Analysis of PSL Frequency Sensor Noise Using the LIGO End-to-End Software Package

Brad Zamft

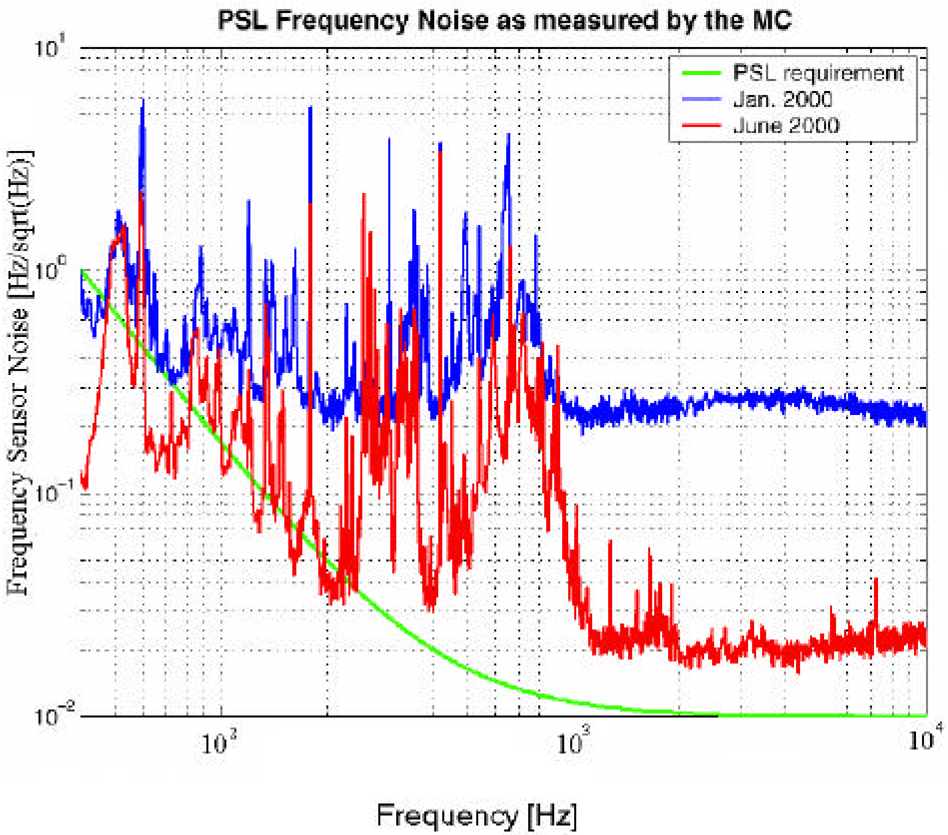
Rick Savage, Biplab Bhawal, Hirohito Yamamoto, David Ottaway

LIGO-G000305-00-D

Introduction

- Motivation: is frequency sensor noise limiting the performance of the Pre-Stabilized Laser (PSL) Frequency Stabilization Servo (FSS)?
- Approach:
  - » Model FSS noise using the end-to-end (e2e) simulation package.
    - – PD vibration.
    - – PD nonuniformity.
  - » Parameterize the effect.

