NSF Review -

Detector and R&D

S. Whitcomb

22 October 1996

Outline

- **Overview (detector organization update)**
- **R&D progress and accomplishments (Mike Zucker)**
- **Detector progress and status**
- **Response to committee recommendations**

LIGO Detector Organization

Detector Group Leader:
S. Whitcomb

Deputy:
D. Shoemaker

Lead Engineer:
D. Coyne

Programmatics:
R. Fischer

Implementation / Operations
F. Raab & M. Coles

40m Interferometer
R. Spero

- **Lasers & Optics Task Leader:** *J. Camp*
- **Suspension and Isolation Task Leader:** *M. Fine*
- **Interferometer Sensing & Control Task Leader:** *M. Zucker*
- **Control & Data Systems Task Leader:** *R. Bork*

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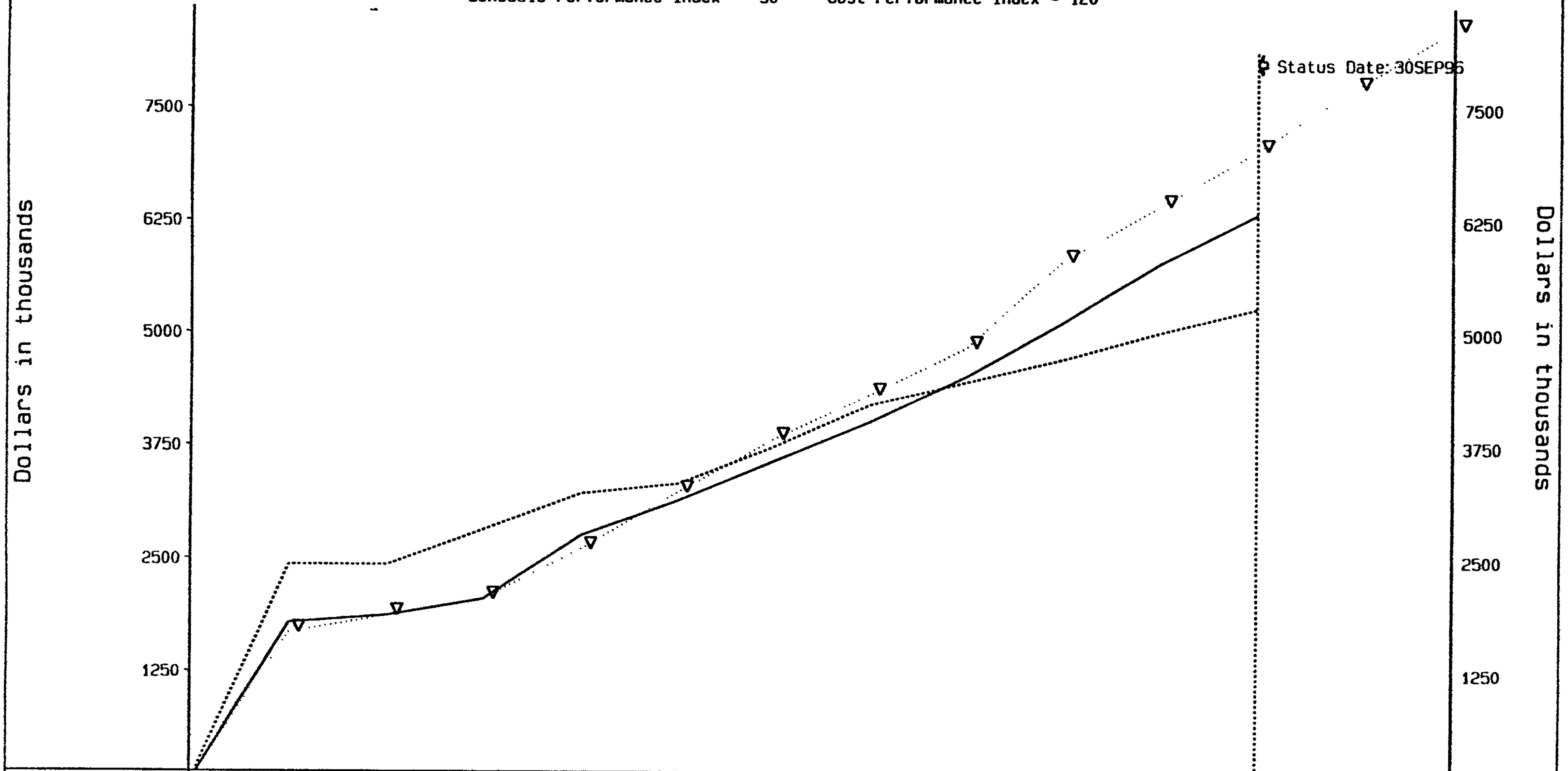
LIGO PROJECT
1.2 Detector

Date: 15OCT96
Program: LIGOPMB2
Report: LIGOSPA
COBRA (R)

Budget vs Performance vs Actual

Schedule Performance Index = 90 Cost Performance Index = 120



	FY95	DEC95	JAN96	FEB96	MAR96	APR96	MAY96	JUN96	JUL96	AUG96	SEP96	OCT96	NOV96	SCALE
Planned Budget	1,679	1,871	2,054	2,610	3,236	3,820	4,314	4,839	5,804	6,421	7,036	7,732	8,382	K$
Performance	1,791	1,872	2,054	2,759	3,141	3,582	4,013	4,521	5,117	5,780	6,322			K$
Actuals	2,429	2,429	2,820	3,218	3,330	3,738	4,199	4,456	4,713	5,011	5,269			K$
Schedule Variance	112	1	0	149	-95	-238	-301	-318	-687	-641	-714			K$
Cost Variance	-638	-557	-766	-459	-189	-156	-186	65	404	769	1,053			K$

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

Key Near Term Detector Activities-----SEP96

10/17/96

Activity Identification	Milestone Description	Plan Dates	Current Month End Status SEP96	Schedule Change	Status
12009100	Award Contract for Nd:YAG Laser Development	Jun-96	May-96	20	Complete
12045020	PDR for Optics Suspension System	Jun-96	Jun-96	0	Complete
12033425	DRR II Alignment Sensing Control	Jun-96	Aug-96	-40	Complete
12003020	Test of new Suspension Design on 40m	Jul-96	Aug-96	-20	Complete
12085065	PDR for Global CDS	Jul-96	Sep-96	-30	Complete
12039059	Core Optics Polishing Procurement	Dec-96	Oct-96	40	
12009020	Completion of Nd: YAG Master Oscillator Stabilization	Aug-96	Nov-96	-60	
13220442	Completion of PNI recycling experiments (with AR Laser)	Aug-96	Dec-96	-80	
12024075	PDR for Length Sensing Control	Oct-96	Dec-96	-33	
12039122	Demonstration of Coating Uniformity	Dec-96	Dec-96	0	
12033445	PDR for Alignment Sensing Control	Oct-96	Jan-97	-52	
12057020	PDR for Seismic Isolation Stacks	Jan-97	Jan-97	0	
13221935	First Operation of 40m with Recycling Mirror	Apr-97	Mar-97	20	
12012120	IR PSL FDR	Apr-97	Apr-97	0	
12062035	PDR for Data Acquisition System	Mar-97	May-97	-45	

