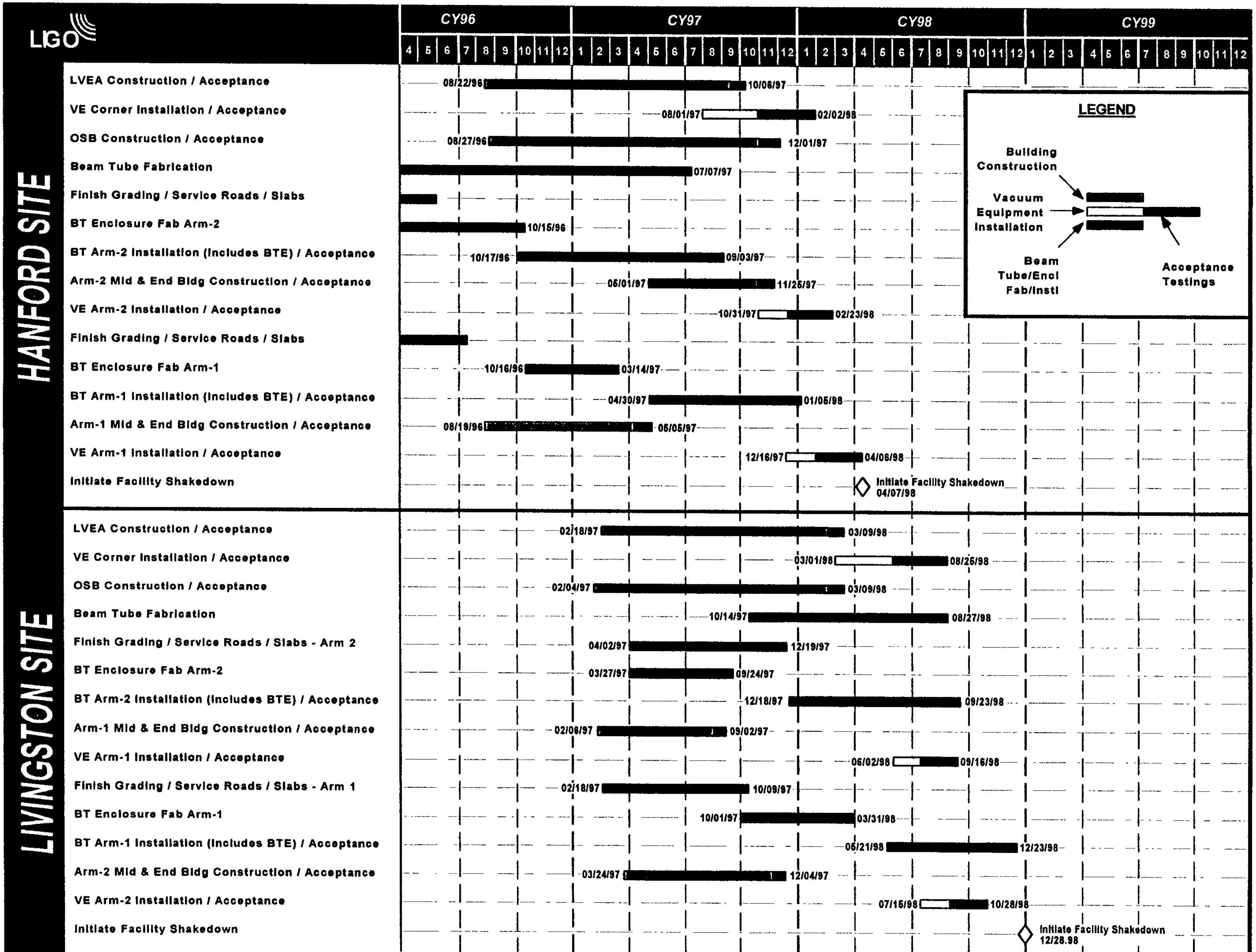
OVERVIEW

- SCHEDULE
  - OVERALL STRATEGY
  - HANFORD
  - LIVINGSTON
- MILESTONES
  - ACHIEVED
  - CURRENT STATUS
- COST
  - BUDGET COST SUMMARY
  - FACILITIES COST PERFORMANCE

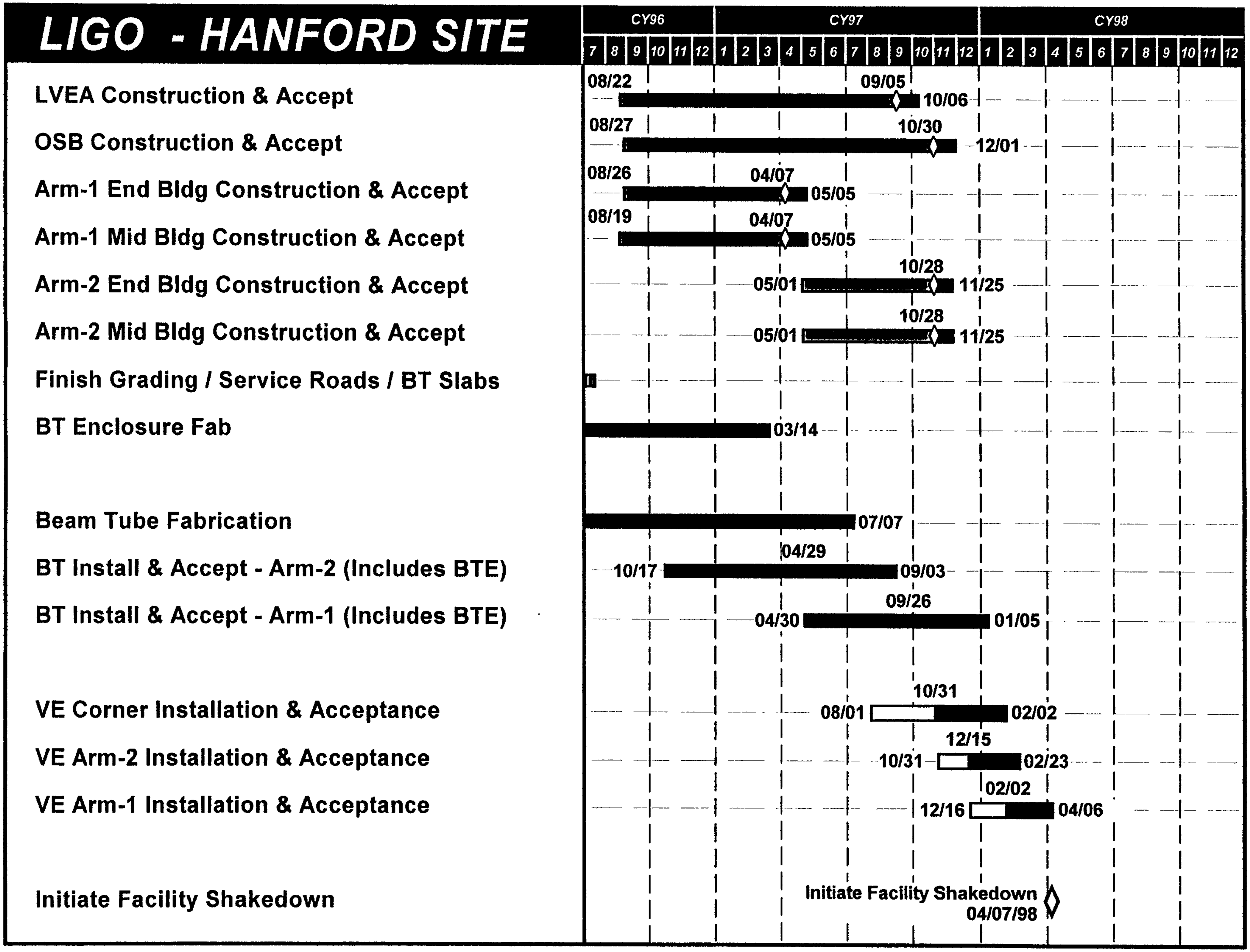
FACILITIES

- THREE MAJOR TASK AREAS
  - VACUUM EQUIPMENT
  - BEAM TUBE
  - BUIDINGS AND INFRASTRUCTURE
- SCHEDULE STRATEGY
  - PROVIDE SEPARATION BETWEEN TASKS, ALLOWING INDEPENDENT DEVELOPMENT AND IMPLEMENTATION TO MINIMIZE SCHEDULE INTERFERENCE
- IMPLEMENTATION
  - ESTABLISH AND MAINTAIN WELL DEFINED, CLEAN INTERFACES BETWEEN TASKS
  - MAINTAIN INTERFACES THROUGH LEVEL 1 MILESTONES

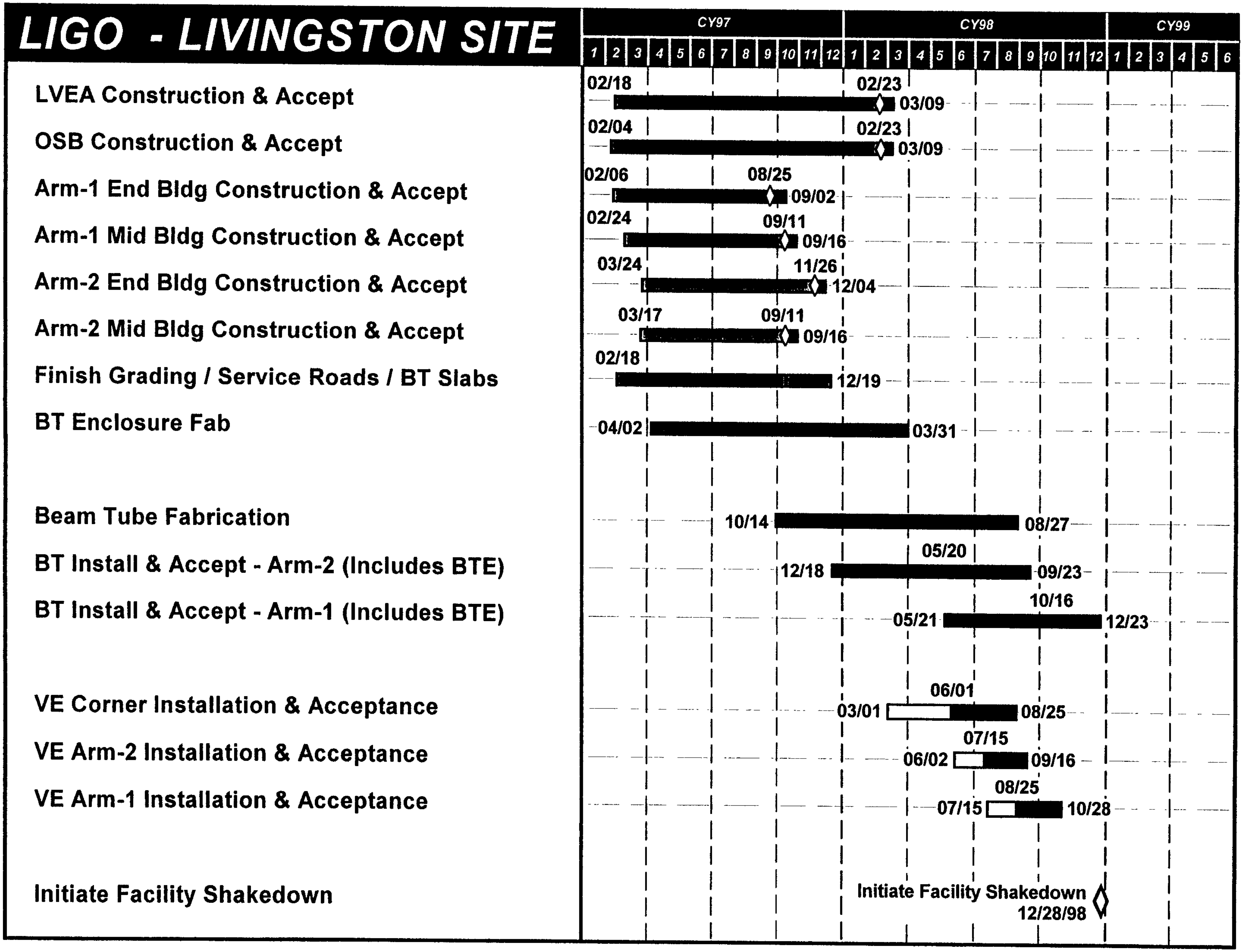
FACILITIES SCHEDULE - HANFORD / LIVINGSTON



FACILITIES CONSTRUCTION & EQUIP. T INSTALLATION SUMMARY SCHEDULE



FACILITIES CONSTRUCTION & EQUIPMENT INSTALLATION SUMMARY SCHEDULE



MILESTONE SUMMARY

- LEVEL 1 MILESTONE
  - HIGHLY VISIBLE MILESTONES TO IDENTIFY MAJOR ACHIEVEMENTS AND INTERFACES
  - 26 MILESTONES WERE ESTABLISHED AND CARRIED IN THE LIGO PROJECT MANAGEMENT PLAN FOR THE FACILITIES TASKS
- CURRENT STATUS
  - 14 MILESTONES COMPLETED PRIOR TO THE LAST REVIEW
  - 2 MILESTONES WERE COMPLETED SINCE THE LAST REVIEW
  - 10 MILESTONES REMAIN
- MILESTONE SCHEDULE
  - ALL COMPLETED MILESTONES WERE ON SCHEDULE

FACILITIES LEVEL 1 MILESTONE STATUS

4/9/97

(Month End February 1997 status)

Milestone Description	Baseline Finish	February Status	Change from B/L
VE COMMISIONING/ACCEPTANCE COMPLETE - WA	4/6/98	4/6/98	0
VE COMMISIONING/ACCEPTANCE COMPLETE - LA	10/28/98	10/28/98	0
BEAM TUBE COMPLETE / ACCEPTED - WA	11/6/97	1/5/98	(60)
BEAM TUBE COMPLETE / ACCEPTED - LA	12/10/98	12/23/98	(13)
ROAD/SLAB & CVR FAB/INSTL CONTRACT - LA	1/10/97	12/17/96	Complete
LVEA JOINT OCCUPANCY - WA	8/5/97	9/5/97	(31)
LVEA BENEFICIAL OCCUPANCY - WA	9/2/97	10/6/97	(34)
INITIATE BLDG CONSTRUCTION CONTRACT - LA	10/10/96	12/12/96	Complete
LVEA JOINT OCCUPANCY - LA	2/2/98	2/27/98	(25)
LVEA BENEFICIAL OCCUPANCY - LA	4/13/98	5/8/98	(25)
INITIATE FACILITY SHAKEDOWN - WA	4/7/98	4/7/98	0
INITIATE FACILITY SHAKEDOWN - LA	3/3/99	12/28/98	65

IPS_4gs1

NOTE: Comparison between Baseline Dates and Month End Status Dates is based on "Calendar Days" NOT "Work Days"

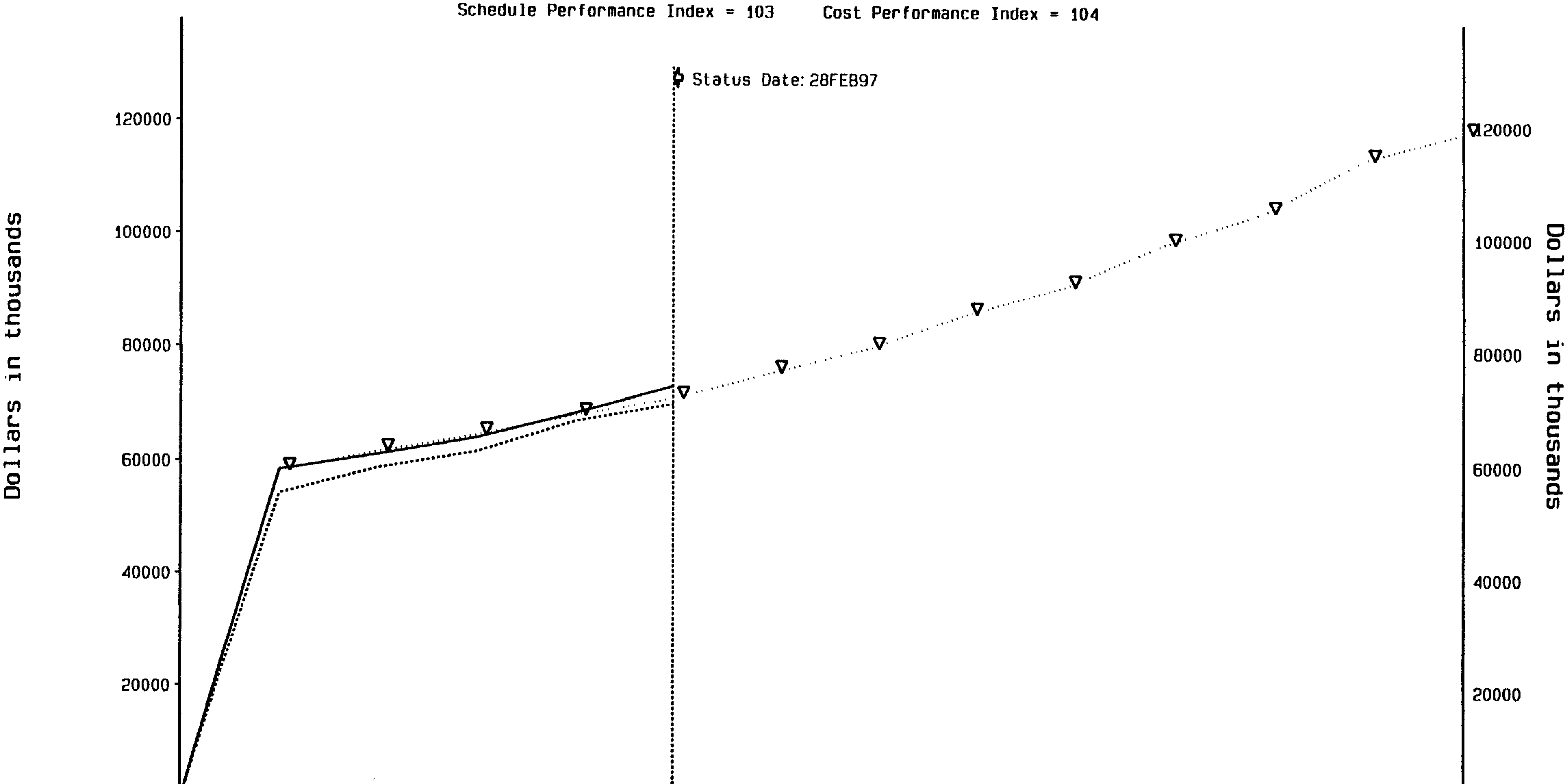
LEGEND	
Bud	▽ (dotted line with triangle markers)
Per	(solid line)
Act	(dotted line)

LIGO PROJECT
1.1 Facilities and Vacuum Systems

Date: 9APR97
Program: LIGOPMB1
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 103 Cost Performance Index = 104



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	58, 298	61, 672	64, 733	68, 241	71, 296	75, 810	80, 040	86, 234	91, 129	98, 729	104, 405	113, 866	118, 668	K$
Performance	58, 529	61, 188	64, 236	68, 658	73, 445									K$
Actuals	54, 366	58, 870	61, 761	67, 257	70, 283									K$
Schedule Variance	231	- 484	- 497	417	2, 149									K$
Cost Variance	4, 163	2, 318	2, 475	1, 401	3, 162									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

WBS 1.1 - Facilities and Vacuum Systems

4/9/97

COST / SCHEDULE STATUS REPORT

(Month End February 1997 Status)

Reporting Level	Cumulative to Date							Budget
	Budgeted Cost		Actual Cost	Schedule Variance		Cost Variance		At Complete
	Work Scheduled	Work Performed	Work Performed	$s	%	$s	%	(BAC)
1.1.1 - Vacuum Equipment	$ 23,580	$ 23,423	$ 22,210	$ (157)	(1%)	$ 1,213	5%	$ 42,113
1.1.2 - Beam Tubes	$ 20,527	$ 22,282	$ 22,057	$ 1,755	9%	$ 225	1%	$ 47,298
1.1.3 - BT Enclosures	$ 8,641	$ 8,151	$ 7,195	$ (490)	(6%)	$ 956	12%	$ 19,384
1.1.4 - Civil Design/Construction	$ 18,548	$ 19,589	$ 18,822	$ 1,041	6%	$ 767	4%	$ 48,311
1.1 - Total	$ 71,296	$ 73,445	$ 70,284	$ 2,149	3%	$ 3,161	4%	$ 157,106

Control Numbers - Charge Numbers - Planned Budget

(Reflects month end February 1997 status)

4/9/97

Control Number	Work Package	WBS Number	Description	Responsible Manager	Planned Budget
1.1.1		1.1.1	Vacuum Equipment	J. Worden	
	5A511	1.1.1.1.1	In-House Engrng/Contract Mgmt		$ 1,227,537
	5A512	1.1.1.1.2	Contracted Design Competition		$ 511,000
	5A513	1.1.1.1.3	Contracted (Final) Design		$ 14,466,997
	5A521	1.1.1.2.1	VE In House Labor & Equip - Wa		$ 576,577
	5A522	1.1.1.2.2	VE Equipment Contract - Wa		$ 15,726,916
	5A523	tbd	Washington State Taxes		$ -
	5A531	1.1.1.3.1	VE In House Labor & Equip - La		$ 657,166
	5A532	1.1.1.3.2	VE Equipment Contract - La		$ 8,946,985
	5A533	tbd	Louisiana State Taxes		$ -
				SubTotal	*$ 42,113,178*

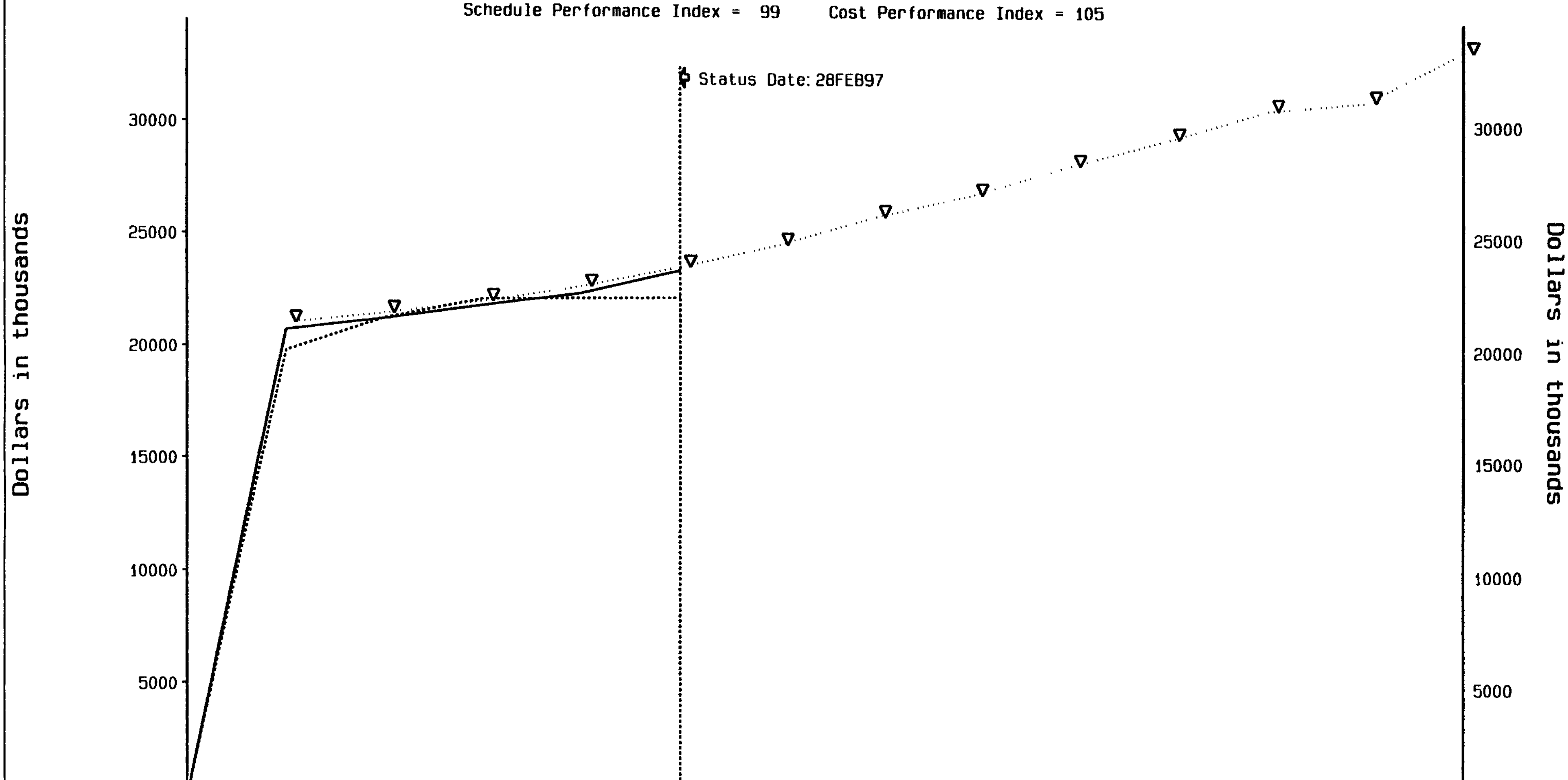
LEGEND		
Bud	▽ ▽ ▽ (dotted)	
Per	(solid line)	
Act	(dotted line)	

LIGO PROJECT
1.1.1 Vacuum Equipment

Date: 9APR97
Program. LIGOPMB1
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 99 Cost Performance Index = 105



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	21,013	21,465	22,014	22,689	23,580	24,567	25,824	26,819	28,135	29,335	30,654	31,032	33,253	K$
Performance	20,707	21,229	21,830	22,389	23,423									K$
Actuals	19,803	21,254	22,122	22,165	22,209									K$
Schedule Variance	- 306	- 236	- 184	- 300	- 157									K$
Cost Variance	904	-25	- 292	224	1,214									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

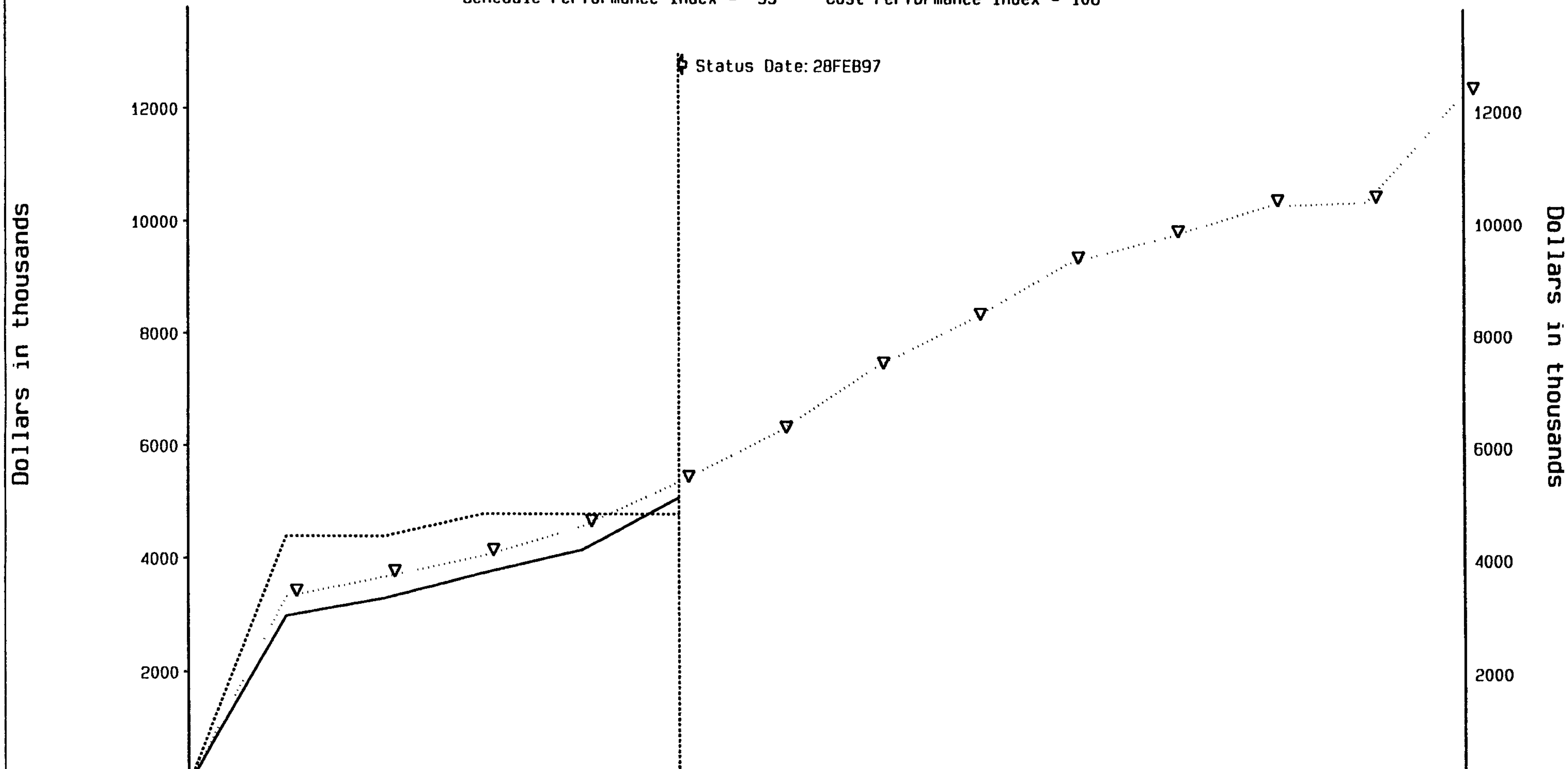
LEGEND		
Bud	▽ ▽ ▽ (dotted)	
Per	(solid)	
Act	(dotted)	

LIGO PROJECT
5A522 VE Contracted - Wa

Date: 9APR97
Program: LIGOPMB1
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 95 Cost Performance Index = 106



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	3,329	3,667	4,039	4,559	5,347	6,231	7,383	8,261	9,271	9,739	10,298	10,372	12,295	K$
Performance	2,992	3,301	3,738	4,144	5,072									K$
Actuals	4,389	4,389	4,780	4,780	4,780									K$
Schedule Variance	- 337	- 366	- 301	- 415	- 275									K$
Cost Variance	-1,397	-1,088	-1,042	- 636	292									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

Control Numbers - Charge Numbers - Planned Budget

4/9/97

(Reflects month end February 1997 status)

Control Number	Work Package	WBS Number	Description	Responsible Manager	Planned Budget
1.1.2		1.1.2	Beam Tubes	L. Jones	
	5B511	1.1.2.1.1	BT Design Contract Mgmt		$ 2,028,988
	5B512	1.1.2.1.2	Beam Tube Design Contract		$ 1,893,487
	5B513	1.1.2.1.2.2	BT Design & Spiral Mill Contract		$ 5,022,829
	5B514	1.1.2.1.2.3	BT Baffle Fabrication		$ 705,901
	5B522	1.1.2.2.2	WA BT Factory Fab		$ 12,383,310
	5B523	1.1.2.2.3	WA BT Field Installation		$ 4,355,649
	5B524	1.1.2.2.4	WA BT Insulate and Bake		$ 1,731,002
	5B525	1.1.2.2.5	WA Beam Tube Acceptance Test		$ 2,255,000
	5B526	tbd	Washington State Taxes		$ -
	5B532	1.1.2.3.2	LA Beam Tube Factory Fab		$ 10,105,140
	5B533	1.1.2.3.3	LA BT Field Installation		$ 3,049,593
	5B534	1.1.2.3.4	LA BT Insulate and Bake		$ 1,509,065
	5B535	1.1.2.3.5	LA BT Tube Acceptance Test		$ 2,258,000
	5B536	tbd	Louisiana State Taxes		$ -
				SubTotal	*$ 47,297,963*

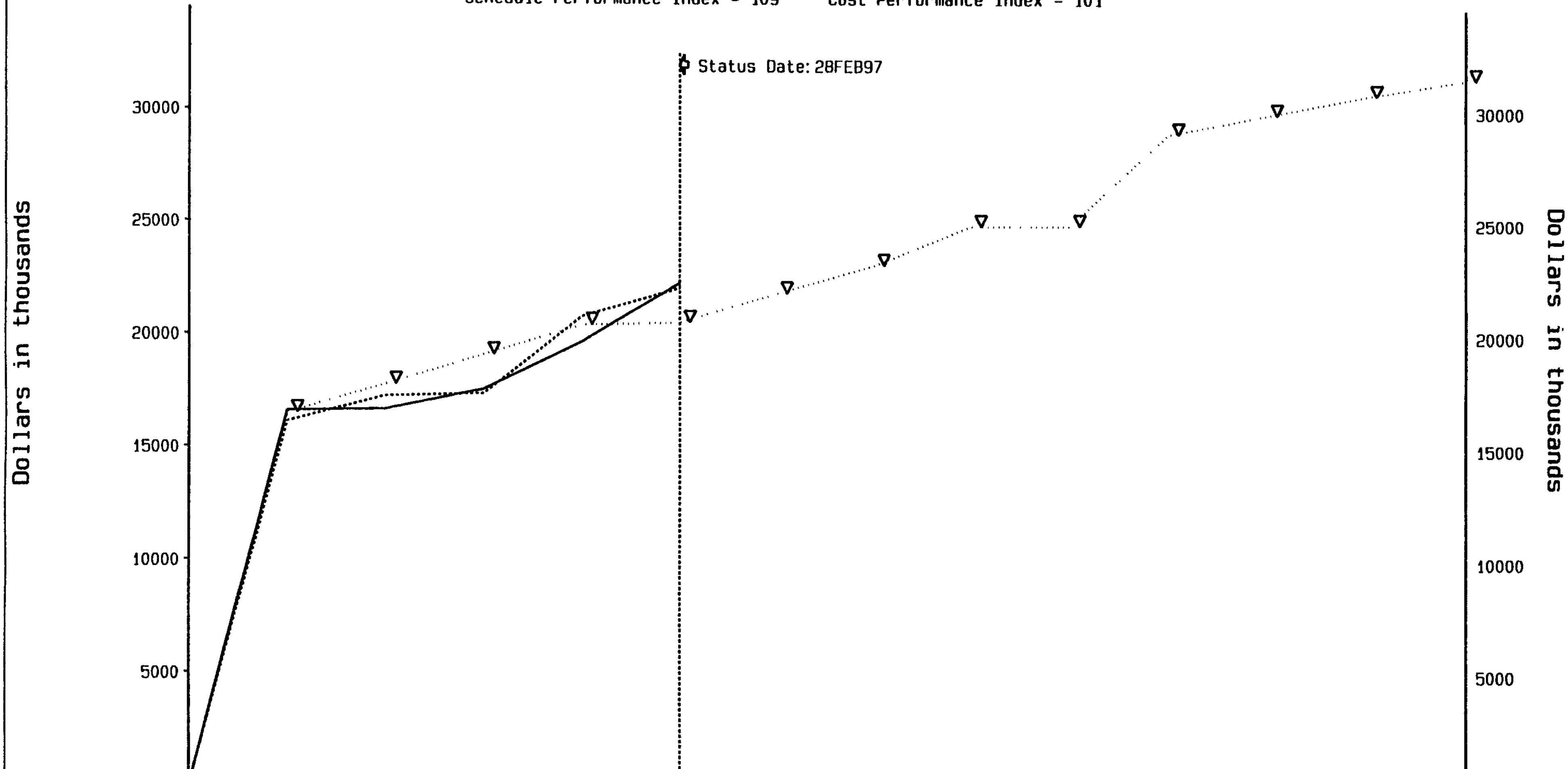
LEGEND	
Bud	▽ ▽ ▽ (dotted)
Per	(solid)
Act	(dotted)

LIGO PROJECT
1.1.2 Beam Tubes

Date: 9APR97
Program: LIGOPMB1
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 109   Cost Performance Index = 101



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	16,504	17,783	19,105	20,433	20,527	21,828	23,082	24,830	24,855	28,974	29,829	30,678	31,405	K$
Performance	16,602	16,671	17,566	19,695	22,282									K$
Actuals	16,116	17,261	17,369	20,796	22,056									K$
Schedule Variance	98	-1,112	-1,539	- 738	1,755									K$
Cost Variance	486	- 590	197	-1,101	226									K$

Schedule Variance = Perf-Budg   Cost Variance = Perf-Actual   Schedule Performance Index = Perf/Budg   Cost Performance Index = Perf/Actual

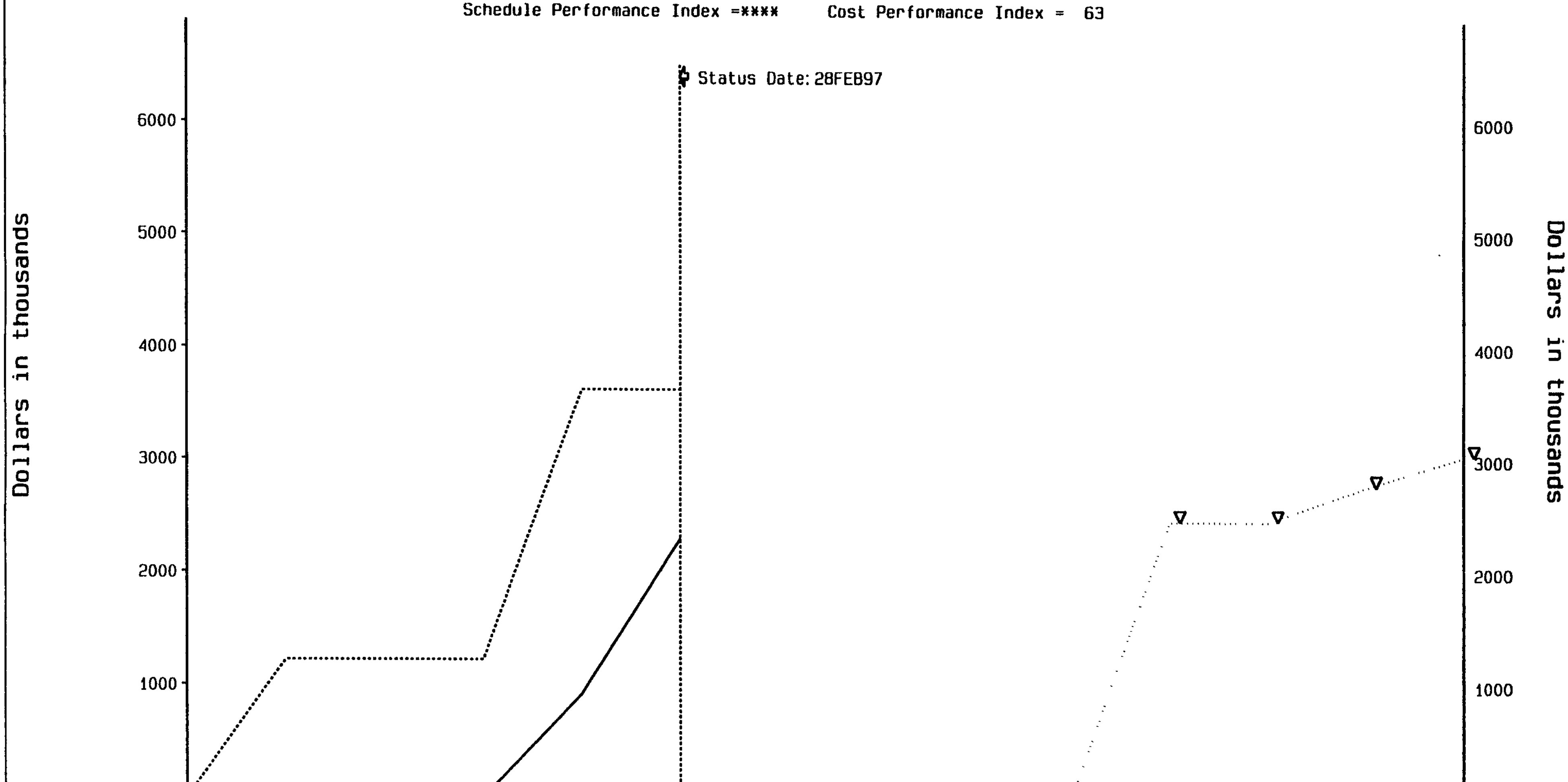
LEGEND	
Bud	·····▽·····▽·····▽···
Per	———
Act	···············

LIGO PROJECT
5B532 LA Beam Tube Factory Fab

Date: 9APR97
Program: LIGOPMB1
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index =**** Cost Performance Index = 63



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	0	0	0	0	0	0	0	0	0	2, 452	2, 452	2, 763	3, 032	K$
Performance	0	0	0	915	2, 290									K$
Actuals	1, 217	1, 217	1, 217	3, 621	3, 621									K$
Schedule Variance	0	0	0	915	2, 290									K$
Cost Variance	-1, 217	-1, 217	-1, 217	-2, 706	-1, 331									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

Control Numbers - Charge Numbers - Planned Budget

4/9/97

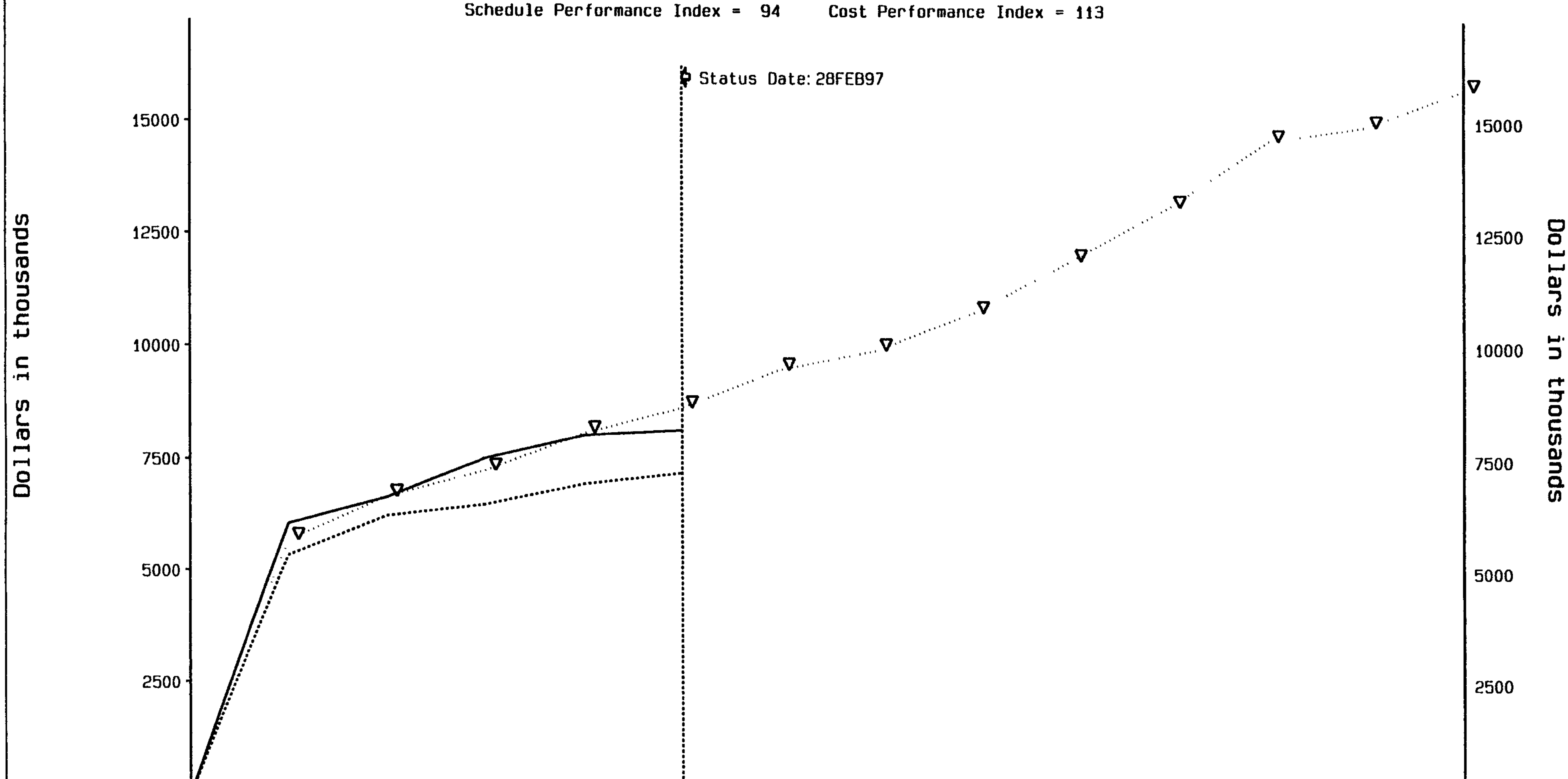
(Reflects month end February 1997 status)

Control Number	Work Package	WBS Number	Description	Responsible Manager	Planned Budget
1.1.3		1.1.3	Beam Tube Enclosures (BTE)	F. Asiri	
	5C511	1.1.3.1.1	Design Engineering & Management		$ 110,093
	5C512	1.1.3.1.2	Design Contract (Parsons)		$ 485,089
	5C521	1.1.3.2.1	WA QA & Survey Contracts		$ 200,640
	5C522	1.1.3.2.2	WA Construction / Instl Contract(s)		$ 9,208,792
	5C523	tbd	Washington State Taxes		$ -
	5C531	1.1.3.3.1	LA QA & Survey Contracts		$ 169,177
	5C532	1.1.3.3.2	LA Construction / Instl Contract		$ 9,210,037
	5C533	tbd	Louisiana State Taxes		$ -
				SubTotal	*$ 19,383,828*
1.1.4		1.1.4	Facility Design & Construction	F. Asiri	
	5D511	1.1.4.1.1	Design Engineering & Management		$ 3,524,445
	5D512	1.1.4.1.2	Design Contract (Parsons)		$ 2,972,798
	5D513	1.1.4.1.3	Site Investigation		$ 992,031
	5D514	tbd	Construction Management (Parsons)		$ 2,385,521
	5D521	tbd	WA QA & Survey Contracts		$ 350,256
	5D522	1.1.4.2.2	WA Construction Contracts		$ 20,099,922
	5D523	tbd	Washington State Taxes		$ -
	5D531	tbd	LA QA & Survey Contracts		$ 386,898
	5D532	1.1.4.3.2	LA Construction Contracts		$ 17,599,366
	5D533	tbd	Louisiana State Taxes		$ -
				SubTotal	*$ 48,311,238*

LEGEND		Date: 9APR97
Bud ▽ ▽ ▽	LIGO PROJECT	Program: LIGOPMB1
Per ——	1.1.3 Beam Tube Enclosures (BTE)	Report LIGOSPA
Act ······		COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 94 Cost Performance Index = 113



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	5,683	6,655	7,245	8,085	8,641	9,484	9,913	10,749	11,910	13,127	14,588	14,904	15,720	K$
Performance	6,060	6,639	7,527	8,041	8,151									K$
Actuals	5,343	6,237	6,488	6,947	7,195									K$
Schedule Variance	377	-16	282	-44	- 490									K$
Cost Variance	717	402	1,039	1,094	956									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

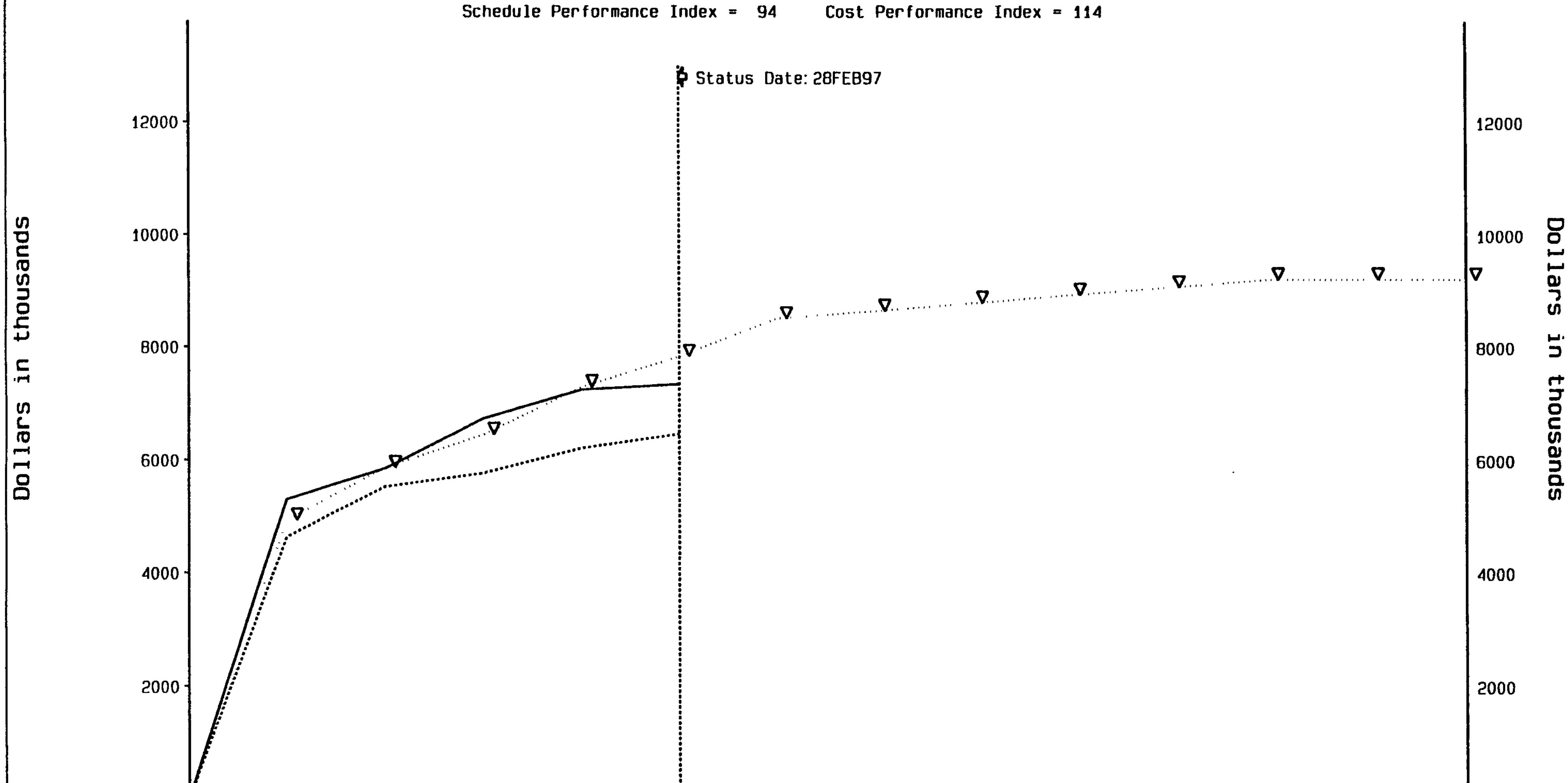
LEGEND		
Bud ·····▽·····▽·····▽··		
Per ————		
Act ···········		

LIGO PROJECT
5C522 WA Construction/Instl Contract

Date: 9APR97
Program: LIGOPMB1
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 94 Cost Performance Index = 114



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	4,919	5,859	6,449	7,289	7,829	8,509	8,649	8,789	8,929	9,069	9,209	9,209	9,209	K$
Performance	5,296	5,844	6,731	7,246	7,339									K$
Actuals	4,626	5,518	5,762	6,214	6,459									K$
Schedule Variance	377	-15	282	-43	- 490									K$
Cost Variance	670	326	969	1,032	880									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

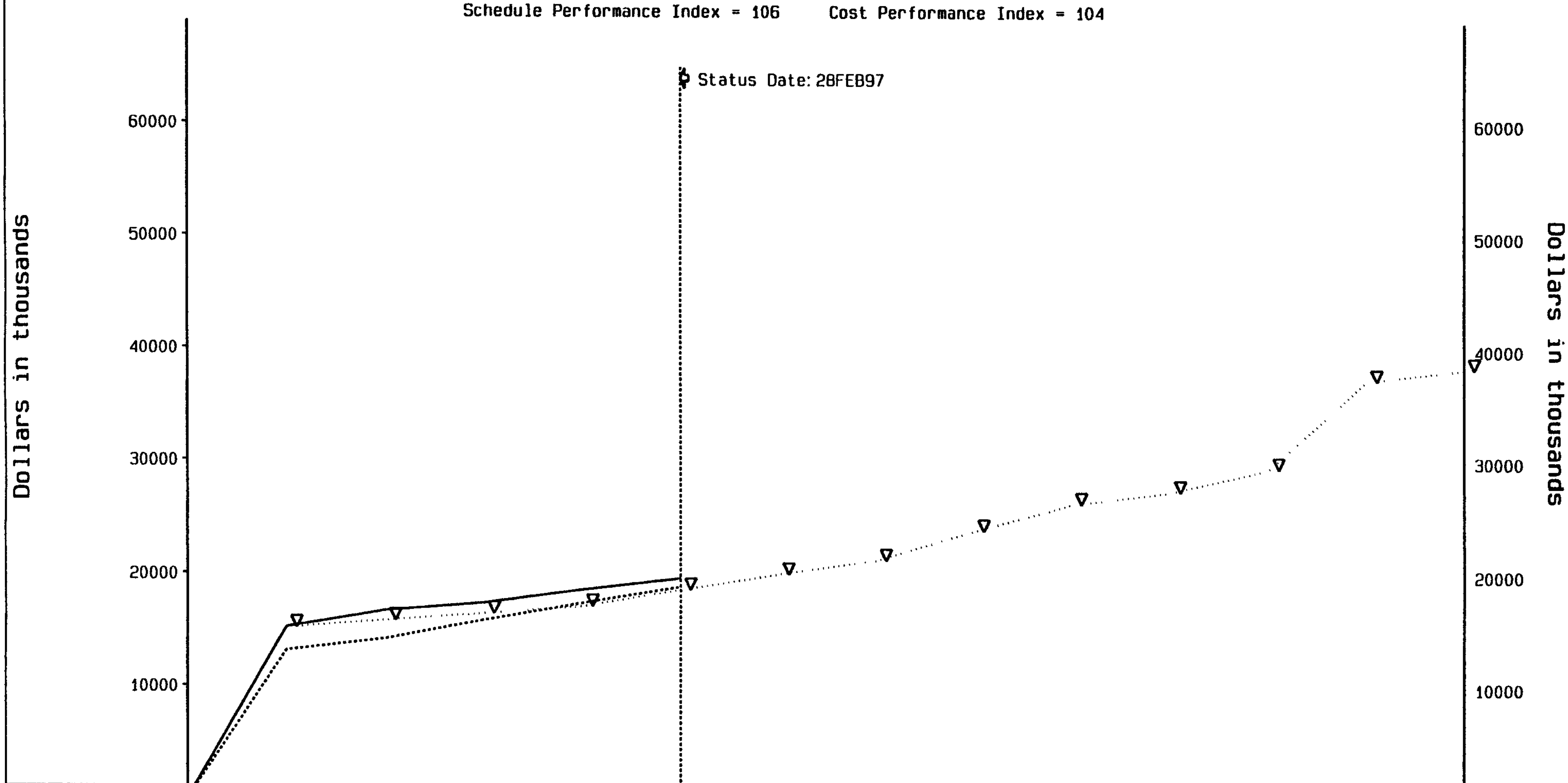
LEGEND		
Bud	Per	Act

LIGO PROJECT
1.1.4 Facility Design & Construction

Date: 9APR97
Program: LIGOPMB1
Report. LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 106 Cost Performance Index = 104



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	15,098	15,769	16,371	17,034	18,548	19,931	21,221	23,836	26,229	27,293	29,333	37,251	38,289	K$
Performance	15,159	16,649	17,314	18,533	19,589									K$
Actuals	13,102	14,116	15,781	17,348	18,821									K$
Schedule Variance	61	880	943	1,499	1,041									K$
Cost Variance	2,057	2,533	1,533	1,185	768									K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

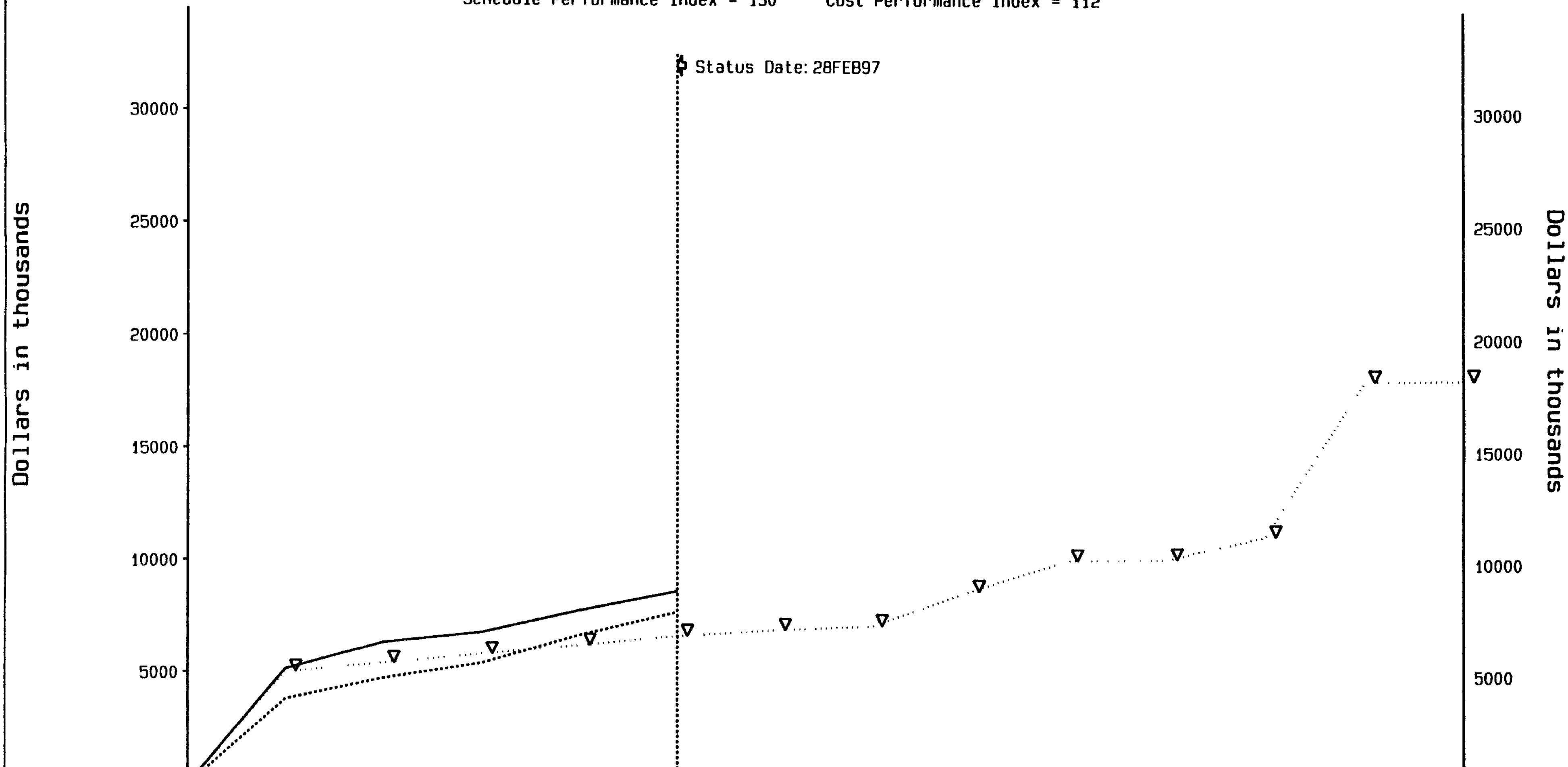
LIGO PROJECT
5D522 WA Construction Contracts

LEGEND	
Bud	···▽···▽···▽···
Per	———
Act	··············

Date: 9APR97
Program: LIGOPMB1
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 130   Cost Performance Index = 112



	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	SCALE
Planned Budget	5,009	5,424	5,838	6,252	6,666	6,951	7,141	8,672	10,065	10,130	11,169	18,108	18,167	K$
Performance	5,148	6,348	6,825	7,809	8,661									K$
Actuals	3,809	4,735	5,432	6,713	7,736									K$
Schedule Variance	139	924	987	1,557	1,995									K$
Cost Variance	1,339	1,613	1,393	1,096	925									K$

Schedule Variance = Perf-Budg   Cost Variance = Perf-Actual   Schedule Performance Index = Perf/Budg   Cost Performance Index = Perf/Actual

Introduction

NSF Technical Review

Barry Barish

April 15, 1997

LIGO Technical Status

**** on track ****

- **Facilities** are under construction with no major technical problems

- Good progress on **R & D**, on FMI,PNI and 40m

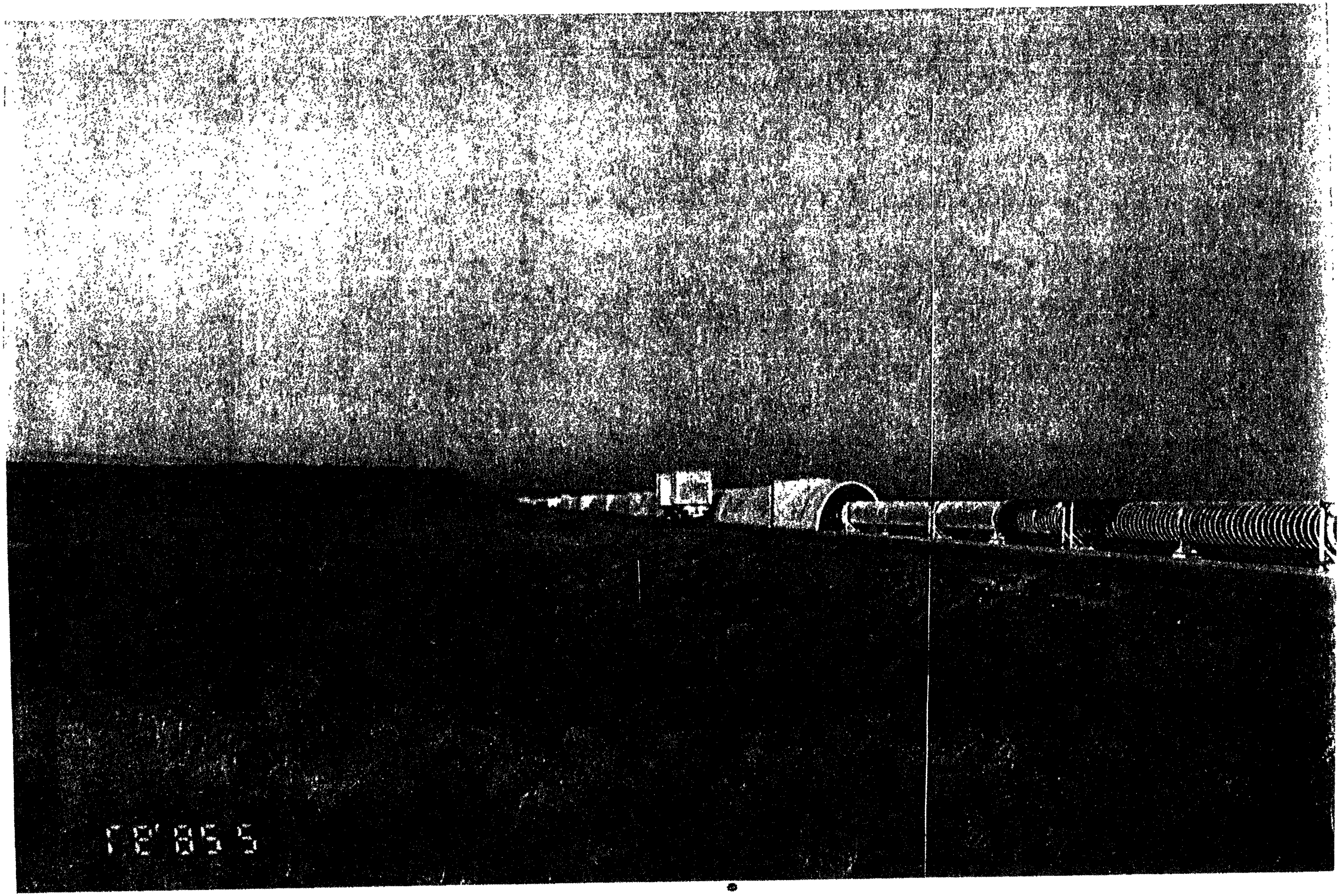
- **Detector** design is progressing well, despite some selected delays
  - » detailed installation and integration issues are being addressed as part of a project replan

- Growing efforts in modeling, data formats, data analysis, networking and computing

Technical Status

facilities

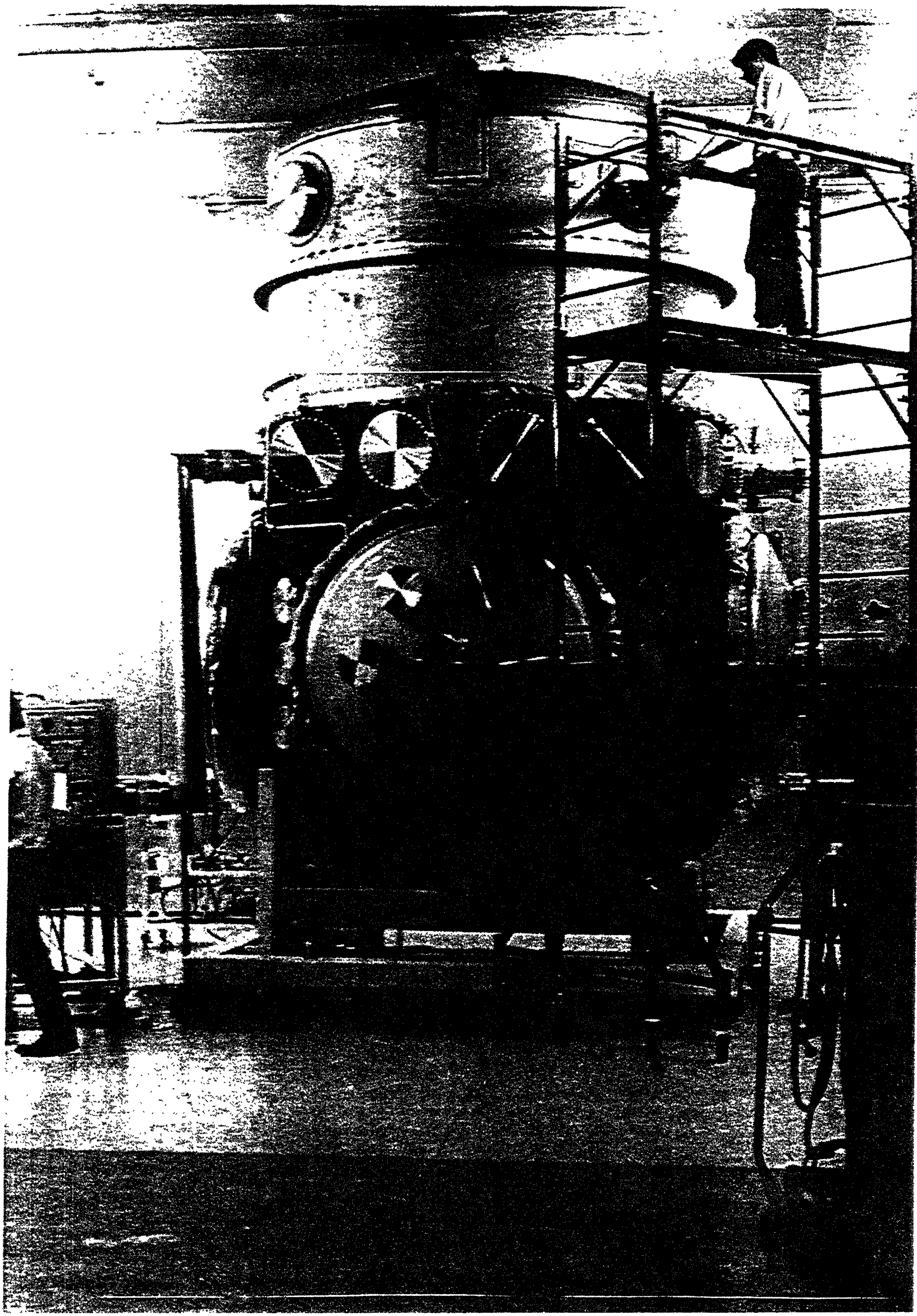
- Hanford Construction (on schedule)
  - » foundation and slab - complete
  - » x arm beam tube, enclosure - complete
  - » y arm beam tube - beginning
  - » buildings under construction
- Louisiana Construction (on schedule)
  - » berm complete, being stabilized
  - » differential settling is OK
  - » poured first concrete
- Technical Status
  - » beam tube dimensions, welding, survey meet specifications.
  - » no leaks found on 65 ft sections or girth welds
  - » full 2 km x arm module pumpdown (end of April)
  - » bakeout technical plan and schedule (Althouse)
  - » baffles - (Lazzarini)
    - – ***PROBLEM*** *- shards from coated baffles;* ***SOLUTION*** *- replace with uncoated baffles.*
    - – ***MEETS OUR REQUIREMENTS***

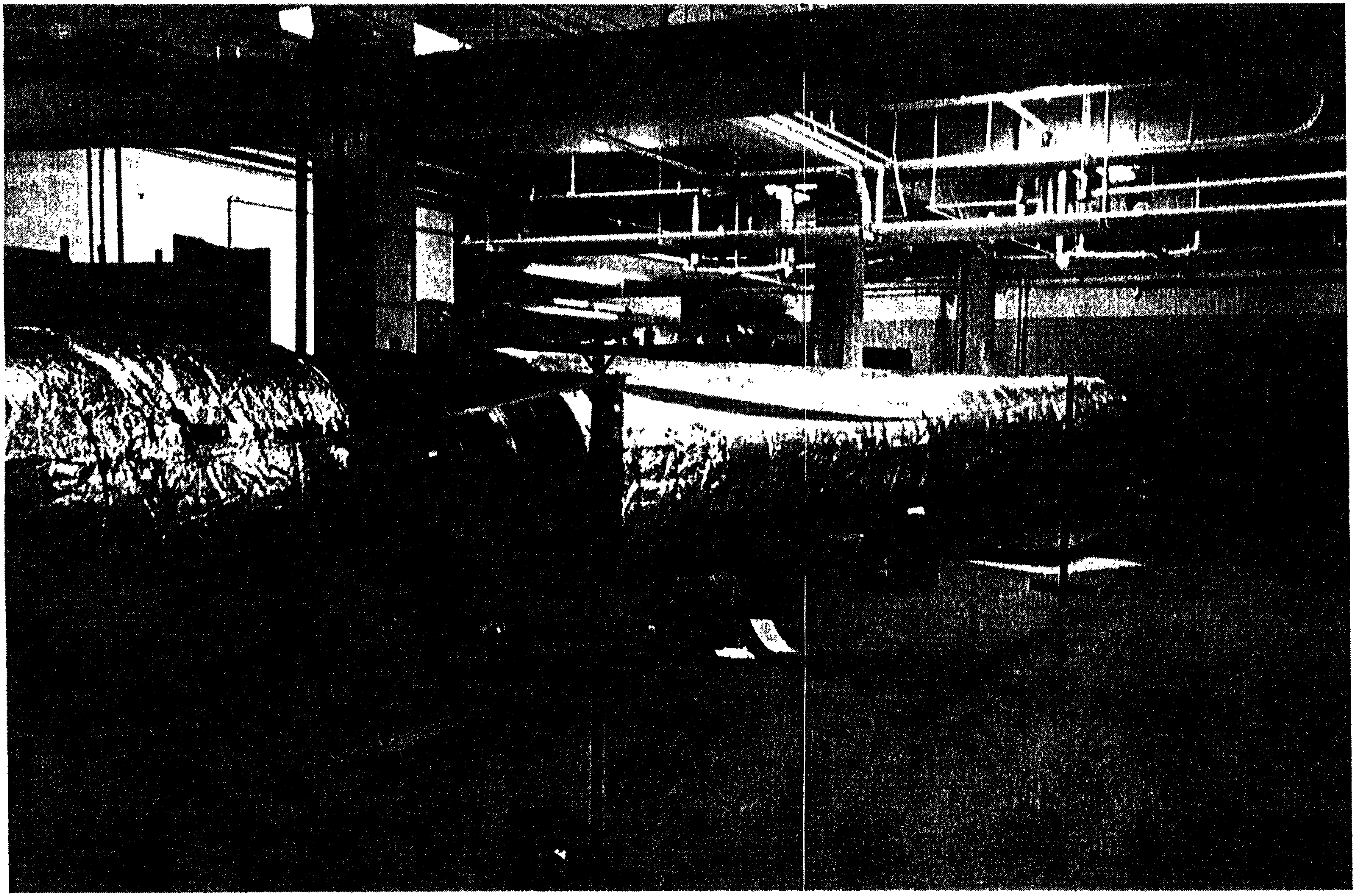


G97004

G970048- 21 -O-py

G970049- -O-PV





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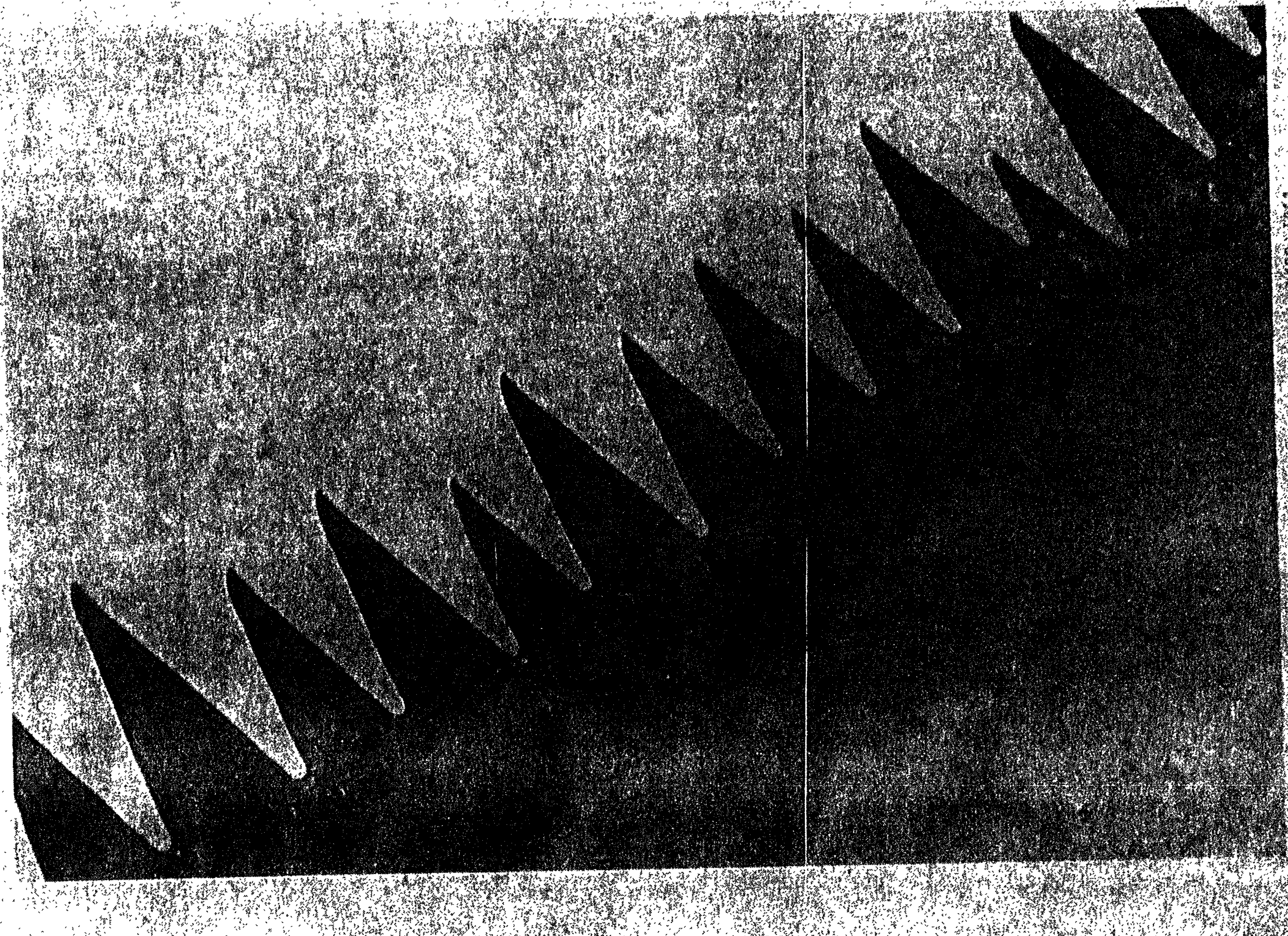
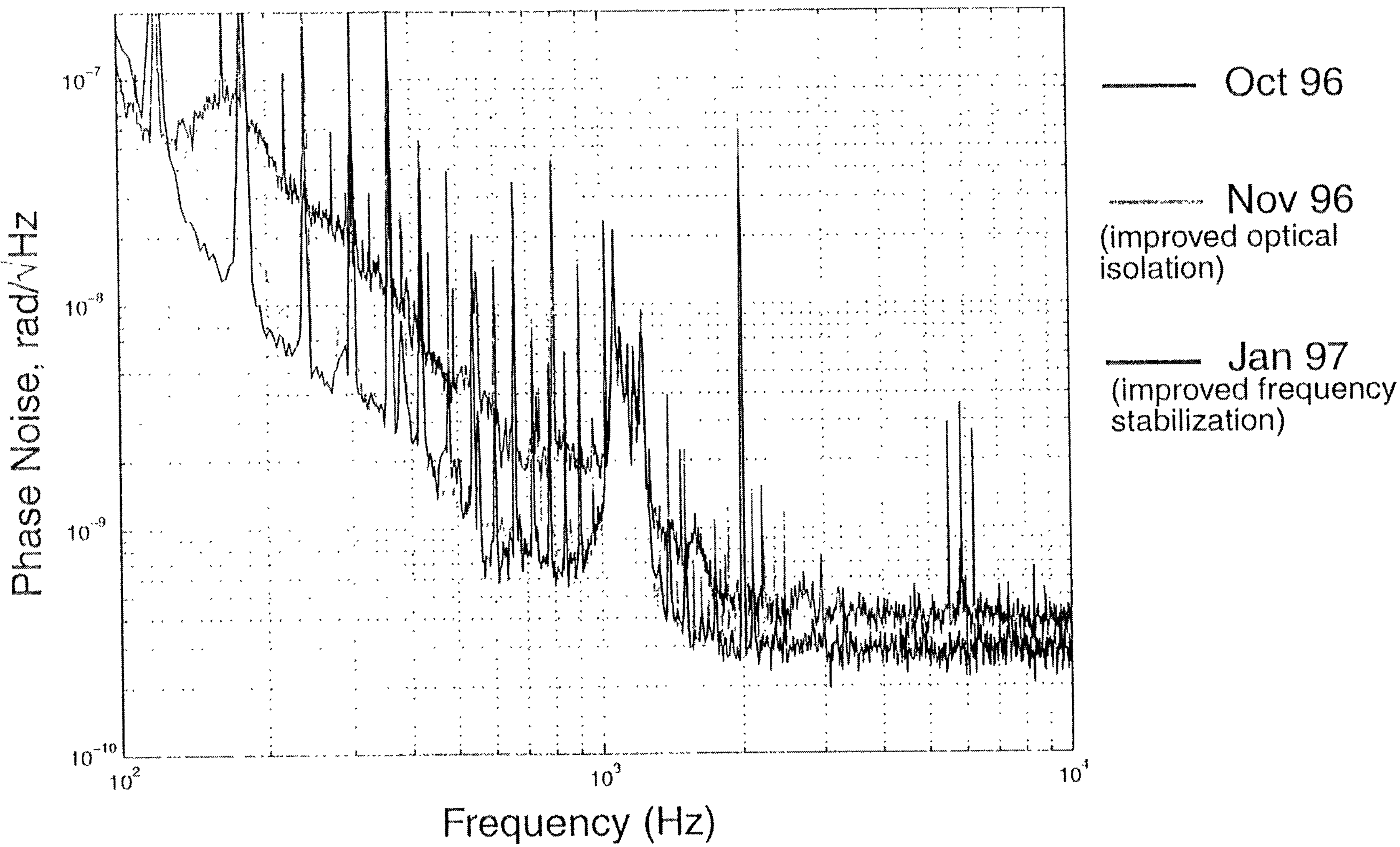


