Mirror Q's and thermal noise in the TNI with ring dampers

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LIGO Seminar

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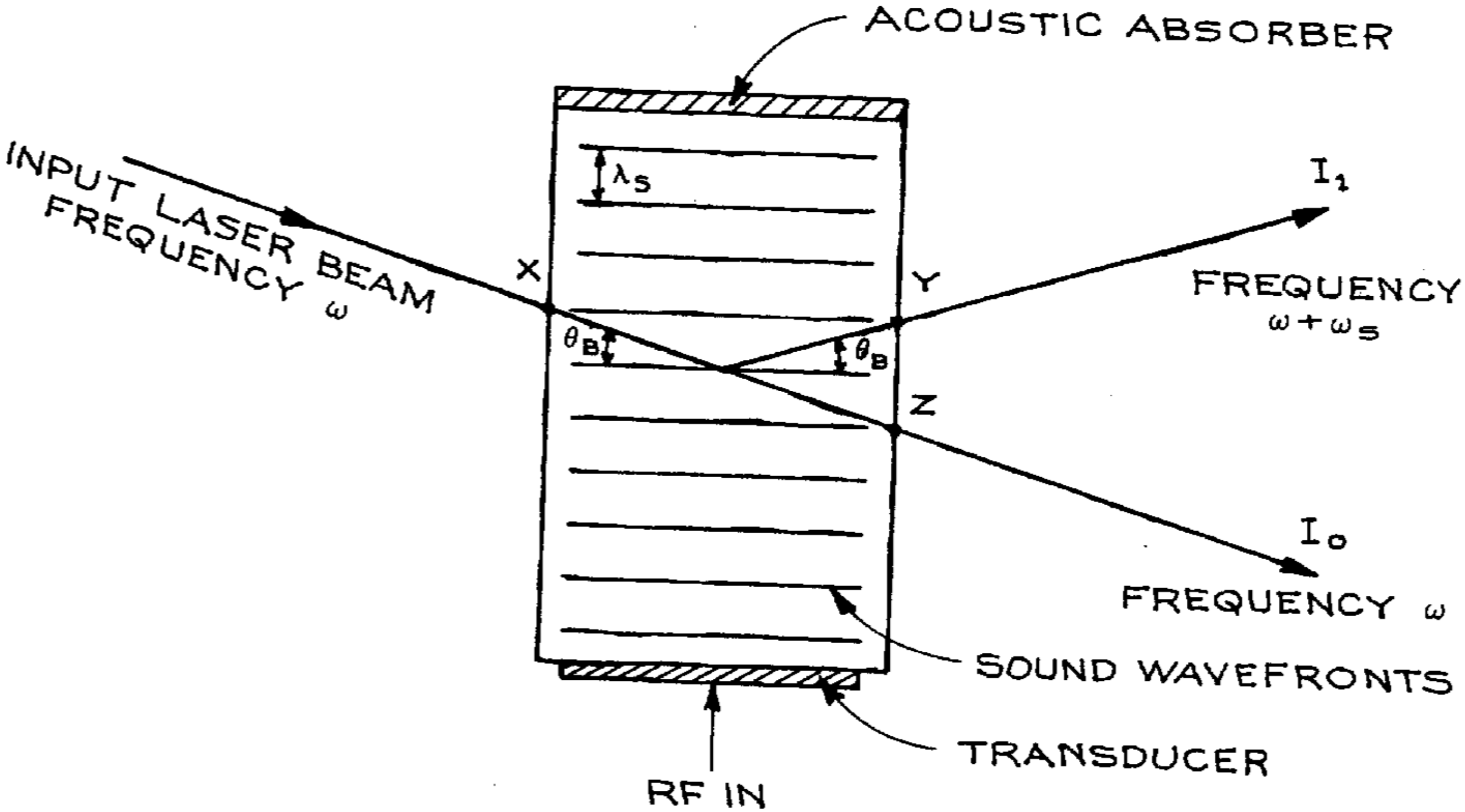
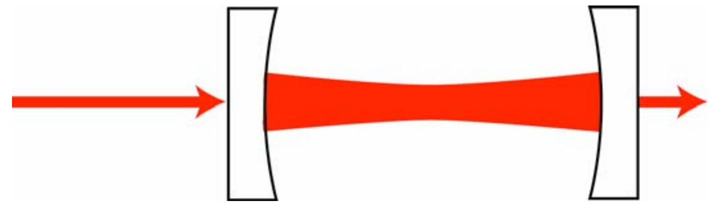
Coupling Between Light and Sound: Acousto-Optic Effect