R&D Progress

see presentation G960219-00-D by

Mike Zucker

Detector System Engineering: Progress and Status

- **Set of consistent detector subsystem requirements developed and nearly ready for review**
- **Several inter-subsystem trade studies in progress**
  - ››Suspension drive range vs. Seismic isolation actuation
- **Definition of key detector-wide parameters**
  - ››Optical configuration, modulation frequencies, cavity lengths
  - ››Wedge angles for Core Optics
  - ››Parameters for 2 km interferometer

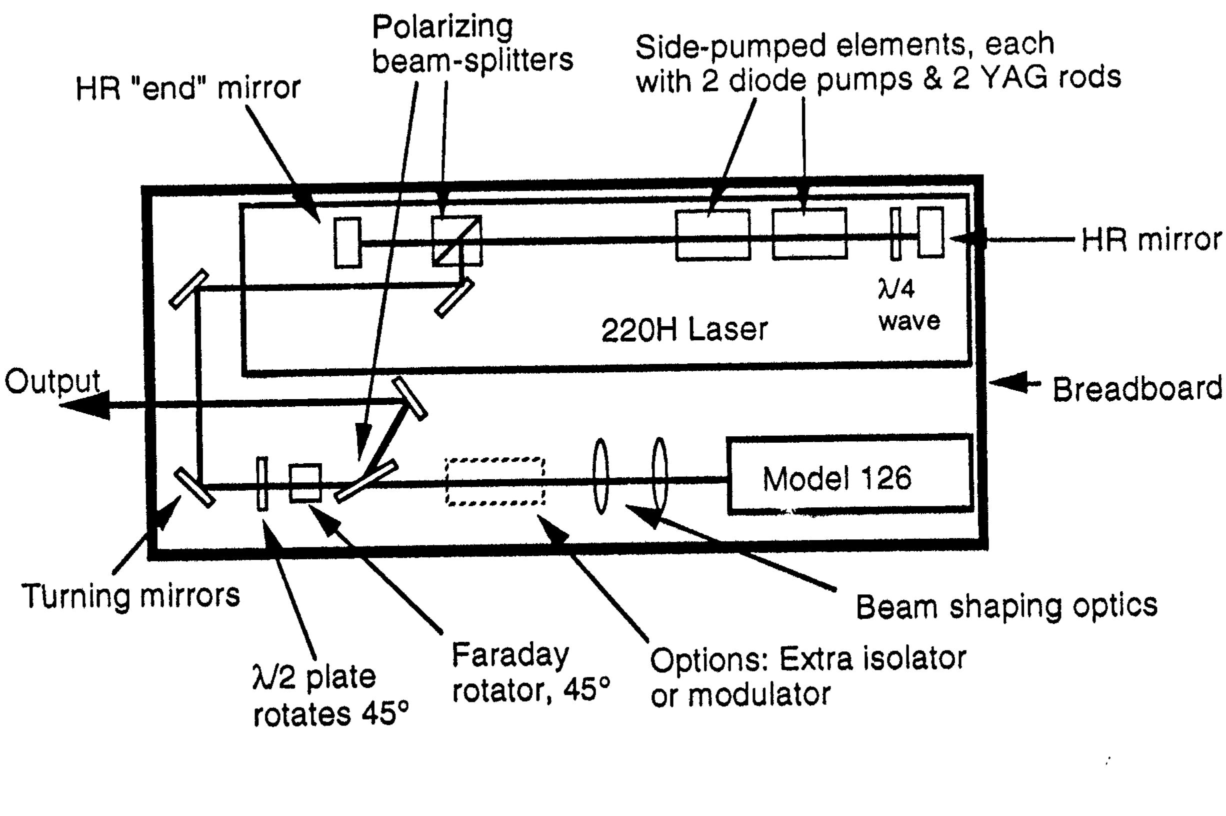
Nd:YAG Laser: Progress and Status

- **Goal: Develop 10 W diode-pumped Nd:YAG laser suitable for LIGO**
  - ››Single Frequency
  - ››Diffraction-Limited, Single Transverse Mode
  - ››Intensity and Frequency Stabilization
- **Contract awarded to Lightwave Electronics for 10W laser**
  - ››Proposed MOPA design using commercial 700 mW NPRO laser as Master Oscillator
- **Started parallel effort in-house to stabilize Lightwave NPRO for use on PNI and 40 m interferomerers**
- **Experience will be directly applicable to 10W laser**

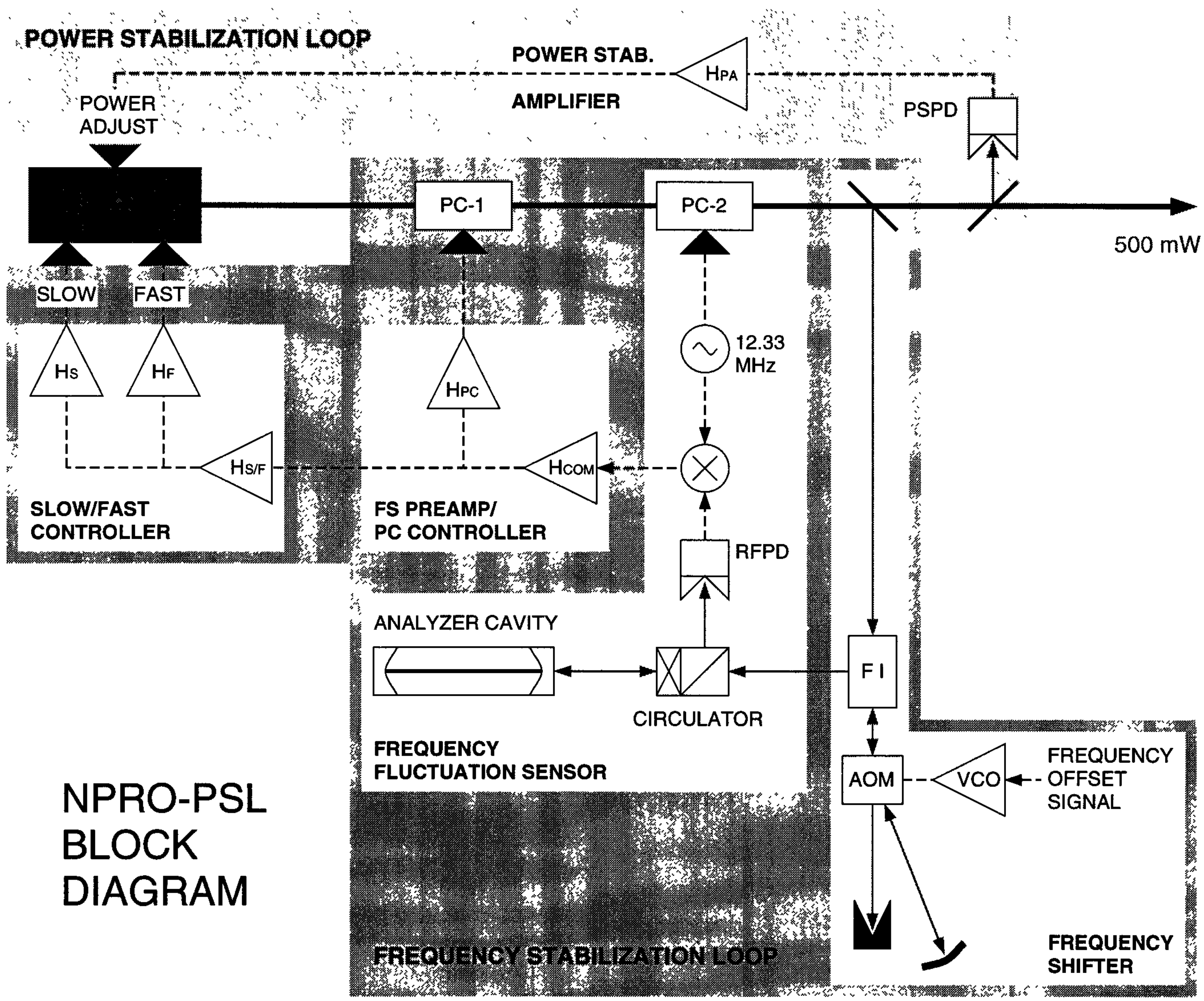
Nd:YAG Laser: Lightwave MOPA Design

- **4-Pass amplifier using polarization to extract final pass**
- **Based on existing commercial lasers**