The LIGO PSL Frequency Requirement

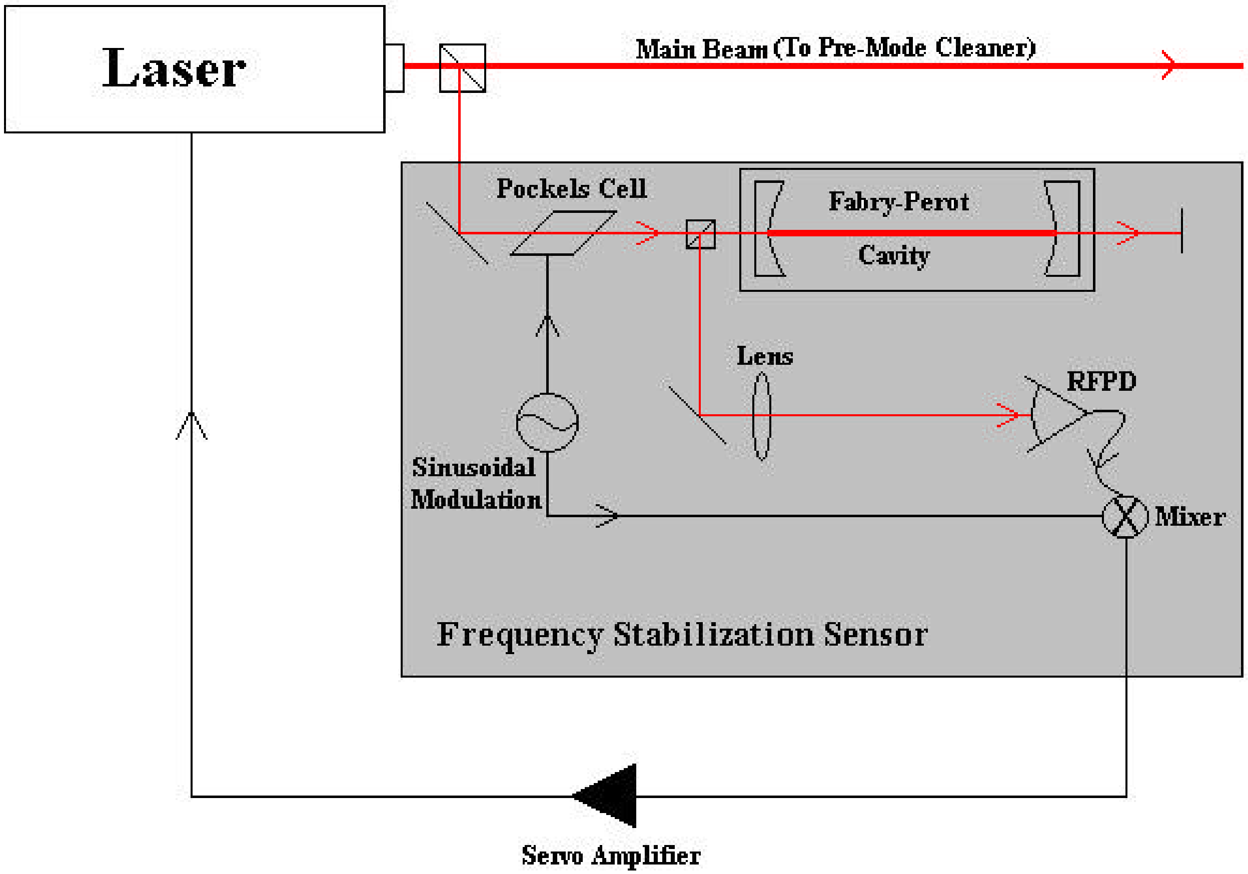


- ~10^{0} (Hz/√Hz) at low frequencies
- ~10^{-2} (Hz/√Hz) at high frequencies

N. Mavalvala

P. Fritschel

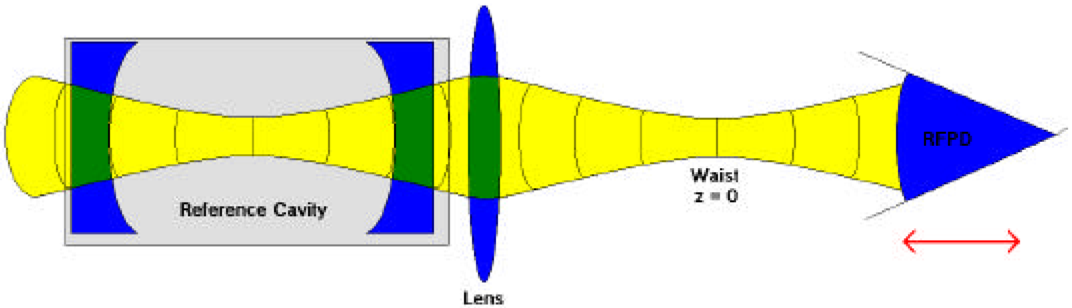
The FSS



Laser
Main Beam (To Pre-Mode Cleaner)
Pockels Cell
Fabry-Perot
Cavity
Lens
RFPD
Sinusoidal
Modulation
Mixer
Frequency Stabilization Sensor
Servo Amplifier

