Simulating Thermal Effects in Gravitational Wave Interferometers using MATLAB

Melody

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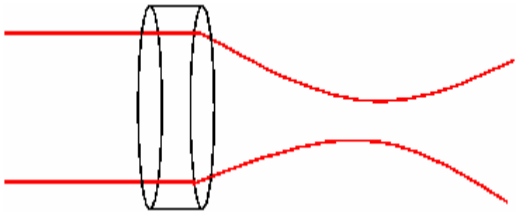
Outline

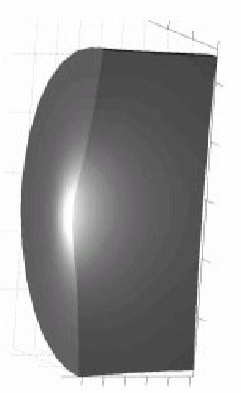
- Motivation
  - Increased Sensitivity with Higher Laser Power
- The Problem
  - Thermal Distortion Reduces Sensitivity
- The Approach
  - Melody: Object-Oriented MATLAB Model
  - Simulates Thermal Loading in Optical Cavities
  - Ref: Beausoleil et al., Model of Thermal Wave-Front Distortion in Interferometric Gravitational Wave Detectors I: Thermal Focusing, JOSA B, June 2003

Thermal Effects

- Thermal Focusing
  - Test mass temperature gradient not too large
  - Temperature distribution yields a weak positive lens



- Thermoelastic Surface Deformation
  - Stress/strain due to coating and substrate absorption



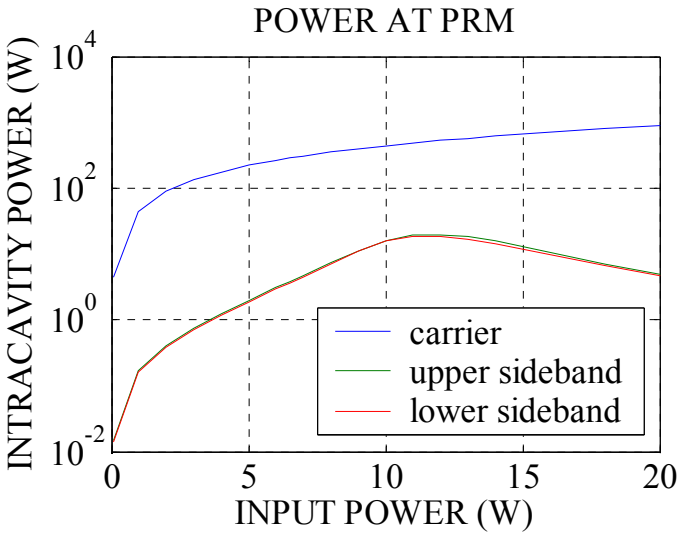
R. Lawrence, thesis, 2003

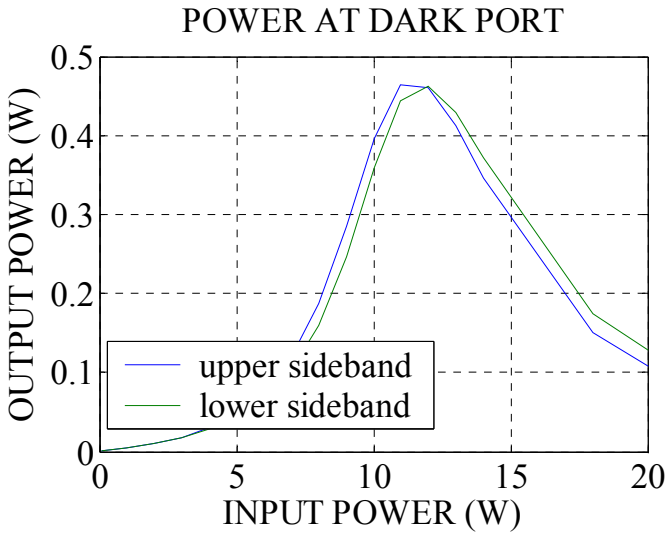
- Elasto-optic Effect
  - Stress changes index of refraction
  - Important for sapphire test masses
  - Alters thermal focusing slightly