System configuration:
Co-linear beams with Polarization and directional multiplexing



Nd:YAG Laser: NPRO Stabilization



NPRO-PSL
BLOCK
DIAGRAM

Input Optics: Progress and Status

- **Change to infrared forced delay in Input Optics design**
- **Collaboration being established with University of Florida, with UF group taking responsibility for Input Optics**
- **Refined scope of Input Optics to simplify interfaces to other subsystems for UF group**
- **Extended visits to LIGO by senior UF staff (Tanner and Reitze) to kickoff design effort**
- **Revew of requirements and conceptual design scheduled for November 7**

Core Optics: Progress and Status

- **Specification written and orders placed for fused silica blanks for core optics (>400 kg)**
- **Pathfinder polishing investigation completed**
  - ››Comparative measurements made at NIST and REO
  - ››Three polishers qualified for LIGO polishing
- **One polishing order placed (End Test Masses), remaining polishing proposals being evaluated**
- **Coating uniformity test apparatus and analysis developed, preliminary uniformity data encouraging**

Core Optics:
Pathfinder Polishing Results

- **NIST measurements of surface figure errors**

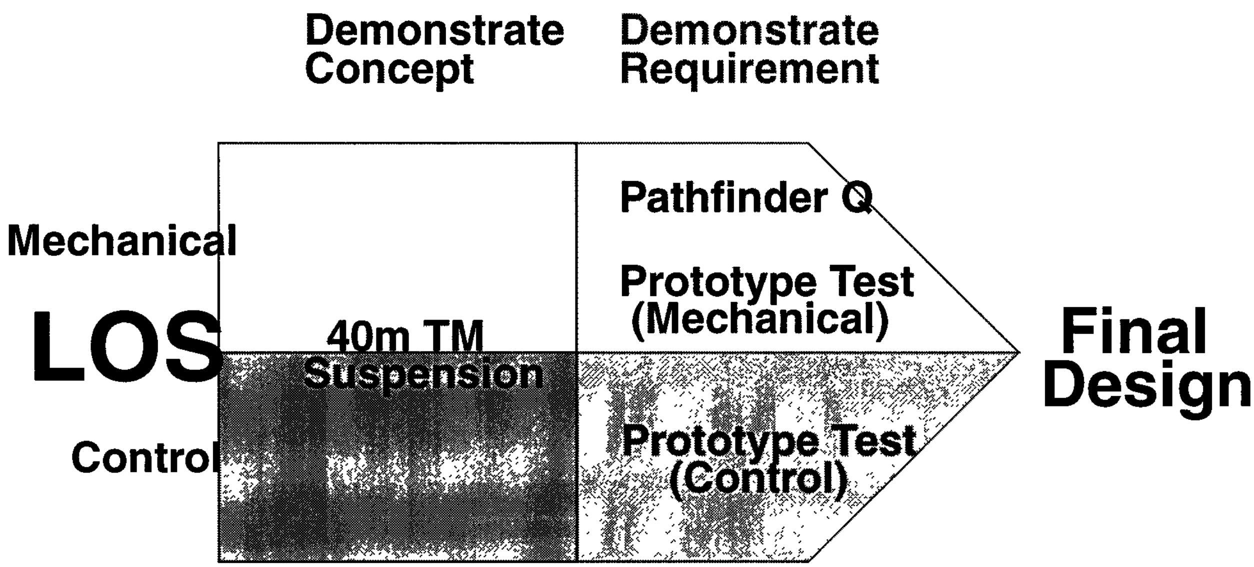
Core Optics:
Pathfinder Polishing Results

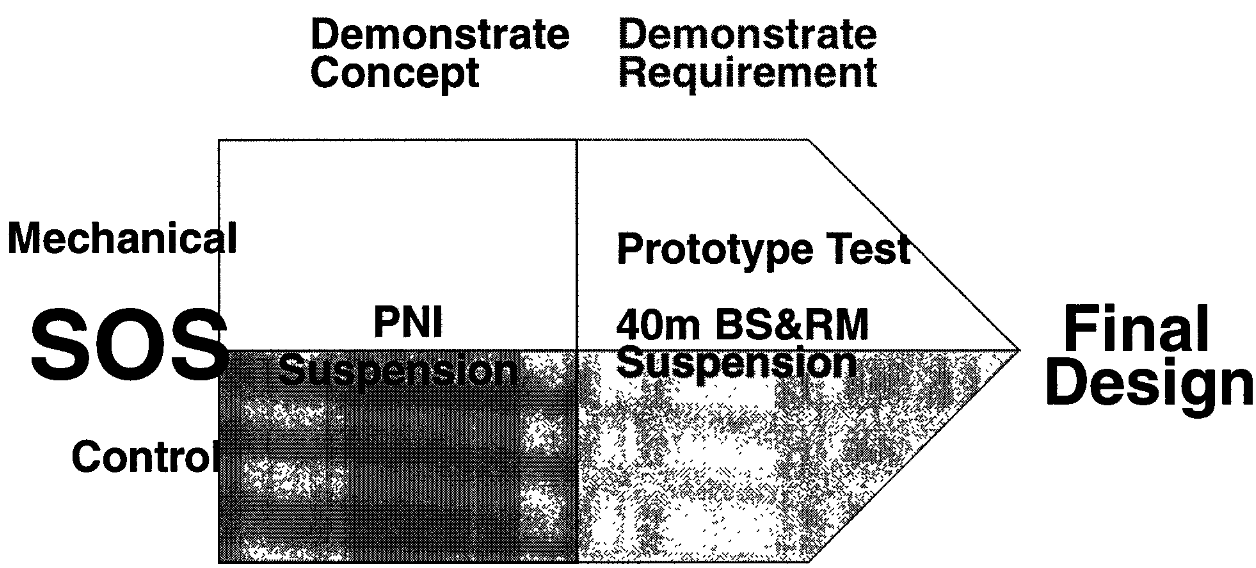
- **Comparative surface roughness measurements made at REO**

Suspension Design: Progress and Status

- **Preliminary Design completed and reviewed**
- **Final design underway**
- **Small Optics Suspension (SOS)**
  - ››Suitable for mode cleaner mirrors, other small components
  - ››Prototype fabricated, being tested (Available for demo tomorrow)
- **Large Optics Suspension (LOS)**
  - ››Designed for Core Optics
  - ››Prototype being fabricated

LIGO Suspension: Design Heritage





Extrapolation to the LIGO

Large Optics Suspension (LOS)