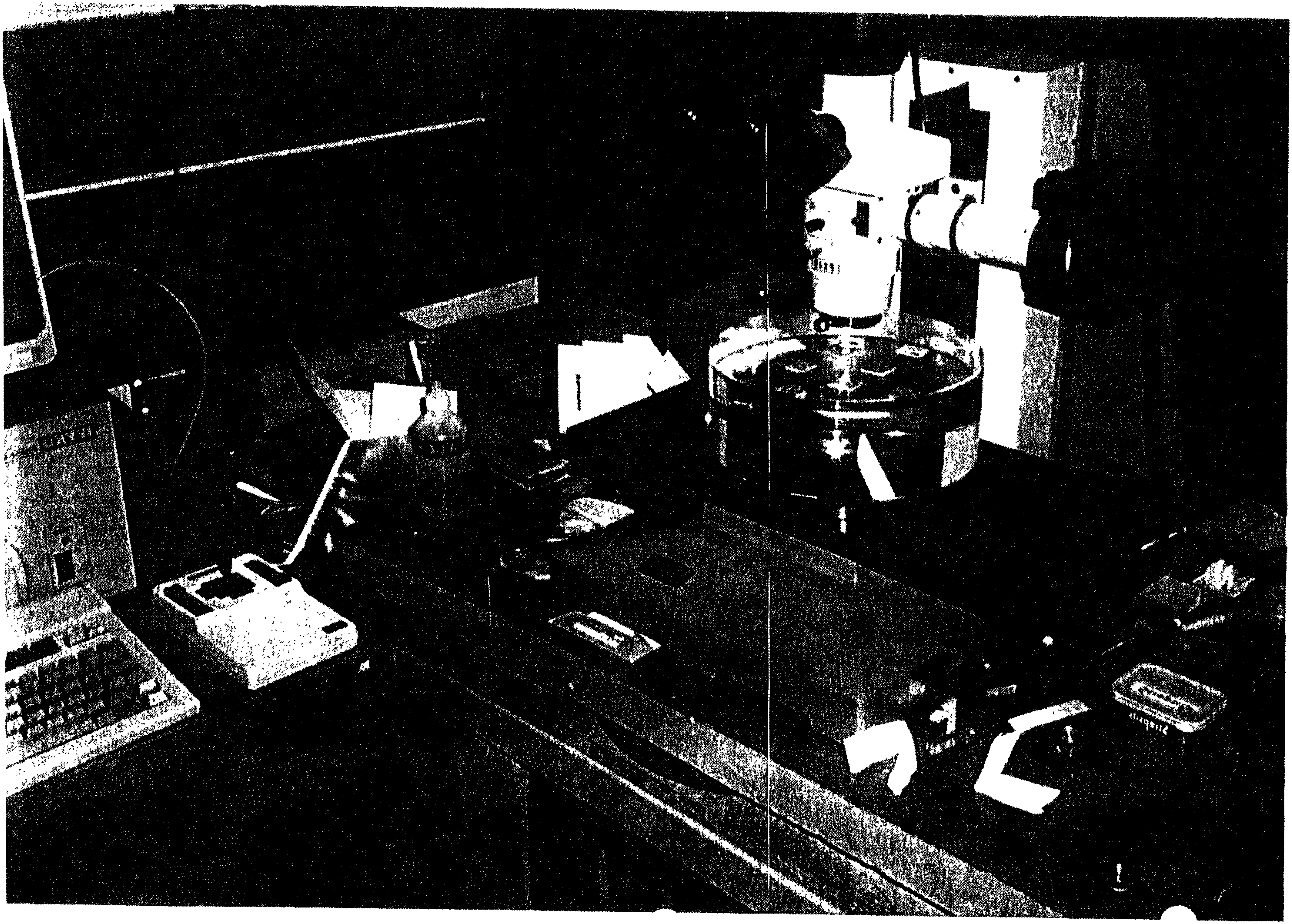
Technical Status

interferometry

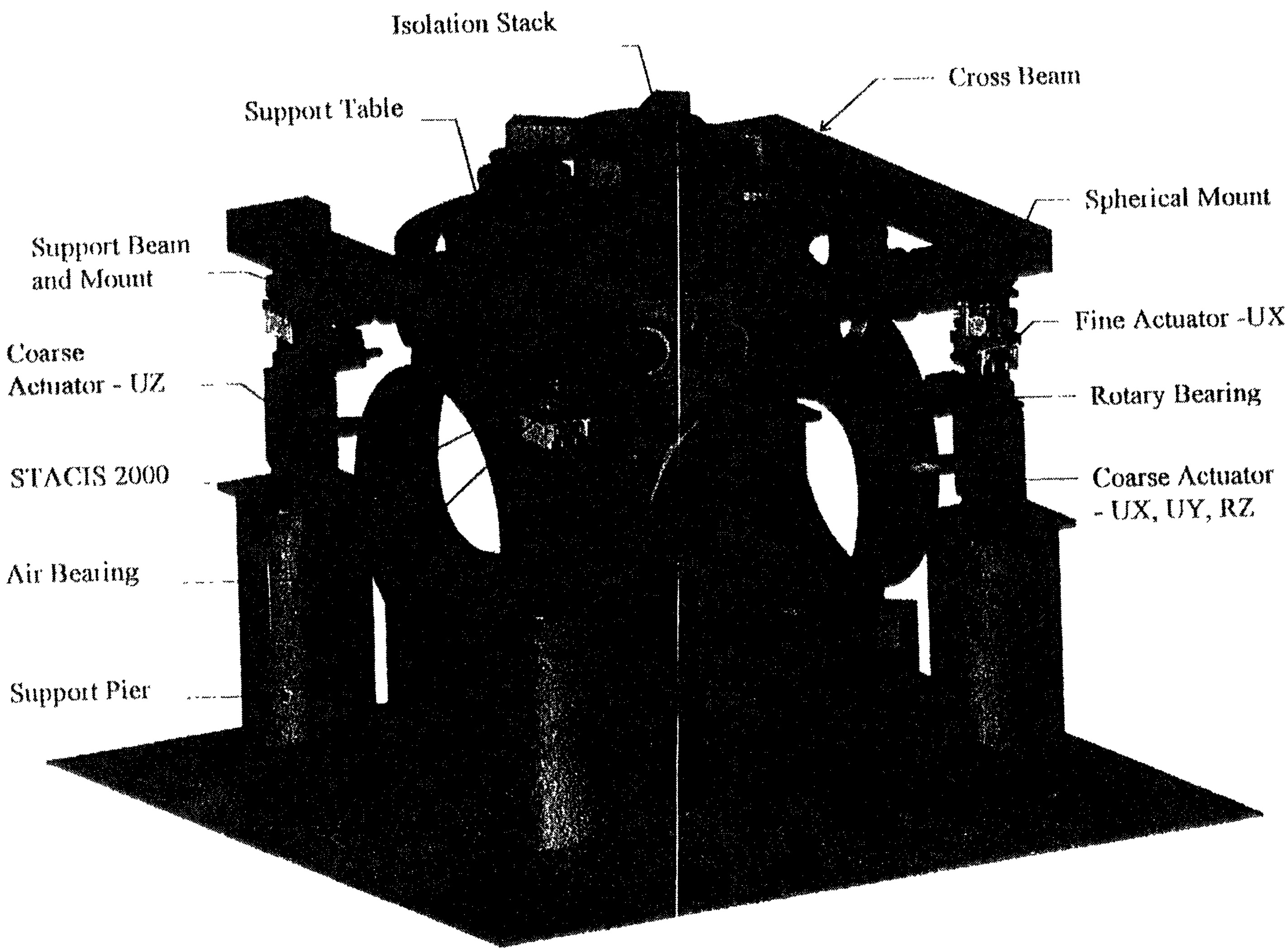
- R & D Program
  - » PNI noise studies and conversion to 1.06 μ
  - » 40m conversion to recycling configuration
  - » submitted a revised advanced r&d workplan('97) and preparations of lab space, etc is underway (awaiting funding)
- Detector
  - » Laser development at Lightwave and prestablization at Caltech (Savage)
  - » Core Optics (Camp)
  - » Input Optics (Reitze/Florida)
  - » Seismic Isolation (Thompson/HYTEC)
  - » Length and Alignment Sensing
    - – design (Zucker)
    - – alignment sensing studies on FMI (Mavalvala)
  - » CDS Electronics - alignment sensing (Heefner)

Phase Noise: Oct 96 vs. Jan 97





BSC Assembly



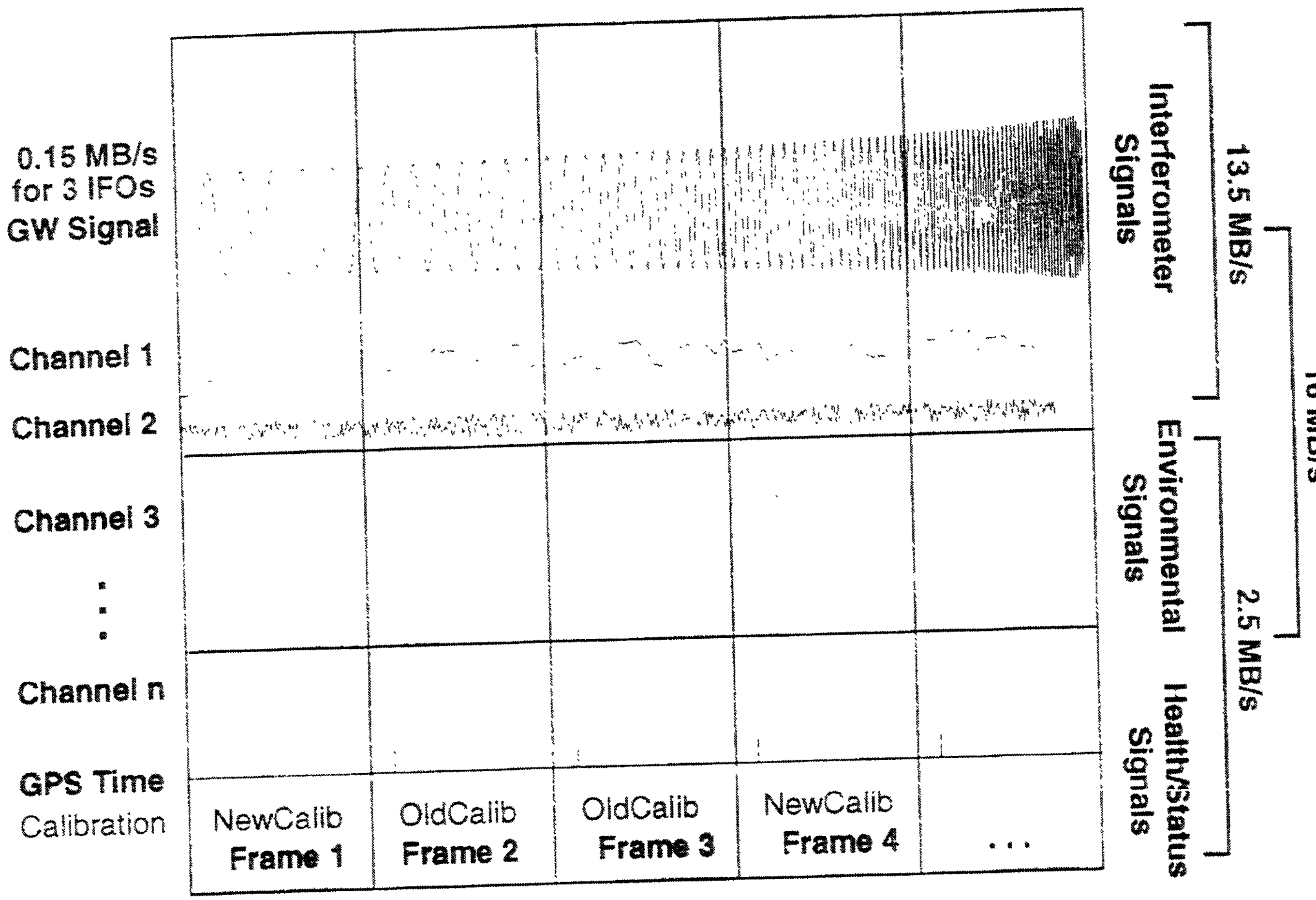
Technical Status

data and computing

- Data Acquisition (Bork)
  - » up to 600 Gbytes/day (continuous)
- Data Processing (Blackburn)
  - » plans, GRASP package (Allen), 40m prototype data analysis
- Networking (Lazzarini)
  - » requirements and analysis of options
- Modeling - lock acquisition (Sievers)
- End to End Modeling (Yamamoto)
  - » 40m and LIGO

White Paper by summer for next PAC meeting

LIGO Data Stream and Data Frame Design



- Frame is (structured) self-contained snapshot of data for a period of time
  - GW channel & ancillary IFO channels
  - Environmental monitoring (veto) channels
  - Facilities/Vacuum health & status

Cost and Schedule

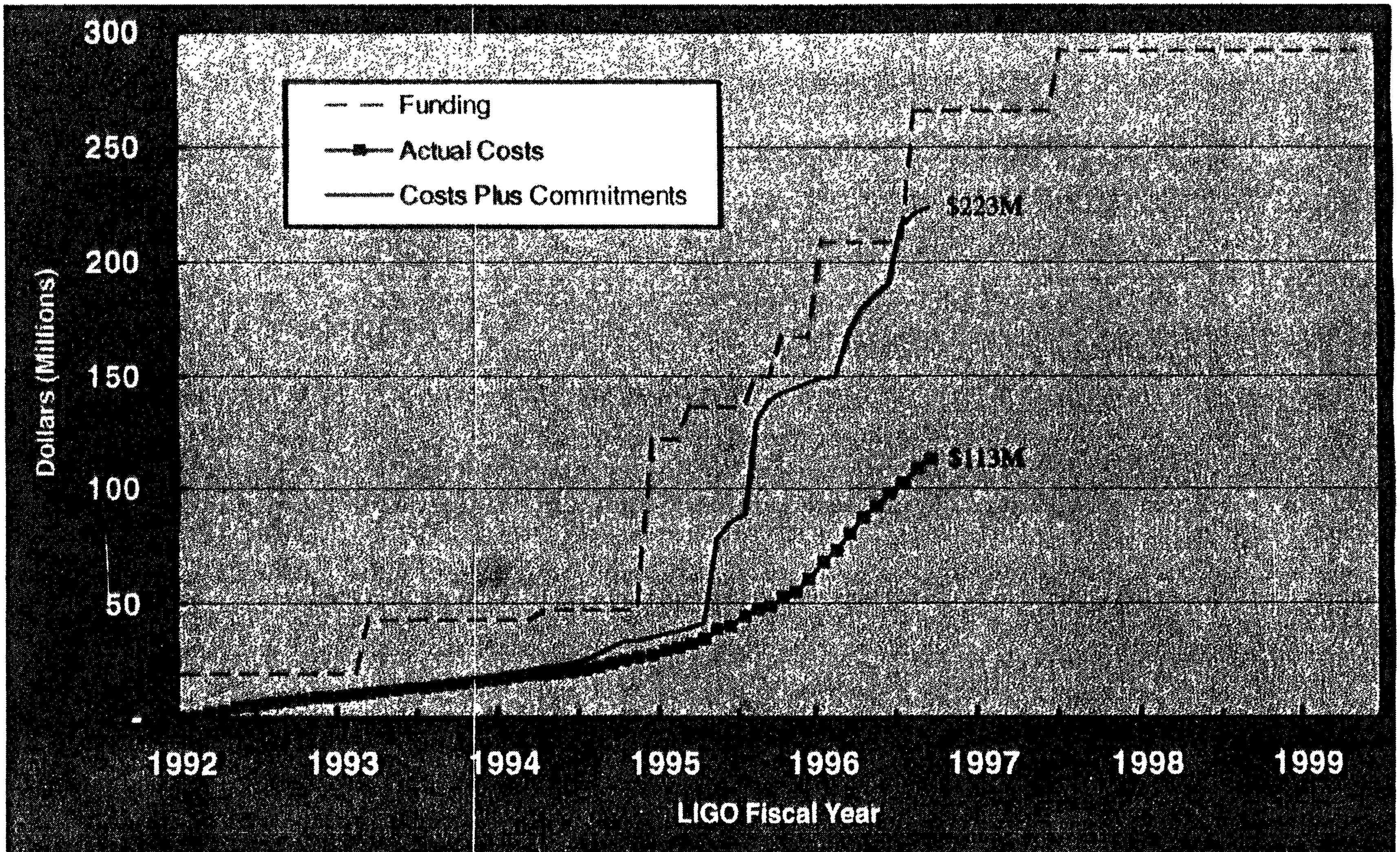
highlights

- LIGO Costs
  - » actual costs ($113M)
  - » costs + commitments ($223M) - all major contracts are awarded
  - » performance
  - » contingency analysis

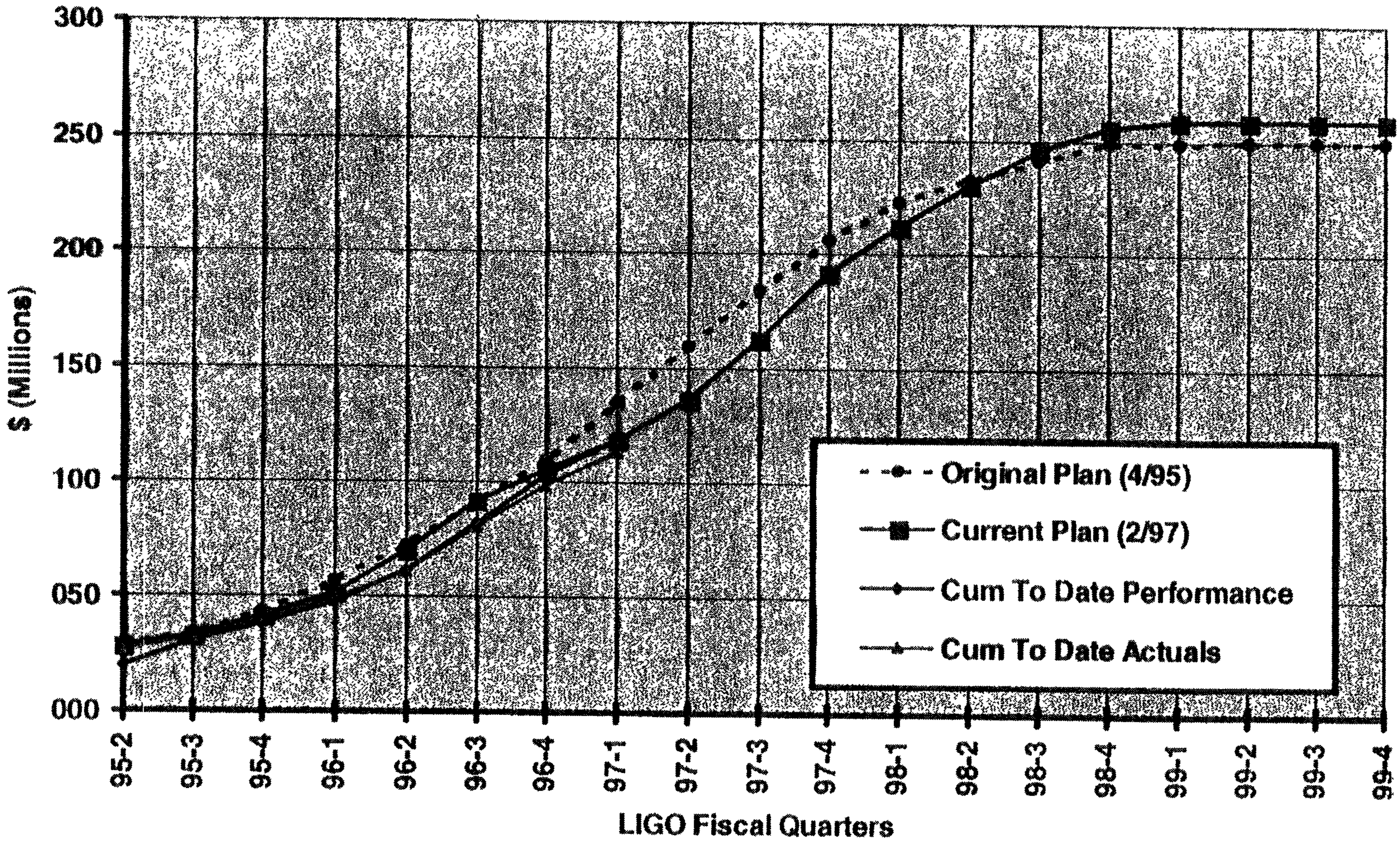
- LIGO Schedule
  - » Milestone summary
  - » Project top level schedule and critical paths

- Commissioning Plan
  - » acceptance and commissioning of faciities
  - » resource loaded schedules to complete construction (replan)
  - » detailed plan for detector installation and commissioning, resource loaded and reconciled with construction schedules (replan)

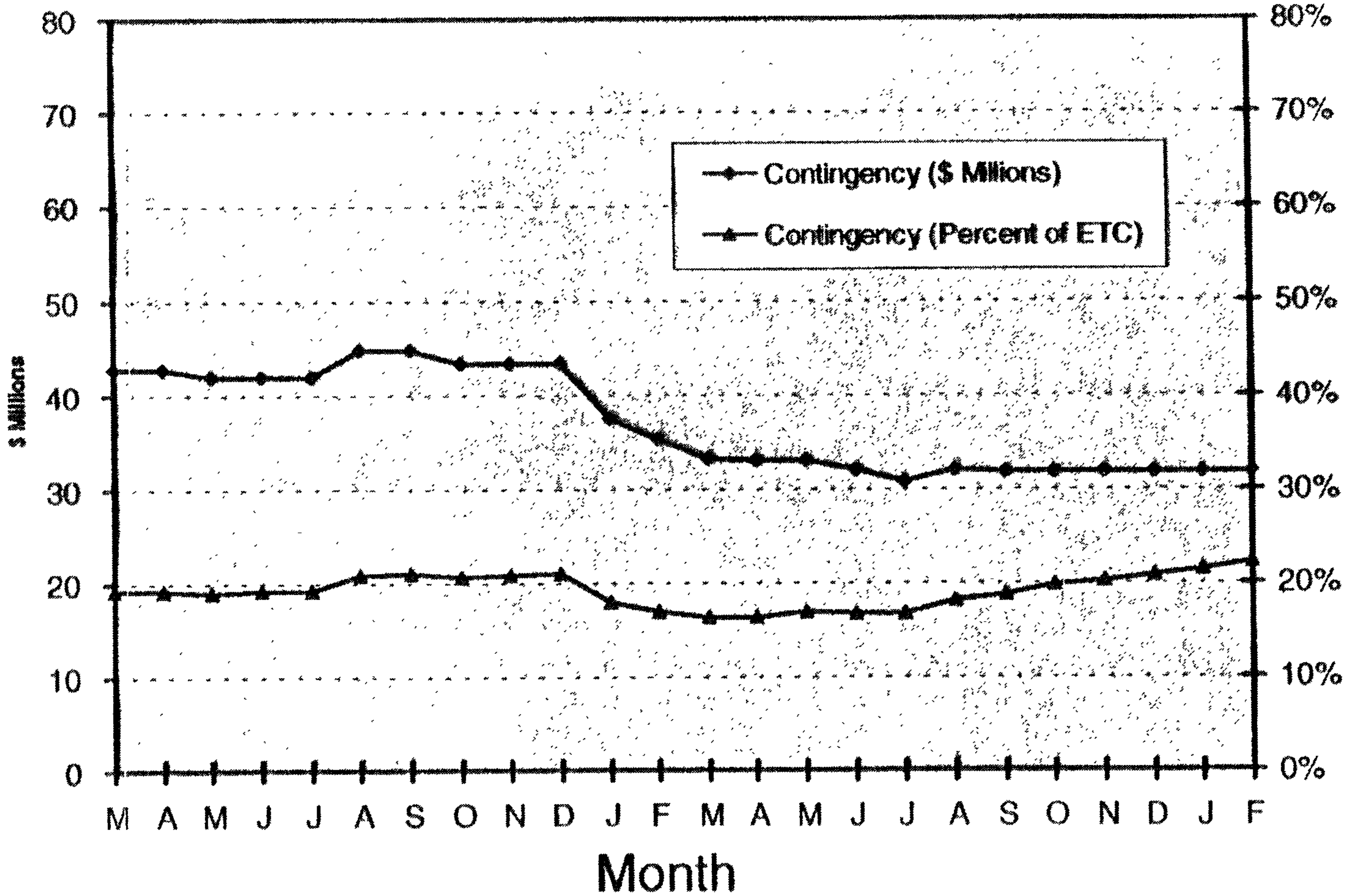
Actual Costs and Commitments
(End of February 1997 Data)



Performance Graphs
(LIGO Construction Project Total)



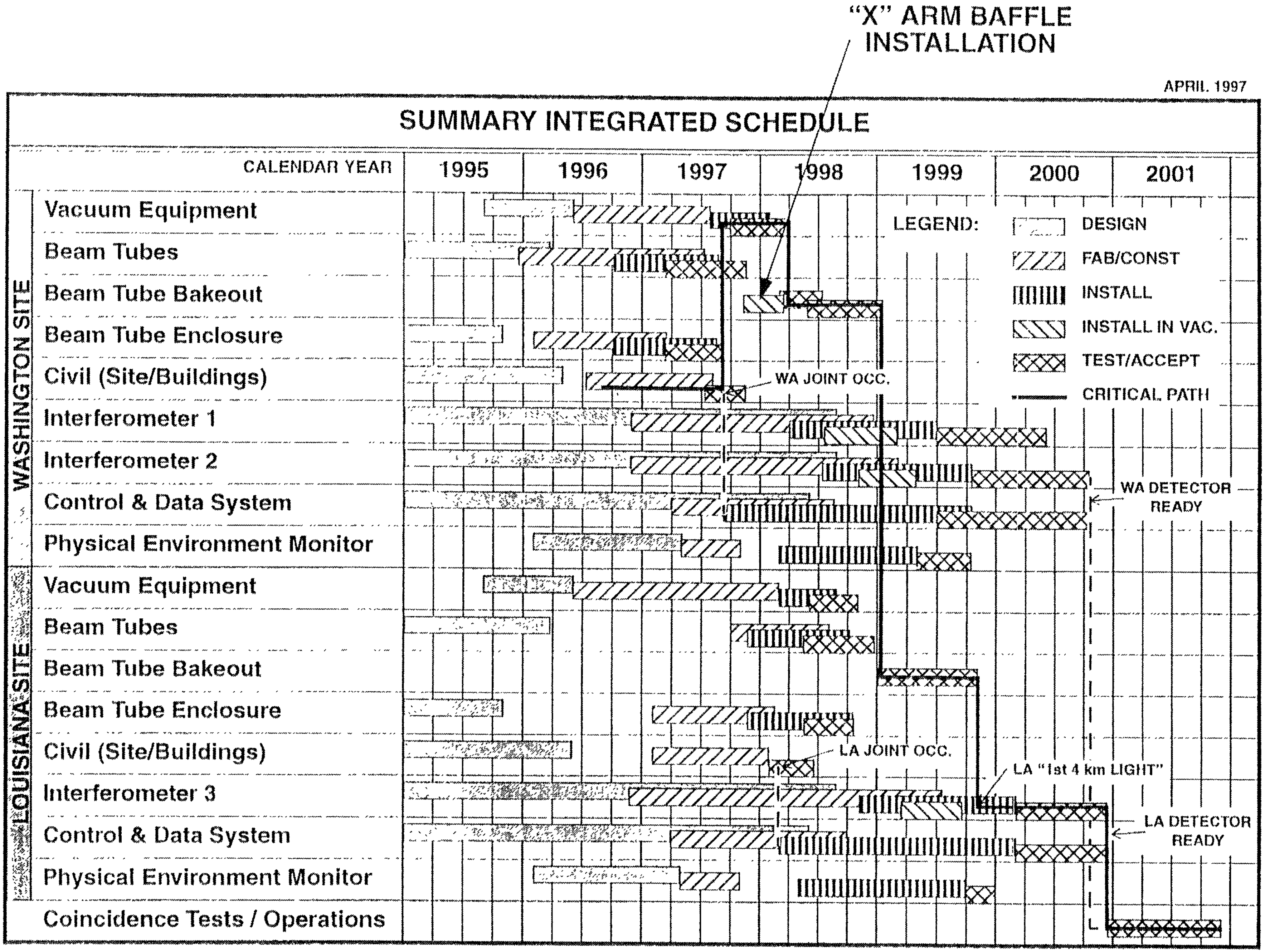
Project Contingency
(As a function of Time)



Project Mgmt Plan Milestones
(Hanford, WA Facilities)

Milestone Description	Project Mgmt Plan	Baseline Dates	Current Status
Initiate Site Development	Mar-94	Mar-94	Mar-94
Beam Tube Final Design Review	Apr-94	Apr-94	Apr-94
Select A&E Contractor	Nov-94	Nov-94	Nov-94
Complete BT Qual Test	Feb-95	Apr-95	Apr-95
Select VE Contractor	Mar-95	Jul-95	Jul-95
Initiate Beam Tube Fabrication	Oct-95	Dec-95	Dec-95
Initiate Slab Construction	Oct-95	Feb-96	Feb-96
Initiate Building Construction	Jun-96	Jul-96	Aug-96
Joint Occupancy	Sep-97	Aug-97	Sep-97
Accept Tubes and Covers	Mar-98	Nov-97 *	Jan-98 *
Accept Vacuum Equipment	Mar-98	Apr-98	Apr-98
Beneficial Occupancy	Mar-98	Sep-97	Oct-97
Initiate Facility Shakedown	Mar-98	Apr-98	Apr-98

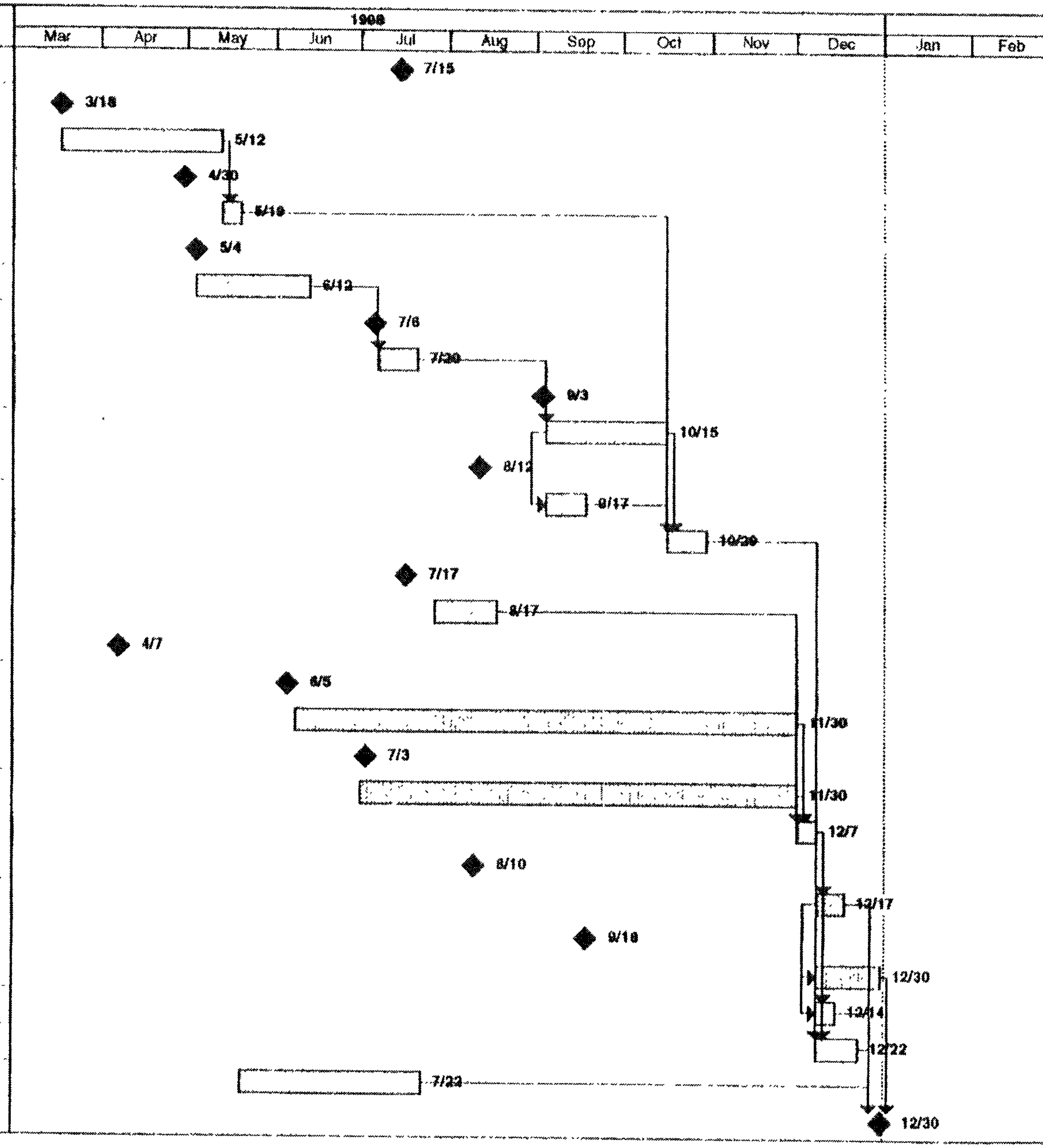
* Beam Tube Bake is planned after Beam Tube Acceptance


"X" ARM BAFFLE INSTALLATION
APRIL 1997
SUMMARY INTEGRATED SCHEDULE
CALENDAR YEAR
1995
1996
1997
1998
1999
2000
2001
WASHINGTON SITE
Vacuum Equipment
Beam Tubes
Beam Tube Bakeout
Beam Tube Enclosure
Civil (Site/Buildings)
Interferometer 1
Interferometer 2
Control & Data System
Physical Environment Monitor
LOUISIANA SITE
Vacuum Equipment
Beam Tubes
Beam Tube Bakeout
Beam Tube Enclosure
Civil (Site/Buildings)
Interferometer 3
Control & Data System
Physical Environment Monitor
Coincidence Tests / Operations
LEGEND:
DESIGN
FAB/CONST
INSTALL
INSTALL IN VAC.
TEST/ACCEPT
CRITICAL PATH
WA JOINT OCC.
WA DETECTOR READY
LA JOINT OCC.
LA "1st 4 km LIGHT"
LA DETECTOR READY

LIGO

Begin WA 4K Installation

ID	Task Name	Days	Start	Finish
1	NSF Level 1 - Begin WA Install	0d	7/15/98	7/15/98
2	Receive PSL Prototype	0d	3/18/98	3/18/98
3	Install PSL Prototype	40d	3/18/98	5/12/98
4	Receive PSL Proto Electronics	0d	4/30/98	4/30/98
5	Install PSL Proto Electronics	5d	5/13/98	5/19/98
6	Receive 3 Ham Stacks + 1 HAM	0d	5/4/98	5/4/98
7	Install 3 HAM Stacks + 1 HAM	30d	5/4/98	6/12/98
8	Receive ASC/LSC Hardware	0d	7/6/98	7/6/98
9	Install ASC/LSC Hardware	10d	7/7/98	7/20/98
10	Receive IOO	0d	9/3/98	9/3/98
11	Install 2 IOO	30d	9/4/98	10/15/98
12	Receive IOO Electronics	0d	8/12/98	8/12/98
13	Install IOO Electronics (SOS)	10d	9/4/98	9/17/98
14	Align IOO	10d	10/16/98	10/29/98
15	Receive LOS Electronics	0d	7/17/98	7/17/98
16	Install Suspension Electronics - (LOS)	16d	7/27/98	8/17/98
17	Receive Core Optics	0d	4/7/98	4/7/98
18	Receive LOS Suspensions	0d	6/5/98	6/5/98
19	Assemble 3 COC into Suspension	126d	6/8/98	11/30/98
20	Receive BSC Stacks	0d	7/3/98	7/3/98
21	Install 3 BSC Stacks	109d	7/1/98	11/30/98
22	Install last of 3 COC Susp Assbmly	5d	12/1/98	12/7/98
23	Receive Wave Front Sensing	0d	8/10/98	8/10/98
24	Install 3rd Wavefront Sensing	8d	12/8/98	12/17/98
25	Receive ASC/LSC Electronics	0d	9/18/98	9/18/98
26	Install ASC/LSC Electronics	17d	12/8/98	12/30/98
27	Install last of 3 COS	5d	12/8/98	12/14/98
28	Align COC	11d	12/8/98	12/22/98
29	Install Remote Diagnostics	46d	5/20/98	7/22/98
30	Lock Vertex Michelson	0d	12/30/98	12/30/98



Management

construction project

- Project Management
  - » Project Control Meeting (weekly)
  - » Cost/Schedule review (monthly)
  - » technical board (eg. baffles, bake)
  - » change control board (eg. stabilization)
- Facilities
  - » on site management, quality assurance, and integration
- Detector
  - » all task leaders in place and subsystems are nearly fully staffed
  - » most subsytems in design phase (50% in preliminary design and 50% in final design
- Staffing Status
  - » total staffing (~100)
  - » site staffing (Hanford = 8; Livingston = 2)

Change Control Log
(Since last NSF Review)

Change Request No.	Description	Submitted By	Submittal Date	Current Status	Disposition Date
CR-970001	WBS 1.1.1 Vacuum Equipment - Replacement of one BSC with proto-type	J. Worden 372-1788	February 7, 1997	Not Approved	March 25, 1997
CR-970002	WBS 1.1.1 Vacuum Equipment - Metal Seal Test	J. Worden 372-1788	February 7, 1997	Approved $21,000	Information only
CR-970003	WBS 1.1.4 Facilities - Air Handling Ducts cleaning procedures and spec-ifications	O. Math-erny 372-1788	February 12, 1997	Approved $150,000 NTE	February 13 1996
CR-970004	WBS 1.1.2 - Beam Tube, Transform-ers	L. Jones	March 12, 1995	Approved ($44,110)	March 25, 1997
CR-970005	WBS 1.1.2 - Beam Tube Miscella-neous	L. Jones	March 12, 1995	Approved $51,200	March 25, 1997

Change Control Log - continued
(Since last NSF Review)

Change Request No.	Description	Submitted By	Submittal Date	Current Status	Disposition Date
CR-970006	WBS 1.1.2 - Beam Tube, BDF Air Monitoring	L. Jones	March 12, 1995	Approved $46,130	March 25, 1997
CR-970007	WBS 1.1.2 - Beam Tube, Hanford Labor Rates	L. Jones	March 19, 1995	Approved $61,316	March 25, 1997
CR-970008	WBS 1.1.4 - Cement Treatment of Berm, Livingston, Louisiana Site	F. Asiri	March 21, 1997	Approved Pending Additional Information $900,000	March 25, 1997
CR-970009	WBS 1.2 - Core Optics Components, Reduced Quantity/Unit Price	G. Billings-ley	March 20, 1997	Approved ($881,636)	March 25, 1997
CR-970010	WBS 1.2 - Input/Output Optics, Delete Output Mode Cleaners	J. Camp	March 21, 1997	Approved ($471,000)	March 25, 1997

LIGO

other activities

- Physics and Technical Workshops
  - » Data Analysis Workshop (MIT) in Dec '96
  - » Advanced R & D (Aspen) Jan '97
- PAC (B. Frazer, chair)
  - » 1st meeting (Caltech/Jan 97)
    - formation - LIGO Lab and Scientific Collaboration
    - proposals for advanced r & d for LIGO
  - » 2nd meeting (MIT/June '97)
    - formation - LIGO Lab and Scientific Collaboration
    - data analysis and computing
    - LIGO program and plans at MIT
- MIT/Caltech Oversight Committee (H. Hornung, chair)
  - » met April '97 - formation of LIGO Laboratory
- Outreach and Education
  - » WWW, newsletter, radio, newspapers ...
  - » LIGO seminars, conference participation
  - » Undergrad summer program - REU Site
  - » Community outreach at the sites

INTEGRATION / ACCEPTANCE RESPONSE TO NSF RECOMMENDATIONS

NSF REVIEW

APRIL 15, 1997

GERRY STAPFER

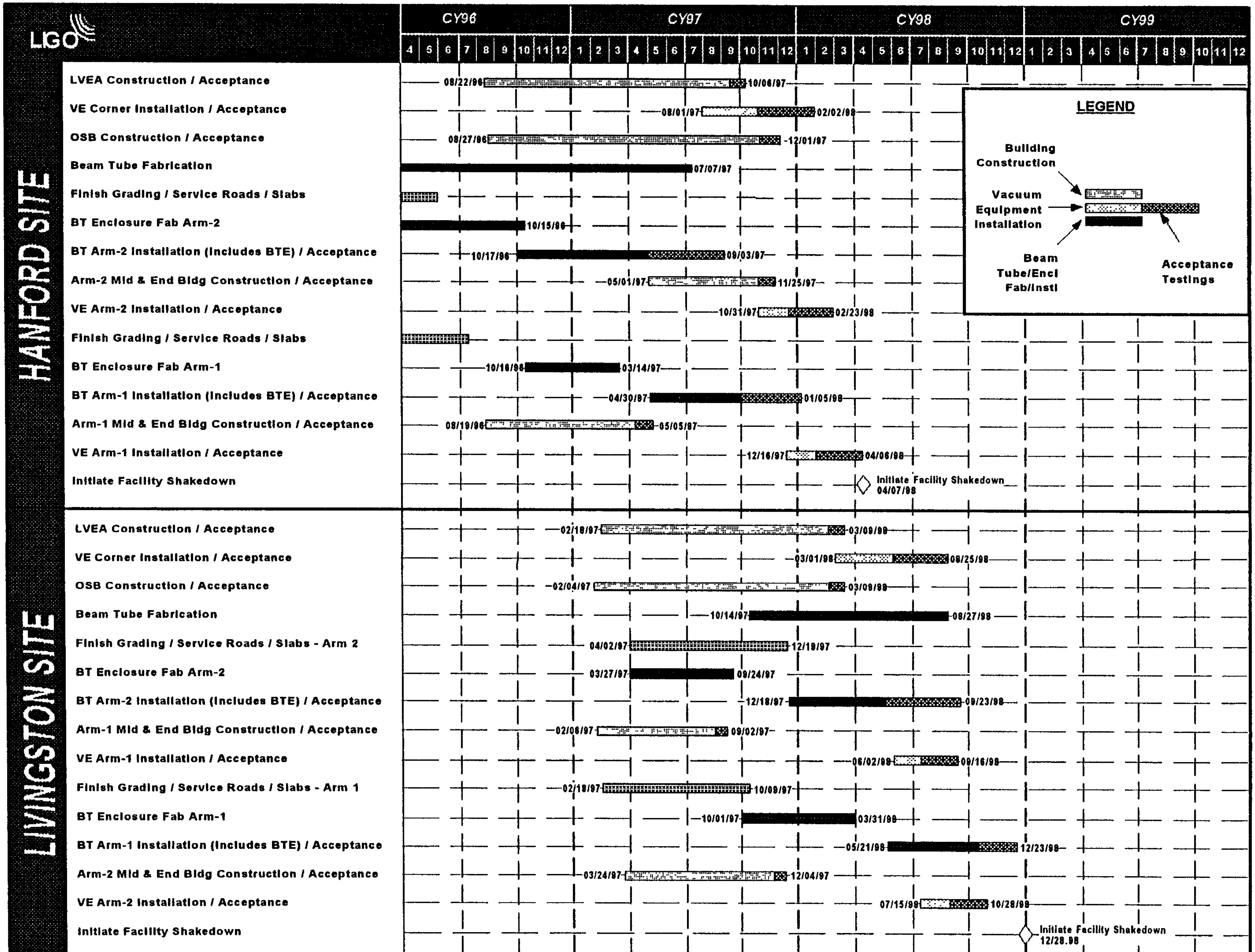
OVERVIEW

- LIGO'S ROLE AS "GENERAL CONTRACTOR"
  - TASKS
  - STRATEGY
  - INTERFACES
  - ACCEPTANCE
  - STAFFING
- INTEGRATION OF DETECTOR WITH FACILITIES
  - INTERFACES

CONSTRUCTION STRATEGY

- THERE ARE THREE MAJOR CONTRACT SCOPES AT EACH LIGO SITE
- INTERFACES BETWEEN TASKS WERE INTENTIONALLY DESIGNED TO BE WELL DEFINED AND ARE KEPT TO A MINIMUM
- LIGO STAFF MAINTAINS CLOSE CONTACT WITH ALL CONTRACTORS
- SITE MANAGER, AT EACH SITE, IS EMPOWERED TO ADJUDICATE POTENTIAL ISSUES
- **CONSTRUCTION IS DISTRIBUTED OVER 5 MILES**

FACILITIES SCHEDULE - HANFORD / LIVINGSTON



CONSTRUCTION TASKS

- BUILDING AND INFRASTRUCTURE
  - CORNER STATION
  - MID AND END STATIONS
  - CHILLER YARDS
- JOINT OCCUPANCY MILESTONE
  - WELL DEFINED (PUNCH LIST ONLY)
  - IS A PREREQUISITE FOR VACUUM EQUIPMENT INSTALLATION
  - SCHEDULED INTERFACE BETWEEN CONSTRUCTION AND VACUUM EQUIPMENT
- BENEFICIAL OCCUPATION
  - DEFINED AS THE FULLY OPERATIONAL ACCEPTANCE OF THE BUILDINGS BY LIGO

BT SLAB CONSTRUCTION

- INCLUDES THE CONSTRUCTION OF:
  - SERVICE ROAD ALONG EACH ARM
  - CONCRETE SLAB UNDER THE BEAM TUBE
  - FABRICATION (INCL.. PLACING IN LA) OF ENCLOSURES
- PRIMARY INTERFACE FOR BEAM TUBE CONTRACTOR
  - SLAB IS SCHEDULED TO BE COMPLETED WELL AHEAD OF NEED DATE BY CB&I
  - TASK INCLUDES BEAM TUBE TERMINATION SLAB
  - ENCLOSURE IS PLACED OVER BEAM TUBE BEHIND THE CB&I INSTALLATION CREWS (MINIMUM OF FOUR TUBE LENGTHS)

VACUUM EQUIPMENT

- FABRICATION OF THE VE COMPONENTS IS PERFORMED AT CONTRACTORS' FACILITY
  - ALLOWS INDEPENDENT SCHEDULES
  - START OF INSTALLATION IS A CONTRACTUAL MILESTONE
- INTERFACE WITH BUILDING CONTRACTOR
  - LIMITED TO FLOOR LOADING AND FLATNESS
  - ELECTRICAL IS PROVIDED BY PSI (EXCEPT FOR UNDER FLOOR CONDUIT)
- BEAM TUBE INTERFACE
  - SINGLE INTERFACE AT WELD FLANGE AT EACH MODULE
- ACCEPTANCE
  - EACH ISOLATABLE VOLUME IS SEPARATELY ACCEPTED

BEAM TUBE

- FABRICATED OFF SITE
  - PROVIDES INDEPENDENT SCHEDULE
  - AVAILABILITY IS MILESTONE CONTROLLED
- INSTALLATION
  - NON CONVENTIONAL TASK
  - SCHEDULED FOR CB&I TO HAVE PRIORITY ON SERVICE ROAD
- INTERFACES
  - SLAB INTERFACE IS CONTROLLED BY REQUIREMENTS
  - INTERFACE WITH BUILDINGS IS LOCATION DEPENDENT AND IS WORKED OUT INDIVIDUALLY
- ACCEPTANCE
  - EACH MODULE (2km) IS SEPARATELY ACCEPTED BY LIGO AFTER LEAK TESTING

PLACING OF BEAM TUBE ENCLOSURES

- PROBLEM
  - ACME WAS TO PREPOSITION THE ENCLOSURES ALONG THE ARM
  - LEVERNIER'S CRANE REQUIRES THE FULL WIDTH OF THE ARM TO PLACE THE ENCLOSURES OVER THE BEAM TUBE
  - CB&I HAS PRIORITY ON THE SERVICE ROAD DURING THE BEAM TUBE INSTALLATION
- SOLUTION
  - "JUST IN TIME" DELIVERY OF ENCLOSURES ALONG THE ARMS
  - ACME PARKS ENCLOSURES <u>ON TRAILERS</u> AT END, MID AND CORNER STATIONS. DELIVERY OF ENCLOSURES DOES NOT INTERFERE WITH CB&I. ALSO ELIMINATES THE REQUIREMENT FOR LEVEL PRE-POSITIONING OF ENCLOSURE SECTIONS.

ACCESS ROAD

- PROBLEM
  - LOUISIANA DEPARTMENT OF TRANSPORTATION (LDOT) WAS LATE INITIATING THE CONSTRUCTION OF THE PRIMARY SITE ACCESS ROAD
  - UNAVAILABILITY OF A SITE ACCESS ROAD REPRESENTED A POTENTIAL SCHEDULE DELAY OF 6 MONTHS
- SOLUTION
  - NEGOTIATED THE REFURBISHMENT OF A TEMPORARY BY-PASS ROAD TO BE BUILT BY LDOT NEAR THE ARM-1 END STATION
  - RE-SCHEDULED THE WOODROW WILSON CONSTRUCTION (WWC) CONTRACT TO PRIORITIZE THE ARM-1 SERVICE ROAD AS THE FIRST TASK

STAFFING

- SITE MANAGER
  - RESPONSIBLE TO MANAGE ALL THE SITE ACTIVITIES, TO OPTIMIZE PROGRESS AND FACILITATE ANY SCHEDULE OR JURISDICTION INTERFERENCES
- CONTRACT TECHNICAL MANAGER
  - RESPONSIBLE FOR ALL ACTIVITIES WITHIN THE CONTRACT
- TECHNICAL SUPPORT
  - FULL TIME SCHEDULER TO MAINTAIN AND UPDATE SCHEDULES
  - CONSTRUCTION MANAGER AND FIELD ENGINEER
  - TECHNICAL STAFF FOR BEAM TUBE AND VACUUM EQUIPMENT
- MEETINGS AND REVIEWS
  - MONTHLY, WEEKLY COORDINATION AND STATUS MEETINGS
  - DAILY CONTACTS WITH CONTRACTS AND STAFF

LIGO INTEGRATION

- FACILITIES
  - SCHEDULE INTERFACES BETWEEN THE FACILITIES AND DETECTOR ARE MINIMIZED
  - FACILITIES ARE DESIGNED AND CONSTRUCTED TO MEET THE DETECTOR TECHNICAL REQUIREMENTS
  - SCHEDULES HAVE BEEN DEVELOPED TO SUPPORT THE DELIVERY OF A FULLY FUNCTIONAL VACUUM SYSTEM, AND AN ACCEPTED BEAM TUBE WITHIN FUNCTIONAL BUILDINGS
- BAKE OUT
  - THE BAKE OUT ACTIVITY IS A SELF CONTAINED TASK. IT INTERFACES WITH THE FACILITIES BY AN AGREED MILESTONE DATE
- DETECTOR
  - DETECTOR DEVELOPMENT PROCEEDS INDEPENDENTLY AND INSTALLATION COORDINATED WITH THE BAKE OUT

Civil Construction and Beam Tube Enclosure Technical Review

Fred Asiri

Technical Manager

April 15, 1997

Civil Construction and Beam Tube Enclosure Technical Review

Outline

- Design Status and Variances
  - ››Hanford, WA
  - ››Livingston, LA
- Construction Status and Variances
  - ››Hanford, Wa
  - ››Livingston, LA

Civil Construction and Beam Tube Enclosure Technical Review

Design Status and Variances

- Design phase for both the Hanford and the Livingston sites were completed.
- Hanford, WA
  - ››During this period, the bid package for the installation of the beam tube enclosure was completed and the contract was awarded to Levernier Construction Co.
  - ››Since the start of the building construction, only one minor revision has been made to the building drawings.
    - –Rearrangement of Office Area

Civil Construction and Beam Tube Enclosure Technical Review

Design Status and Variances

- Hanford, WA
  - ››Since the start of the beam tube enclosure/slab contract, also, one minor revision has been made to the design drawings
    - –The beam tube enclosure slab design was revised to facilitate the slipforming operation
    - –No cost impact
    - –Accelerated the performance schedule

Civil Construction and Beam Tube Enclosure Technical Review

Design Status and Variances

- Livingston, LA
  - ››The construction bid documents for Building and Infrastructure were completed and the contract was awarded to Hensel Phelps Construction Co.
    - –Livingston design is similar to Hanford design except for the site specific conditions.
    - –LVEA building is sized to accommodate two full length interferometers.
    - –Mid stations are significantly smaller, will house a Gate Valve only.

Civil Construction and Beam Tube Enclosure Technical Review

Design Status and Variances

- Livingston, LA
  - ››The construction bid documents for the beam tube enclosure were completed and the contract was awarded to Woodrow Wilson Construction Co.
    - –Design is similar to the Hanford design except for the site specific conditions.
  - ››Settlement study of the berm was performed:
    - –When it was determined that the majority of the settlements had occurred, the construction activities were initiated.

Civil Construction and Beam Tube Enclosure Technical Review

Construction Status and Variances

- Hanford, WA
  - ››Building and Infrastructure
    - –Construction is about 40 to 45% complete:
    - –Total days lost due to inclement weather is 28. Completion dates are still within late finish dates.
    - –Following the inspection of initial deliveries, performed an audit of the HVAC system to determine the cleaning requirements.This effort delayed some equipment deliveries.
    - –Substitution of siding material resulted in minor cost growth and minimal schedule impact.

Civil Construction and Beam Tube Enclosure Technical Review

Construction Status and Variances

- Hanford, WA
  - ››Beam Tube Enclosure - Fabrication and Installation
    - –The fabrication of the beam tube enclosure segments was completed on schedule within the awarded contract value.
    - –A secondary lifting fixture was added to the lifting device for Safety
    - –Installation of the beam tube enclosure segments is nearly completed on the northwest arm (x arm)

Civil Construction and Beam Tube Enclosure Technical Review

Construction Status and Variances

- Livingston, LA
  - ››Site
    - – Rough grading of the site was completed within the budget
    - – 166 days lost to inclement weather resulted in a schedule slip of 5 months (8/96 to 1/97)
    - –Rough grading of the berm at the end station of the southeast arm was completed 8/96. The measured settlement rate was better than predicted
    - –The distribution of electric power along arms started
    - –Contract for QA was awarded to Delta Testing and Inspection, Inc.
    - –Contract for Surveying Support was awarded to Simmons J. Barry & Associates

Civil Construction and Beam Tube Enclosure Technical Review

Construction Status and Variances

- Livingston, LA
  - ››Building and Infrastructure
    - –Construction of the Building and Infrastructure has been started at corner and end stations
  - ››Beam Tube Enclosure - Fabrication and Installation
    - –The service roads subgrade was treated with cement to provide a stronger subbase and to assure a stable working surface.
    - –The gravel base for the service roads was completed.

BEAM TUBE TECHNICAL REVIEW OUTLINE

Larry Jones, Technical Manager

April 15, 1997

Tube Production: Plan View and Photos

Tube Production History: Spiral Forming and Leak Testing

Tube Installation Photos

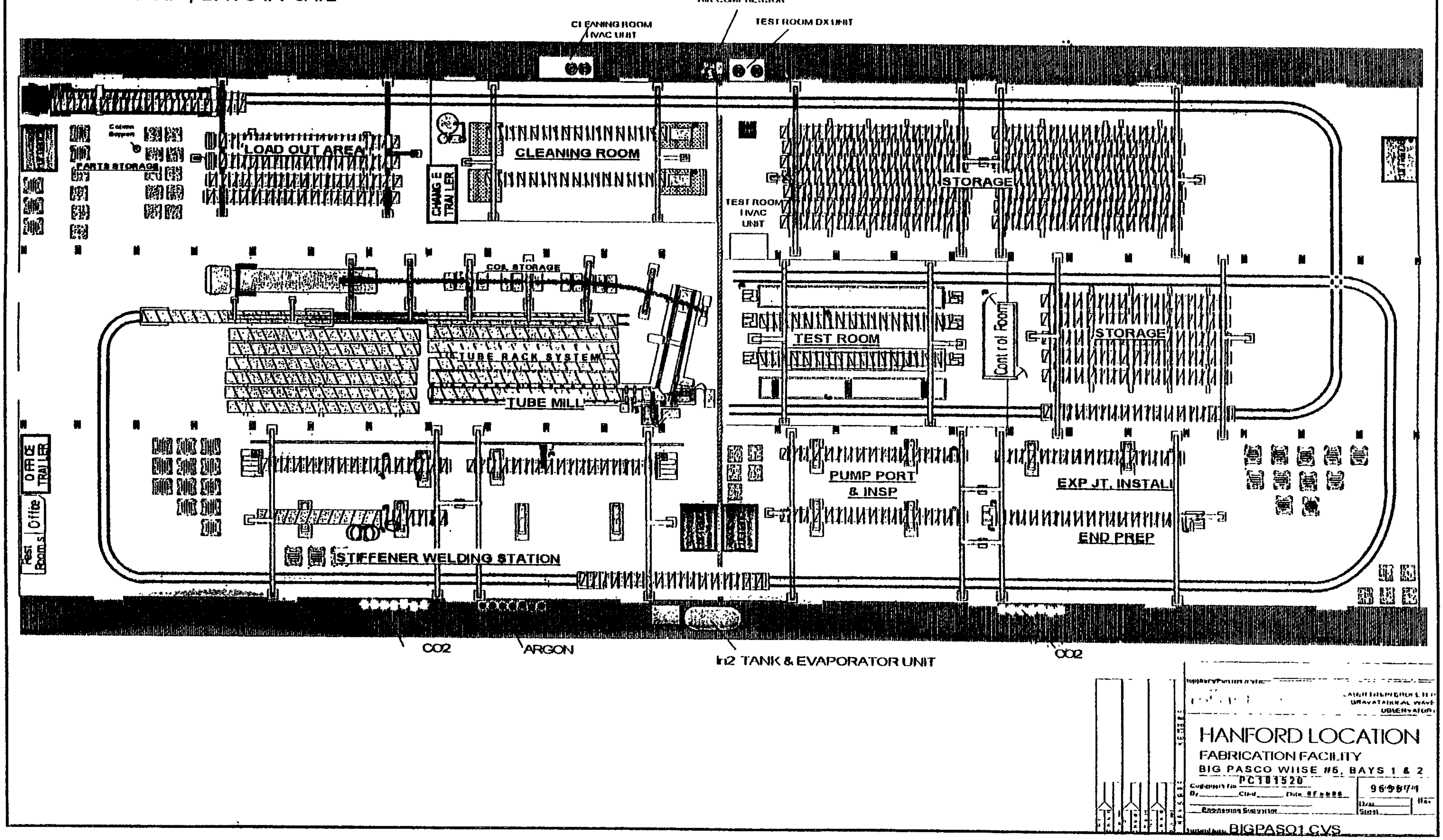
Tube Installation History

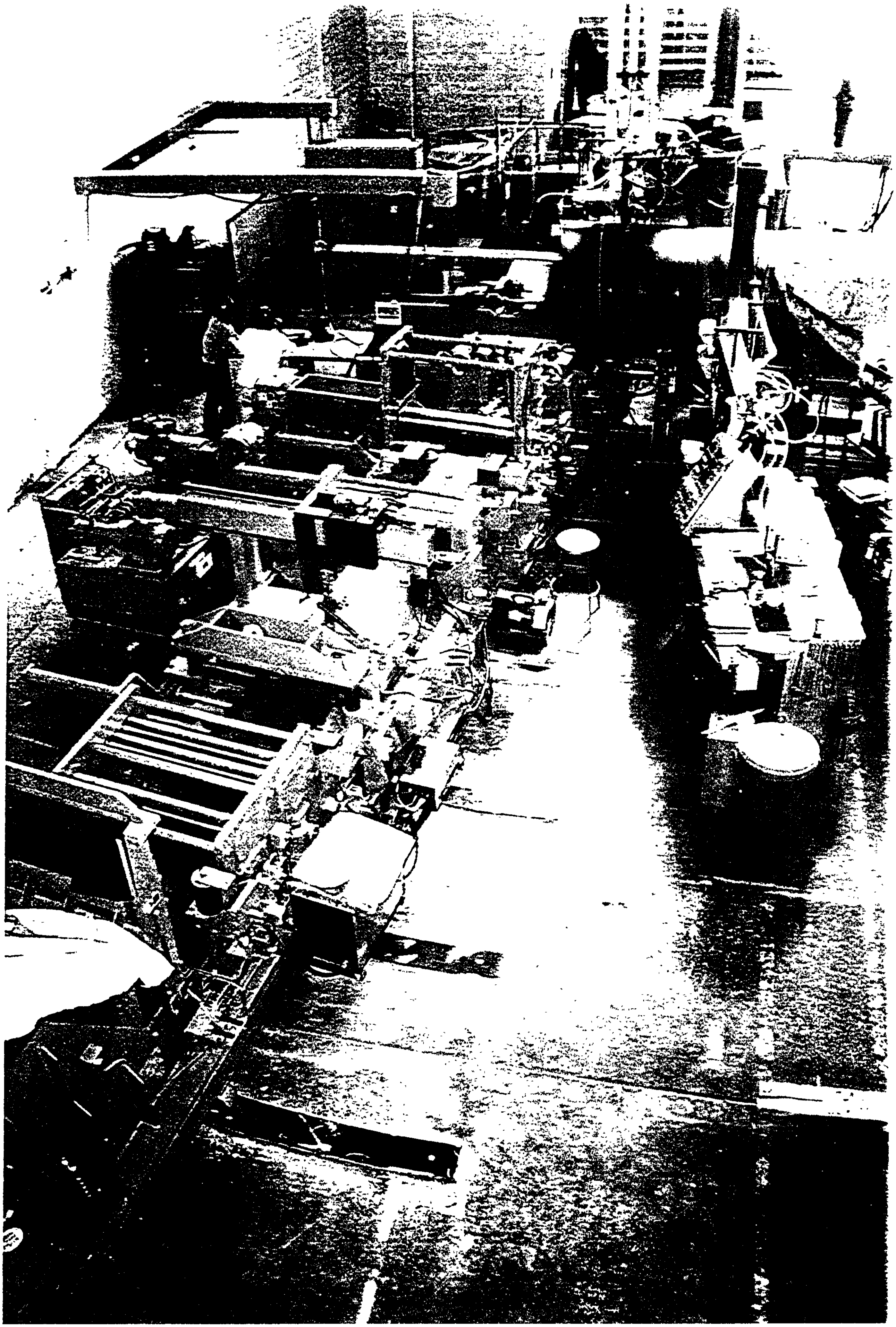
Tube Alignment & Module Leak Test Preparations

Louisiana Fabrication Shop Plans

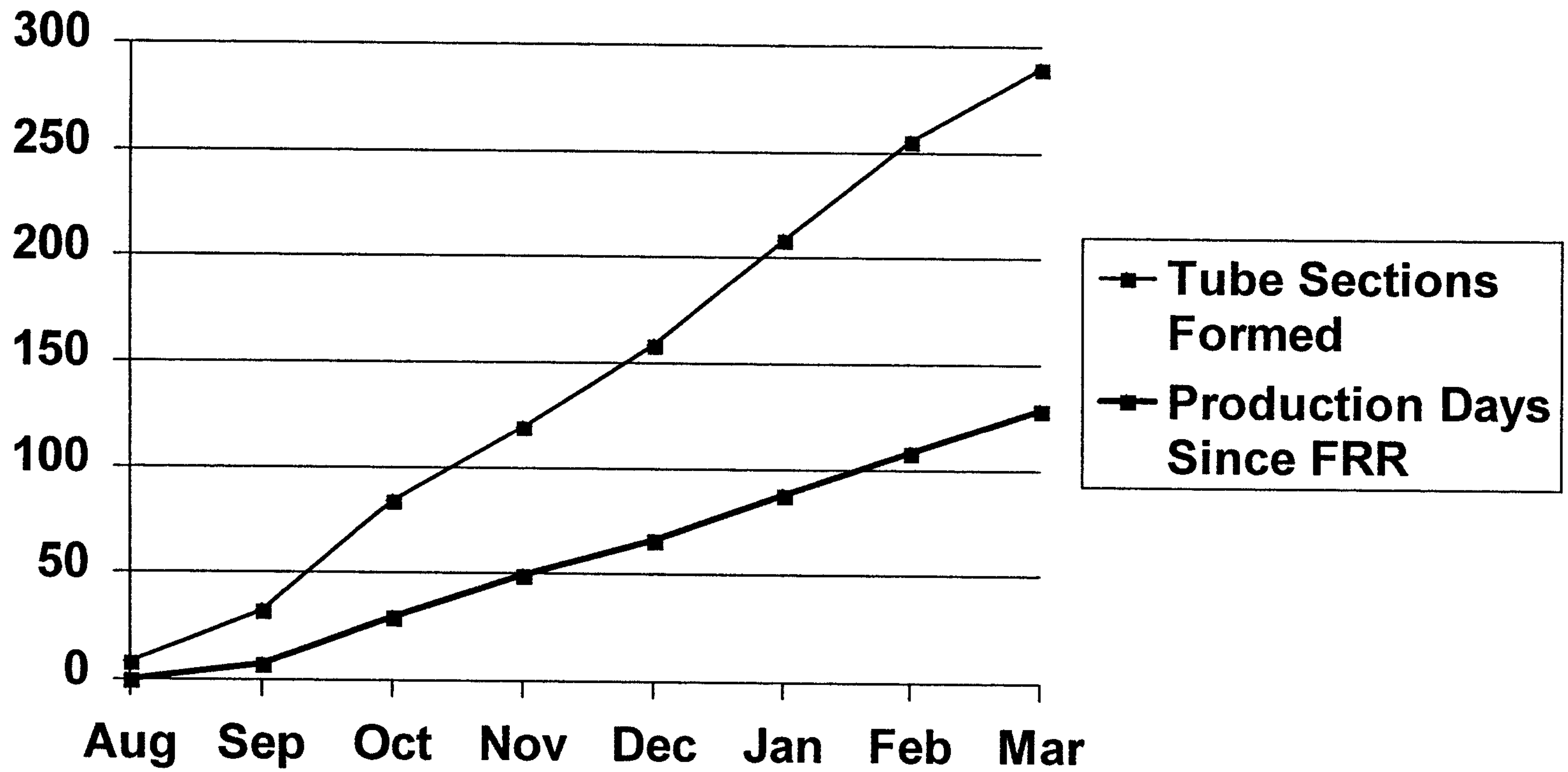
BIG PASCO

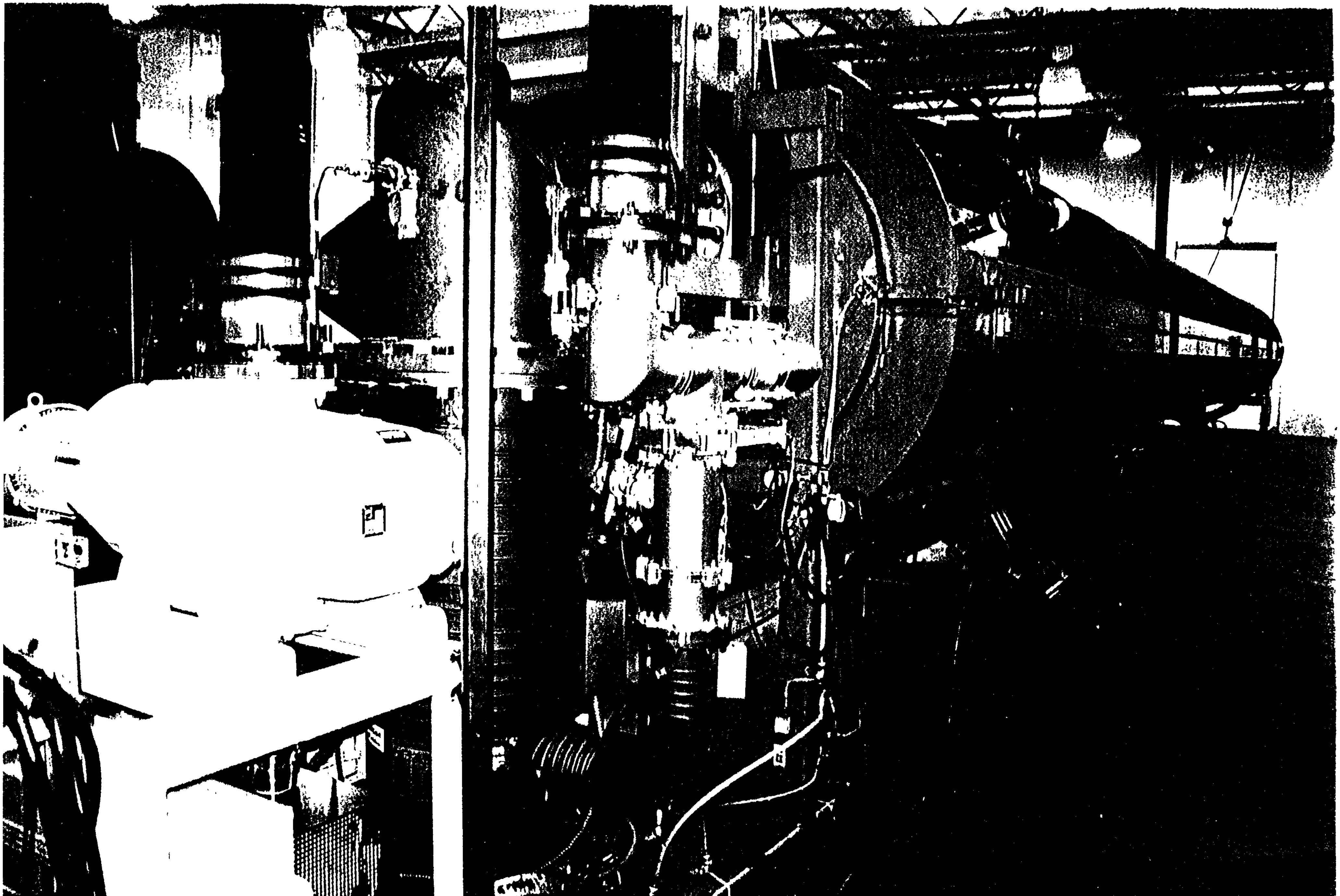
WAREHOUSE #5, BAYS #1 & #2



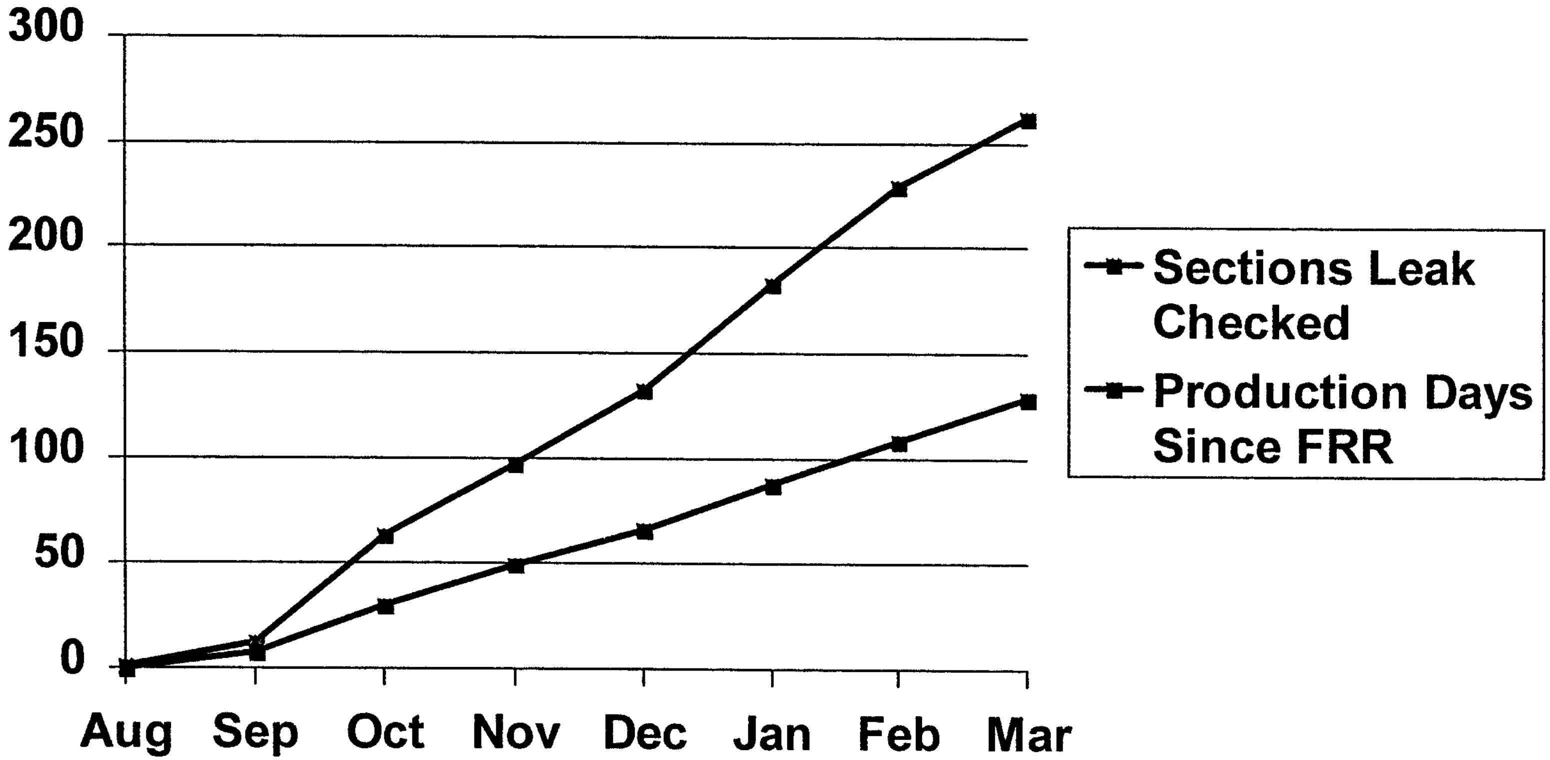


Tube Section Production
Spiral Forming History

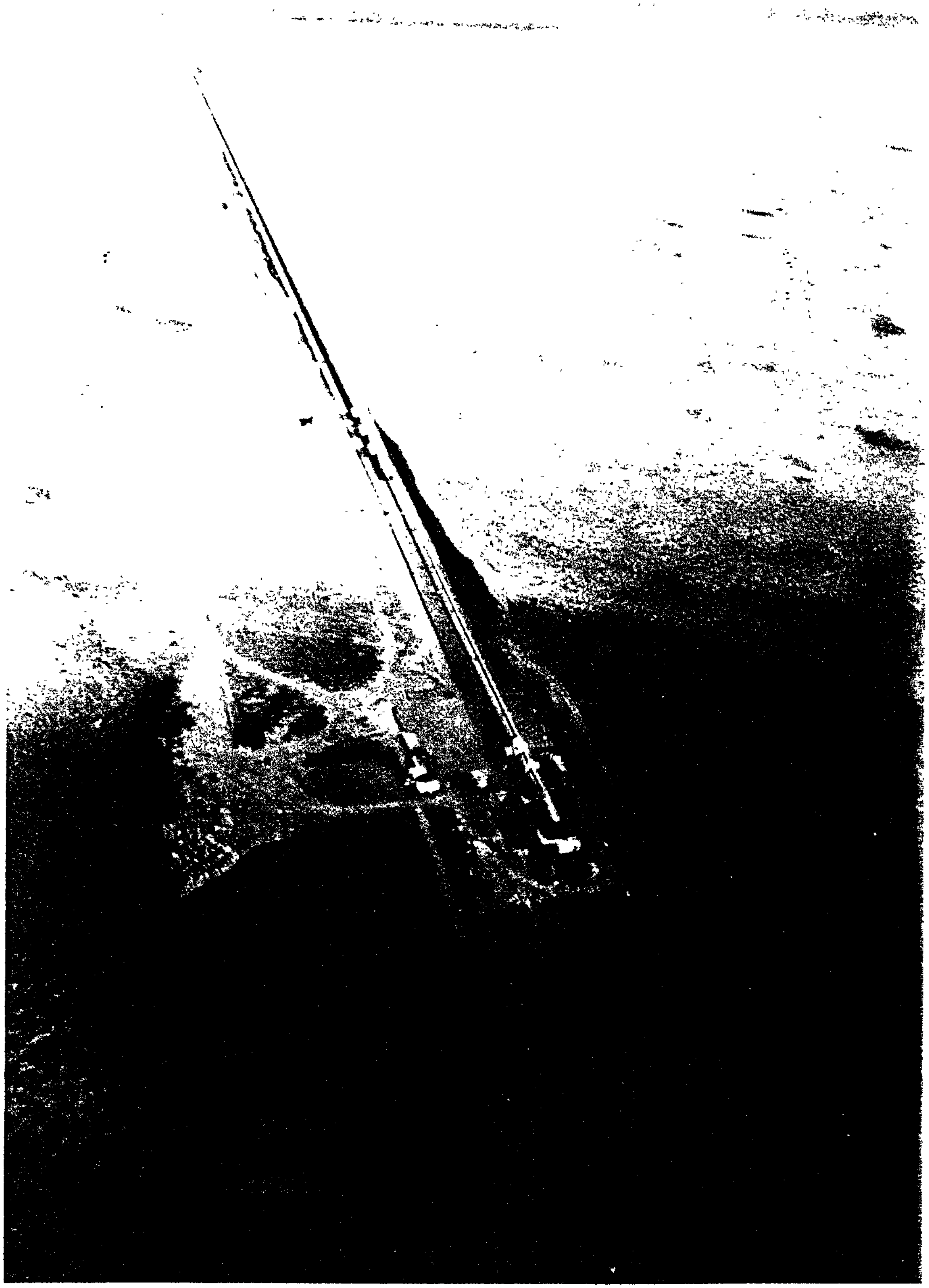


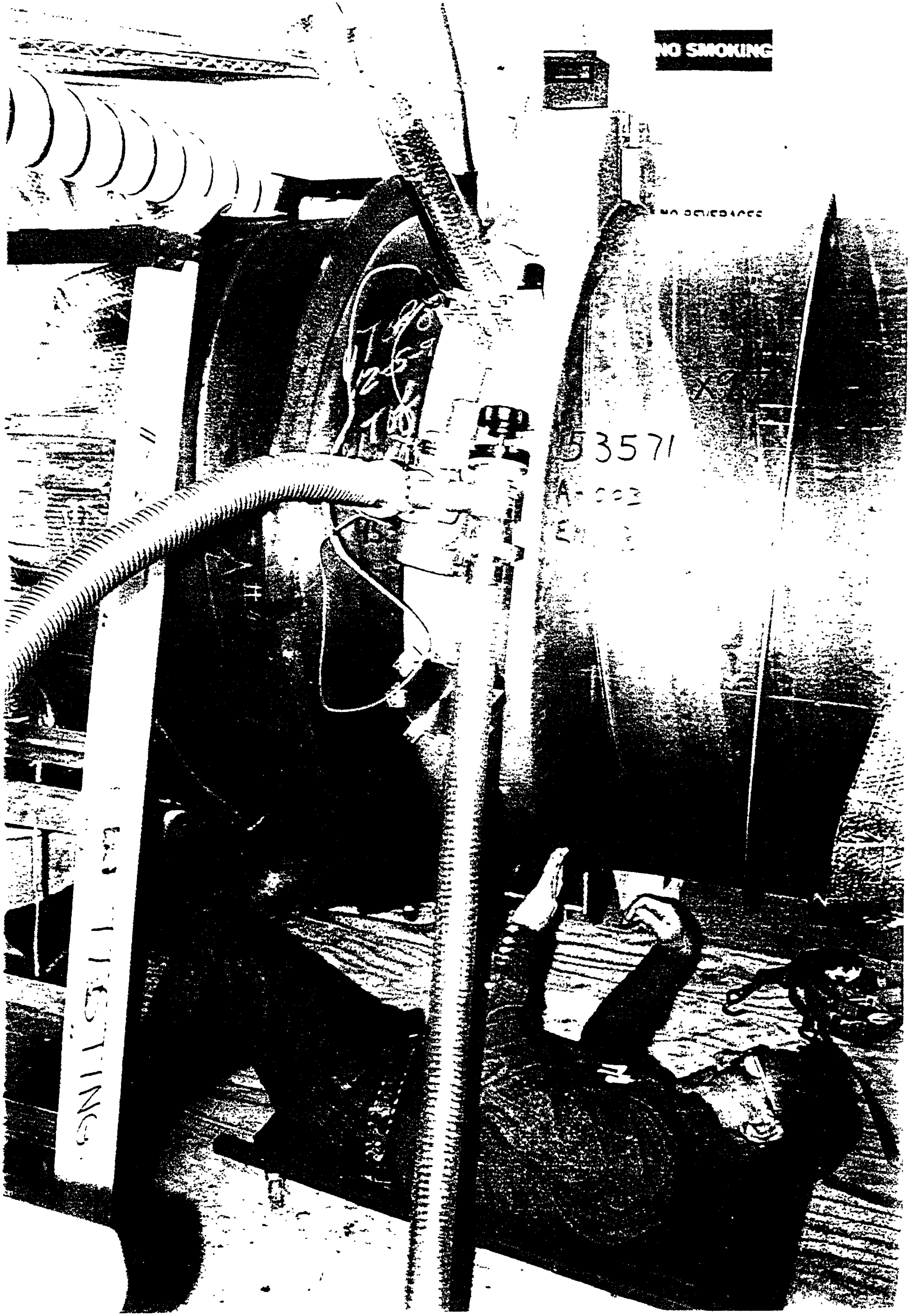


Tube Section Production Leak Check History

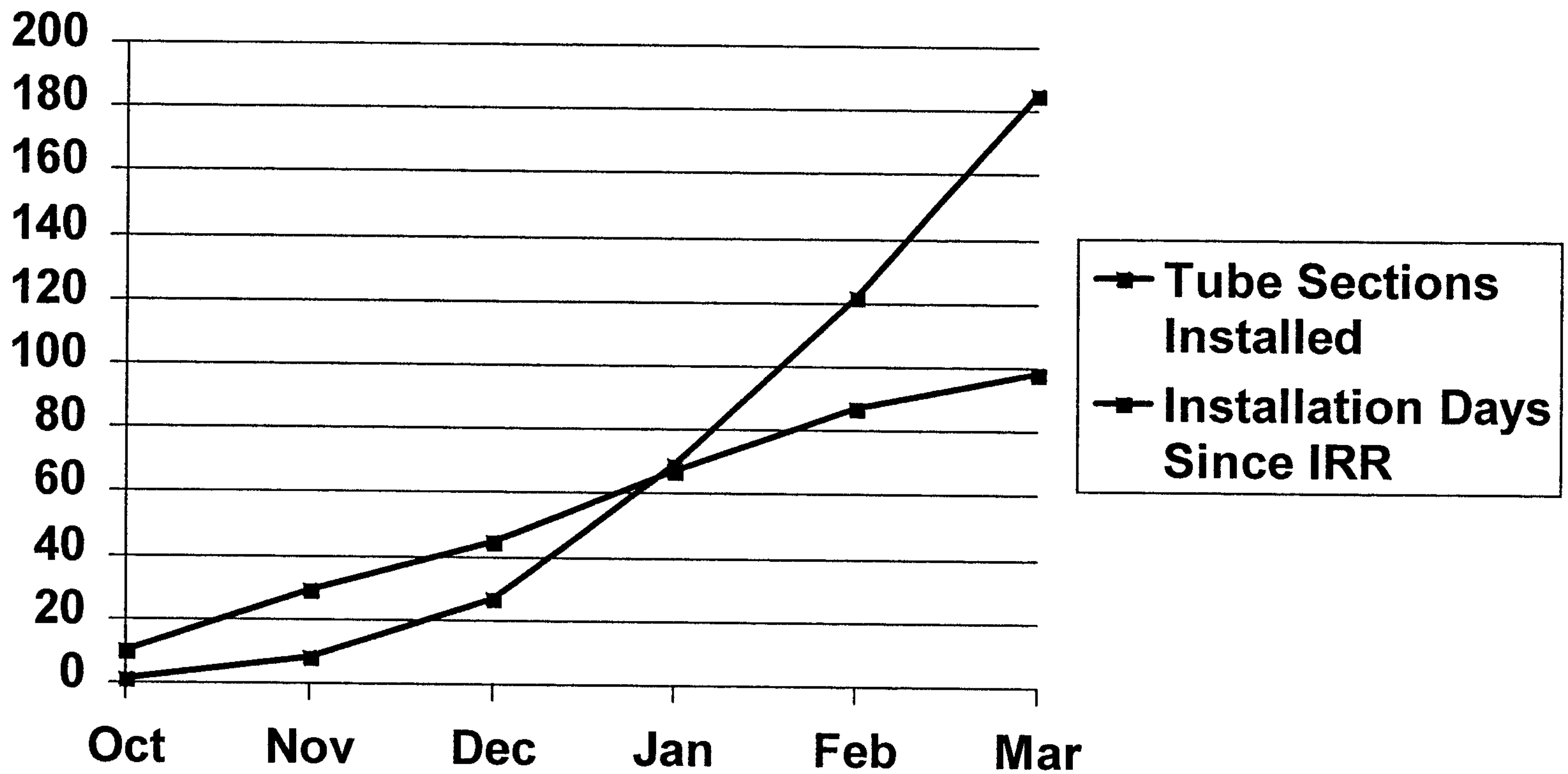


With over 17 miles of weld, zero tube sections failed leak test!