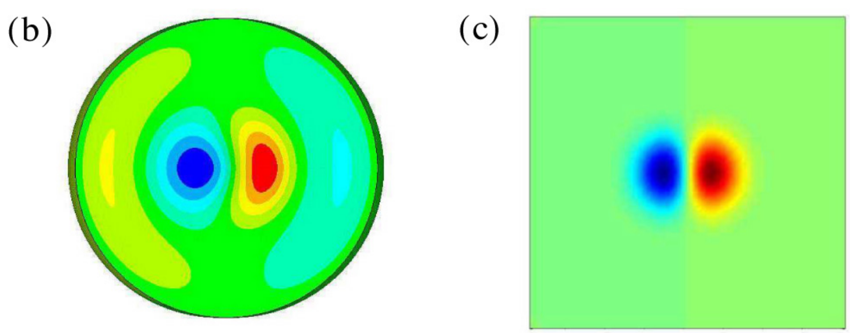


Parametric Oscillations in Fabry-Perot Cavities

Cavity length determines field inside.
Mirror mechanical oscillations affect cavity length.
If radiation pressure can drive mechanical oscillations, feedback will occur.



$$E_c = \frac{E_{inc} t_1}{1 - r_1 r_2 e^{i2kL}}$$

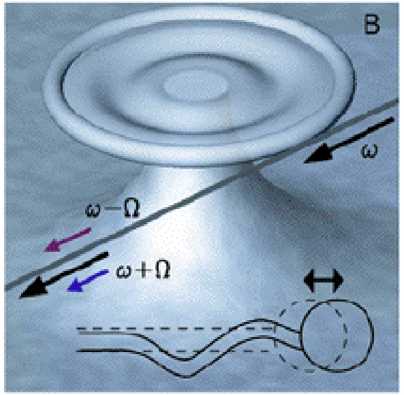


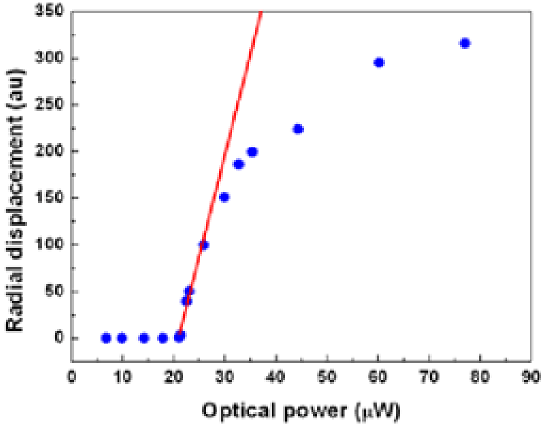
Spatial overlap between optical and mechanical modes complicates the picture, rings up multiple mechanical and optical modes and bleeds power out of the TEM00 mode.

b) Mirror mechanical mode
c) Associated optical mode
(from Zhao, et al., PRL 94, 121102 (2005).)

Potential Problem for AdLIGO

- David Blair & group observe parametric *damping* of mechanical modes in bar detector transducers
  - Phys. Rev. Lett. 74, 1908-1911 (1995)
- Braginsky, et al. point out that acousto-optic feedback can ring up body modes in a F-P cavity, bleeding power out of the TEM00 mode - parametric *amplification*.
  - Phys. Lett. A 287, 331-338 (2001)
- Vahala's group observes radiation-pressure-driven oscillations in microcavities
  - Optics Express 13, 5293-5301 (24 June, 2005)
  - Phys. Rev. Lett. 95, 033901 (2005)
- N. Mavalvala observes the effect in a macroscopic cavity with suspended mirrors
  - LIGO-P050045-00-R (Oct. 27, 2005)





Instability Condition: R>1

Power

Mechanical Q

$$R \approx \frac{2PQ_m}{McL\omega_m^2}\left(\frac{Q_1\Lambda_1}{1+\Delta\omega_1^2/\delta_1^2} - \frac{Q_{1a}\Lambda_{1a}}{1+\Delta\omega_{1a}^2/\delta_{1a}^2}\right) > 1$$

Ju, et al. G050325-00 who got it from
Braginsky, et al. Phys. Lett. A 305, 111 (2002)

Reducing Q’s
without affecting thermal noise (much)