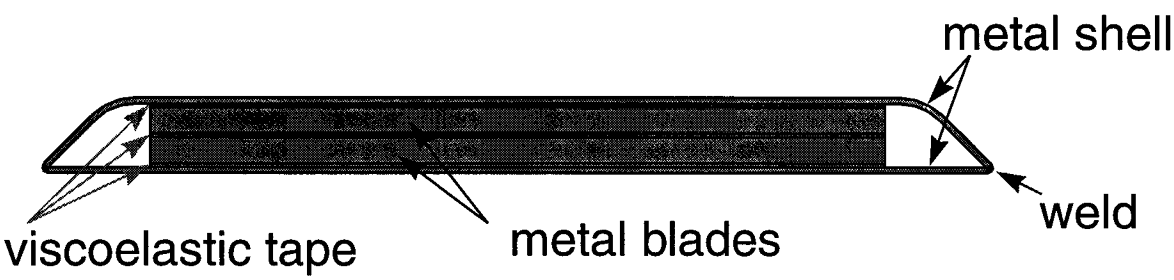
Items	40m TM Suspension or Pathfinder Q measurement	Extrapolated to LIGO	LIGO Requirements
Residual Q when damped	< 3	< 3	< 3
Internal Mode Loss	3×10^{-7}	3×10^{-7}	$< 4 \times 10^{-7}$
Pendulum Mode Loss	2×10^{-5} (Violin Mode)	7×10^{-6}	$< 7 \times 10^{-6}$
Actuator Range ($f < 0.15$ Hz)	44 μm_{pp}	8 μm_{pp}	>80 μm_{pp}
Driver Noise (at 40 Hz)	$6 \times 10^{-19} m/\sqrt{Hz}$	$9 \times 10^{-20} m/\sqrt{Hz}$	$< 5 \times 10^{-20} m/\sqrt{Hz}$
Sensor Noise (at 40 Hz)	$4 \times 10^{-20} m/\sqrt{Hz}$	$4 \times 10^{-20} m/\sqrt{Hz}$	(Option) $< 5 \times 10^{-20} m/\sqrt{Hz}$

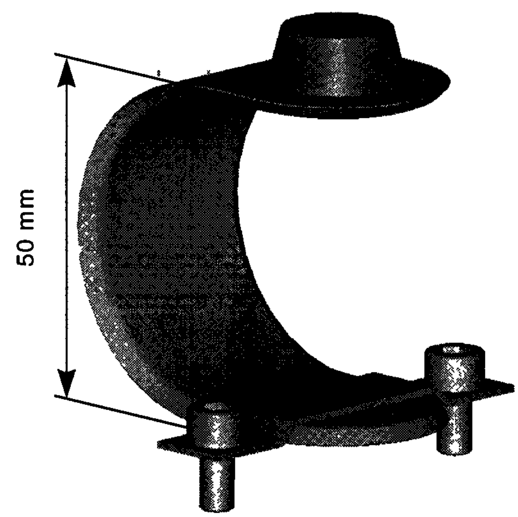
Seismic Isolation: Progress and Status

- **Requirements and conceptual design completed and reviewed**
- **Contract given to HYTEC to perform design of seismic isolation system**
- **Trade study to investigate constrained layer metal springs yielded two promising designs**
  - Prototypes to investigate fabricability and performance under construction
- **Preliminary design continuing in parallel with spring development**

Metal Spring Concept:
Constrained Layer Coil Spring

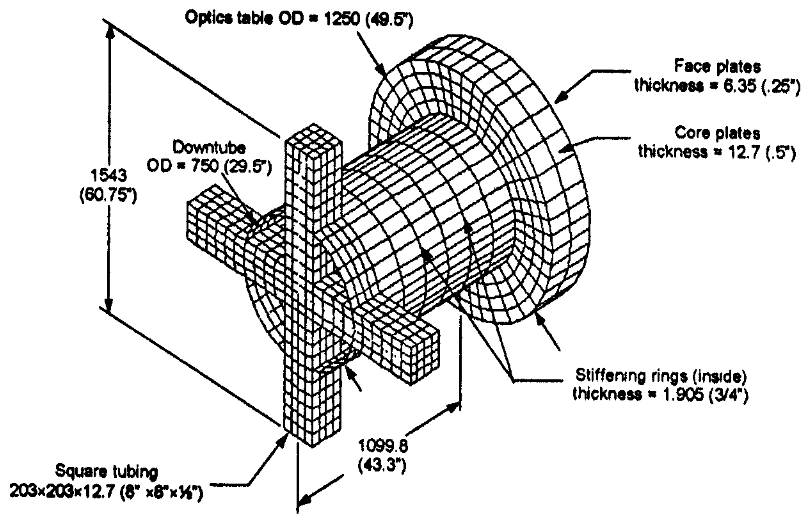
Metal Spring Concept: Semicircular Leaf Spring





Seismic Isolation: Preliminary Design

- **Detailed modal analysis of seismic isolation structures**



- **Working with vendors to improve fabricability and cost**
- **Current seismic stack weight estimates**

Chamber Type	Original LIGO Estimate	Current HYTEC Estimate
HAM	6850 lbs	3835 lbs
BSC	13020 lbs	6321 lbs

Seismic Isolation: Design Issues

- **Vacuum penetrations (bellows)**
  - ››Large range of motion
  - ››Constrained volume
- **Q of stack resonances**
  - ››Important to get test data from constrained layer springs
- **Actuators for "Drift Compensation"**
  - ››Must compensate for tidal motion (~400 μm)
  - ››May need to compensate for microseismic peak (0.15 Hz)
- **Cost**

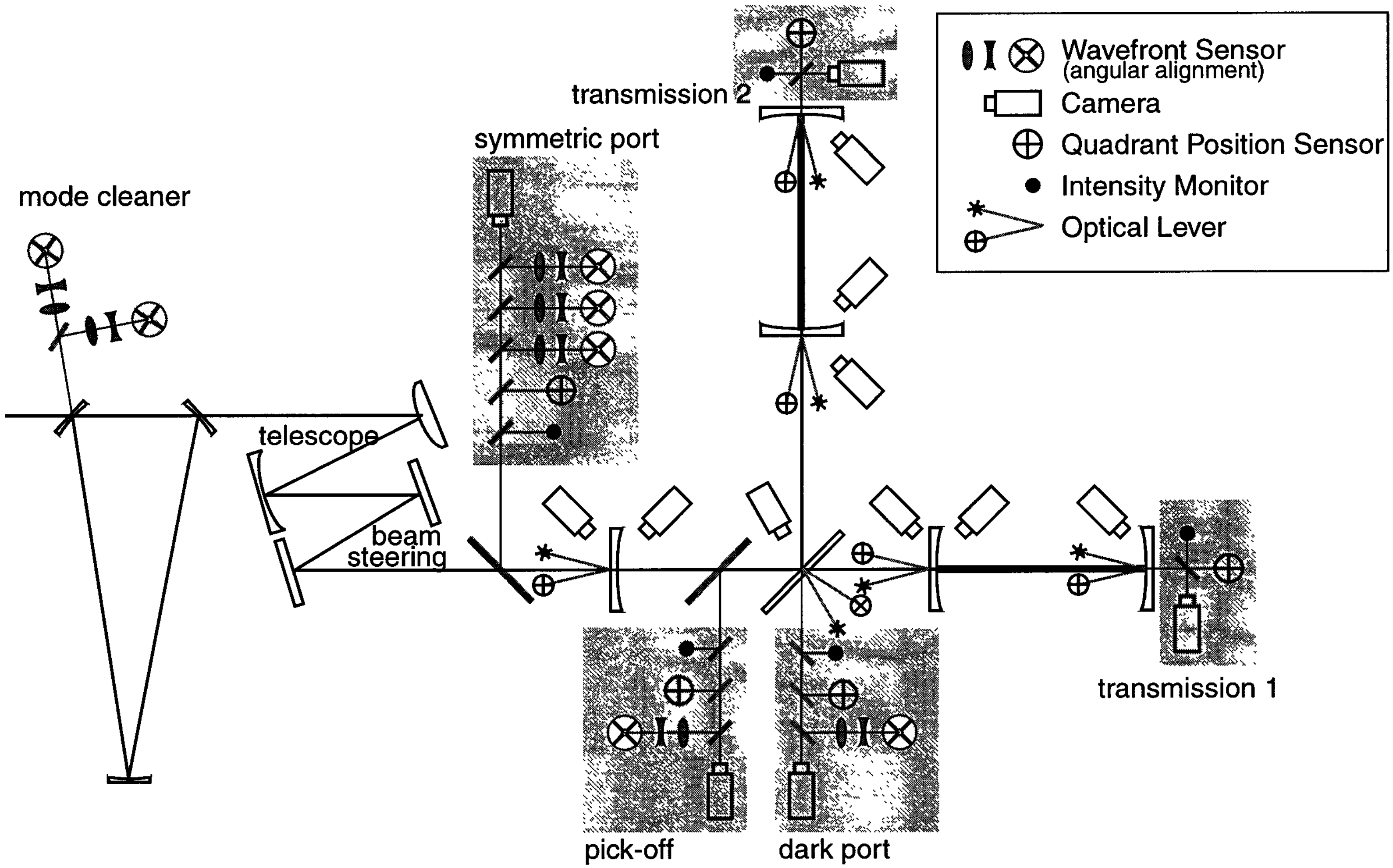
Alignment Sensing & Control: Progress and Status