Noise Sources Considered

- Shot noise
  - » ~2x10^{-4} Hz/√Hz
- RFPD motion induced noise
  - » PD nonuniformity breaks orthogonality of between modes
  - » Carrier of one mode will beat with sidebands of another mode, and vice versa
  - » Gouy phase between different modes will create z-dependent error signal
  - » PD vibration then becomes a noise source



$$f_{Gouy} = \Delta_{mpm'p'} \tan^{-1}\left(\frac{z}{z_0}\right)$$

$$\Delta_{mpm'p'} = (m+p) - (m'+p')$$

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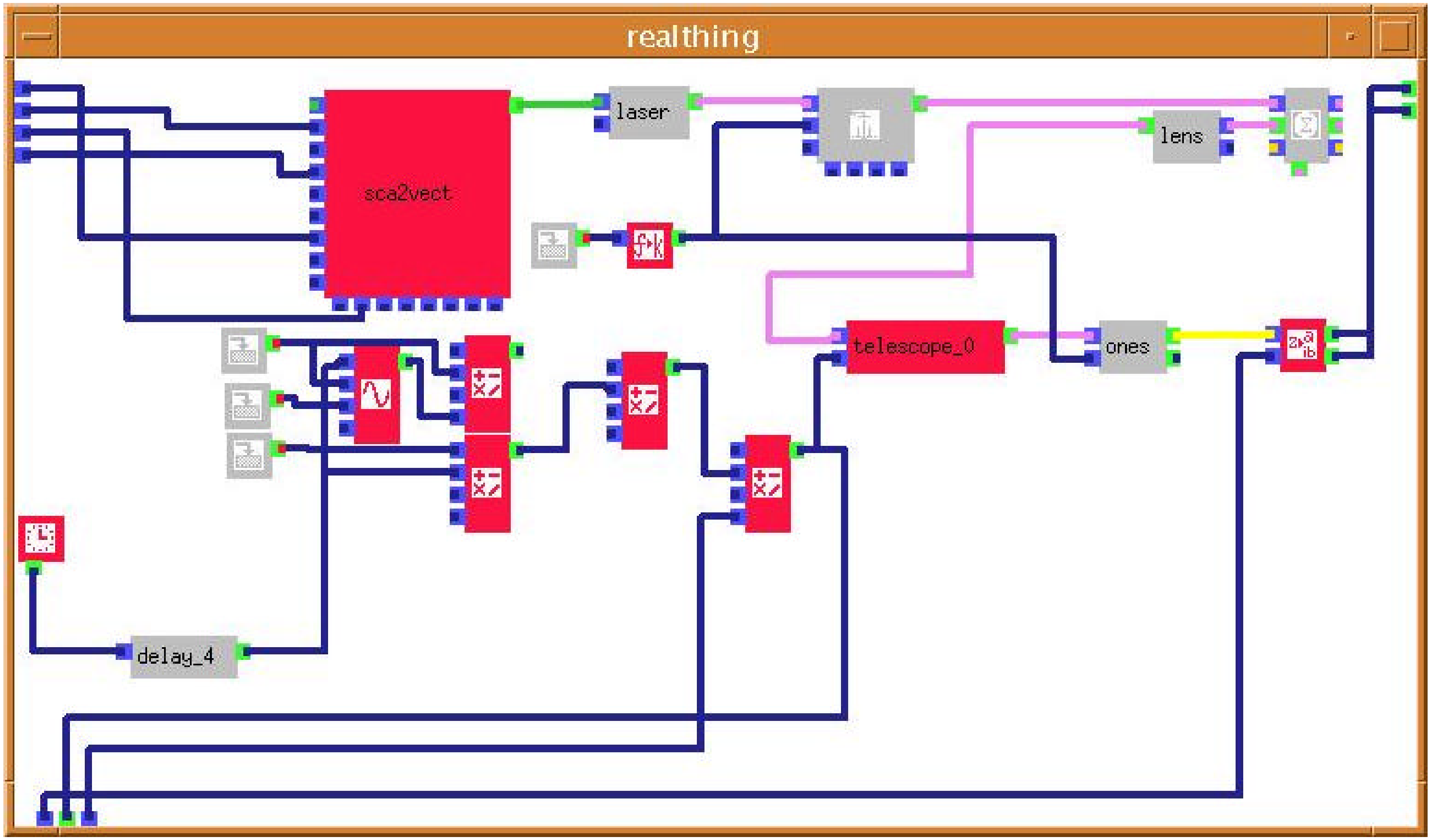
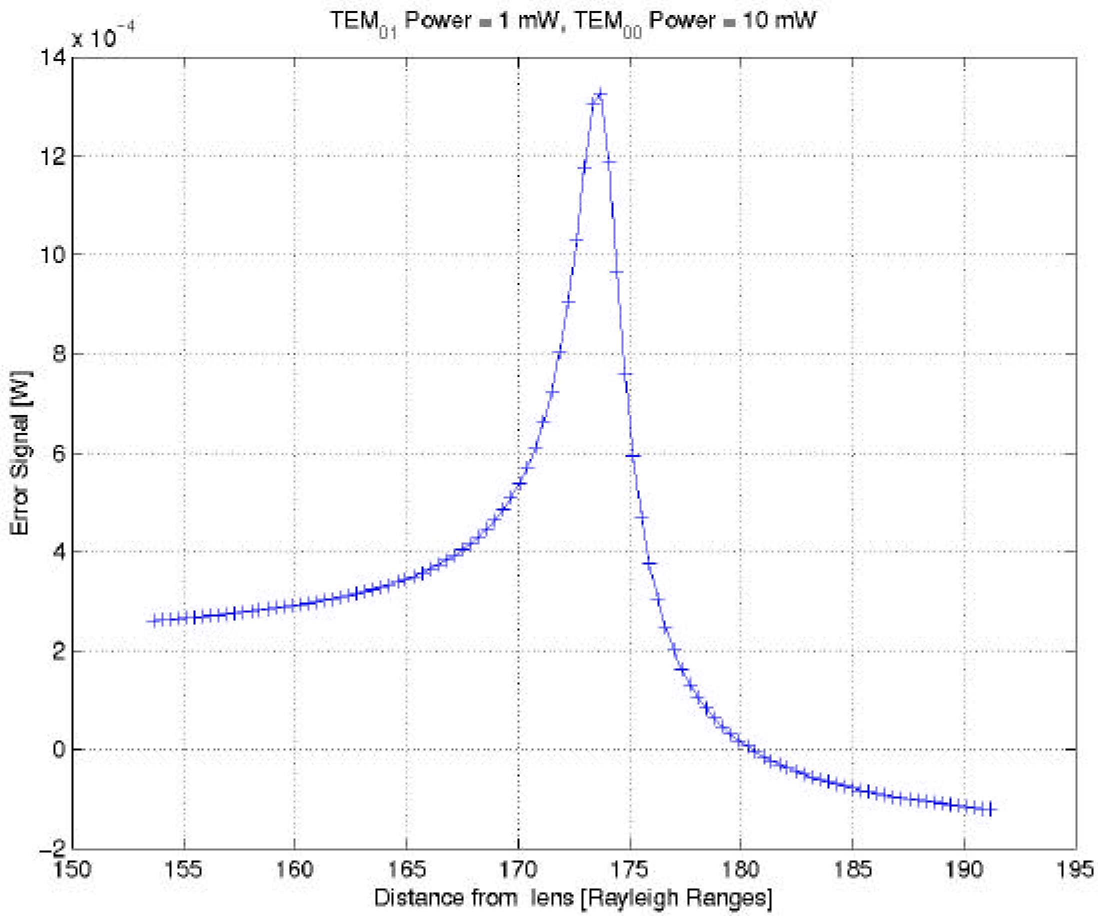
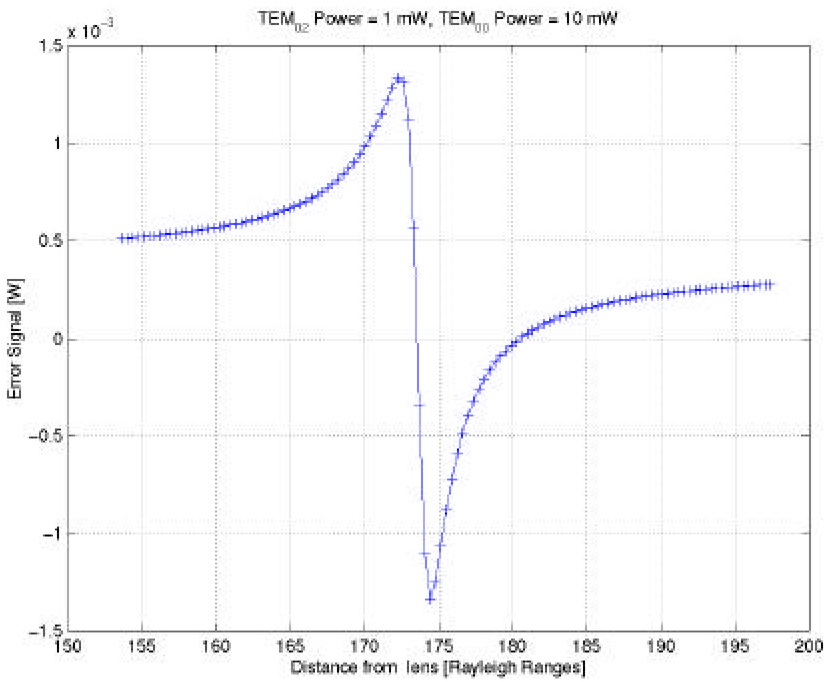
Using the End-to-End Simulation Package

