Optimization of Michelson Interferometer Signals in Crackle Noise Detection

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LIGO SURF Project

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Crackle Noise

- Crackle noise may affect LIGO detection
- Impulsive release of energy or acoustic pressure
- Changes in geometry
- Question: is crackle noise a problem to LIGO?

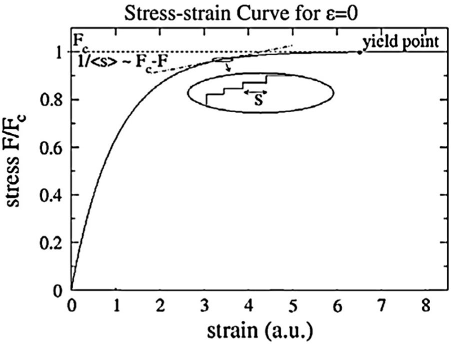
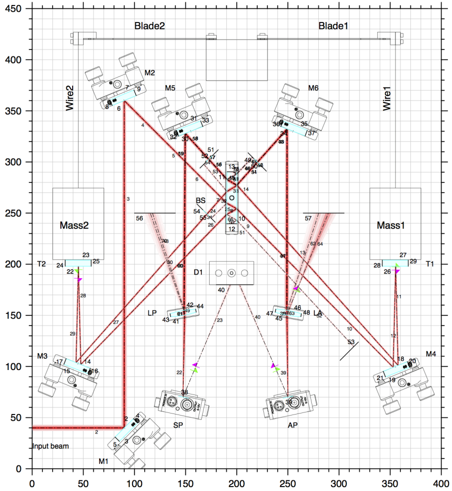


Figure : Dahmen, Benzion, and Uhl, Phys. Rev. Lett. (2009)

Crackle Setup



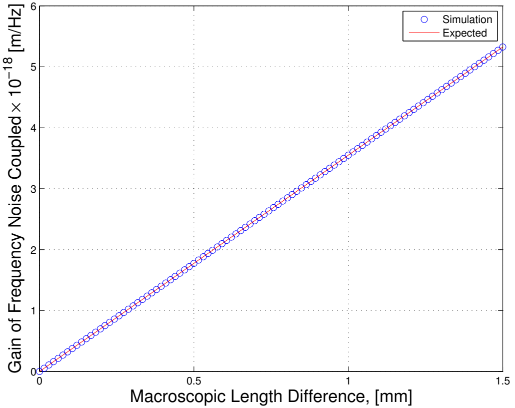
- Output: Difference between symmetric and antisymmetric port readings

Motivation

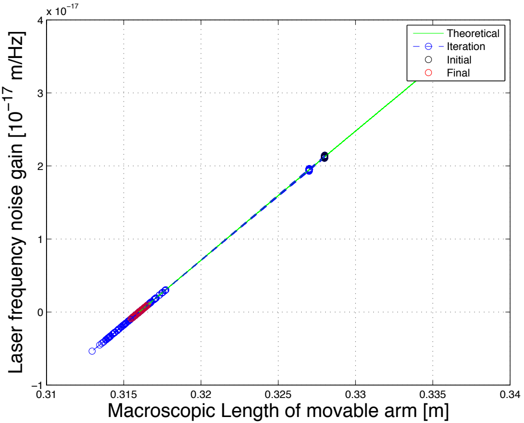
- Crackle experiment is prone to noises:
  1. Laser frequency noise
  2. Laser intensity noise
- Mirror misalignment also affects signal output
- Coupling of noises can be minimized by adjusting parameters of setup
- Before (Crackle 1 experiment):
  - trial and error
  - ideal parameters drift away due to environmental factors
- Now (Crackle 2 experiment):
  - Goal: automatically adjust these parameters to optimize output
- Simulation - MIST optical toolbox

Laser Frequency Noise

- Variation of laser frequency
- Laser Frequency Noise Coupling, $g_{freq} = \Delta L/\nu$
- Aim: equalize macroscopic length difference, O(1mm)
- Piezo-translation stage controls length of one arm



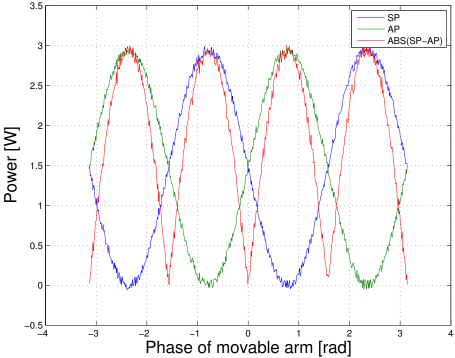
Laser Frequency Noise (Algorithm)