- **Design Requirements Review held, currently in preliminary design phase**
- **Alignment requirements for mirror angles and beam centering were refined and frozen**
- **Significant progress was made in modeling the environmentally induced alignment fluctuations expected at the sites**
- **Detection mode alignment strategy developed:**

  ›› Wavefront Sensor system will be used to detect the mirror orientation degrees-of-freedom

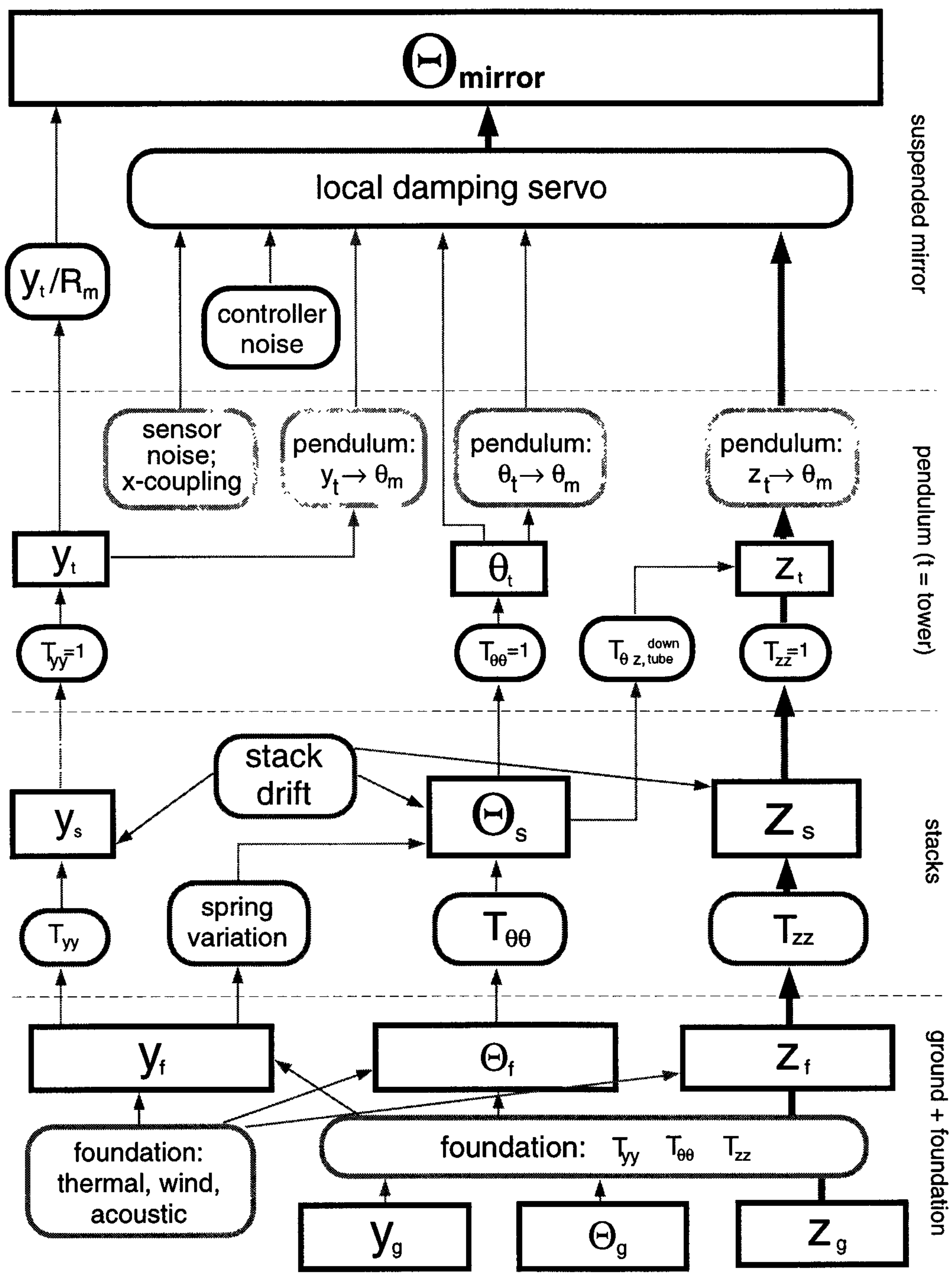
  ›› Modeling of the alignment sensor signals for the full interferometer was completed
- **Strategies identified for determining and maintaining proper alignment during the interferometer lock acquisition period**