Key Features of Melody

- Object-Oriented Design
  - Classes: Laser_Field, Mirror, Beamsplitter, LIGO
- Cavity Modes
  - Hermite-Gauss Basis (TEM_{mn})
  - User specifies number of modes
- Melody accounts for
  - Thermal distortion
  - Aperture diffraction
  - Mirror/Incident field curvature mismatch
  - Optic displacement from servo control
- Seeks Self-Consistent Solution to a System Perturbed from Steady State

Simulations of LIGO





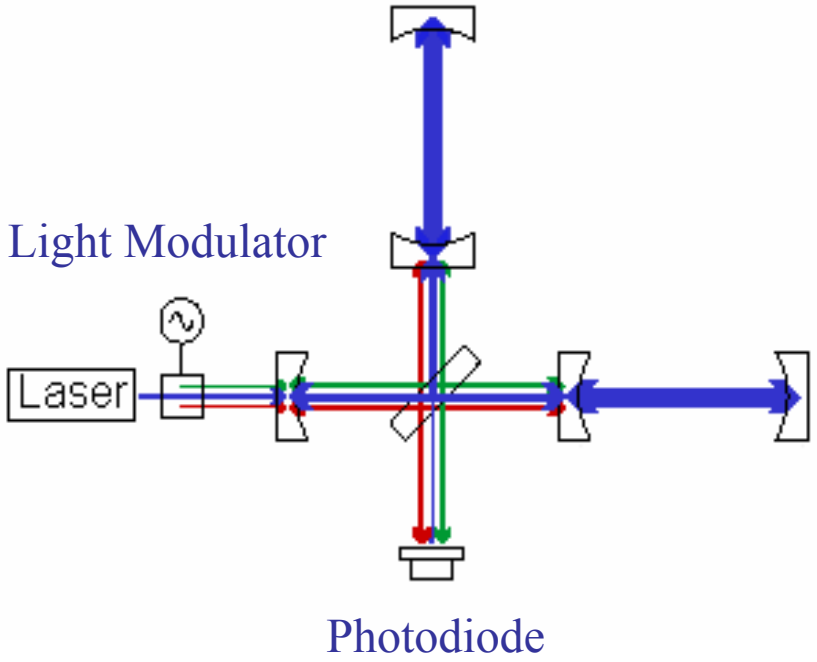
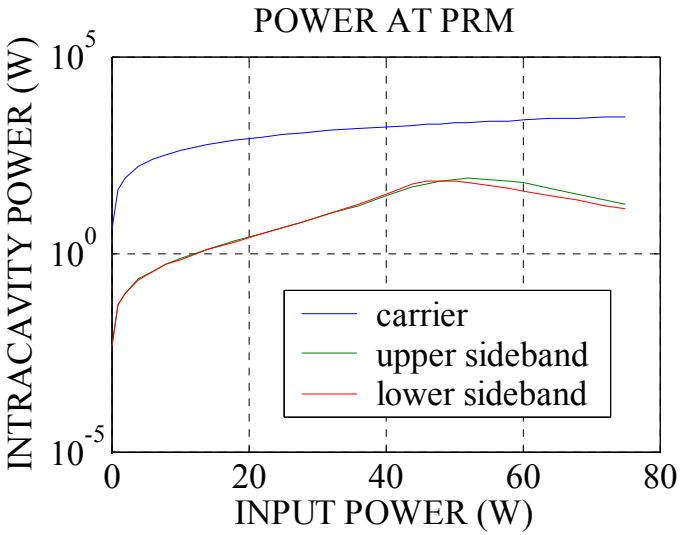
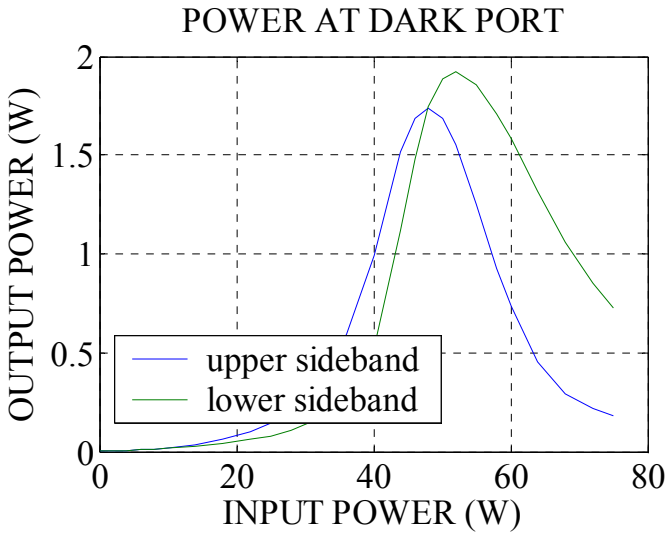


