MIT Technical Program

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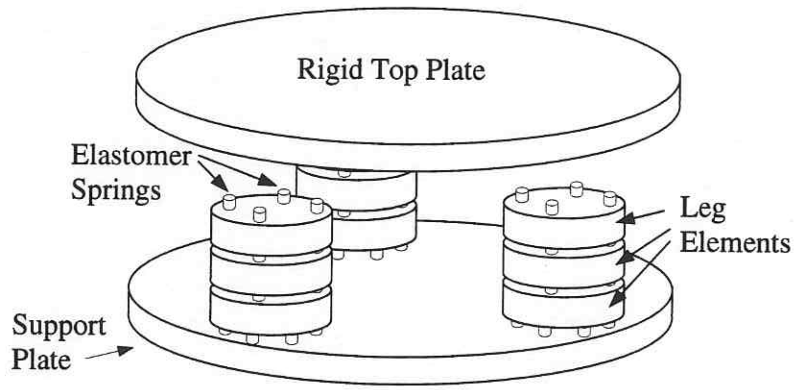
Areas of LIGO Research and Development at MIT

- Seismic Isolation
- Modulation Configuration
- Phase Noise Interferometer
- Interferometer Alignment
- Optical Modeling
- Engineering support

Seismic Isolation

- ☐ Prototype passive isolator: built, tested and modeled
- ☐ System:
  - three legs, three spring-mass elements each
  - all Fluorel, mixed Fluorel/RTV springs
  - 100 kg steel masses
  - 80 kg top table



- ☐ Measurements:
  - Mechanical transfer functions: 2×10^{-6} for horizontal → horizontal at 100 Hz
  - Drift of top table position
- ☐ At the end of the prototype research, this isolator was engineered for the 40 m interferometer, and has given large improvements in its low frequency performance.

Active isolation system

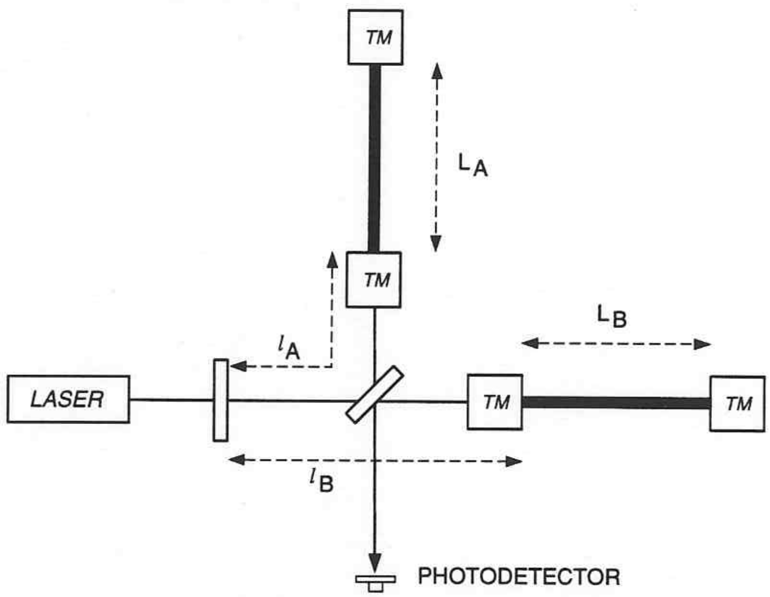
- ☐ Currently testing an alpha version of an active isolator being developed by Barry Controls
  - 3 mounting feet, each controlled in 3 degs of freedom
  - active band: 0.5–100 Hz; factor or 30 suppression from 2–20 Hz
- ☐ Application to LIGO:
  - facilitate lock acquisition
  - servo implementation: ease requirements on mirror transducers
  - reduction of upconversion effects
  - noise reduction in GW band
- ☐ Future: isolators will be used in MIT's prototype interferometer and evaluated for use in LIGO