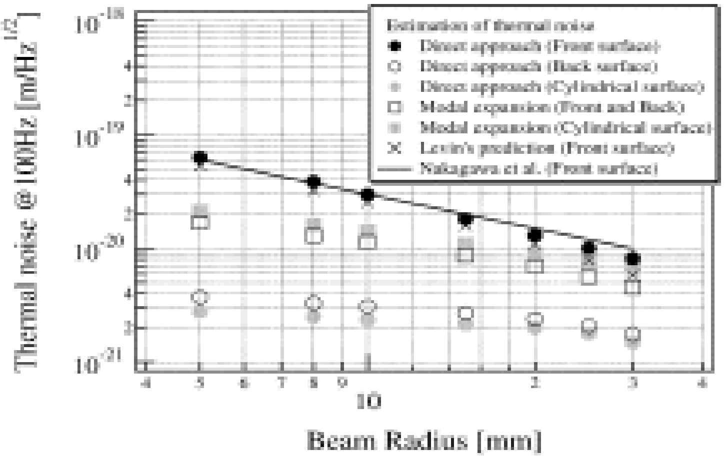


Fig. 3. Thermal fluctuations of surface models. This graph shows the dependence of the amplitude of the thermal noise at 100 Hz on the beam radius. The closed, open, and grey circles represent the thermal motions of the Front, Back, and Cylindrical surface models calculated from the direct approaches, respectively. The open squares are an estimation of the Front and Back surface models from the modal expansion. The estimations from the modal expansion in both cases are the same because the -values are the same. The grey squares show the evaluation of the Cylindrical surface models derived from the modal expansion. The crosses represent Levin’s prediction about the Front surface model. The line shows an analytical estimation by Nakagawa et al. of the thermal noise of the Front surface model.

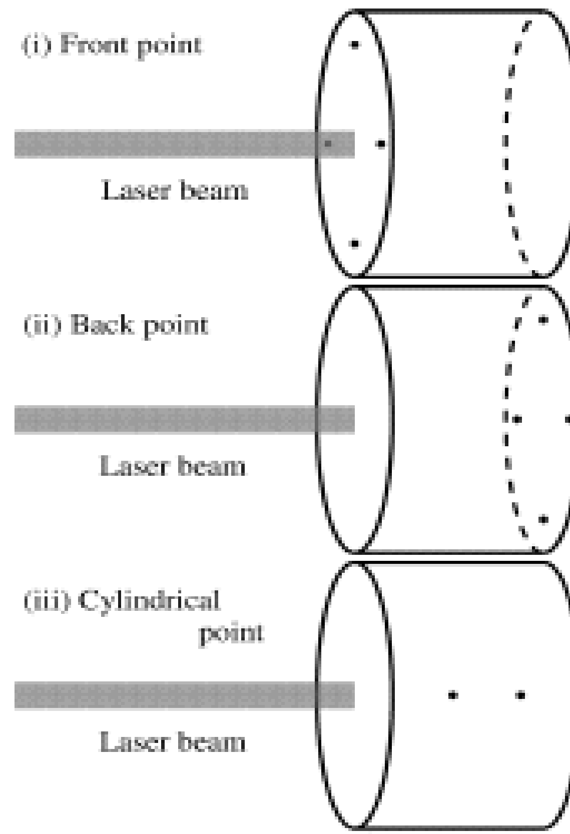
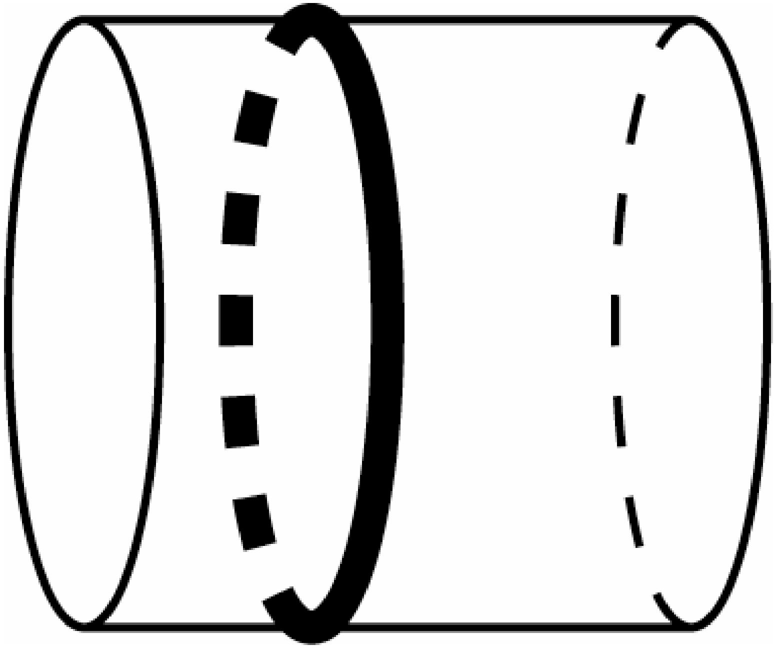


