LIGO Overview

Aspen ‘97

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27 January 97

G970021- 00- D

Organization of presentation

- Detector research and design
- Facilities status
- Schedule

LIGO Interferometer Design

Philosophy of initial design

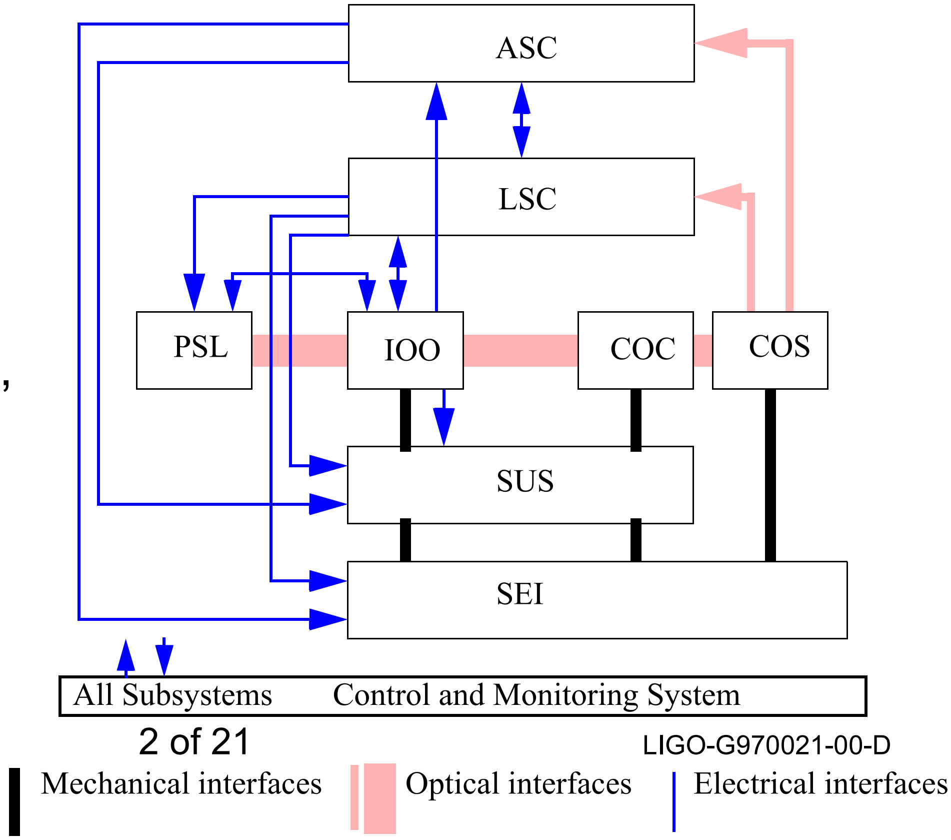
- conservative: designs tested, many in sensitive interferometers
- minimum of extrapolation required
  - › displacement, phase sensitivity demonstrated
- some systems revised from first design
  - › Argon laser, Viton springs

Role of R&D in process

- modeling helps target important/difficult design questions
- small-scale experiments test models in some regimes
- in general, test in sensitive interferometer follows
- actual LIGO design then possible

Subsystems breakdown

- Length Control
- Alignment Control
- Pre-Stabilized Laser
- Input Optics
- Core Optics Components, Support
- Suspension
- Seismic Isolation
- Physics Environment Monitor
- Control and Data System



Length Sensing/Control

Phase modulation key to obtaining signals

- Pound-Drever-Hall reflection locking techniques
- Asymmetry in Michelson to give differential signals

Designs tightly coupled to work on 40m, Phase Noise Ifo.

- acquisition and operation are both challenges
- modeling crucial, due to scaling required from lab to LIGO
- recycling experiment on 40m will give system test

Largely digital servoloop to be used

- transmission of signals over 4km eased (dynamic range!)

