Modeling Thermal Effects in Advanced LIGO with SIS.

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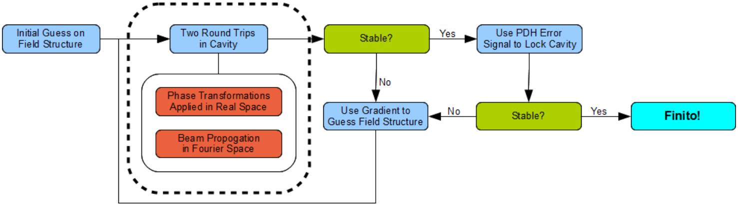
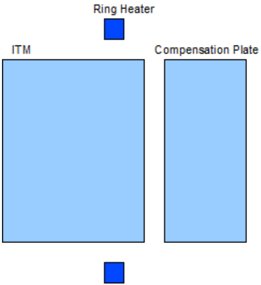
Outline

- Written by Hiro Yamamoto
- Can presently be used to simulate FP cavities as well as two coupled cavities.
- Workflow:



Thermal Compensations Systems in Advanced LIGO

- Ring heaters correct thermoelastic expansion of the test mass surfaces.
- CO_2 laser projectors acting on compensation plates correct for the leftover thermal lens.
- The CO_2 system is essentially uncoupled from the ring heater system.



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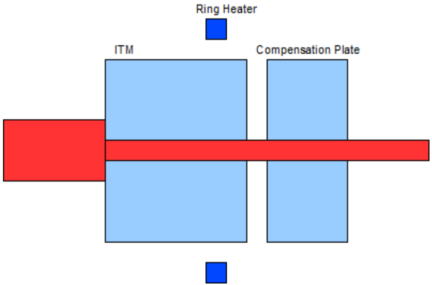

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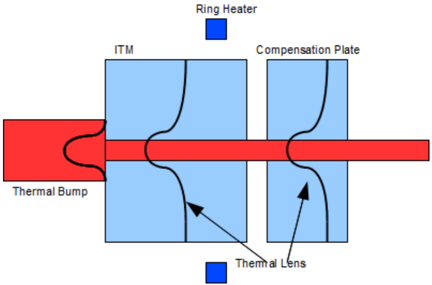

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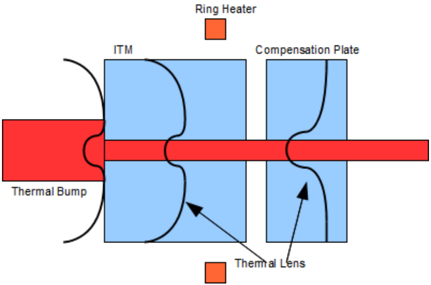

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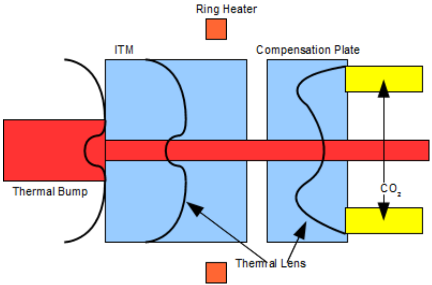
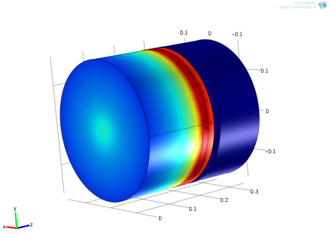
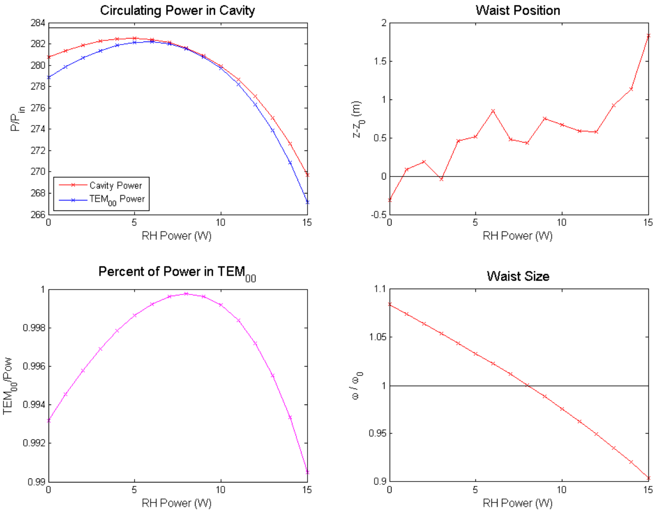


FEM Model Description



- Simplifications
  - Flat surfaces for suspension wires are neglected.
  - Residual gas effects are neglected.
  - Test masses are not wedged.
  - **Ring heater is treated as a heat source applied directly to the optic.**
  - The substrate absorption of the ITM is set at its worst case value of 3 ppm/cm.