NO SMOKING
53571

Tube Section
Field Installation History



With 185 sections installed, zero girth seams failed leak test!

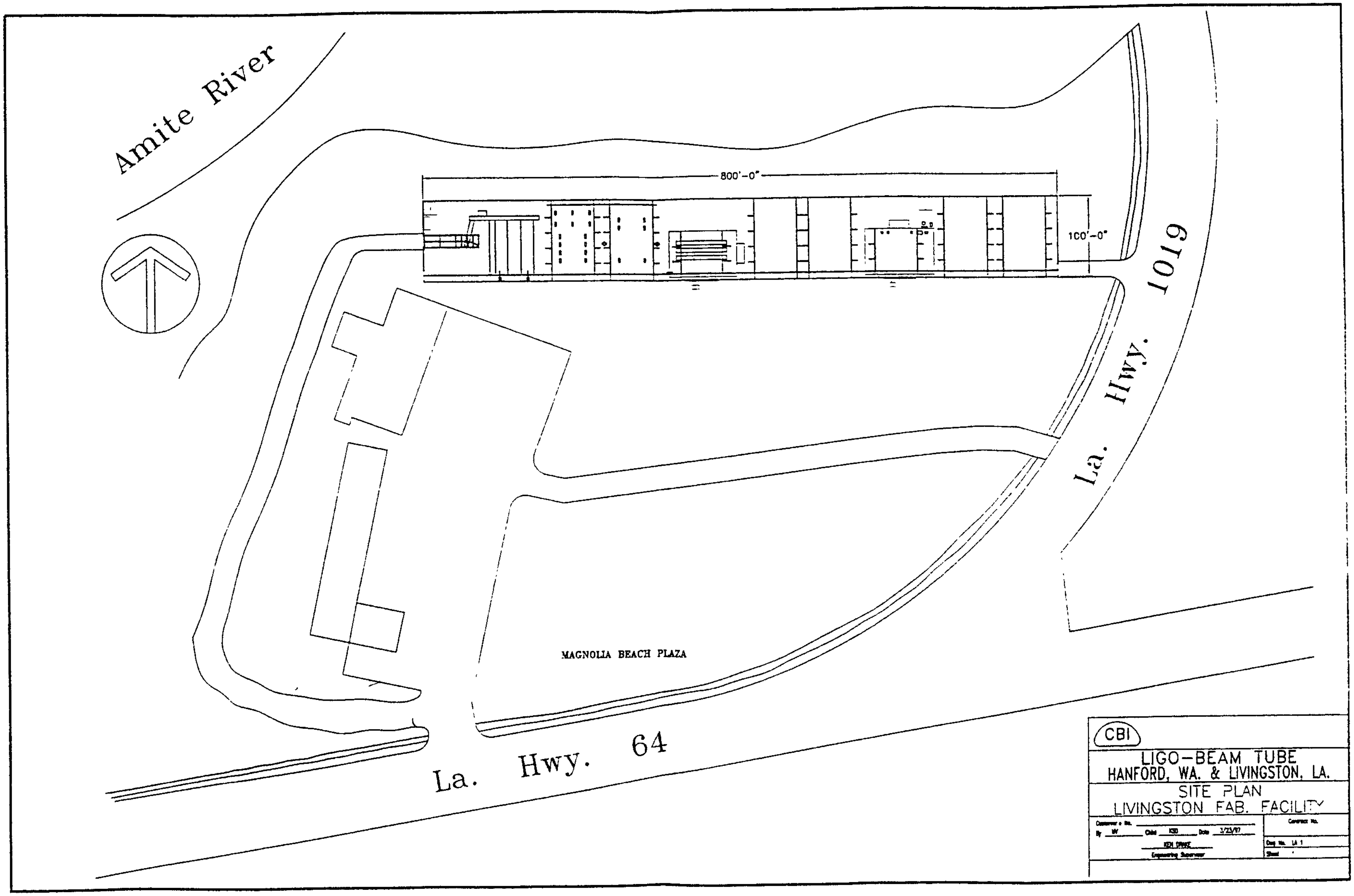
Beam Tube Module
Remaining New Activities

Final Alignment:

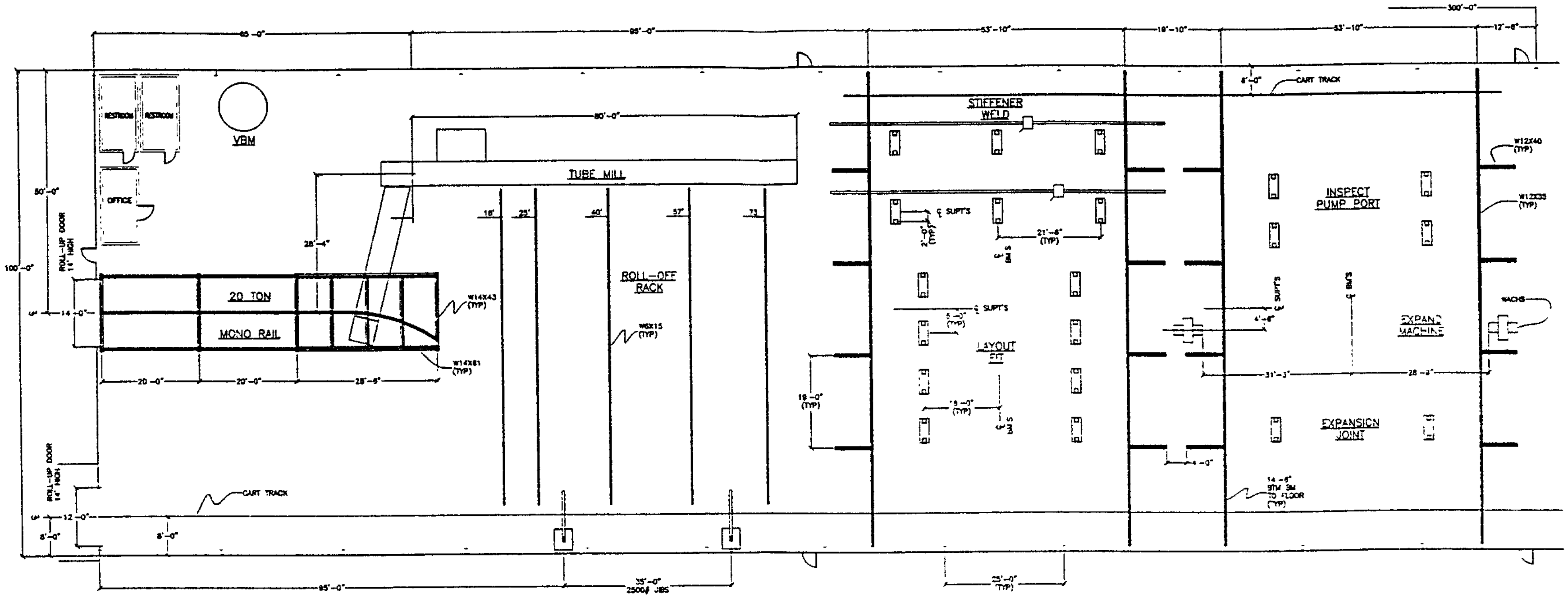
- 14 tube supports have been final aligned to date

Module Leak Testing:

- Equipment is being readied for starting module pumpdown on 4/28
- Calibration and leakage measurement (by air signature) will occur in May



Amite River
800'-0"
100'-0"
La. Hwy. 1019
MAGNOLIA BEACH PLAZA
La. Hwy. 64
CBI
LIGO-BEAM TUBE
HANFORD, WA. & LIVINGSTON, LA.
SITE PLAN
LIVINGSTON FAB. FACILITY
Contract No.
Dwg No. LA 1
Engineering Supervisor



PLAN VIEW 0' TO 300'

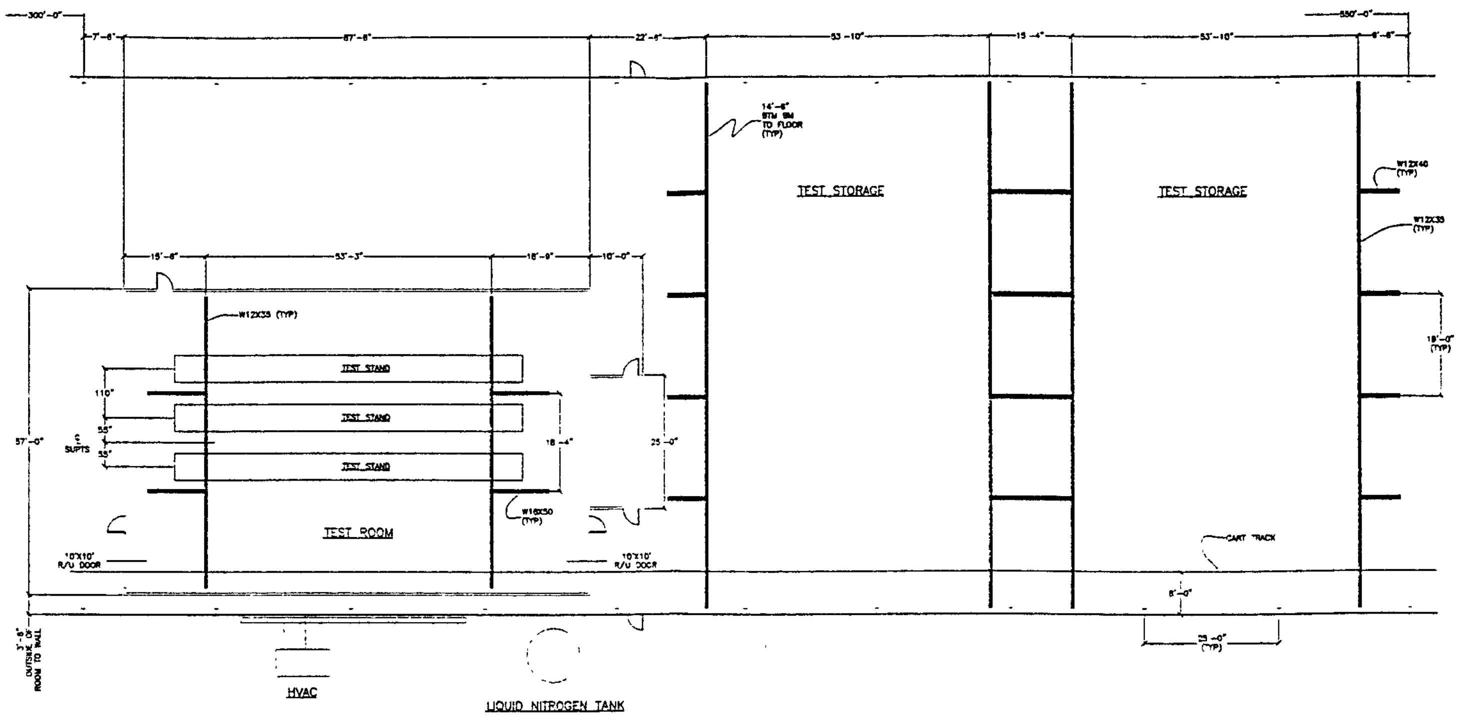
LIVINGSTON FAB. FACILITY

CBI

LIGO-BEAM TUBE
HANFORD, WA. & LIVINGSTON, LA.

0' - 300'
LIVINGSTON FAB FACILITY

Customer's No.	Contract No.
By WV Chkd XSD Date 3/23/97	
Engineering Supervisor	Dwg No. LA 2
	Sheet 1



PLAN VIEW 300' TO 550'
LIVINGSTON FAB. FACILITY

CBI

LIGO–BEAM TUBE
HANFORD, WA. & LIVINGSTON, LA.

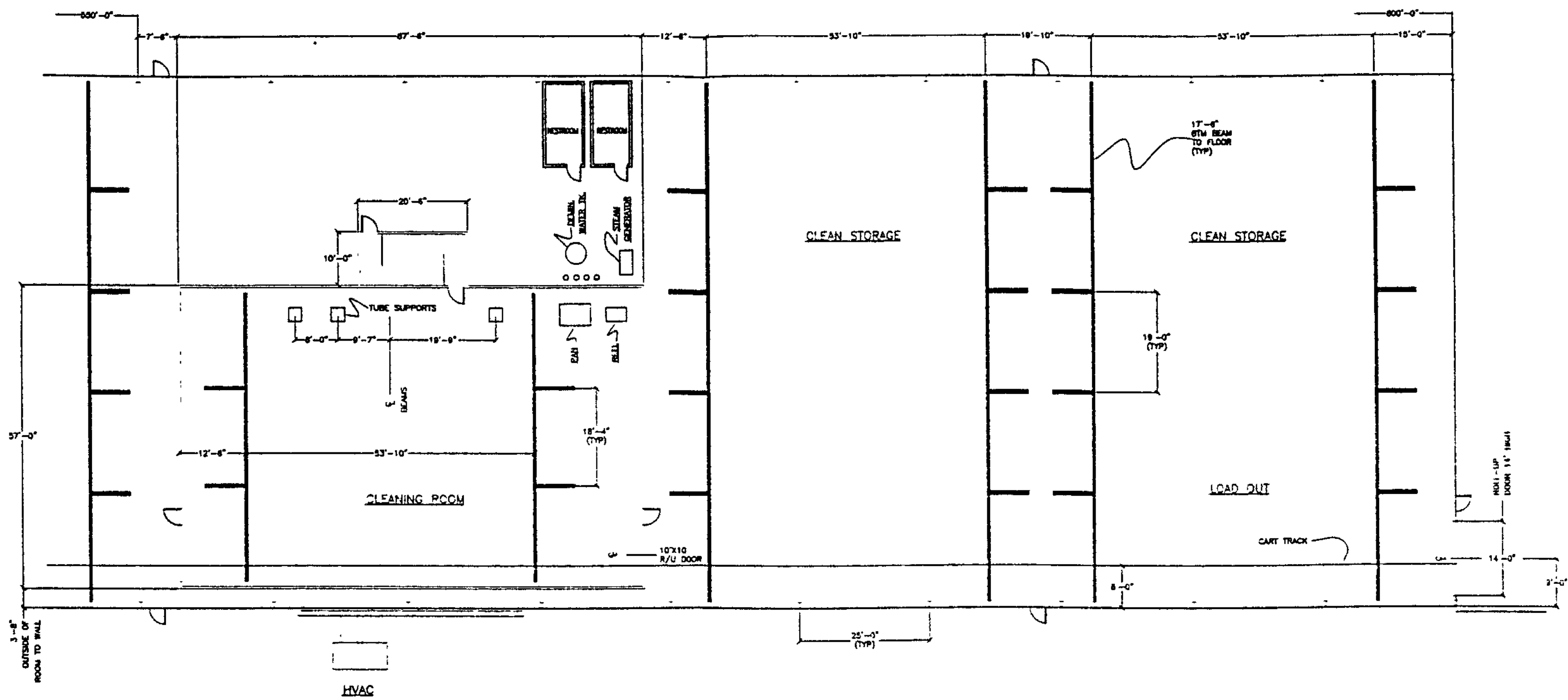
300' – 550'
LIVINGSTON FAB. FACILITY

Customer's No. ______ Contract No.

By W Chkd KSD Date 3/23/97

KEN DRAKE
Engineering Supervisor

Dwg No. LA 3
Sheet 1



PLAN VIEW 550' TO 800'

LIVINGSTON FAB. FACILITY

CBI

LIGO–BEAM TUBE
HANFORD, WA. & LIVINGSTON, LA.

550' – 800'
LIVINGSTON FAB. FACILITY

Investigation and Resolution of Baffle Shedding in the LIGO BT

Albert Lazzarini
LIGO Integration Group

NSF Review
15 - 17 April 1997

Background

- In late November 1996 reports from field indicated that particulate accumulation was present in bagged baffles. In mid-December accumulations reported at installed baffles within BT.
- R. Weiss entered into integrated BT to inspect and confirmed particle accumulation was glass shedding from baffles. Small scale laboratory experiments confirmed this.
- Technical Review Board was held on 16 January 1997 to review what was known and to develop action items to resolve problem:
  - It was determined that particle shedding rate was unacceptable because of the implied affect on LIGO non-Gaussian noise (discrete pulses) event rate from phase noise produced by particles which cross the interferometer beams.
  - Baffle installation was put on hold indefinitely until a resolution could be found
  - A team from Systems Engineering, Facilities and QA was assembled to investigate cause(s)
  - A backup approach for the baffles was reconsidered (oxidized 304SS)
  - The impact of deferring installation of X-arm baffles was assessed

Background

- Eight week series of investigation were initiated.
- Identify rework of existing baffles to salvage inventory (if possible)
  - ›› Candidate rework options:
    - — Thinning glaze
      - - GRINDING & REFIRING - COULD NOT FIND VENDOR
      - - GRIT BLASTING & REFIRING -- NOT PRECISE ENOUGH
      - - ETCHING -- NOT OF ECONOMIC INTEREST (TOO SMALL A VOLUME); ENVIRONMENTAL ISSUES WITH WASTE DISPOSAL
    - — Reprocessing glazed surface at melt temperature (850C) using an O_2 - rich flame to alter surface chemistry of glaze -- labor intensive; marginal performance improvement; deformed baffle due to localized heating
- Firing new baffles with thinner (by factor of 2X) glaze
- Thermal cycling at aerospace test facility used to reproduce diurnal thermal variations experienced by baffles in field and to test candidate baffle "fixes" and to characterize existing baffles.
- Develop backup using non-glazed surfaces (oxidized 304SS)
  - ›› Use porcelain manufacturer's 850C tunnel oven to explore oxidation process at much higher temperatures than earlier testing in 1995 (850C vs. 450C).
- Audit estimated performance using latest information:
  - ›› BT wall motion
  - ›› Pathfinder optics

Results of Baffle Shedding Investigations

- Initial findings

Description Baffle ID	Comment	Exposure Time days	Estimated minimum particle size microns	Projected rate LIGO beam number/hr d>100 microns
#18 Serrated	0.3 accel. on shaker table	3	100	160
#19 Serrated	0.3 accel. on shaker table	2	100	9
CIT 1 Serrated	In BT mock-up	16	100	22
WA 1 Serrated	In situ	21	500	69
WA2 Serrated	In situ	21	500	10
WA3 Serrated	In situ	16	500	7
WA4 Serrated	In situ	16	500	4
WA5 Nonserrated	In situ	20	500	0.2 - 0.6
CIT2 Nonserrated	In BT mock-up	4	100	<5 - 10

signal: $\delta\varphi \sim \frac{d^2}{\lambda L} \sim 10^{-10}$ rad for $d = 1\mu m$; duration: $\Delta t \sim \frac{2w}{\sqrt{2gR}} \leq 0.016 s$

Maximum shedding allowed rate: $R_{WA} \cdot R_{LA} \cdot \tau \leq 0.1/yr$ => $R_{WA, LA} \leq 1/hr$ ***no margin***

$$R_{WA, LA} = N_B \cdot \frac{D_{beam}}{D_{tube}} \cdot \dot{n}_{shed}$$

Results of Baffle Shedding Investigations

- Thermal cycling results

Description Baffle ID	Comment	Exposure Time days	Estimated minimum particle size microns	Projected rate LIGO beam number/hr d>100 microns
#52 Serrated	Control for thermal cycling tests	5 days		160
#52 Serrated	NTS, Normalization for thermal cycling tests	12 cycles		160
#52 Serrated	NTS	2nd 12 cycles		25
#54 Serrated	NTS	12 cycles		118
#57 Nonserrated	NTS	12 cycles		42
#57 Nonserrated	NTS	2nd 12 cycles		33
#58 Nonserrated	NTS	12 cycles		3
#58 Nonserrated	NTS	2nd 12 cycles		2
#64 Serrated	NTS, thinner glaze	12 cycles		5
#73 Serrated	NTS, thinner glaze	12 cycles		6
#73 Serrated	**NTS, surface taped over, control for bkgnd, thinner glaze**	**2nd 12 cycles**		**0.8**
#65 Serrated	NTS, thinner glaze	12 cycles		8
#76 Serrated	NTS, thinner glaze	12 cycles		8

Results of Baffle Shedding Investigations

- Thermal cycling results (cont.)

Description Baffle ID	Comment	Exposure Time days	Estimated minimum particle size microns	Projected rate LIGO beam number/hr d>100 microns
#75 Nonserrated	NTS	12 cycles		13
#61 Nonserrated	NTS	12 cycles		3
#82 Nonserrated	NTS	12 cycles		2
#83 s O_2 rich flame treatment	NTS, reworked baffle	12 cycles		19
#69 s O_2 rich flame treatment	NTS, reworked baffle	12 cycles		30

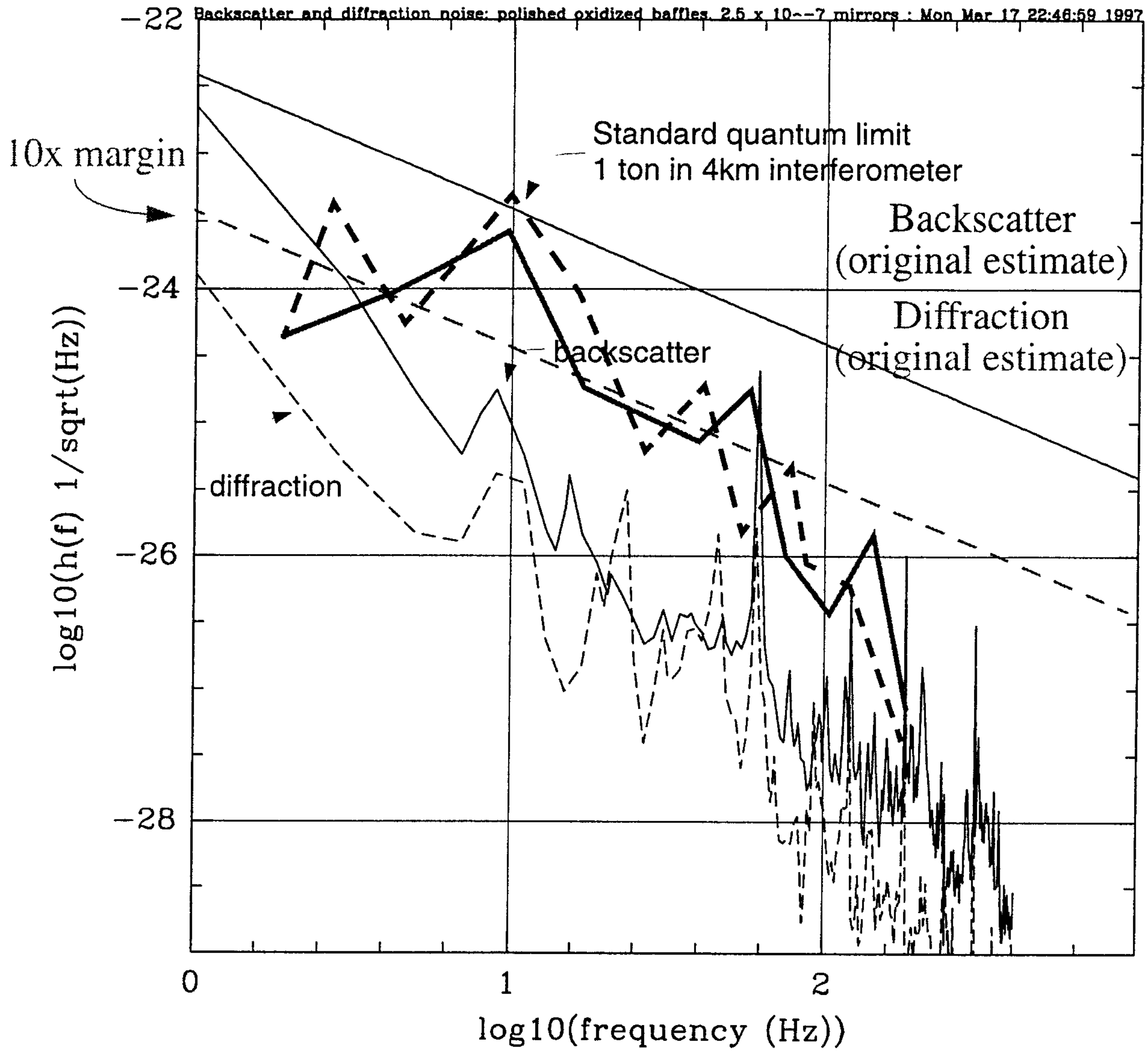
Investigation Outcomes

- Cycling discriminates between heavily and weakly shedding baffles
  - Non-serrated baffles shed much less
  - Repeated cycling reduces shedding (1 example)
  - The smaller the scale one inspects on, the more particles that are found - used Optical Test Facility (OTF) microscope to scan 0.2 cm^2 patch where nothing was seen @ 2x magnification - detected many particles smaller than 5 microns - particle count continues to grow at smaller scales.
  - Baffle shedding comes primarily from roots of serrations
  - Residual stresses in glass from CTE mismatch
  - Thicker glaze is worse - latest thinner glaze much better
  - Shedding is energetic and produces many particles in coincidence - particle distribution alone not sufficient to estimate coincidence rate for 2 interferometers (Hanford)
  - NONE of the baffles tested passed allowed limit
- Second TRB on 18 March 1997 held to review findings, recommend pursuing the alternative solution of oxidized baffles.
  - NONE of baffles presently in BT were judged acceptable - they should be removed
  - *Higher temperature oxidation leads to a baffle optical surface which performs comparably with black glaze.*

Comparative Optical Performance

Material	Oxide	A $BRDF_{baffle}$ $1000 \cdot sr^{-1}$ (1μm @ 55°)	R_{baffle}	B $R^2 \cdot BRDF_{BT}$ $1000 \cdot sr^{-1}$ ($BRDF_{BT}$=.06 sr^{-1} @20°)	A+B $1000 \cdot sr^{-1}$	Effect on Strain Sensitivity $h \propto \sqrt{A+B}$
Black Glass Enamel	–	1-3	<.13	< 1	1-3	1
BT wall	450C/36hr	30	diffuse	–	30	5
Oxidized Bright Anneal 304SS	450C/8hr	4	.35 - .45	7 - 12	11 - 16	2 - 4
Oxidized Bright Anneal 304SS	850C/12 min	4 - 5	0.1	<1	4 - 5	1.2 - 2.2

Projected performance of LIGO BT Baffles - 4/97



- Baffle backscatter BRDF = $4.8 \times 10^{-3}\ sr^{-1}$ Polished oxidized baffles
- Mirror scattering BRDF = $\frac{2.5\times10^{-7}}{\theta^2}$ Super polished GO mirrors (uncoated)
- BT wall motion measured in still conditions (v_{wind}< 5mph) and at fixed supports
  - **LONGITUDINAL SPECTRUM 1/30/97 USED FOR BACKSCATTER MODULATION**
  - **HORIZONTAL SPECTRUM 1/30/97 USED FOR DIFFRACTION MODULATION**
  - **WORST CASE 5X - 10X HIGHER ON NARROW RESONANT PEAKS**

Schedule Impact

- Procurement is on schedule to allow resumption of installation on Y arm in 4/97.
- X arm will need to be re-entered to recover existing glazed baffles and to re-install oxidized baffles
- Evaluation/Planning:
  - 3/97:
    Installed 7 baffles with purchased carts, 1140 m into module X1 (experienced problems with contamination from cart wheels and clean room booties)
  - 4/97:
    Install 20 baffles with modified carts and shoe covers, 1580 m into module X1.
- Other Scheduled Operations:
  - 5/97-6/97:
    Perform module leak tests on modules X1 and X2.
  - by 11/97:
    Complete construction/cleaning of high bays of X arm buildings; fabricate and test module HEPA/blower assembly; fabricate baffles
- Baffle Removal/Installation:
  - 11/97-12/97:
    Remove glass coated baffles and install new baffles 980 m into X arm modules, sequencing by half modules.

List of Acronyms (LoA)

- BT - Beam Tube system
- TRB - Technical Review Board
- QA - Quality Assurance
- 304SS - Type 304 stainless steel
- CTE - coefficient of thermal expansion
- OTF - LIGO optical test facility (labs in W. Bridge)
- BRDF - bidirectional reflectance distribution function - angular distribution of scattered light

BEAM TUBE BAKEOUT

W. E. ALTHOUSE

APRIL 15, 1997

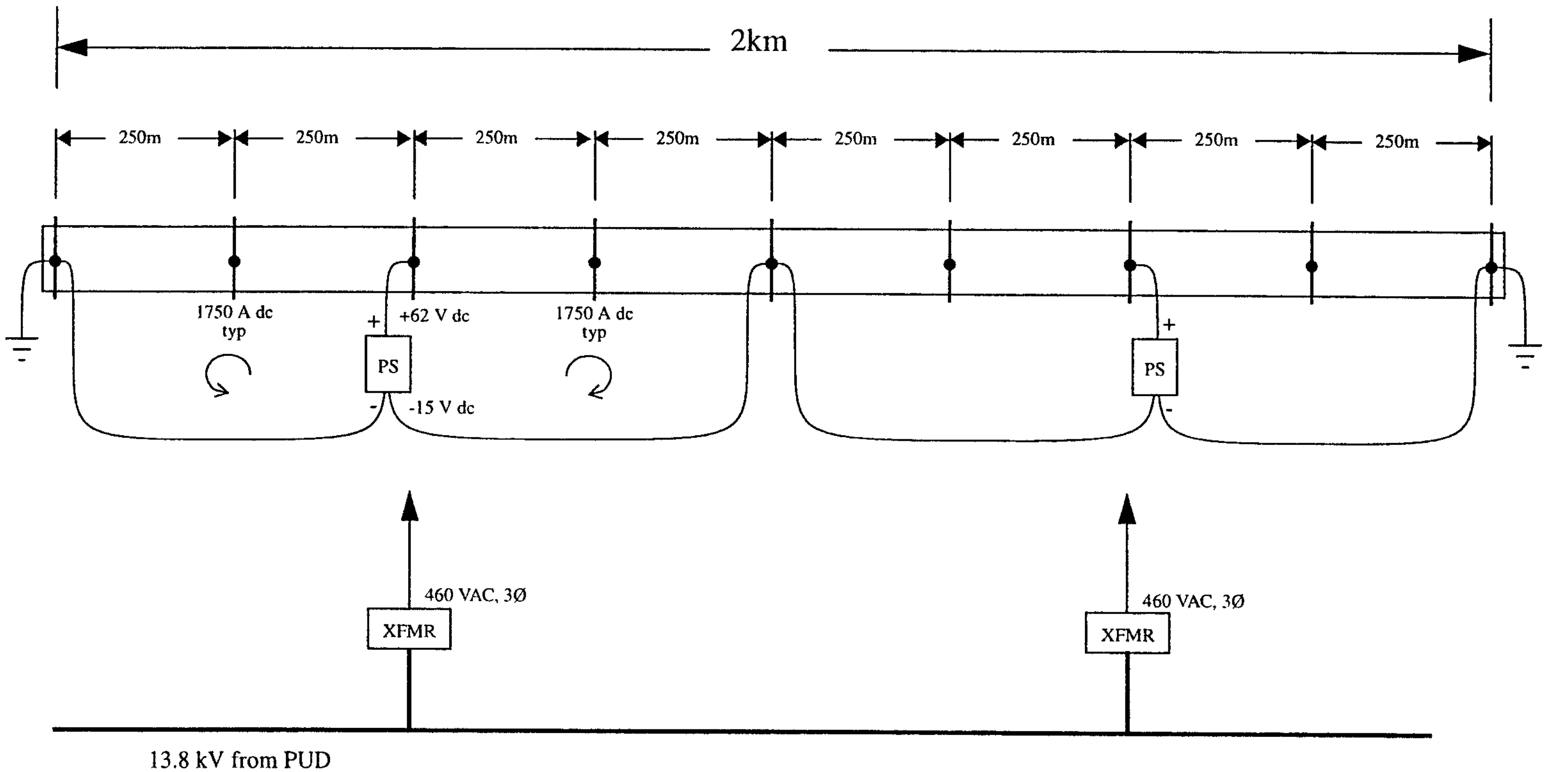
LIGO-G970071-01-P

BEAM TUBE BAKEOUT REQUIREMENTS & OBJECTIVES

- LIGO Science Requirement Document
  - Sets the GOAL for residual gas pressure "... at a level or below an equivalent strain noise of 2×10^{-25} $Hz^{-1/2}$ "
  - GOAL level supports future advanced interferometers (additional pumping may be used if needed)
  - Initial interferometer requirement is much more relaxed

- Bakeout Objectives
  - Reduce H_2O, CH_4, CO, CO_2, etc. outgassing to achieve partial pressures less than LIGO goal level (10^{-10} torr for H_2O, corresponds to strain noise of 2×10^{-25} $Hz^{-1/2}$)
  - Reduce outgassing of contaminating hydrocarbons to minimize risk to interferometer optics

BEAM TUBE BAKEOUT
ELECTRICAL HEATING POWER



NEED FOR TUBE HEAT[1] -

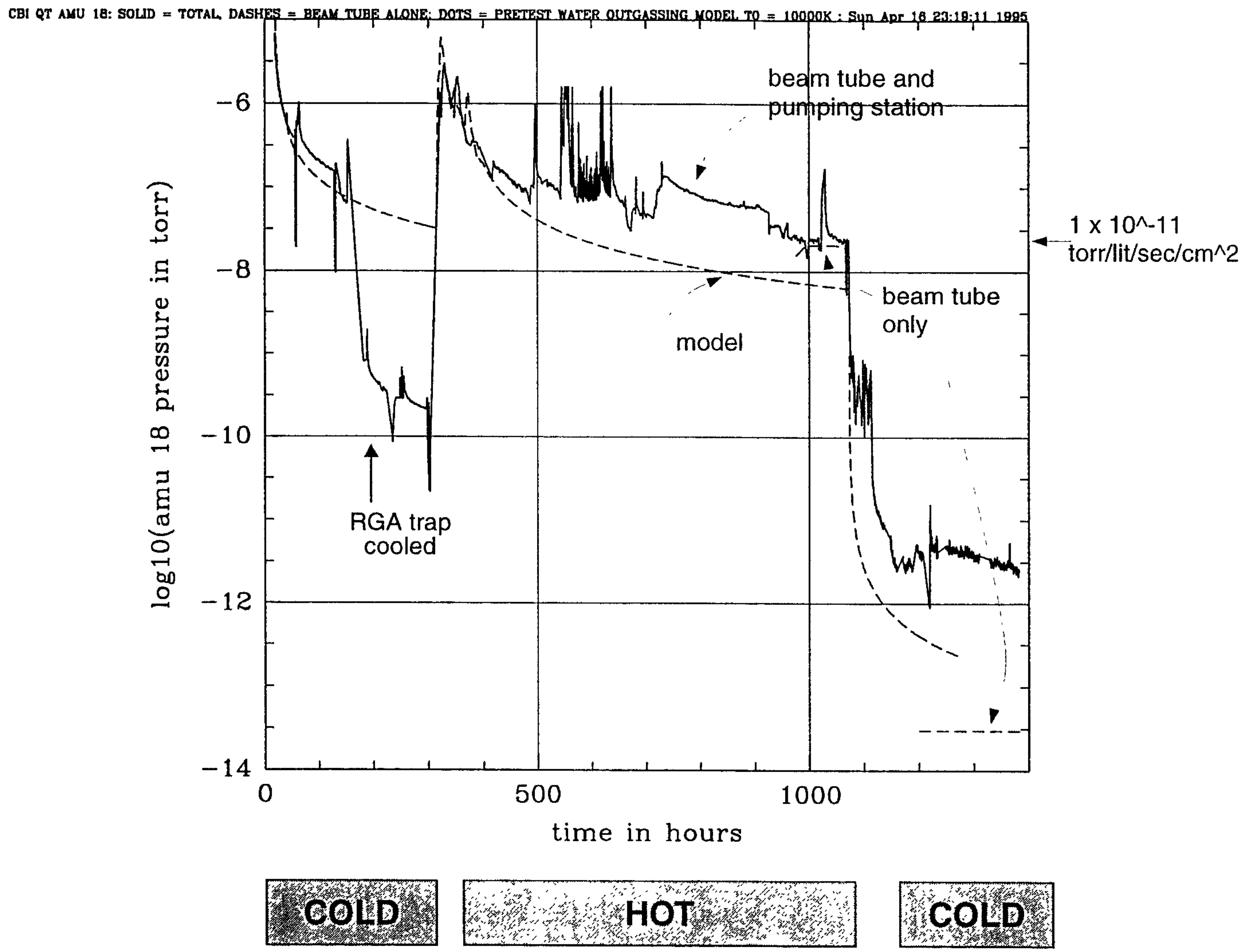
2 x 400 kVA = 800 kVA (summer days)
2 x 460 kVA = 920 kVA (summer nights)
2 x 505 kVA = 1010 kVA (winter nights)
2 x 550 kVA = 1100 kVA (coldest winter nights)

[1]Additional power required for pumps, instrumentation, auxiliary heating

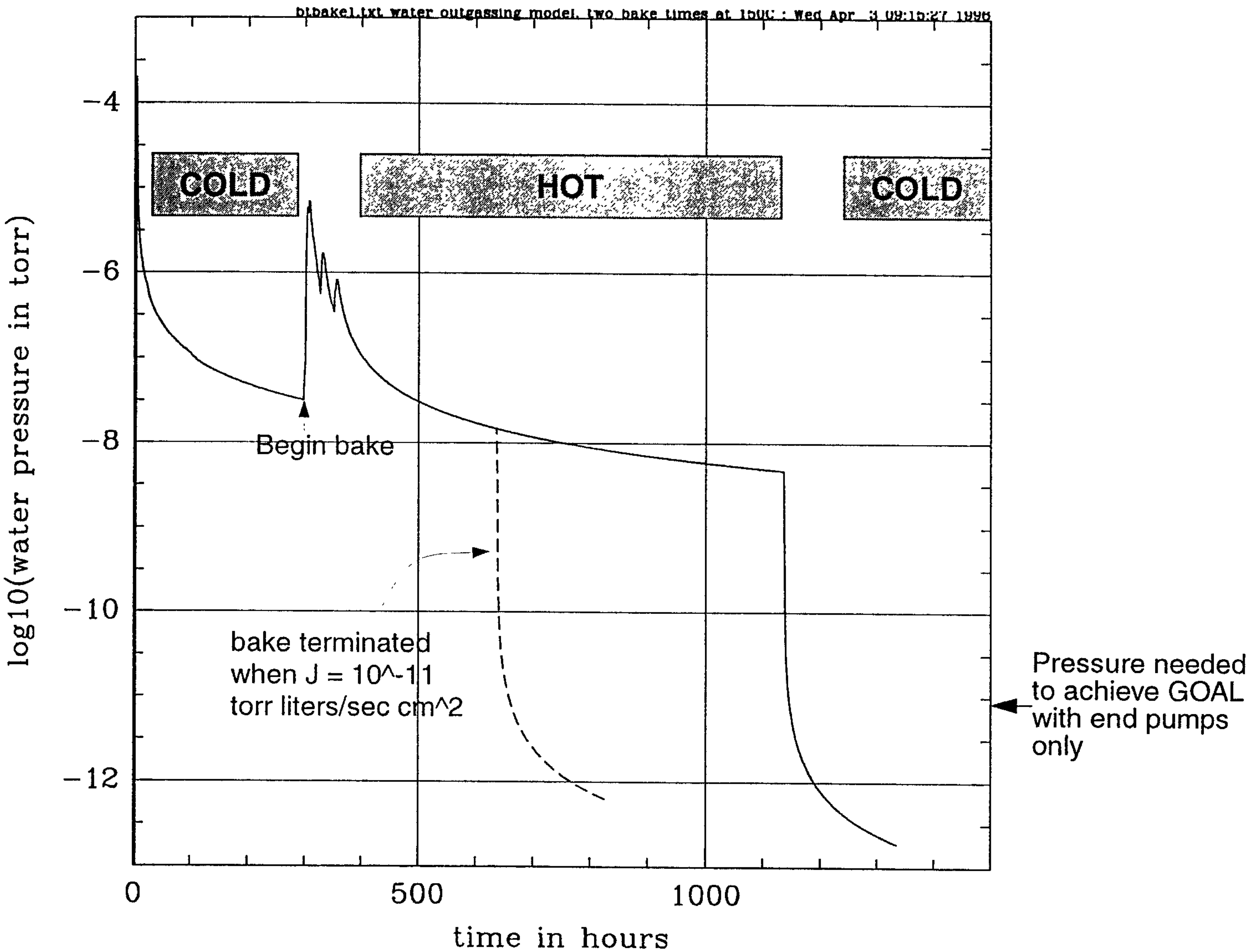
Legends:

PS	Low voltage, high current DC power supply
XFMR	Power Transformer

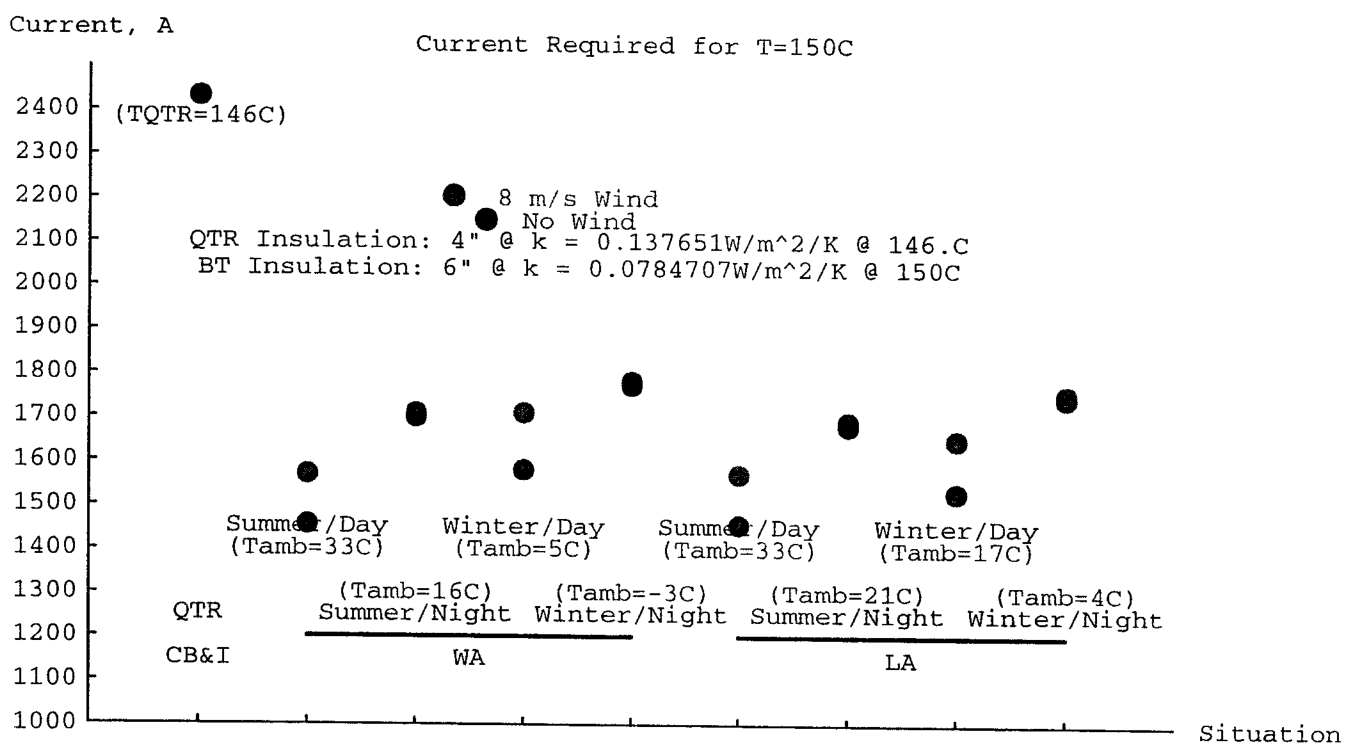
H_2O PRESSURE - QT BAKEOUT



H_2O PRESSURE REDUCTION MODEL



BAKEOUT POWER MODEL



BAKEOUT PLAN

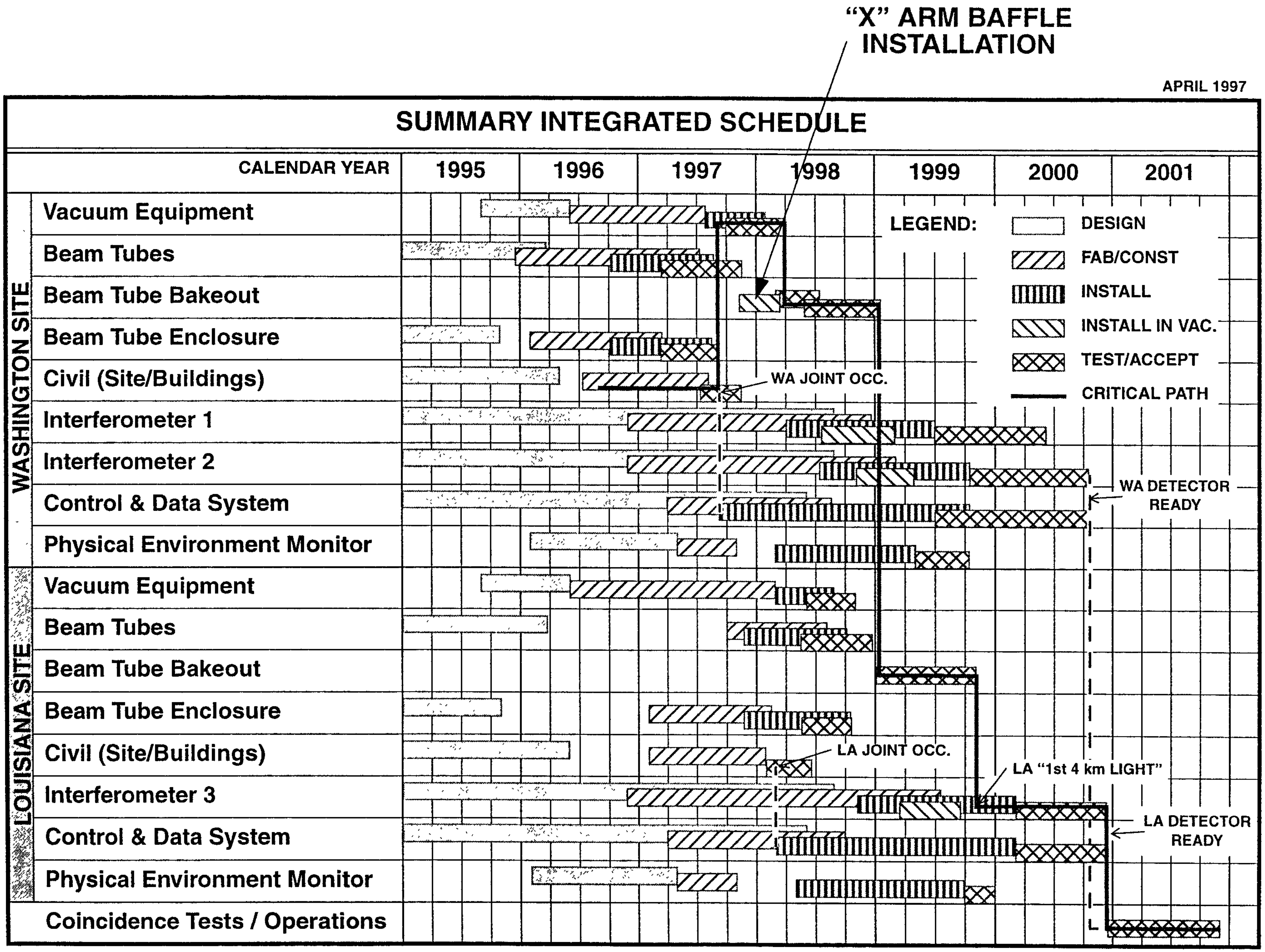
- Conduct bakeout without interference with CBI and PSI installation activities
- Schedule bakeouts so that on-site LIGO staff can handle setup and execution
- Conduct first 2 km module bakeout to:
  - Validate insulation, heating and pumping designs
  - Evaluate beam tube mechanical behavior during bake
  - Shakedown the setup, bakeout and post-bake procedures (and maybe the post-bake leak localization and repair procedures)
- Iterate procedures and designs as needed
- Bake 3 remaining modules at Hanford, ship equipment to Louisiana, and bake 4 modules

STAFFING & SUBCONTRACTS

- On-site staffing requirements:
  - Site scientist/engineer to supervise setup, bakeout, data evaluation
  - 2 site technicians (2 m-yr. per site) for equipment installation, checkout and removal
  - 4 site or temp. technicians, 1.5 m-yr. per site for 1-person-24 hr. bake monitoring
- Subcontracts:
  - Insulation contractor: purchase, prepare and install beam tube insulation
  - Power company: furnish, install and connect temporary transformers for primary AC power
  - Electrical contractor: install and connect DC power source and auxiliary AC power for pumps, instrumentation and controls

IN-HOUSE VS. SUBCONTRACTED BAKEOUT

- Advantages to carrying out the bakeout with on-site staff
  - First module bakeout conducted like a scientific experiment - our “only” beam tube is at risk
  - Appropriate scientific and engineering expertise already “mobilized” on site
  - Experiences of on-site technical support staff during bakeout will remain with and benefit LIGO
  - Reduced possibility of interference with other on-site activities
- Found no advantage to subcontracting the bakeout
  - Not a standard subcontracting item/activity
  - Insulation/equipment costs same (equipment will be recycled into LIGO operations activities)
  - Labor costs higher per m-hr (contractor overhead and profit) and experience disappears after completion



"X" ARM BAFFLE INSTALLATION
APRIL 1997
SUMMARY INTEGRATED SCHEDULE
CALENDAR YEAR
1995
1996
1997
1998
1999
2000
2001
WASHINGTON SITE
Vacuum Equipment
Beam Tubes
Beam Tube Bakeout
Beam Tube Enclosure
Civil (Site/Buildings)
Interferometer 1
Interferometer 2
Control & Data System
Physical Environment Monitor
LOUISIANA SITE
Vacuum Equipment
Beam Tubes
Beam Tube Bakeout
Beam Tube Enclosure
Civil (Site/Buildings)
Interferometer 3
Control & Data System
Physical Environment Monitor
Coincidence Tests / Operations
LEGEND:
DESIGN
FAB/CONST
INSTALL
INSTALL IN VAC.
TEST/ACCEPT
CRITICAL PATH
WA JOINT OCC.
WA DETECTOR READY
LA JOINT OCC.
LA "1st 4 km LIGHT"
LA DETECTOR READY

Vacuum Equipment Technical Review 4/97

John Worden, Technical Manager
April 15, 1997

- Recap: What is PSI supplying?
  - ›› Vacuum boundary (iso drawing):
    - – Large chambers; BSCs and HAMs,
    - – Connecting spools/bellows,
    - – Liquid nitrogen pumps,
    - – Gate valves; 8 are on the WA site now (photo).
  - ›› Vacuum Pumps (photos):
    - – Roughing and turbo molecular pumps.
    - – Main ion pumps and annulus ion pumps

Vacuum Equipment Technical Review 4/97

- Recap (continued):
  - » Clean air system, bakeout system, instrumentation:
    - – Air compressors and portable soft wall clean rooms,
    - – Bakeout blankets and controllers (photo),
    - – Pirani and Cold Cathode gauges, temperature, pressure, and level sensors for liquid nitrogen system.
  - » Beam Tube Gate Valves and Pumps:
    - – Portable roughing and turbo-molecular pumps for the initial beam tube pump-down by Chicago Bridge and Iron (photo).
    - – Large gate valves for the Beam Tube installation (photo).

Vacuum Equipment Technical Review 4/97

- Fabrication/Procurement Status:
  - Chambers (photos):
    - BSC, HAM, 80K pump vessels, spools are being fabricated by both PSI and their subcontractor Ranor.
    - Plate material, Flanges, Heads, Bellows, Carbon steel parts - Avesta Sheffield, Standard Steel, Arland Tool, Trinity Industries, Hyspan, Atlas Metal. All raw material (plate, flange forgings, bellows, heads) on hand.
  - Large gate valves - GNB - 8 valves on site for the Beam Tube contractor, 4 complete in Hayward, CA(photos)
  - Clean air equipment -(JPL Consulting, Servicor)
  - Ion pumps, small valves, conflat flanges - Varian, A&N Corp.
  - Roughing and turbomolecular pumps - Edwards (photos)
  - Bakeout blankets - HTD Heat Trace (photo).
  - Liquid nitrogen dewars and VJ piping - Process Engineering Inc., CVI.
  - Vacuum gauges - MKS/HPS.

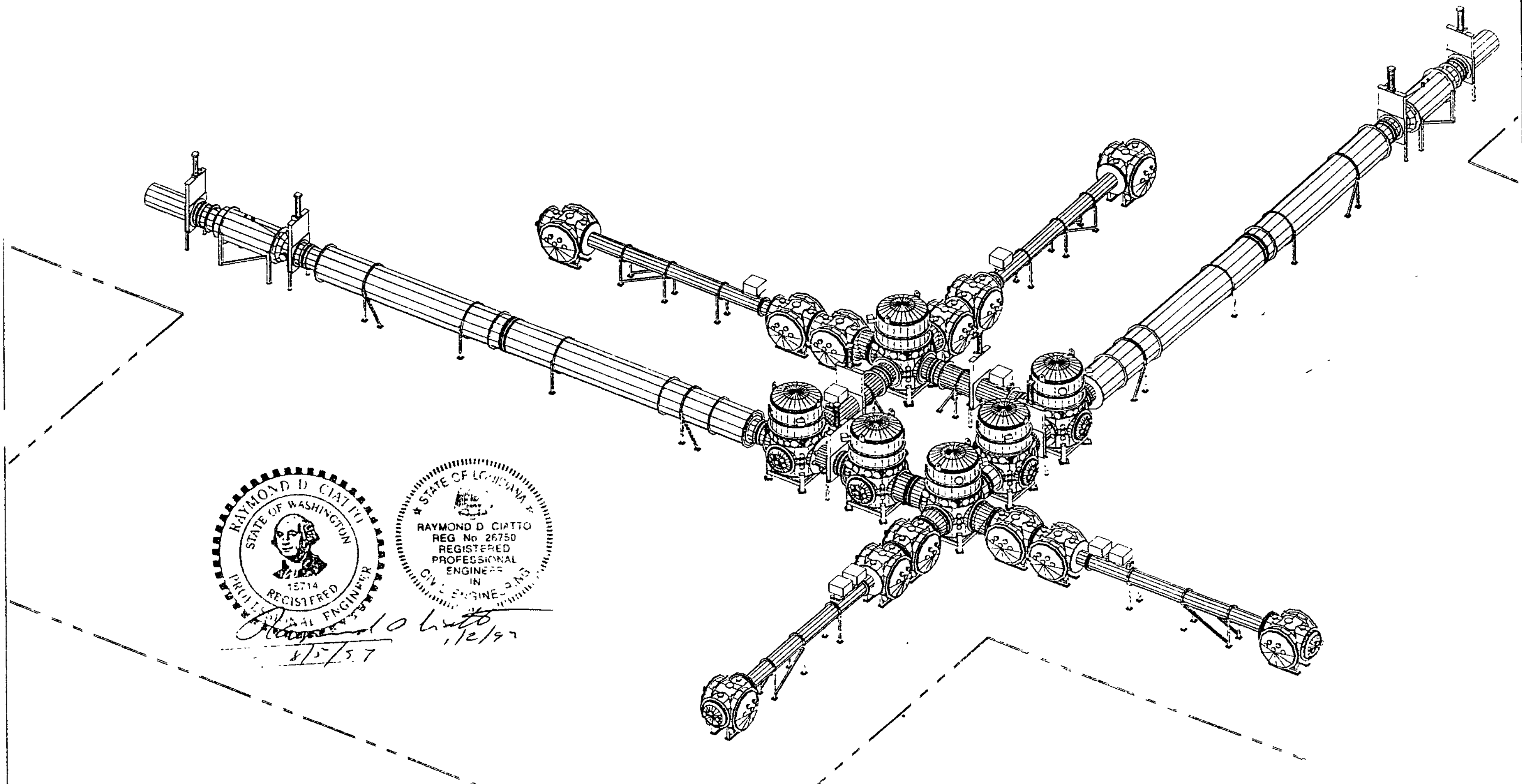
Vacuum Equipment Technical Review 4/97

- Factory preparation and testing:
  - Automated wash station for large vessels:
  - Clean vessels move direct into assembly/bake/test area.(photos)
  - Bakeout - several systems - blankets, hot air oven.(photos)
  - Each component or assembly goes through a vacuum bakeout and RGA screening before packaging for shipment.

Vacuum Equipment Technical Review 4/97

- Installation:
  - IFB in December, Best and finals in March/April, contractor selection due May. Apollo Sheet Metal, J. H. Kelly, Haskell Construction, Lundeen's are the bidders.
  - Start of installation in August 97 on left arm mid station.
  - Interfaces - such as electrical, wall penetrations, LN tank anchors - ongoing monitoring by on site LIGO personnel during the building construction.
  - Acceptance testing - Will be done by PSI/installation contractor to demonstrate performance of completed vacuum systems on a per volume basis. PSI will relocate some staff to the site to oversee this task.

- Summary: On schedule/budget.



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REFERENCE DRAWINGS

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DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONAL ±
ANGULAR ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
FINISHED SURFACE
BREAK CORNERS
REMOVE ALL BURRS

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NEXT ASS'Y

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ISSUE DESCRIPTION

PROCESS SYSTEMS INTERNATIONAL, INC.
20 WALKUP DR. WESTBOROUGH, MASSACHUSETTS 01581 USA

EQUIPMENT ARRANGEMENT
ISO
CORNER STATION WASHINGTON
LIGO VACUUM EQUIPMENT

CAD FILE	SIZE	DWG NO	REV
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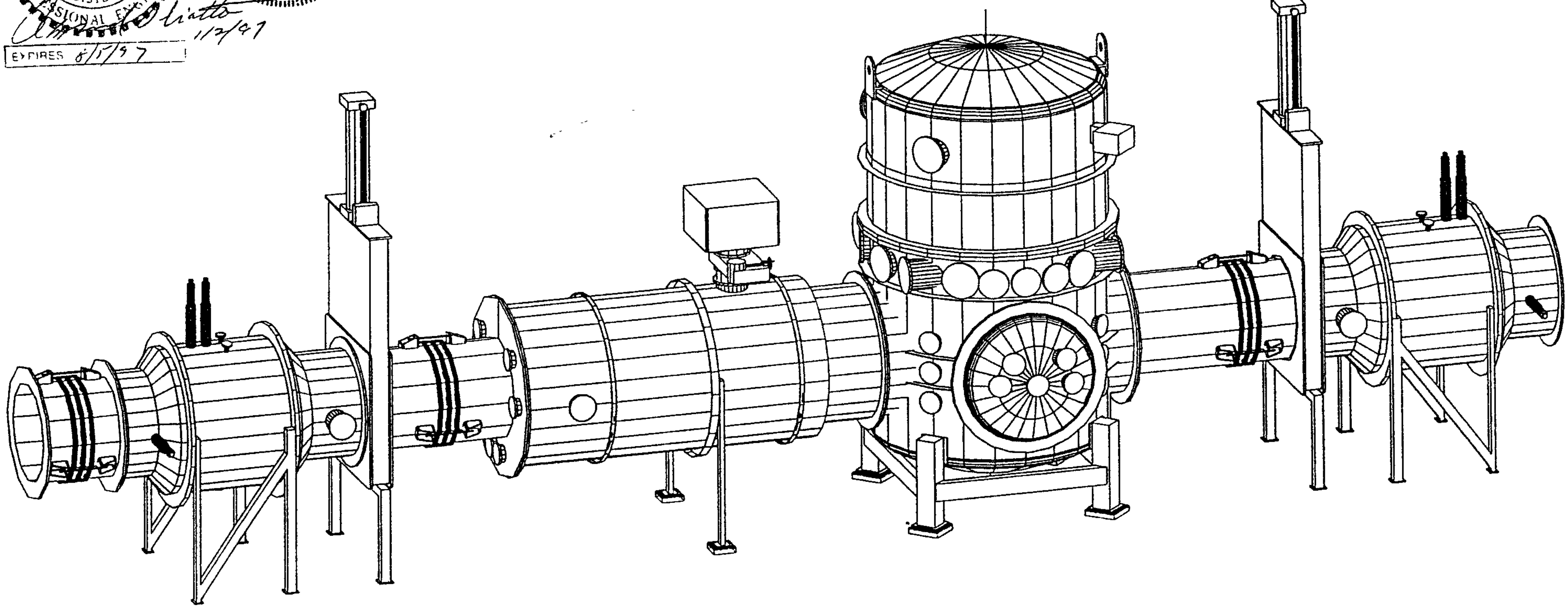
SCALE NONE | SHEET 1 OF 1

RAYMOND D. CIATTO
STATE OF WASHINGTON
15714
REGISTERED
PROFESSIONAL ENGINEER

STATE OF LOUISIANA
RAYMOND D. CIATTO
REG. No. 26750
REGISTERED
PROFESSIONAL
ENGINEER
IN
CIVIL ENGINEERING

R. D. Ciatto 1/7/97

EXPIRES 8/7/97



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ISSUE DESCRIPTION

PROCESS SYSTEMS INTERNATIONAL, INC.

EQUIPMENT ARRANGEMENT ISO
RIGHT MID STATION
WASHINGTON
LIGO VACUUM EQUIPMENT

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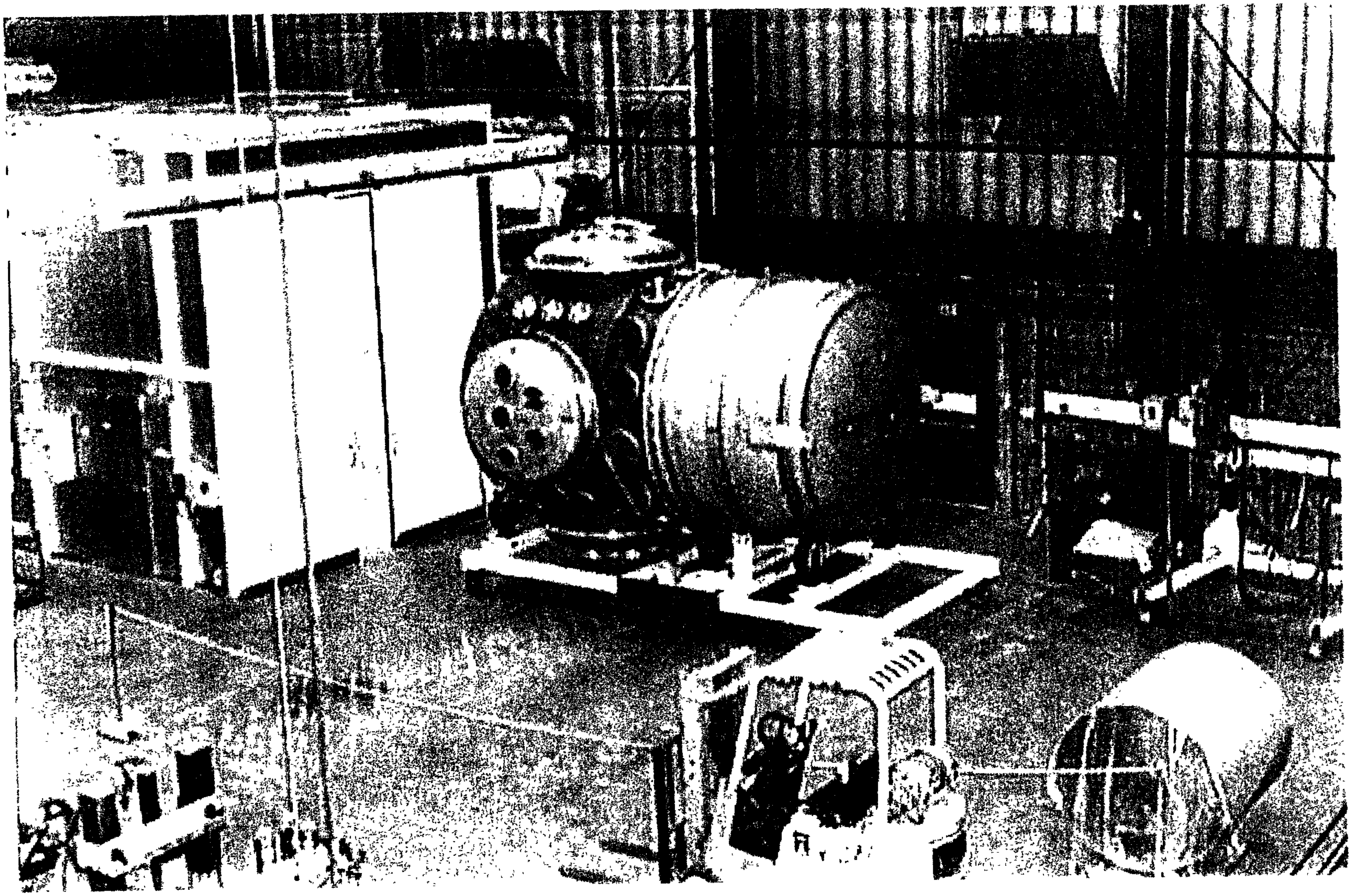