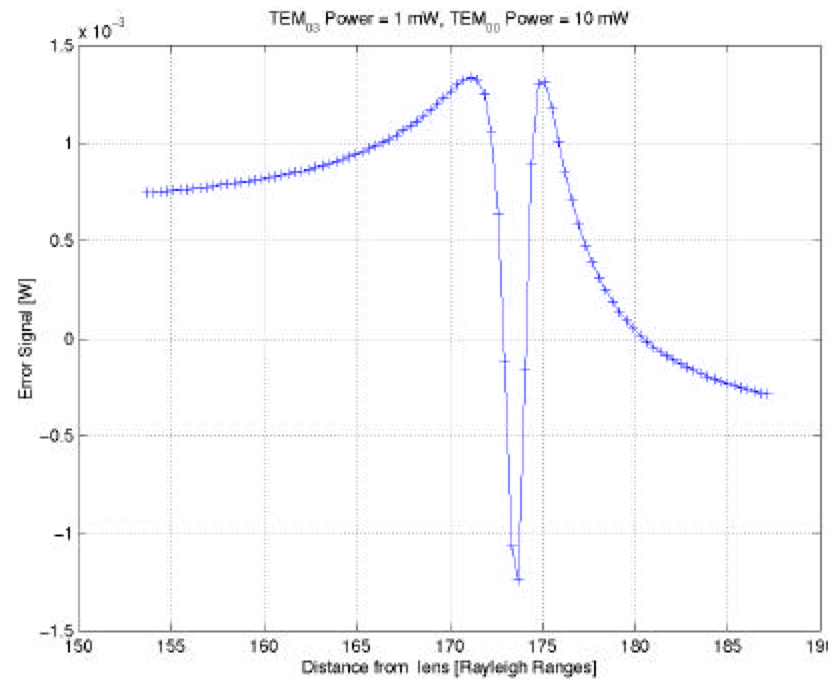


Z-dependence of Error Signal – TEM_{01} Mode



Z-dependence of Error Signal – TEM_{02} and TEM_{03} Modes

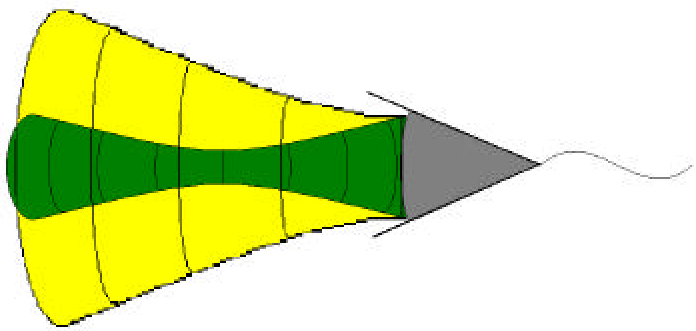




Functional Dependence of Effect

$$\Delta f_{gouy} \propto \Delta z_{pd} \cdot \frac{\partial e\left(w(z), f_{lens}, D\right)}{\partial z} \cdot I \cdot g \cdot h$$

- RFPD motion
- Phase shift at lens:
  - » Distance lens is from cavity
  - » Waist-size in cavity
- Spot size
- Relative NRM power
- RFPD shape, homogeneity, and efficiency