Detectors and Sensors for the ASC



LIGO-G960218-00-D

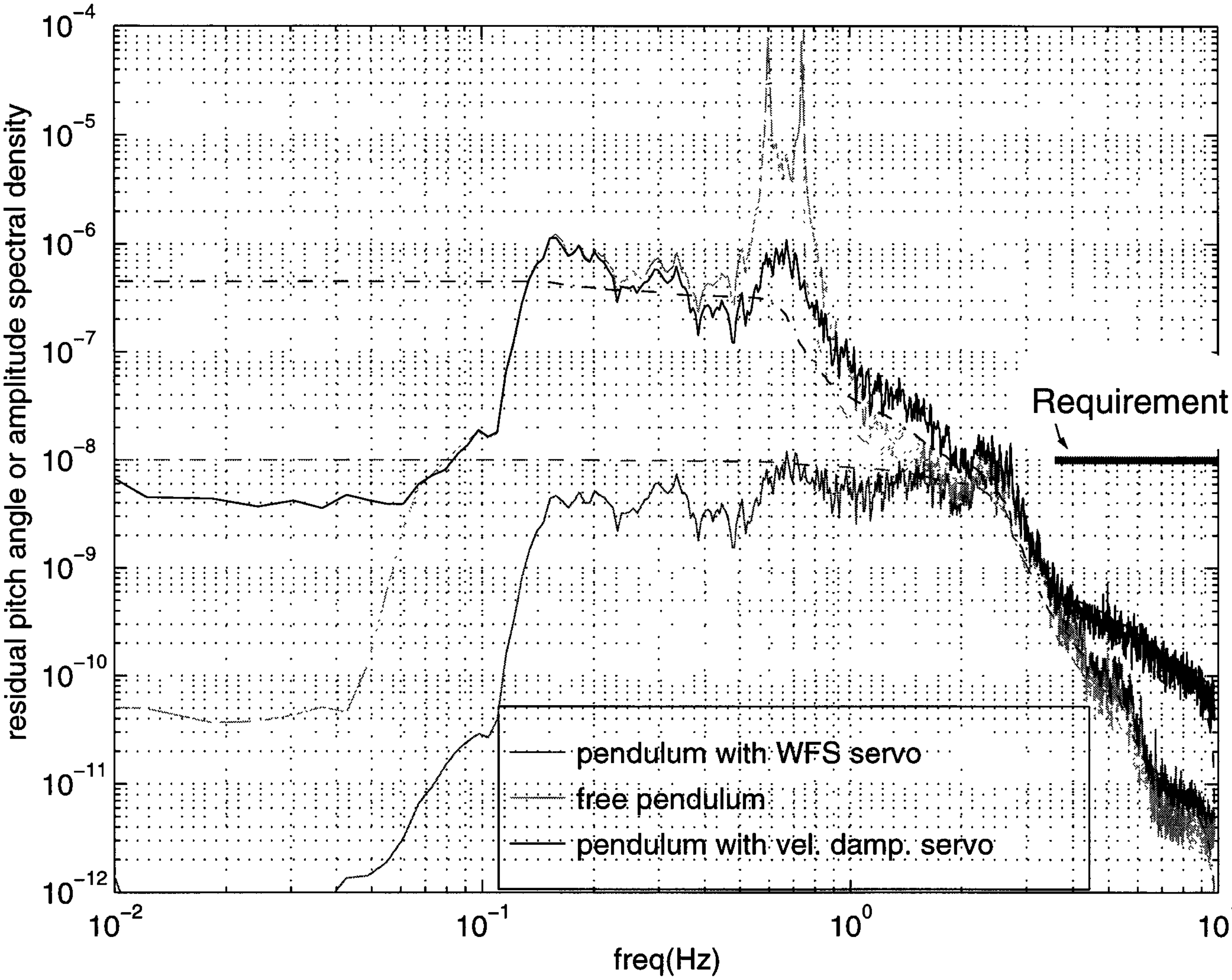
Modeling Alignment Fluctuations



Propagation paths from environment inputs to mirror angle fluctuations

Dominant path shown in red

Alignment Servo Modeling

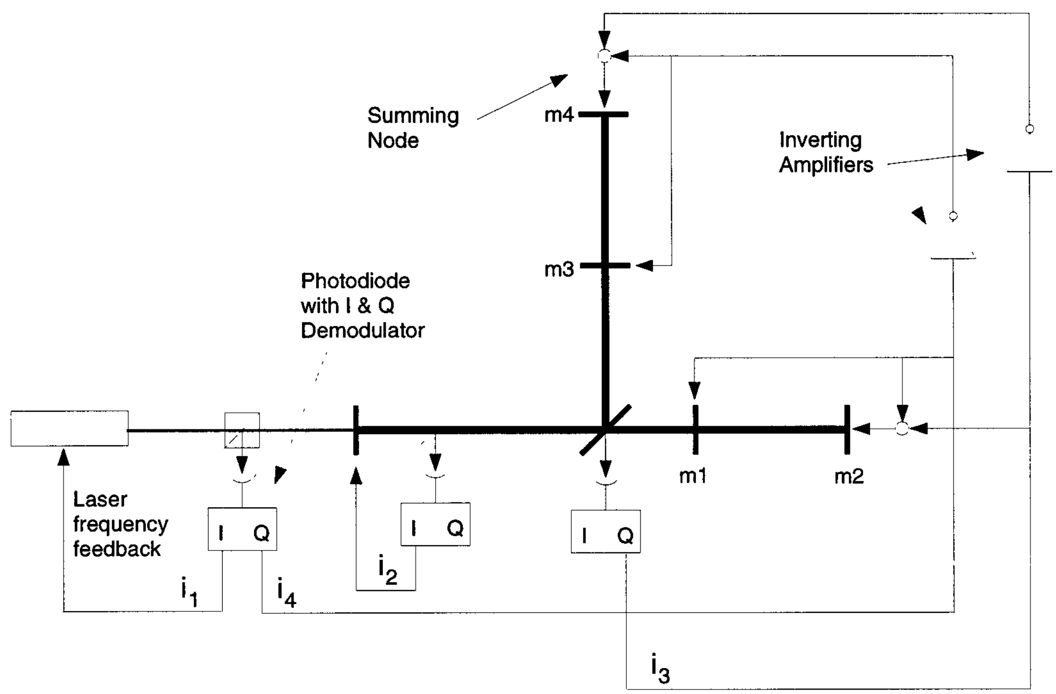


- solid lines: amplitude spectral density, radians/√Hz
- dashed lines: integrated rms fluctuation from freq →10Hz

Length Sensing & Control: Progress and Status

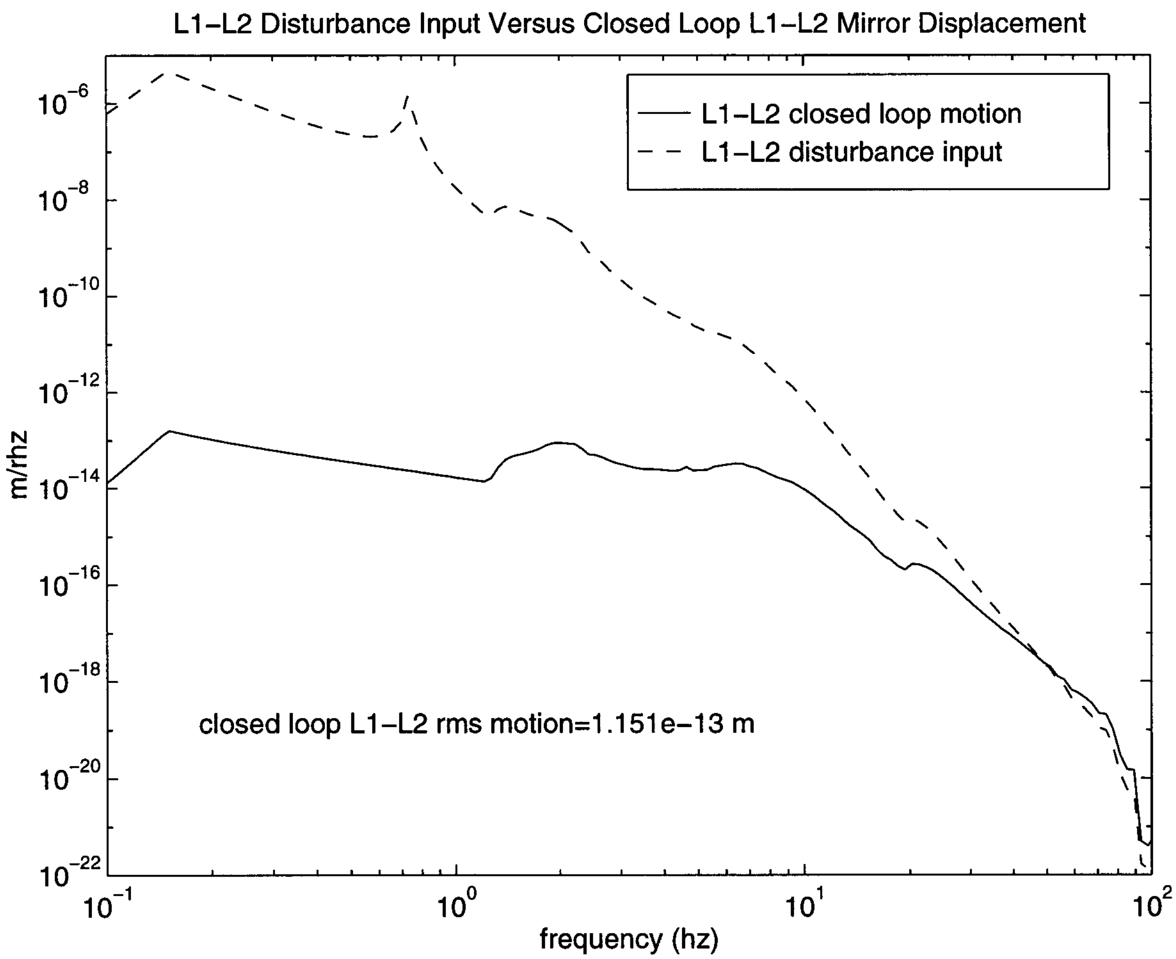
- **Reviewed requirements and conceptual design**
- **Sample control loops analyzed to demonstrate viability**
- **Senior EE hired and assigned to length control electronics design**
- **Full nonlinear optical response model completed for use in lock acquisition studies**

