LIGO

The Effect of Transverse Shifts on the LIGO Interferometer

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Purpose and Motivation

Purpose

- Through computer simulations I will map the response of the interferometer to various transverse shifts in the optics.
- Determine how these shifts will effect the detector's performance.

Motivation

- It is believed that one of the input mirrors at the Hanford observatory is misaligned by 1-2 cm.
- Also, the laser beam, at times, has been shifted on the order of 1 cm.

Transverse Shifts

- Figure 1 shows the interferometer in the normal operating state or the unperturbed state.

- Figure 2 shows the interferometer in a perturbed state where all the mirrors have been shifted in the x-direction by 1cm.

Figure1

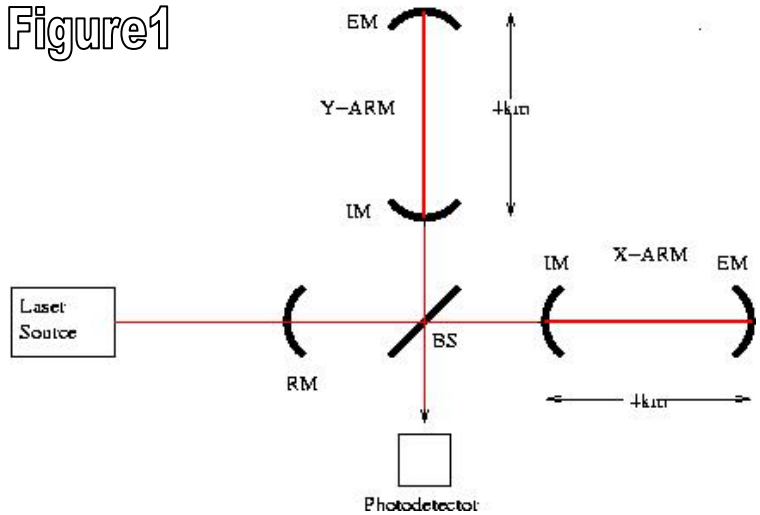
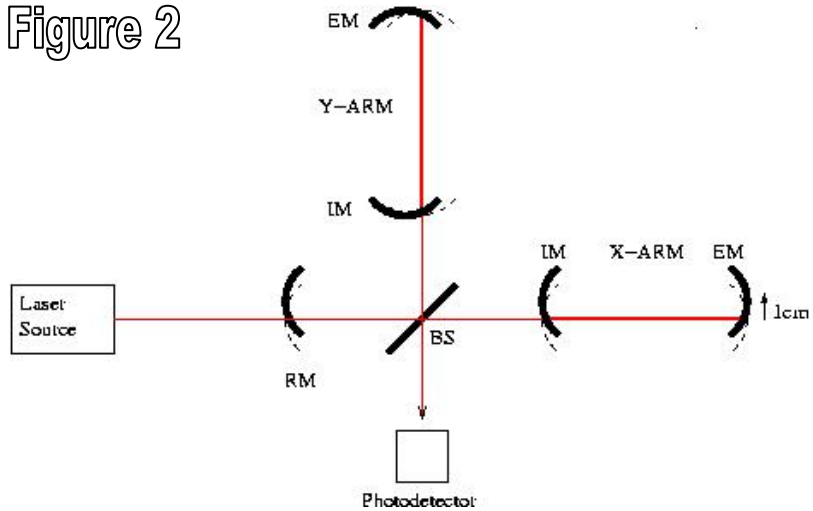


Figure 2



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Comparison of Simulation Tools

End-to-End (e2e)

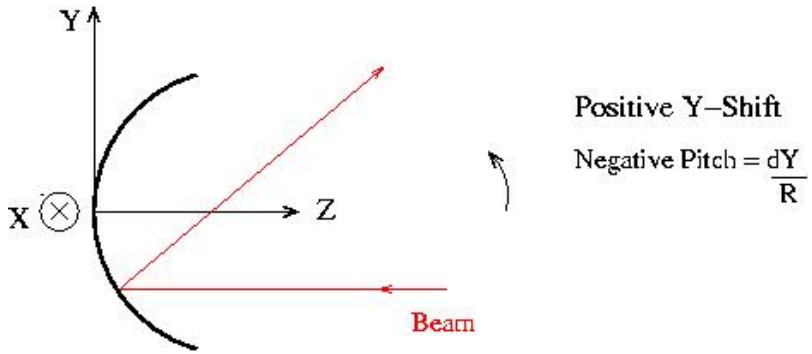
- Time domain simulation package.
- SimLIGO is a good description of the LIGO detector with detailed models of the optics, suspension system, noise sources, wavefront and length sensors, etc.
- Relatively Long simulation time.

MIT FFT Code

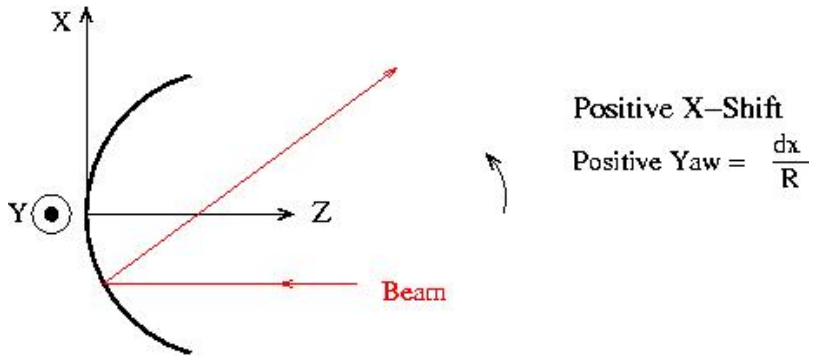
- Frequency domain simulation package.
- Gives a very accurate description of the interferometer in the steady state.
- Static simulation that doesn't simulate feedback corrections.
- Relatively short simulation time.

Transverse shifts are equivalent to rotations

- Rotation about the x-axis is known as pitch. If the mirror is offset by 1cm in the Y-direction, a pitch of 0.01/R radians is needed to counter the shift, where R is the radius of curvature for that mirror.



- Similarly, rotation about the y-axis is called yaw (notice the sign difference between the two).