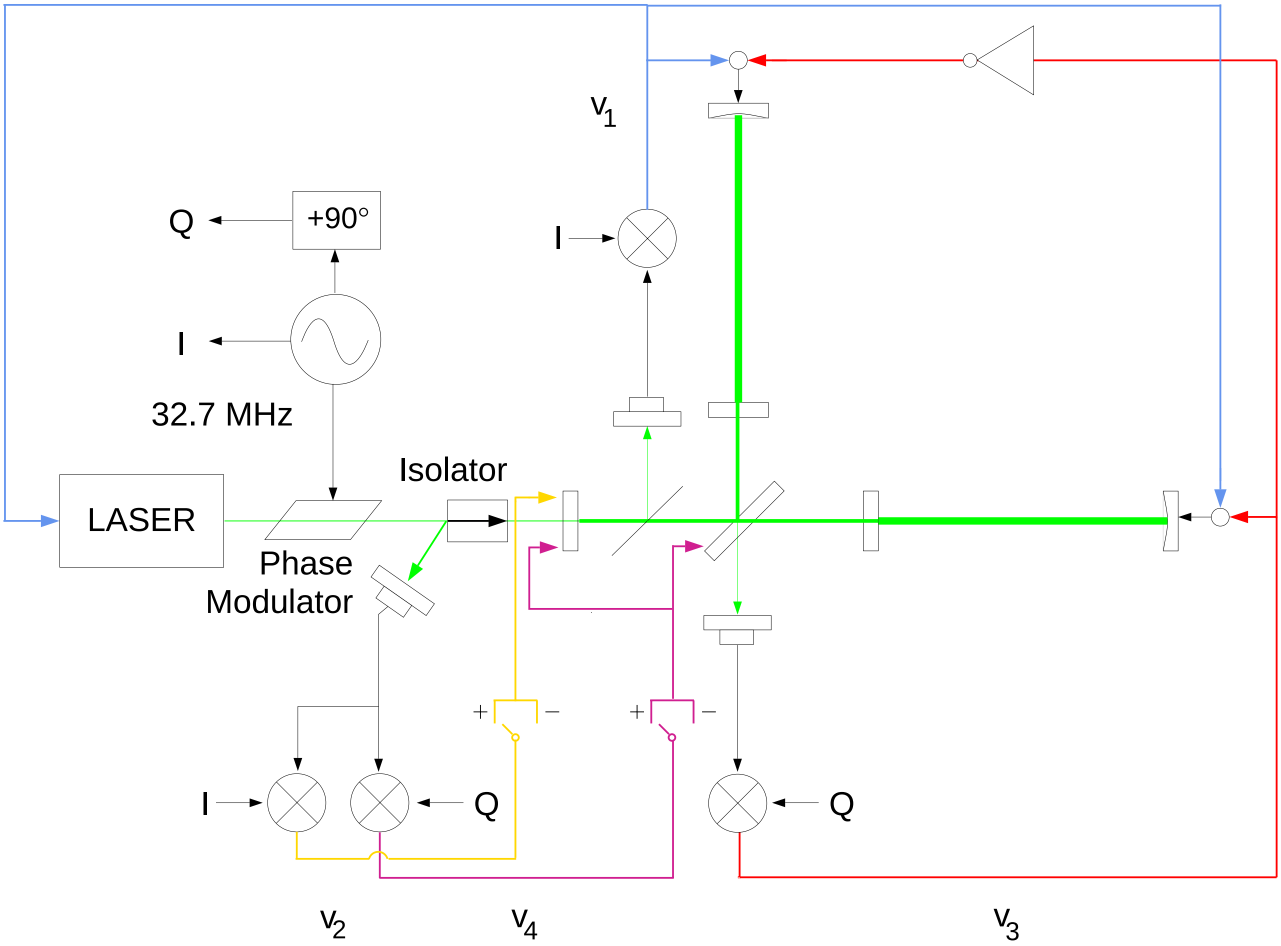
Reconfiguration of 40m as recycled Fabry-Perot Michelson

- significant activity in ‘97
- gives data directly to interferometer length control design
- allows tests of models in dynamic regime