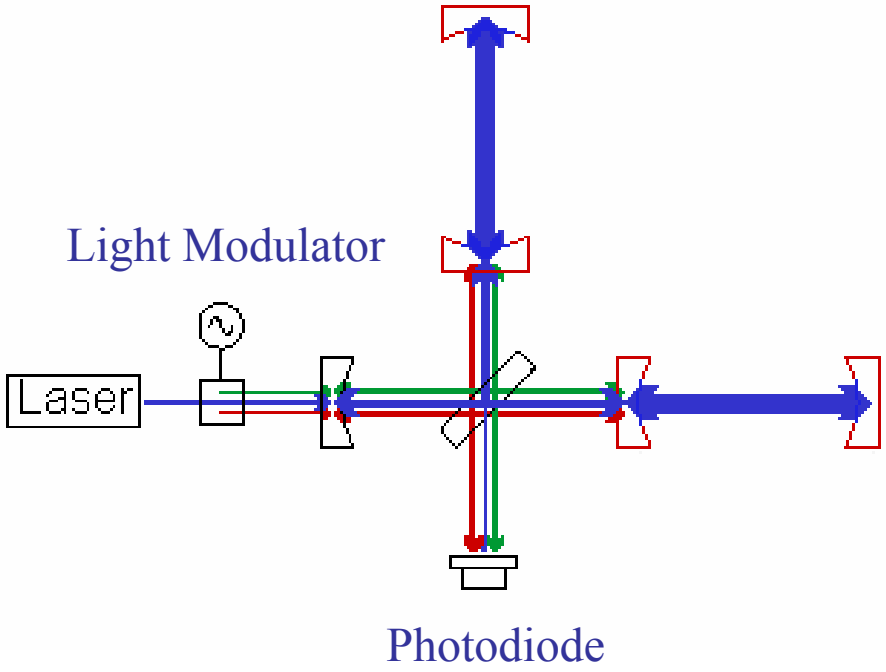
Fig. from R. Beausoleil

LIGO with Sapphire

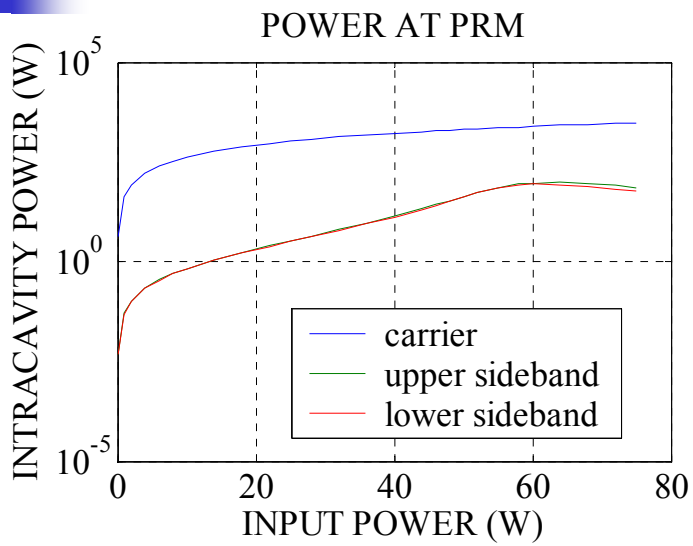


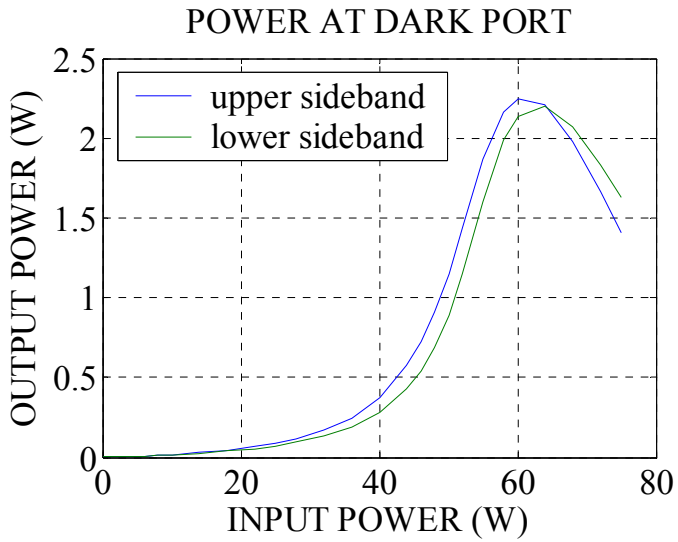


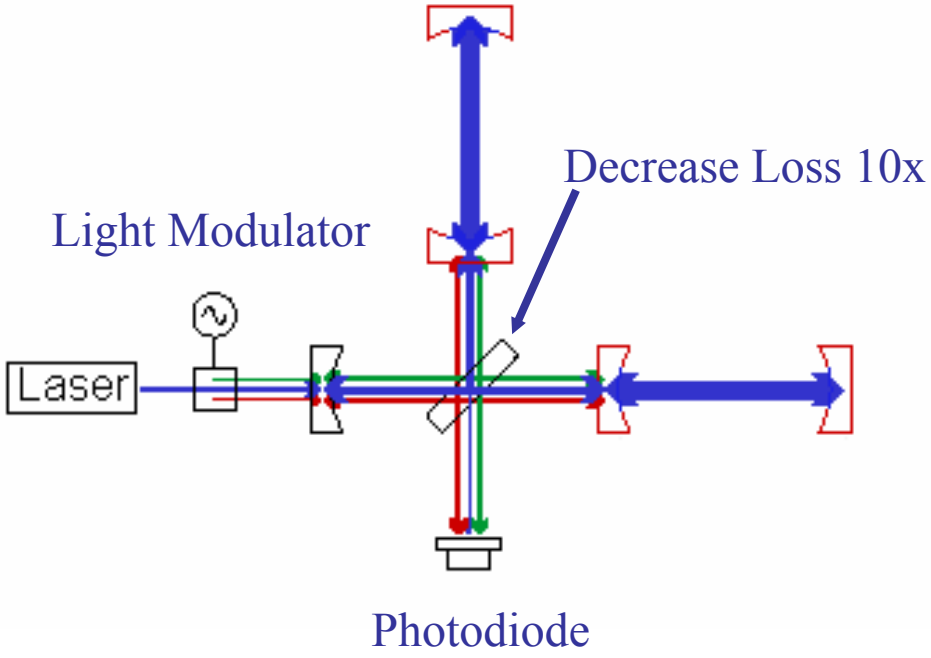
Sapphire Absorption: 40ppm/cm



LIGO w/ Sapphire: Lower Loss Beamsplitter

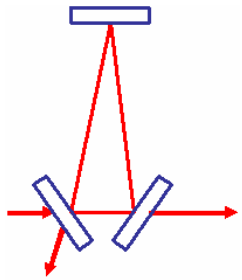






Conclusion

- Thermal Effects
  - Important factor for GW sensitivity
- Melody provides insight into impact of thermal effects on passive cavities
  - When do thermal effects become significant?
- Future Work
  - Add Parameters for Modeling a Curved Beamsplitter
  - Verify Results with Experiment



Website for Melody

- http://www.phys.ufl.edu/LIGO/LIGO/STAIC/SOFT/