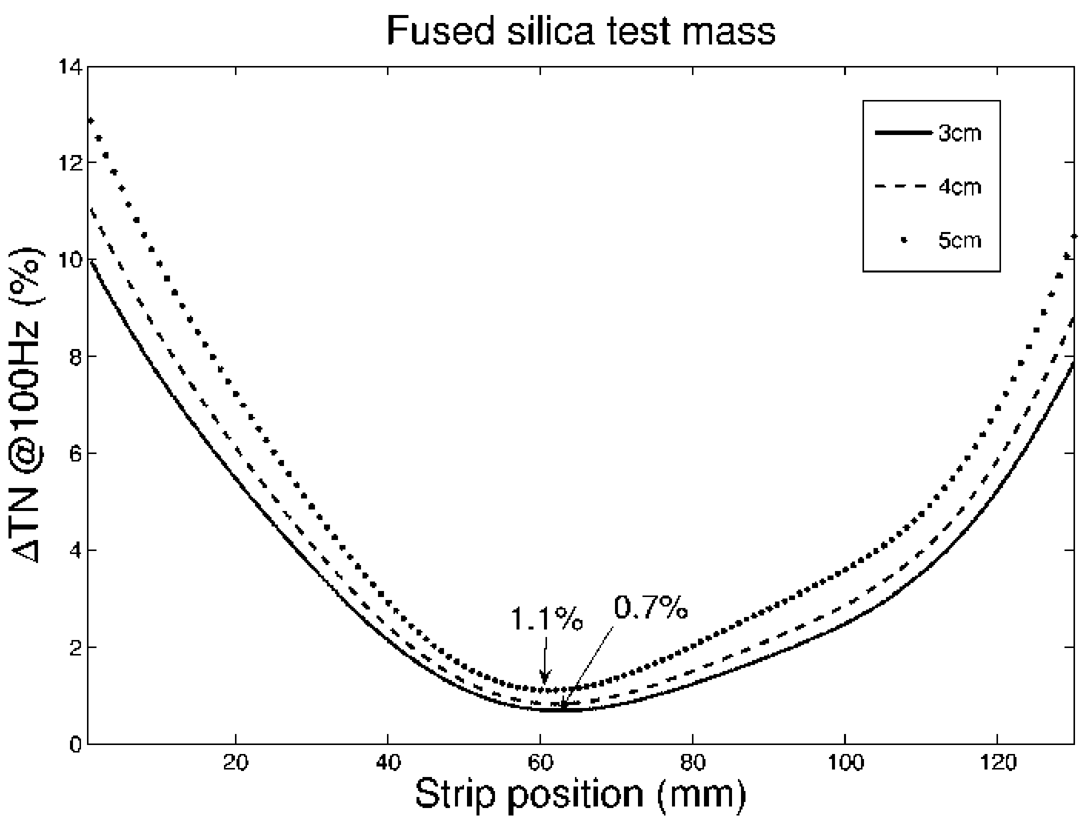
Fig. 4. Dissipation concentrated at points. The black dots indicate points at which the loss was concentrated. The other part had no

Ring Damper

Idea: Lossy ring around mirror barrel could suppress mechanical Q's of many modes, without affecting thermal noise on the face (much)