40 m Recycling

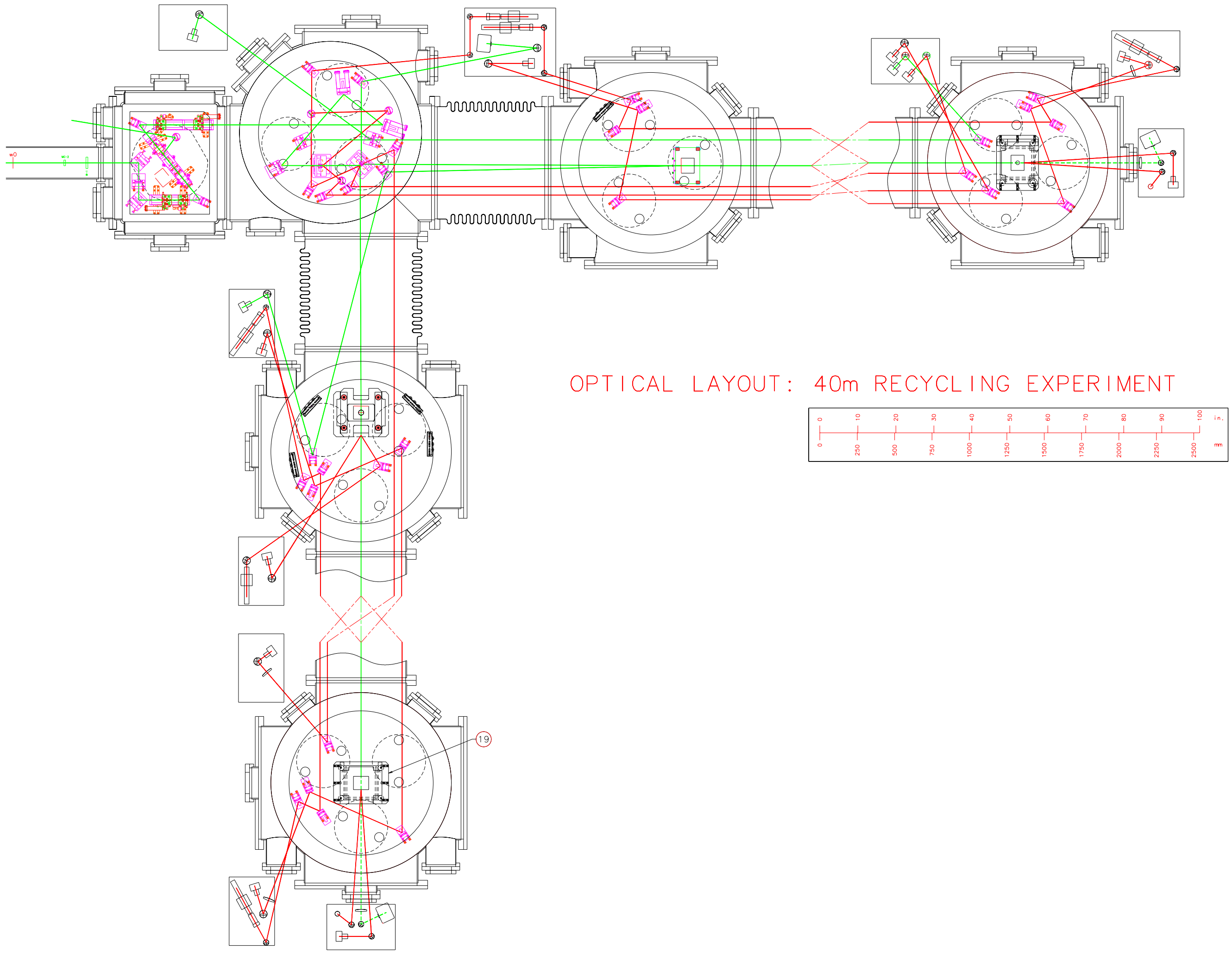
Theory:

Optical and Servo Topology for the Recycled 40-m Interferometer



40 m Recycling

Practice:



Alignment Sensing/Control

Alignment of cavities to laser beam

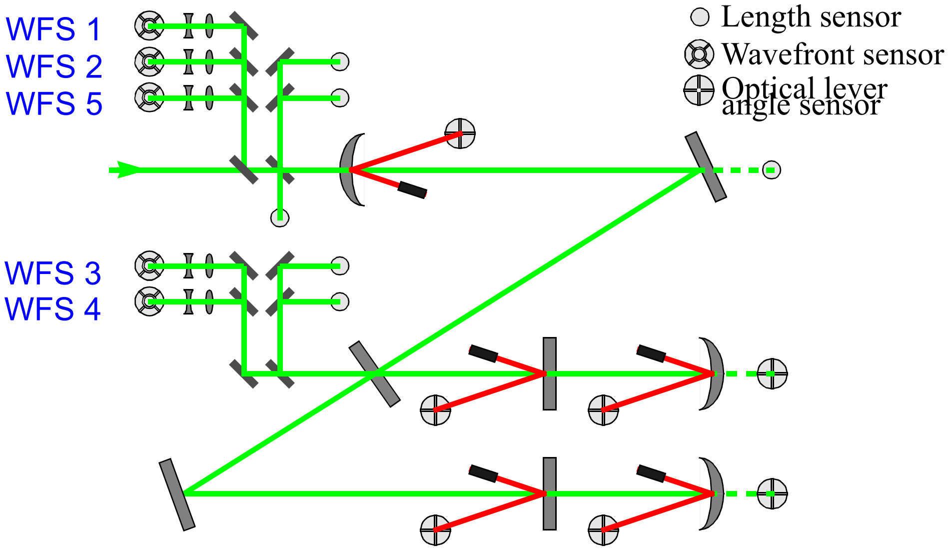
- effective use of laser power
- avoid spurious effects from undesired modes
- performance requirement of ~10^{-8} rad
- elegant model using expansion in modes of cavities

Sensing analogous to length sensing

- add spatial resolution to photodetectors
- look in near field/far field to separate translations, angles

Experimental test on table-top

- model verified



Alignment Sensing/Control

Model and prototypes tested on table-top system

- beautiful confirmation of Modal Model
  - predictions for placement of sensors, telescopes
  - predictions for signal decomposition at ports
- digital acquisition/control demonstrated
  - each quadrant digitized
  - all ‘matrix operations’ in software
  - all dithering of elements, read-in of monitors, data
  - servoloop transfer function
- wavefront sensor head, demodulation system shaken down
  - basically ready for production

Many aspects to complete design

- initial alignment
  - get the beam down the tube (10^{-4} rad)
  - get close enough for length control (10^{-7} rad)
- ; pre-operational; operational alignment
- centering: <1mm to limit noise coupling