Estimate for Wa 2K PSL

$$\frac{\partial e}{\partial z} = -5\times10^{-5}(Hz/m)$$

$$w(z) = .4(mm)$$

$$D = -1\times10^{-7}\left({}^{W}\!/_{Hz}\right)$$

$$\Delta z = 2\times10^{-8}(m)$$

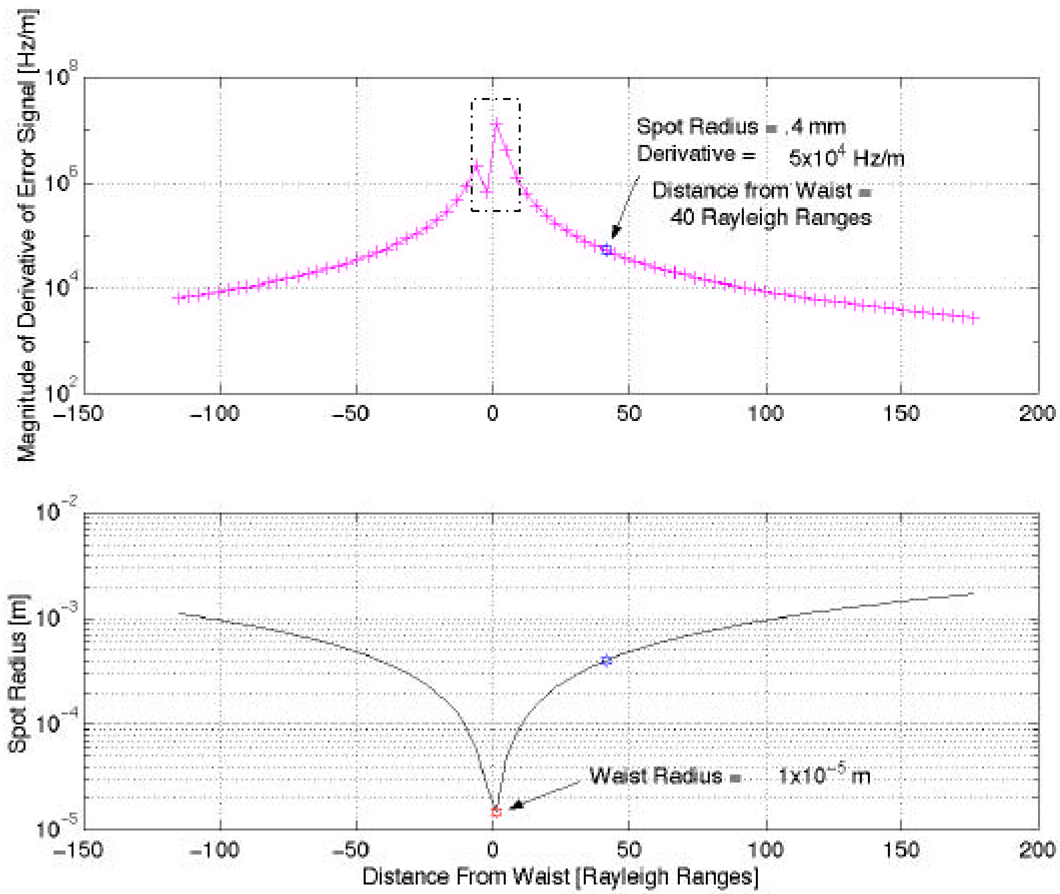
$$I = -0.1$$

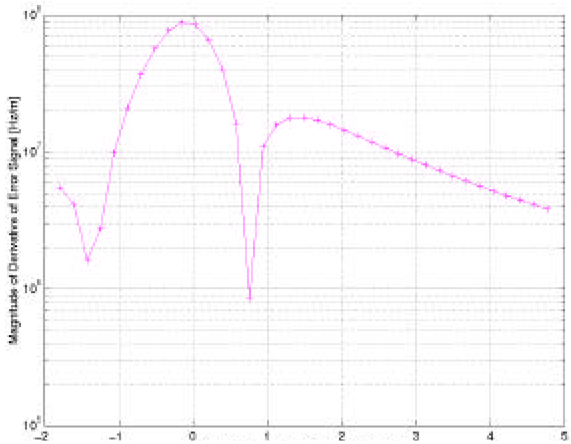
$$g = 0.2$$

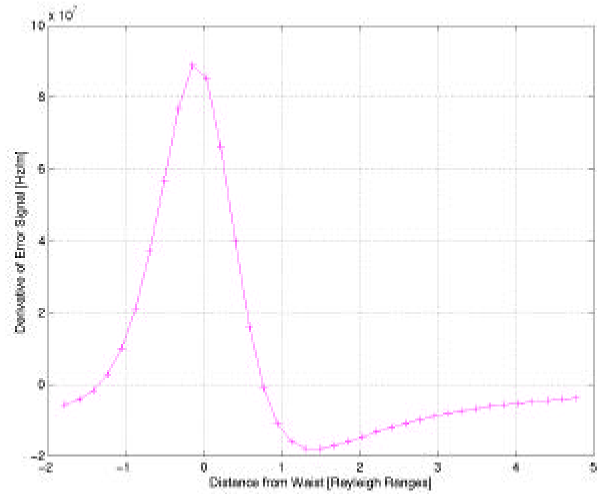
$$h = 0.8$$

$$\boxed{\Delta f_{gouy} \sim 2\times10^{-5} \sim \text{shot noise}}$$

Spot Size Dependence of the Noise







Topics for Further Investigation

- Input realistic PD nonuniformity
- Include actual RFPD motion
- Consider reference cavity motion
- Consider coupling between different HOM