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Comparison of angles

$$\text{Yaw} = \frac{\Delta x}{R}$$

Example of Rotation: If R = 7500m, then a 1cm shift would produce equivalent yaw (or pitch) of

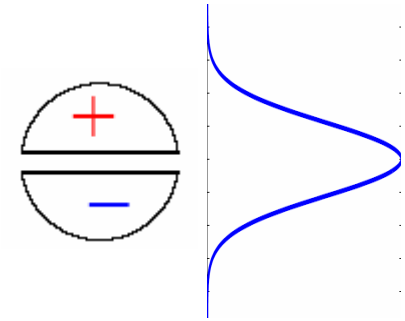
$$\frac{0.01\ \text{m}}{7500\ \text{m}} = 1.3 \times 10^{-6}\ \text{radians}$$

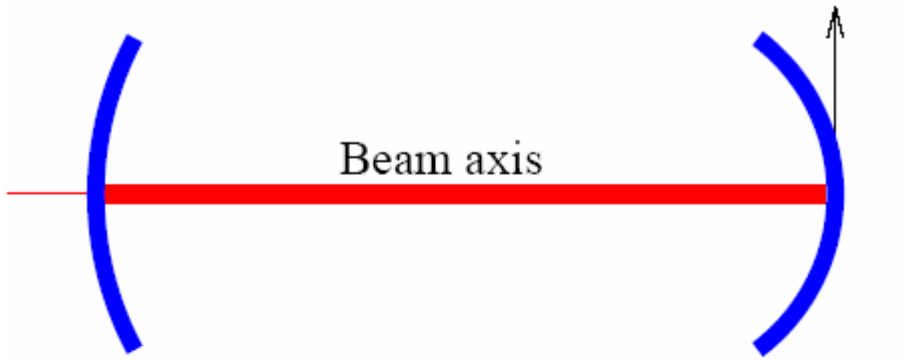
Divergence angle: $\phi = \frac{\lambda}{\pi \omega_0} = 1 \times 10^{-5}$ radians

A calculation by Fritschel suggests that a misalignment of 1×10^{-8} radians should result in a 0.5% increase in shot noise.