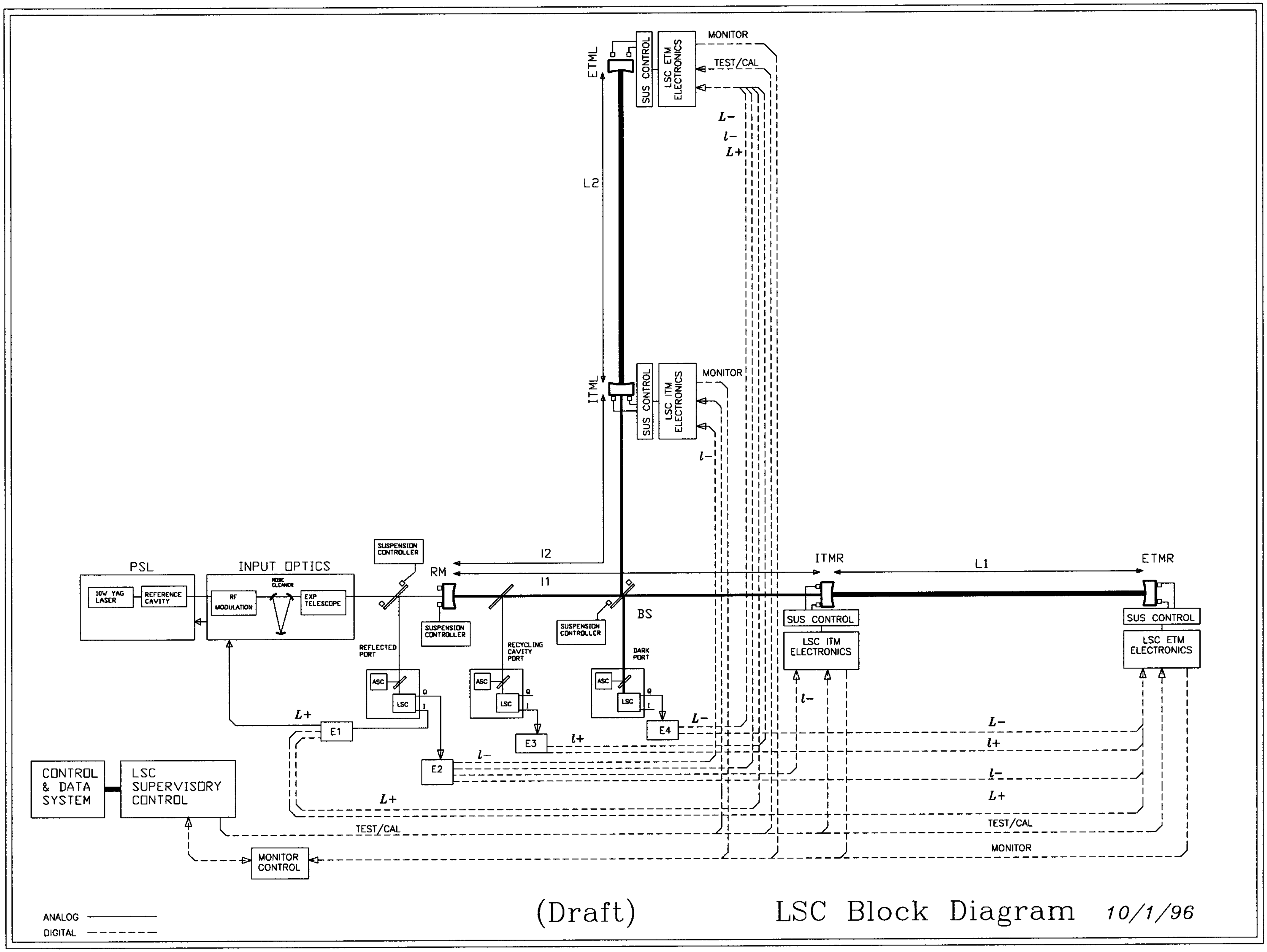
Length Sensing & Control: Control Loop Configuration