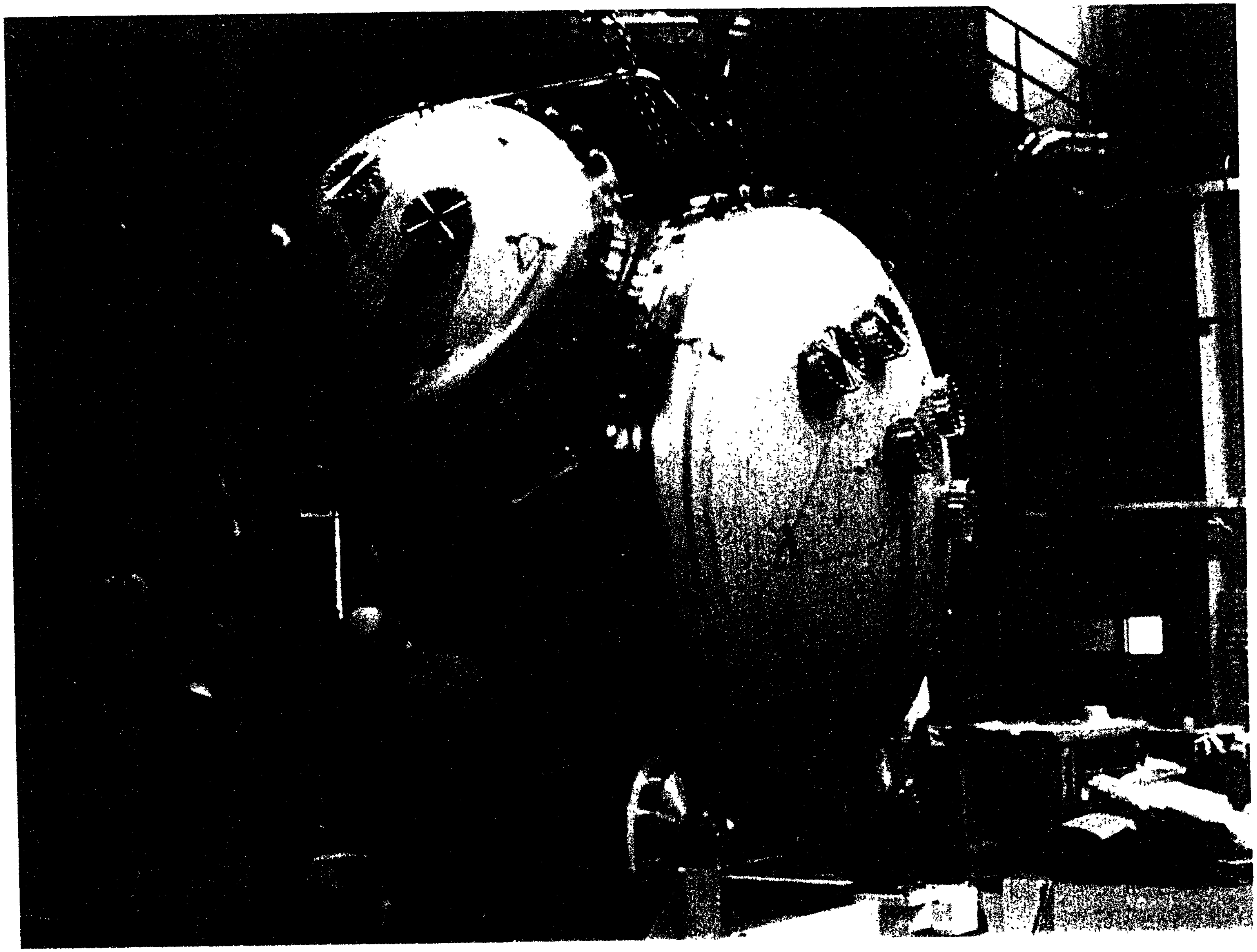


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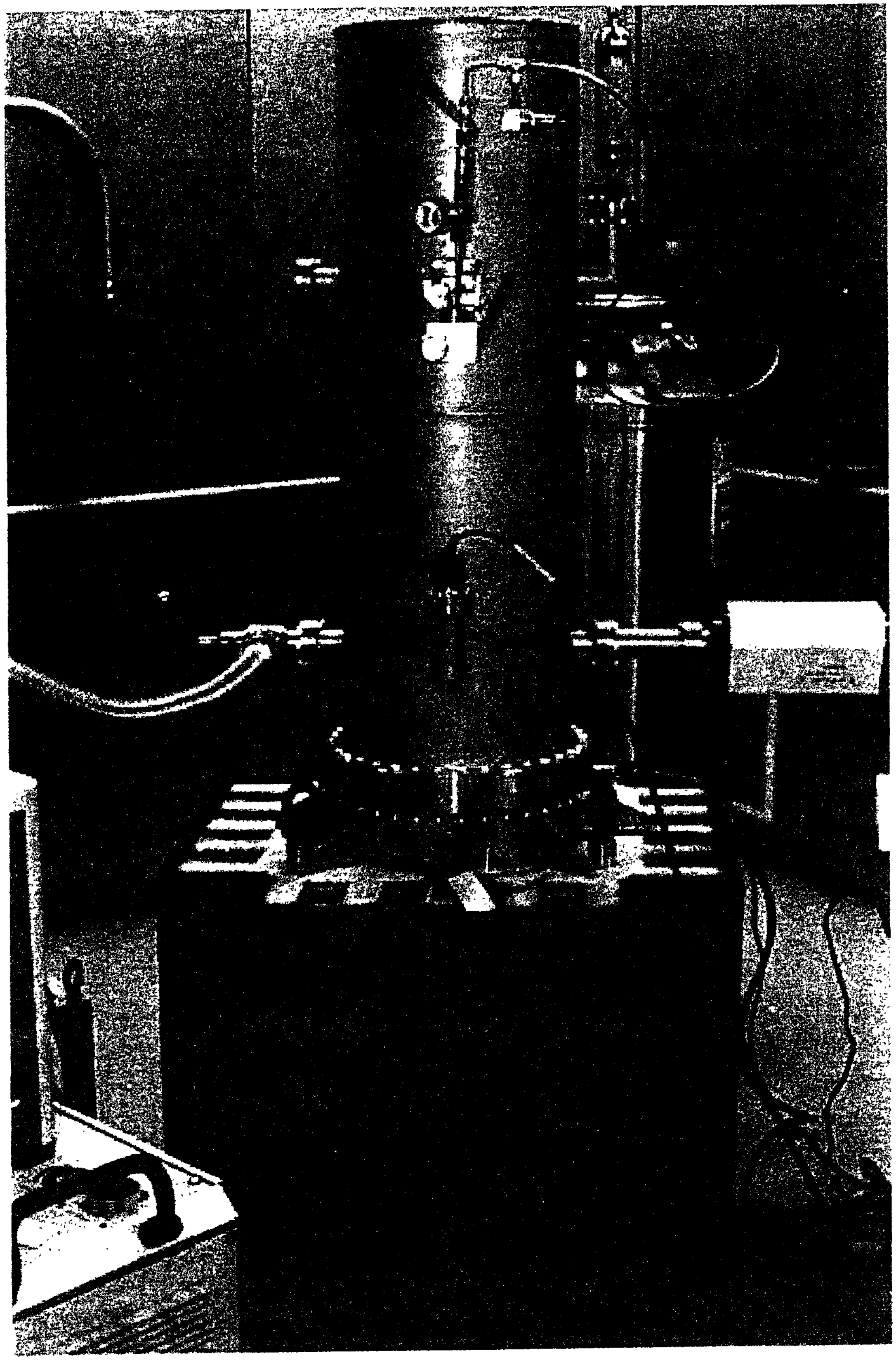
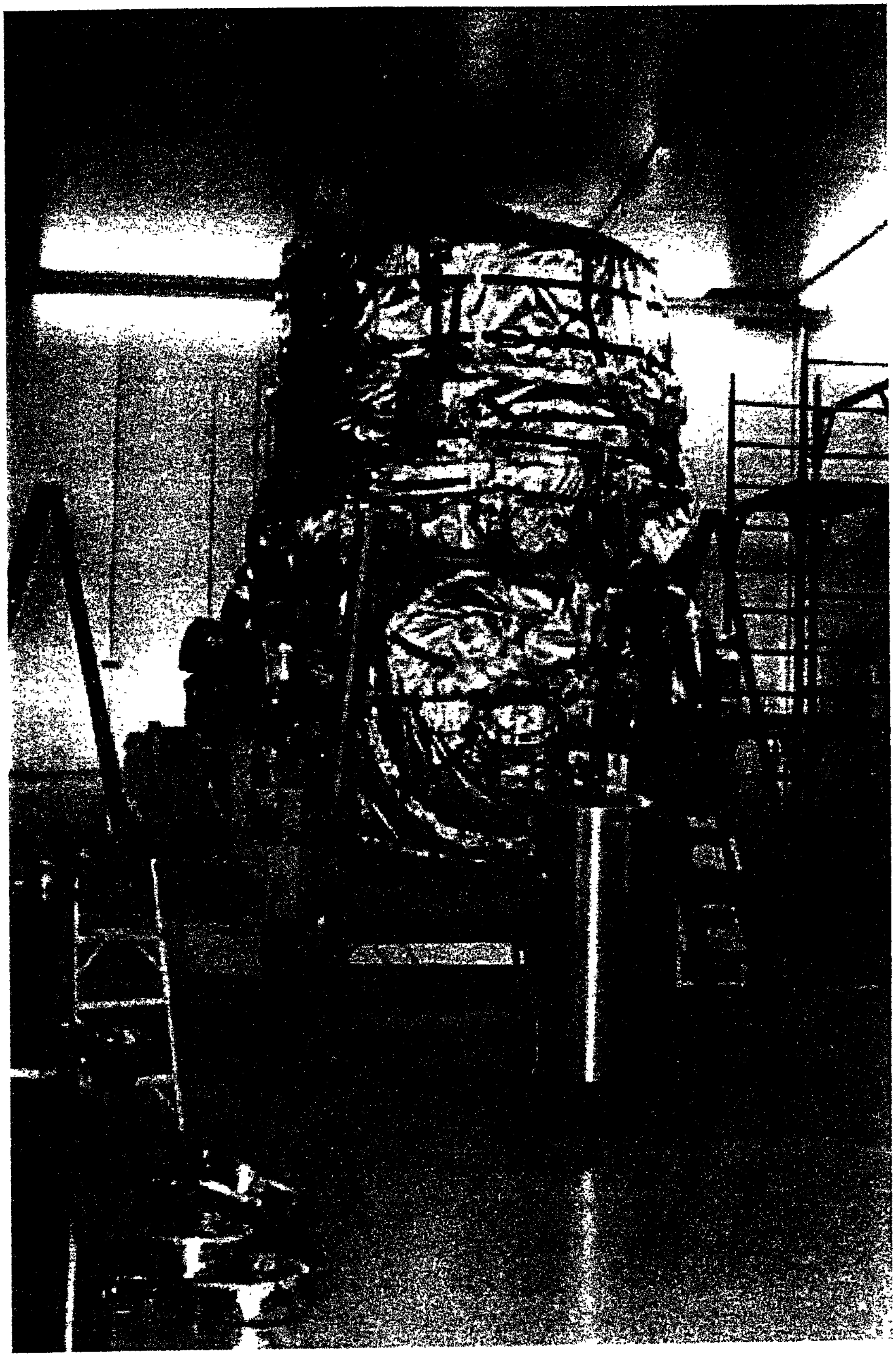
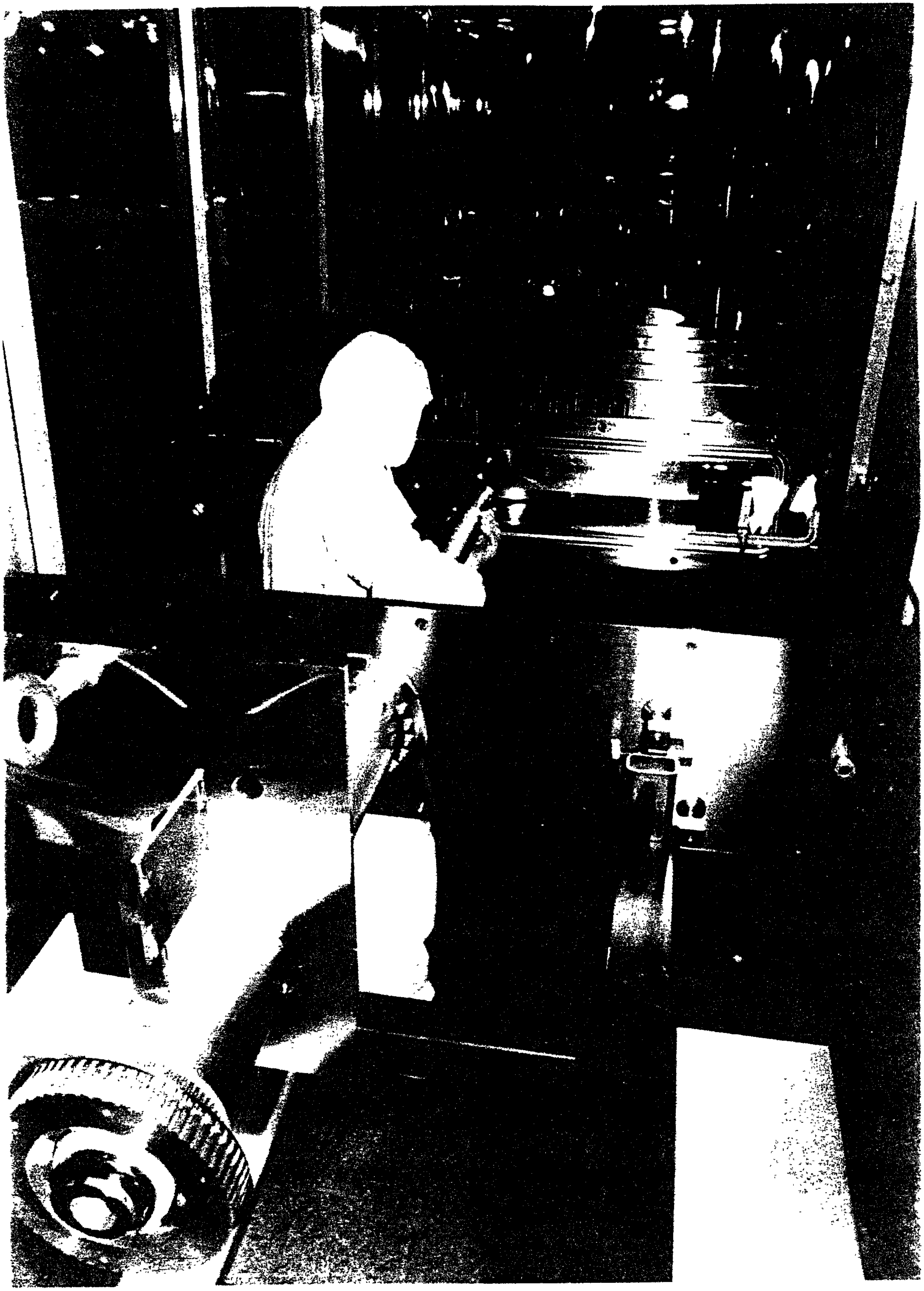
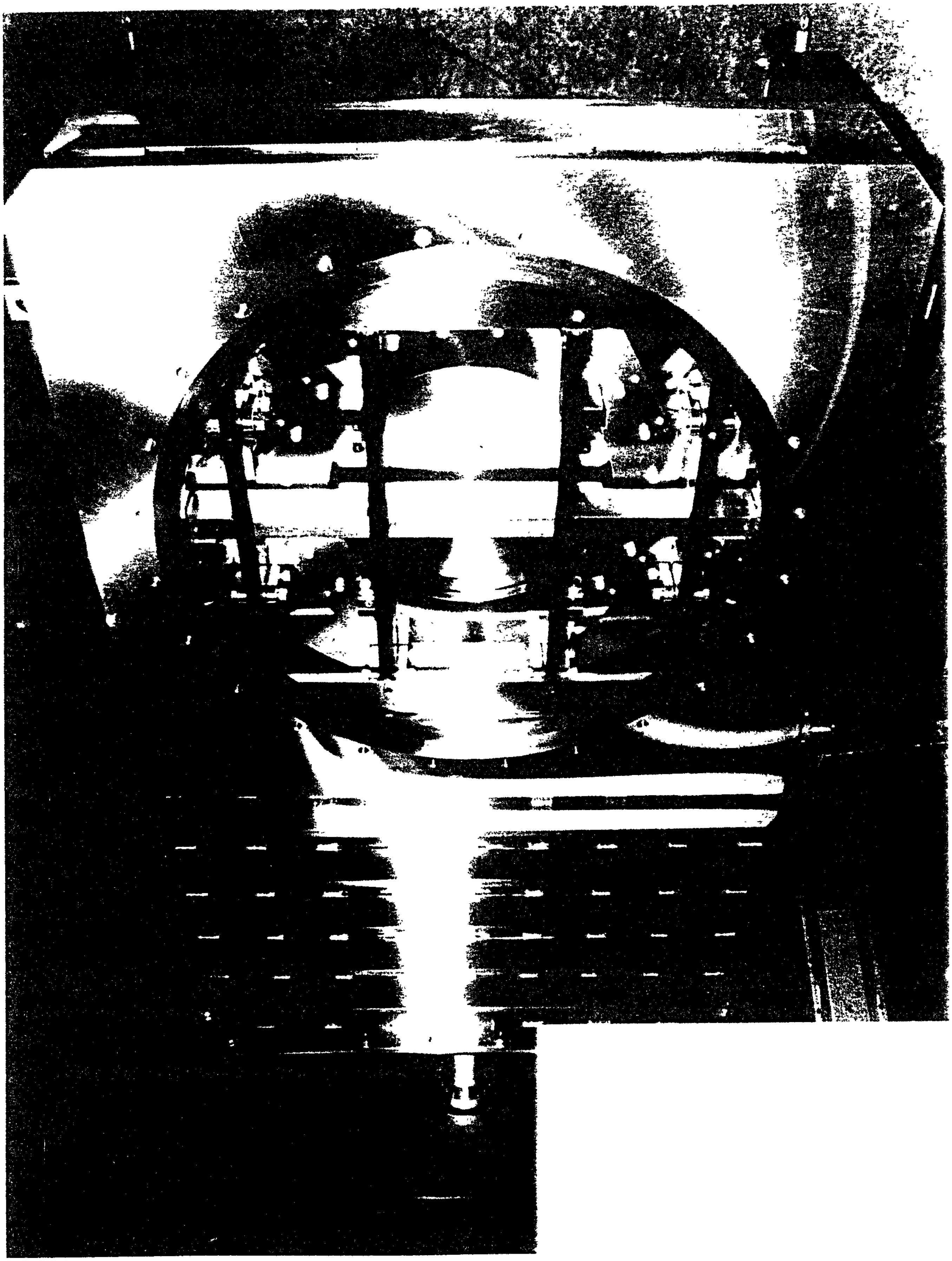








The LIGO Phase Noise Interferometer

LIGO NSF Review

15 April 1997

Peter Fritschel

LIGO-G970084-00-D

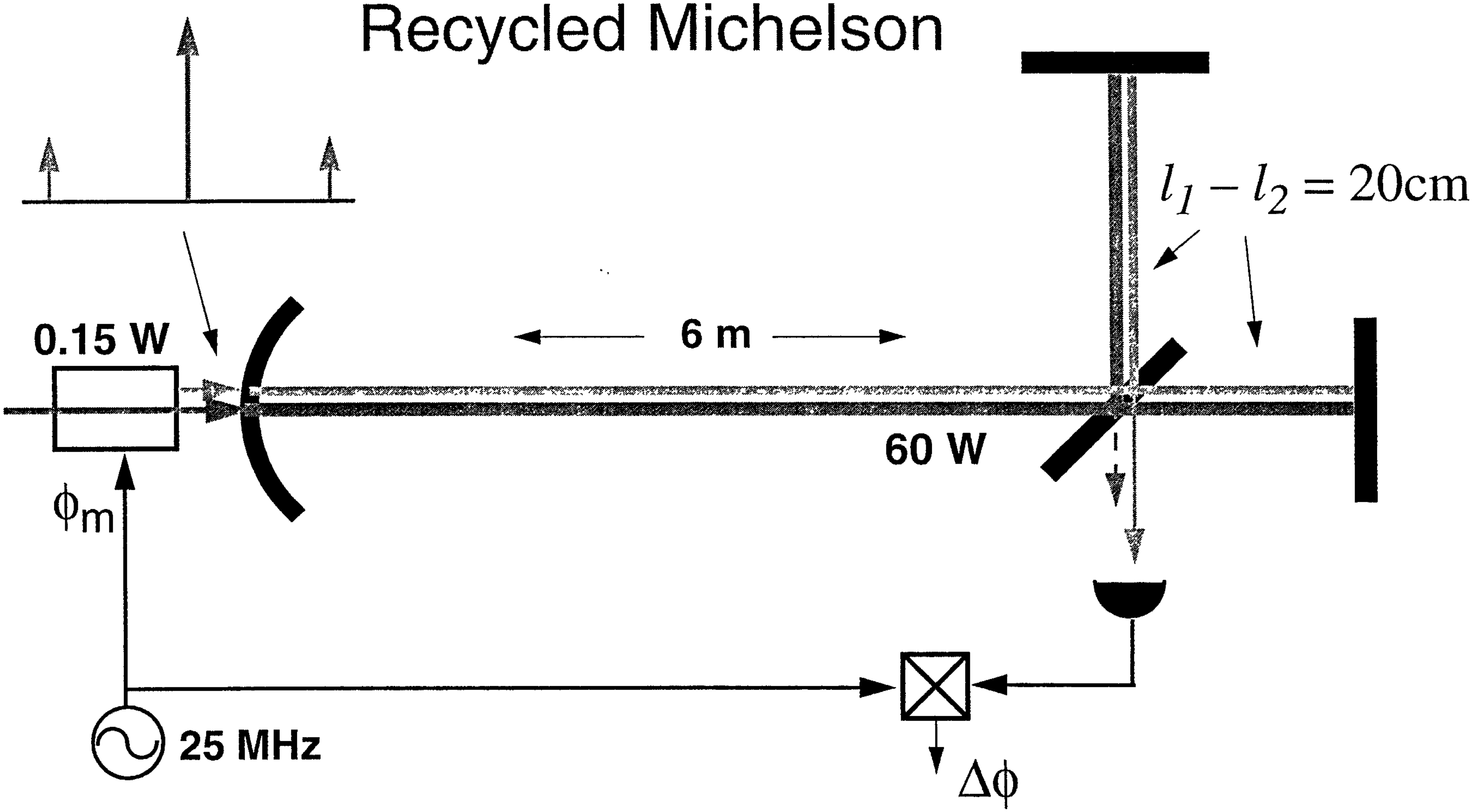
9

Phase Noise Interferometer (PNI) Goals

- Demonstrate optical phase measurement sensitivity
  - LIGO requires $\tilde{\phi}(f) < 10^{-10}\ \mathrm{rad}/\sqrt{\mathrm{Hz}}$
- Discover and understand technical noise sources
  - Scattered light
  - RF laser noise & modulation artifacts
  - Unknown...
- Test LIGO sensing subsystems
  - high-power photodetectors
  - length and alignment controls
- Gain experience with Nd:YAG lasers & laser stabilization, 1064 nm optics
- Develop diagnostics (and learn to do them!)

Optical Configuration

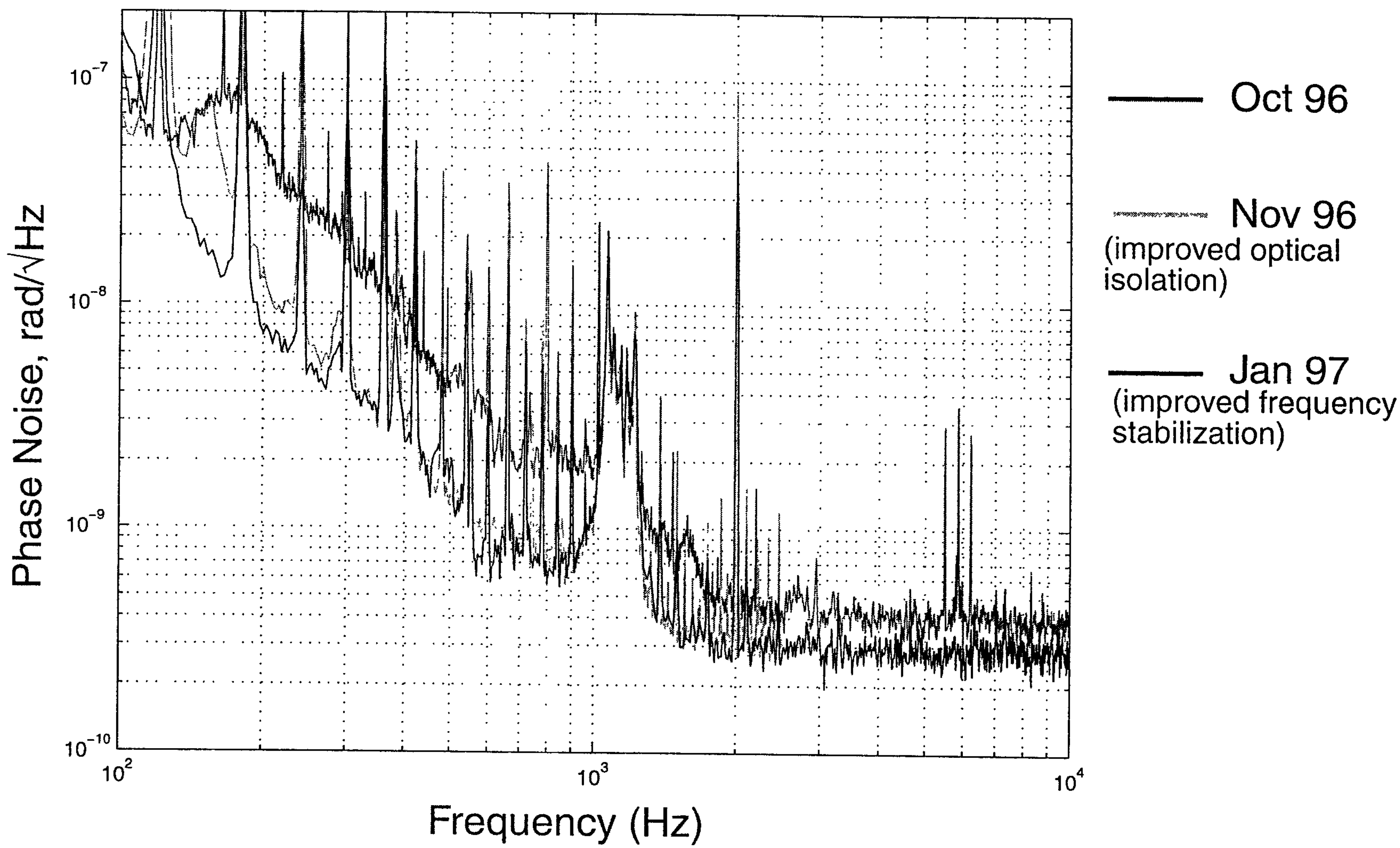
Recycled Michelson



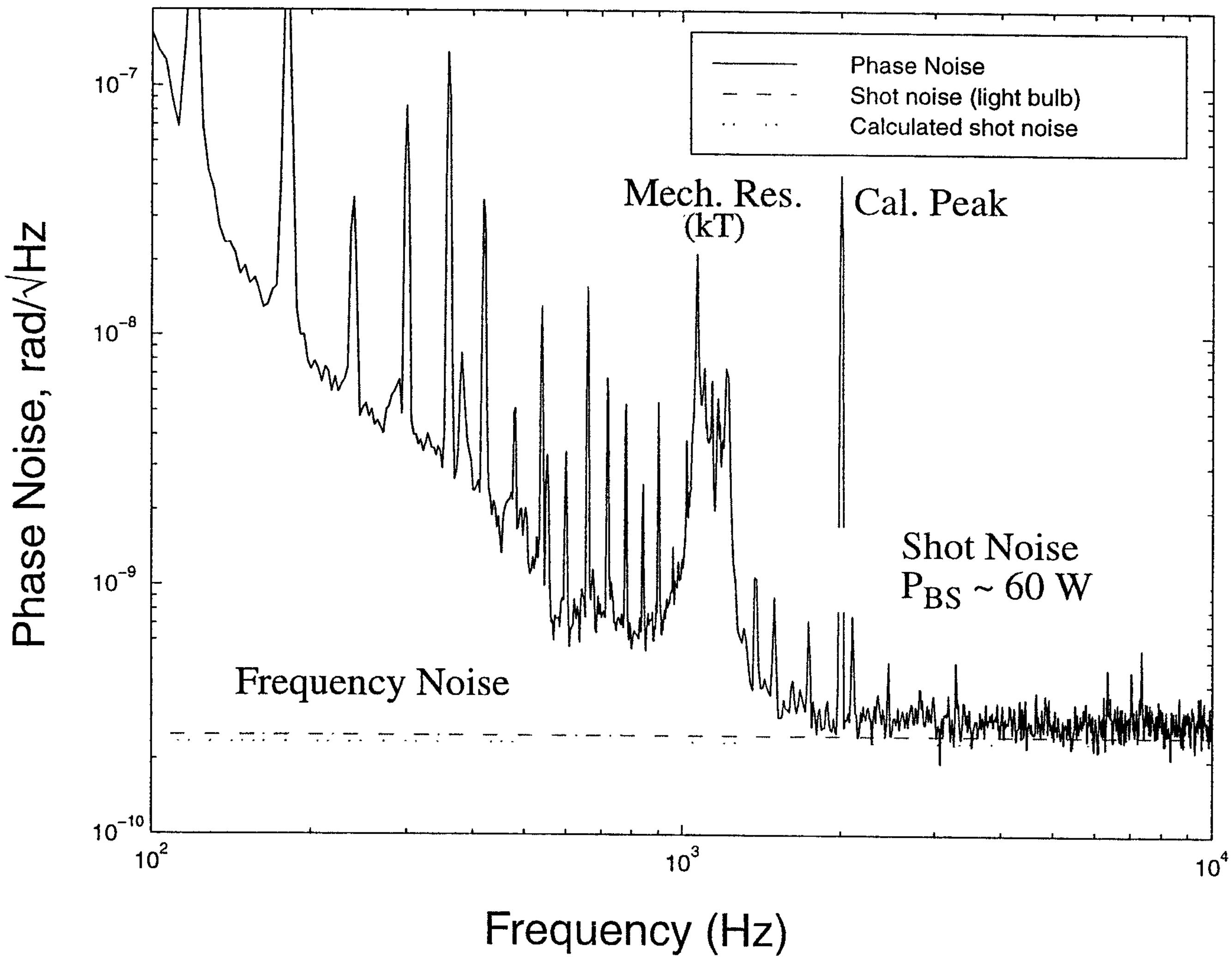
PNI Status

- Work with Ar laser (515 nm) version completed in January
  - ›› In nearly the entire 100 Hz - 10 kHz band, significant improvements were made in the phase noise spectrum, as compared to the Oct 96 data
  - ›› Good understanding achieved of the noise sources dominant in the best spectrum
  - ›› Lower shot noise sensitivity achieved: 2.9×10^{-10} rad/$\sqrt{\text{Hz}}$
  - ›› Ph.D. granted to Partha Saha for thesis on the PNI
- Conversion to Nd:YAG laser/1064 nm well underway
  - ›› NPRO laser has been frequency stabilized
  - ›› Input laser/optic table setup is complete
  - ›› Two-mirror suspended cavity now installed in vacuum system and ready for Phase I measurements

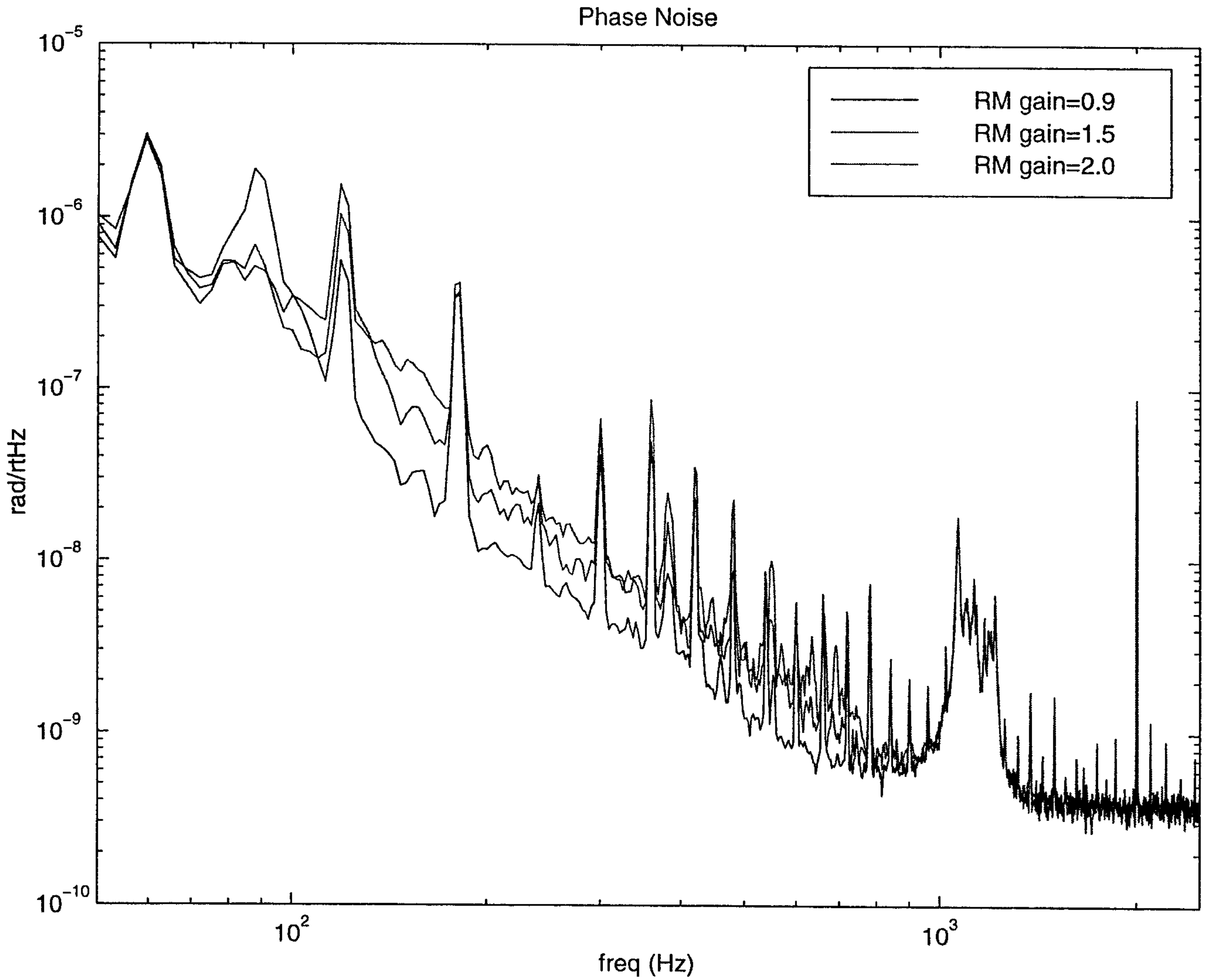
Phase Noise: Oct 96 vs. Jan 97



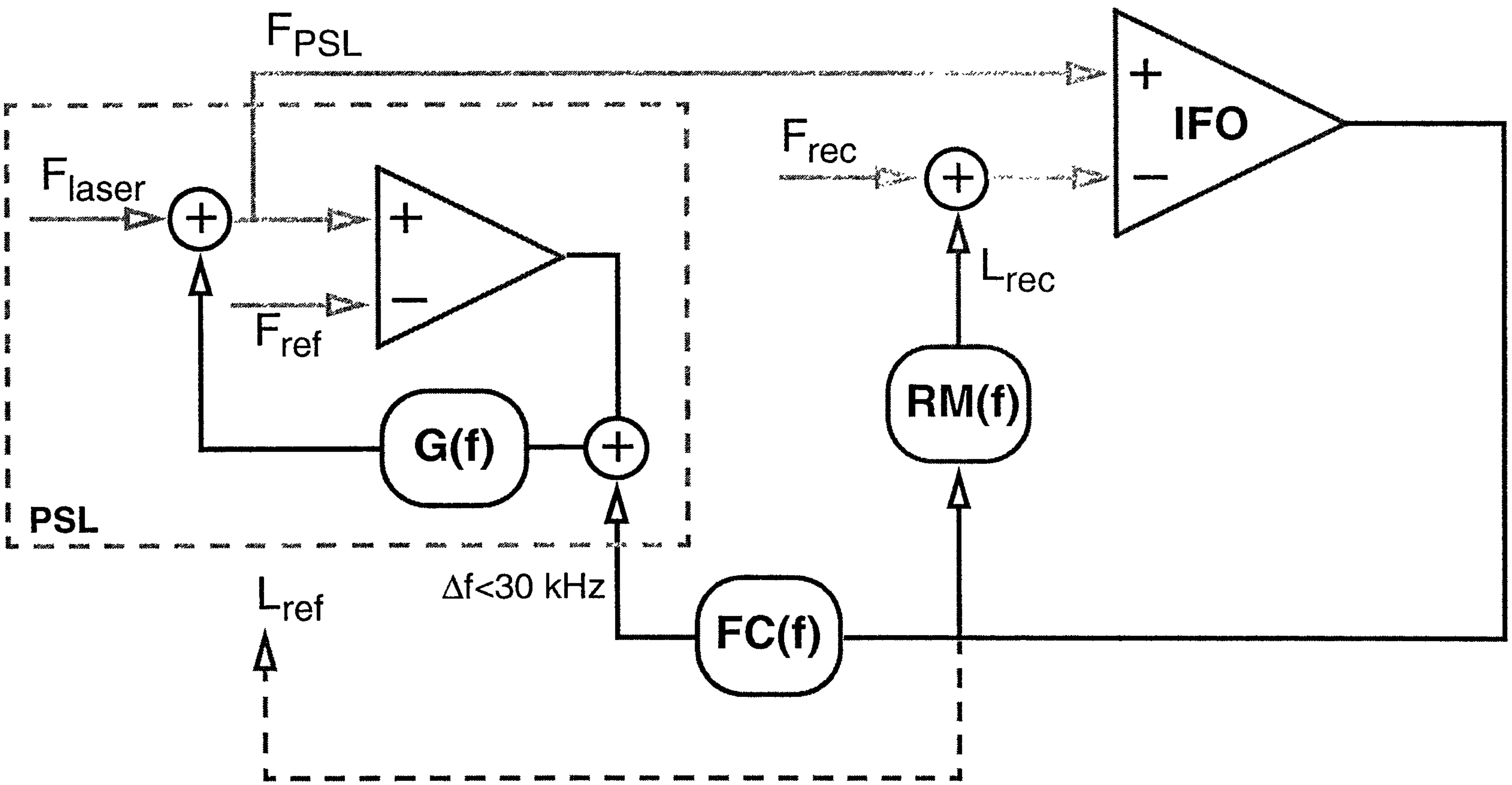
PNI Spectrum: Dominant Noise Sources



Phase Noise vs. δf suppression



Common Mode Servo



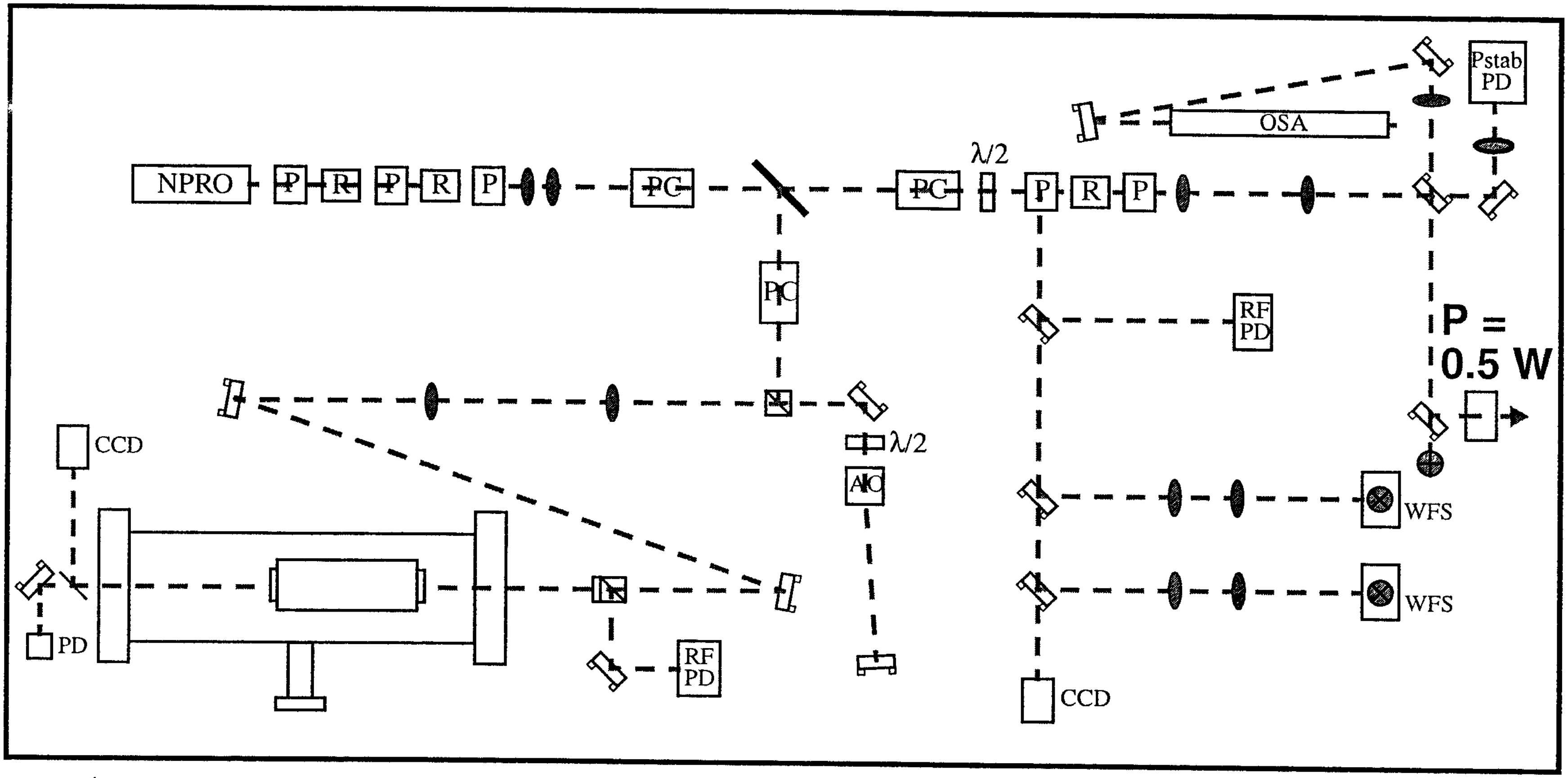
Nd:YAG PNI - 1064 nm

- Re-build began in mid-January (one month after Oct 96 estimate)
- Laser: Beginning with prestabilized 700 mW NPRO
  - ›› Using servo electronic modules produced by the PSL/CDS group at Caltech
  - ›› Modules delivered in mid-Feb, laser locked a few days later
- Phase I: 2 mirror, 6m long suspended cavity
  - ›› characterize frequency noise of prestabilized NPRO - important for PNI & the LIGO PSL design
  - ›› develop controls for additional frequency stabilization using new frequency shifter, consisting of Acousto-Optic Modulator/Voltage-Controlled Oscillator

Nd:YAG PNI - Status

- Prestabilized NPRO is operational, and partway through a complete internal characterization of performance, including a characterization of the AOM/VCO frequency shifter
- Suspended optics for Phase I are mounted, balanced, and installed in the vacuum system
  - ›› system was pumped down on 4 April
  - ›› controls currently being worked on (cavity locked briefly using only cavity length feedback)
- Construction in progress of wavefront sensor-based alignment control electronics for additional degrees-of-freedom

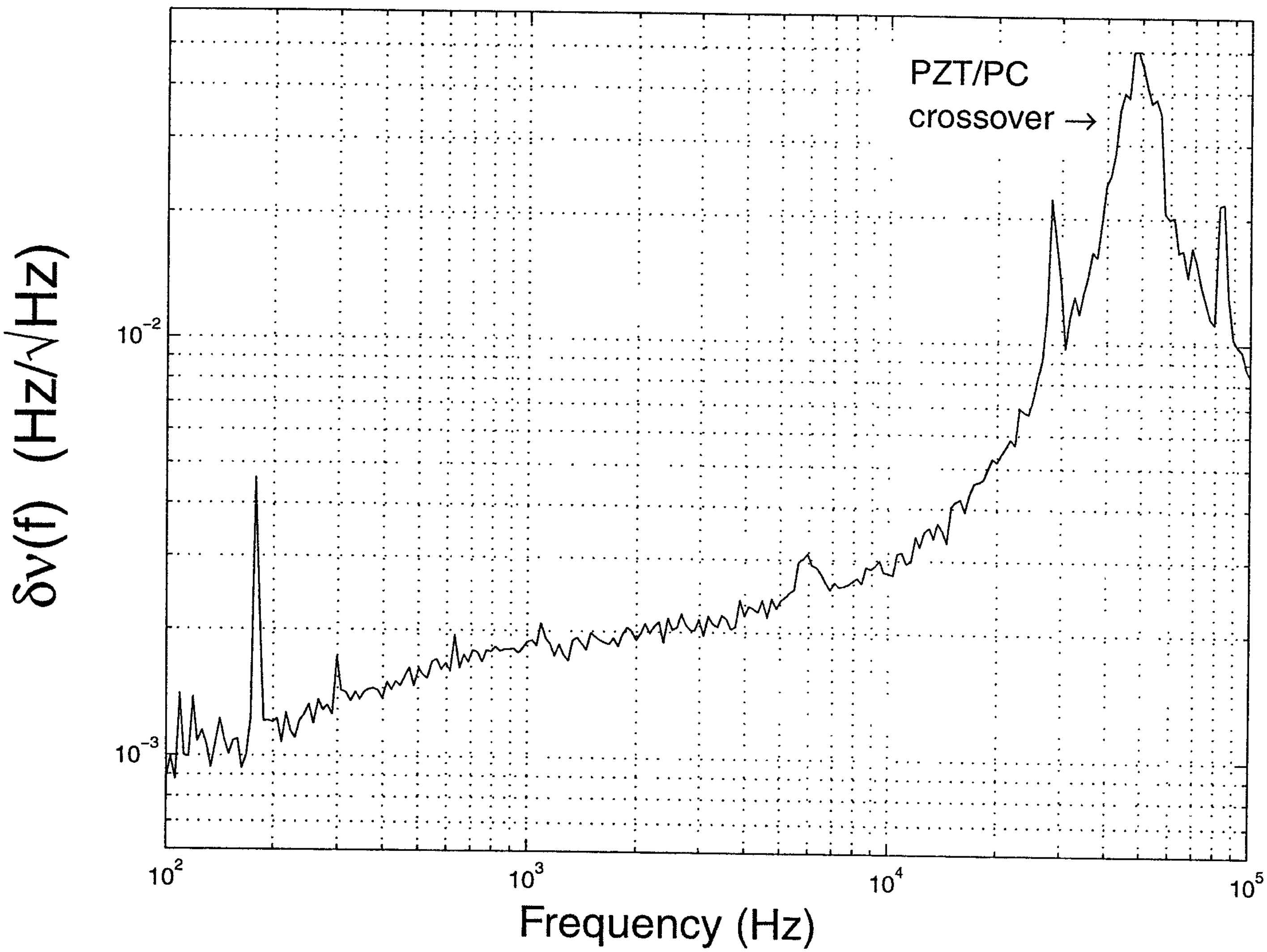
Laser & Input Optics Table



Optical Table mounted
on STACIS Active Isolators

P	Brewster Angle Polarizer
R	Faraday Rotator
PC	Pockels Cell

Frequency Prestabilization Error Signal



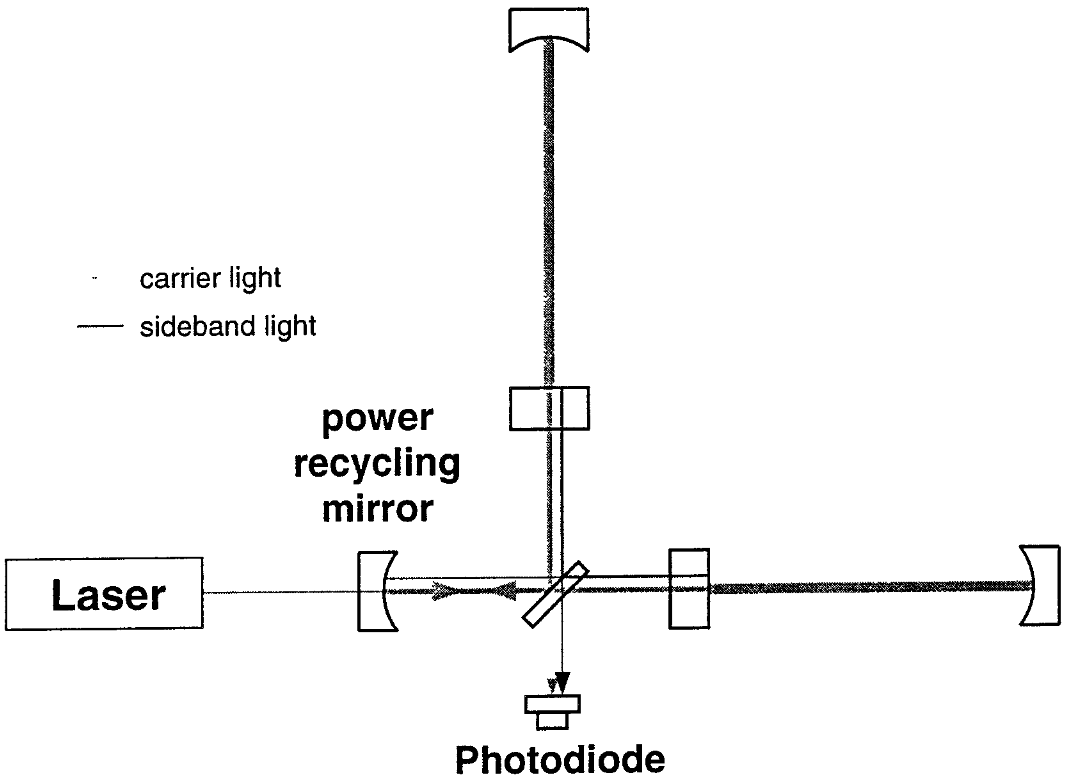
Future Plans for the PNI

- Phase I:
  - Expect ~2 months of investigations with the linear cavity
  - Will be installing Wavefront Sensor alignment control for both suspended optics
- Phase II: Recycled Michelson
  - Installation will commence early June
  - test high-power photodetector prototype
  - test digital length control prototype hard/software
- Completion end of '97: just before lab move!

Recycling at the 40m

- The motivation for power recycling
  - Deliverables
- Implementation at the 40m
  - Control topology
  - Optical topology
  - Expected Sensitivity
- Current status of work

Power Recycling

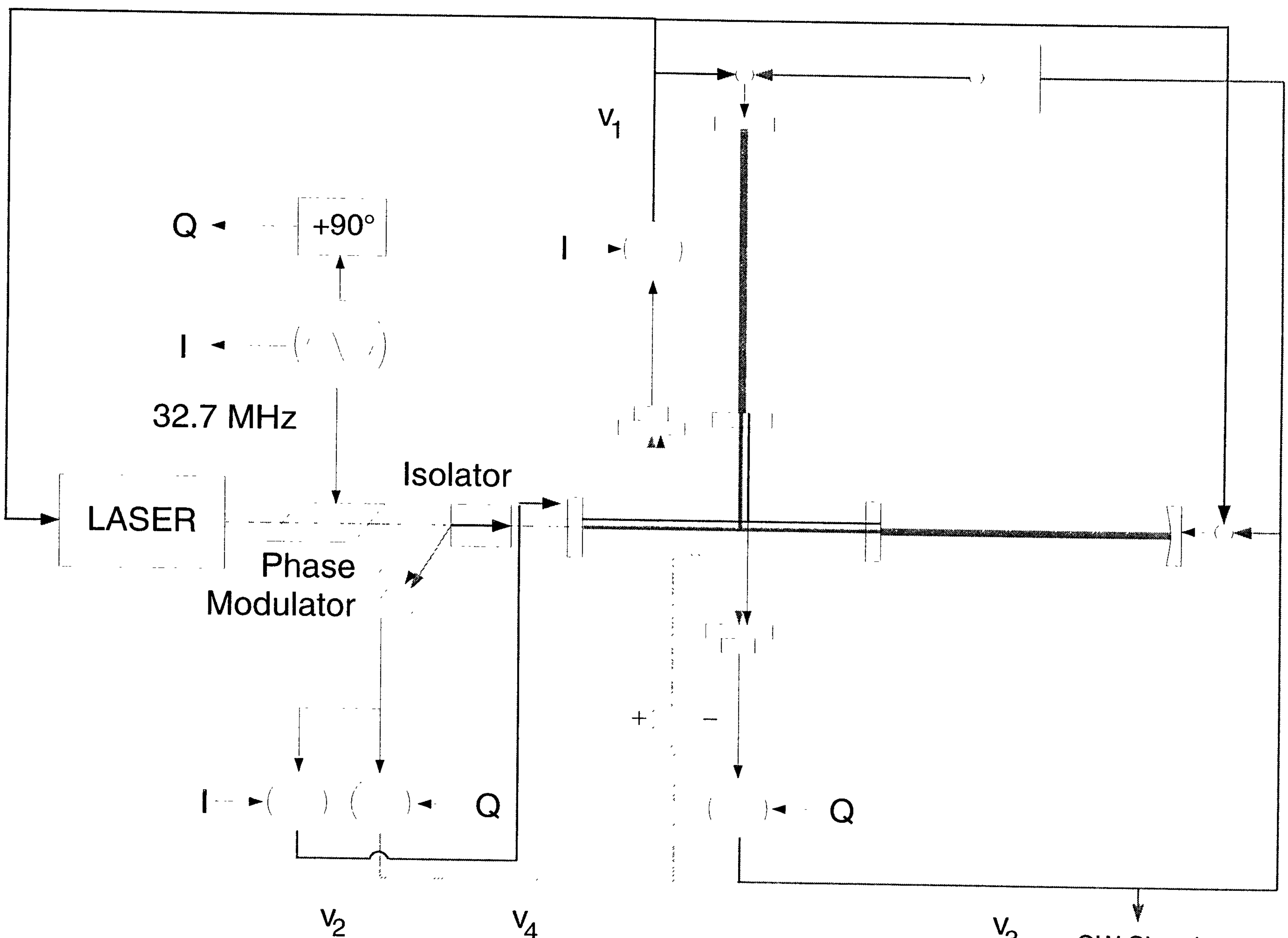


In recombination, the detector is operated on a dark fringe ∴ most of the light returns towards the laser. This light is coherently added to the initial laser beam by the power recycling mirror increasing power in the detector and hence the sensitivity of the detector.

Deliverables

- model validation
  - ›› both optics and servos
- a known and understood lock acquisition sequence(i.e. how to bring all cavities into resonance together)
  - ›› sequential tests for bringing the interferometer on line
  - ›› how to acquire lock with relative ease
- a set of diagnostics
  - ››how to hold lock robustly - understanding of mechanisms that cause system to loose lock
  - ››development of methodologies for standard noise tests; this will be naturally accompanied by work to lower the noise floor at the 40m
- an experienced crew

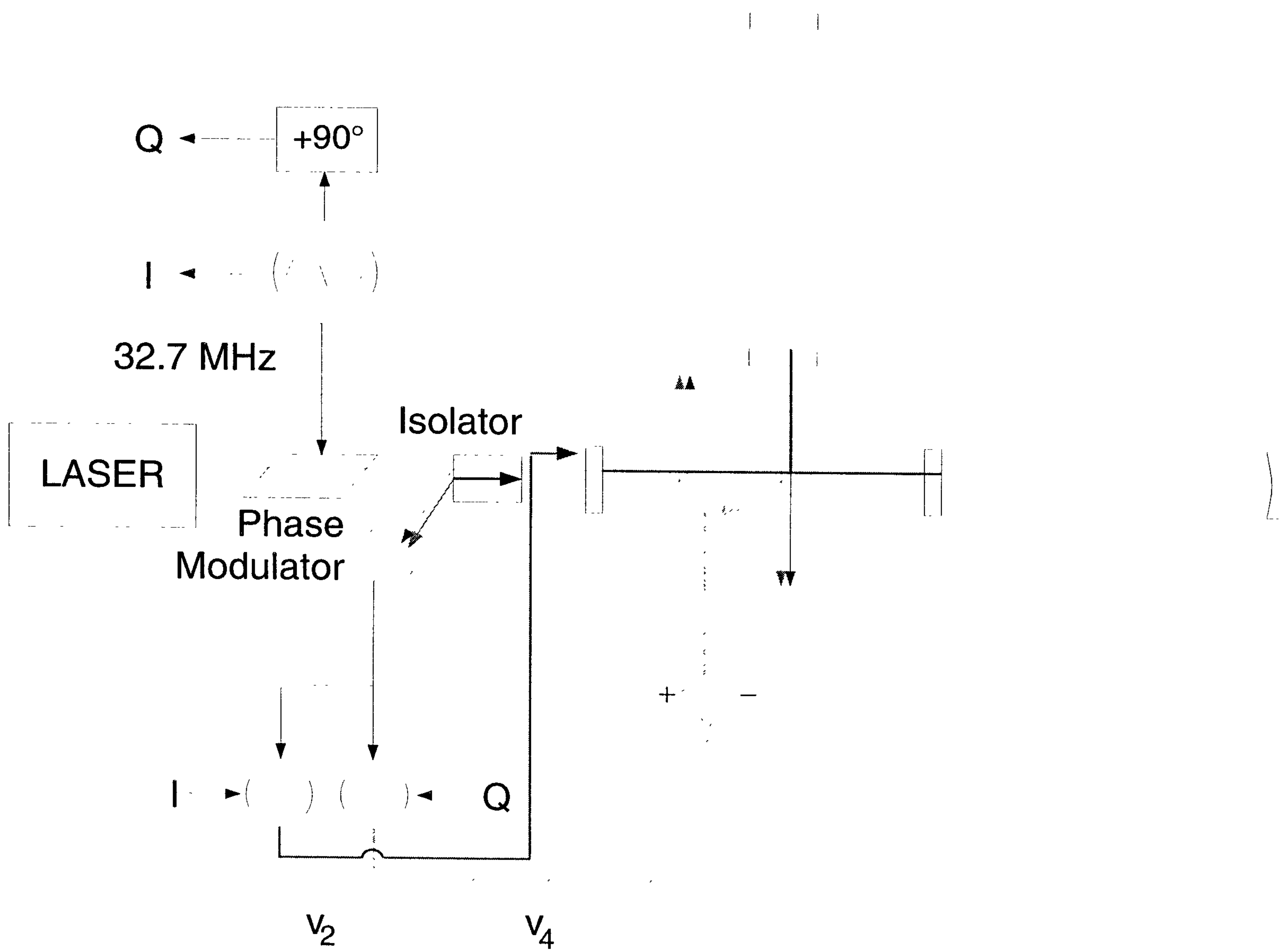
Optical and Servo Topology for the Recycled 40-m Interferometer



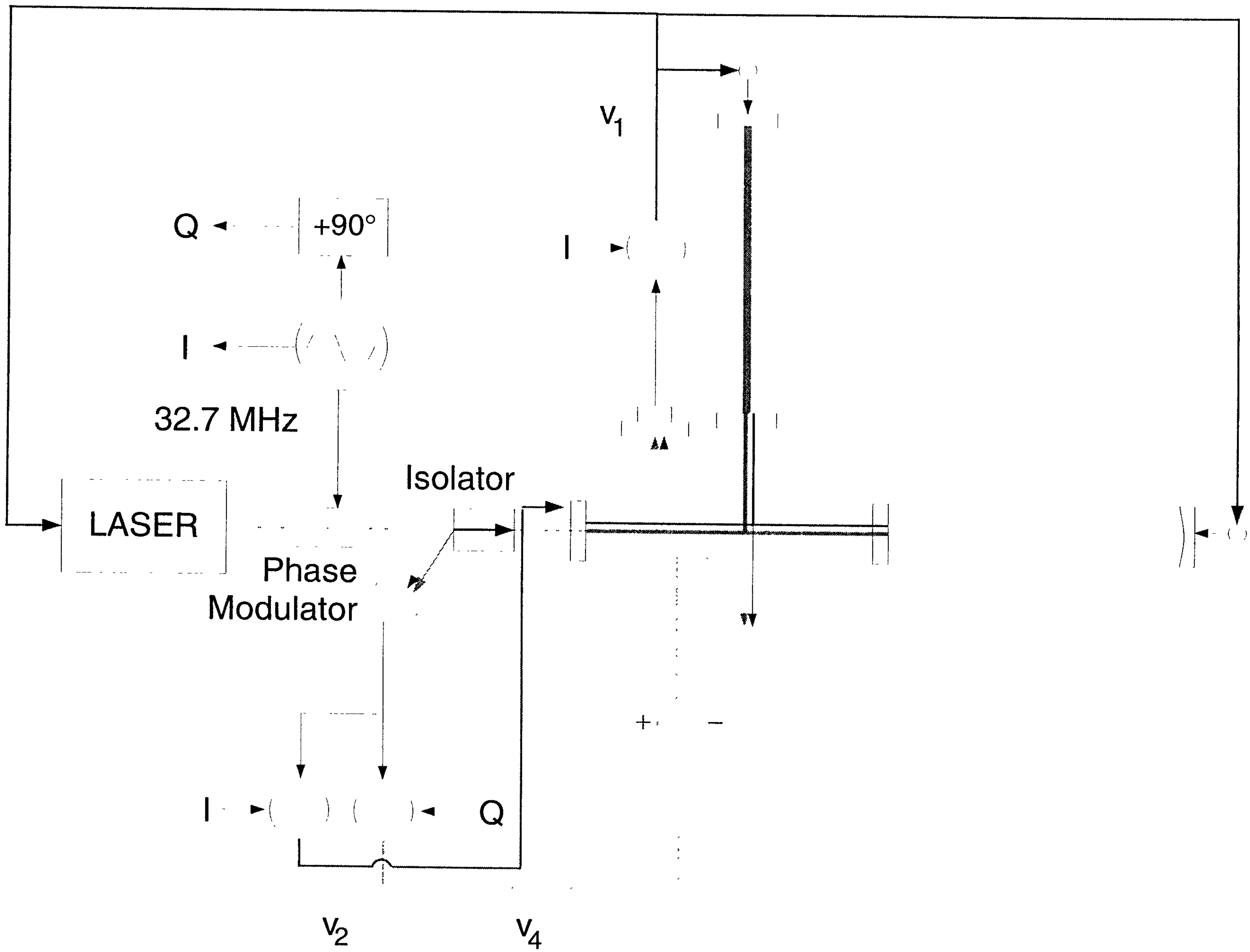
Control Topology

- Lock acquisition design utilising SMAC (L. Sievers, D. Redding and L. Needels)
- Results from this have changed the baseline servo topology
- Servo design utilising LIGO code

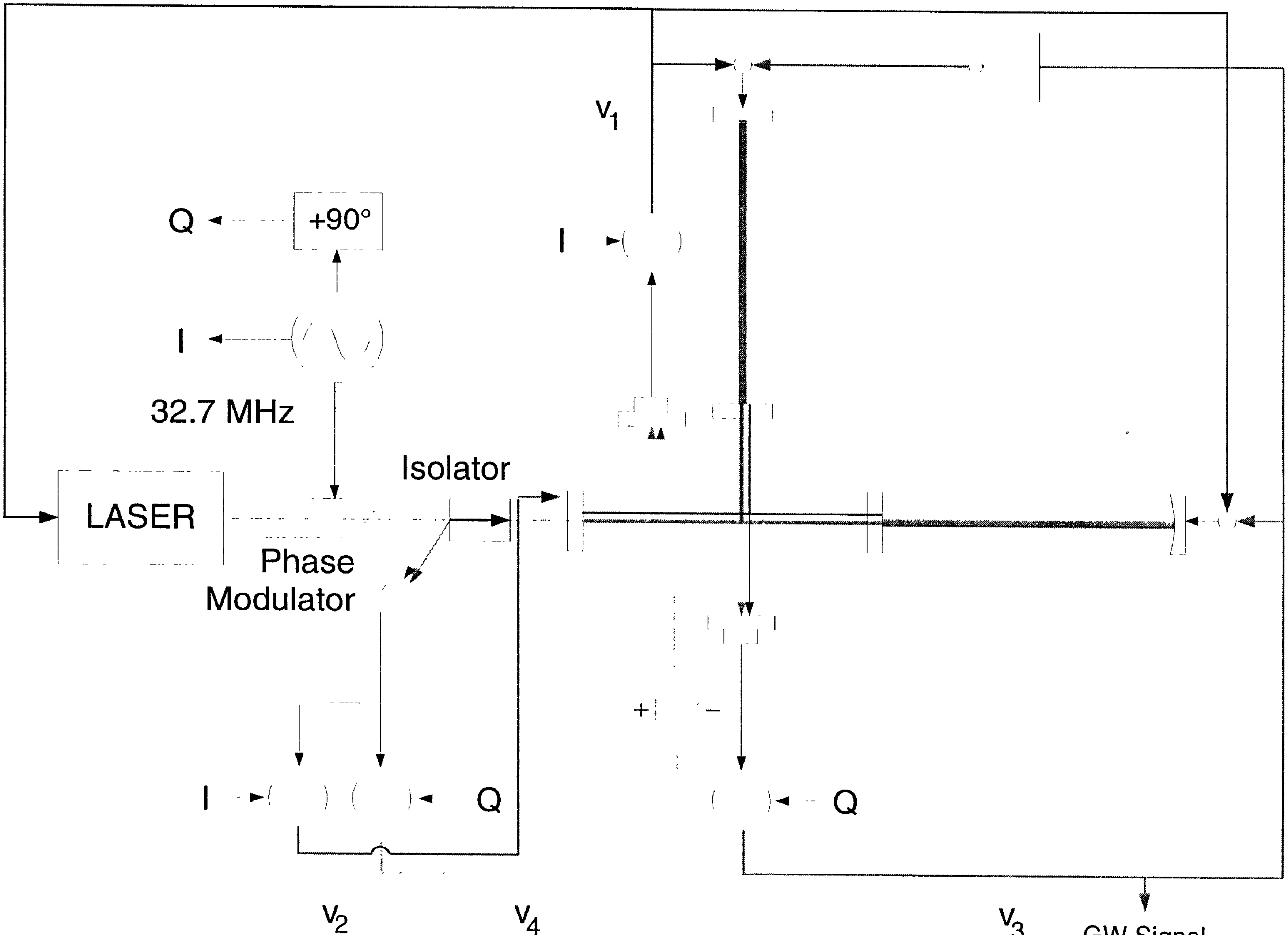
Optical and Servo Topology for the Recycled 40-m Interferometer



Optical and Servo Topology for the Recycled 40-m Interferometer



Optical and Servo Topology for the Recycled 40-m Interferometer



Implementation of Servos

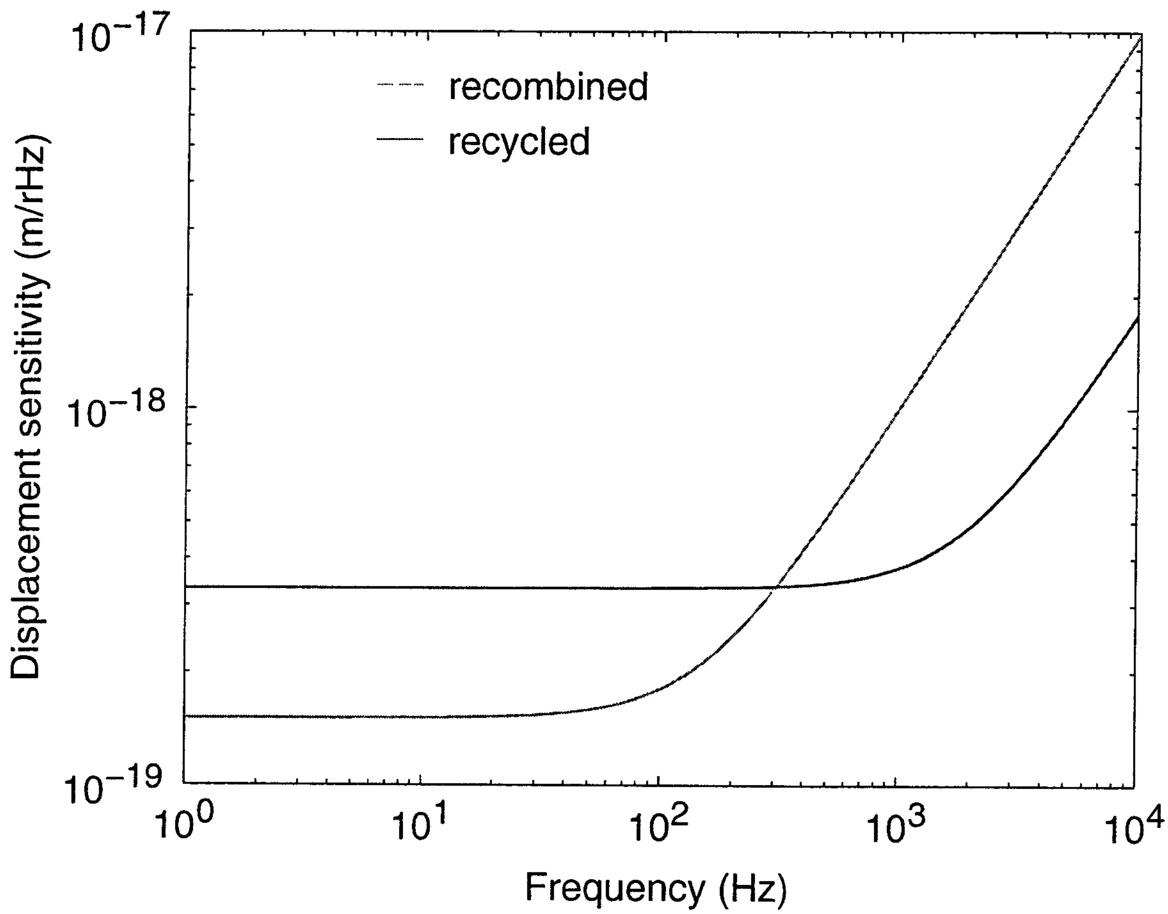
- In the light of lock acquisition modeling results, some redesign of servos was required
- initial implementation will be achieved first altering current (recombination) electronics
  - should provide results on faster timescale than upfront redesign and building of VME electronics
  - provides greater flexibility
- final implementation via full conversion to VME with software interface - an integrated system test
- wavefront sensing will be incorporated to control alignment
  - will make use of FMI hardware

Optical Topology

- Planned recycling factor of N ~ 5
  - due to difference in length scales, a more modest recycling factor has been chosen in order to keep overall configuration similar to LIGO.
- -> Installation of higher transmission vertex mirrors (have apertured coating to make them more equivalent to LIGO; allowed removal of apertures - a potential scattering surface)
- Recycling gain = (Sum of Losses)-1. Knowledge of losses in recombined configuration with high transmission mirrors

  => $T_R = 0.14$, N ~ 7

Predicted Shot Noise Limited Sensitivity

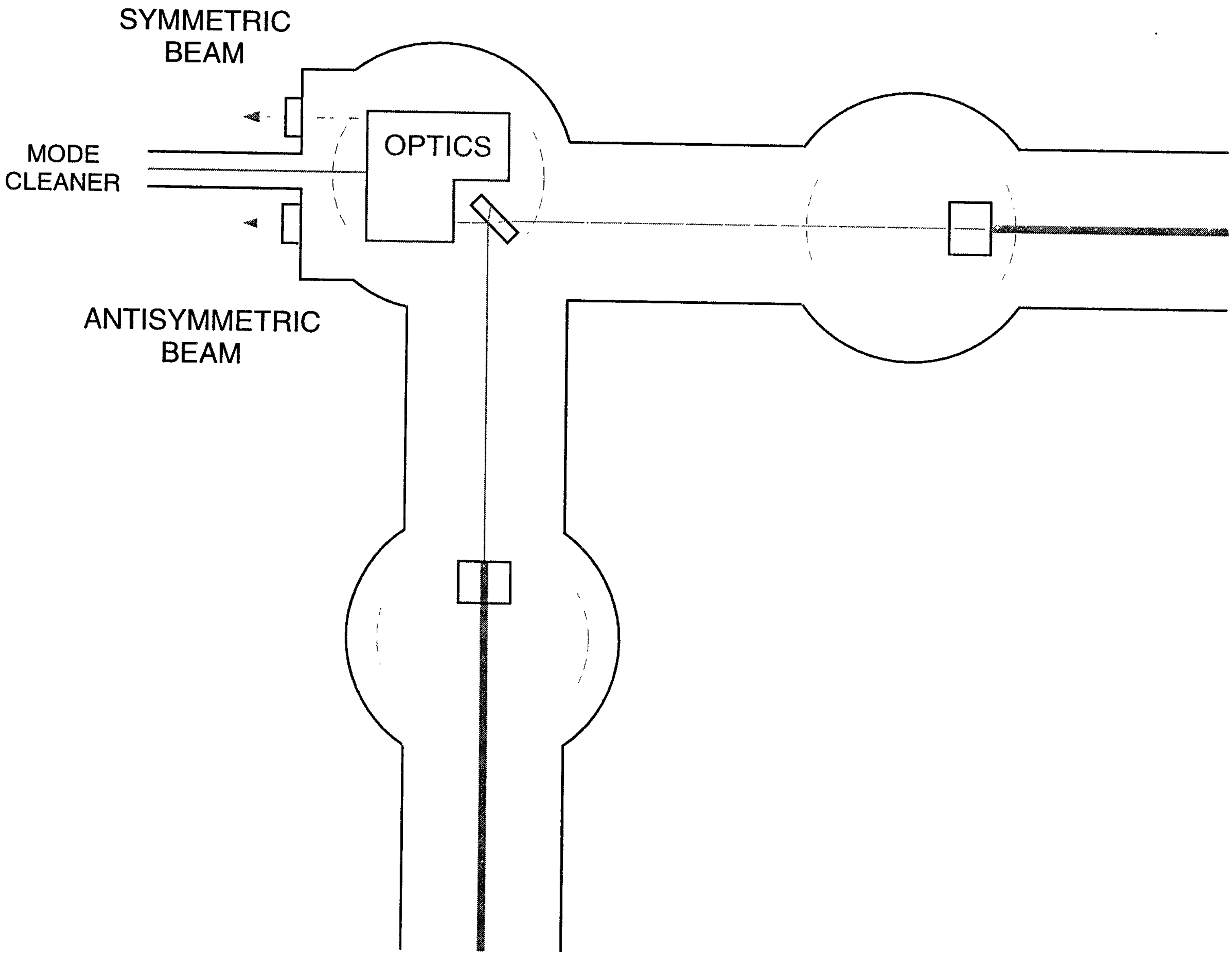


Steps Required to Achieve Recycling

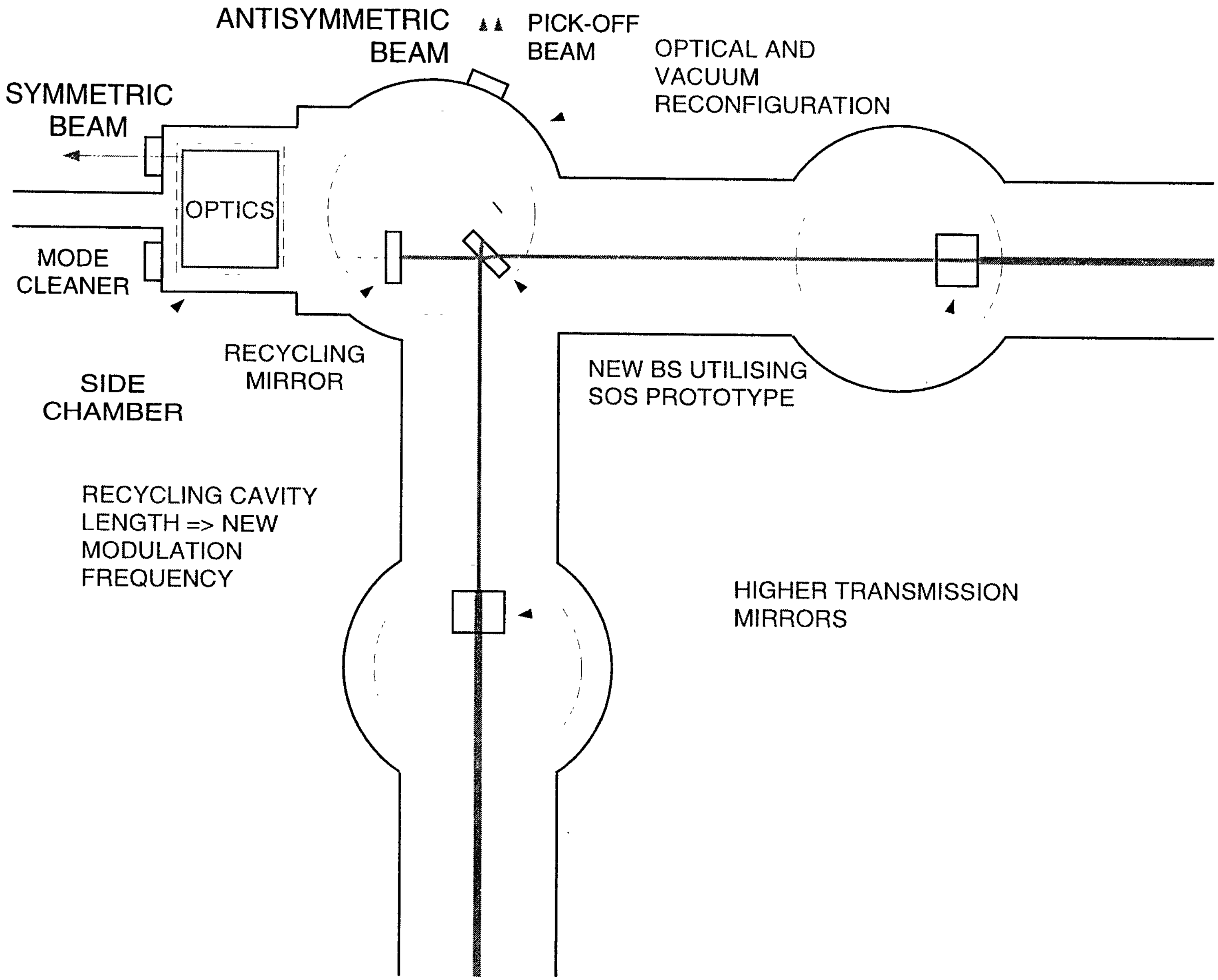
- change vertex mirrors for ones of higher transmission
  - Completed 09/96
- reconfigure vacuum envelope and optical layout, replacing beamsplitter with LIGO prototype suspension
  - Completed 01/97
- change modulation frequency
  - About to commence
- install recycling mirror and lock interferometer
  - scheduled to start mid May
- Current status: ~ 6 weeks behind April '96 schedule

New Mirrors + Beamsplitter

- Full recombined interferometer is locking
- Allows final measurements of system to be made to allow final choice of recycling mirror to be made



PREVIOUS OPTICAL TOPOLOGY FOR RECOMBINATION



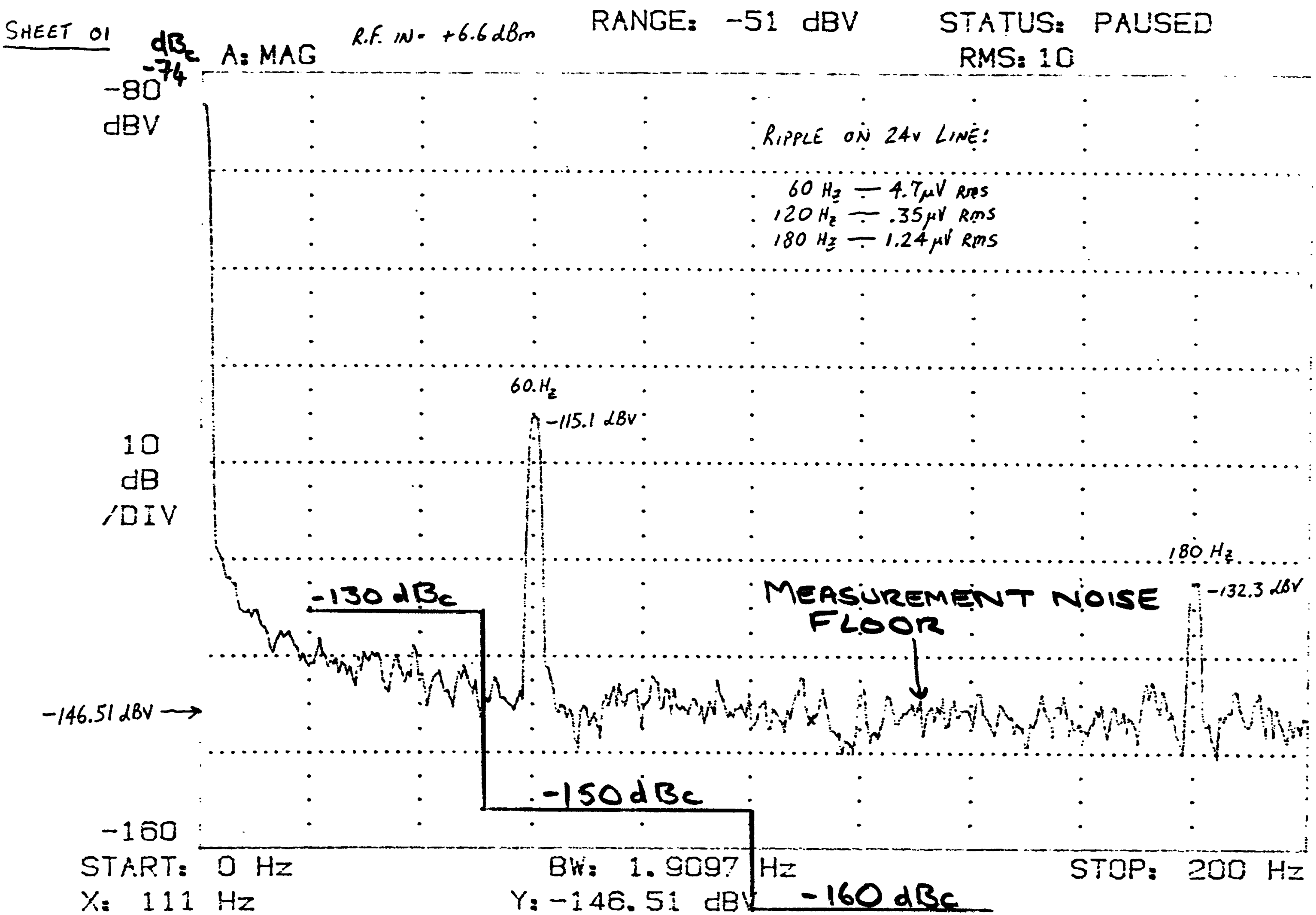
OPTICAL TOPOLOGY FOR RECYCLING

Reference Source

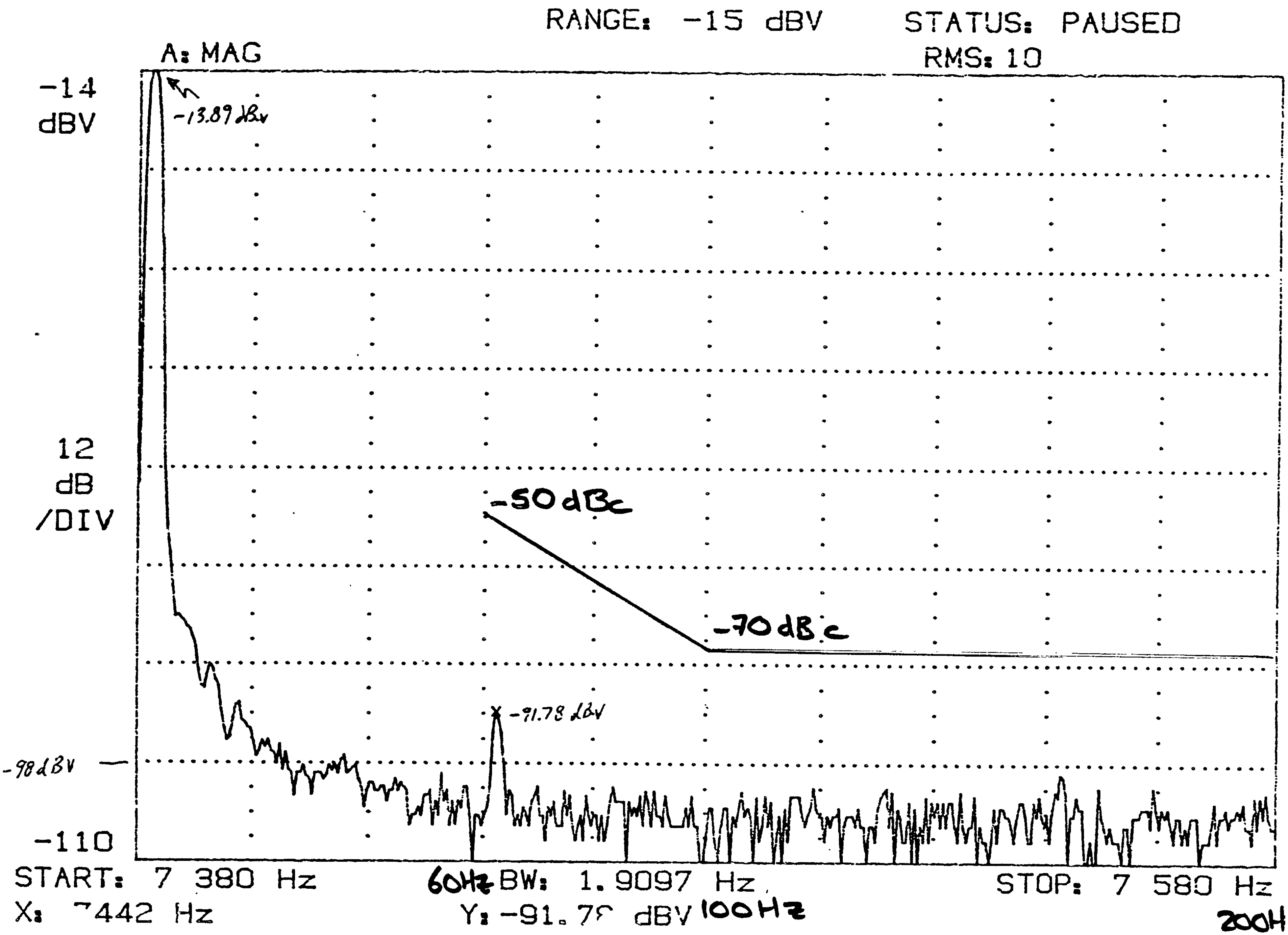
- Reference source designed for LIGO requirements
  - with LIGO optical topology AM and PM on the sidebands is not strongly filtered
  - sideband AM and PM resulting from oscillator instabilities affect detector output in a similar way to laser intensity and phase noise
  - stringent oscillator requirements, particularly for AM
- Will have first test at 40m

A.M. NOIS ALL INTERNAL V_{IF} = 339mV max. C₁ NEL-5 12/17/96 ORIGINAL

24v REGULATOR IN R.F. COMPARTMENT.