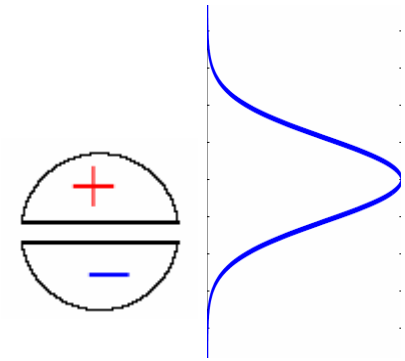
Wavefront sensors: Misalignment signal

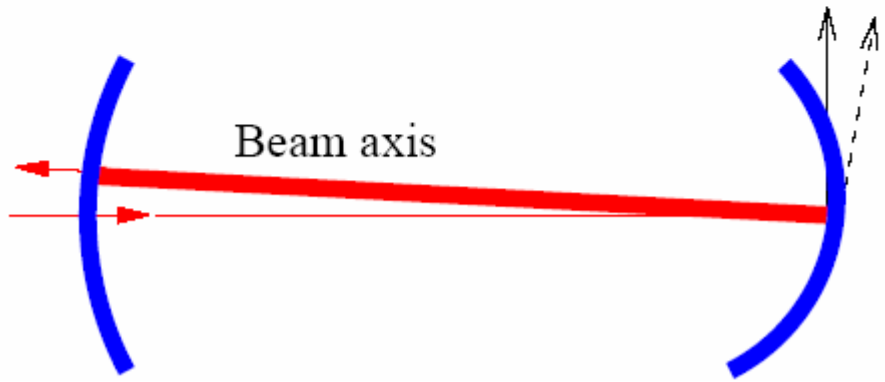
Signal 0 <=



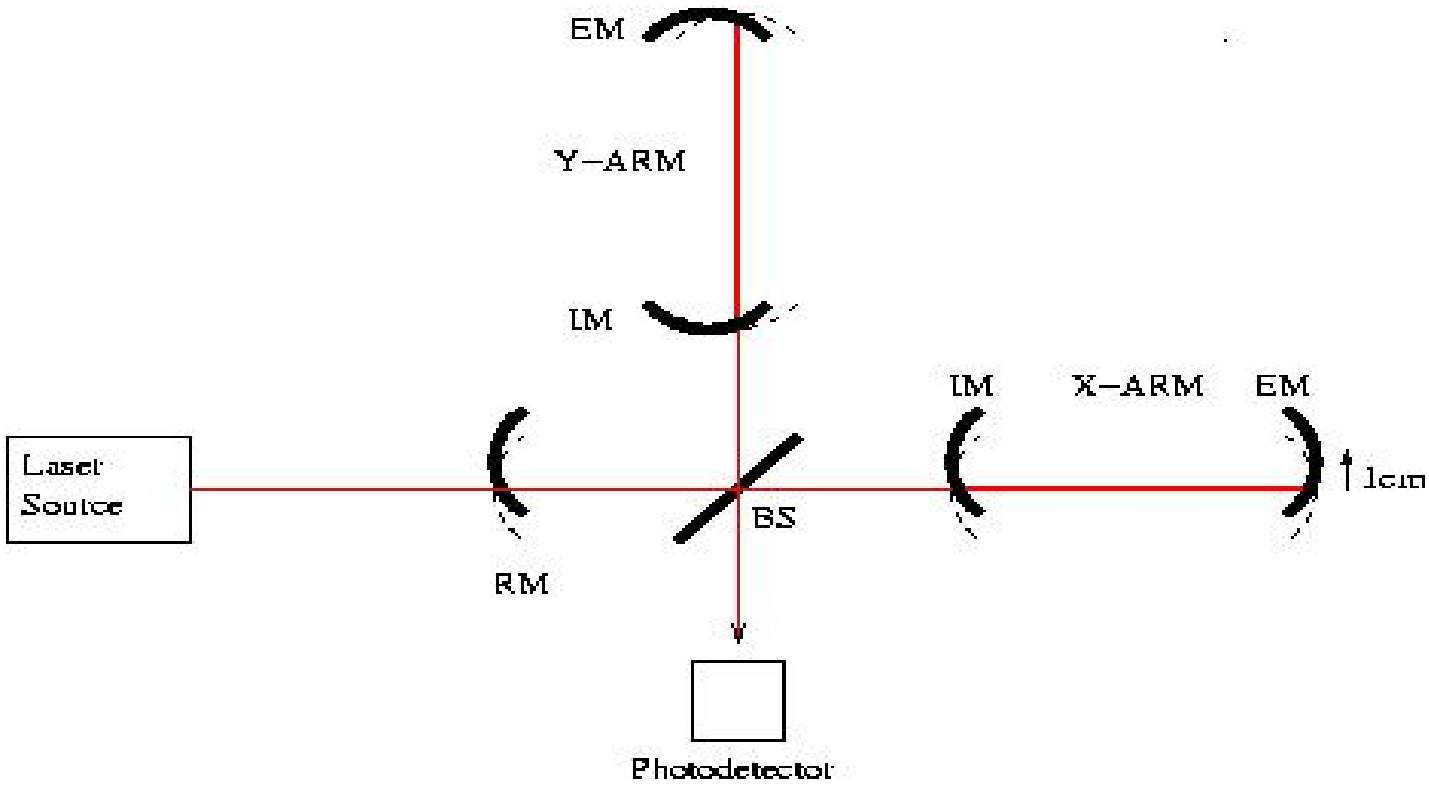


Signal non0 <=



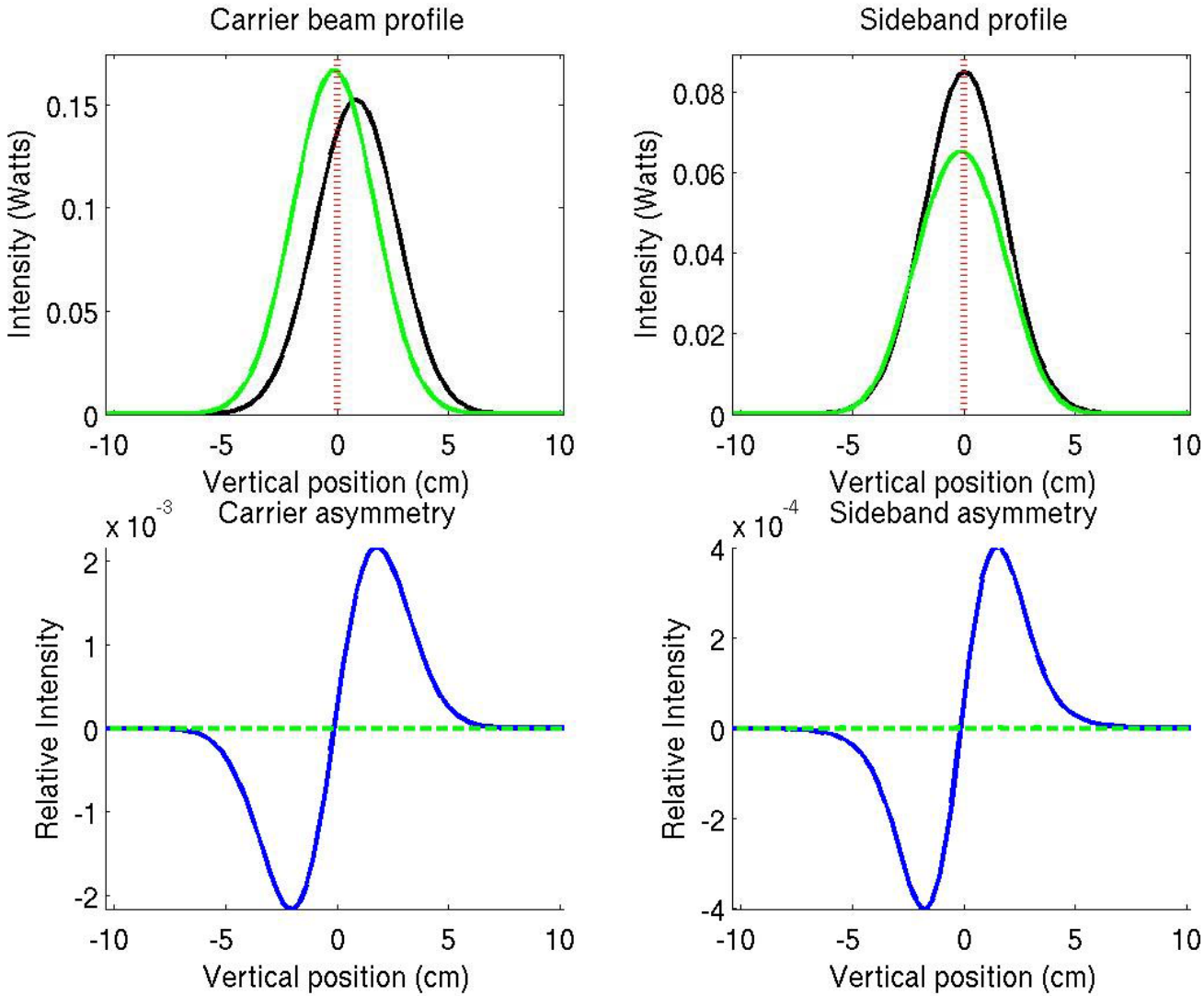


FFT simulation

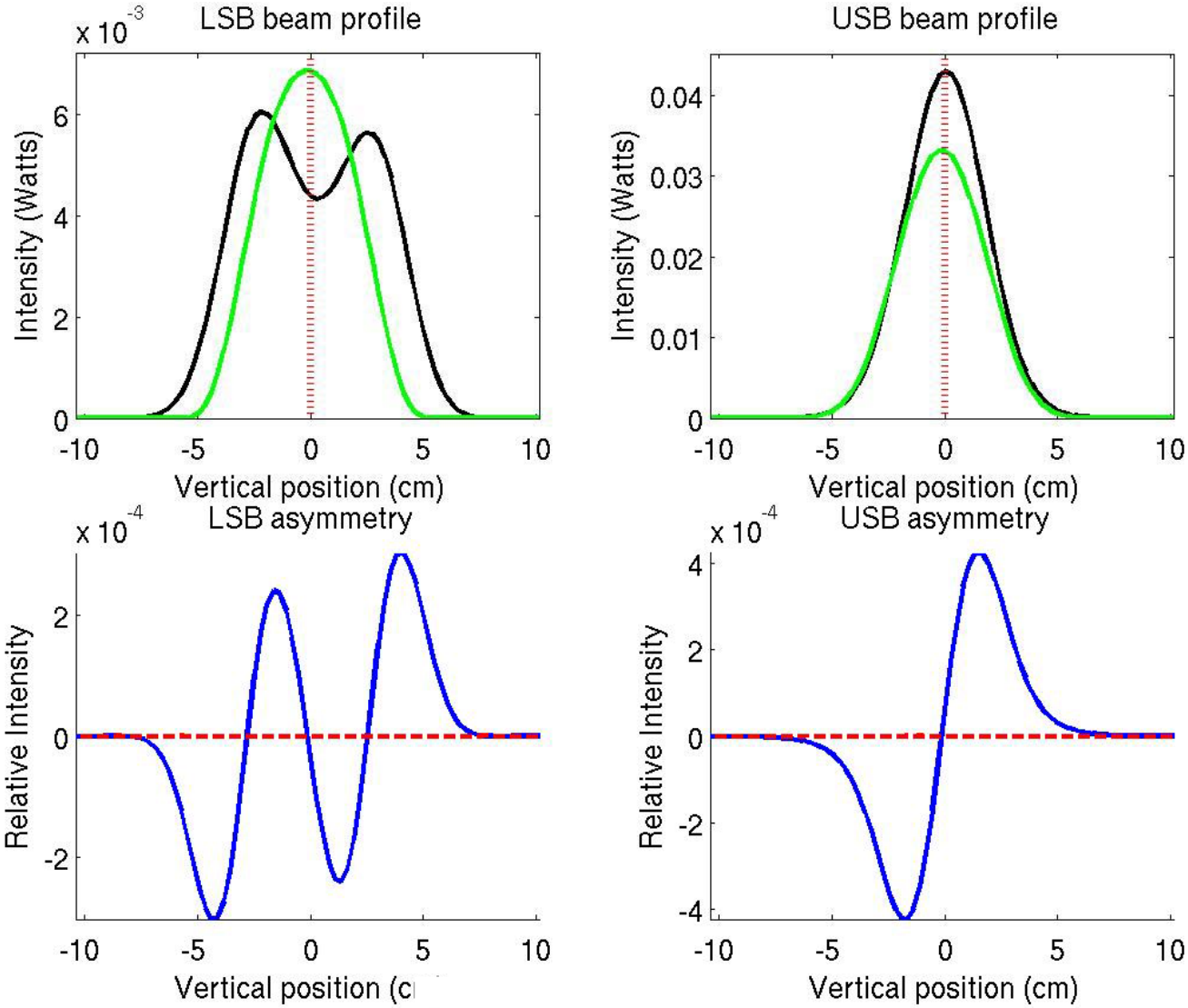