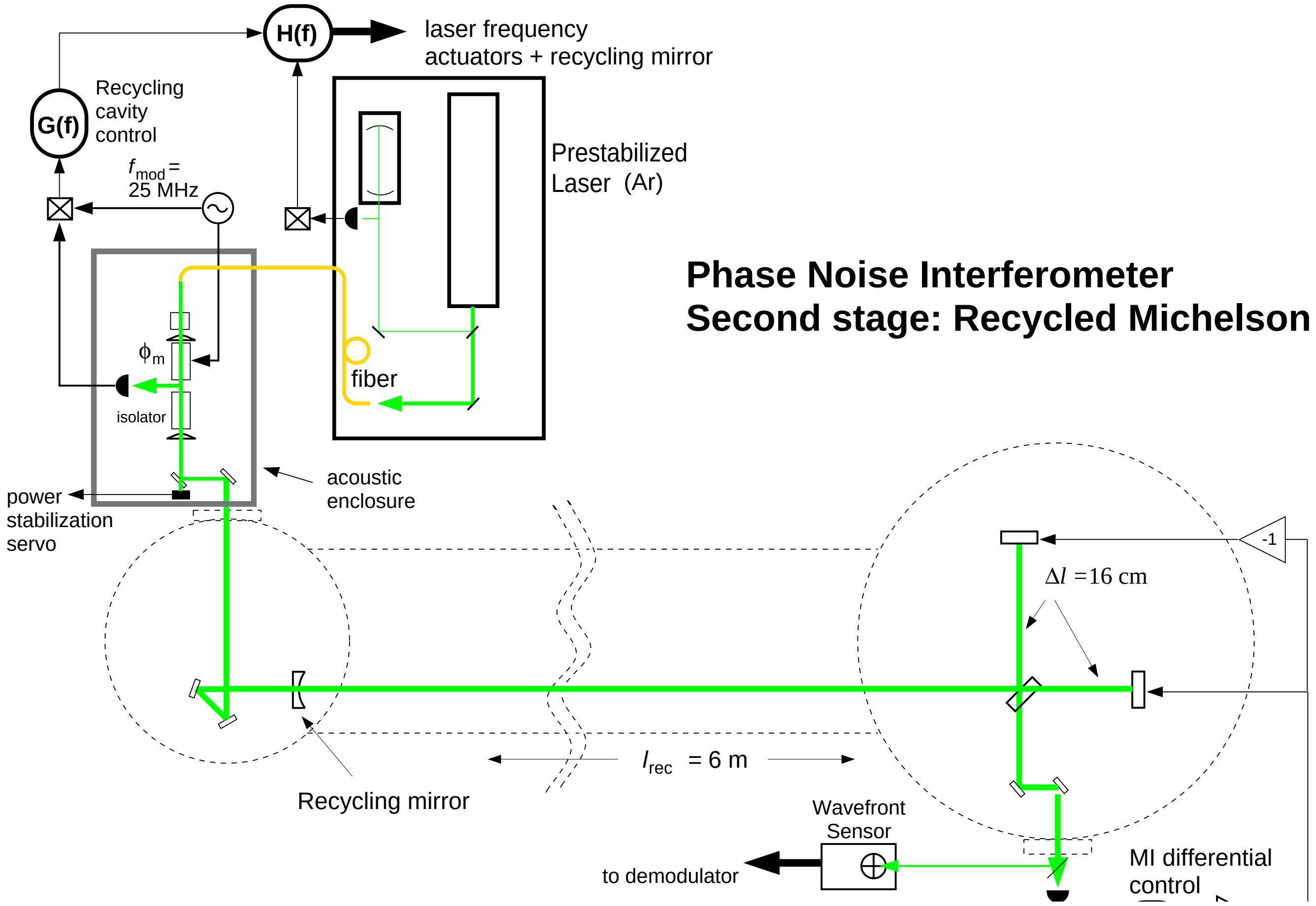
R&D: Phase Noise Research

Goal: to demonstrate required initial LIGO phase sensitivity

- test models for shot-noise, sensing system
- develop photodetector technology
- uncover laser, servo, scattered light problems/solutions