Modulation Configuration

☐ Part of LIGO's Length Sensing subsystem

☐ Given the interferometer optical layout (recycled Fabry-Perot arm Michelson), need a system which generates error signals for controlling the longitudinal degrees of freedom:

- arm cavity lengths (resonances)
- recycling cavity length (resonance)
- output at dark fringe
- detection of GW signal



☐ Parallel research at MIT and CIT to choose between several phase modulation/demodulation schemes

- experiments on 'fixed-mass' table-top interferometers
- modeling of these and large-scale interferometers

☐ Research converged in September 1993: hybrid scheme chosen as most suitable for LIGO

☐ Future work at MIT: GW detection scheme to be further tested in the Phase Noise Interferometer

Phase Noise Interferometer

- ☐ Initial LIGO requires a sensitivity to the Michelson fringe of $10^{-10}\ \mathrm{rad}/\sqrt{\mathrm{Hz}}$
  - requires circulating power of 70 W
  - presently, 40 m uses roughly 0.2 W beamsplitter power
- ☐ Starting (2 yr) research program to build an interferometer that can:
  - achieve this phase sensitivity
  - serve as a 'high phase sensitivity' testbed for technologies and subsystems: complementary to 40 m
- ☐ Interferometer characteristics:
  - LIGO-like system for phase (GW) detection
  - Low displacement sensitivity: simple Michelson
  - LIGO circulating power via recycling
  - Suspended mirrors, seismic isolation, vacuum system
- ☐ Research goals:
  - LIGO phase sensitivity
  - Understanding of noise mechanisms: scattered light, laser amplitude noise, . . .
- ☐ Technology development goals:
  - Photodetection system
  - Modulation system
  - Laser amplitude stabilization
  - Beam absorbers and baffling

Interferometer Alignment

- Consists of:
  - Initial coarse angular alignment
    pointing lasers, quad diodes, CCD cameras
  - Centering of beams on masses
    CCD cameras
  - Maintenance of optimal angular alignment
    phase-front detectors

- Research and development plan
  - Establish requirements
    modeling, including non-ideal optics
  - Develop and test sensor/servo prototypes
    benchtop setups
    Fixed Mass Interferometer
    suspended cavities & interferometers
  - Develop 'system' (coordination)
    tests with hardware and software prototypes
  - Complete system test

- Current work:
  - Modeling has established requirements for low frequency angular deviations $\rightarrow 10^{-8}$ radians/mirror
  - Development of Phase Front Sensor for 'optics/beam — referenced' control signals
    a. prototype sensor built
    b. being used to control alignment of a 6m suspended cavity in all 4 degs of freedom
    c. implements computer processing of sensor signals
  - Will begin experimental verification of phase front sensor signals on the Fixed Mass Interferometer, in a LIGO-configuration

Optical Modeling

- ☐ Mode Decomposition Model: TEM_{nm} modes of the system
  - specify alignment requirements for LIGO
  - tool for designing alignment strategy and sensors
- ☐ Perturbation Analysis:
  - analytical solutions for simple mirror distortions
  - useful for determining mirror specifications
- ☐ FFT Numerical Model: what are the effects of imperfect optics?
  - Computer Program:
    a. Divide mirror surface (substrate) into a grid
    b. Apply: [mirror reflection, FFT, propagation, FFT], until field distributions converge and are maximized
    c. Field distributions determine optical performance of interferometer
  - Applications:
    a. Determine mirror specifications by modeling 'fake' mirror surfaces
    b. Simulation of LIGO performance using measured mirror surfaces
  - Status:
    a. Full interferometer code running, with optimizations
    b. Test runs made with: AXAF mirrors; measured substrate inhomogeneity
    c. Interaction with Path-Finder Team

Vacuum System Scientific Support

- ☐ Outgassing models
- ☐ Surface contamination measurements
- ☐ Bakeout strategy
- ☐ Leak assessment and localization strategies
- ☐ Tube alignment strategies
- ☐ Thermal analysis
- ☐ Stray light control and baffling
- ☐ Beam tube qualification test: planning and data analysis