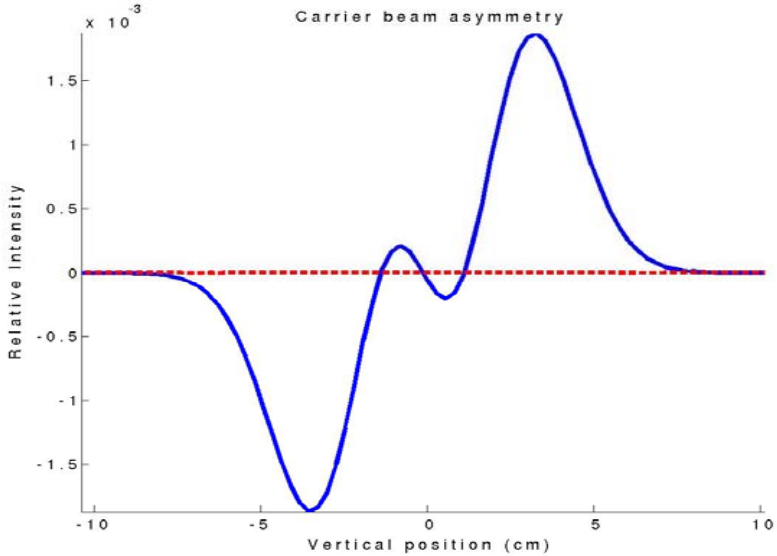
- In FFT I used the parameters and specifications to model LIGO Hanford's detector. In this simulation I shifted the 5 mirrors, Recycling, ITMX, ETMX, ITMY, ETMY, by 1cm in the x direction.

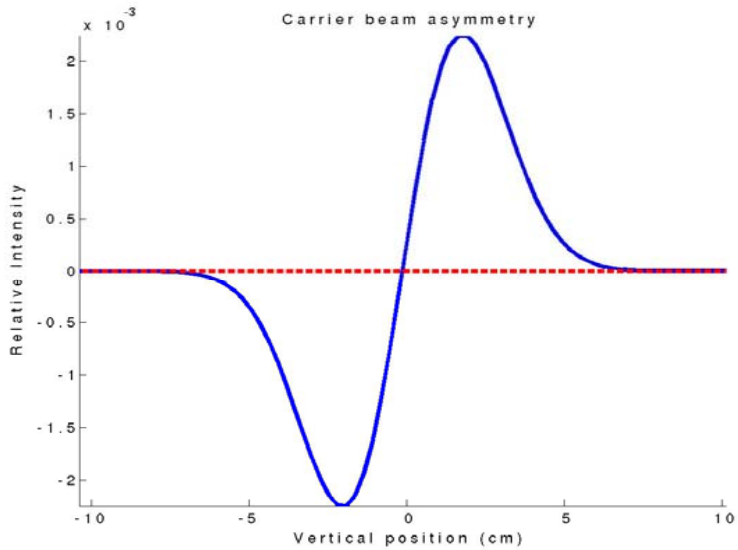
FFT: Results from a 1cm Shift in all mirrors