Simplified optical system to minimize position sensitivity

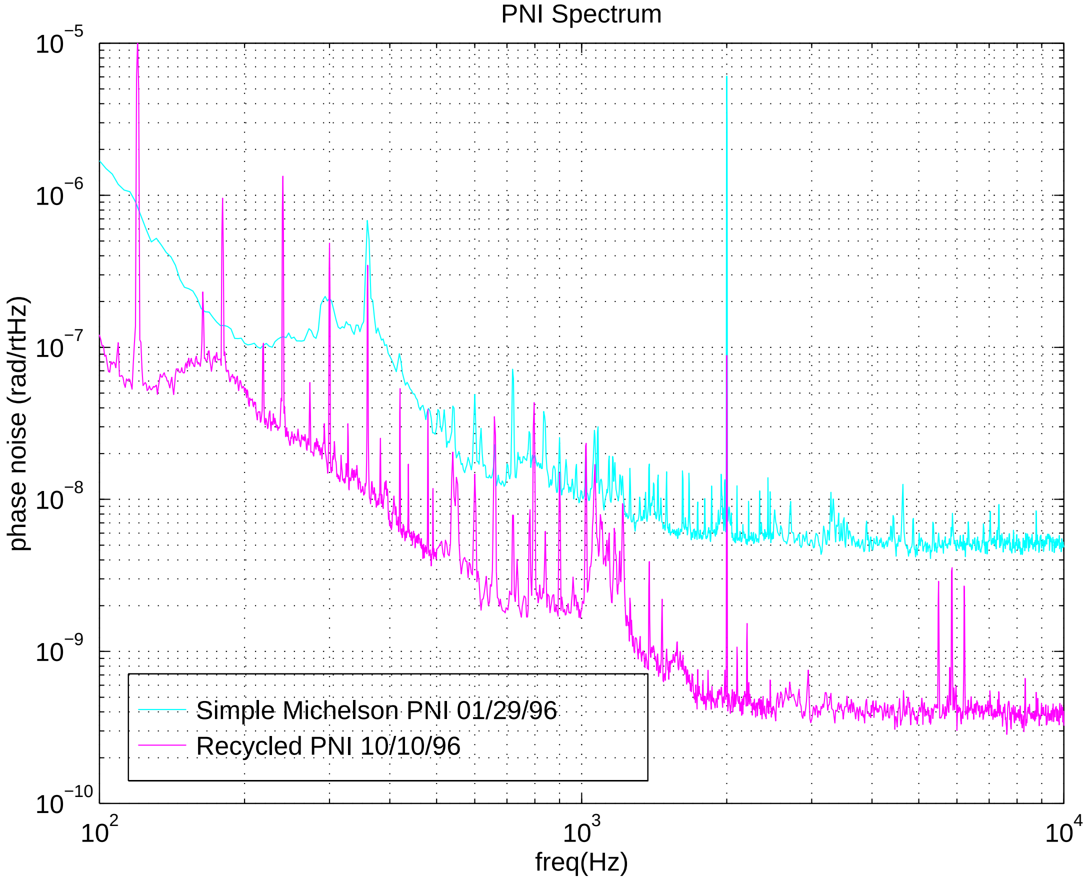
Phase Noise Interferometer
Second stage: Recycled Michelson



R&D: Phase noise research

Comparison of recycled, unrecycled cases

- high-frequency noise, $4 \times 10^{-10}\ \mathrm{rad}/\sqrt{\mathrm{Hz}}$, shot noise limited
- low-frequency noise from parasitics, frequency noise....



Next phase: conversion to Nd:YAG/1064 nm

- experiment will run to ~Jan 98
- tests low-power IR laser in characterized testbed

Pre-stabilized laser

Laser Source

- being developed and produced by Lightwave, Inc.
- monolithic Nd:YAG oscillator, followed by amplifier; 10 W output
- first units to be delivered in Oct 97

Stabilization

- based on rich experience with Argon Ion lasers
- modifications for Nd:YAG; e.g., filter cavity (Stanford)
- development underway using available 700 mW laser
- initial prototype for test in Phase Noise Ifo., in coming months

Input Optics

Under development in collaboration with Univ. Florida

- helped by clean interfaces, frequent visits, good communication

Principal components

- phase modulation system (multiple sidebands required)
- 3-mirror Fabry-Perot suspended mode cleaner
- matching telescope to main optics; reflective

Core Optics

‘Pathfinder’ process

- exploring/developing polishing, metrology, coating technologies
- significant progress on all fronts

Substrates: fused quartz, 25cm x 10 cm

- Heraeus low-OH material where absorption critical
- Corning for other applications

Polishing

- Three firms qualified for LIGO polishing
- 1 nm surface figure over 10cm required, and possible!

Coating

- REO and LIGO cooperating in measurement, characterization
- use AR coating reflectivity designs to study uniformity