PHASE NOISE #2 (I.F. To +200Hz) 12/16/96 ORIGINAL



NSF Review -

Detector Overview

S. Whitcomb

15 April 1997

//

Outline

- **Cost/schedule status**
- **Subsystem requirements definition**
- **Subsystem progress and status**
- **Summary**

Key Near Term Detector Activities-----Month End February 1997

4/4/97

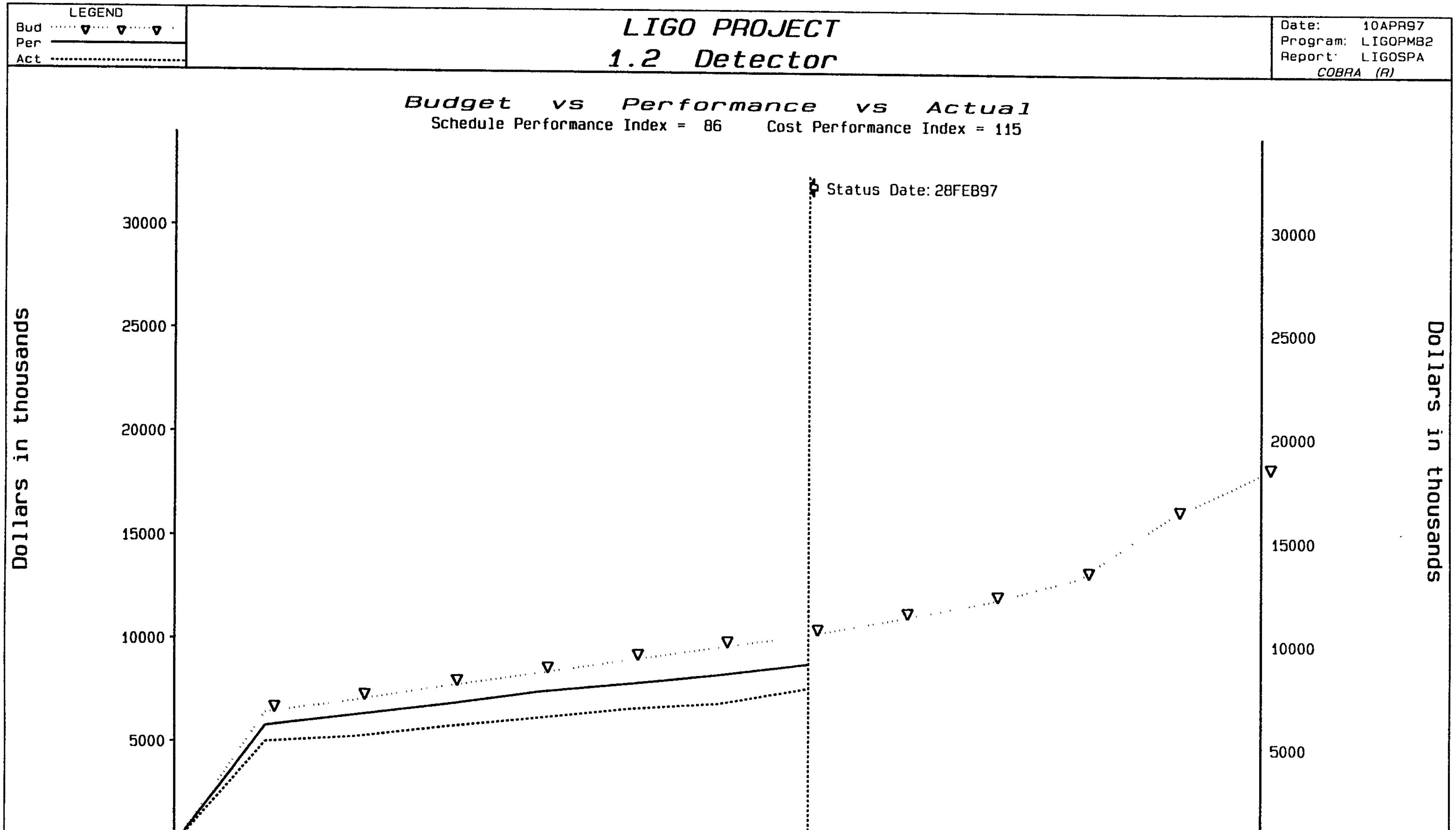
Activity Identification	Milestone Description	Plan Dates	Current Month End Status FEB-1997	Schedule Change
12009100	Award Contract for Nd:YAG Laser Development	Jun-96	May-96	Complete
12045020	PDR for Optics Suspension System	Jun-96	Jun-96	Complete
12033425	DRR II Alignment Sensing Control	Jun-96	Aug-96	Complete
12003020	Test of new Suspension Design on 40m	Jul-96	Aug-96	Complete
12039058	Award Contract for Core Optics Polishing	Dec-96	Oct-96	Complete
12085065	PDR for Global CDS	Jul-96	Sep-96	Complete
12039122	Demonstration of Coating Uniformity	Dec-96	Dec-96	Complete
13220442	Completion of PNI recycling experiments (with AR Laser)	Aug-96	Dec-96	Complete
12009020	Completion of Nd: YAG Master Oscillator Stabilization	Aug-96	Jan-97	Complete
12057020	PDR for Seismic Isolation Stacks	Jan-97	Feb-97	Complete
12033445	PDR for Alignment Sensing Control	Oct-96	Feb-97	Complete
12024075	PDR for Length Sensing Control	Oct-96	May-97	-153
13221935	First Operation of 40m with Recycling Mirror	Apr-97	May-97	-20
12012120	Nd:YAG LASER PDR	Apr-97	Apr-97	0
12062035	PDR for Data Acquisition System	Mar-97	May-97	-45

LIGO PROJECT
1.2 Detector

Date: 10APR97
Program: LIGOPMB2
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 86 Cost Performance Index = 115



	AUG96	SEP96	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	SCALE
Planned Budget	6,421	7,036	7,746	8,396	9,067	9,716	10,327	11,148	11,991	13,178	16,155	18,219	K$
Performance	5,780	6,322	6,869	7,486	7,921	8,379	8,928						K$
Actuals	5,011	5,269	5,791	6,231	6,710	6,991	7,752						K$
Schedule Variance	- 641	- 714	- 877	- 910	-1,146	-1,337	-1,399						K$
Cost Variance	769	1,053	1,078	1,255	1,211	1,388	1,176						K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index = Perf/Budg Cost Performance Index = Perf/Actual

Detector System Engineering: Progress and Status

- **Subsystem Requirements Document reviewed and consistent set of detector subsystem requirements adopted**
  - ››Confirms that requirements identified by individual subsystem leaders adequate for overall performance
  - ››Still some TBD's
    - — Nongaussian noise
    - — Parameters for 2 km interferometer
- **Definition of key detector-wide parameters**
  - ››Optical configuration, modulation frequencies, cavity lengths
  - ››Wedge angles and radii of curvature for Core Optics
  - ››Beginning work on optical/mechanical layout

Nd:YAG Laser: Lightwave Contract

- **Goal: Develop 10 W diode-pumped Nd:YAG laser suitable for LIGO**
  - ››Single Frequency
  - ››Diffraction-Limited, Single Transverse Mode
  - ››Intensity and Frequency Stabilization
- **Lightwave Electronics proposed 4-pass MOPA design (efficient use of diodes)**
  - ››Problems uncovered in 4-pass amplifier
  - ››Thermal depolarization gives intensity/spatial instabilities
- **Improvements in pump/laser geometry allow >10 W output in "practical" single and double pass configuration**
  - ››Preliminary measurements of beam quality promising
- **Preliminary Design Review - 4/25**

Nd:YAG Laser:
NPRO Stabilization

- **In-house effort to stabilize Lightwave NPRO for use on PNI and 40 m interferometers**
  - ››Lightwave design uses commercial 700 mW NPRO laser as Master Oscillator
  - ››Experience will be directly applicable to 10W laser
- **Frequency stabilization meets LIGO req't**

$$\delta\nu \leq 10^{-2}\ \mathrm{Hz}/\sqrt{\mathrm{Hz}}$$

  - ››Inferred from error point in servo
- **Intensity stabilization near LIGO req't**

$$\frac{\Delta I}{I} \leq 4\times10^{-8}/\sqrt{\mathrm{Hz}}$$

  - ››Intensity stabilization gain reduced by relaxation oscillation suppression circuit in NPRO
- **Prototype delivered to PNI for IR conversion and further testing**

Input Optics:
Progress and Status

- **Collaboration established with University of Florida, with UF group taking responsibility for Input Optics**
- **Conceptual design review held 11/7/96**
- **Optical layout of in-vacuum components underway**
- **Prototyping of scheme for applying multifrequency modulation underway (experiments performed at Caltech by UF scientist)**
- **Optical design of mode-matching telescope underway**
  - ››Independent adjustment of waist size and position
- **Interfaces to ASC and LSC outlined**

Core Optics: Procurement Status

- **Fused silica blanks for core optics**
  - ››Corning (21 ordered): 17 delivered
  - ››Heraeus (18 ordered): First delivery scheduled for July
- **Polishing contracts placed with General Optics and CSIRO**
  - ››General Optics (8 ETM's): 4 in final polish
  - ››CSIRO (20 Optics): 4 in final polish
  - ››12 Input Test Masses still to be awarded
- **Single layer coating uniformity meets LIGO requirements**
  - ››Ta_2O_5, SiO_2 sensitive coatings tested and results analyzed using FFT program
  - ›› Tooling for coating full-sized LIGO optics fabricated at REO and first Pathfinder optic coated for testing at NIST

Core Optics Support: Progress and Status

- **Responsible for:**
  - ››Telescopes and beam steering optics to extract light for LSC/ASC from vacuum system
  - ››Baffles and beamdumps in vacuum chambers
- **Subsystem requirements and conceptual design reviewed - 4/4/97**
- **Identified most important scattered light paths in the vacuum chambers**
  - ››Most important appears to be antisymmetric port light scattered back into interferometer from photodetectors
  - ››Requires some care, but no showstoppers

Suspensions: Prototype Testing

- **Small Optics Suspension**
  - Designed for mode cleaner mirrors, other small components
  - Prototype fabricated, bench testing complete
  - Installed in 40 m interferometer for performance testing inside servoloop, under low noise conditions
- **Large Optics Suspension**
  - Designed for Core Optics (two variants: test masses, beamsplitter)
  - Prototype mechanical fabrication complete
  - Testing underway
    - Frequencies of suspension tower vibrational modes matched to model
    - Tests of static alignment control/reproducibility underway
    - Electronics breadboards for testing different approaches to range/noise trade-offs

Seismic Isolation: Preliminary Design

- **Preliminary Design Review held 3/5/97**
  - ››HYTEC authorized to initiate final design of seismic isolation system
- **Tests of constrained-layer-damped metal springs promising**
  - ››Practical fabrication techniques developed
  - ››Fairly good agreement with modeled performance
    - Load capacity, stiffness, damping
    - Further test planned for acoustic transmission, creak
- **Final design/fabrication plan reworked (using vendor estimates of fabrication times) to include first article fabrication**
  - ››Q of stack resonances with constrained layer springs
  - ››Actuators for compensation of tidal motion (~200 µm) and microseismic peak (0.15 Hz)
  - ››Cost

Alignment Sensing & Control: Progress and Status

- **Preliminary Design Review held 2/97**
- **FMI experiment confirms model used for wavefront sensor signals**
- **Preliminary servo designs meet range, noise reduction requirements**
- **Significant progress on practical aspects of optical levers, initial alignment**
- **Plan for prototype test of ASC hardware/ software developed**
  - »Will be based on modecleaner alignment system
  - »First alignment system needed for installation
  - »Tests key aspects of ASC system

Length Sensing & Control: Progress and Status

- **Significant information gained from R&D efforts (LSC most closely linked to R&D)**
- **Progress slower than planned**
  - ››Sharing of staff with 40 m and PNI
  - ››Scope of work underestimated in original detector plan
- **Preliminary Design Review planned 5/97**
- **Full nonlinear optical response model completed for use in lock acquisition studies**
- **Significant new insights into the locking process**
  - ››Importance of signals in partially-locked states
  - ››Recombined 40 m giving testbed for strategies developed by model
- **Promising results on linearity/power handling capability of InGaAs photodiodes**

Control & Data System: Progress and Status

- **Procurement of CDS infrastructure for WA site (racks, VME crates, etc.) underway**
- **Prototype data acquisition system being installed for test on 40 m**
  - ››PDR for data acquisition planned for 5/97
- **Prototyping and testing in support of R&D and detector development**
  - ››40 m Recycling
  - ››Suspension prototypes
  - ››NPRO stabilization
- **Preliminary design of ASC electronics underway**
- **Preliminary design of data acquisition for Physics Environment Monitoring system underway**

Control & Data System: Vacuum Control and Monitoring

- **Interfaces to PSI-provided Vacuum Equipment to give user interface/control/ data logging**
- **Final Design Review held 12/96**
- **Rack wiring in progress and being shipped to Hanford**
- **Software development group established at Hanford with VCM system as first task**
  - ››Important first step toward establishing on-site networking infrastructure

Summary

- **Good progress on detector design and prototyping activities**
  - ~1/2 of detector subsystems have completed preliminary design reviews
- **SEW opinion: Technical challenges about where expected**
  - Good progress on lock acquisition, but not yet “nailed”
  - Core optics tolerances very tight, will require continued vigilance
  - Electronics dynamic range req’ts need continued attention
- **Some detector milestones have slipped, but have maintained schedule along critical path**

Data Acquisition System

- Requirements/Design Overview
- 40M Prototype DAQ System
- Next 6 Months

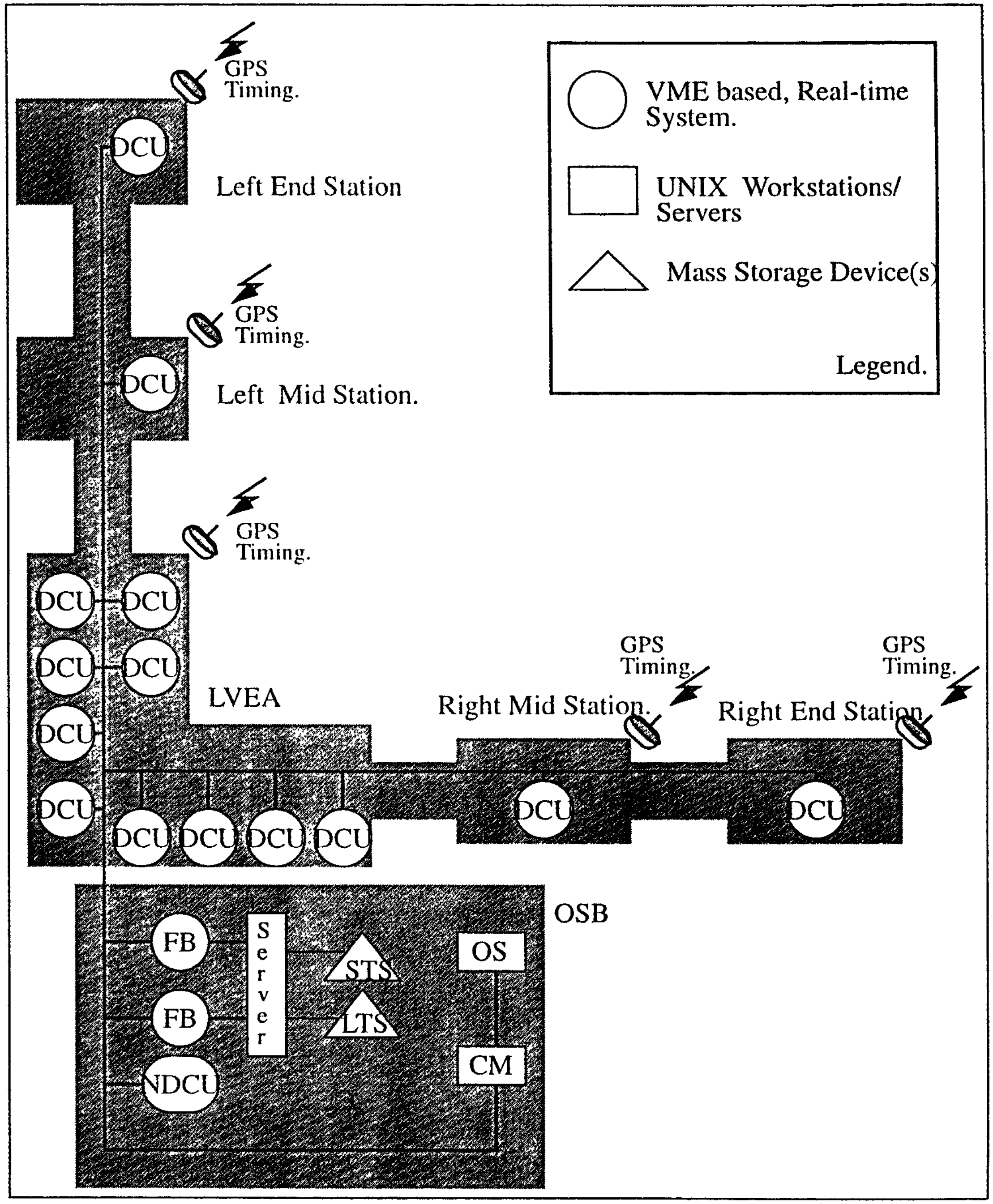
DAQ Data Channels/Rates

Interferometer Data Channels and Rates

System	*Number of Channels/Sample Rate* 2 Hz	256 Hz	2048 Hz	16384 Hz	*Total*
Sensitive Component Suspension	120	90	30	60	300
Prestabilized Laser	20	10	5	8	43
Mode Cleaner	30	20	10	20	80
Injection Optics	20	15	5	10	50
Interferometer Readout	20	15	0	30	65
Auto Alignment	20	15	0	0	35
Total Acquisition Channels/IFO	230	165	50	128	573
Total Data Rates (KBytes/sec)/IFO	0.9	84.5	204.8	4194.3	4484.5
PEM & Vacuum / Site (KBytes/sec)					500

Hanford DAQS Layout

- **VME Based Data Collection Units (DCU) in the VE areas**
  - ›› 16bit ADC modules
  - ›› GPS Timing Clocks
  - ›› Reflected Memory Networks (30MByte/sec)
- **VME Based FrameBuilders**
  - ›› Format data into LIGO/VIRGO standard data formats
- **Short and Long Term storage devices**

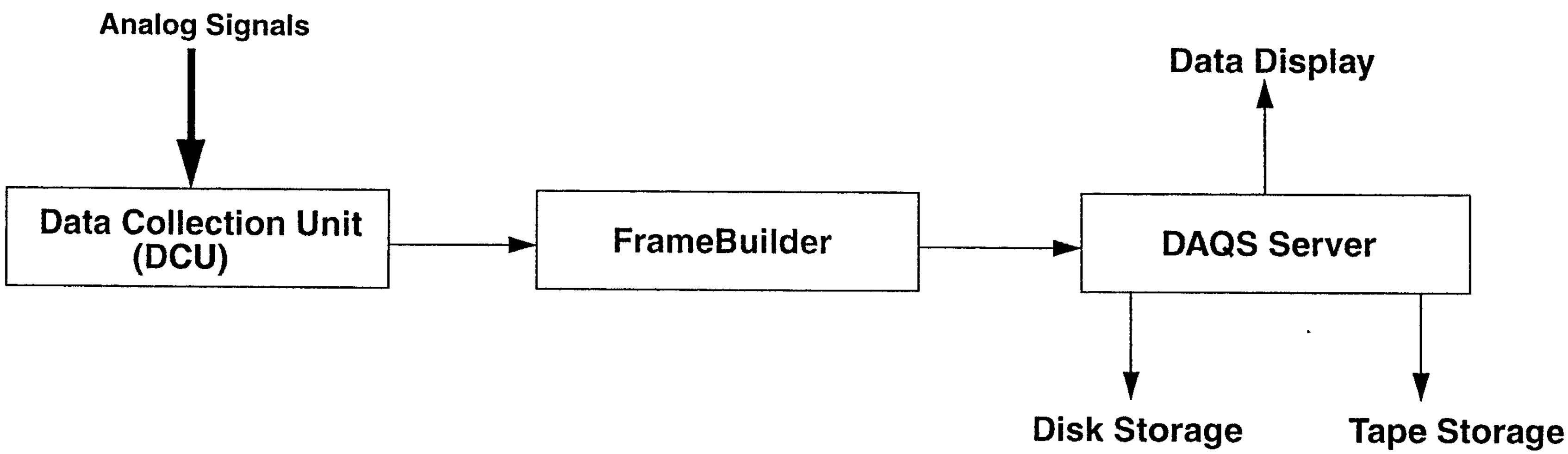


LIGO

40m DAQS Prototype

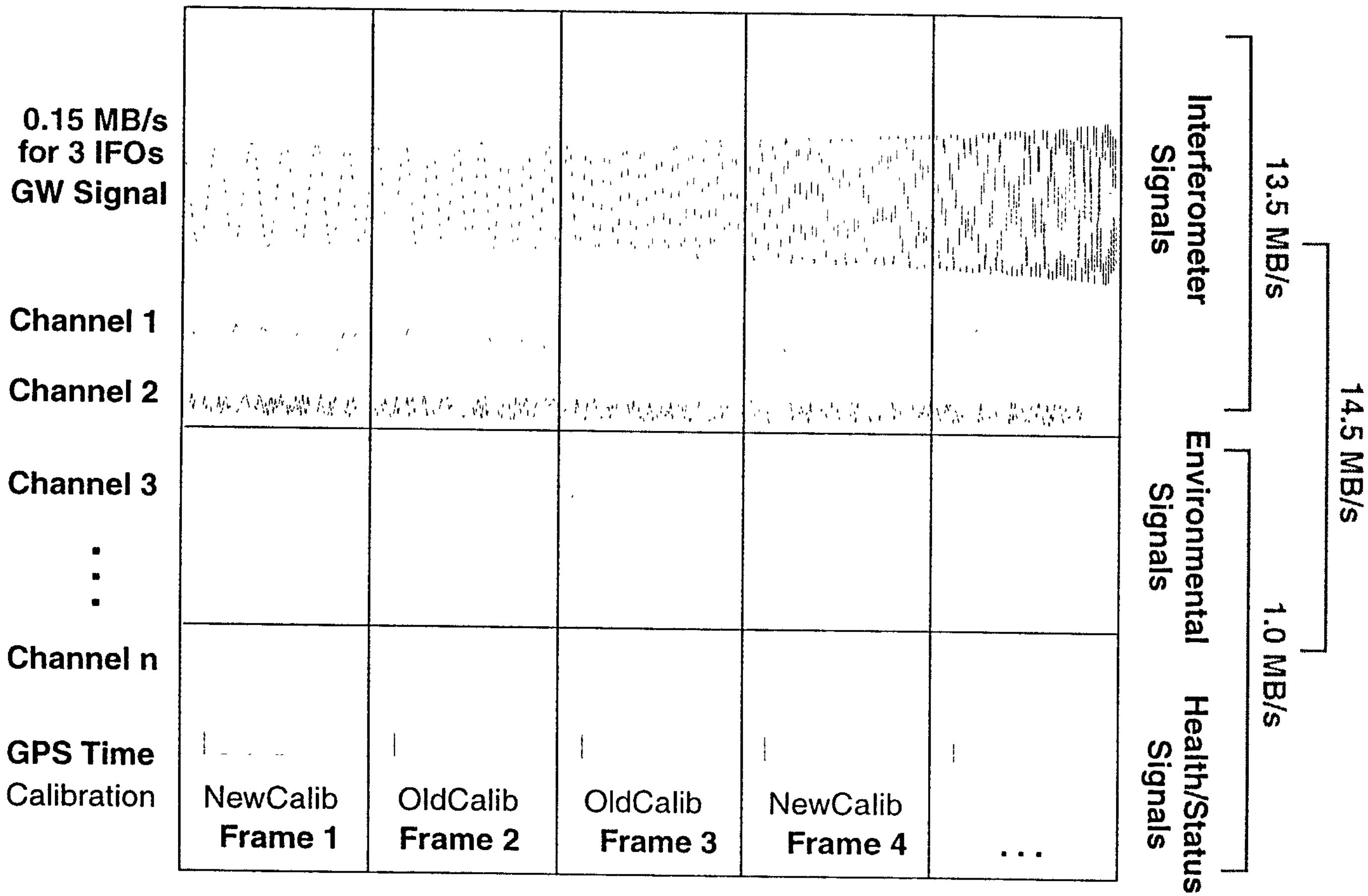
- Goals
  - ›› Verify conceptual design
  - ›› Provide test system for hardware/software
  - ›› Provide base for integrating analysis software
  - ›› Provide users with an example to further define requirements
- Features included in initial release
  - ›› 32, 16 bit ADC channels with sampling rates of 16384 K samples/sec
  - ›› Integration of previously developed Slow Data Acq. system
  - ›› Digital networks to move data to a central framebuilder
  - ›› Framebuilding, using VIRGO defined frames and software library
  - ›› Data storage to disk and tape

DAQS Prototype Overview



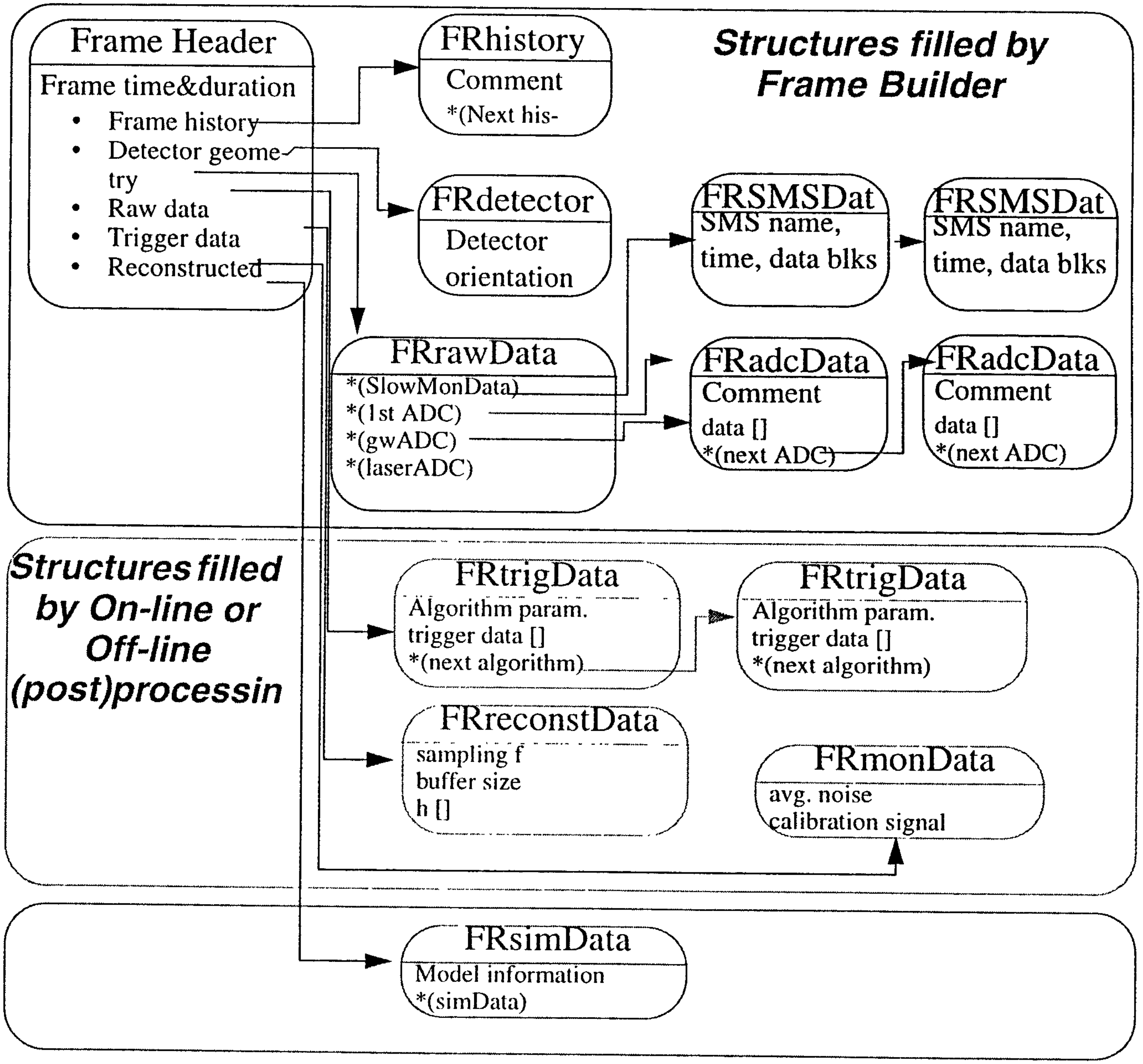
- **Data Collection Unit (DCU)**
  - Interfaces to and digitizes analog signals
  - 32 channels of 16bit ADC clocked at 16KHz; 128 channels of 12 bit ADC clocked at 16Hz
  - 30 MByte/sec optical network link to FrameBuilder
- **FrameBuilder**
  - Formats ADC data into 1 second data "frames"
  - Employs VIRGO developed frame software
  - Data link to DAQS server
- **DAQS Server**
  - Writes/Reads frames to disk and tape storage
  - Software provided for DAQS configuration and control; on line data display

DAQS Data Frames



DAQS Frame Structure

- **Frame has tree structure:**
- **Individual blocks are C structures**
- **Extensible to arbitrary length with design evolution**
- **Utilized for both on-line & off-line analyses**

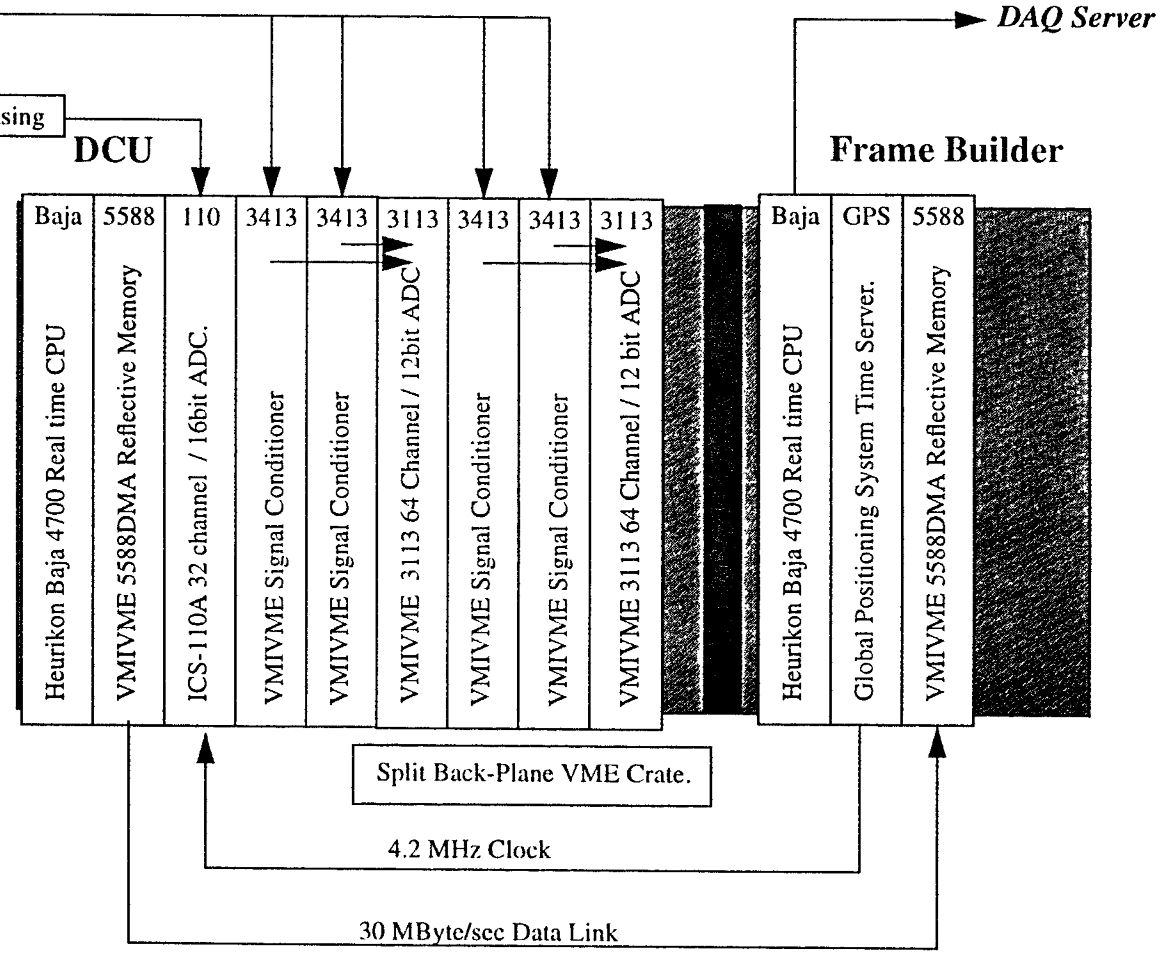


LIGO-G960000-00-M

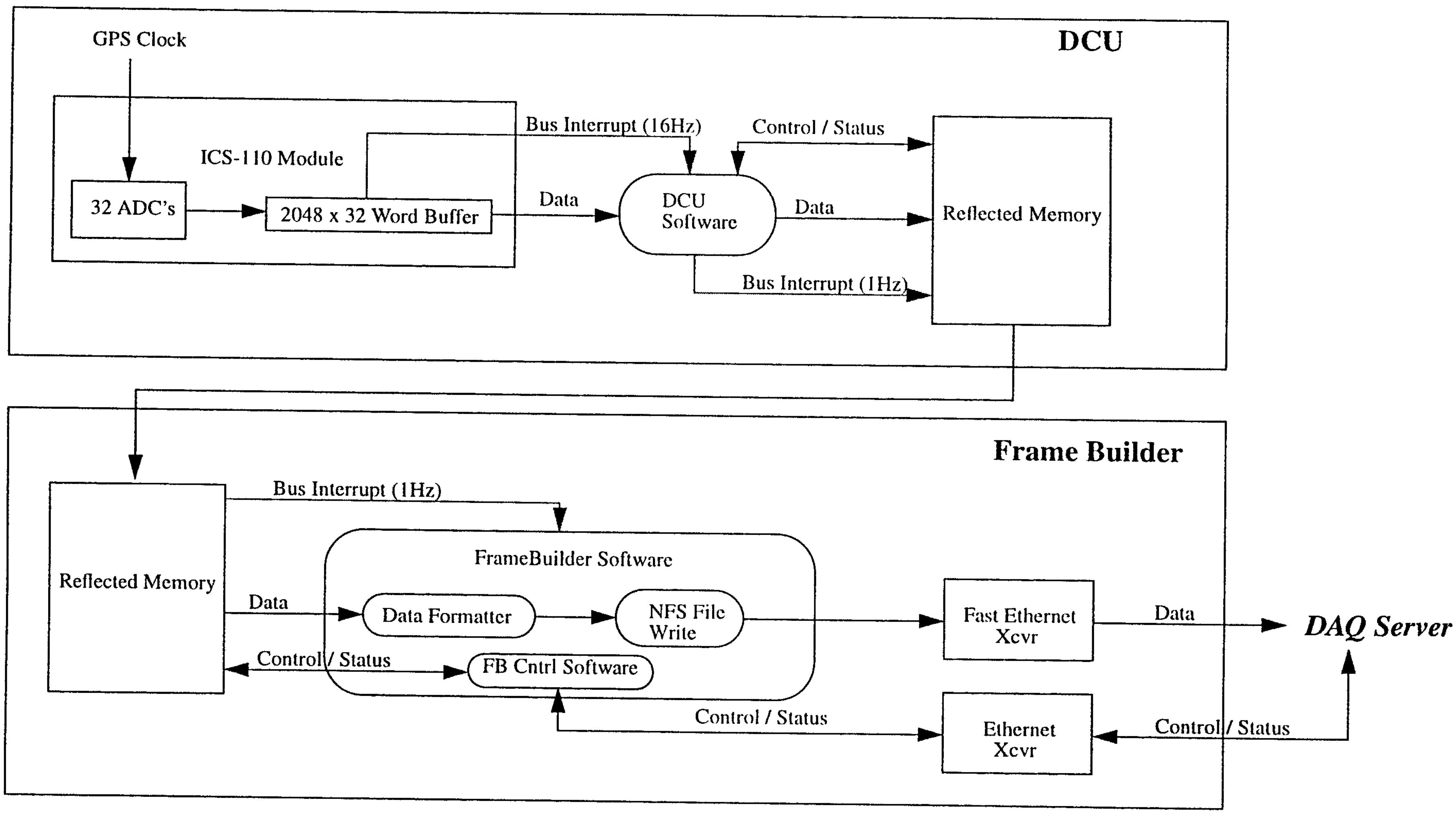
DCU/FrameBuilder Hardware

128 "Slow" Data Channels (16Hz)

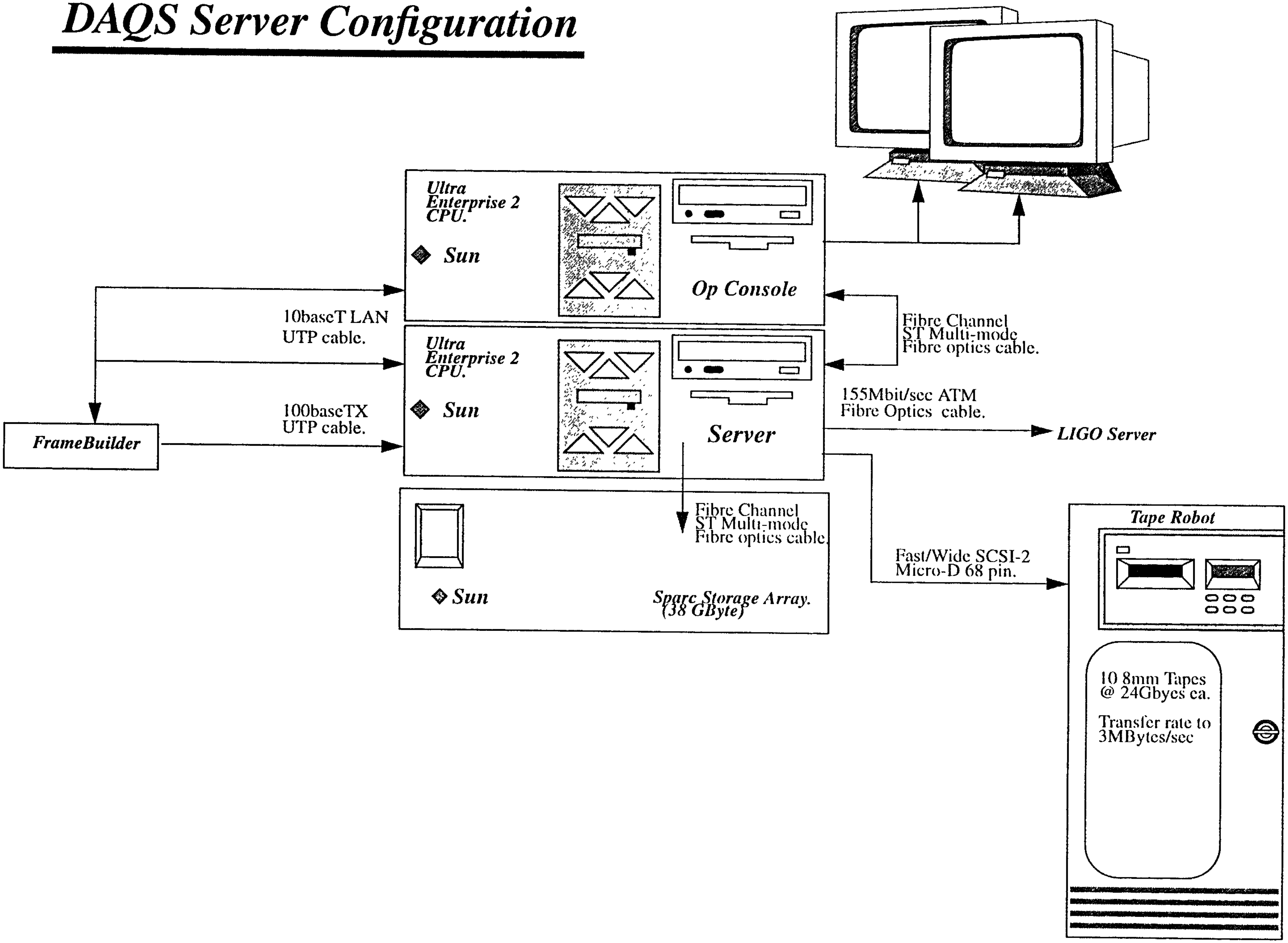
32 "Fast" Data Channels (16KHz):
- Differential-Mode Readout
- Common-Mode Readout
- Beam Splitter Readout
- Recycling Mirror Readout
- DC-Coupled Differential Mode
- PSL Slow PZT Feedback Signal
- Calibration Signal
- Mode Cleaner Transmitted Light
- East Arm Transmitted Light
- South Arm Transmitted Light
- Antisymmetric Port DC coupled Light
- Symmetric Port DC Coupled Light
- Magnetometer
- Seismometer
- Microphone



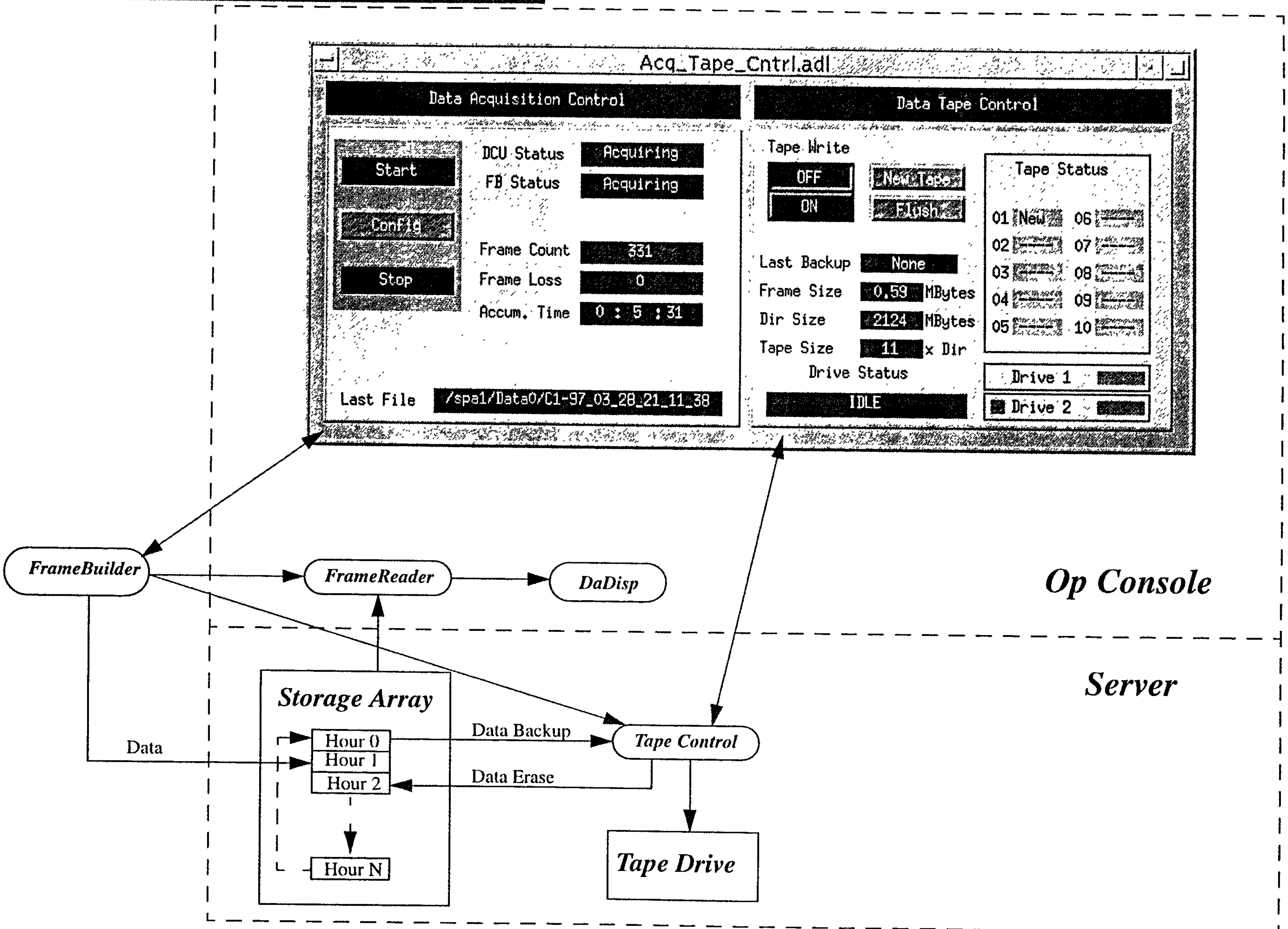
DCU/FrameBuilder Data Flow



DAQS Server Configuration

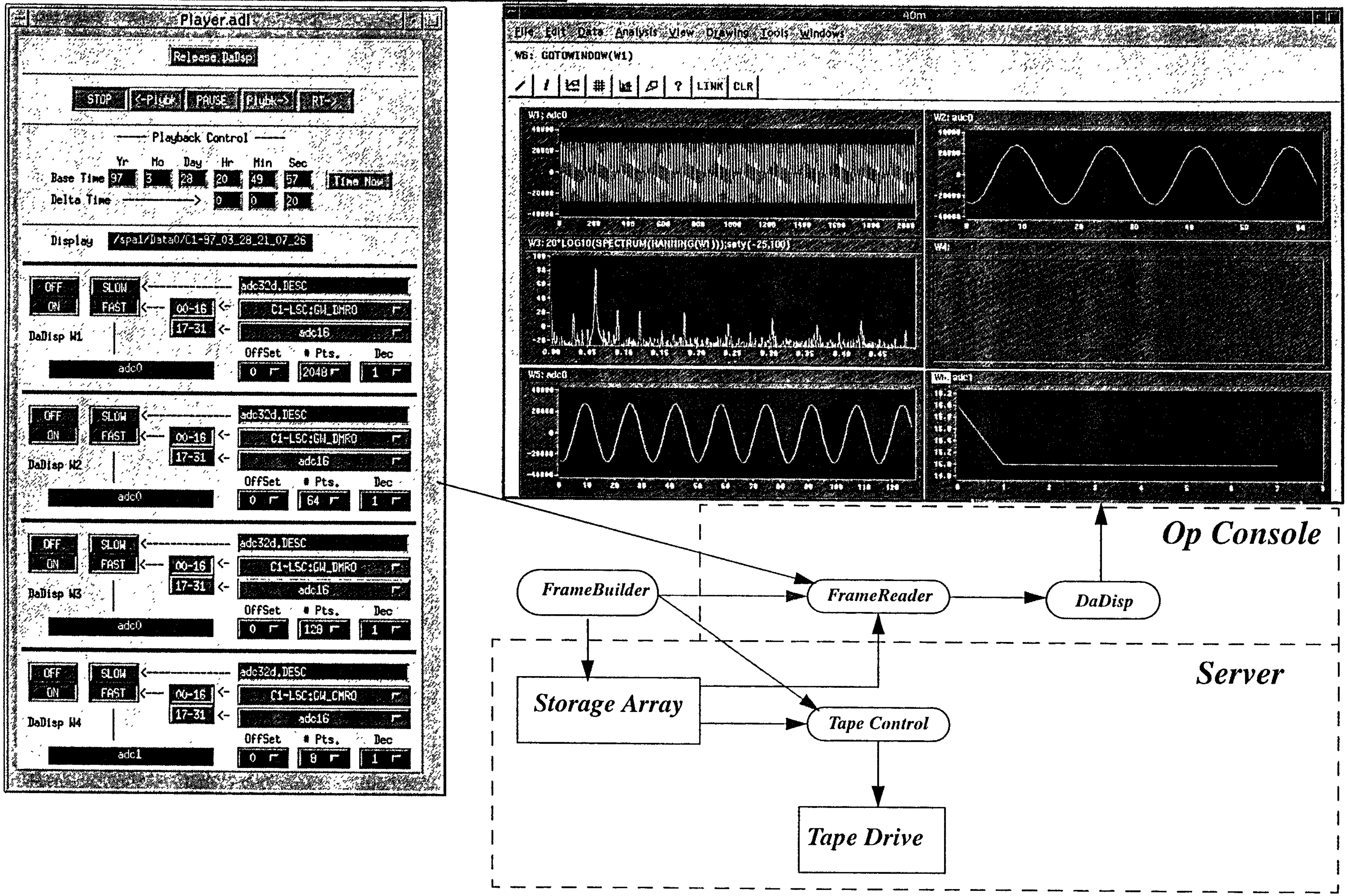


DAQS Control Software



LIGO-G960000-00-M

DAQS Data Display Software



DAQS Prototype Status

- System installed at 40m and initial testing begun.
- Measured throughput of ~1MByte/sec, limited by:
  - NFS write over Fast Ethernet (To be replaced by FC and client/server software and larger file sizes)
  - CYbernetics Accelerated File Access (CYAFA) write to tape
- Initial Frame libraries are functional, both read and write, with "real-time" connections to DaDsp and GRASP tested.

DAQS - Next 6 Months

- Run prototype with 40m system
    - ›› Integrate with On-Line Analysis software
    - ›› Link to Caltech supercomputing facility
    - ›› Add new GPS w/4.2MHz clock
    - ›› Integrate and test various ADC modules
- Continue meetings with VIRGO to finalize frame formats
- Conduct Preliminary Design Review (~May 22, 1997)
- Initiate Final Design and development of Rev. 1 software

LIGO DATA PROCESSING

NSF REVIEW

April 15th, 1997

James Kent Blackburn
LIGO Integration Group

OUTLINE

1) Plans for 40 Meter Data Analysis

a) Data Analysis background
b) On-line Analysis
c) Center for Advanced Computing Research (Off-line)
d) Gravitational Radiation Analysis & Simulation Package

2) Refined Data Flow Models for Initial LIGO Data Analysis

a) Estimated Data Rates & Channel Counts
b) Data Flow Diagram for Binary Inspiral Search
c) Data Flow Diagram for Periodic Source Search
d) Computational Requirements associated with b) & c)

Plans for 40 Meter Data Analysis

Data Analysis Background Info:

- *46 hours of data collected in November, 1994 of which 88.5% of the data is in lock*
- *13.5 hours of this data previously analyzed as part of thesis research*
- *49 Newtonian templates between 1.2 and 1.6 solar masses used as filters*
- *noise characterized using pulse height histograms*
- *data contained significant non-Gaussian events (some later determined to be software artifacts)*

\+ *reanalysis of data using current understanding to achieve higher signal sensitivity has begun*

On-line Analysis:

LIGO prototype data acquisition system installed at the 40 meter

- *This system will collect data from up to 32 fast channels and 128 slow channels*
- *The data will be stored in the pre-release Frame structure planned for LIGO and VIRGO*
- *DADisp is being used for quick look data display and simple signal processing*

High Speed ATM access to data over wide area

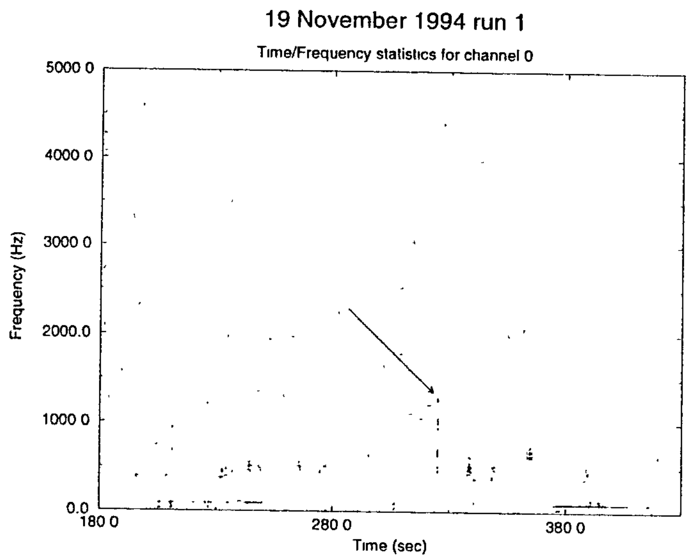
- *ATM backbone connecting 40 meter lab with LIGO general computing in place*
- *ATM connectivity to the Center for Advanced Computing Research in the works*

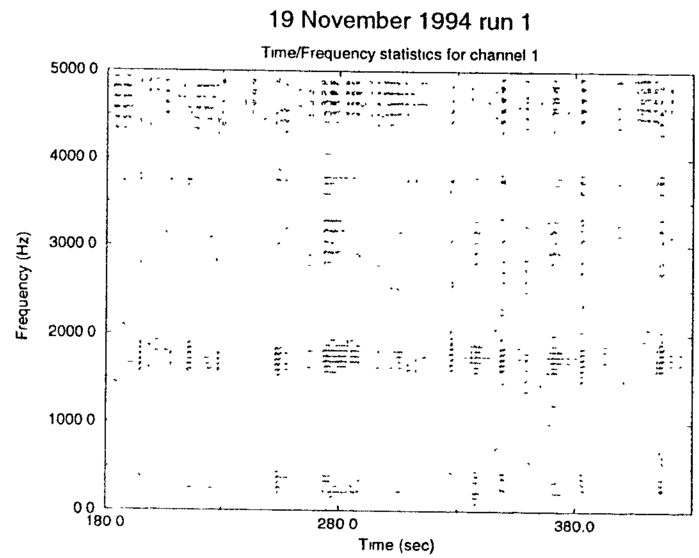
New algorithms and filtering techniques for characterizing the noise

- *time-frequency "carpets" of the running power spectrum*
- *multi-taper methods for tracking narrow lines*
- *2PN binary inspiral template for optimal filtering*

Plans for 40 Meter Data Analysis

On-line Analysis: *(Time-Frequency Method)*

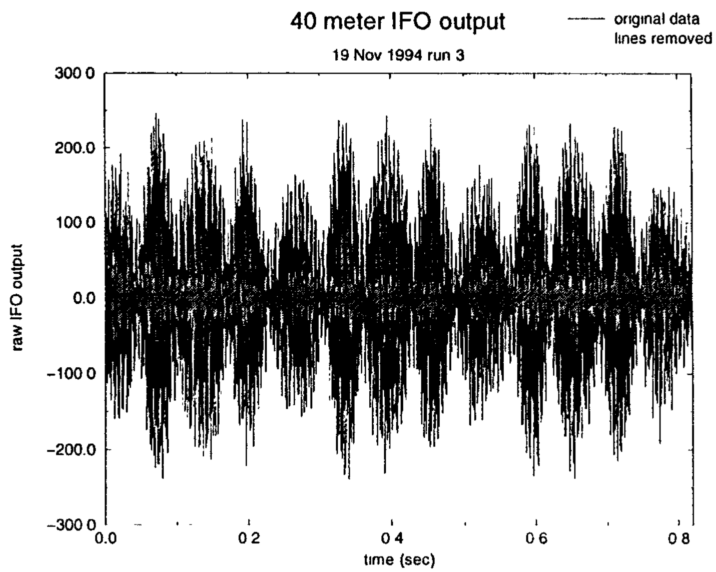


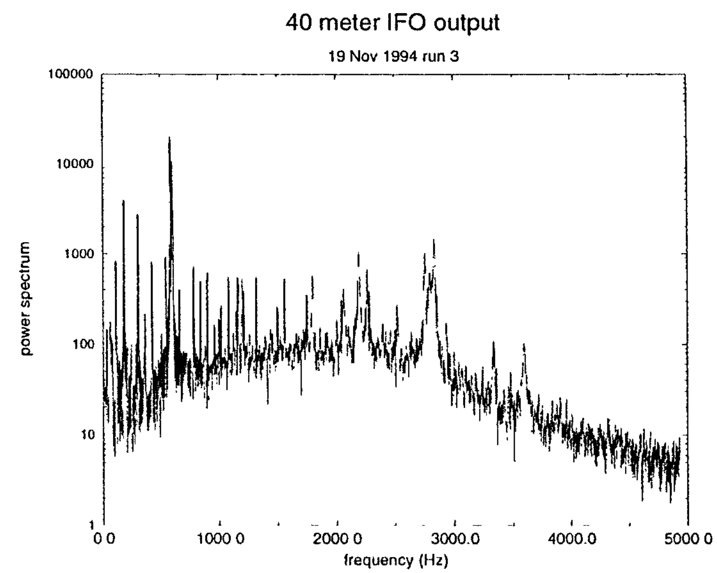


- Gravitational wave channel on left
- Coincident magnetometer channel on right
- Exponentially wieghted running power spectrum
- Provides detector diagnostics
- Allows non-Gaussian noise characterization

Plans for 40 Meter Data Analysis

On-line Analysis: *(Multi-Taper Methods)*

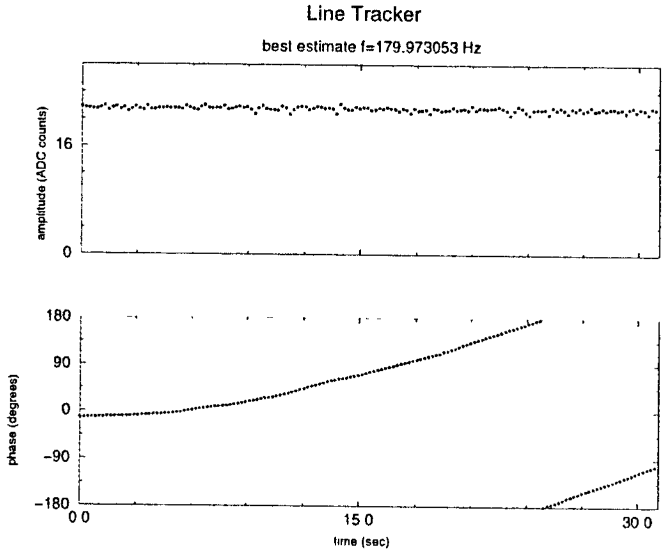


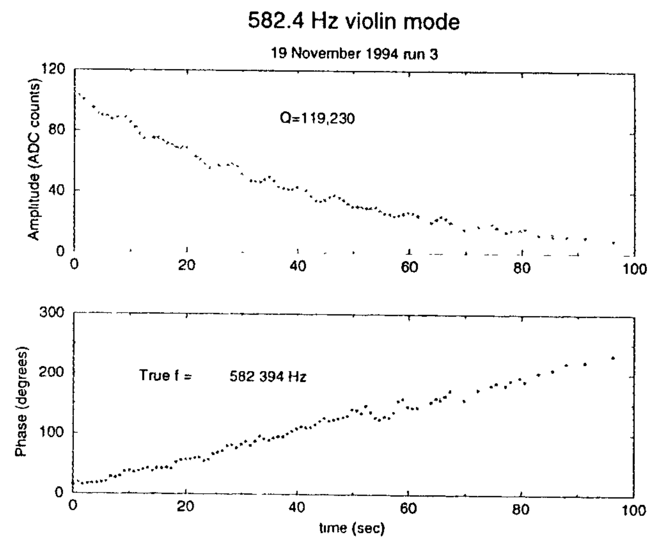


- **Uses multiple sets of special windows called Slepians**
- **39 narrow lines identified and removed in the red plots**
- **Provides better spectral estimation**
- **Provides spectral line parameter estimation and removal**
- **30% improvement in signal to noise ratio after lines removed**

Plans for 40 Meter Data Analysis

On-line Analysis: *(Multi-Taper Methods, cont.)*



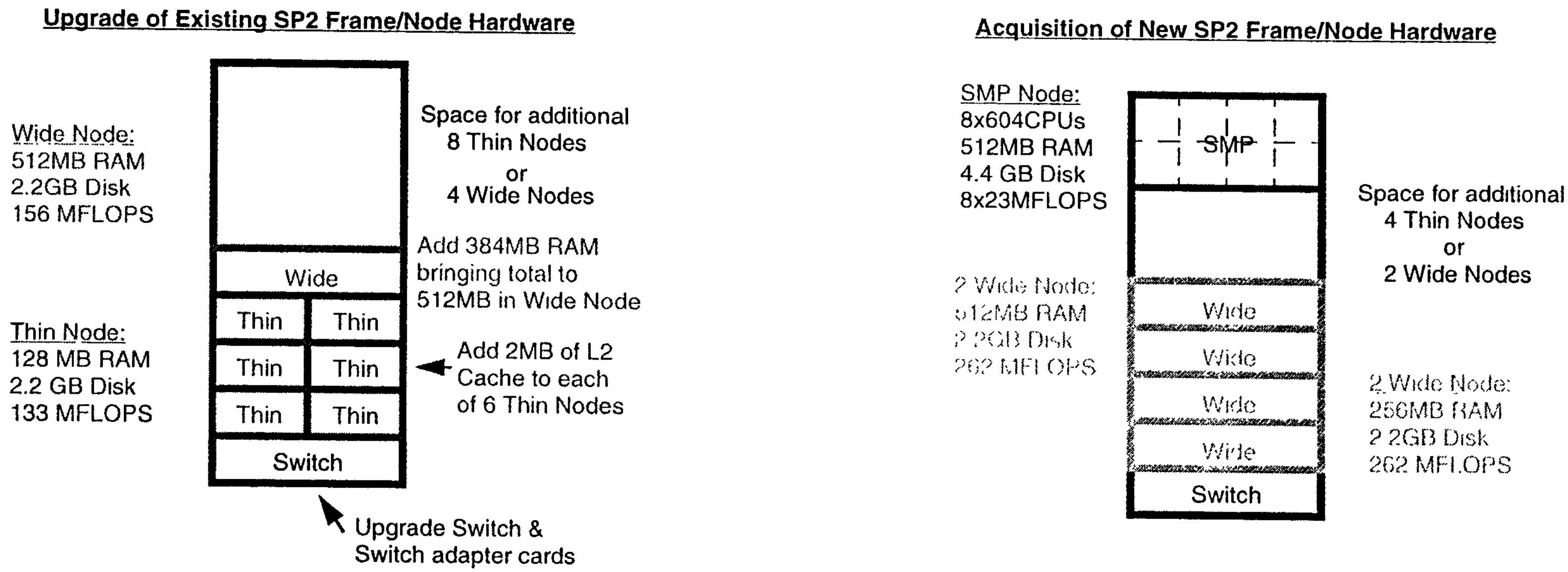


- **Useful as a diagnostic tool**
- **Allows track of narrow lines**
- **Using UltraSparcs1 workstation, line can easily be tracked in real time**

Plans for 40 Meter Data Analysis

Center for Advanced Computing Research (Off-line):

IBM SP2 Scalable Parallel Computer Hardware (SUR Award)



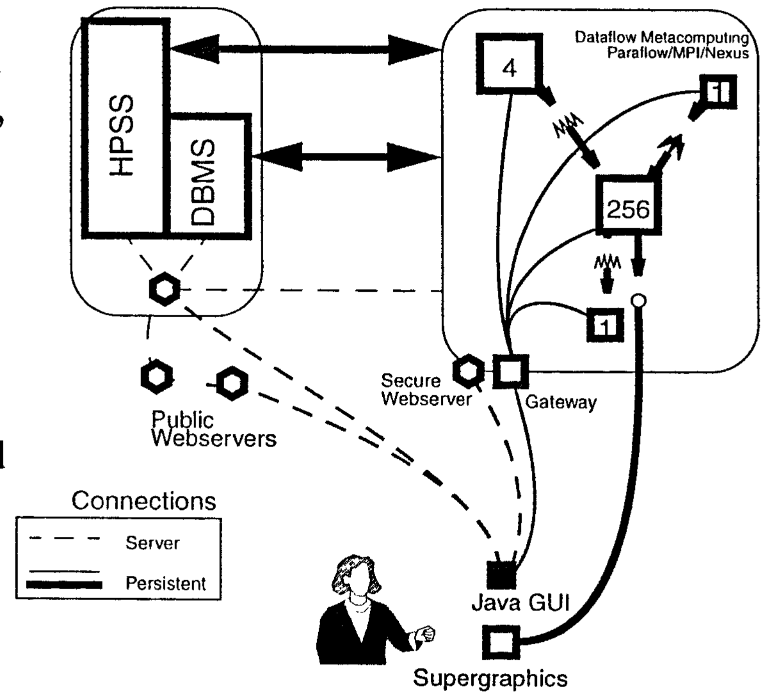
- New hardware arrived the first week of January, 1997'
- Current configuration consists of 12 nodes capable of 2,186 MFLOPS
- System presently operational and in verification phase
- Minimal mass in binary search for one LIGO data stream: 1.34 solar masses
- Preliminary 40 meter data analysis for binary inspiral has begun using GRASP
- Other resources at the CACR include 15 TB tape robot and 512 node Paragon

Plans for 40 Meter Data Analysis

Center for Advanced Computing Research (Off-line):

PARAFLOW: A Dataflow Distributed Data-Computing System

- Developed by Roy Williams & Bruce Sears, CACR
- Prototype based on MPICH, includes Users Guide, http://www.cacr.caltech.edu/~roy/paraflow
- Combines heterogeneous computing resources into a flexible efficient data-mining metacomputer
- Three levels of parallelism provided:
  - functional parallelism in dataflow paradigm
  - each service can be a parallel program
  - each node of the service can be multithreaded
- easily integrated with web-computing
- meant to provide bridge between public browsing of data and high performance computing



Plans for 40 Meter Data Analysis

Gravitational Radiation Analysis & Simulation Package (GRASP):

USERS MANUAL

GRASP: a data analysis package for gravitational wave detection

Bruce Allen*
Department of Physics
University of Wisconsin - Milwaukee
PO Box 413
Milwaukee WI 53201, USA

March 31, 1997

Abstract

GRASP (Gravitational Radiation Analysis & Simulation Package) is a public-domain software tool kit designed for analysis and simulation of data from gravitational wave detectors. This users manual describes the use and features of this package.

GRASP RELEASE 1.0
manual version 1.0.2

*ballen@dirac.phys.uwm.edu

1

- Developed by Bruce Allen
- Software Toolkit w/ Library & Examples
- User's Manual currently over 200 pages
- Binary Inspiral Search implemented
- 2PN templates/spacing based on $S_N(f)$
- Optimal filtering uses MPI
- Stochastic Background search implemented
- Diagnostic tools: time-freq., multi-taper
- Plans for Periodic and Supernovae searches
- Primary testbed has been Nov. 94 40 meter
- Handles data calibration
- I/O to data based on Frames implemented
- Software developed in C language
- Under CVS software management

Plans for 40 Meter Data Analysis

Gravitational Radiation Analysis & Simulation Package (GRASP):

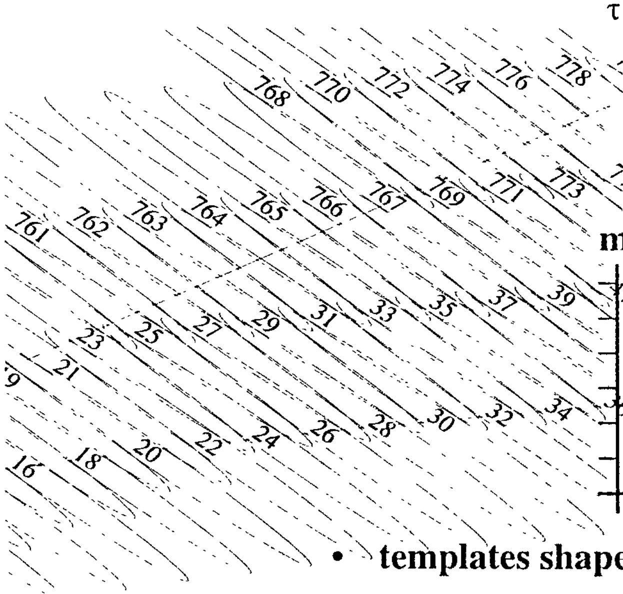
Binary Inspiral Template Spacing

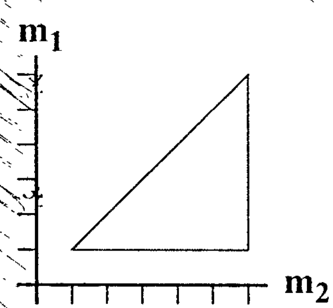
$$\tau_0 = \frac{5}{256} \cdot \left(\frac{G \cdot M}{c^3}\right)^{-5/3} \cdot \eta^{-1} \cdot (\pi \cdot f_o)^{-8/3}$$

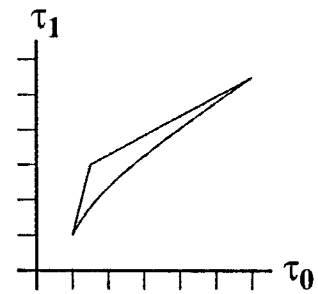
$$\tau_1 = \frac{5}{192} \cdot \left(\frac{c^3}{G \cdot \eta \cdot M}\right) \cdot \left(\frac{743}{336} + \frac{11}{4} \cdot \eta\right) \cdot (\pi \cdot f_o)^{-2}$$

$$M \equiv m_1 + m_2$$

$$\eta \equiv \frac{m_1 \cdot m_2}{(m_1 + m_2)^2}$$





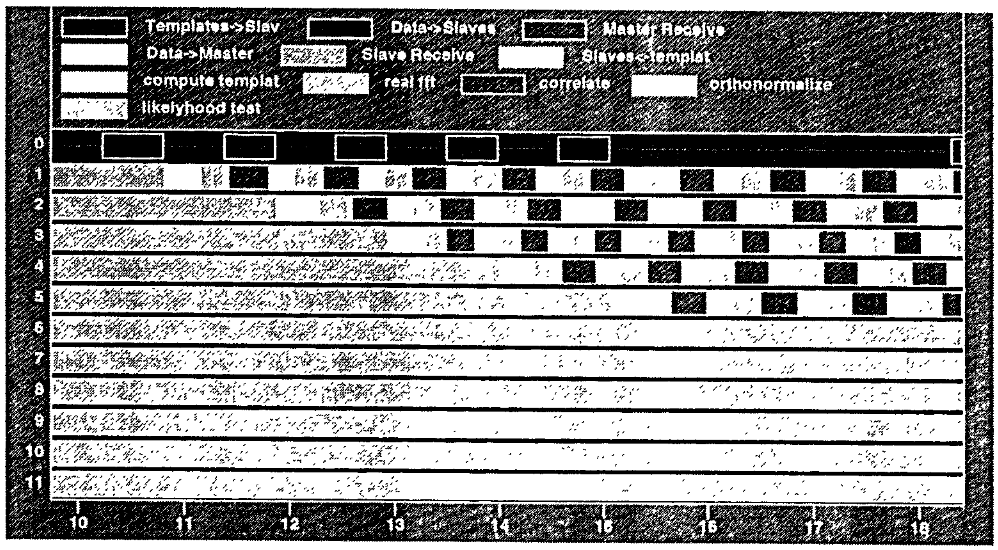


- **templates shaped like ellipses in the coordinates of (τ_1,τ_2)**
- **size and orientation determined by shape of detector noise**
- **location determined by desired ambiguity (~3%used in figure)**
- **Nov. 94 40 meter data needs 403 templates, 0.8 <= (m_1,m_2) <= 50 M_{sun}**

Plans for 40 Meter Data Analysis

Gravitational Radiation Analysis & Simulation Package (GRASP):

Binary Inspiral Optimal Filtering using MPI



- optimal filtering code uses the Message Passing Interface (MPI)
- MPI provides portability, code tested on SUNs, Paragon and SP2
- each node analyzing different date with full template bank used on each node
- templates can either be stored and read back or recomputed as needed
- spanning 1.2 -> 1.6 solar mass, templates for the Nov. 1994 data needs 66 templates
- 5 hours of 40 meter filtered by 66 template in 10.3 minutes using 256 nodes on Paragon

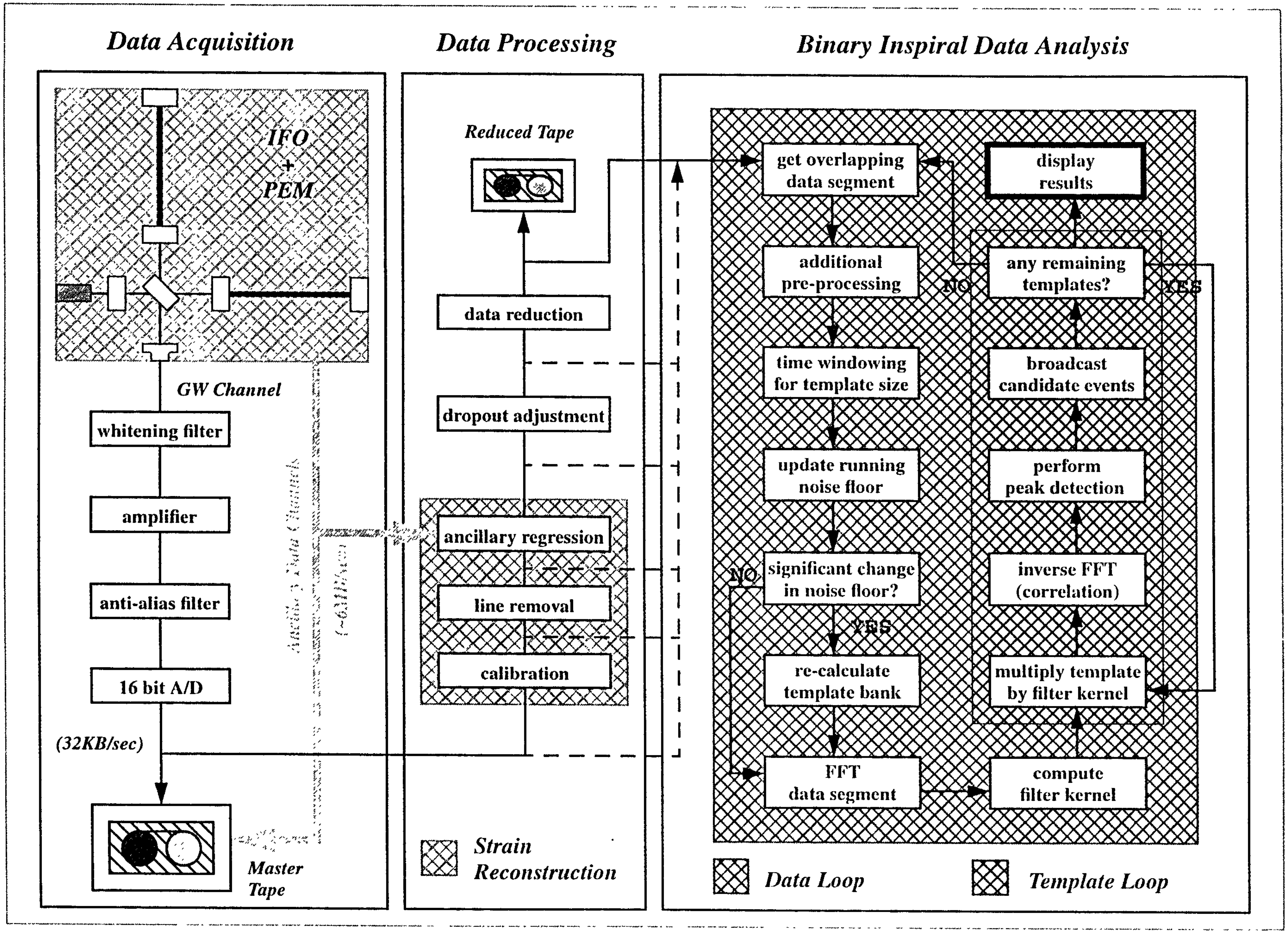
Refined Data Flow Models for Initial LIGO Data Analysis

Estimated Data Rates & Channel Counts:

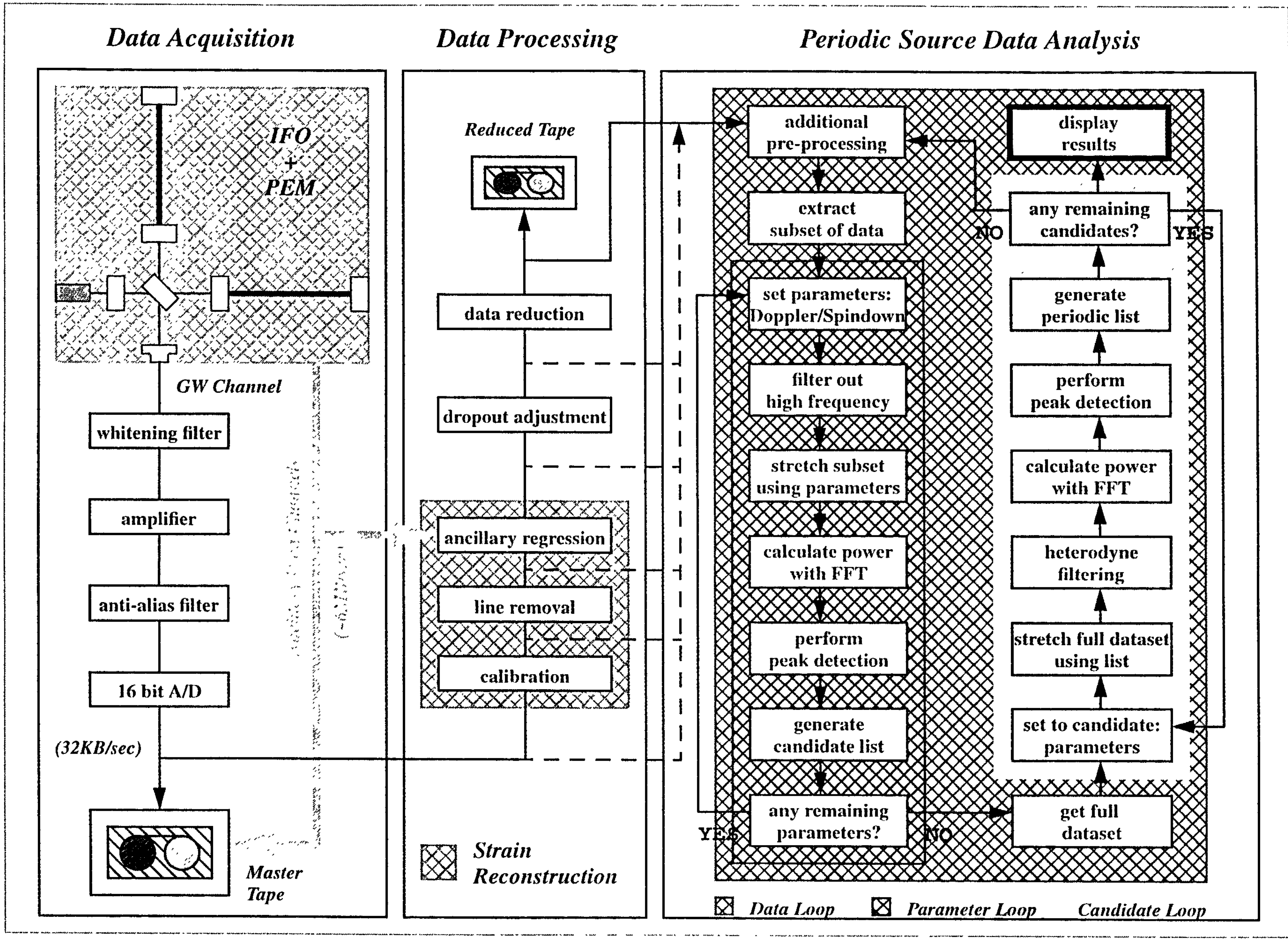
Estimates of LIGO IFO and PEM channel counts and sampling rates

System	2 Hz	256 Hz	2048 KHz	16384 KHz	Total (KHz)
Suspension	120	90	30	60	300
Prestablized Laser	20	10	5	8	43
Mode Cleaner	30	20	10	20	80
Injection Optics	20	15	5	10	50
IFO Readout	20	15	0	30	65
Auto Alignment	20	15	0	0	35
Channels/IFO	230	165	50	128	573
KBytes/sec/IFO	0.9	84.5	204.8	4194.3	4484.5
Auxiliary	0	200	10	30	240
Housekeeping	300	50	20	0	370
Channels/site	300	250	30	30	610
KBytes/sec/site	1.2	128	122.9	983.0	1235.1