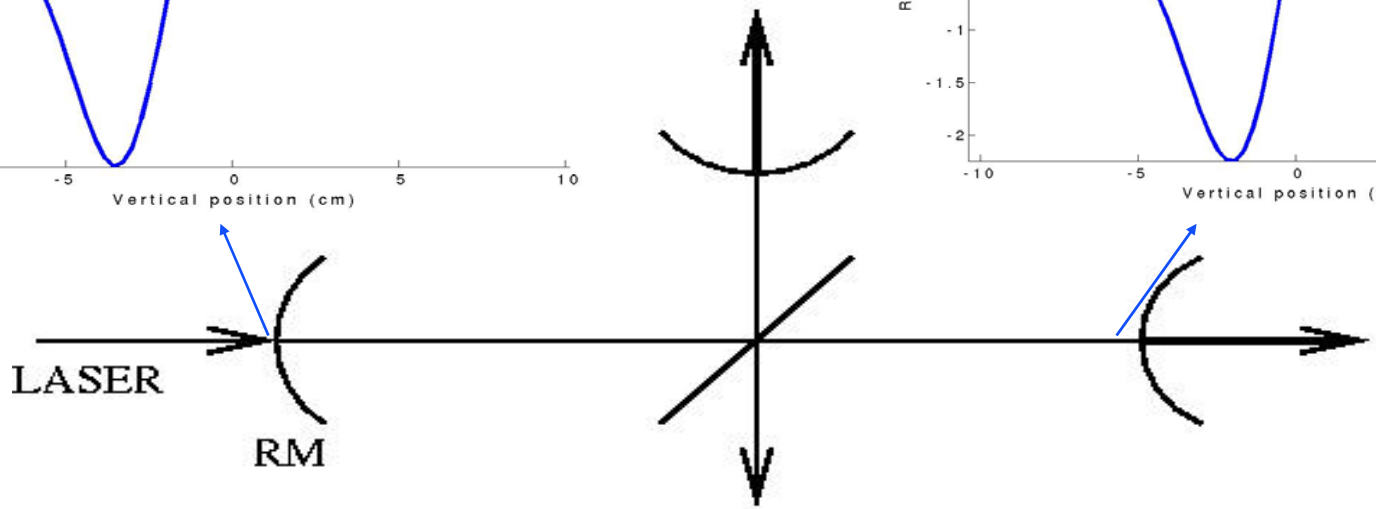


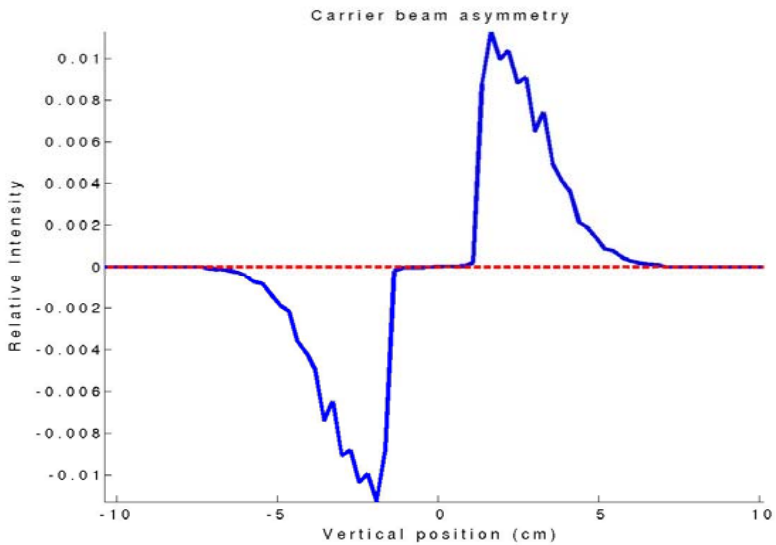
Sideband Comparison at ITMX backside

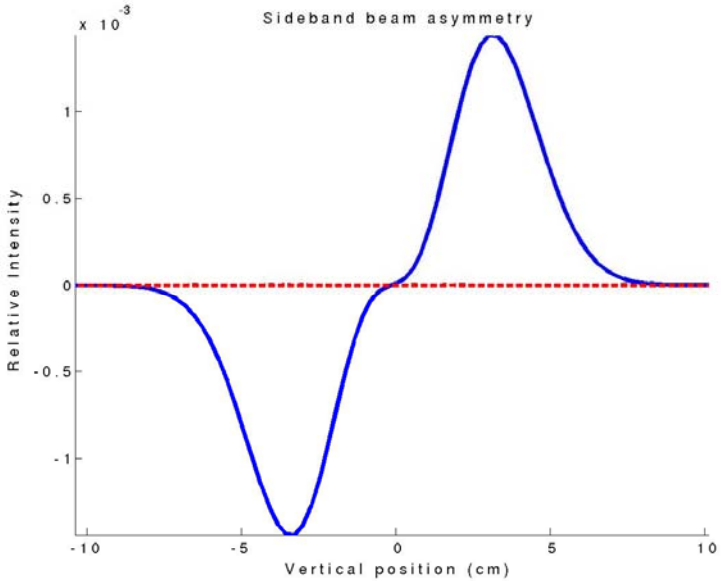


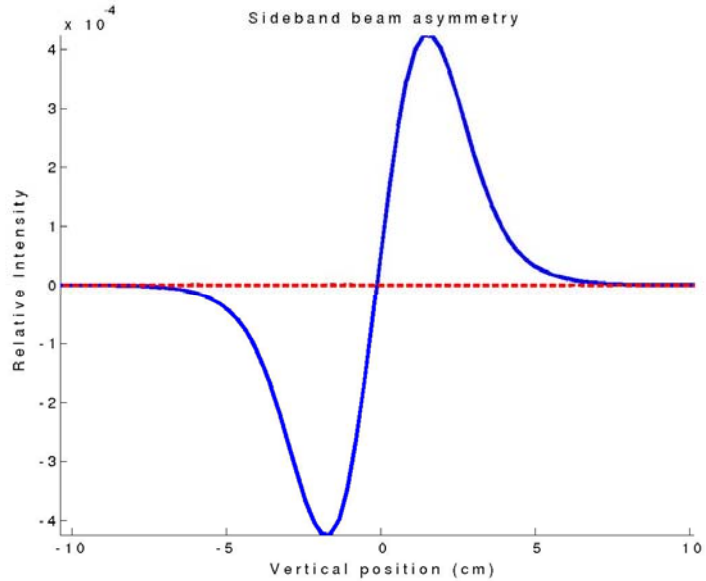

Carrier beam asymmetry
x 10^-3
Relative Intensity
Vertical position (cm)

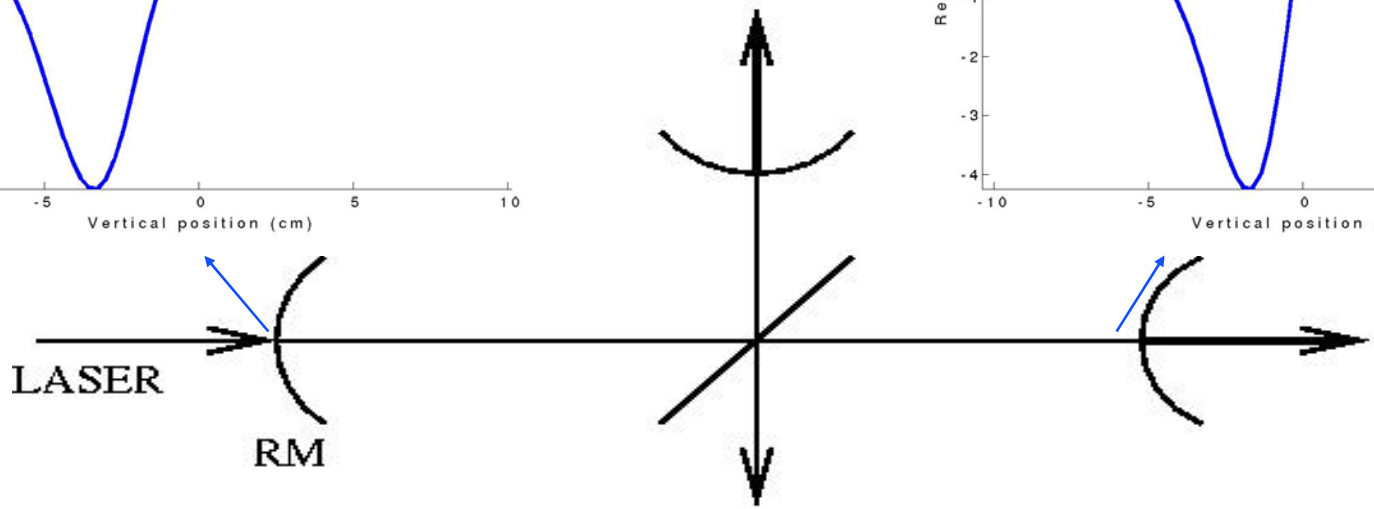

Carrier beam asymmetry
x 10^-3
Relative Intensity
Vertical position (cm)