Metrology

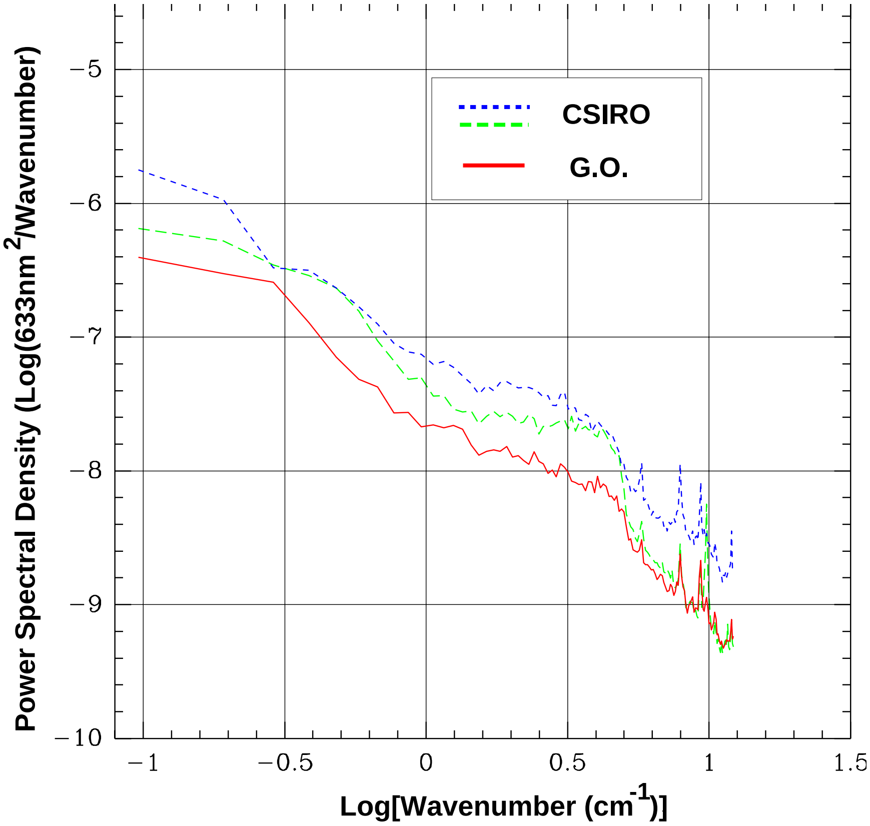
- NIST is the independent contractor for Pathfinder
- comparisons with vendor metrology; probably the limiting technology

Core Optics Support

- baffling, in-vacuum relay mirrors, etc.

Polished Surfaces

<1 nm over a 20cm diameter!



One dimensional power spectra from NIST metrology of curved surfaces. Z(0,0),Z(1,1) Z(2,0),Z(2,2),Z(3,1),Z(3,3),Z(4,0) removed

Coating

Use properties of AR coating to advantage

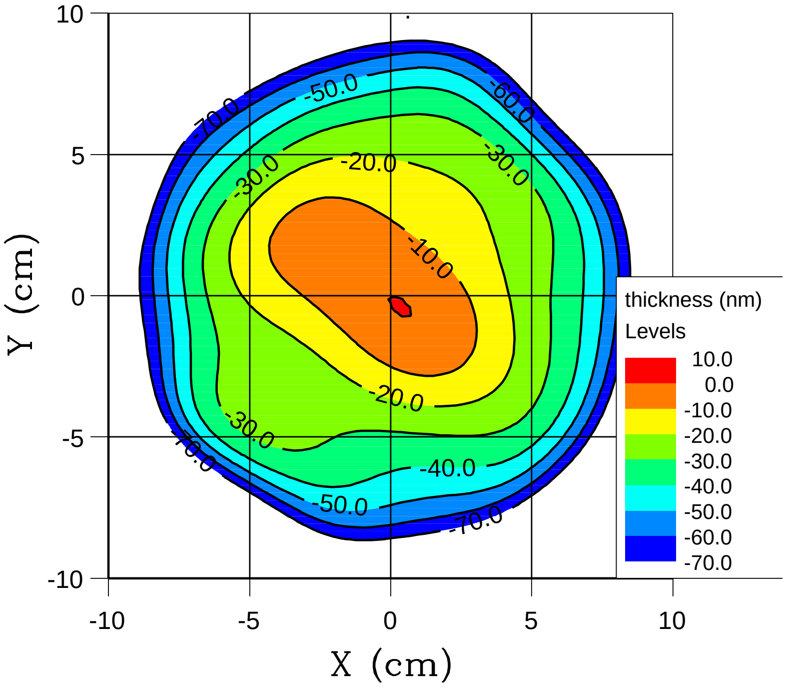
- reflectivity very strong function of thickness near zero reflection
- tune layer thickness to study uniformity, scan samples

Synthesize complete coating from these measurements

- fit to complete the surface
- make fictive 40-layer coating
- give feedback to REO on nature of problems

Rapidly approaching design flatness

40 layer HR coating phase map



Suspensions

Two basic flavors:

- Small Optic Suspensions: Input Optics components
- Large Optic Suspensions: Core Optics

Prototypes in construction/test

- challenges in fiber attachment (Q), initial balancing
- also in control electronics: severe dynamic range requirements
- tests in 40m interferometer for control, noise performance

Seismic Isolation

Design contracted to Hytec, Inc.