- roughly 3600 channels total for LIGO
- sampling rates ranging from 2 to 16384 samples per second
- approximately 5 megabytes per second per IFO
- yearly data rate of $5.02 \times 10^{+14}$ bytes for three interferometers
- 50 gigabyte tapes requires 10,000 tapes to record the raw data (*no duplicates*)



Data Acquisition
Data Processing
Binary Inspiral Data Analysis
IFO + PEM
GW Channel
whitening filter
amplifier
anti-alias filter
16 bit A/D
(32KB/sec)
Master Tape
Reduced Tape
data reduction
dropout adjustment
ancillary regression
line removal
calibration
Strain Reconstruction
get overlapping data segment
additional pre-processing
time windowing for template size
update running noise floor
significant change in noise floor?
NO
YES
re-calculate template bank
FFT data segment
compute filter kernel
multiply template by filter kernel
inverse FFT (correlation)
perform peak detection
broadcast candidate events
any remaining templates?
NO
YES
display results
Data Loop
Template Loop

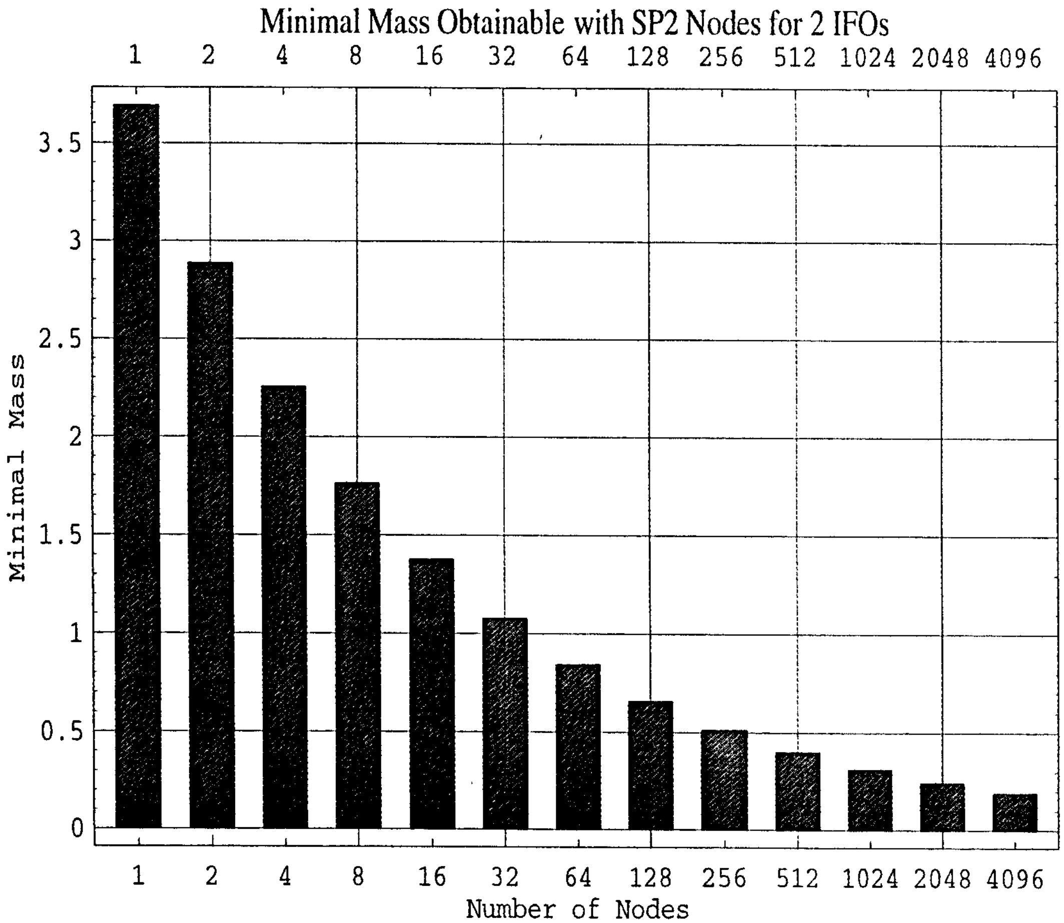


Data Acquisition
Data Processing
Periodic Source Data Analysis
IFO
+
PEM
GW Channel
whitening filter
amplifier
anti-alias filter
16 bit A/D
(32KB/sec)
Master
Tape
Reduced Tape
data reduction
dropout adjustment
ancillary regression
line removal
calibration
Strain
Reconstruction
additional
pre-processing
extract
subset of data
set parameters:
Doppler/Spindown
filter out
high frequency
stretch subset
using parameters
calculate power
with FFT
perform
peak detection
generate
candidate list
any remaining
parameters?
YES
NO
get full
dataset
set to candidate:
parameters
stretch full dataset
using list
heterodyne
filtering
calculate power
with FFT
perform
peak detection
generate
periodic list
any remaining
candidates?
NO
YES
display
results
Data Loop
Parameter Loop
Candidate Loop

Refined Data Flow Models for Initial LIGO Data Analysis

Estimated Computing Requirements for Binary Inspiral Search:

Compute Model for Hanford Binary Search based on IBM SP2 Hardware



Model Assumptions:

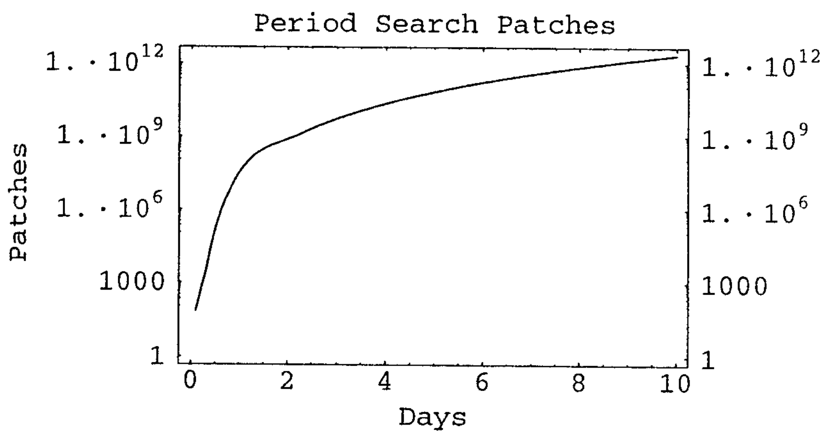
- 2 IFO data streams
- 2km IFO <=> 4km IFO
- 70% (235 MFLOPS per NODE)
- 256 MB RAM per NODE
- 32 MB RAM used by code
- 2GB HD per NODE
- FFT ~ $5N\log_2(N)$ "complex"
- 14 MB/s Xfer rates
- GW frequency < 2KHz
- Templates stored on HD
- ~ $90K per NODE list price
- $N_t = 7592(0.1/\text{loss})\,(M_{min})^{-2.7}$

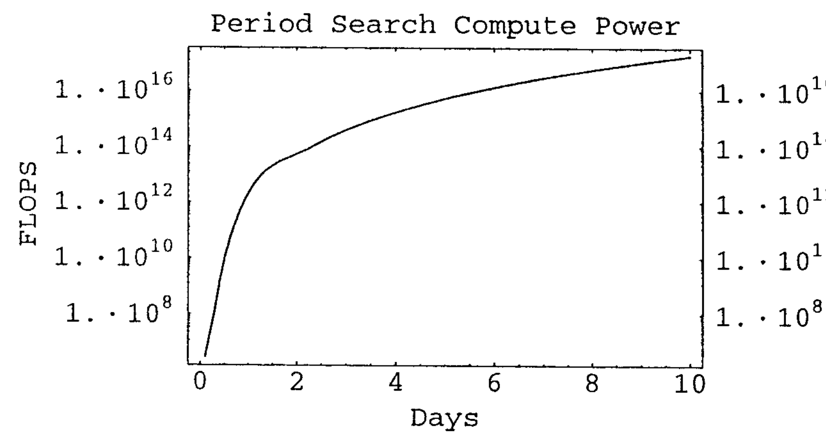
Model Predictions:

- Analysis is CPU limited!
- FFT & IFFT drive CPU usage!
- optimal padding => $36xN_t$
- 16 NODEs = 1.4 M_{sun} = $1.4M
- 40 NODEs = 1.0 M_{sun} = $3.6M
- $P = 7186\,(M_{min})^{-2.806}$ MFLOPS

Refined Data Flow Models for Initial LIGO Data Analysis

Estimated Computing Requirements for Periodic Source Search:m





- maximum frequency to be searched set at 1000 Hz
- maximum patch mismatch with signal set at 0.3
- number of spindown parameter set at 3
- a coherent search of 10 days of data would require greater than 10^{+16} FLOPS to analyze in 10 days

With a teraflops computer the flowing reductions in the search become possible:

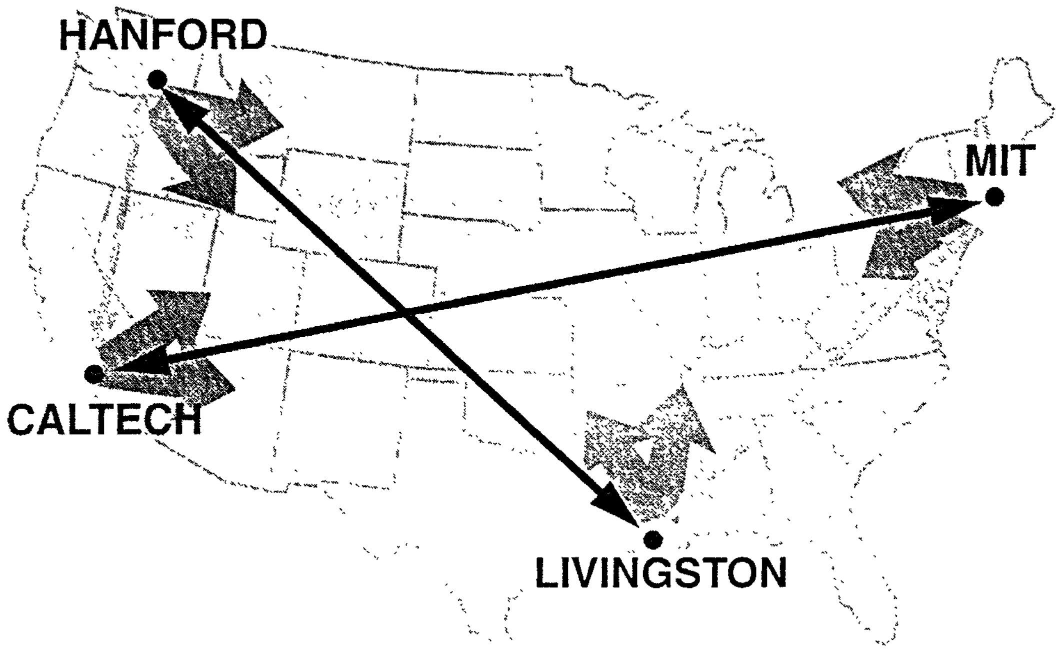
- 18 days coherently searched for gw with f<200 Hz and τ > 1000 years
- 0.8 days coherently searched for gw with f<1kHz and τ as low as 40 years
- directed searches increase observation times only by order of magnitude

LIGO Wide Area Network Development

Albert Lazzarini
LIGO Integration Group

NSF Review
15 - 17 April 1997

LIGO Site-to-site Communications
- Requirements -



- Hanford-Livingston link permits real-time cross-correlations among instruments
- Caltech-MIT link provides high speed link to data archives; data tapes to be archived at university.
- Site-University links provides site scientific staff access to archived data
- University/observatory gateways provide broader access to database
- Data tapes transported to Caltech (CACR) repository

Wide Area Network for the Initial LIGO
- Update -

- Hanford, WA
  - March meeting at Pacific Northwest National Laboratory (PNNL) to meet with Gerry Johnson, DOE
  - Exchanged information regarding DOE connections in Pacific Northwest and LIGO projected needs
    - ESNet hub is in computer sciences facility, Battelle.
    - Northwest net (formerly NSFNet) used as a backup (T1)
    - Precedent exists for providing NSF access to ESNet in Pacific Northwest: Washington State University
  - Johnson has begun pursuing access to ESNet for LIGO within DOE:
    - James Leighton (LBL/ESNet Mgr) - indicated DOE and NSF are working on several interagency cross-connects between ESNet and vBNS.
    - George Seweryniak (ESNet PM) thought access for LIGO a good idea, willing to pursue within DOE
    - Dan Hitchcock, Acting Director, MICS, hesitant - lack of DOE involvement in LIGO.
    - Mutual interest in improving Hanford<->Caltech connectivity - PNNL is a member of NPACI team -- needs access to CACR resources.
  - Existing DOE/NSF MOU providing Hanford land for LIGO also provides for access to LIGO of DOE telecommunications infrastructure.

Wide Area Network for the Initial LIGO
- Update -

- Livingston, LA
  - ›› January meeting at LSU with H. Eaton (Vice Chancellor, LSU) and C. Dodson (Director, LSU Computer Center) to initiate discussions.
    - LIGO Site Proposal to NSF by LA/LSU contains commitment to providing access to University (communications) infrastructure on an equal basis to resident faculty.
    - Commitment to provide near term access for LIGO construction activities through LSU Physics Dept. - in progress
    - LIGO obtaining access to telecommunications at site - connection via centrex in nearby technology center.
  - ›› Subsequent discussions with Dr. J. Drayer, Louisiana Board of Regents.
    - Louisiana developing a proposal to NSF for vBNS access in the state -- LaSERnet II
    - T3 ring within the state, linking to SEPSCoR (NSF) vBNS backbone to University of Kentucky->NCSA
    - LIGO to gain access via LSU
    - LIGO provided a letter of intent to use infrastructure.
  - ›› LSU has access to NASA T1 link to MSFC

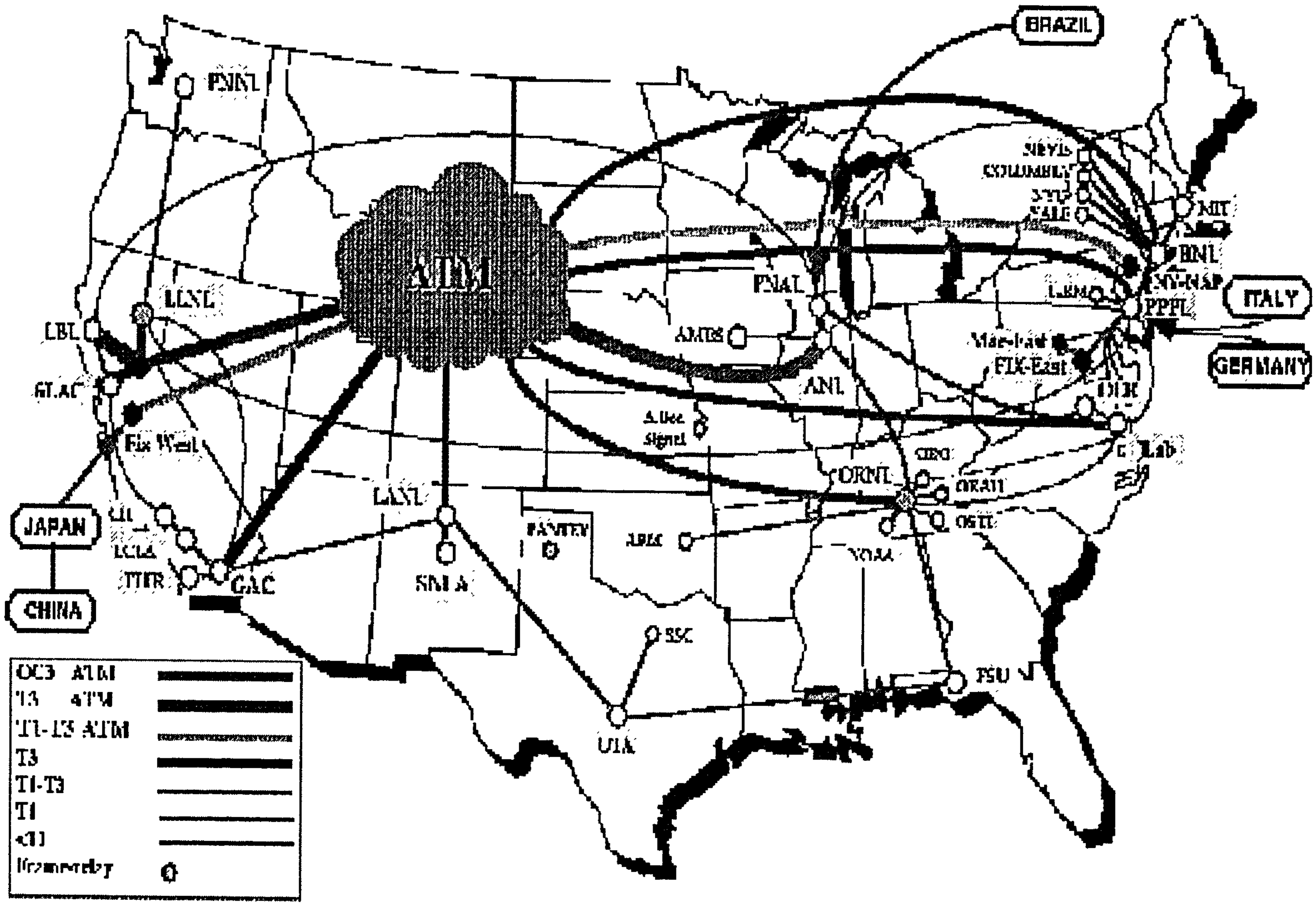
Wide Area Network for the Initial LIGO
- Update -

- MIT
  - December meeting with LNS administrators - R. Bruen, P. Dreher
  - LNS/ESNet has T3 bandwidth capability
  - CSR will provide MIT/LIGO with high bandwidth connectivity to university infrastructure
  - vBNS
- Caltech
  - CACR -- proposed site for data repository/off-line analysis system.
    - CACR member NPACI Team
      - National partnership for Advanced Computational Infrastructure
      - One of two NSF selected supercomputing partnerships -- PNNL/EMSL also member
      - Multi-agency project support: Network access to be Jointly funded by DoD/NSF - OC3 to vBNS
      - Technology thrusts: data-intensive computational challenges on multiple platforms: HP/Convex; SGI/Cray; IBM
    - hosting LIGO Prototype Off-Line analysis software system
    - access to LIGO Laboratory facilities (40m prototype) using ATM for data transfer/analysis to CACR
  - Access to vBNS via SDSC link to NSF backbone
  - ESNET/HEP - alternative option

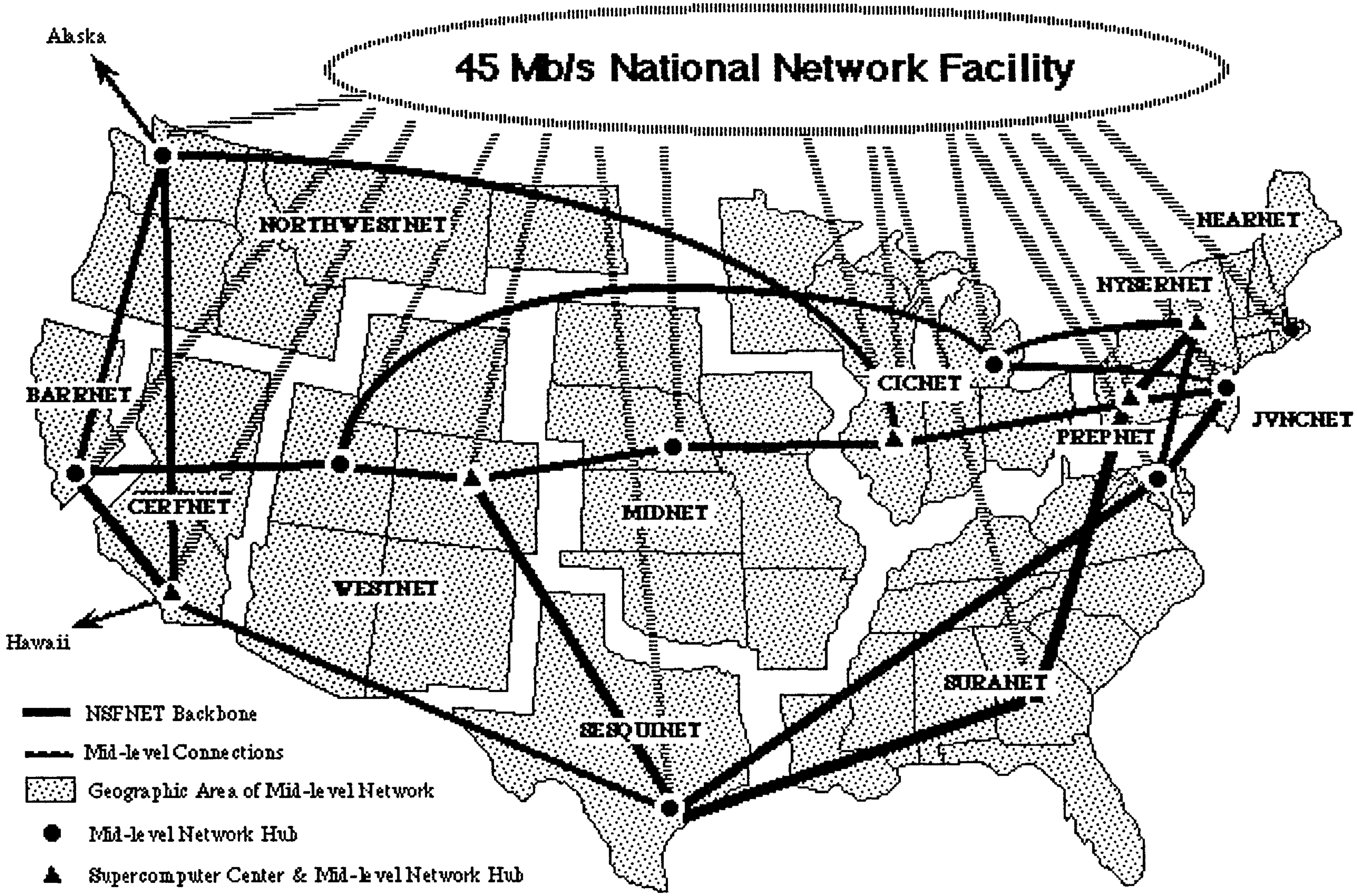
Planned Activities
Timeline for Development

Milestone or Event	Date	Communications	Hardware	Software
System DRR	5/97	Definition	Design & Prototyping	Development; Design & Prototyping
System PDR	11/97			
System FDR	11/98	Agreements		Specifications
	11/98		Specifications	Verification
	3/99-12/99	Implementation	Procurement & Integration	
Begin Coincidence Operations	7/00	Common		
On-Line System Available	1/00	Common		

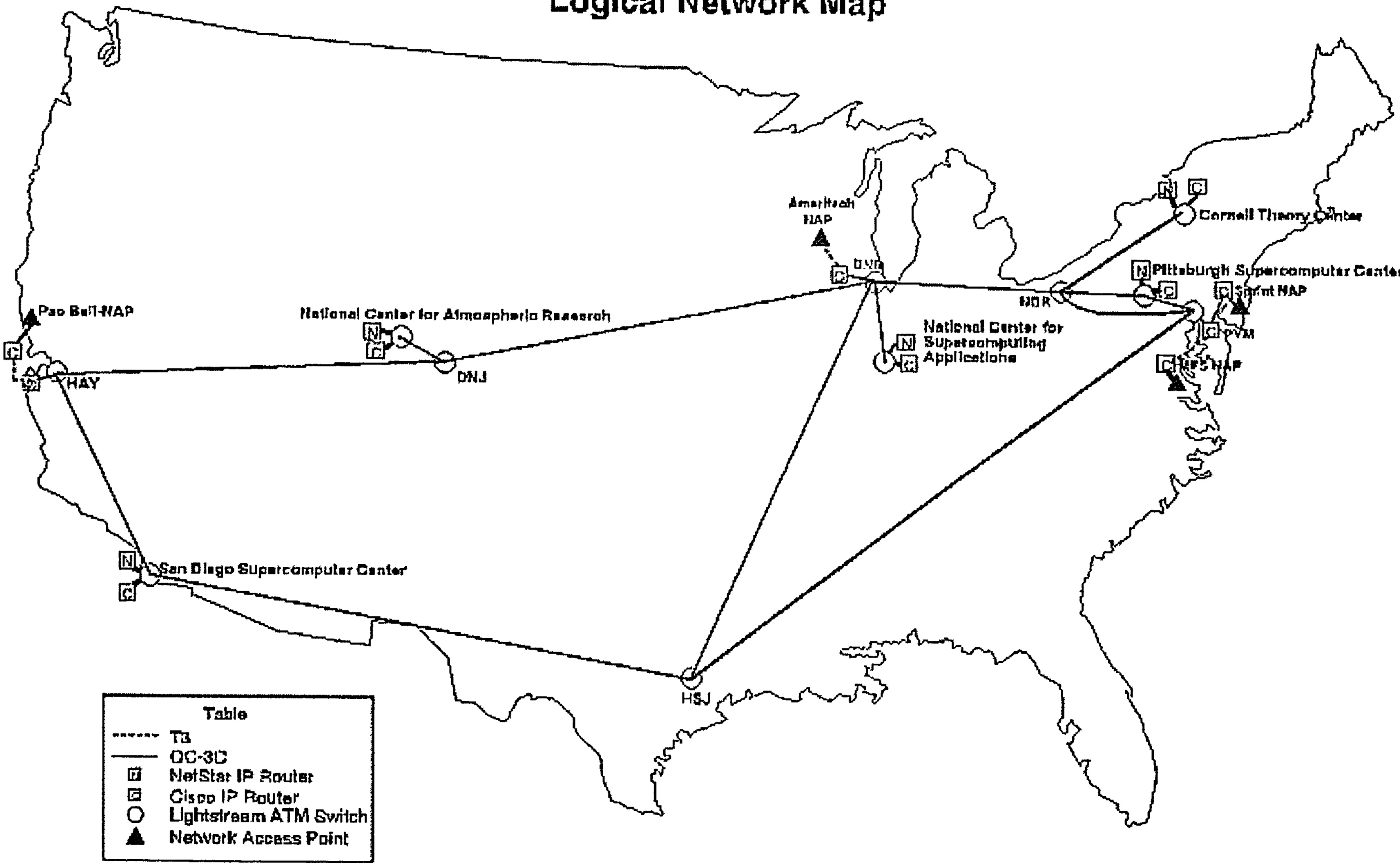
ESnet BACKBONE
Mid 1996



The Old NSFNET Backbone

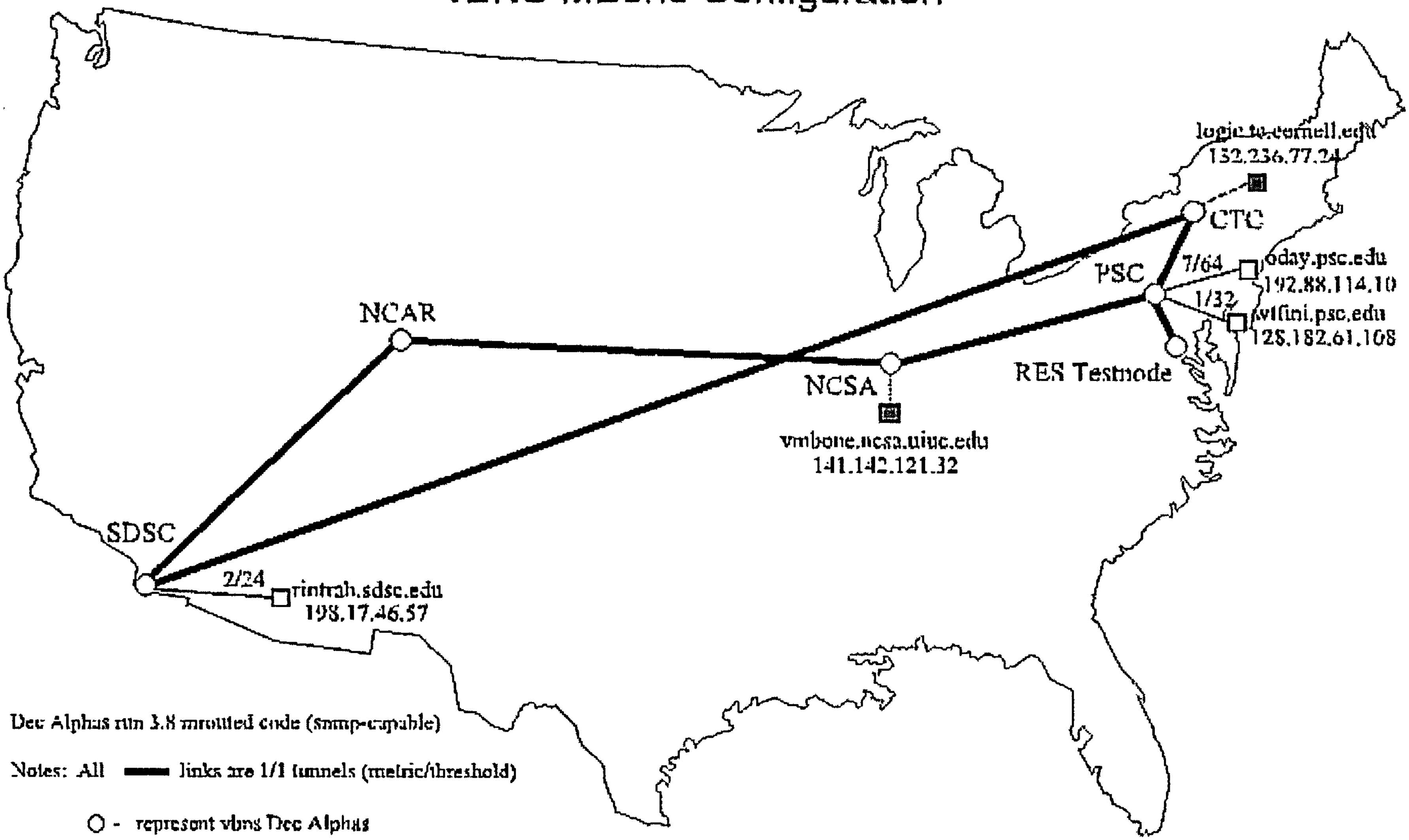


The National Science Foundation Very-High-Speed Backbone Network Service
Logical Network Map



vBNS MBONE MAP

vBNS MBone Configuration



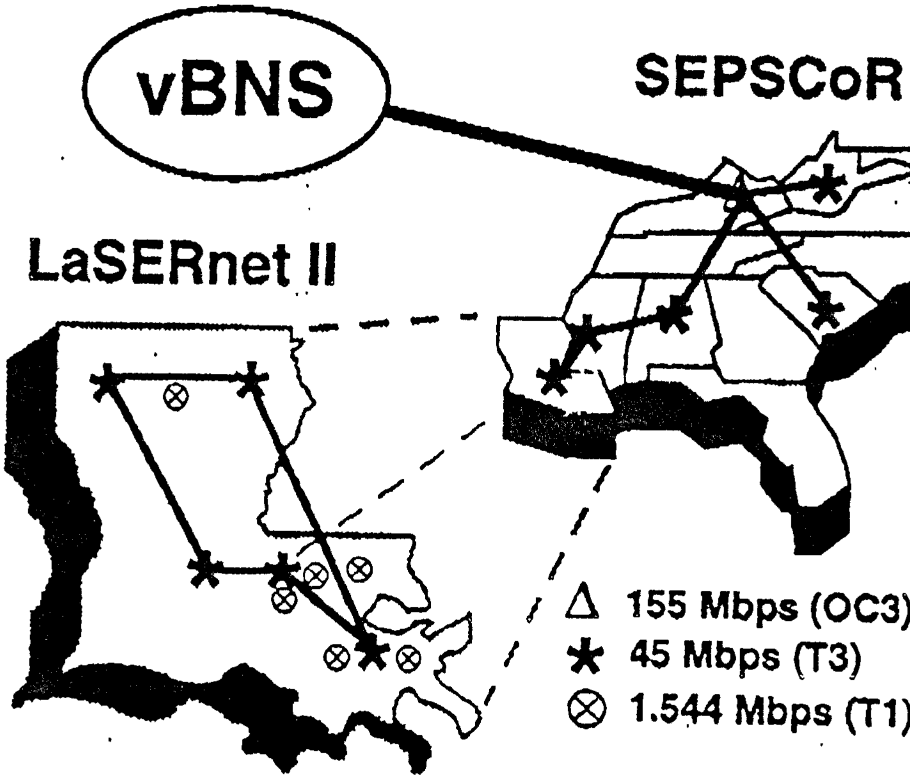
Dec Alphas run 3.8 mrouted code (snmp-capable)

Notes: All ▬▬ links are 1/1 tunnels (metric/threshold)

○ - represent vbns Dec Alphas

▣ - querying mrouted on local subnet (1/1)

Configuration is subject to change



vBNS
SEPSCoR
LaSERnet II
△ 155 Mbps (OC3)
★ 45 Mbps (T3)
⊗ 1.544 Mbps (T1)

List of Acronyms (LoA)

- ATM - Asynchronous Transfer Mode - high bandwidth communications protocol
- CACR - Center for Advanced Computing Research (Caltech)
- CSR - Center for Space Research (MIT)
- DoD - Department of Defense
- DOE - Department of Energy
- EMSL - Environmental Molecular Sciences Laboratory (Battelle)
- ESNET - Energy Sciences Net (DOE)
- HEP - High Energy Physics
- Internet II - Consortium of universities form in Fall 1996.
- kbps - kilobits per second
- kBps - kilobytes per second
- LaSERnet II - Louisiana Southeast Regional net
- LBL - Lawrence Berkley National Laboratory
- LNS - Laboratory for Nuclear Science (MIT)
- LSU - Louisiana State University
- MICS -- DOE Mathematics, Information & Computer Sciences
- Mbps - megabits per second
- MB - megabytes
- MSFC - NASA Marshall Space Flight Center
- NPACI - National Partnership for Advanced Computational Infrastructure
- PNNL - Pacific Northwest National Laboratory
- SDSC- San Diego Supercomputing Center (UCSD)
- T3 - Telecommunications standard, 45 Mbps
- SEPSCOR - South East Partnership for Shared Computational Resources
- vBNS - very high speed Backbone Network Service (NSF)

Control System Modeling and Design for Acquisition of a LIGO Interferometer

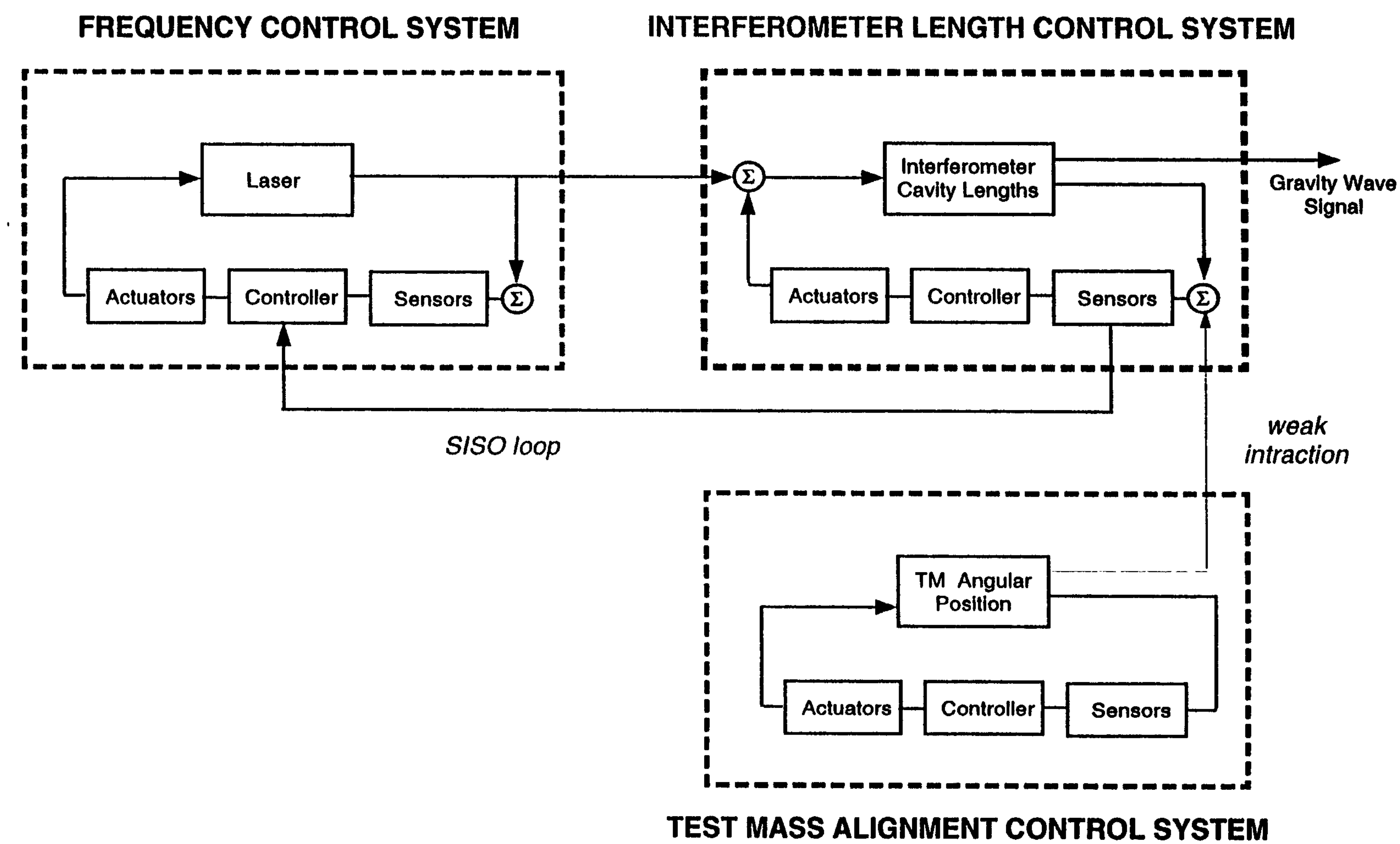
Lisa Sievers

April 15, 1997

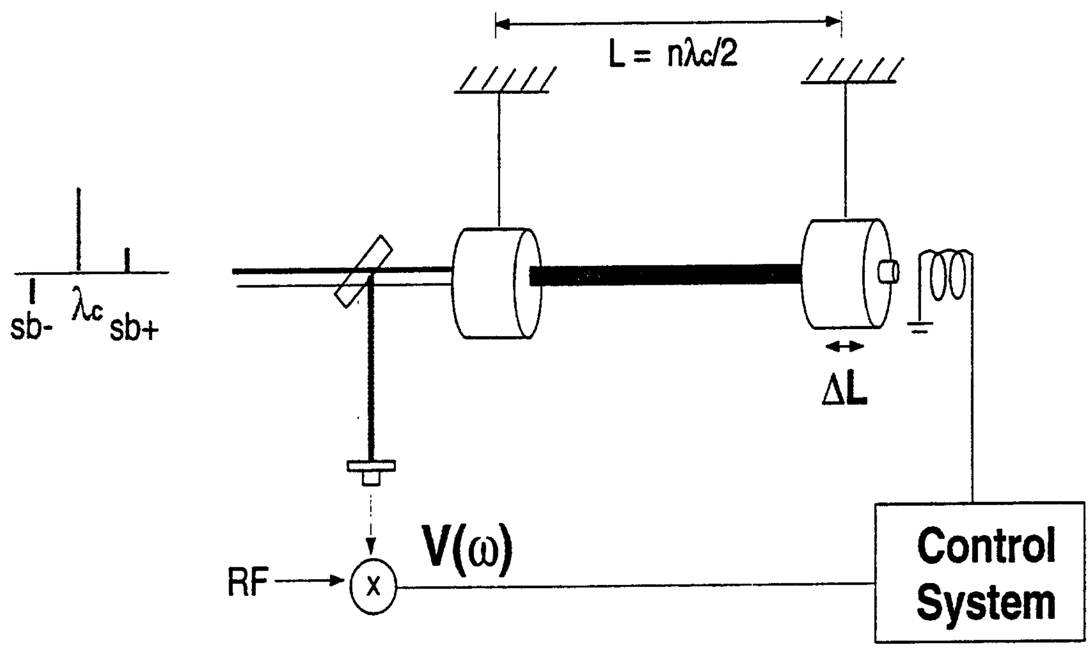
Outline of Presentation

- Description of Interferometer Length Control System
  - ›› Operations Mode
  - ›› Acquisition Mode
- Building Block Modeling Approach and Status of Acquisition Modeling Program
- Insights Gained from Acquisition Model
- Conclusions

BLOCK DIAGRAM OF INTERFEROMETER SERVO CONTROL SYSTEMS



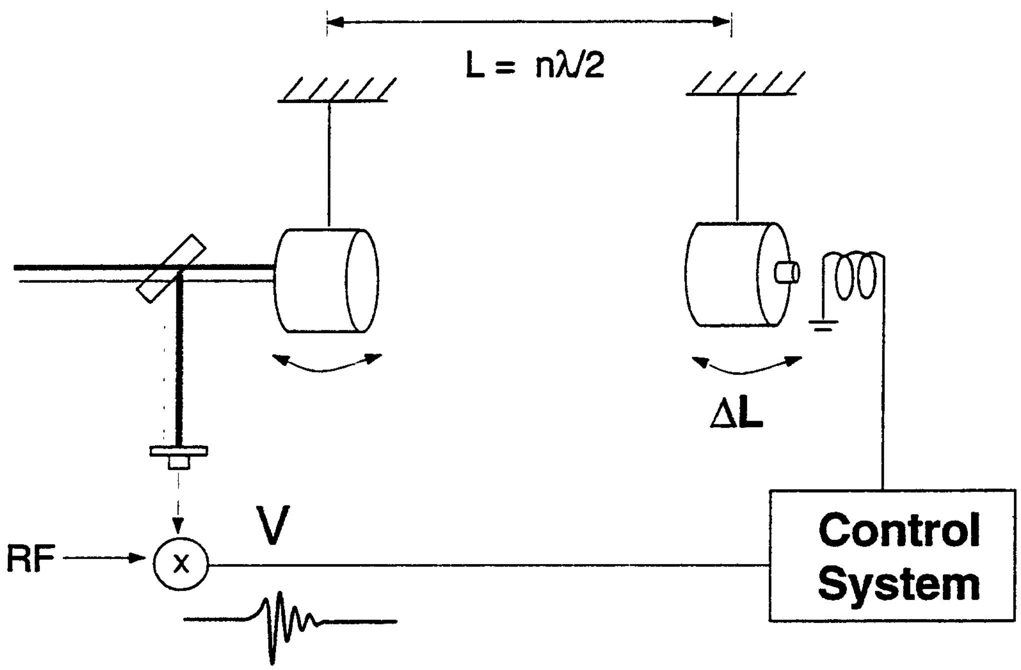
Interferometer Length Control System



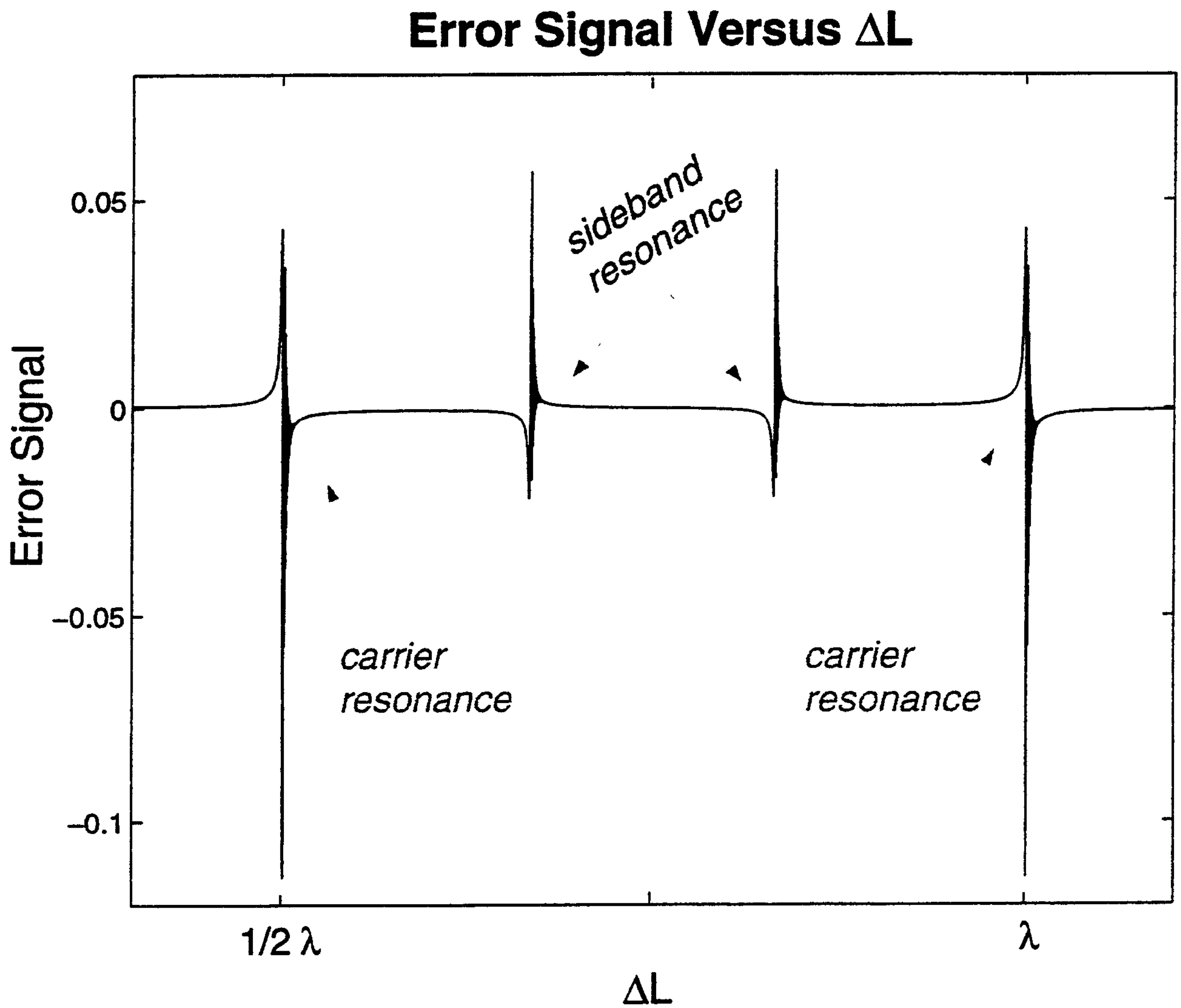
- Operations Mode
  - ›› Interferometer on resonance ==> ΔL <1 nm
  - ›› Can model as a simple linear system

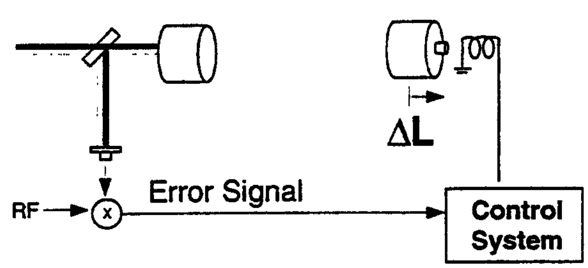
$$V(\omega) = \left(\frac{G}{2\pi j\omega + p_c}\right) \cdot \Delta L$$

Interferometer Length Control System (contd. 2)



- Acquisition Mode
  - ›› ΔL goes through many fringes
  - ›› Control signal is usable for only μsecs at a time
  - ›› Can **NOT** model as simple linear system; is a system with memory

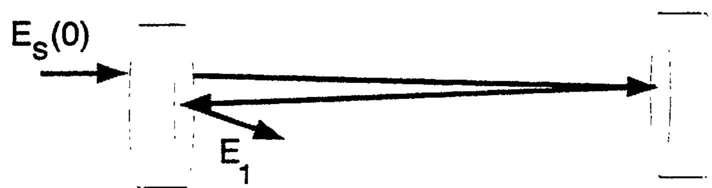

Error Signal Versus ΔL
0.05
0
−0.05
−0.1
Error Signal
sideband resonance
carrier resonance
carrier resonance
1/2 λ
λ
ΔL


ΔL
RF
Error Signal
Control System

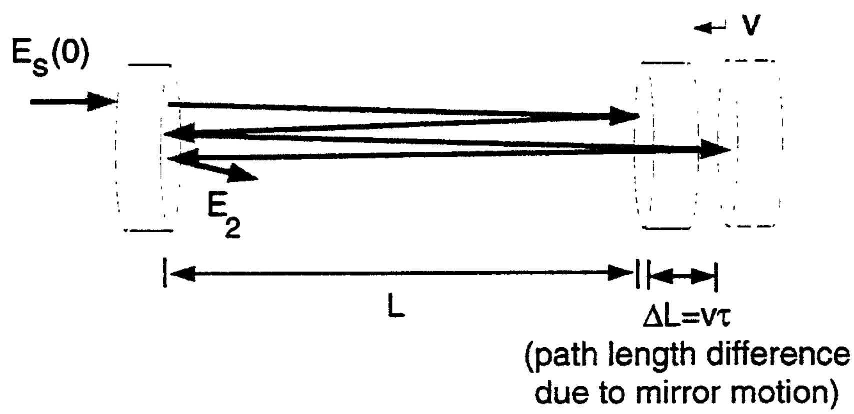
Optical Dynamics During Acquisition (memory!)

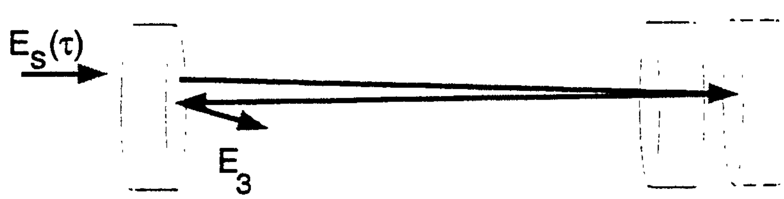
- E field in cavity at time "t" equals Σ of fields due to light entering cavity at discrete times, t, t-τ,...

E field in cavity at τ: $E(\tau) = E_1 + tE_s$



E field in cavity at 2τ: $E(2\tau) = E_2 + E_3 + tE_s$



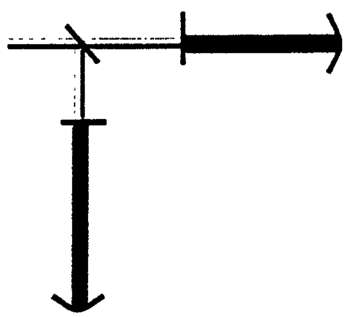


Acquisition Modeling Program: Building Block Approach

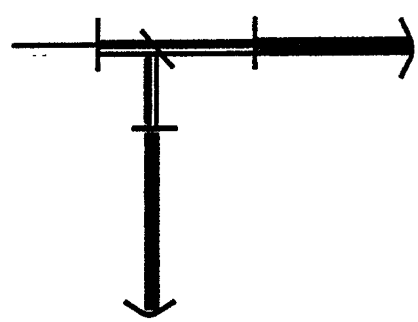
SINGLE CAVITY:
(1) Confidence in modeling techniques
(2) Concept of thresh. vel. revealed
(3) Testbed for computer control

COUPLED CAVITY:
(1) Computational issues for Optical Modeling solved
(2) Locking Sequence Identified

RECOMBINED:
(1) Identified Need for Switching Feedback Signs During Acq

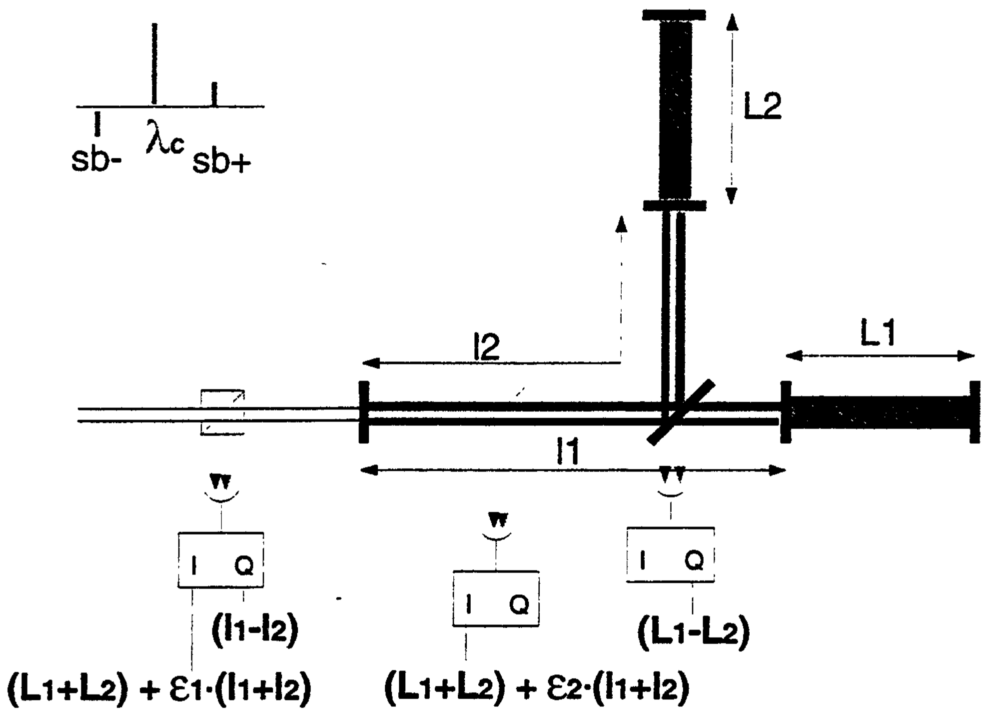


RECYCLED INTERFEROMETER



Recycled Interferometer Configuration

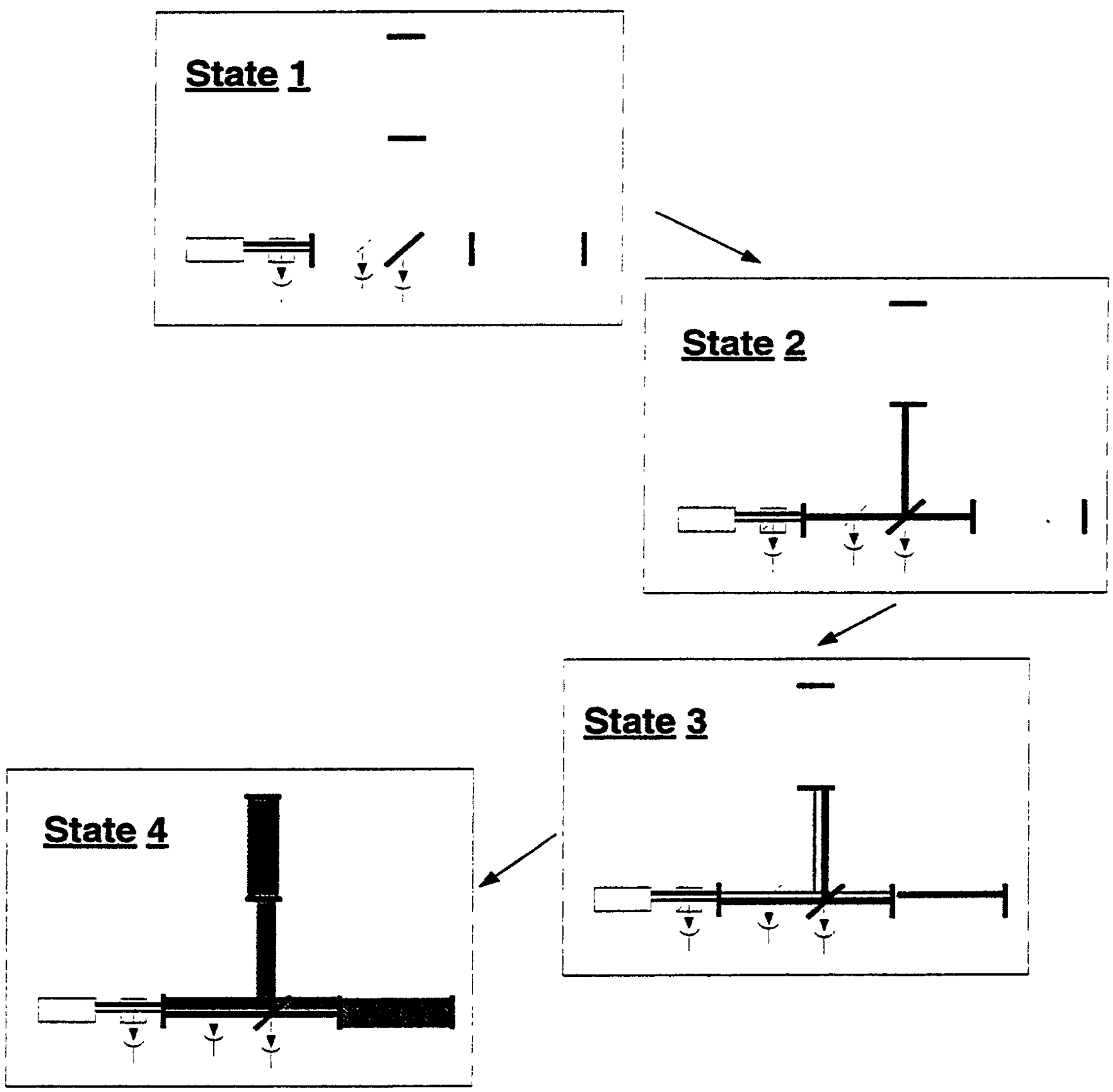
- Quad signals proportional to differential motions
- In-phase signals proportional to common mode motions



	FSR	Finesse	δf	L1	l1
40 m parameters	3.9 MHz	1050	3 KHz	40 m	2 m
LIGO parameters	.0375 MHz	206	.18 KHz	4000 m	6 m

Insights for LIGO from Recycling Model

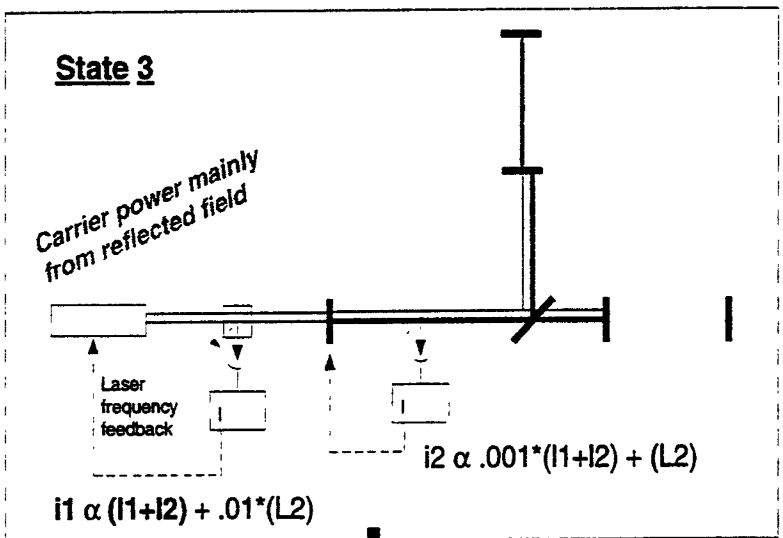
1. Locking sidebands in State 2 sets up lengths correctly for proper carrier resonance condition

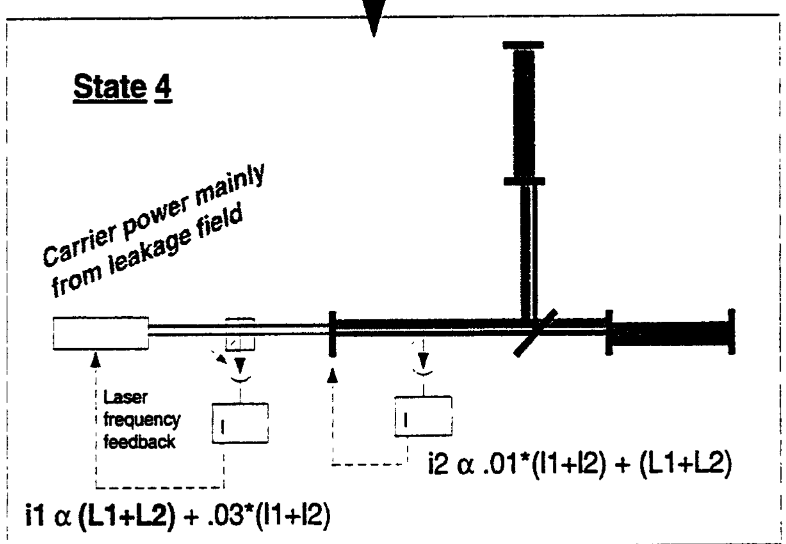


Insights for LIGO from Recycling Model (contd. 2)

2. Sensing points must be chosen so servos stable in all states

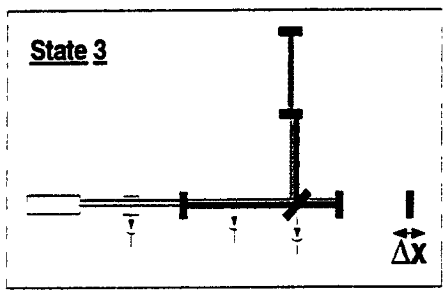
UNSTABLE

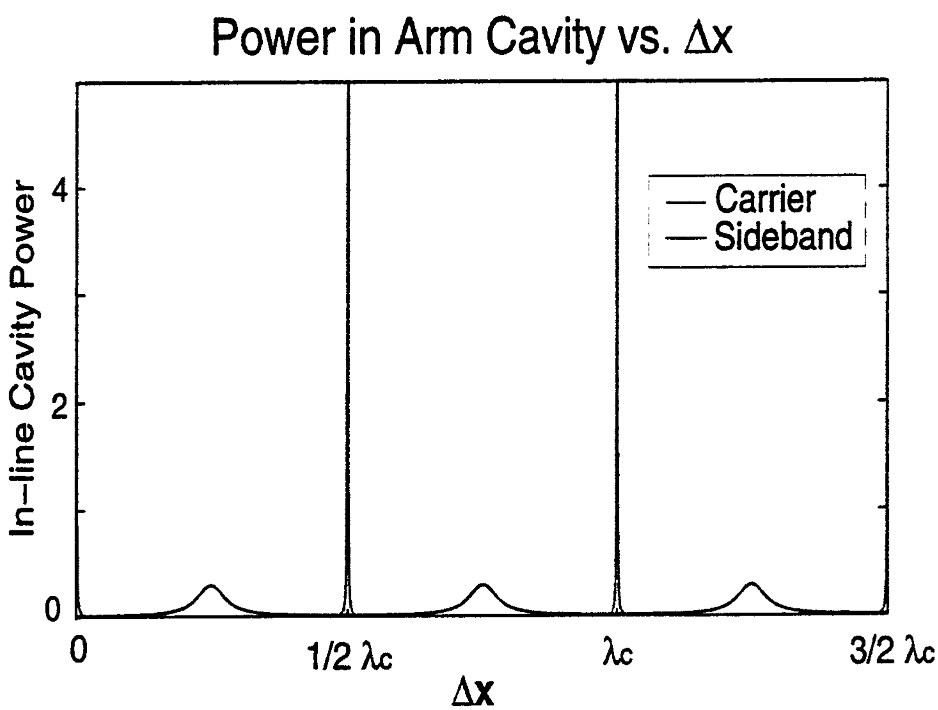




Insights for LIGO from Recycling Model (contd. 3)

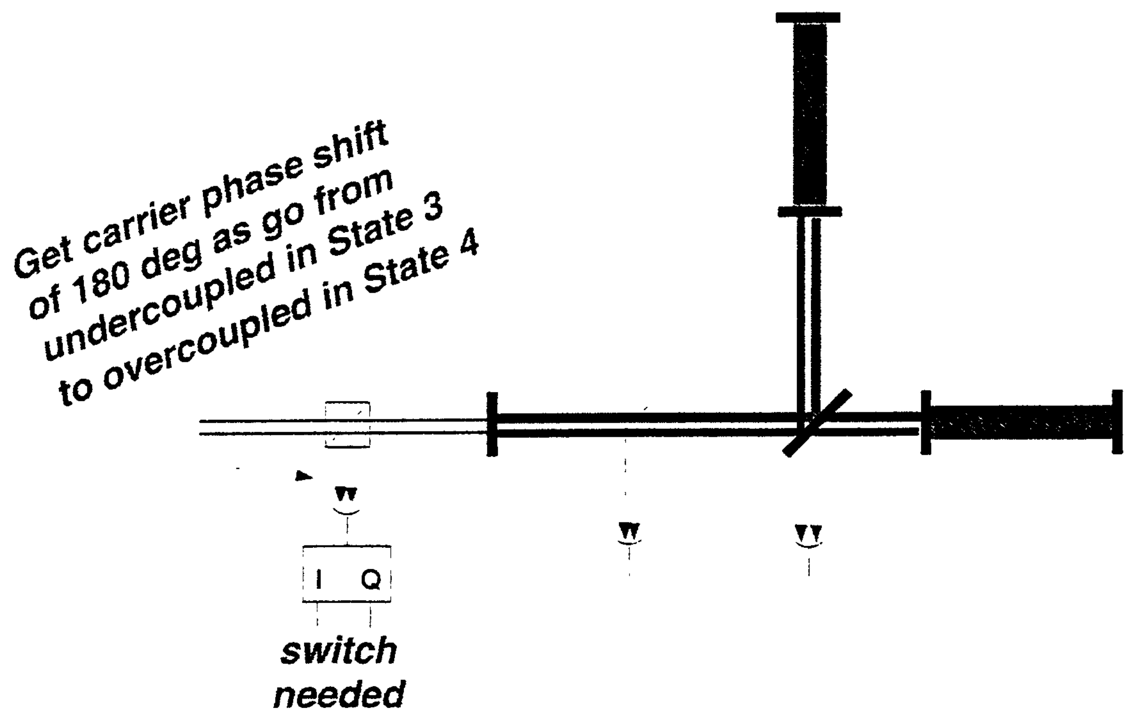
3. Servos get disruptive signals when arm goes through sideband resonance---can address this through control design





Lessons for LIGO from Recycling Model (contd. 4)

4. Michelson differential mode servo requires sign flip when it advances from State 3 to State 4



Conclusions

- Development of model for the acquisition of a LIGO interferometer is complete (SMAC code)
  - ›› Has provided us with fundamental understanding of locking process
- Exploiting full potential of model capability is underway
  - ›› Used as a tool for control system design, including computer control when necessary
  - ›› Will be used as a tool for trouble-shooting experimental locking problems
  - ›› May be used as a diagnostic tool for the interferometer
- Next phase of modeling program includes addition of higher order modes to acquisition model (MMAC)

LIGO Systems Engineering and Integration

End-to-End Simulation

Hiro Yamamoto

NSF review on April 15, 1997

- End-to-End model overview
  - Frequency domain model
  - Time domain model
  - Time domain Optics Cavity model with 3 degree of freedom
- 40m model
  - Time domain model based on digital filter written in C++
  - Modular/expandable at low and high level
  - Base for LIGO simulation

End-to-End model

- Frequency domain model
  - ›› Status
    - – AVS-based Optics and noise modéls completed and used
  - ›› Future
    - – Porting to C++ classes for more broader use
- Time domain model
  - ›› Purpose
    - – Long period LIGO simulation
    - – Generate pseudo-data for data analysis study
    - – LIGO software/hardware diagnostics
    - – Advanced technology trade study
  - ›› Status
    - – SMAC (single mode acquisition code) for control design
    - – 40m model (see below)
  - ›› Future
    - – Realistic, faster, expandable, modular

Time domain Optical Cavity model with 3 degree of freedom

- Status
  - ›› Two separate developments
    - Validate each other
    - Complemental each other
  - ›› Model by R.Beausoleil
    - Coding completed
    - Model validation started
    - Interface to SMAC
  - ›› Model by D. Redding (JPL)
    - Development started
    - Based on the single mode cavity model in SMAC
- Future
  - ›› Speedup
    - Full cavity simulation is slow because of many degrees of freedom
    - Parallelization using MPI/PVM/CACR

LIGO Systems Engineering and Integration

40m model

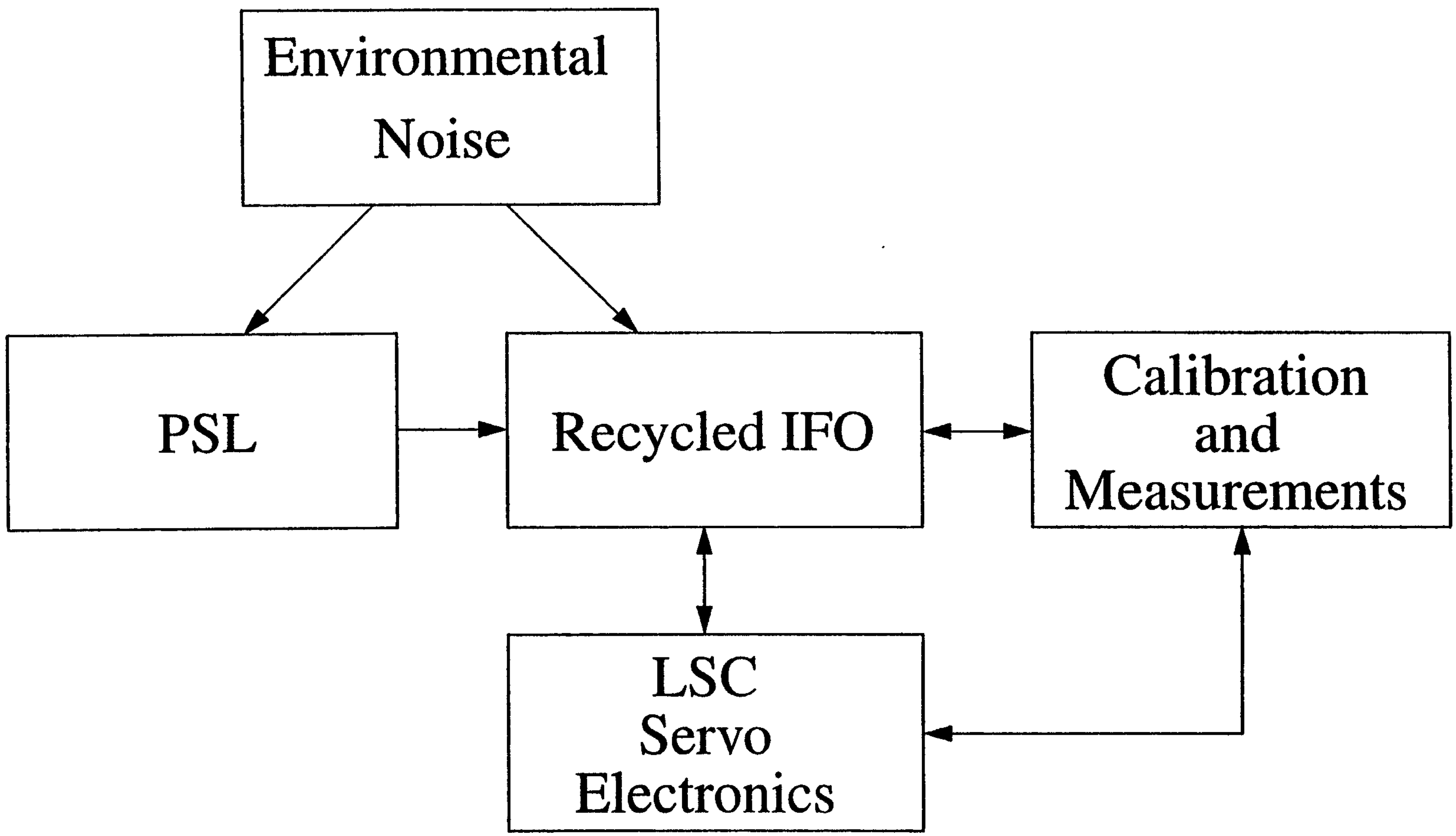
(M. Evans, M. Rakhmanov, H.Yamamoto)

- Purpose
  - ›› Long period 40m simulation and pseudo-data generation
  - ›› 40m software / hardware diagnostics
  - ›› Bases of LIGO End-to-End model
    - Build necessary tools
    - Validate core parts
    - Understand "hard to calculate" parts quantitatively
- Framework
  - ›› Time domain model written in C++
    - Object oriented modular design
    - Speed optimization best suited for LIGO simulation
  - ›› Digital Filter
  - ›› Modular and Expandable
    - both low level and high level

LIGO Systems Engineering and Integration

40m model

overview

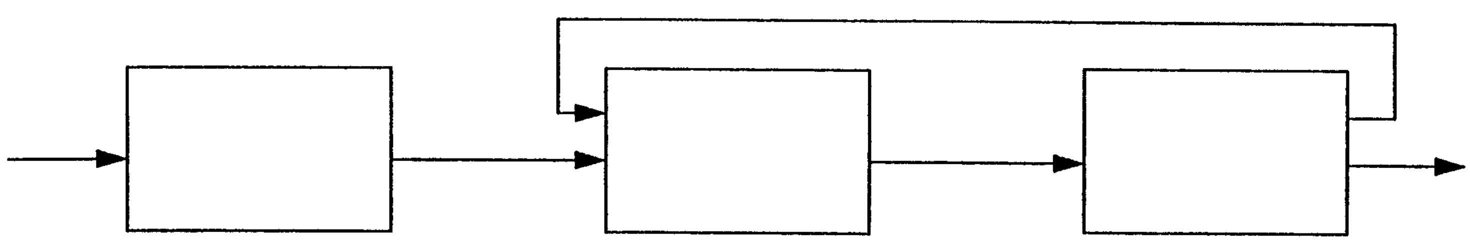


LIGO Systems Engineering and Integration

40m model

Status

- Framework completed
  - ›› Optimized data flow structure
  - ›› Easy-to-understand user interface, which does not degrade performance
  - ›› single time step
  - ›› arbitrary data passing



LIGO Systems Engineering and Integration

40m model

Status

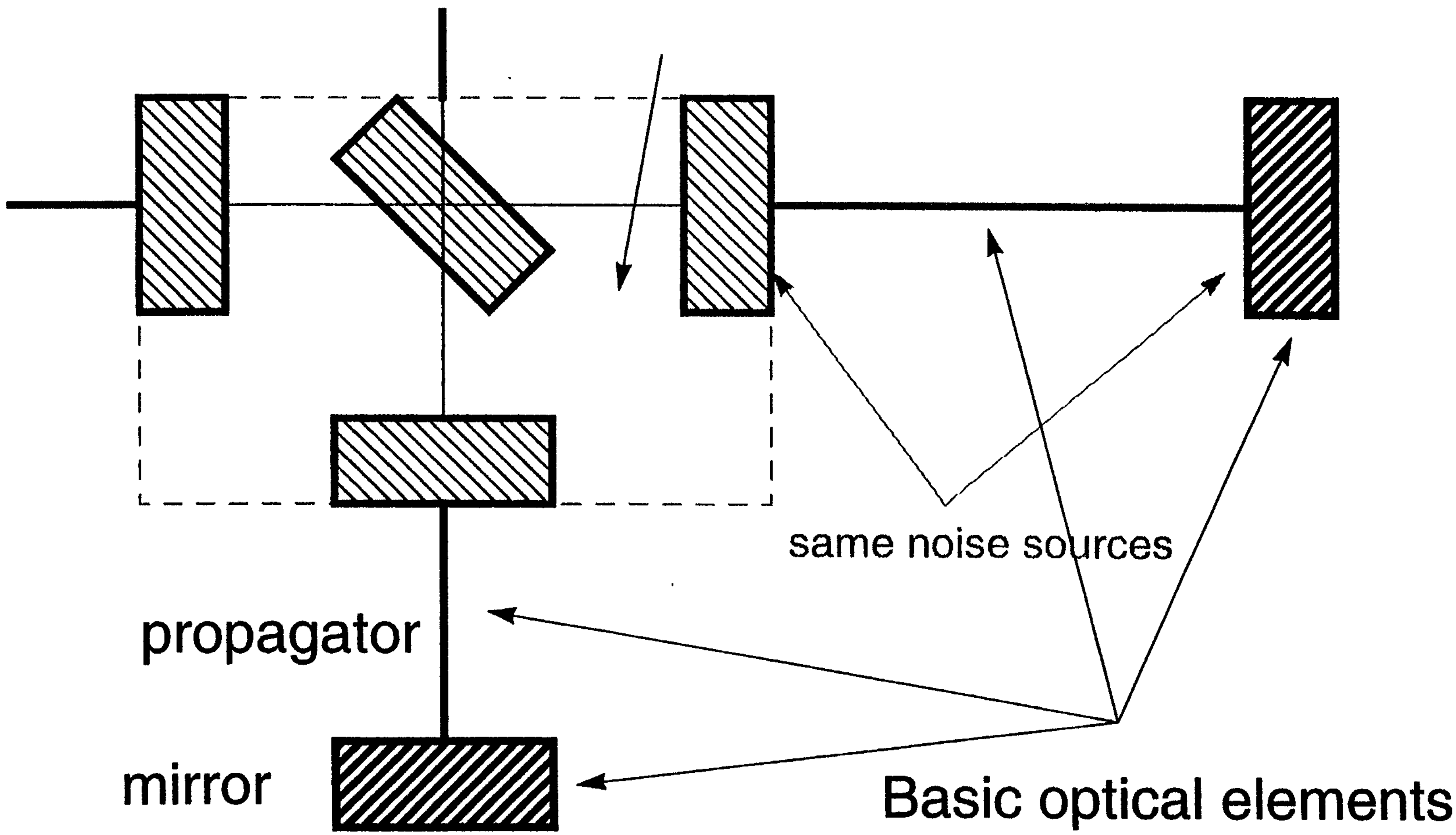
- Fundamental building blocks have been made
  - Basic tools
    - Arithmetic
    - Digital filter
    - Limiter
  - Optics
    - Basic optic elements (mirror, beam splitter, etc.)
    - Propagator (link between mirrors)
    - Optimized Optical Systems (Michelson, FP)
    - Phase modulation Pockels cell
    - photodiode w/ demodulation
  - Macro or wrapper
    - **Box**