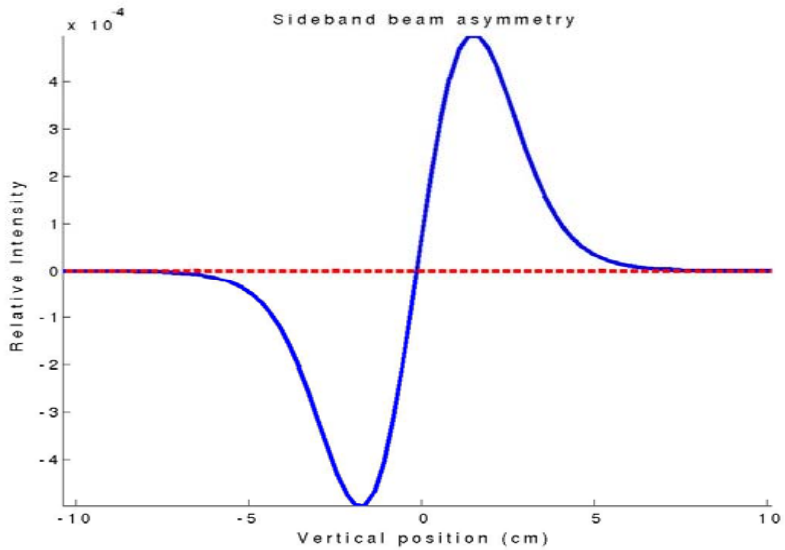

LASER
RM

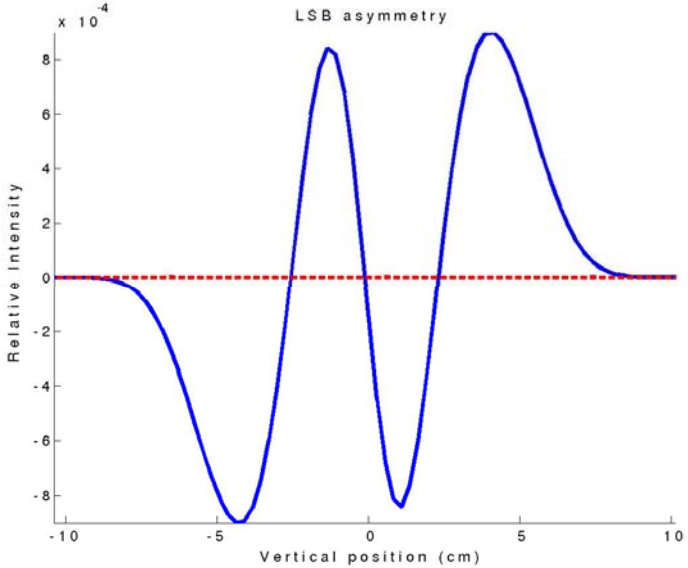

Carrier beam asymmetry
Relative Intensity
Vertical position (cm)

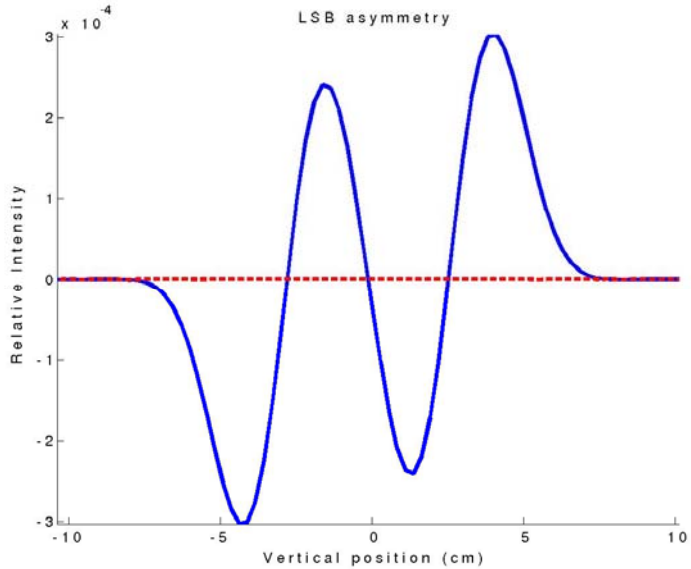

Sideband beam asymmetry
x 10^-3
Relative Intensity
Vertical position (cm)

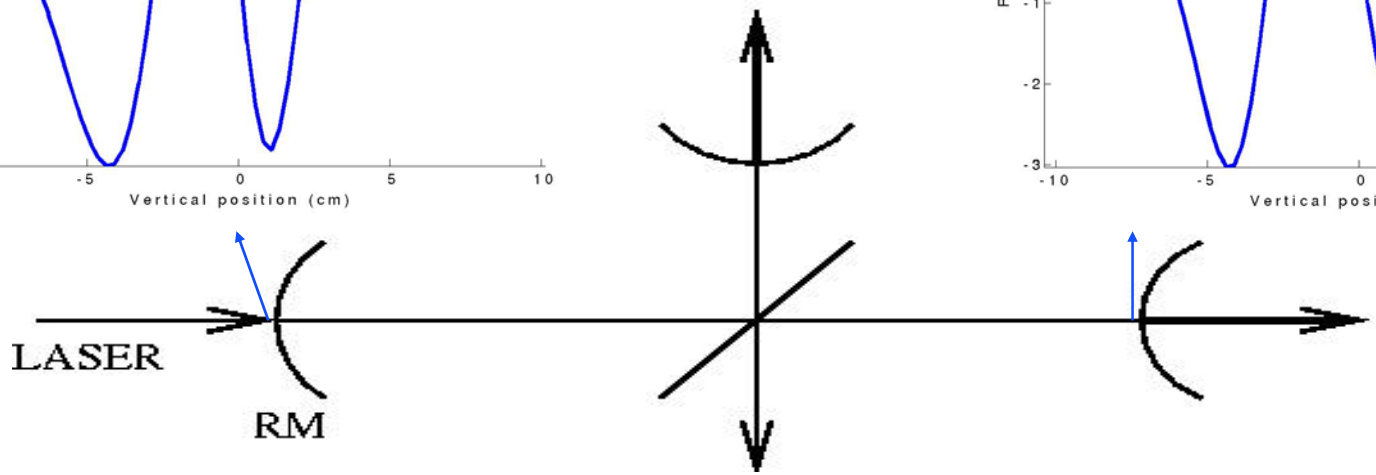

Sideband beam asymmetry
x 10^-4
Relative Intensity
Vertical position (cm)