- requirements developed by LIGO
- design makes incremental changes in initial design
- principal change in springs: Constrained Layer Damping

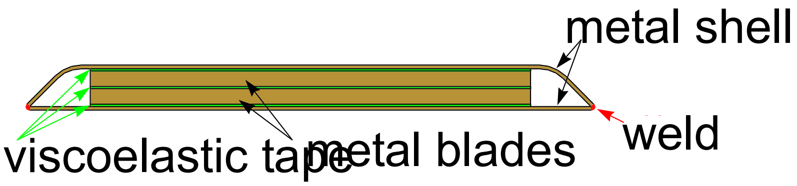
Requirements in control, GW band

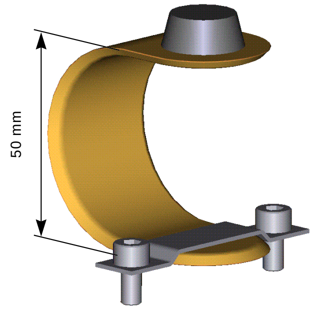
- resonances create servo-control challenges, but...
- attenuation in signal band crucial

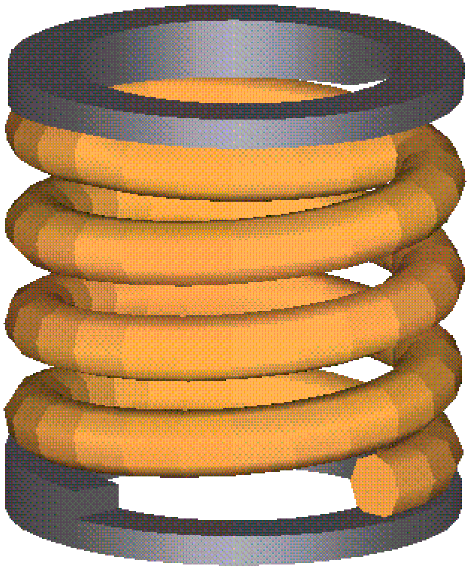
Preliminary design well advanced

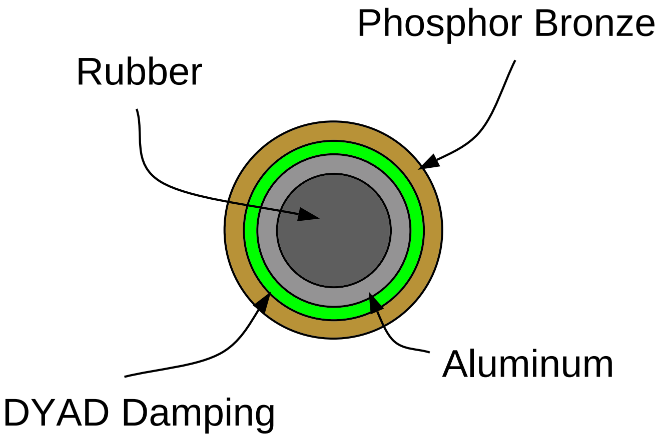
- actuators for drift, tidal, microseismic peak also in development

Coil and Leaf Spring concepts









Control and Data System

Backbone of the interferometer

- electronics standards and design
- communications between subsystems
- all centralized control, monitor, operator consoles
- timing
- software up to the data analysis

Data Acquisition

- order of 5 MB/sec per interferometer total data rate
- data assembled into frames, short and long term storage

On-line Diagnostics

- interferometer console to allow quick-look, scripts

Prototyping and design well advanced

- much R&D now using CDS electronics
- several subsystems tests (laser)
- data acquisition/frame builder in test

Physics Environment Monitor

All probable paths from environment to interferometer

- seismic (low ‘drift’ frequencies to GW band)
- acoustic
- electromagnetic: lightening, RFI, magnetic fields
- temperature humidity, wind, rain, etc.

Characterization of transfer functions

- stimulus-response

System separate from interferometer

- to be used for veto, correlation, regressions
- principally commercial instruments

Early to the sites

- portable carts to enable measurements as buildings go up
- measure changes in the environment
- early data on correlations between sites

R&D Plans for ‘97

R&D for initial interferometer: ends in ‘97

- all designs finished, fabrication underway
- 40m recycling
    - length control acquisition
    - length control operational mode
    - tests of CDS electronics, data acquisition, etc.
- Phase noise measurements
    - characterization of Nd:YAG laser
    - guidance to Pre-Stabilized Laser design
    - experience with infra-red optics, components
- Suspension tests in 40m
    - control and mechanical stability
    - internally-generated noise mechanisms
    - installation practice
- Thermal noise research
    - measurements of Q for suspended test mass optics
- Temporal, spatial modeling
    - to support design activities; integration of models

Beam Tube

Beam Tube slabs in place

- a short interstate, laid in a week

Tubes in full production

- all activity is at Hanford for now; Livingston in Spring ‘98
- an enormous steel mill/factory churning away
- some 190 tube sections formed, 52 installed; no leaks!

Baffles baffling

- designed to limit scattered light
- coated with powdered glass and ‘fired’ to reduce backscatter
- some spalling; tiny glass missiles launched through beam
- solutions under study

Covers covering (cowering?)