LIGO Systems Engineering and Integration

40m model

Optics

Optimized Optical Systems



40m model

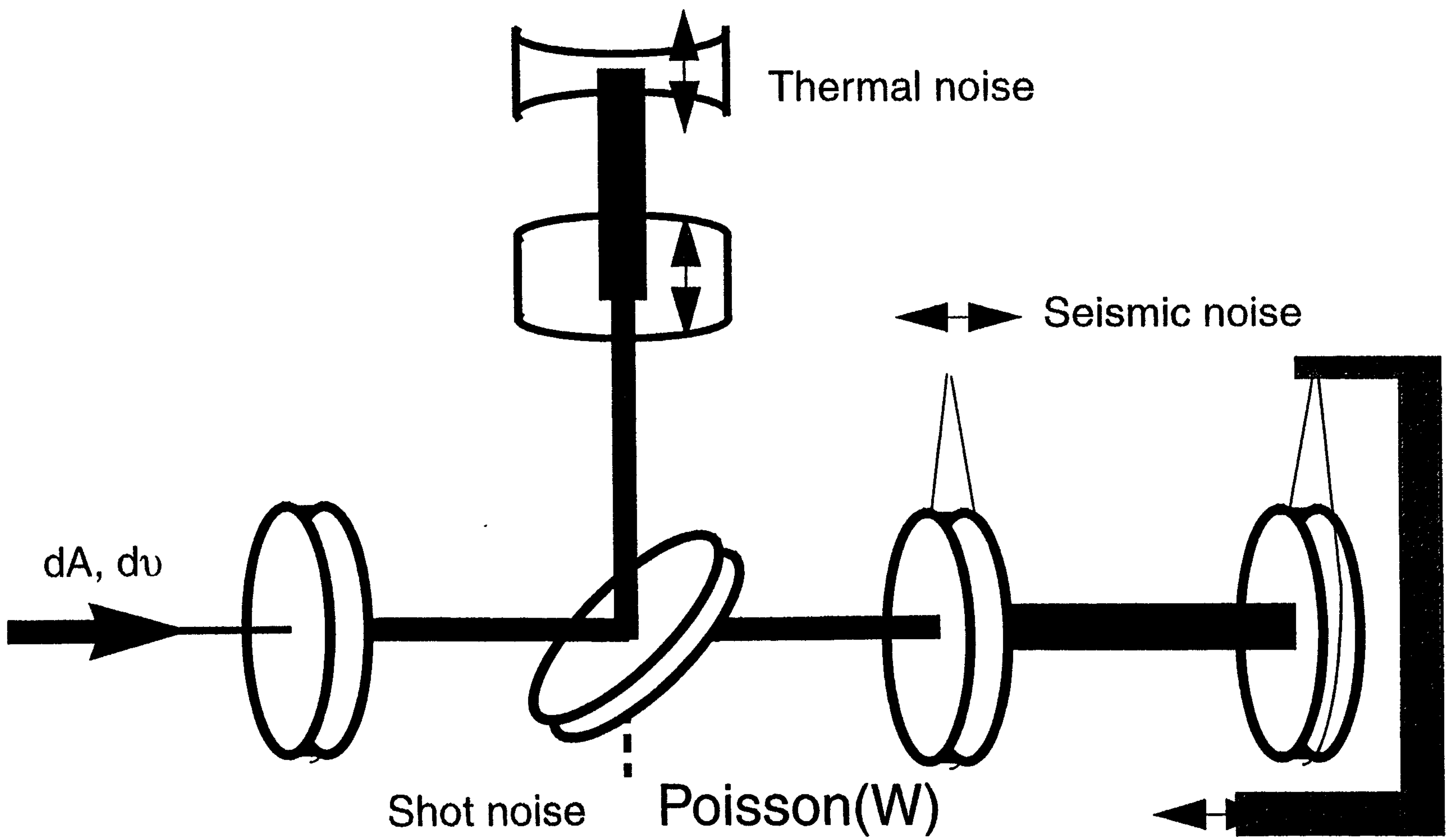
Status

- Compound systems
  - Michelson and FP (optimized vs. constructed)
  - Suspension system (pendulum and velocity damping)
  - Thermal Noises (test mass, suspension wire and MC resonances)
  - PSL (Ar+ laser and Mode Cleaner)

LIGO Systems Engineering and Integration

40m model

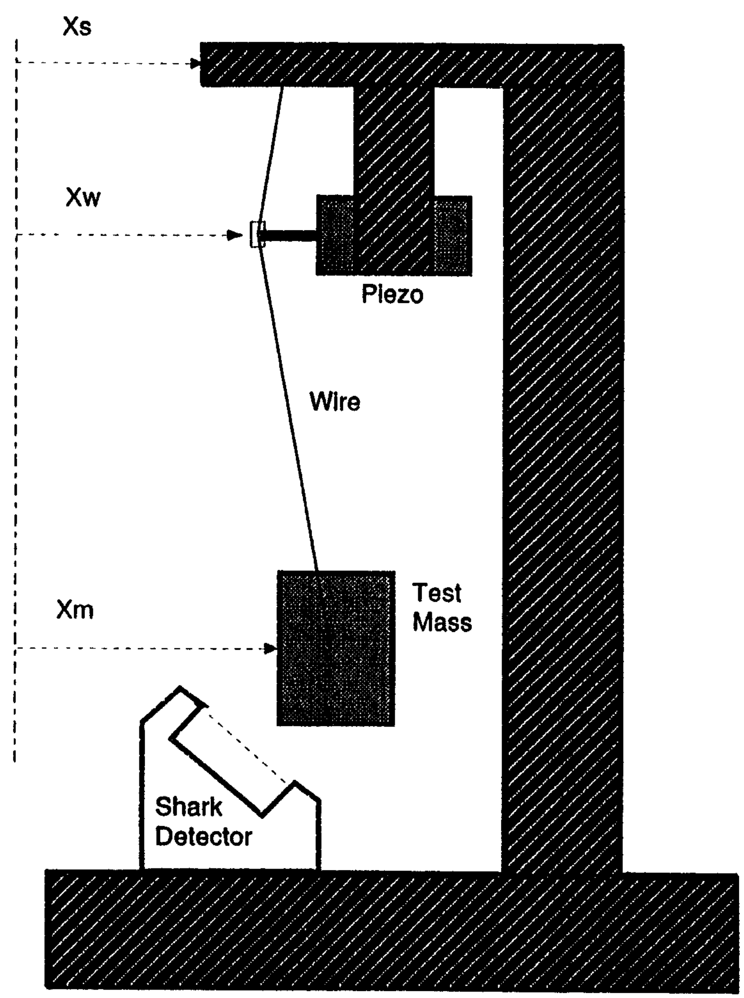
Noise sources



LIGO Systems Engineering and Integration

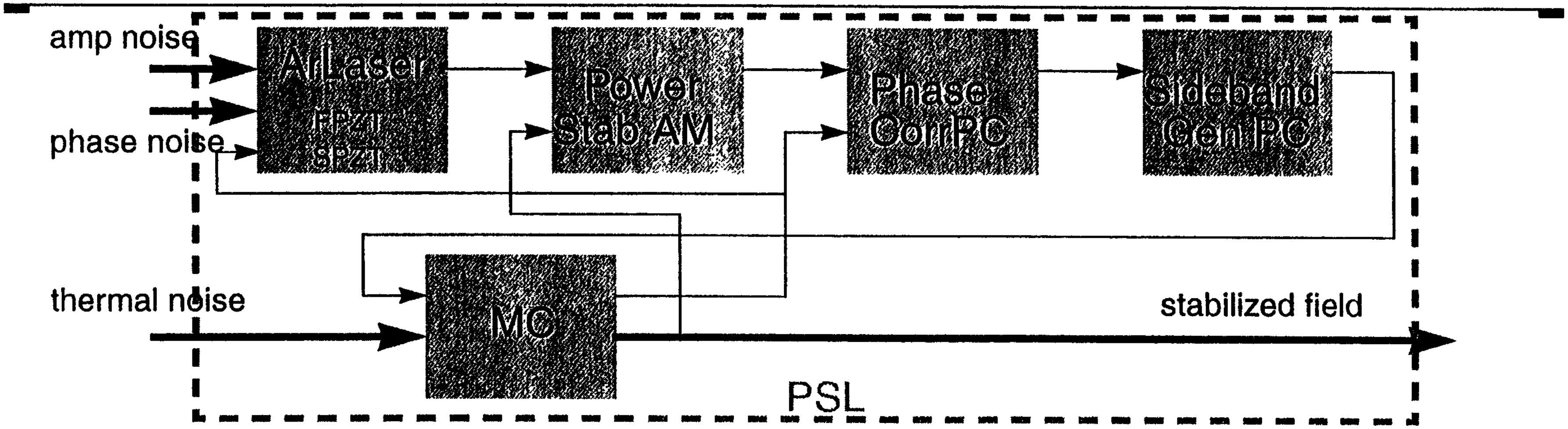
40m model

Suspension system



40m model

Compound box - PSL example



Submodules

%Module Type	Reference Name	Build File Name
box	ArLaser	ArLaser.box
box	PowerStab	PowerStab.box
box	PhaseCorrPC	PhaseCorrPC.box
sbpockel	SBGenPC	
box	MCMC.box	

End

Connections

% submodule output -> submodule inputs
this 0 -> ArLaser 0
this 1 -> ArLaser 1
this 2 -> MC 0

% submodule output -> module output
ArLaser 0 -> PowerStab 0
MC 0 -> PowerStab 1
PowerStab 0 -> PhaseCorrPC 0
MC 1 -> PhaseCorrPC 1
PhaseCorrPC 0 -> SBGenPC 0
SBGenPC 0 -> MC 1
MC 1 -> ArLaser 2

% submodule output -> module output
MC 0 -> this 0

End

40m model

Future

- Refine components
- Validation using 40m
  - proposal being prepared
- Adoption of Twiddle as Compound Optics system
  - Twiddle - frequency domain, small signal model, fast and reliable
  - Use it in time domain using digital filter
- Inclusion of alignment degree of freedom
- Graphical User Interface
  - Easy construction of modules
  - Integrated data visualization

Construction of LIGO model

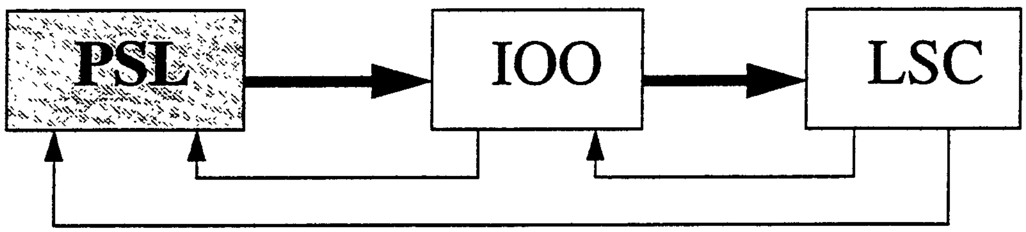
Prestabilized Laser (PSL) Subsystem

Rick Savage

Rich Abbott, Lee Cardenas, Peter King, Stefan Seel

- PSL System Overview
- Lightwave Electronics, Inc. 10-W Laser Development Contract
- Prestabilized Master Oscillator Results

PSL Performance Requirements



- Output Power

  ››Greater than 8.5 Watts in circular TEM_{00} mode

- Fractional Power Fluctuations

  ››$f \geq 40\mathrm{Hz}$: $\delta I(f)/I \leq 10^{-8}/\sqrt{\mathrm{Hz}}$ at COC input

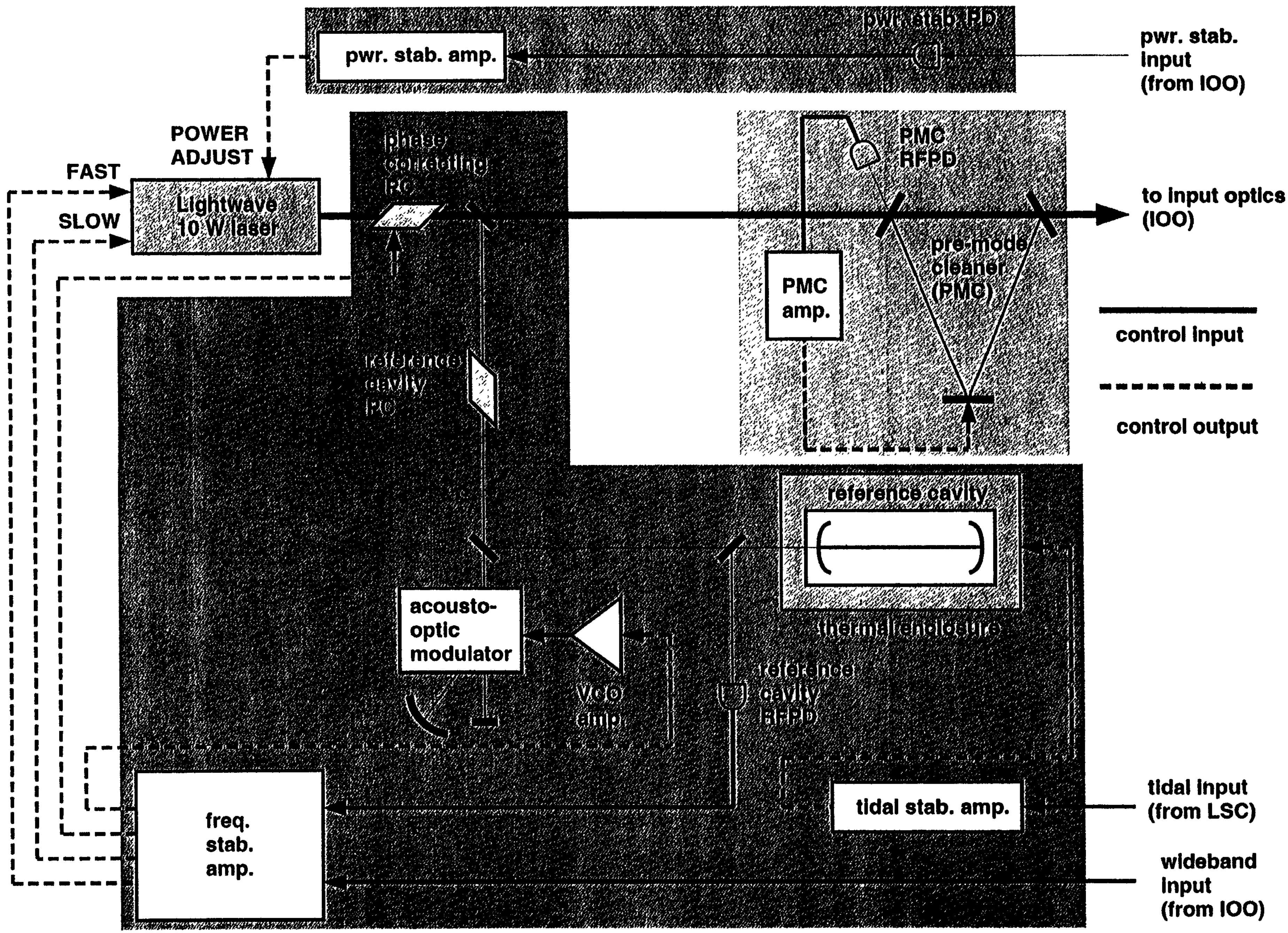
  ››$f = 34.5\mathrm{MHz}$: $\delta I(f)/I \leq 9 \times 10^{-10}/\sqrt{\mathrm{Hz}}$ (shot noise limit for 600mW power at dark port)

- Frequency Fluctuations

  ››$40\mathrm{Hz} \leq f \leq 10\mathrm{kHz}$: $\delta f \leq (10^{-2}\mathrm{Hz}/\sqrt{\mathrm{Hz}})$ (further suppressed by IOO and LSC)

- Output Beam Angular Fluctuations

  ››$f \geq 150\mathrm{Hz}$: $\delta\theta \leq 3 \times 10^{-11}$ radians / $\sqrt{\mathrm{Hz}}$


pwr. stab. PD
pwr. stab. amp.
pwr. stab. input (from IOO)
POWER ADJUST
FAST
SLOW
Lightwave 10 W laser
phase correcting PC
PMC RFPD
to input optics (IOO)
pre-mode cleaner (PMC)
PMC amp.
control input
control output
reference cavity PC
reference cavity
thermal enclosure
acousto-optic modulator
VCO amp
reference cavity RFPD
freq. stab. amp.
tidal stab. amp.
tidal input (from LSC)
wideband input (from IOO)

Lightwave 10-W Laser Requirements

- Output Power
  - ››Greater than 10 Watts in circular TEM_{00} mode
  - ››Less than 0.5 Watts in all other modes
- Fractional Power Fluctuations
  - ››$100\text{Hz} \le f \le 10\text{kHz}: \quad \delta I(f)/I \le 10^{-5}/\sqrt{\text{Hz}}$
  - ››$10\text{kHz} \le f \le 3\text{MHz}: \quad \delta I(f)/I \le 10^{-6}/\sqrt{\text{Hz}}$
  - ››$f = 10\text{MHz}: \quad \delta I(f)/I \le 6 \times 10^{-9}/\sqrt{\text{Hz}}$ (shot noise limit for 10 mA photocurrent)
- Frequency Fluctuations
  - ››$f = 100\text{Hz}: \quad \delta f \le 3 \times 10^{3}\text{Hz}/\sqrt{\text{Hz}}$
  - ››$f = 1\text{kHz}: \quad \delta f \le 3 \times 10^{2}\text{Hz}/\sqrt{\text{Hz}}$
- Output Beam Angular Fluctuations
  - ››$f \ge 150\text{Hz}: \quad \delta\theta \le 3 \times 10^{-11}$ radians / $\sqrt{\text{Hz}}$

Lightwave 10-W Laser Schedule

- Phase I: Preliminary Laser Design
  - ››Initiate contract: 6/1/96
  - ›› Interim Design Review: 12/18/96
  - ››Preliminary Design Review: 4/25/97
- Phase II - Fabrication of Three Lasers
  - ››Initiate product development team: 4/1/97
  - ››Deliver first Alpha laser: 7/6/97
  - ››Deliver three Beta lasers: 10/15/97
- Phase III- Option: Fabrication of Additional Lasers
  - ››Deliver up to five additional lasers: 4 mos. ARO

Master Oscillator Stabilization (NPRO-PSL)

- Goal: Frequency and power stabilization of Lightwave model 126 laser
  - ››Head start on IR-PSL
    - —Same oscillator used for Lightwave 10-W laser
  - ››Provide stabilized IR source for PNI IR conversion
    - —System delivered to MIT in January 1997
- Strategy and techniques similar to strawman conceptual design for PSL
  - ››Fixed-spacer reference cavity and frequency shifter (VCO)
  - ››Frequency stabilization via SLOW, FAST, and PC actuators
  - ››Power stabilization via POWER ADJUST actuator
  - ››Feedback control loop electronics designed and fabricated by LIGO CDS group
    - —implemented in NIM- no computer interface

15:30 23 JAN 97 RA

HIGH FREQUENCY RESIDUAL NOISE OF FSS. TRACE "A" IS PSA OFF, TRACE "B" IS PSA ON.

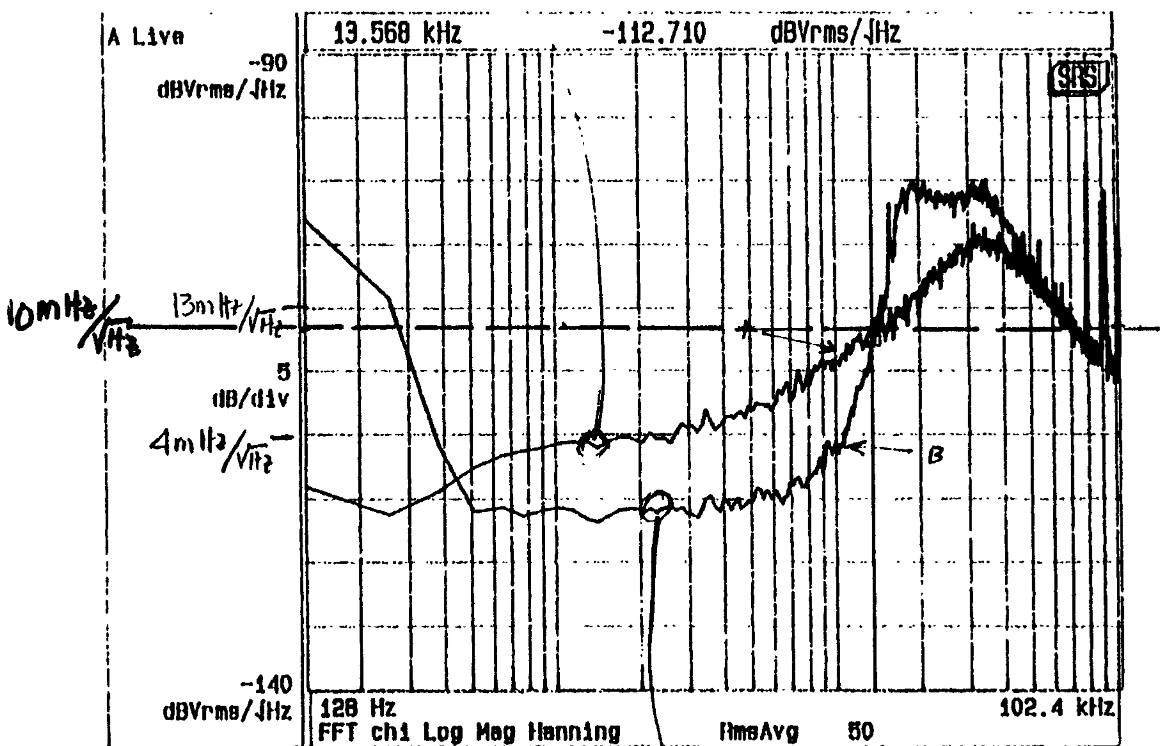
FREQ. DETECTOR GAIN AT THIS PLANE = $\frac{1\ \text{VOLT}}{4.15\ \text{KHz}}$ => -112 dBc = 10 mHz / $\sqrt{\text{Hz}}$

SETTINGS: FSS: SLOW = 0.4, FAST = 1.04, COM = 0.65

PSA GAIN = 3.4, OFFSET = ~~0.~~5.0 ~~[illegible]~~ (NO OFFSET)

TAKEN @ MIXER TEST PORT

Pwr. stab. loop inactive.

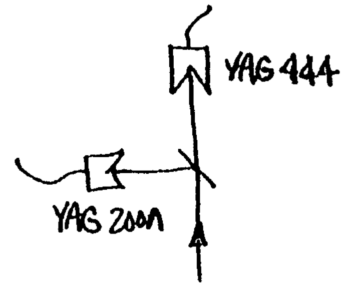


1/23/97 15:29:14

pwr. stab. loop active.

Frequency Stabilization loop - Error Point (inside loop?).

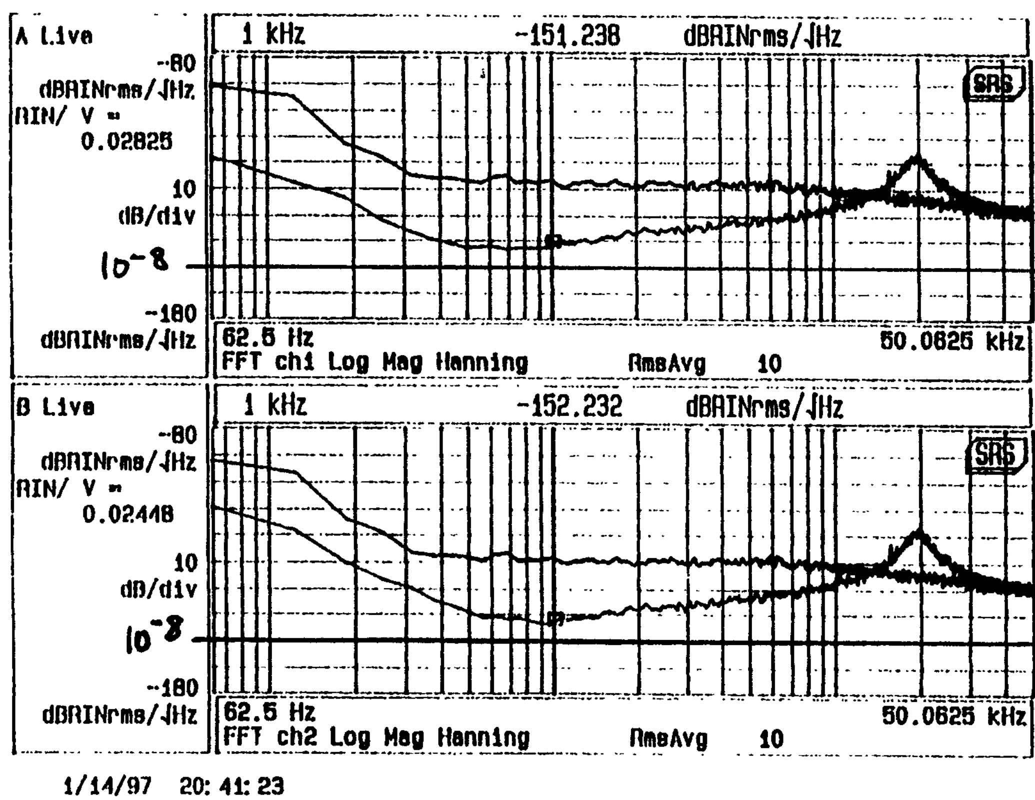
1/14/97 RLS



Stabilized RIN NPRO S/N 170
PSA Gain knob: 3.4
Switch ~~pot~~ : 10
PSA input YAG 444 (in-line)

"inside the loop"

"outside the loop"



PSPD w/ YAG 444
upper trace - file RIN44FRA
lower trace - file RIN 444C

PSPD w/ YAG 200A
upper trace - file RIN20FRA
lower trace - file RIN200C

Lights off, AC off, NE ON

Conclusions

- 10-W laser procurement proceeding well
  - ›› Lightwave preliminary design review - 4/25/97
    - — required output power demonstrated
    - — power fluctuations - meet requirements (maybe better?)
    - — frequency fluctuations - not measured (expect to follow NPRO)
    - — beam quality - meets requirement (maybe better?)
    - — pointing fluctuations - measurements underway
- Master oscillator stabilization
  - ››Frequency stabilization results promising
    - — frequency noise measurements underway at MIT
  - ››Power stabilization close to requirement
    - — experience applicable to 10-W laser
- Prestabilized laser subsystem design
  - ››Conceptual design well underway
    - — PSL hiring completed
    - —Design requirements review - May 1997

Core Optics Components: Requirements and Status

Jordan Camp

April 16, 1997

18

Requirements / Status Overview

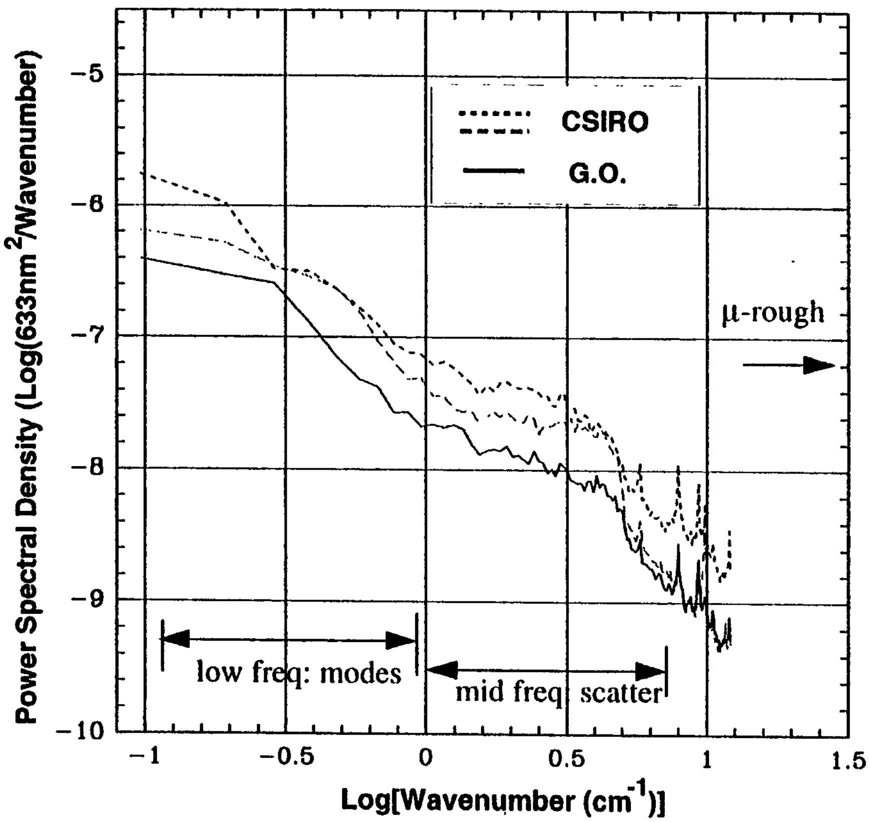
Table 1: COC Requirements and Status

Parameter	Requirement	Status	Interferometer Coupling
Surface Figure Surface Error (0.1 - 4 cm^{-1})	< 50 nm p-v over 20 cm < 1 nm rms over 8 cm diameter	~ 10 nm p-v < 1 nm rms over 20 cm diameter	Increased Power at Dark Port (Shot Noise)
Coating Uniformity	consistent with above	~ 5 nm p-v < 1 nm rms over 8 cm diameter	as above

Requirements Overview (cont.)

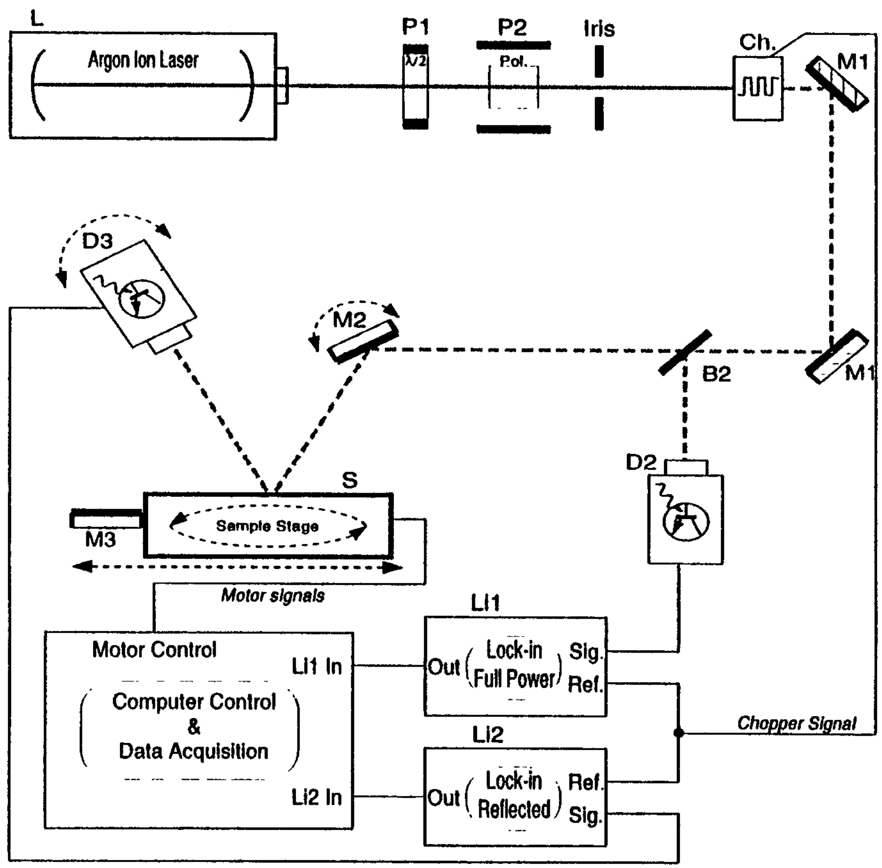
Parameter	Requirement	Status	Interferometer Coupling
Scatter losses	< 50 ppm	< 30 ppm	Loss of Power in FP arms
Absorption Losses:			Thermal Lensing -> Loss of Sideband Power
Bulk	< 5 ppm / cm	~ 5 ppm / cm	
Surface (coating)	< 2 ppm	~ 1 ppm	

Surface Error Polish Demonstration



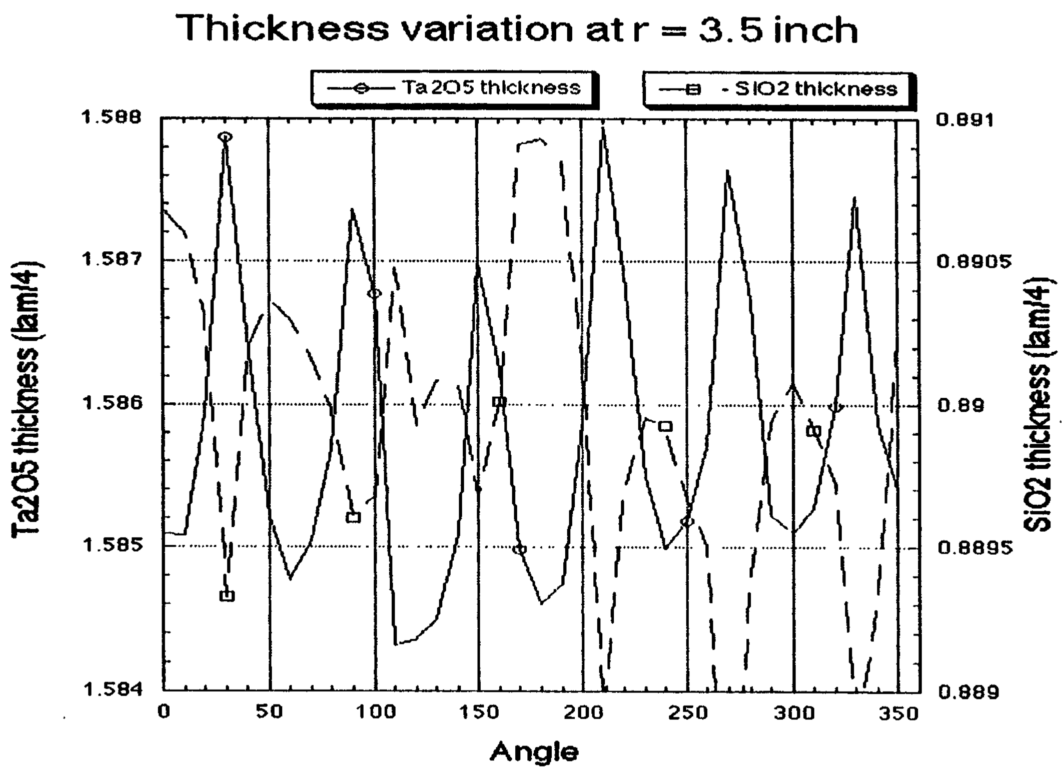
- RMS deviation < 1 nm over 20 cm diameter achieved

Coating Uniformity Measurements (Jungwirth, Golovitser, Yamamoto)



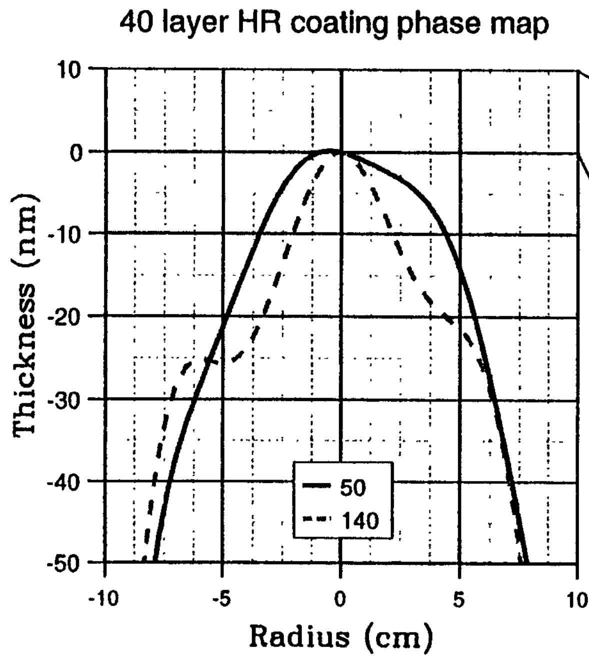
- Map reflectivity of specially designed AR coating
  - Insensitive to surface figure of underlying substrate
  - Can investigate uniformity of individual coating layers
- Make measurements at:
  - 2 Polarizations
  - 3 Angles

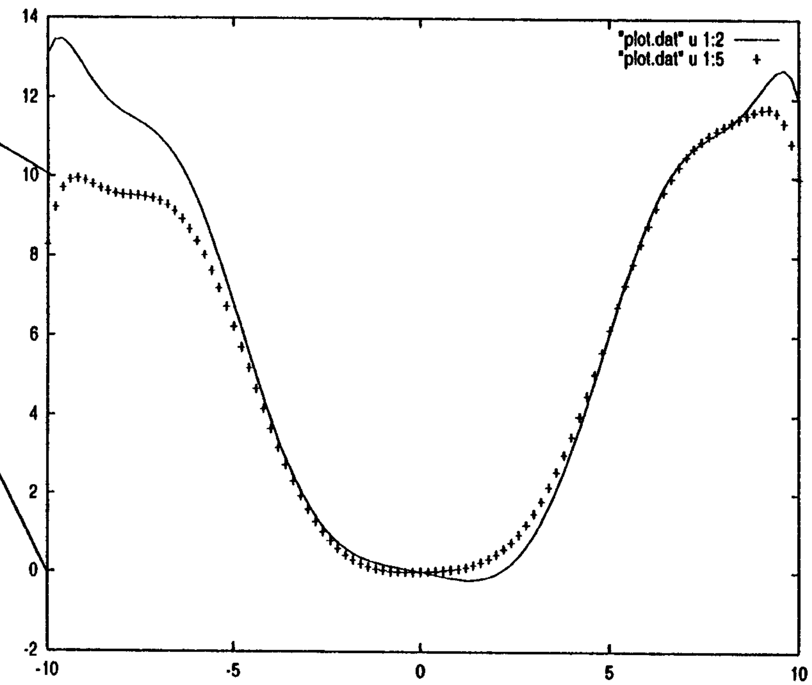
Coating Thickness Variations



- Reflectivity accuracy 0.2 % -> thickness accuracy 0.02%
- Above azimuthal structure not significant for LIGO

Extrapolation to HR Phase Map
(Yamamoto, Kells)





1st coating runs
~ 10 nm rms

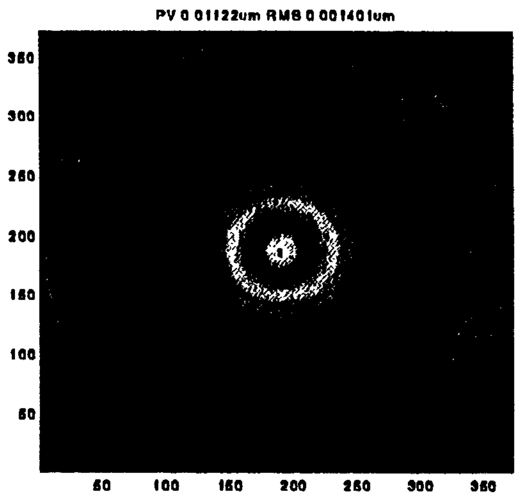
after iteration with REO
~ 1 nm rms
~ 5 nm p-v over 20 cm dia

FFT Analysis of Coating Variations (Kells)

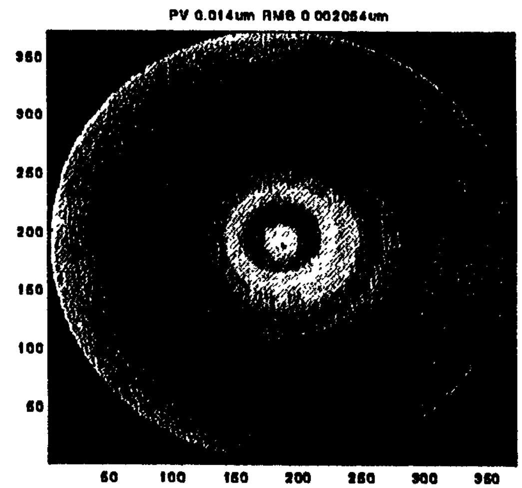
- FFT model of Interferometer resonant fields
  - ››inputs measured optic phase maps
  - ››calculates stored power in arms, recycling cavity

Run Conditions	*Surface Figure (nm rms)*	*Recycling Factor*	*h(100 Hz) ($x10^{-23}$ $Hz^{-1/2}$)*
Standard Configuration: **Measured Substrate OPD's** **Surface Phase Maps Based on Polished Substrates**	**0.8**	**52**	**1.4**
40 Layer HR substituted on End Test Mass	**1.7**	**42**	**1.6**
16 Layer HR substituted on Input Test Mass	**0.8**	**57**	**1.3**
40 Layer HR substituted on End Test Mass, **16 Layer HR substituted on Input Test Mass**	**1.7 (End)** **0.8 (Input)**	**45**	**1.5**

Coated Optic Phase Map



Coated Optic
1.4 nm rms



Bare Substrate
2 nm rms

- Implied coating variation of ~ 1 nm rms meets requirements

Scatter Losses

- Mid Spatial Frequency $1 - 10^2$ cm^{-1}
  - ›› L ~ 20 ppm
    - — loss inferred from NIST surface map measurement
- Microroughness $> 10^2$ cm^{-1}
  - ›› L < 10 ppm   CSIRO
  - ››   < 2 ppm   GO
    - — loss inferred from REO micromap measurement
- Surface Defects
  - ›› spec on point defects gives L < 10 ppm
  - ›› will be monitored with RTS scanner

Absorption Losses

- Heraeus process gives < 5 ppm / cm absorption
  - ››beam splitter, input test mass transmit high intensity light
    - – thermal lensing -> mode mismatch of sideband light
- Corning process < 20 ppm / cm adequate for other optics
  - ››recycling mirror, end test mass
- QA program in planning with Z. Wu, E. Michigan University
  - ››Photodeflection of probe laser beam shows thermal lensing from absorption
  - ››Measurements start ~ July

Core Optics Production (Billingsley)

- Feb 97 - July 98   GO, CSIRO polish substrates
- April 97   NIST Phase Map of coated large optic
  - ››test of both polish and coating uniformity on single optic - 633 nm
  - ››further tests at 1064 nm
- Dec 97 - Aug 98 REO coat of polished substrates
- Jan - Dec 98 In House Metrology of LIGO coated optics
  - ››Surface Phase Map
  - ››Surface scan for loss and defect
- April 98   Start delivery of optics to Hanford

In House Test Development: QA of LIGO Optics

- Reflection Transmission Scatter (RTS) Scanner

  ››QA of reflection uniformity, defect scatter and total loss of (40) LIGO optics at tens of ppm level

  ››operational ~ July 97

- IR Interferometer

  ››QA of surface phase map of (40) LIGO optics at 1 nm level

  ››assitance from NIST in qualifying apparatus

  ››operational ~ Mar 98

Status of the LIGO Input Optics

David Reitze

Physics Department

University of Florida

Gainesville, FL 32611

April 16, 1997

University of Florida Participation/Integration in LIGO

- UF LIGO Group: 6 faculty, 2 postdocs, 2 students
- MOU between LIGO and UF signed in October, 1996
- UF subcontract to design Input Optics awarded November 1996.
- Successful Input Optics Design Requirements / Conceptual Design completed November 1996
- UF - LIGO collaboration: Integration issues
  - ›› detailed reporting structure (weekly, monthly, quarterly)
  - ›› monthly visits of UF personnel to Caltech and LIGO personnel to UF
  - ›› UF participation in LIGO review panels
  - ›› standard design, analysis software packages

Input Optics Functions and Design

- Input Optics Functions
  - Provide RF modulation for interferometer aligning and locking
  - Provide diagnostic beams to alignment/locking control systems
  - Provide spatial stabilization and mode filtering of the laser beam
  - Couple the laser to the interferometer Fabry-Perot arm and recycling cavities via mode matching telescope
  - Isolate the laser from back-reflected light from the interferometer

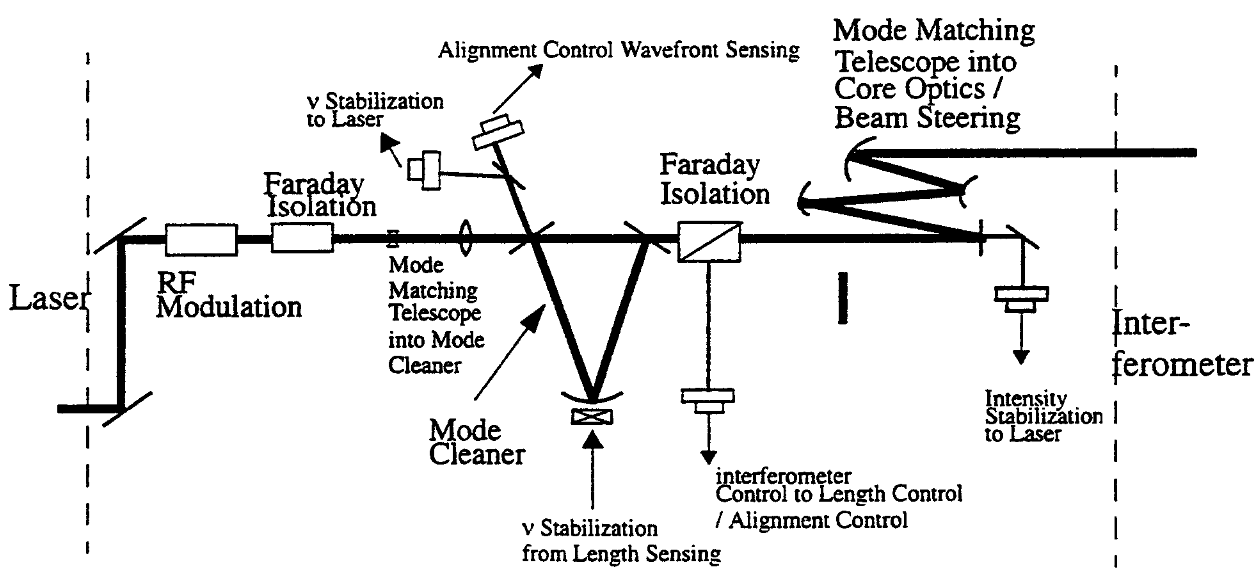
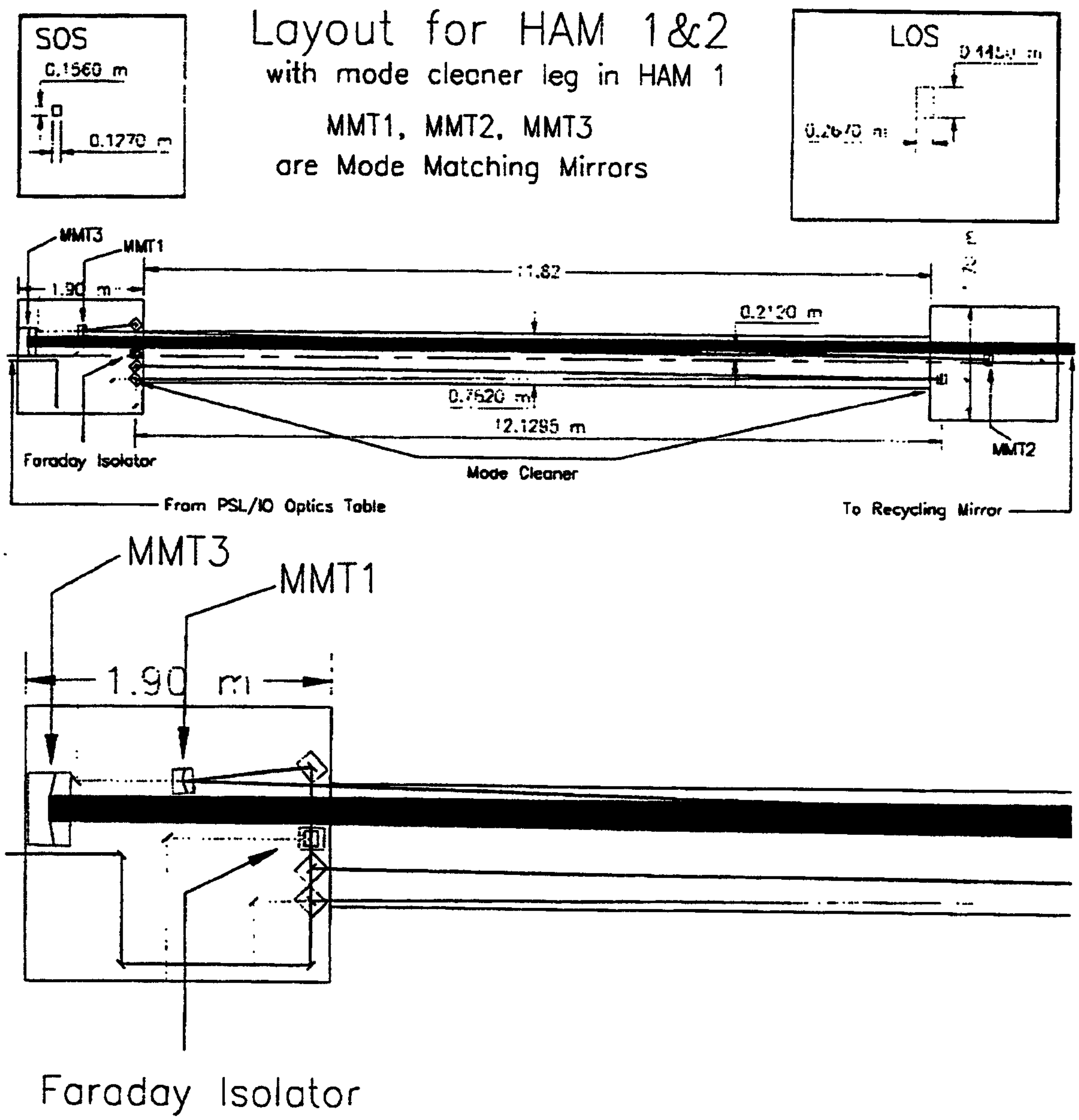


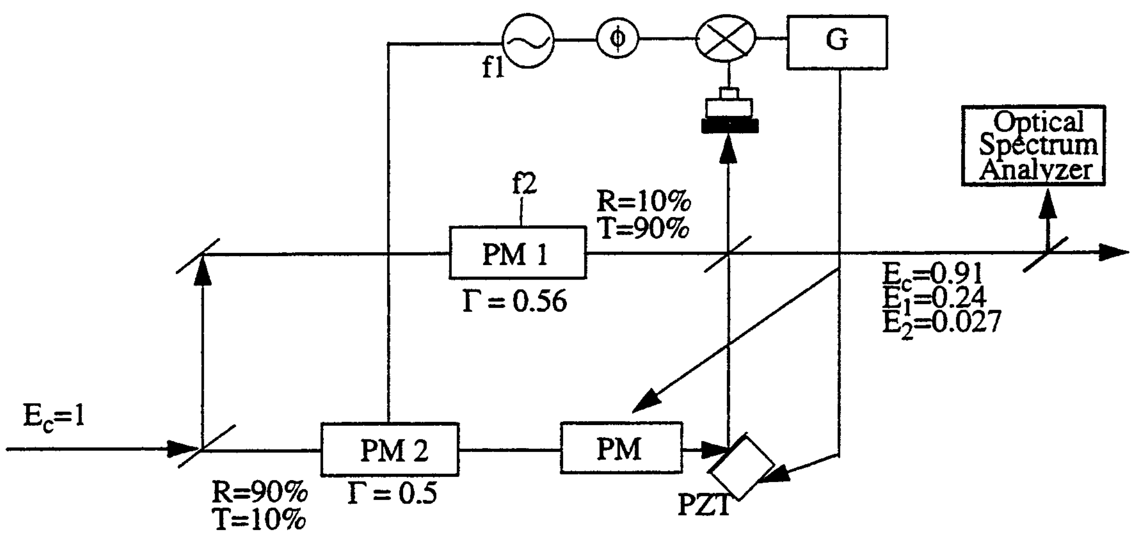
Figure 1: Conceptual layout of Input Optics components

Input Optics Vacuum Layout



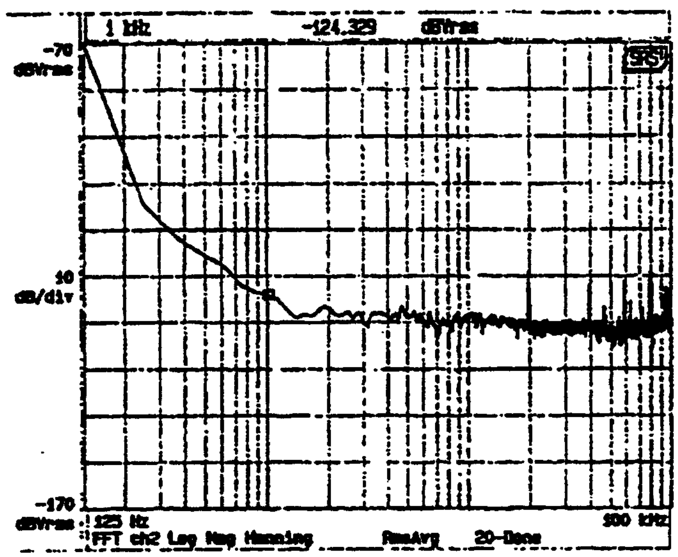
RF Modulation

- Modulation depths
  - Resonant sideband (set by GW shot noise considerations) - $\Gamma = 0.56$
  - Non-resonant sideband (set by reflected light shot noise and ASC sensitivity) - $\Gamma = 0.05$
- Require 'clean' RF spectrum: *no in-band cross-products*



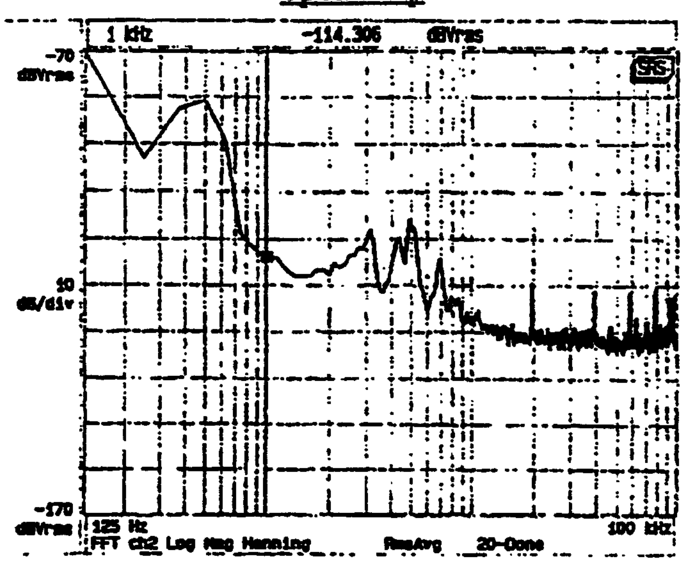
RF Modulation (con't.)

- Intensity noise: PSL

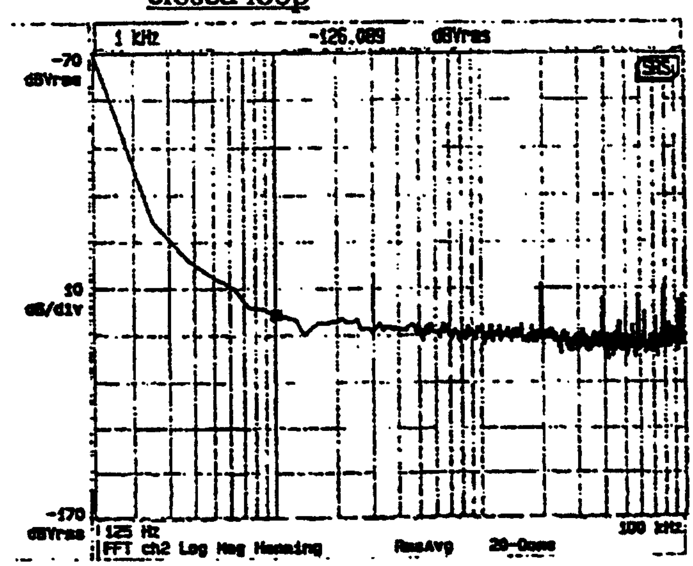


- Intensity noise: after modulation

open loop

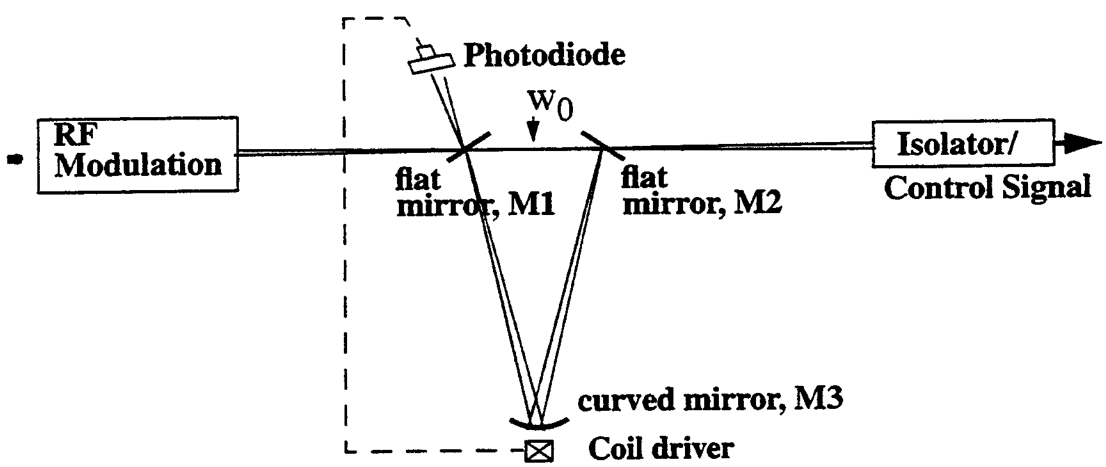


closed loop



Mode Cleaner

- Provide frequency and spatial stabilization
  - ›› Frequency noise < 1×10^{-5} Hz / $Hz^{1/2}$ at MC output
  - ›› Intensity noise after mode cleaner: $\delta I(f) / I < 10^{-8}$ $1/Hz^{1/2}$
  - ›› spatial stabilization: $TEM_{01,10}/TEM_{00} < 3.5 \times 10^{-9} / Hz^{1/2}$
- Must pass RF side-bands cleanly

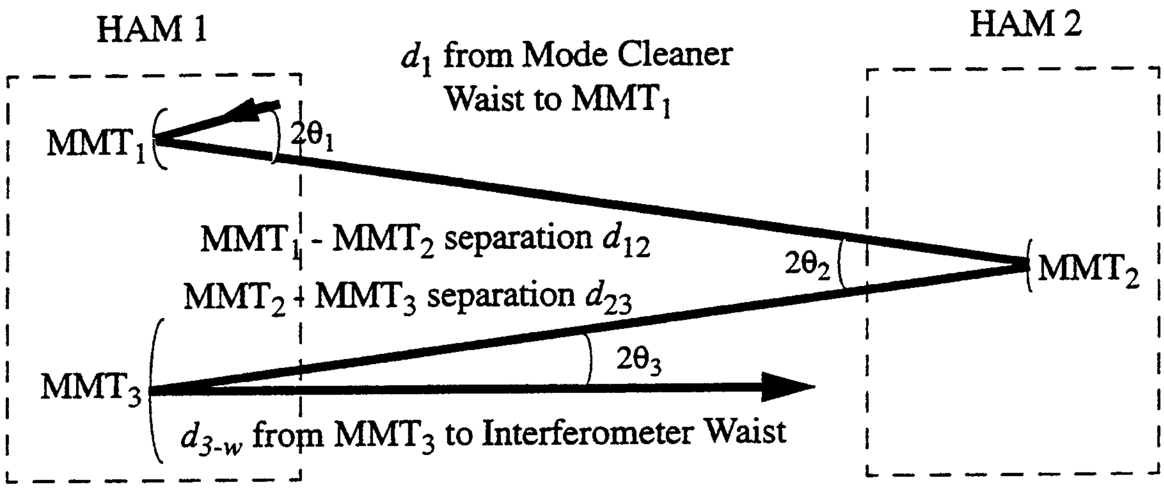


- L_{cav} = 12.255 m (4 km), f_m = 24.46 MHz set by RF considerations
- RC_{M3} = 17.74 m set by attentuation of TEM_{mn} modes
- δf < 50 Hz set by amplitude modulation limit on RF sidebands

LIGO

Mode Matching Telescope

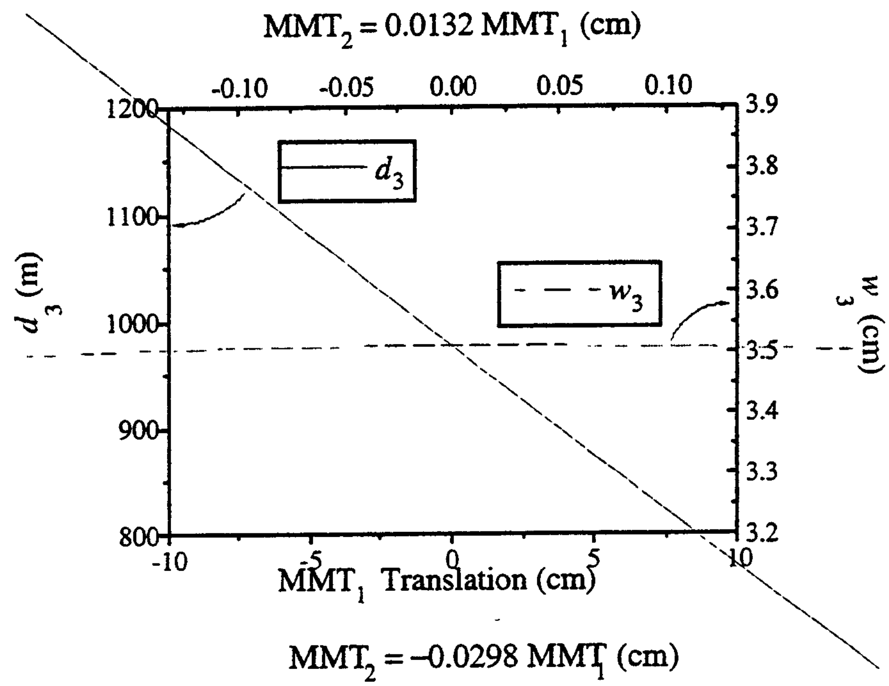
- Reflective Three Element Design



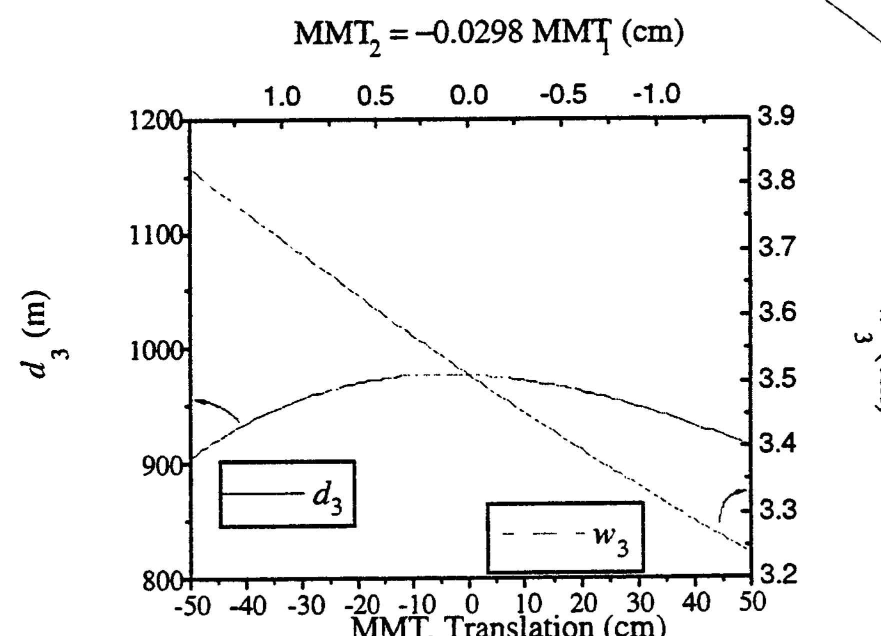
- Radii of Curvature Selection
  - waist magnification: $\omega_{o,IFO} / \omega_{o,MC}$ = 20.9 (4 km)
    = 17.1 (2 km)
- d_1, d_{12}, d_{23} constrained by vacuum dimensions and separation
- Must accommodate deviations in interferometer, mode cleaner mode parameters due to thermal deformations, surface figure errors in optics, stack drift, pump out shifts.
- Must deliver 95% of TEM_{00} power to interferometer and preserve modal quality

Mode Matching Telescope (con't.)

Adjustment of Waist Position



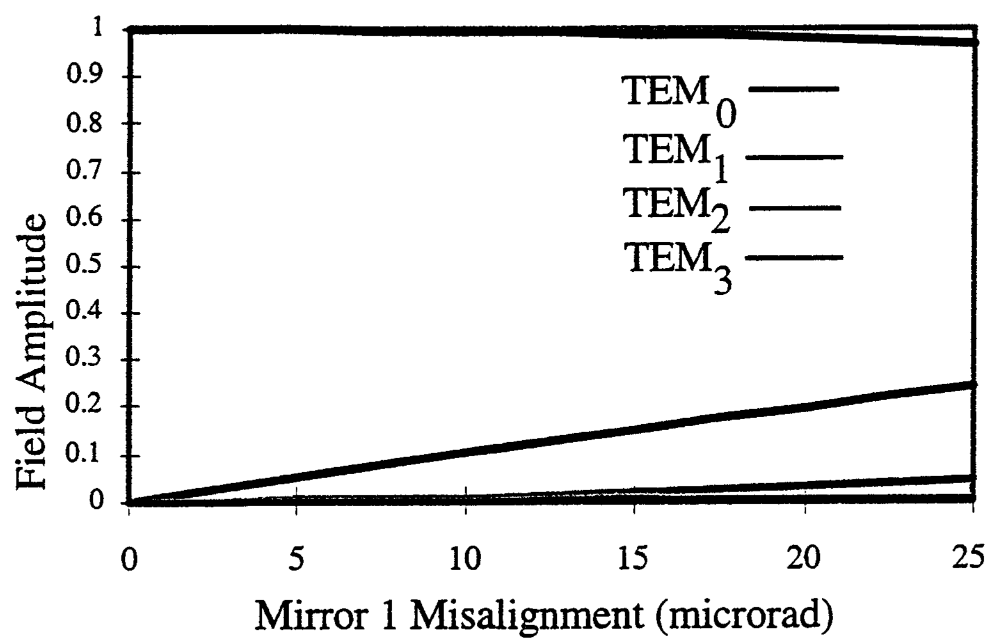
Adjustment of Waist Size



Beam Steering: Flat Mirror vs.: Spherical Mirrors

- Interferometer alignment system uses $TEM_{10,01}$ modes for error signal

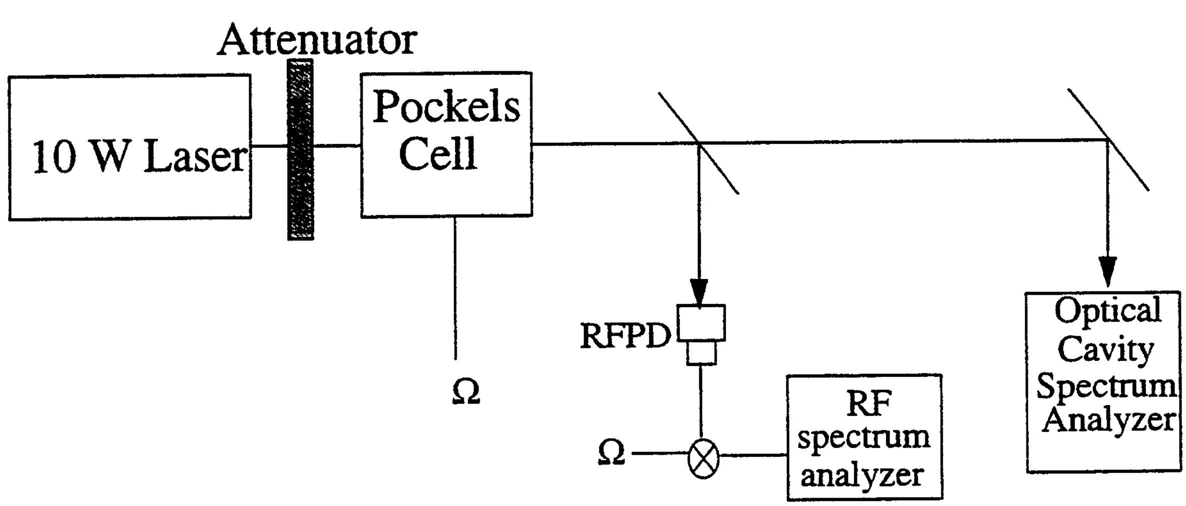
Beam Steering: Flat & Curved Optics



- Negligible difference between flat and curved mirrors; *identical alignment error signals*

High Power Effects on IO Components

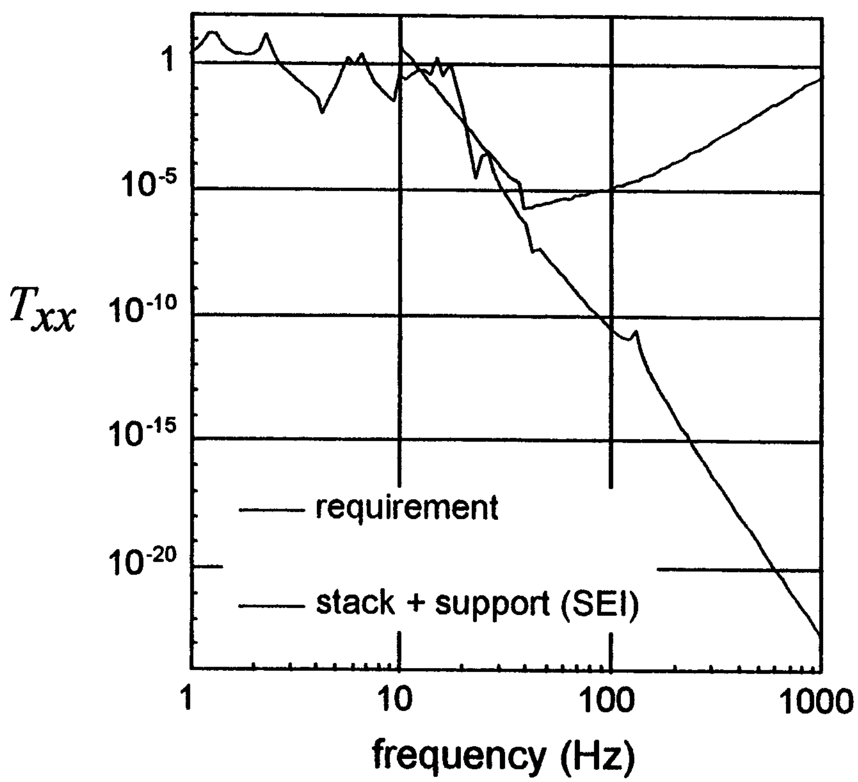
- Transmissive optics (modulators, Faraday isolators) will be subjected to sustained power levels during LIGO operation
- Possible adverse effects on beam quality
  - ››thermal lensing.
  - ››output pointing fluctuations.
  - ››polarization contamination (elliptization).
  - ››absorption of the laser beam.
- Relevant to other LIGO subsystems
- Trade study designed to measure effects and select optimum performing

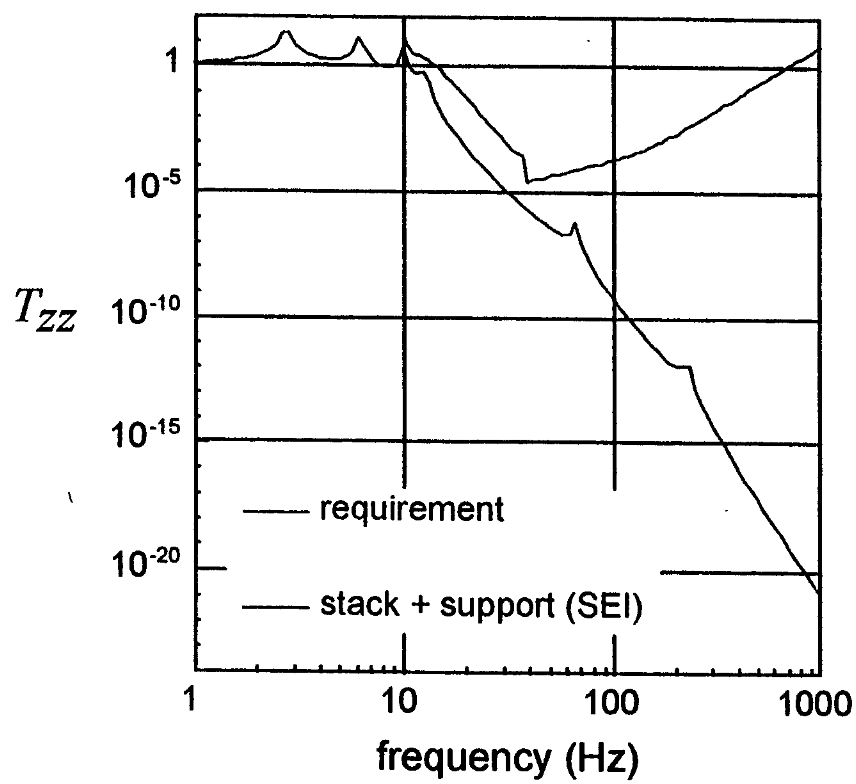


LIGO SEI Status Summary
NSF Review April 1997

- SEI Performance Predictions
- System Layout
  - Configuration
    - BSC & HAM
      - Support Structure
      - Isolation Stack
    - Actuators
- Metal Spring Development

SEI Predicted Performance vs. DRD Req'mts

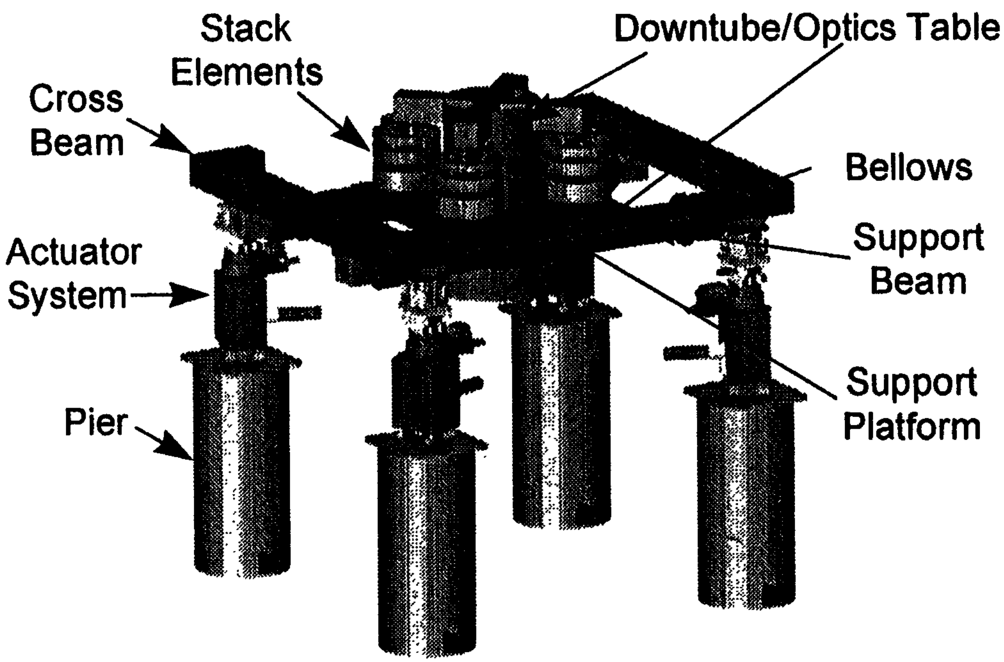




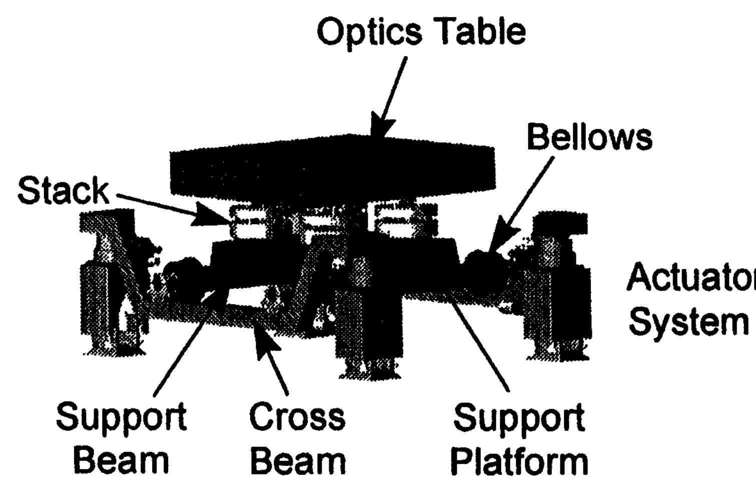
Nominal isolation performance of BSC stack with *COIL springs* compared to requirements

SEI Overview

SEI Design Elements



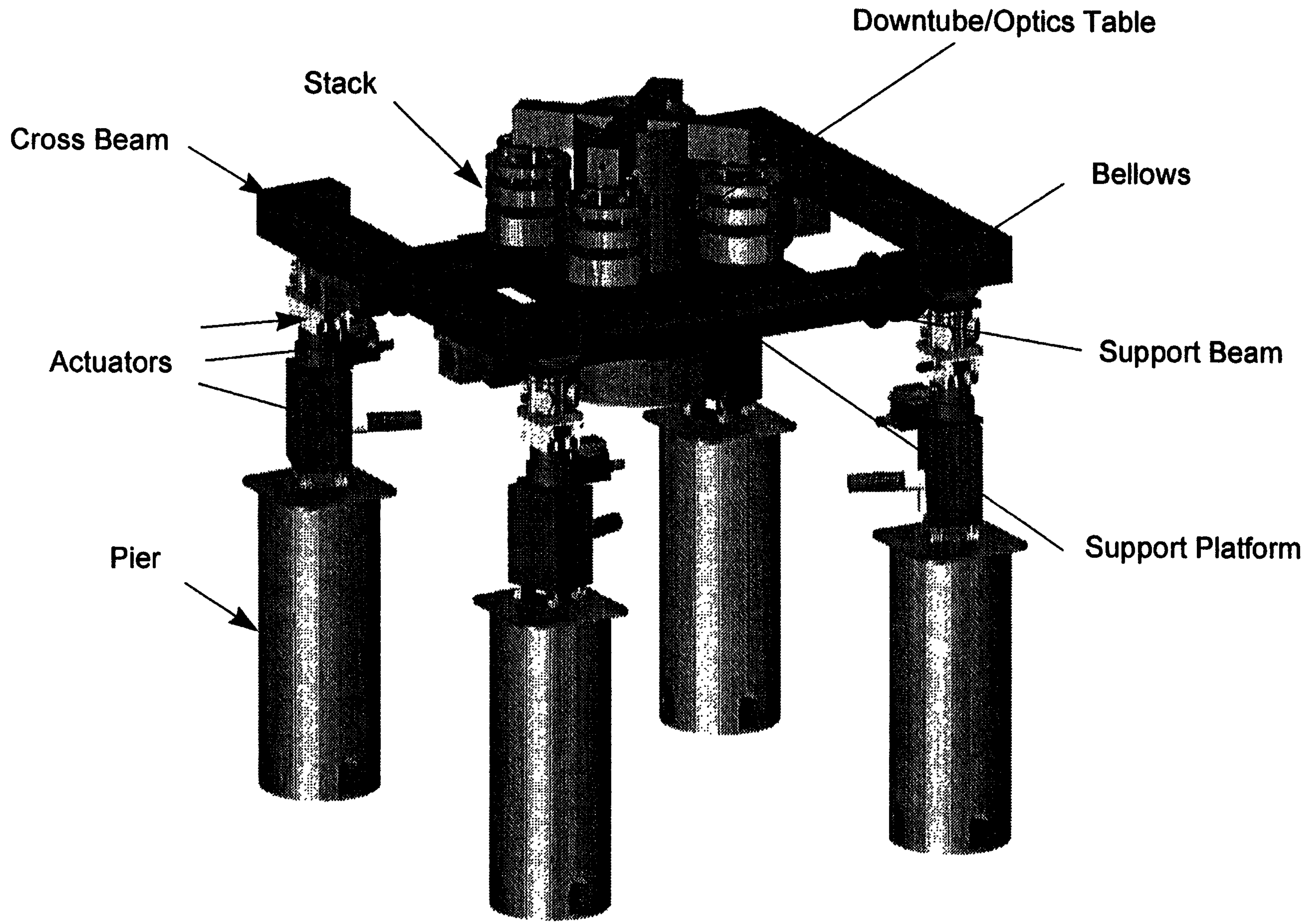
BSC



HAM

SEI Overview

BSC SEI Components



Actuator Requirements

Coarse

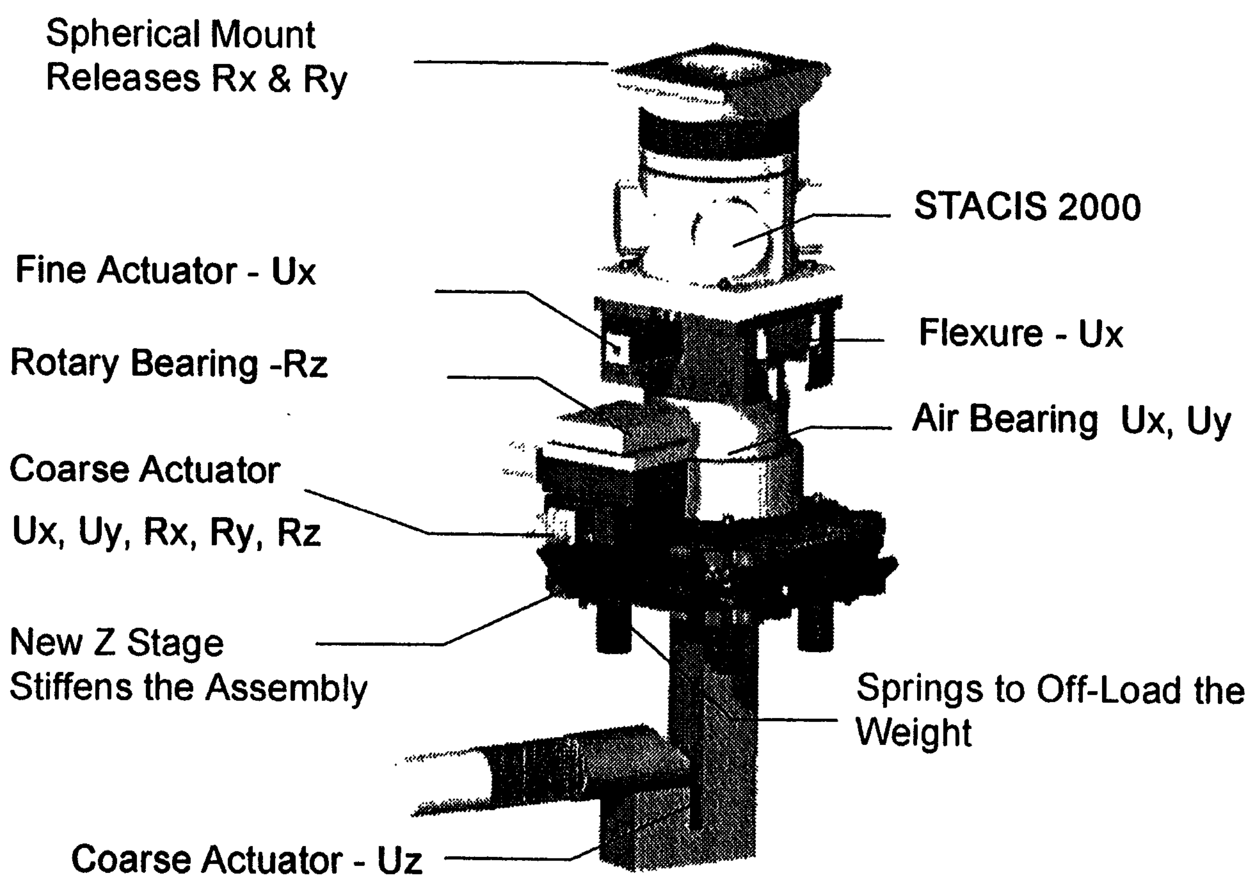
- Objectives:
  - Correct for Long Term Drift
  - One Mechanical Design Compatible for Both BSC & HAM
  - Stiff Design
- X, Y, Z Translation
  - +/- 0.5 cm Travel
  - Resolution 10 μm
  - Repeatability 25 μm
  - Backlash = None
  - Duty Cycle < 1%
- X, Y, Z Rotation
  - +/- 4 mrad
  - Resolution 10 μm
  - Repeatability 25 μm

Fine

- Objectives:
  - Correct for Earth's Tides
  - Smooth Operation, Vibration Less Than 1/10 of Facilities Vibration
  - Stiff Design
  - Able to Tolerate the Bellows Loads
- X Translation
  - 120 μm Travel
  - Resolution < 1 μm
  - Repeatability < 1 μm
  - Backlash = None
  - Duty Cycle = 100%
  - Operational Freq = Up to 1/6 Hz
  - Driven Mass = 5744 kg (12,257 lb)

SEI Overview

Actuator Assembly



Changes since CDR

Spring Requirements

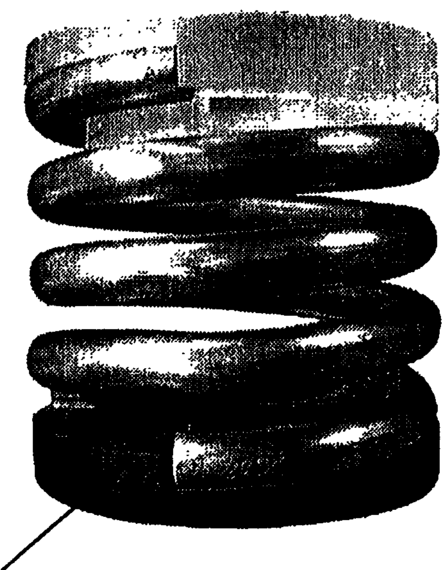
- Mechanical Properties
  - Static Load Capacity ~ 100 lb (445 Nt) or more (limit # springs)
  - Stiffnesses : as low as possible, $\delta_{(35\ Hz)}$ > 1/4 inch (6 mm)
  - Damping :
    - Q of 1st stack resonance < 70
    - high at low frequency (0 to 15 Hz)
    - low at high frequency (above 15 Hz)

      loss factor around 1 Hz : $\eta_{(1\ Hz)} > 1.4\ \%$
  - Internal Resonances > 300-400 Hz
  - Creak: None
  - Acoustic Transmission: << Low
- Vacuum Compatible

SEI Overview

Damped Metal Spring Prototypes

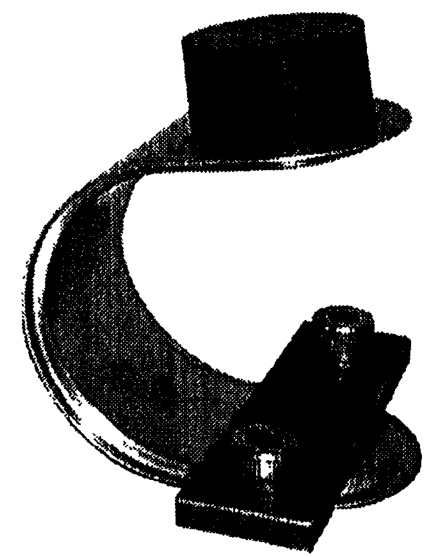
Coil Spring
-Segmented Constrained Layer Damping (CLD) Inside PhBr Tube



Epoxy Seats Replaced With VITON Seats

Loss Factor > 2.5%@ f > 4 Hz

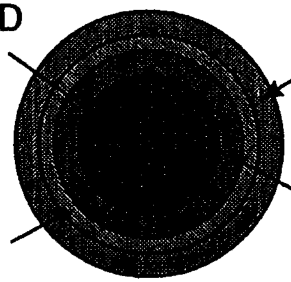
Leaf Spring
-4 Layer BeCu CLD Sandwich

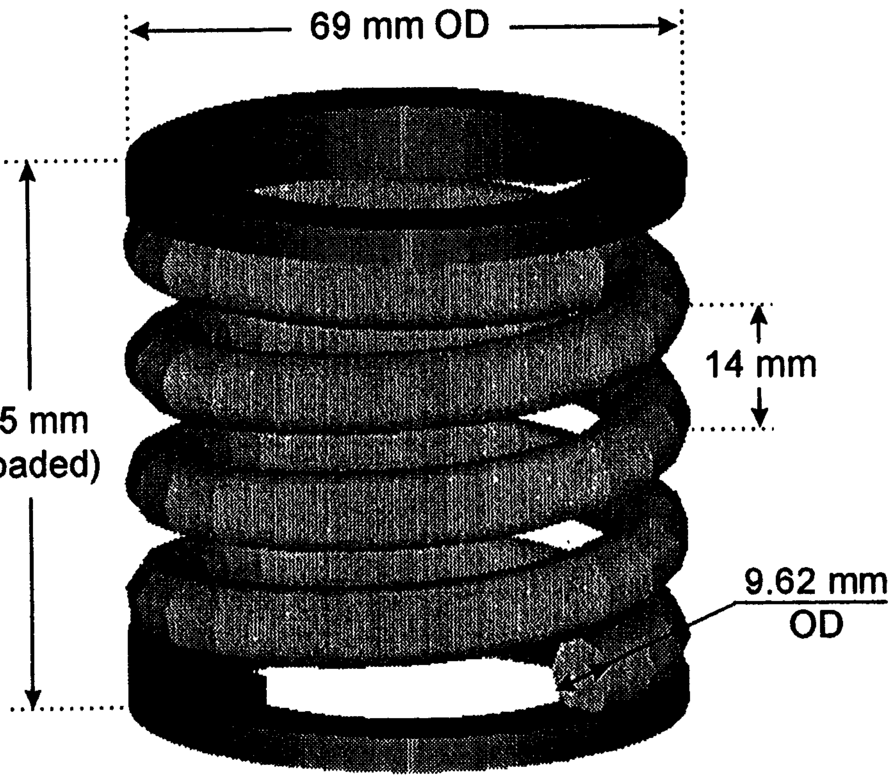


Waiting On Test Facility

SEI Overview

Design

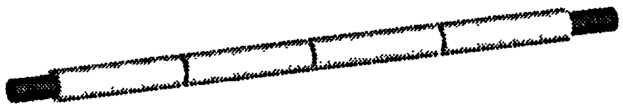


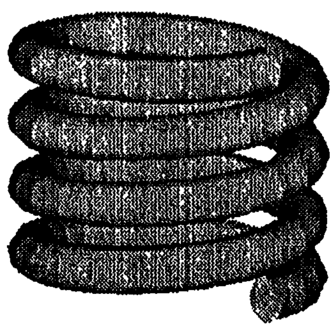


- Outer Tube: Ph. Bronze
  (high yield, good cold winding)
- Inner Sections: Aluminum
  (6061-O, fully annealed, pliable)
- Viscoelastic Layer: Soundcoat DYAD 606
  (stiff, high loss)
- Design Optimization:
  - adjust cross section & coil geometry
  - maximize $P_{max}/k_{ax} > 1/4$ *in (6mm)*

SEI Overview

Manufacturing





- Degrease all Components
- Prepare Core
  - Slide aluminum sections & rubber O-rings on stretched VITON
- Assemble Straight Tube (3ft)
  - Pull core + DYAD + epoxy into PhBr tube
  - Swage PhBr tube
- Coil Tube and Cure
- Weld End Caps
- Molded Viton/(Alum?) Seats

Testing

- Undamped Coils (3)
  - Permanent Set
  - Cyclic Loading (0-solid), 2000 cycles
  - Stiffness – number of "active" coils
- Damped Coil (1) unchamfered slugs
  - Axial Loss Factor (free decay)
- Damped Coils (3) chamfered slugs
  - Permanent Set
  - Cyclic Loading (0-solid), 1000 cycles
  - Stiffness
  - Axial Loss Factor (free decay)
  - Single Stage Platform Shear Properties
- Damped Coils on Viton Seats

Performance Status

- Observed VS Expected Performance
  - better than expectations:
    - shear loss factor = 70% of axial loss factor (40% expected)
  - close to expectations:
    - axial damping ~ 3% loss factor from 5 to 10 Hz
    - axial stiffness ~ 42 N/mm (245 lb/in)
  - worse than expected: (Still Not a Problem)
    - shear stiffness ~ 210 % of axial stiffness (40% assumed)
- Viton Seats Required for Acoustic and Creak Issues:
    - decrease stiffnesses, increase damping (+ 20% @ 5 - 10 Hz)
    - BUT: large volume & exposed area
- Damping data at Low Frequency Needed (Q of first stack mode)

SEI Overview

WHAT HAVE WE ACCOMPLISHED?