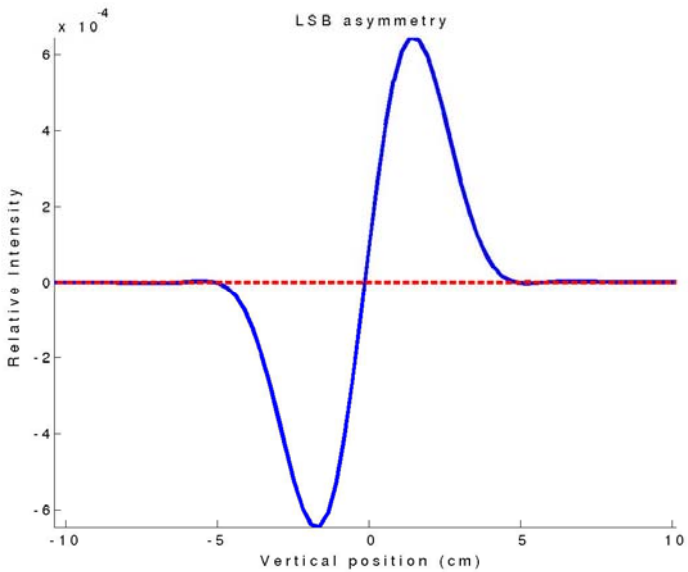

LASER
RM


Sideband beam asymmetry
x 10^-4
Relative Intensity
Vertical position (cm)

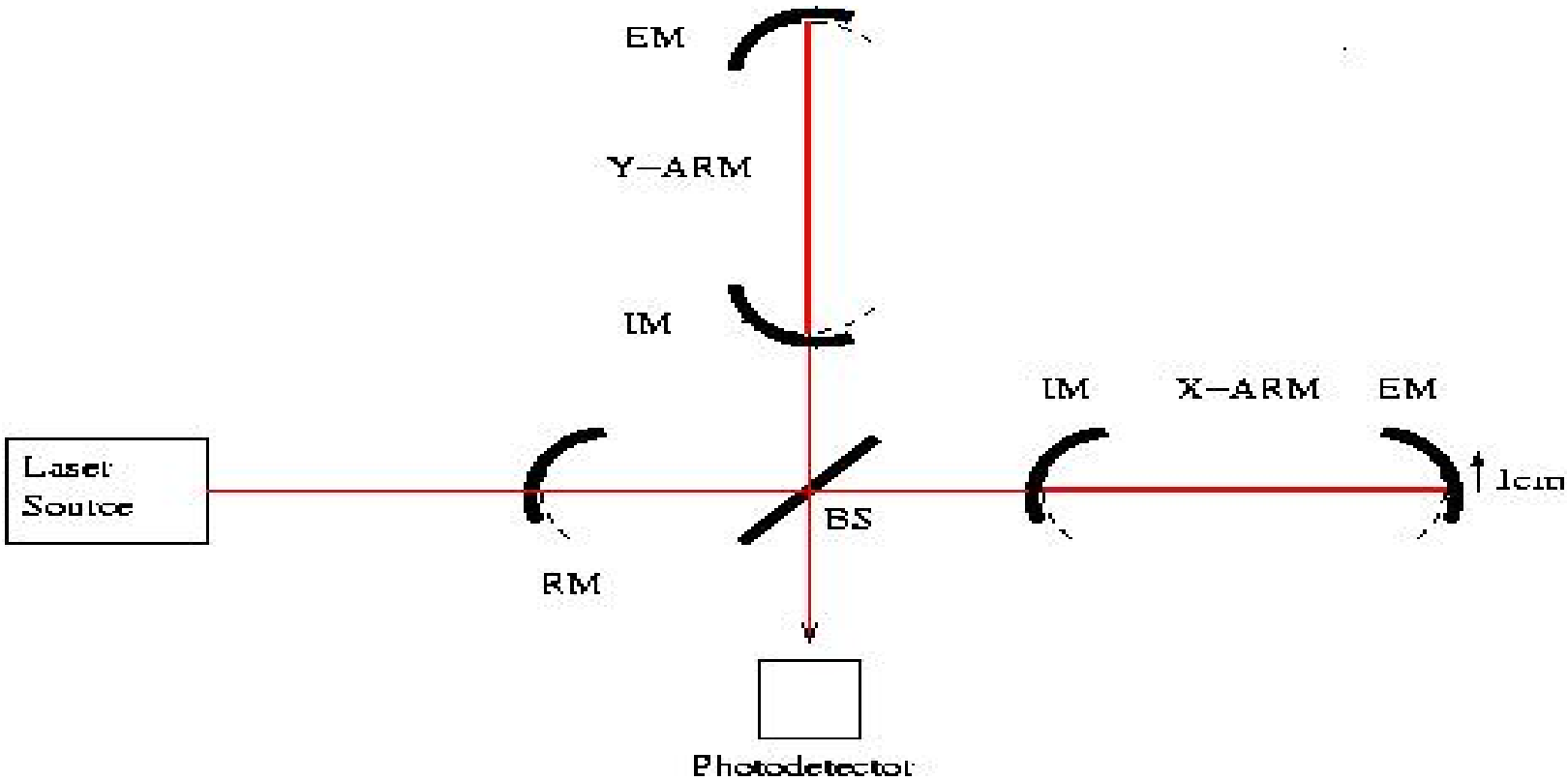

LSB asymmetry
x 10^-4
Relative Intensity
Vertical position (cm)


LSB asymmetry
x 10^-4
Relative Intensity
Vertical position (cm)