Needed Ring Heater Power at Full IFO Power



Required Ring Heater Power at Other IFO Power Levels

- Sweeping the ring heater power similarly at other IFO power levels, we find that the required ring heater power is very linear in the arm cavity power;

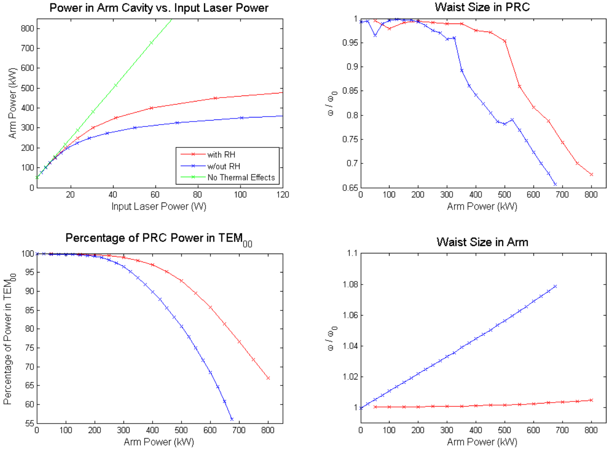
$$P_{RH} = 1.05 \times 10^{-5} P_{arm} - 0.05\text{W}. \tag{1}$$

- Note that the simulations were only run for equal amounts of ring heater power on both test masses, so this should be treated as a nominal value.

Simulation Setup

- We treat the power recycling cavity coupled to the x arm of the interferometer taking into account the beamsplitter.
- The input beam is fixed at its cold state IFO value.
- Deformation and phase maps are generated using the FEM model and imported directly into SIS.
- Simulation was run once for an interferometer without any thermal compensation and once for an interferometer with ring heaters but no CO_2.
- Both the test mass curvatures and the integrated phase through the CP and ITM is included.

IFO Simulation Results

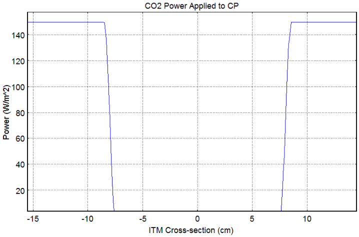


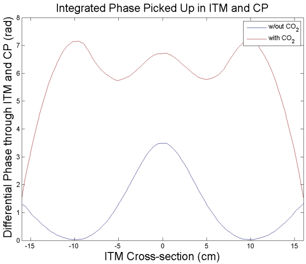
CO_2 Model

- The CO_2 beam was naively modeled as a step function of radius, i.e.

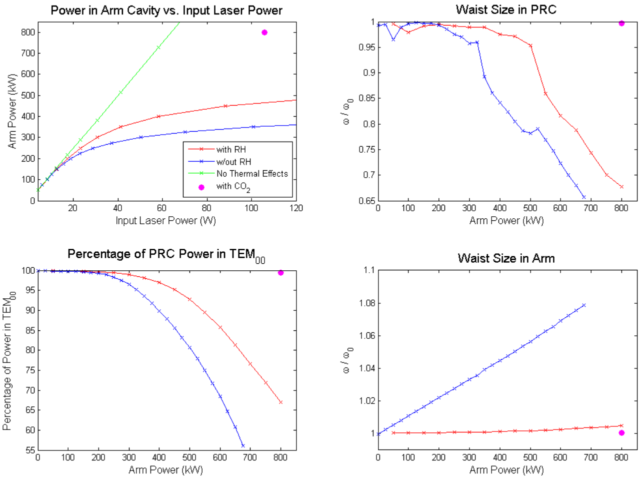
$$150\frac{\mathrm{W}}{\mathrm{m}^2} * \Theta\left(r - \frac{3}{2}\omega_{ITM}\right). \tag{2}$$

- Varying the parameters while looking for a reasonably flat phase profile gives the above result.





CO_2 Results


Power in Arm Cavity vs. Input Laser Power
Arm Power (kW)
Input Laser Power (W)
with RH
w/out RH
No Thermal Effects
with CO2
Waist Size in PRC
ω / ω0
Arm Power (kW)
Percentage of PRC Power in TEM00
Percentage of Power in TEM00
Arm Power (kW)
Waist Size in Arm
ω / ω0
Arm Power (kW)

Conclusions and Future Work

- Conclusions
  - TCS will be invaluable to reaching Advanced LIGO's design goals.
  - In particular, the CO_2 system will be necessary.
- Future Work
  - More realistic model of ITM and ETM (underway).
  - Compare FEM models to experiment (underway).
  - Allow for different ring heater powers.
  - More realistic CO_2 model.
  - How do these effects depend on substrate absorption?
  - Include measured ring heater profile in FEM models.
  - Development and modeling of TCS error signals.
  - Could adaptive mode matching help out?
  - Distinguish between carrier and sidebands in the PRC.