TASK	BSC	HAM
FEA Studies		
• Downtube/Optics Table	√	N/A
• Optics Table	N/A	√
• Base Supp't/ Supp't Tubes/Cross Beams	√	√
• Coarse Actuator (Z)	√	√
• Bellows	√	√
• Vacuum Tank	√	√
• Stack Components	√	√
SEI Performance Studies	√	√
Prel. Construction Drwgs	√	√
• Downtube/Optics Table	√	N/A
• Leg Elements	√	√
• Optics Table	N/A	√
• Base Supp't/ Supp't Tubes/Cross Beams	√	√
• Piers	√	√
• Mtg. Plates/Spacers/Misc. Hardware	√	√
• Bellows	√	√
• Actuators/External Supports	√	√
Prel. Hardware Costing	√	√
Conceptual Design Ext. Supp'ts/Actuators	√	√

WHAT HAVE WE ACCOMPLISHED?
(continued)

TASK	Coil	Leaf
Damped Spring Development		
• Spring Design Optimization- Anal. & FEA	√	√
• Assembly Tooling Design	√	√
• Assembly Tooling Fab.	√	√
• Assembly Procedure (Viscoelastic Layers)	√	√
• Tooling Devlopment	√	√
• Static Load Tests	√	√
• 2000 Load Cycles Undamped	√	
• Production Tooling	√	
• 1000 Load Cycles Damped	√	
• Dynamic-Loss Factor		
• Simple Pendulum	√	
• Single Layer Test	√	

Summary

- SEI system design is progressing rapidly
- Plan for resolving technical concerns and getting prototype hardware in the users hand earlier than originally planned
- Test equipment and facilities are being installed to assess performance

Interferometer Sensing/Control

Detector Subsystem Design Status Report

M. E. Zucker

LIGO Detector ISC Task Group

National Science Foundation Technical Review

April 16, 1997

ISC Design Scope

- Principal Functions:
  - Interferometer length and alignment sensing (ISC = LSC + ASC)
    - Fiducial references/tooling for optics installation, length & angle setup
    - Low-noise sensors for detection-mode alignment and cavity length
  - Length & alignment control system design
    - Electronics & networks implemented by LIGO CDS partners
  - Strain signal readout & calibration
  - End-to-end interferometer diagnostics
- ISC has three Modes of operation:
  - Initial alignment (all mirrors within 0.5 μrad)
  - Acquisition (acquire resonance)
  - Detection (hold lengths/angles to < 0.1 pm /10 nrad; provide readout)

LIGO-G970085-00-D

Lock Acquisition Simulation & Design

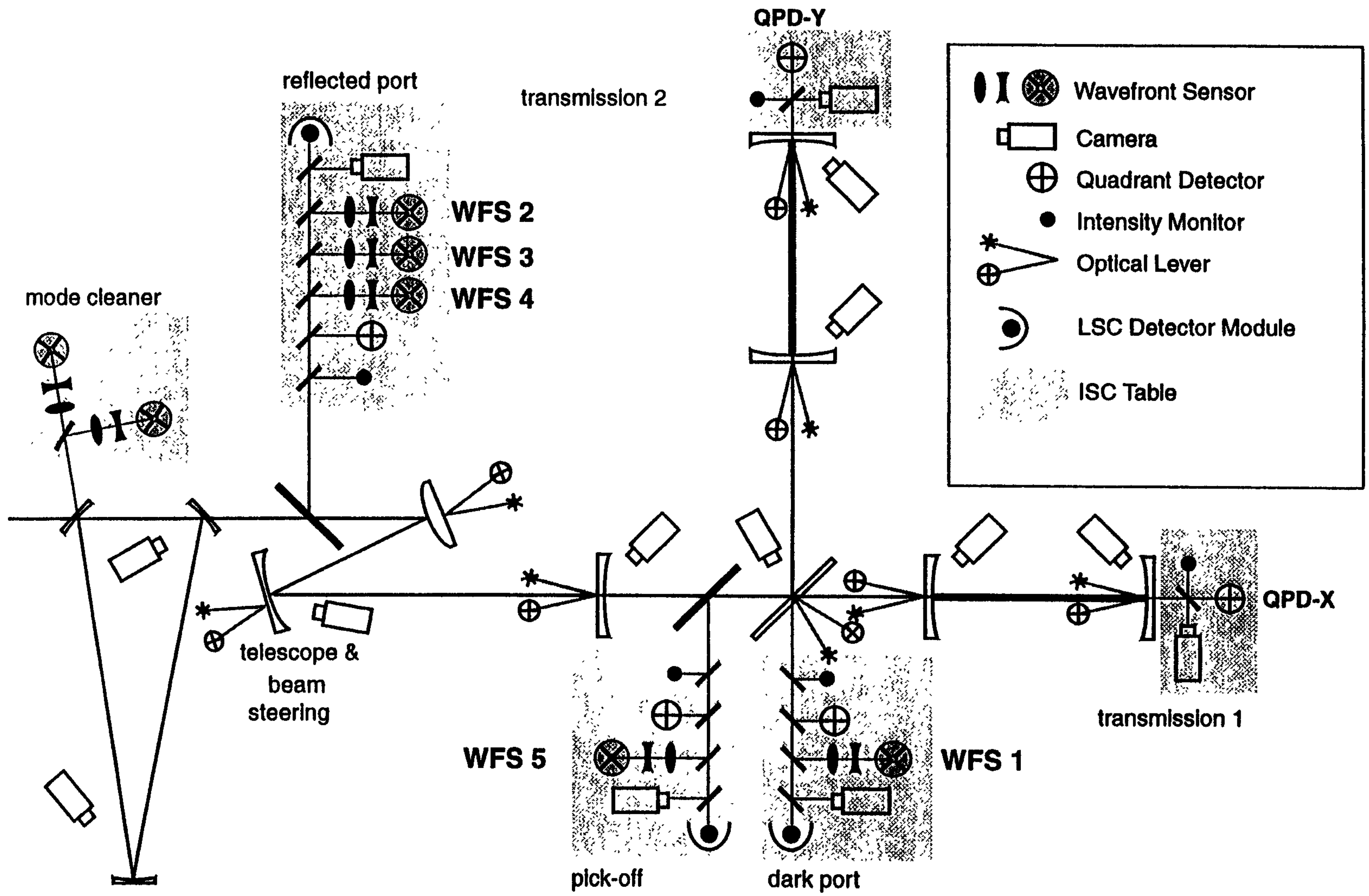
- Single Mode Acquisition Code (SMAC) simulation model (Redding, Needels, Sievers)
  - Used to develop baseline lock sequence; now used to classify optical plant features affecting acquisition
  - Developed triggered sign flip technique, sensing signal swap
  - Extension to higher-order spatial modes (MMAC) in progress
- SpatioTemporal Model (Beausoleil, Yamamoto, Sigg)
  - Different mathematical basis, same target problem: misalignment tolerance for successful lock acquisition
  - Formulated directly in modal basis
- Validation: 40 meter Recycling Experiment

LIGO-G970085-00-D

Detection Mode Sensor Design

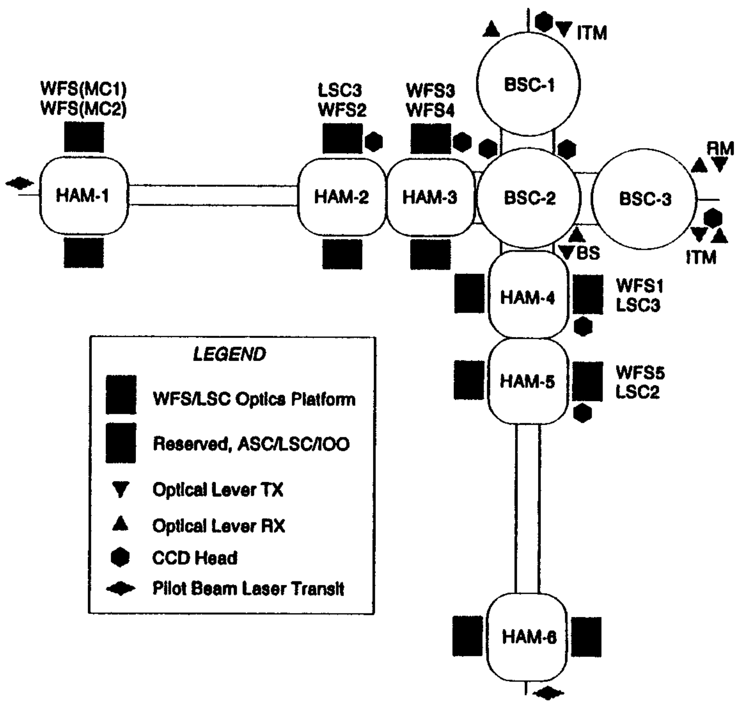
- ASC:
  - Preliminary design based on FMI-tested Wavefront Sensor prototype (almost no changes required!)
  - Additional wavefront sensor prototype experience with 40 meter recycling, phase noise interferometer R&D
  - Integrated hardware/software test of first article, 4 degree-of-freedom input optics control system (will deliver to Hanford 4km on completion)
- LSC:
  - Tests of InGaAs photodiodes & radiofrequency circuits advancing rapidly
  - Preliminary results highly encouraging
  - More bench tests plus integrated test on PNI (summer)
  - Optical backscattering tests planned

Detection Mode Sensor Schematic



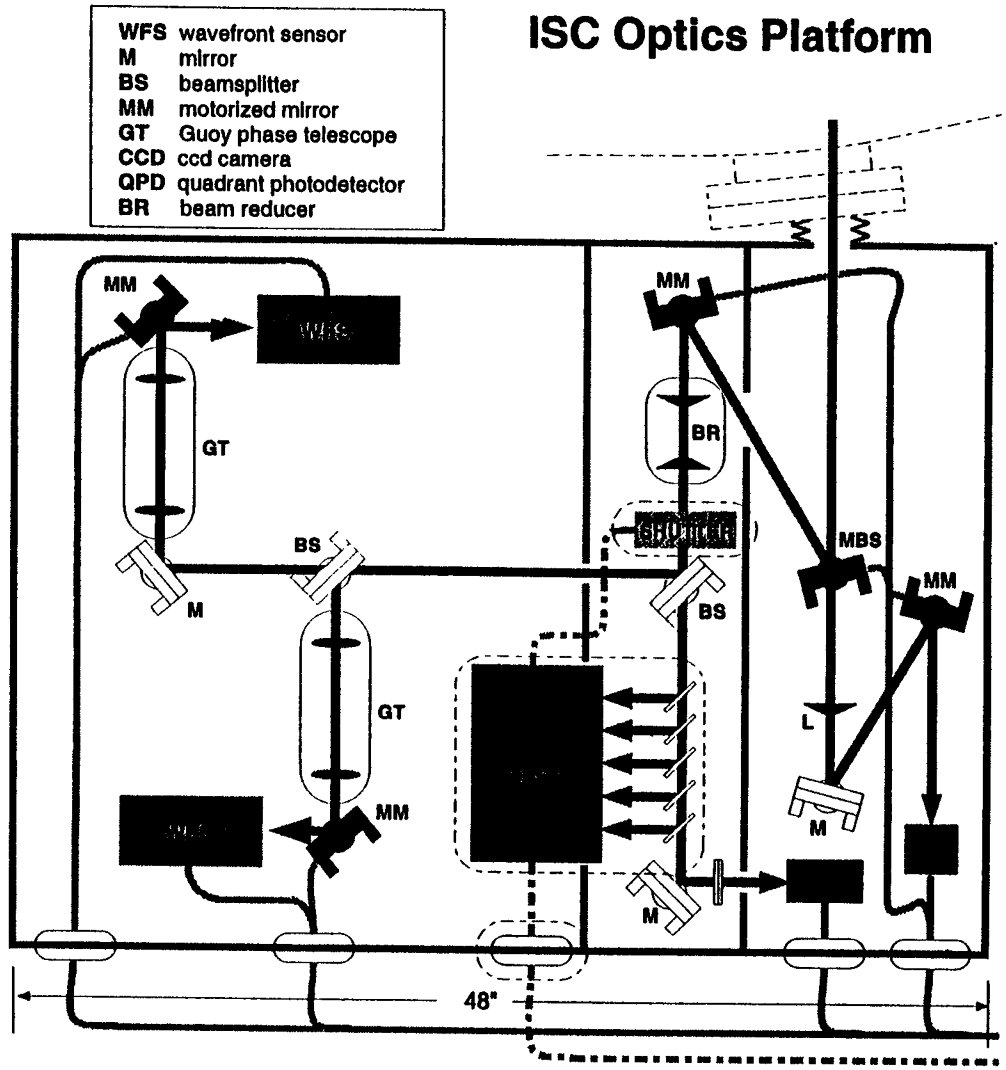
LIGO-G970085-00-D

Detection Mode Sensor Arrangement



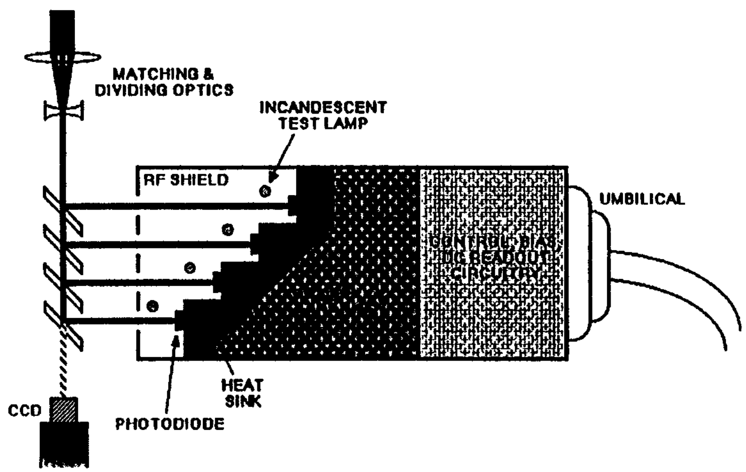
ISC sensor layout
(WA 4km, corner station)

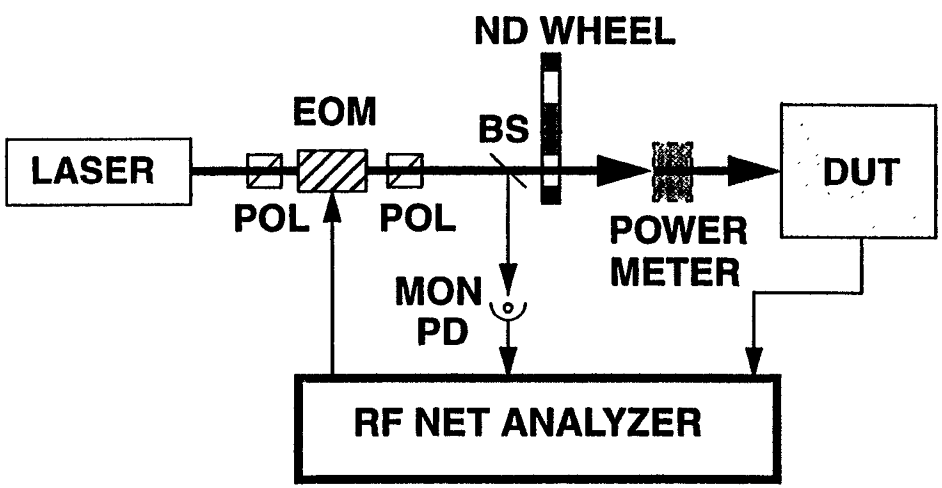
ISC Optics Platform



LIGO-G970085-00-D

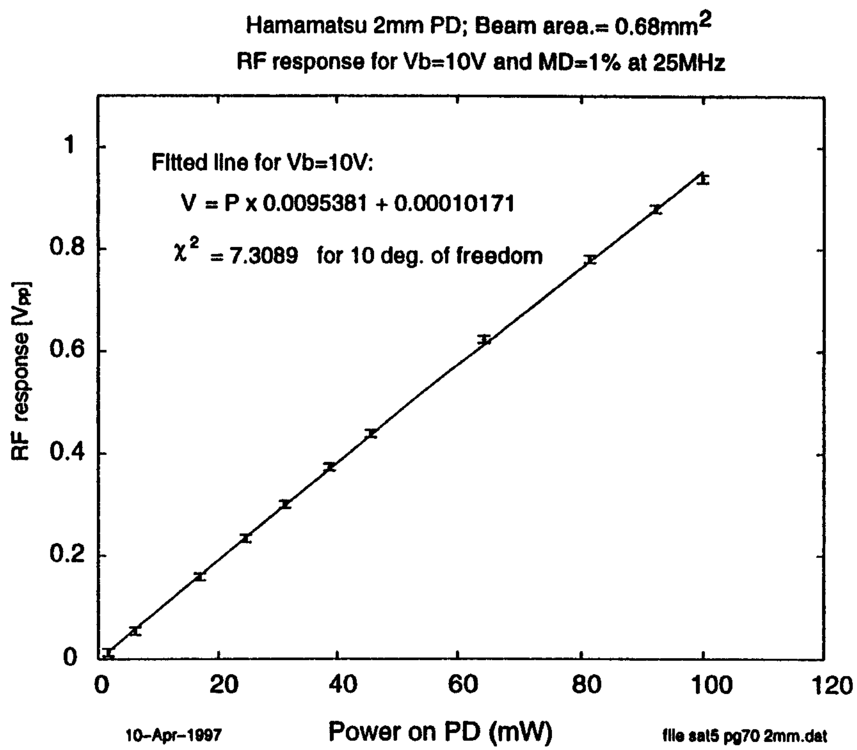
High-Power RF Photodetectors



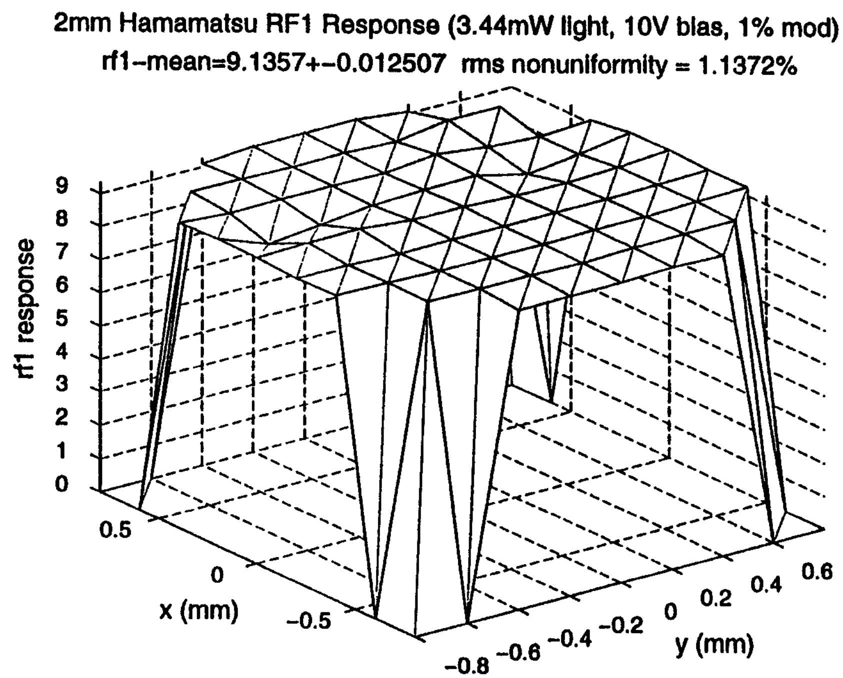


- ❍ Multiple InGaAs diodes for high "dark port" power (~ 0.6 W)
- ❍ LIGO program builds on VIRGO research (Dominjon, Flaminio)
- ❍ Preliminary results:
  - ❑ Intensity I > 350 W/cm^2 ! ✓
  - ❑ RF impedance ✓
  - ❑ Linearity, spatial uniformity ✓
- ❍ Renewed concern: PD backscattering

PD device bench test results (prelim.)



RF response vs. incident power, beam area 0.68 mm^2, diode dia. 2.0 mm



RF response vs. beam position, 2.0 mm dia. diode

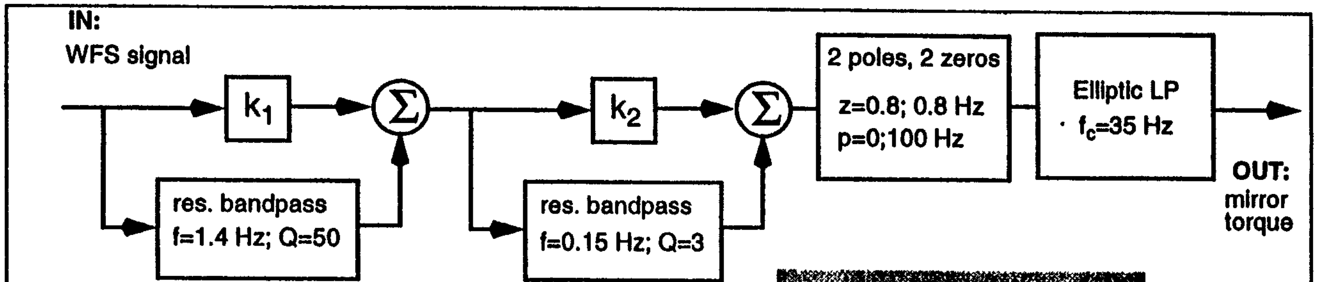
Detection Mode Controls Design

- Multi-Input/Multi-Output (MIMO) loop analysis using Twiddle, Modal Model, and Matlab/Simulink-based time-domain network simulations
- Excitation time series directly from Hanford & Livingston seismic measurements (Battelle), filtered by seismic isolation stack model (Hytec) and suspension model (LIGO)
- Model features (so far)
  - Gain constraints from RMS deviation tolerances & noise coupling coefficients (e.g., laser intensity noise)
  - Includes crosstalk and length/alignment interactions
  - Can propagate noise from laser, radiofrequency local oscillator, electronics, nonlinearity...
  - Can treat digitization, numerical precision, latency effects

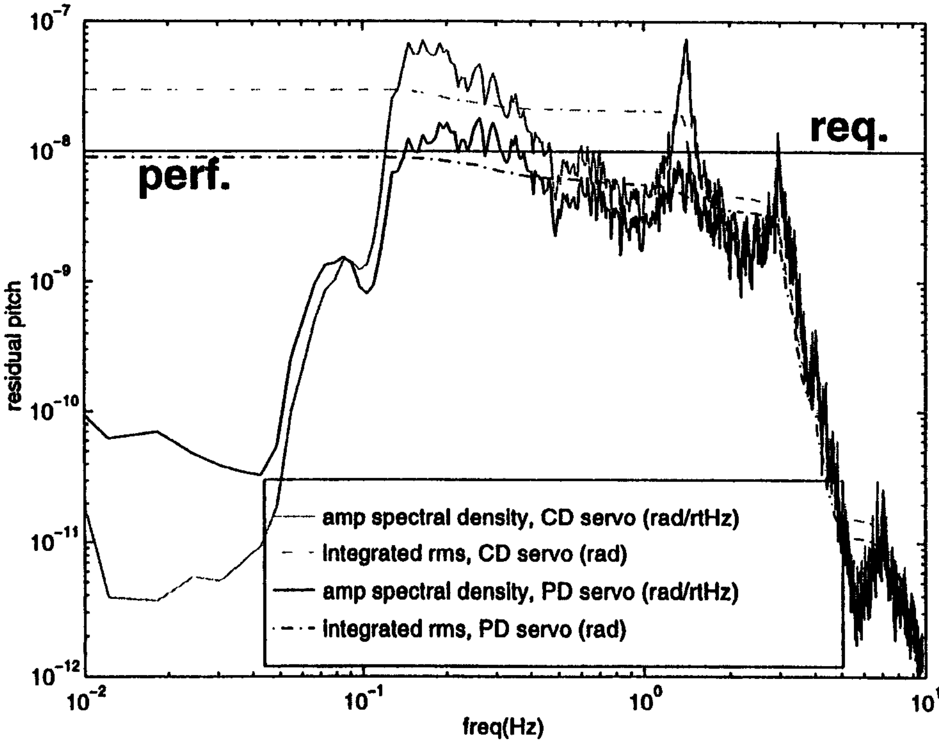
LIGO-G970085-00-D

Design example: WFS alignment servo

Equivalent SISO model



bandpass function: $\dfrac{(2\omega_0/Q)s}{s^2 + \frac{\omega_0}{Q}s + \omega_0^2}$



Performance vs. RMS residual requirement (end test mass pitch, Livingston seismic noise, Hytec Leaf Spring stack model

Current Status & Tasks in Progress

- ASC Preliminary Design complete (PDR 2/97)
  - Final design in progress, concurrent engineering prototype/first article tests
    - Initial alignment components (optical levers, video, autocollimators, theodolites)
    - ASC electronics, digital control hardware/software implementation
    - goals: one of everything tested in '97,+ deliverable first articles for Hanford 4 km Input Optics alignment
- LSC Preliminary Design in progress (PDR planned 6/97)
  - Lock acquisition models advancing rapidly: baseline sequence identified
  - Photodetector development nearing maturity; prototype trial planned on Phase Noise Interferometer for summer
  - Detection mode controls preliminary design nearly complete, meeting gain and noise requirements
  - Digital control simulations in progress; bench test planned for summer

Conclusions

- Issues:
  - Lock acquisition (especially alignment tolerance)
  - Photodetector development
  - Controls implementation
- Priorities:
  - Complete Phase Noise and 40m Recycling R&D
  - Complete nonlinear control model simulations
  - Sensor & Control Electronics engineering prototype/first article tests
  - Complete final designs on current plan
    - ASC & LSC delayed, but within original 3/96 plan float
    - New scientist, student, & optical/mechanical engineer added since January

THE FMI ALIGNMENT EXPERIMENT

DANIEL SIGG, NERGIS MAVALVALA

April 16, 1997

❑ Effects of misalignment

- ❍ Degradation of GW sensitivity ⇒ $\theta_i \sim 10^{-8}$ rad
- ❍ Misalignment-beam jitter coupling ⇔ $\theta_i \sim 10^{-8}$ rad

❑ Need for wavefront sensing

- ❍ drifts of the local frame ⇒ $\theta_i \sim 10^{-7}$ rad
- ❍ interferometric sensing using existing modulated light

❑ Objectives of the FMI experiment

- ❍ Establish and verify a wavefront sensing scheme for LIGO
- ❍ Experimentally validate the theoretical model
- ❍ Develop and characterize the wavefront sensing hardware
- ❍ Implement closed loop control of all angular degrees of freedom

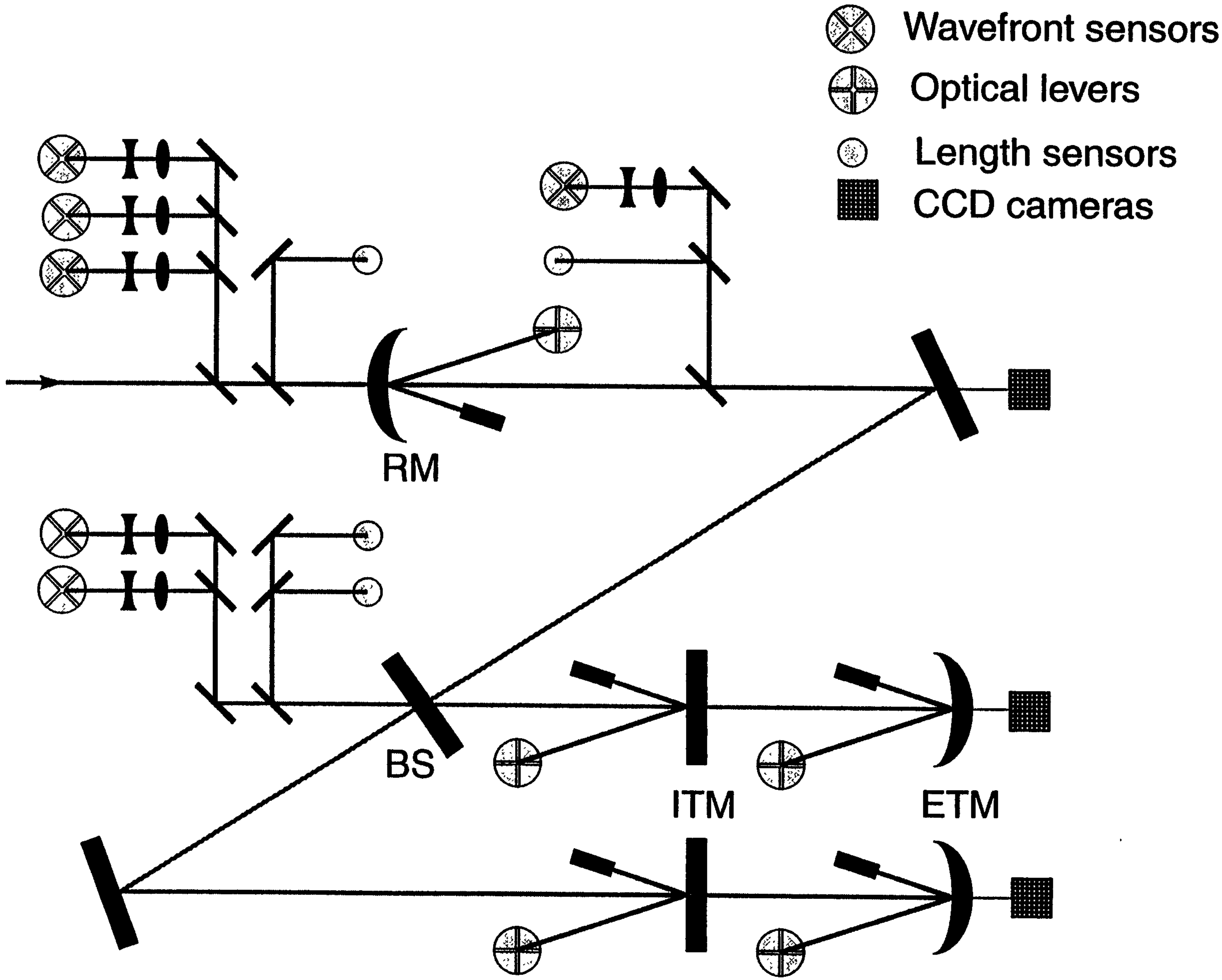
Principles of Wavefront Sensing

Angular misalignments excite higher-order transverse modes

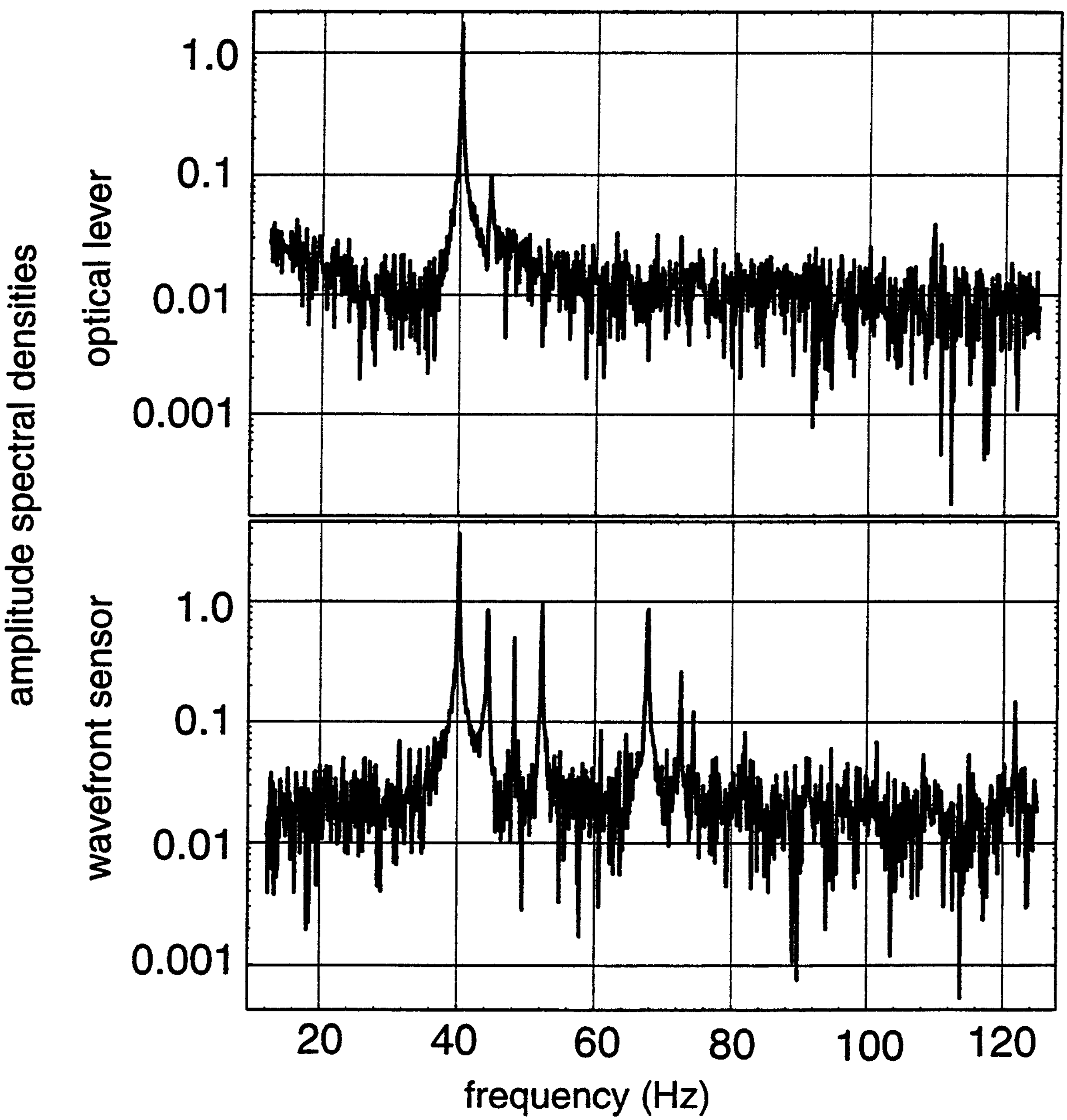
- **TEM_{10} amplitude $\propto$ misalignment angle**
- **Modal model**
- **Wavefront sensor measures TEM_{10} amplitude**
- **Detection Scheme**
  - Length sensor signal:
    beating of carrier TEM_{00} field against sideband TEM_{00} field
  - Wavefront sensor signal:
    Beating of carrier TEM_{00} field against sideband TEM_{10} field
    ⇨ spatial map of this TEM_{10} mode at modulation frequency
    ⇨ segmented photodetector

LIGO

THE FMI ALIGNMENT EXPERIMENT

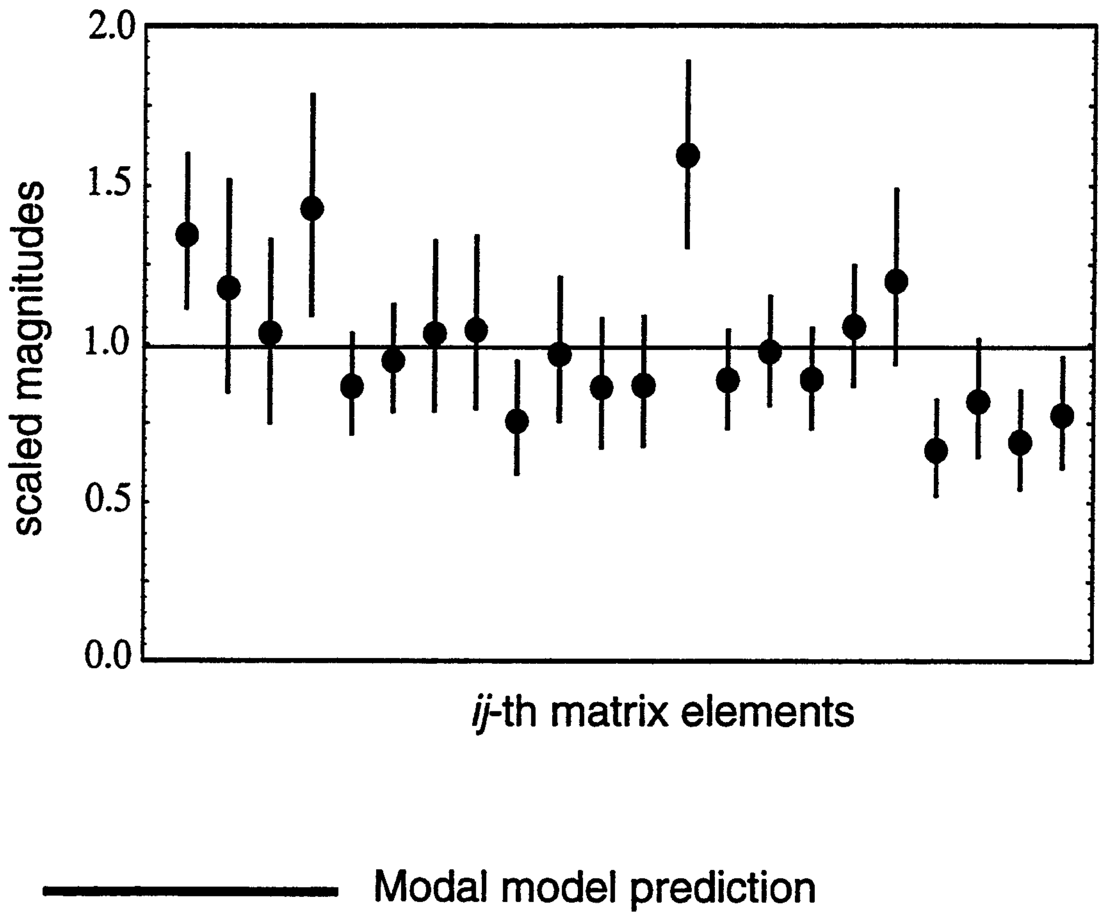


DATA


amplitude spectral densities
optical lever
wavefront sensor
1.0
0.1
0.01
0.001
20
40
60
80
100
120
frequency (Hz)

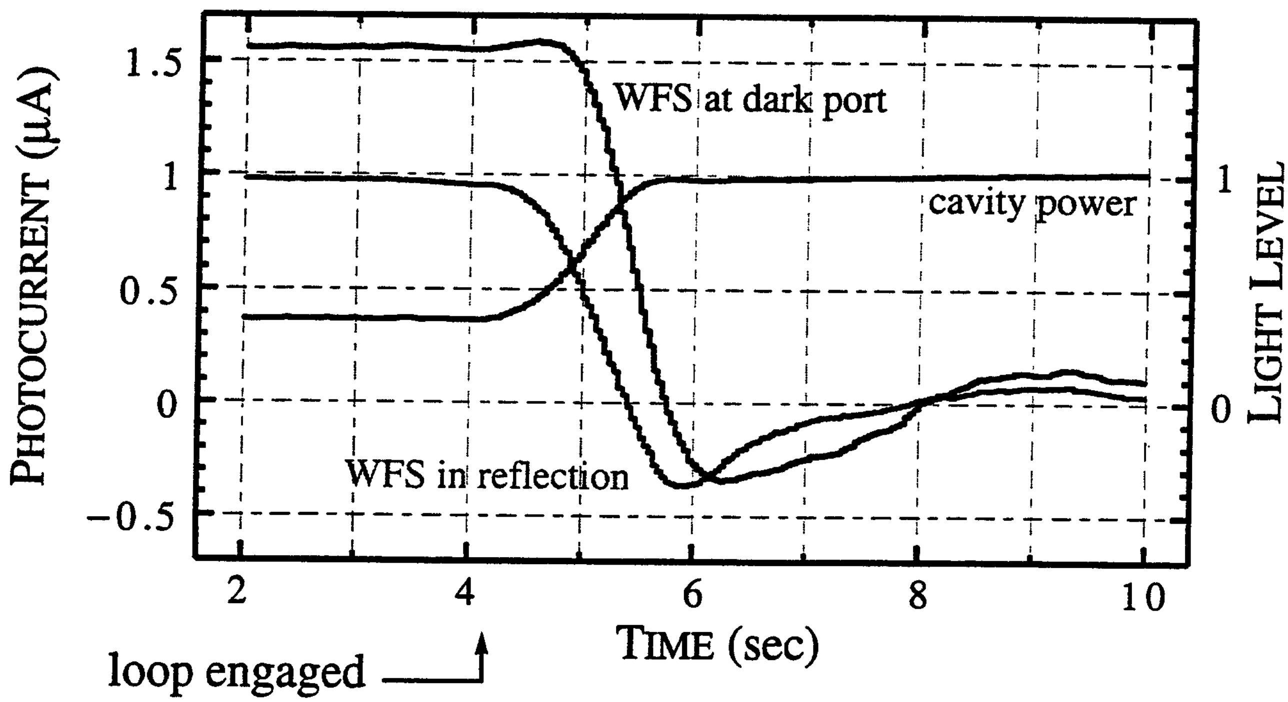
RESULTS

❑ Dominant matrix elements



WAVEFRONT SENSORS AT WORK

- **Closed loop control**



Conclusions

- ❑ All 10 angular degrees of freedom under closed loop control ➪ wavefront sensing works
- ❑ Measurement of matrix elements ➪ modal model works
- ❑ Design tool for LIGO

LIGO Control and Data System
Control and Monitoring

LIGO NSF Review

April 1997

Jay Heefner

LIGO Control and Data System
Control and Monitoring

- Definition:

  ››For design purposes, the LIGO CDS has been divided into 3 major components: Control and Monitoring, Data Acquisition and Interferometer Diagnostics.

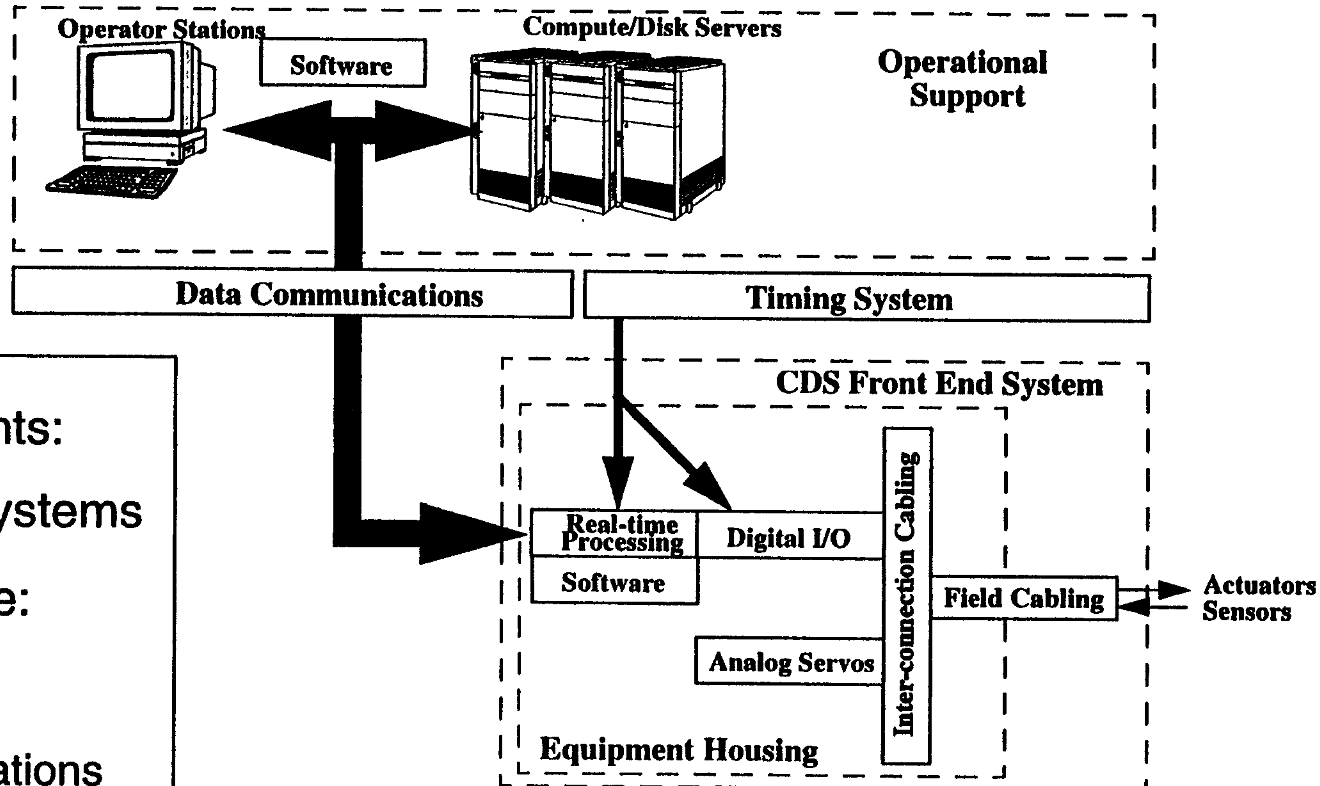
  ››The Control and Monitoring systems are designed as a Distributed Control System and provide and cabling, electronics hardware and software required to monitor and control each of the LIGO subsystems, i.e. vacuum, Interferometer subsystems, etc.

- Purpose of talk:

  ››Present a general overview of the control and monitoring portion of the LIGO CDS

  ››Present the conceptual designs for the ASC wavefront sensing and control and ASC video systems as an illustrative of how the various components of the LIGO CDS are being used to develop controls for the various LIGO systems.

LIGO Control and Monitoring



- Major Components:
  - ››Front End Systems
  - ››Infrastructure:
    - —Timing
    - —Communications
    - —Operations Support

LIGO Front End Systems

- Front End I/O Bus- VME
- Real-Time Control Processors: present
  - Heurikon Baja4700: MIPS based
  - Motorola MVME162-333: 68040 based
  - VxWorks operating system
  - DSP based processors for advanced signal processing
- Analog Servos and Signal Conditioning
  - Modules developed in 6U Eurocard format
  - Field boxes for signal amplification and conditioning near sensors/actuators
- Equipment Housing
  - 19 inch equipment racks
  - interconnect wiring through DIN rail blocks on side of rack
  - Critical signals routed directly

LIGO CDS Infrastructure

- Timing System
  - ››GPS based
  - ››Antennas and receivers located at each building
  - ››Time info available via the VME backplane
  - ››slave units use IRIG-B connections
  - ››Various clocks output via the front panel
- Communications
  - ››ATM backbone: OC-3
  - ››Direct fiber connections for reflective memory
  - ››Video to ATM converters for video transmission

LIGO CDS Communications

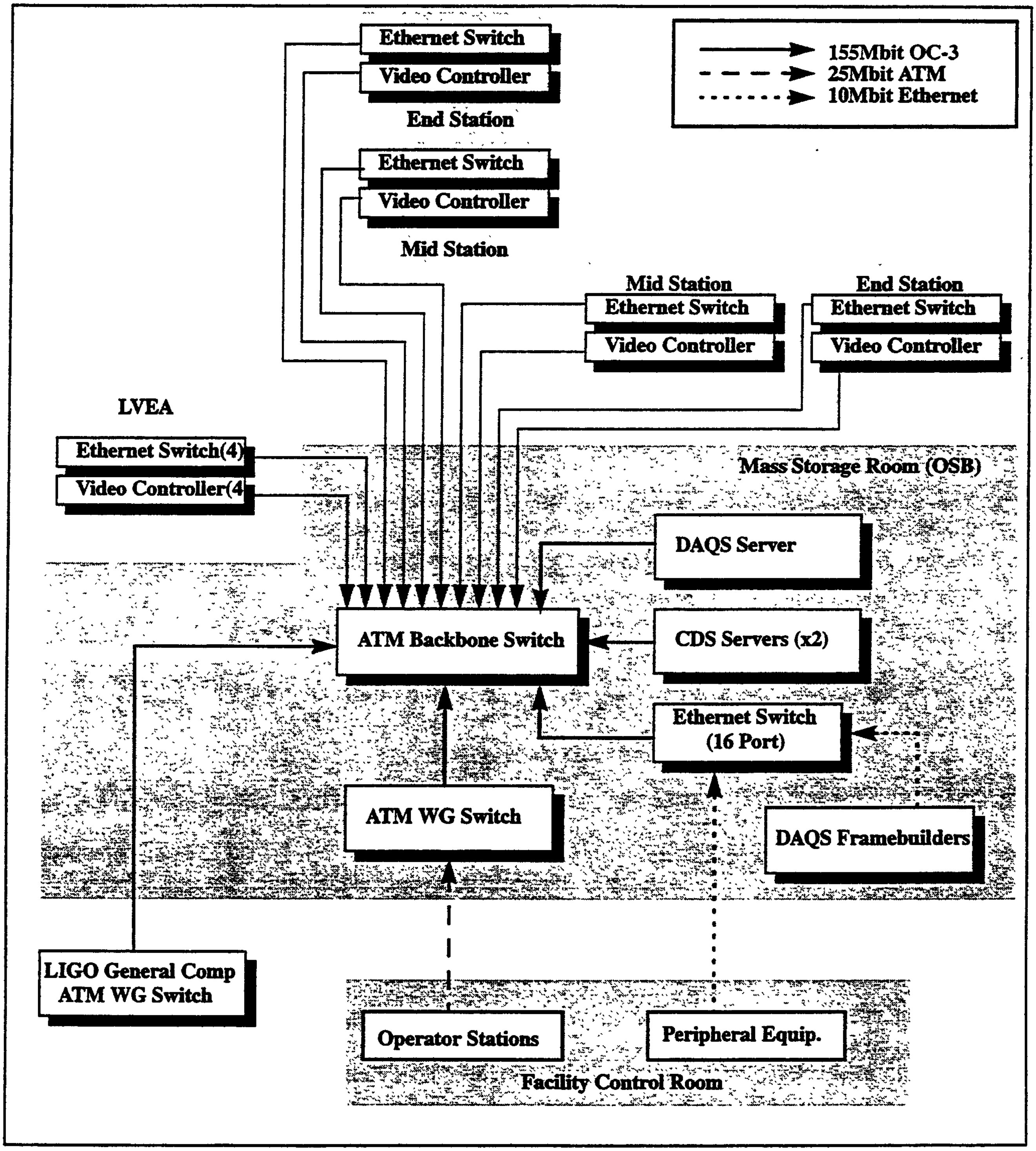


Figure 1: CDS Control and Monitoring Network

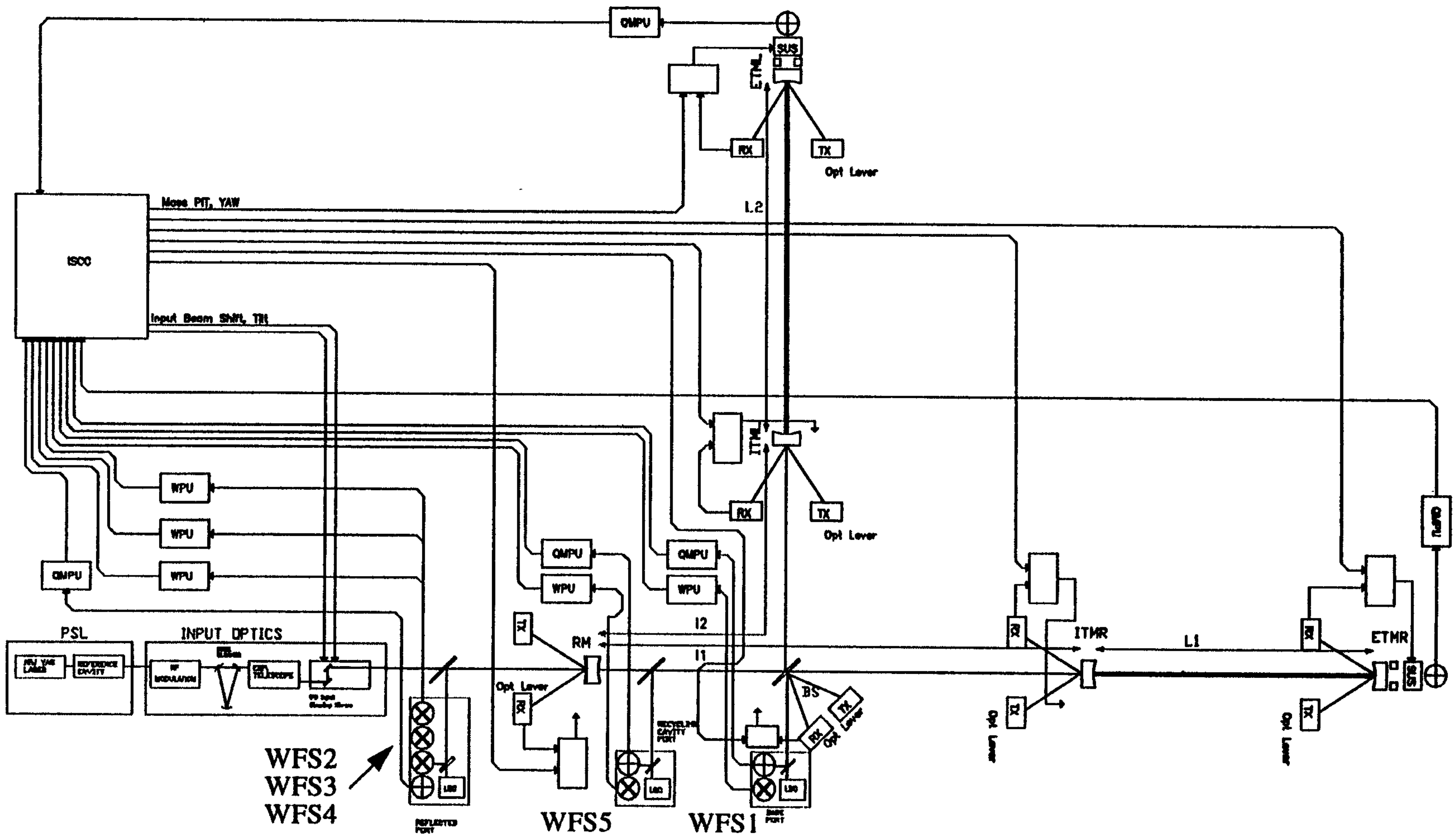
LIGO CDS Infrastructure Operations Support

- Operator Stations
  - ››Fixed Control Room Consoles
  - ››Portable Operator Stations (laptops)
  - ››Remote Access
- Computer and Mass Storage Area
  - ››Control and Monitoring Server
  - ››UPSs
- Human-Machine Interface
  - ››MEDM
  - ››SAMMI

LIGO CDS Infrastructure Operations Support

- EPICS provides:
  - Data Archival and Retrieval
  - Alarm Management
  - Save and Restore
- System Diagnostics are being developed for:
  - Status of CDS software modules
  - Status of CDS I/O modules
  - Status of CDS networks
  - Status of CDS mass storage systems
- Applications Programmer's Interfaces are used to interface other software and systems to the Control and Monitoring system.

ASC Functional Layout



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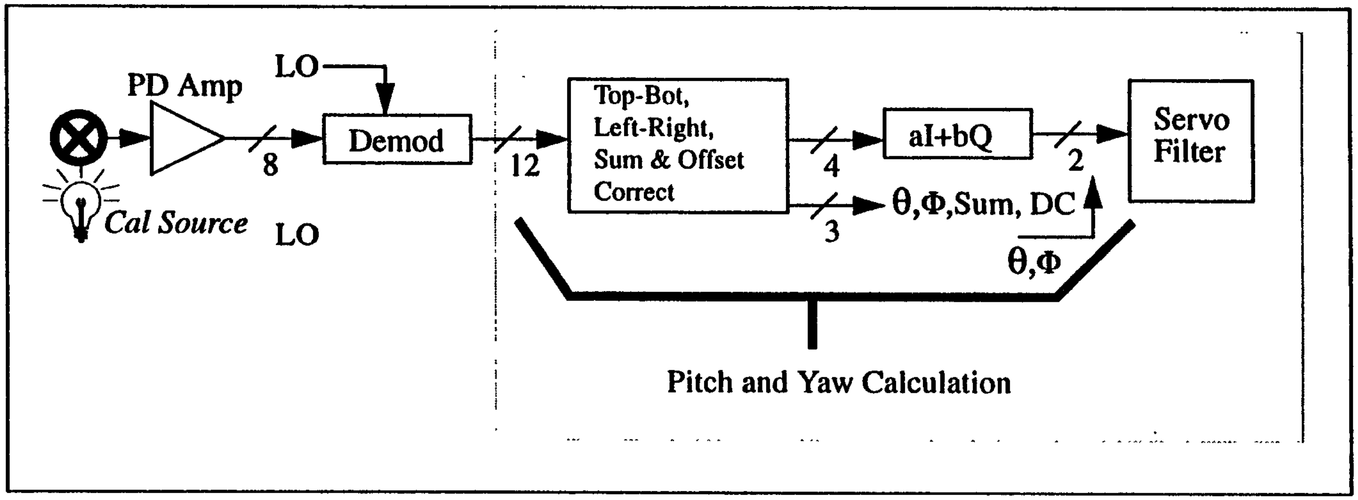
ASC Wavefront Processing Unit

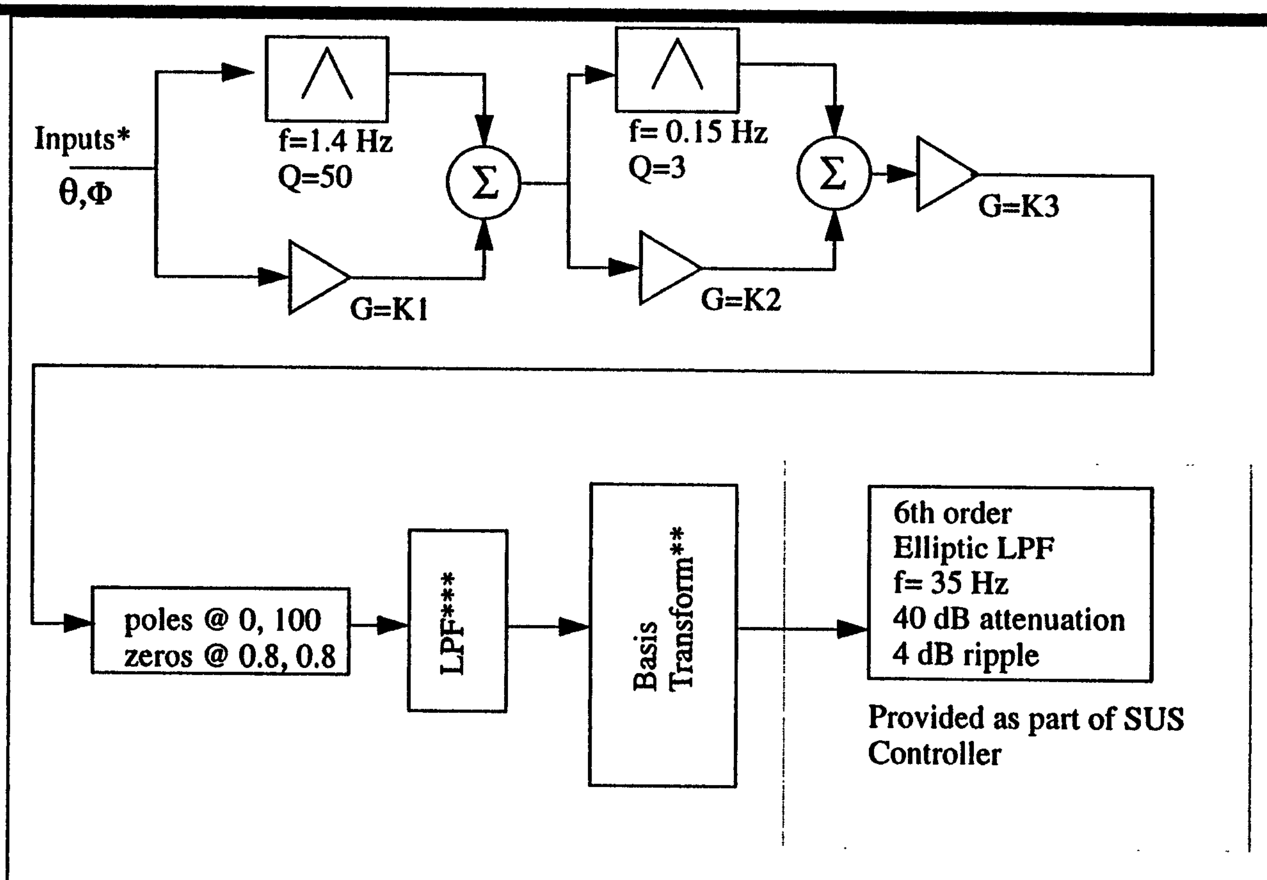


››Photodiode amplifier located in field box near WFS head.

››Demodulator module located in VME/Eurocard crate.

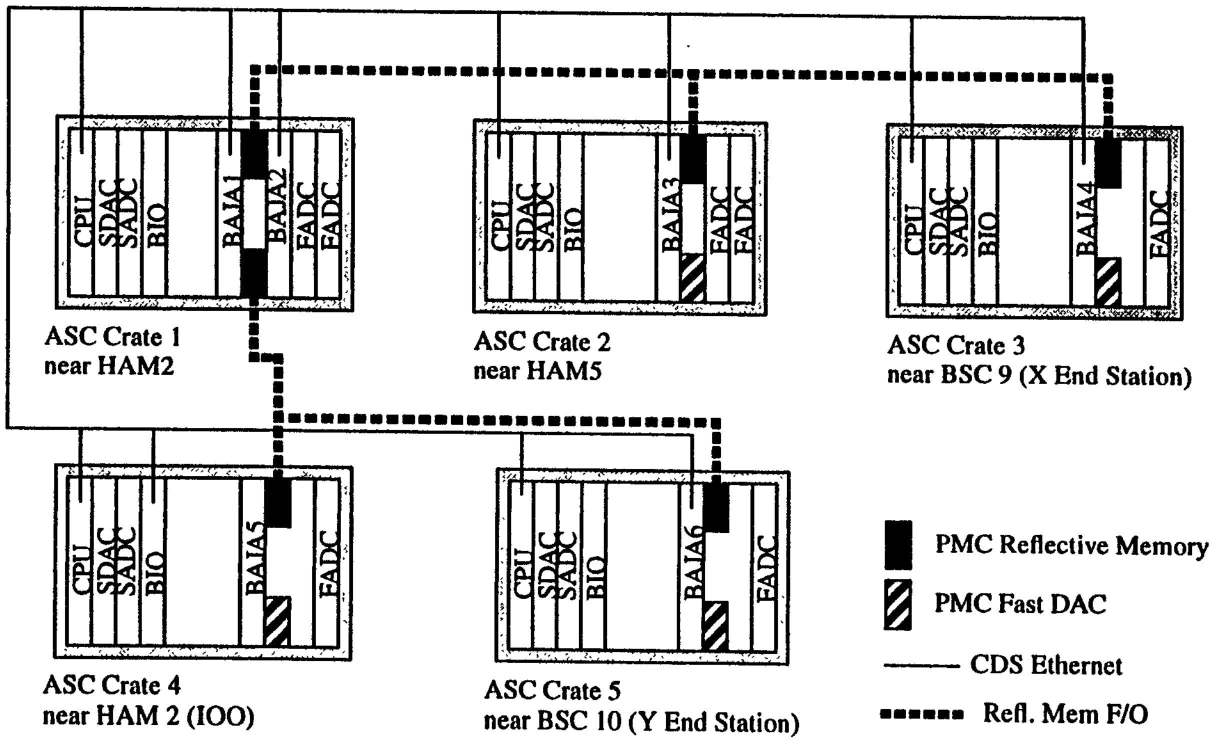
››Pitch and yaw calculation, servo filtering and basis transformation implemented in software.

ASC Wavefront Servo Controller



*Note 1- Each WFU and QMPU input is filtered with this filter (7 total θ, 7 total Φ).
**Note 2- The basis transform is described in the next section
***Note 3- This is an additional low pass filter required by WFS2, 3, and 4.

ASC CDS System Layout



BAJA1 - WPU2 and Basis Transform
BAJA2 - WPU3 and WPU4
BAJA3- WPU5 and ITM output angles
BAJA4- X arm QMPU and X arm ETM output angles
BAJA5- WPU1 and RCM, BS and IB output angles
BAJA6- Y arm QMPU and Y arm ETM output angles

BAJA = Baja 4700 CPU
FADC = VMIC 3123
FDAC = VMIC 4116
SADC = TBD
SDAC = TBD
CPU = MVME 162-333
BIO = Binary I/O

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ASC CDS Camera Systems

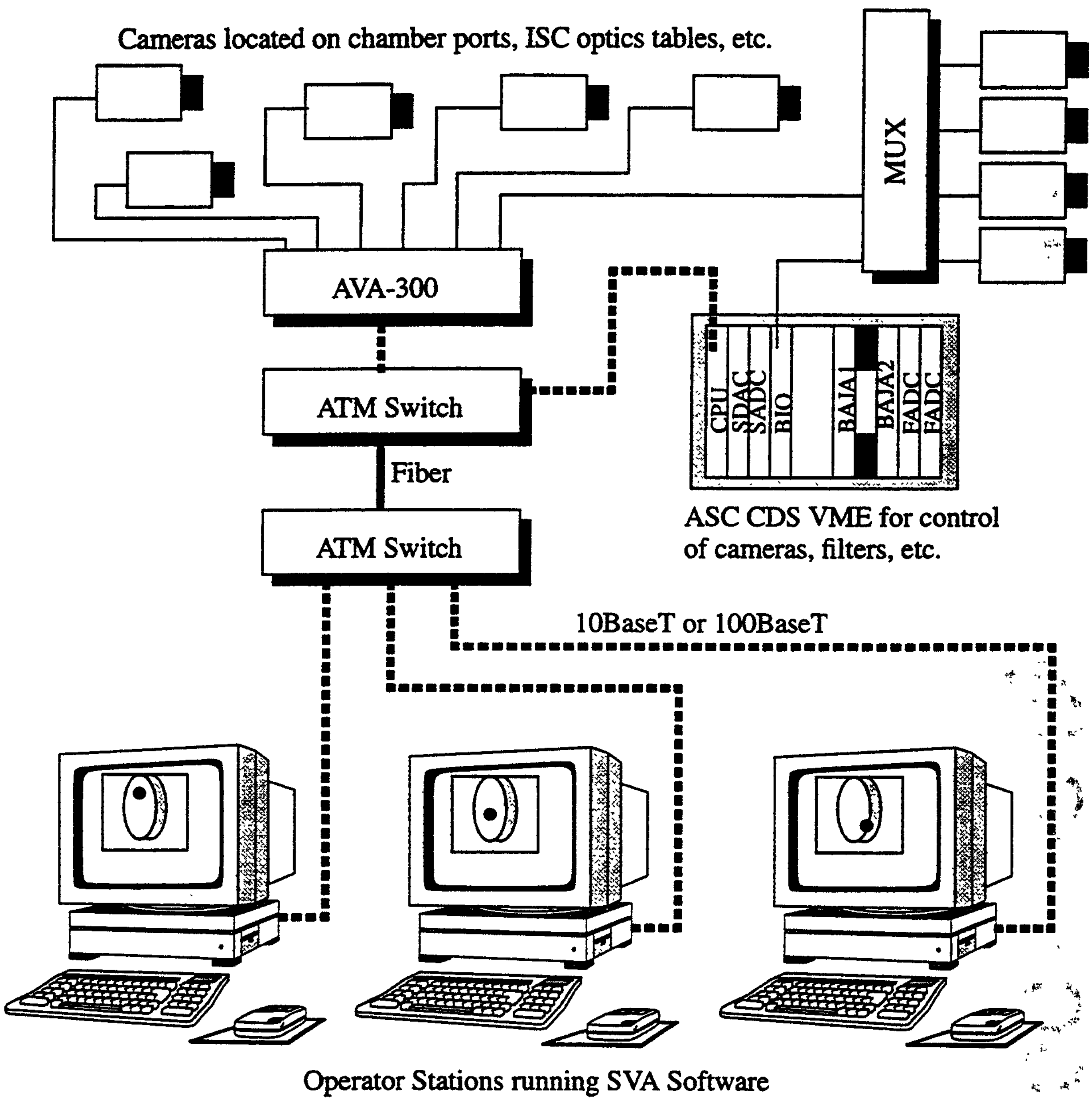

Figure 1: ASC CDS Camera Connections