LASER
RM

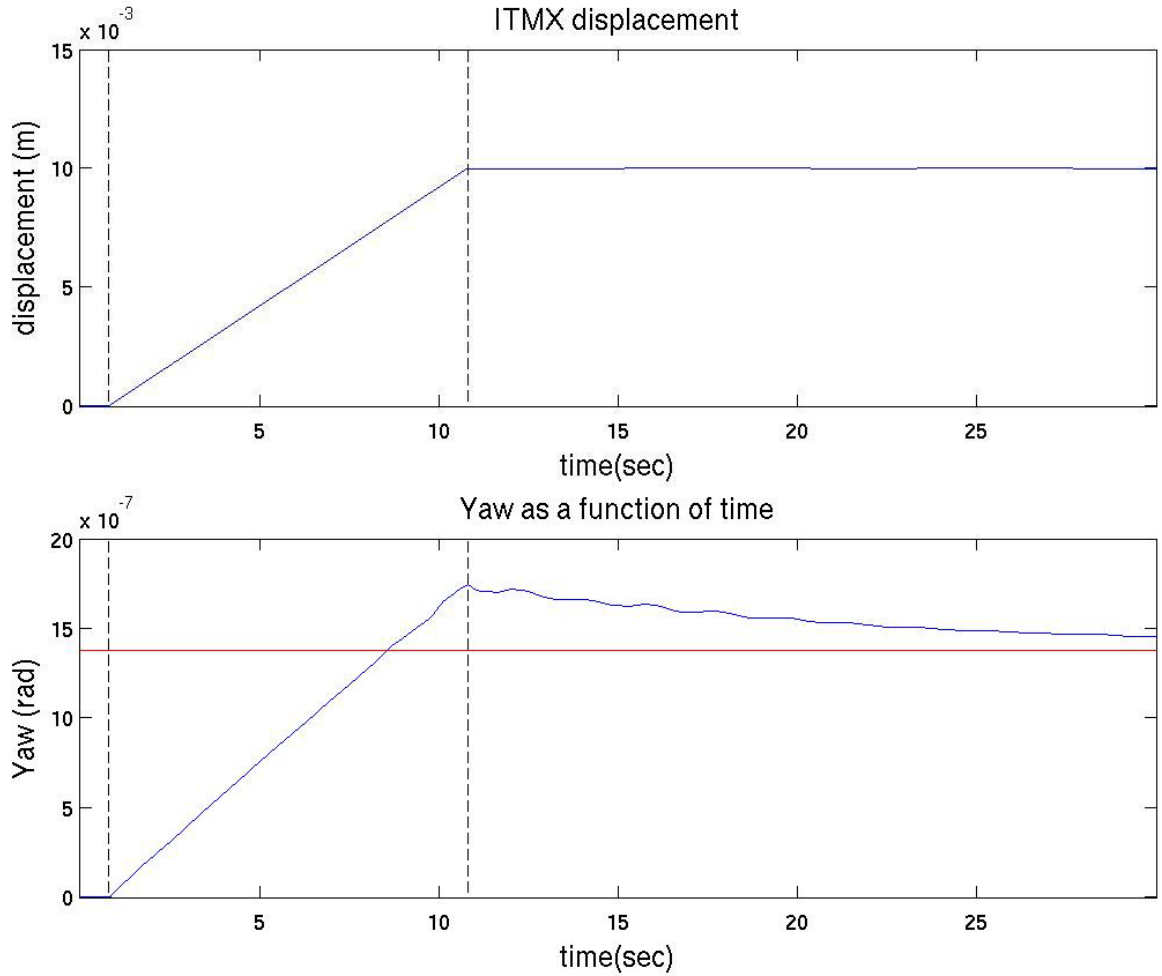

LSB asymmetry
x 10^-4
Relative Intensity
Vertical position (cm)

Interferometer's Response to Shifts

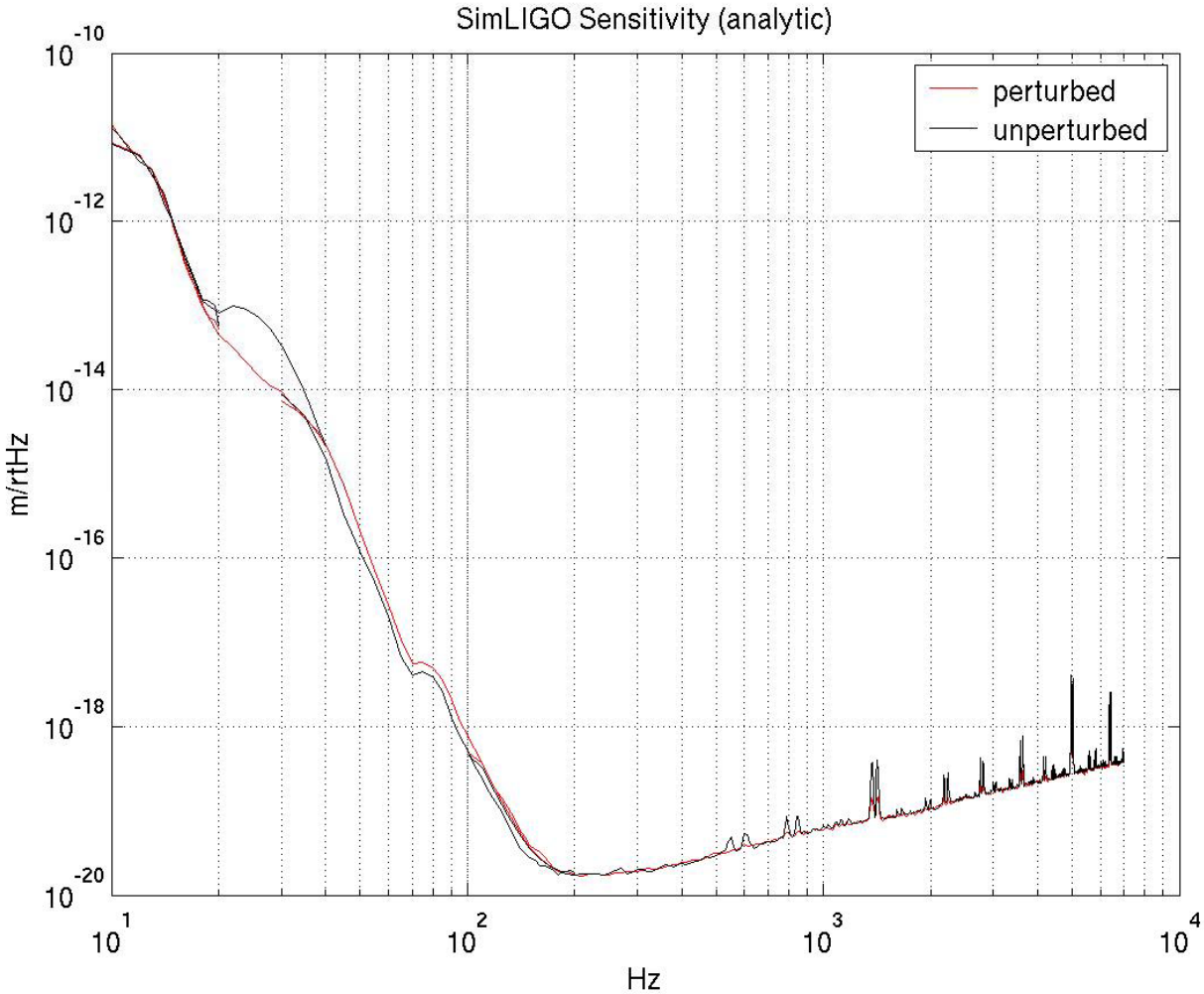


- To stay in a resonant and locked state, the mirrors of the interferometer must rotate to counteract the 1cm shift.

e2e Run: Shift in All mirrors



Sensitivity/Noise Curve



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Concluding Remarks

- Through my investigations this summer, I was able to diagnose some errors in the simulation programs.
- The independent simulation packages gave coinciding results, which adds some credibility to the simulations.
- Many of the results obtained agree with prior predictions made about how transverse shifts should affect the interferometer.

Acknowledgements

Special Thanks to

- Biplab Bhawal
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- LIGO/SURF
- NSF