Length Sensing & Control: Performance Example

- **Suppression of seismically driven arm length difference**





(Draft) LSC Block Diagram 10/1/96

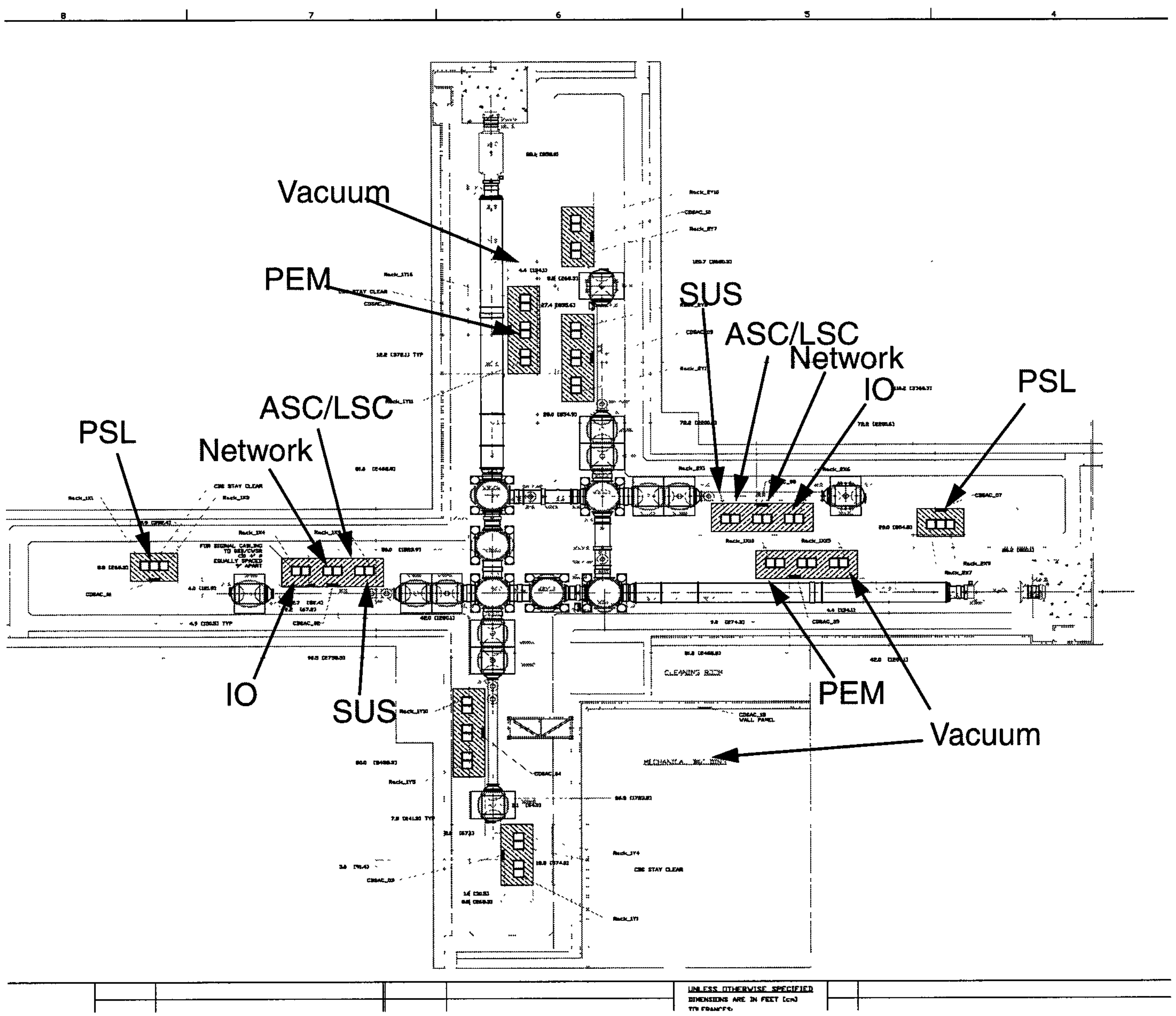
Control & Data System: Progress and Status

- **Completed preliminary design of CDS infrastructure**
  - ››Operator systems
  - ››Data networks
  - ››Timing system
  - ››Front end standards (hardware and software)
  - ››Software tools and standards
- **Completed preliminary design of in-vacuum cabling**
- **Reviewed requirements and conceptual design for Data Acquisition System**
- **Prototyping and testing of communications links, data acquisition hardware, etc.**
- **Preliminary design of vacuum control system nearly complete**

Control & Data System: Control and Monitoring Network

- **Asynchronous Transfer Mode (ATM) backbone.**
  - ››Point to point throughput : 3.8MBytes/sec between two Sparc10, CPU limited
  - ››Single ATM line to 155Mbits/sec (OC-3)
  - ››Aggregate bandwidth to 4Gbits/sec (Switch limit)
- **ATM to Ethernet Switches**
  - ›› 16 ethernet ports / ATM uplink
  - ›› Provides full 1MByte/sec to each connected processor
- **Video to ATM uplinks**

Control & Data System: Rack Locations and Functions



Detector and R&D Overview

- **"Project Management should monitor the technical interactions with the vendors of the Laser/Detector/ Suspension areas and arrange mechanisms to control potential change orders and cost overruns as presently being implemented in the conventional construction and vacuum areas."**
  - Technical representative assigned to each major contract
  - Use Technical Direction Memorandum (same as for Facilities) for giving all significant inputs to contractors
    - Must be approved by appropriate level of management
    - By definition (in contract), cannot change cost or scope
    - Any change of cost or scope must be made through the contract
  - Frequent interactions with contractors to avoid surprises

Recommendations From Last Review

Lasers

- **"A contract with well-defined milestones should be placed expeditiously for the development and delivery of 10W Nd:YAG lasers, and this contract should be supported through intensive technical exchange with the vendor."**
  - ››Contract placed with Lightwave Electronics approximately one month after last Review
  - ››Key Milestones:
    - Kick-off Meeting -- June 1996
    - Breadboard demonstration of Power and Beam Quality -- December 1996
    - Preliminary Design Review -- March 1997
    - Delivery of first Units -- Sept 1997
  - ››On-going technical interchange established; proprietary agreement signed to allow detailed technical discussions
  - ››Collaborating with Byer group (Stanford) for laser testing and technical consultation

Recommendations From Last Review

Seismic Isolation

- **"Continue to monitor carefully the progress of HYTEC in developing the seismic isolation system for the optics mounting"**
  - ›› Regular and frequent contact with HYTEC
    - – Weekly email progress reports to cognizant Detector personnel
    - – Weekly telephone conference call to assess progress and to address areas of technical/programmatic concern
    - – Detailed technical reports on major results for LIGO information and review

Recommendations From Last Review

Seismic Isolation

- **“The combination springs appear to be attractive but their R&D should not be allowed to generate schedule risk for the final seismic isolation system design and construction.”**
  - Design of seismic stacks compatible with either viton or constrained layer springs
  - Prototype fabrication efforts give information about possible impact on fabrication schedule
  - Decision on constrained layer springs to be reviewed at Seismic Isolation PDR January 1997

Recommendations From MIT Review

Conversion to Nd:YAG Laser

- **"With the switch to 1.06 μm system and the lead time that this must entail, the Panel strongly recommends the successful pursuit and addition of a scientist to lead the conversion of the PNI at MIT as soon as possible. Otherwise, the risk factor to the successful operation of the initial detector without this PNI experience base grows uncomfortable to the Panel."**
  - Haisheng Rong added to MIT Staff
    - Ph.D + 4 years Experience in High Precision Laser Spectroscopy
    - Assigned full-time to PNI Conversion
  - Long-lead IR optics for PNI conversion ordered at early date to enable fast start

Recommendations From MIT Review

Laboratory Space

- **"The Panel recommends that every effort be made to explore creative approaches that would allow the new laboratory space for the MIT LIGO group to remain on campus and still satisfy their seismic isolation needs."**
  - ››Suitable MIT building (WW15) identified just a few blocks off campus
    - Seismic levels 3-4 x less than current lab, fewer large pulses
    - MIT to provide active seismic isolators to give further isolation
  - ››Adequate floor space for up to 15 m long interferometer
  - ››Adjacent office space to be supplemented by office space in CSR to maintain close contact with other MIT groups
  - ››Take advantage of move to upgrade MIT vacuum system, minimize interuption of MIT laboratory effort
    - More like LIGO, longer cavities (to permit operation of realistic interferometers at correct RF frequencies)
    - Improve cleanliness and ease of operation

Summary

- **New detector organization functioning well**
- **Significant results from R&D program**
  - ››PNI optical phase sensitivity advances state of the art
  - ››Completion of 40 m optical recombination
- **Good progress on detector design and prototyping activities**
  - ››Most detector subsystems have completed requirements/ conceptual design review, and are well into preliminary design phase
  - ››First orders of detector hardware placed
- **Some detector milestones have slipped (typically ~2 months), but have recovered schedule along Critical Path**
- **No indication of significant cost growth**