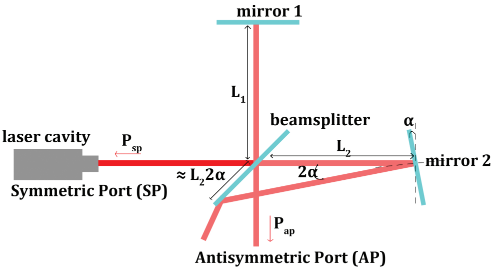
- 100 measurements with random measurement uncertainties
- Average of 5 steps to complete algorithm

Laser Intensity Noise

- Variation of laser power
- $RIN = \frac{\delta P}{P}$
- Aim: adjust microscopic length difference, O(1 nm)
- Strategy: Locking (negative feedback) $\Longrightarrow$ half fringe condition



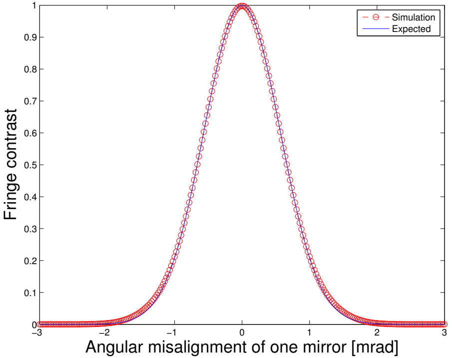
Mirror Misalignment



- Effects of misalignment: (i) additional phase added by mirror misalignment (ii) shifted beam center $\implies$ reduced fringe contrast
- Aim: align mirrors so fringe contrast is close to unity
- Fringe contrast $= \frac{P_{max} - P_{min}}{P_{max} + P_{min}} = \int \int Re[\psi_1 \psi_2^*] dx dy$

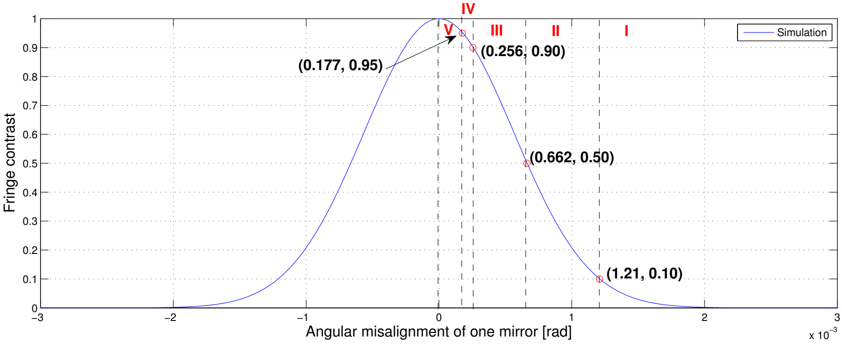
Mirror Misalignment (Model)

- $\int\int Re[\psi_r \psi_o^*]dxdy = e^{-\frac{2L_2^2\alpha^2}{w^2} - \frac{k^2w^2\alpha^2}{2} + \frac{k^2w^2L_2\alpha^2}{R} - \frac{k^2L_2^2w^2\alpha^2}{2R^2}}$
- L_2 = length of arm, w = beam radius, k = wavenumber, α = misalignment angle, R = radius of curvature of wavefront

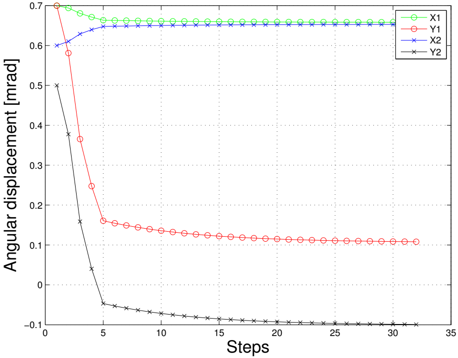


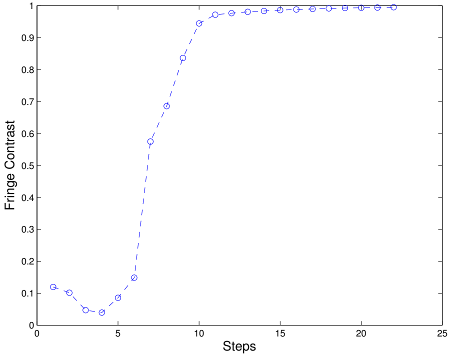
Gradient Ascent Optimization

- Crucial parameter: step size
- Divide fringe contrast pattern into approximate linear regimes
- $\delta = \delta_{max} \frac{grad_{local}}{grad_{max}}$, where $grad_{local} = \begin{pmatrix} grad_{x1} \\ grad_{y1} \\ grad_{x2} \\ grad_{y2} \end{pmatrix}$



Alignment Plots





Conclusion

- All 3 algorithms have been tested rigorously
- Next step: implement in real crackle experiment
- Acknowledge: Gabriele Vajente, Xiaoyue Ni, Alan Weinstein, LIGO SURF students, NSF
- Thank You!

Alignment Plots