- over 2200 manufactured, awaiting installation

Installation and bakeout finished by end-98; LA end-99

Civil Construction

Hanford

- slab just poured and cured for LVEA (large vertex building)
- structural steel frame going up
- other buildings nearing completion

Livingston

- heavy equipment now arriving

Schedule

- Hanford occupancy fall ‘97
- Livingston occupancy spring ‘98

Vacuum Equipment

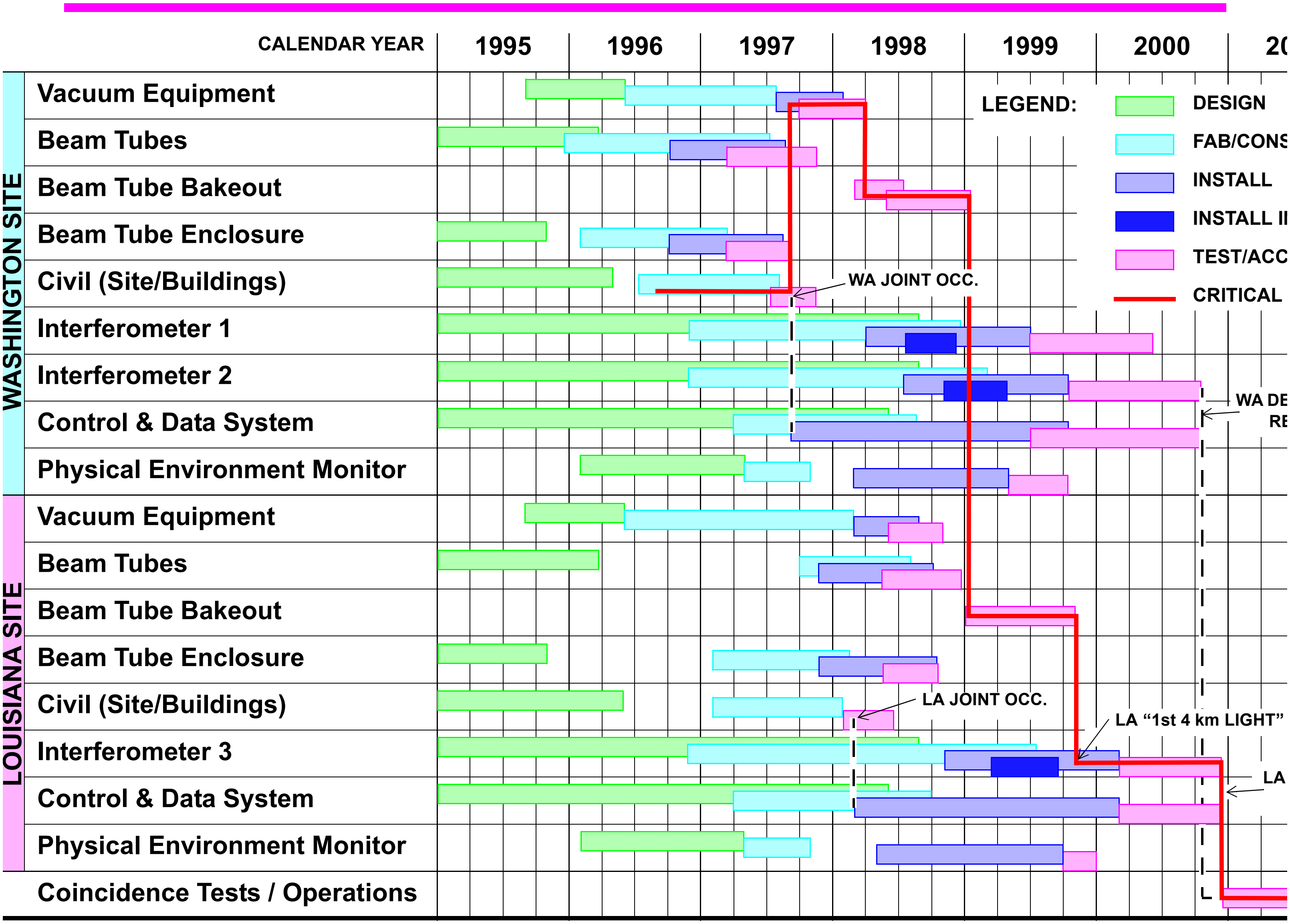
Main chambers (BSC)

- 5 chambers largely finished (~1/2 WA complement)
- other 10 in various states of construction

Input/Output chambers (HAM)

- 8 chambers look like chambers
- material for the other 11 on hand

Other elements (spool pieces, valves, pumps) keeping up


CALENDAR YEAR
1995
1996
1997
1998
1999
2000
20
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/CONS
INSTALL
INSTALL II
TEST/ACC
CRITICAL
WA JOINT OCC.
WA DE
RE
LA JOINT OCC.
LA “1st 4 km LIGHT”
LA