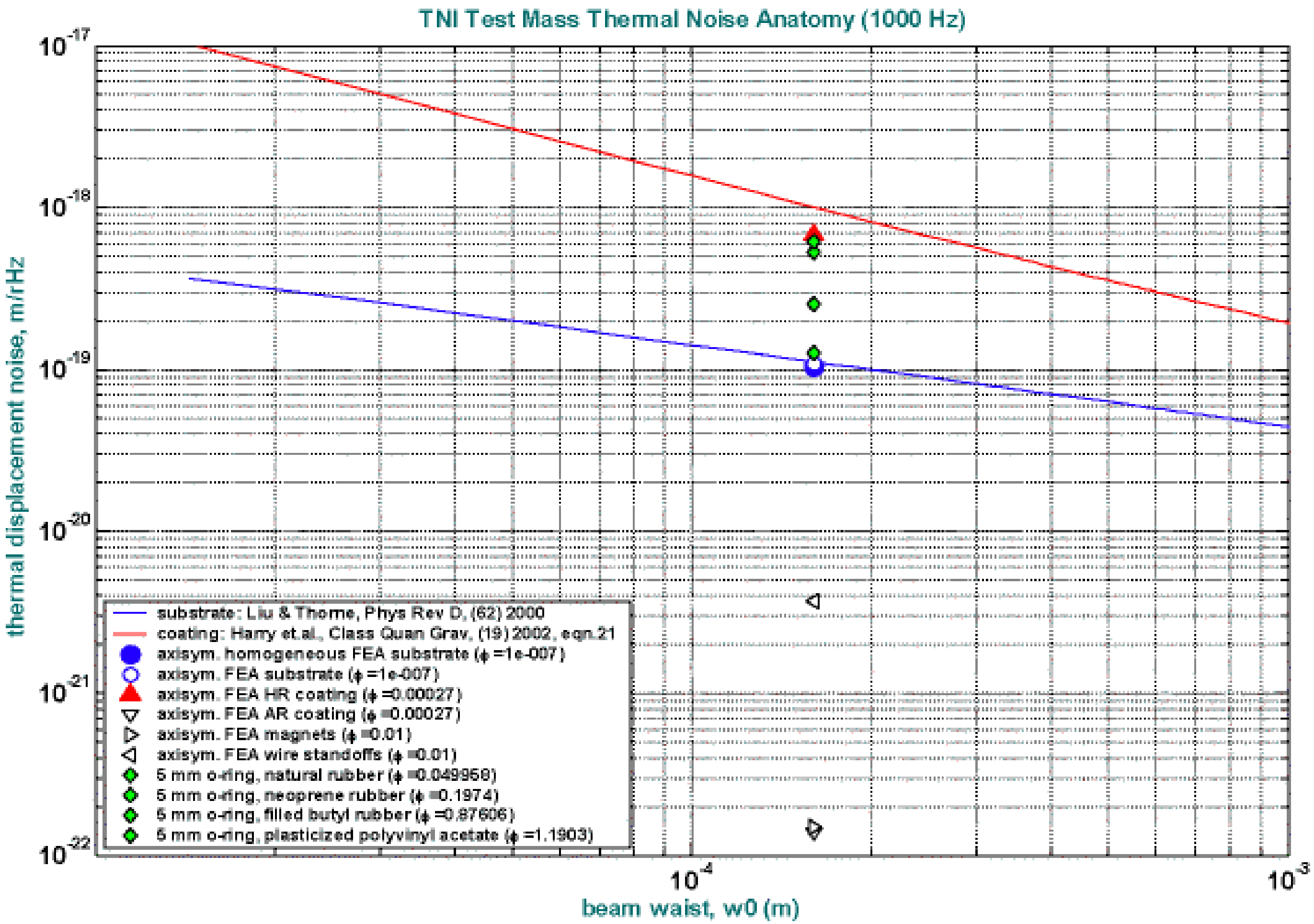
FEA Model 1



Gras, et al. preprint

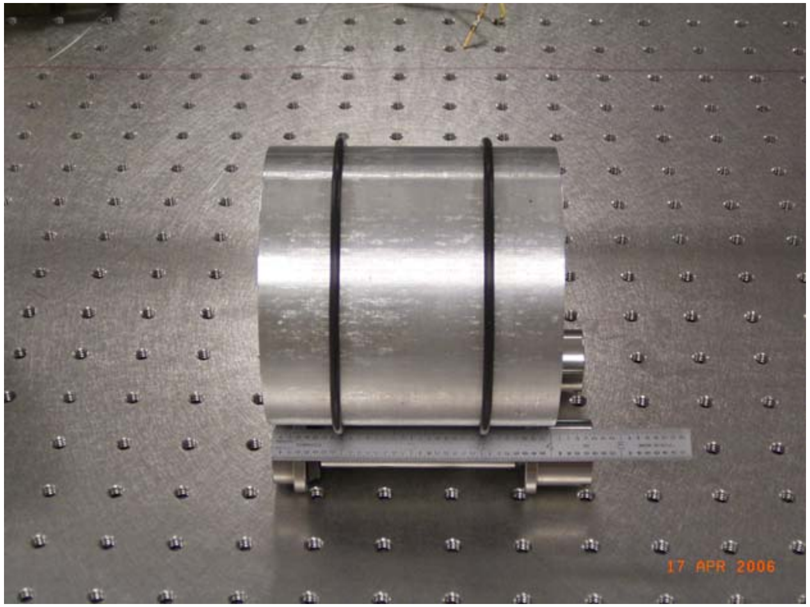
Test Mass Ring Dampers with Minimum Thermal Noise

FEA Model 2



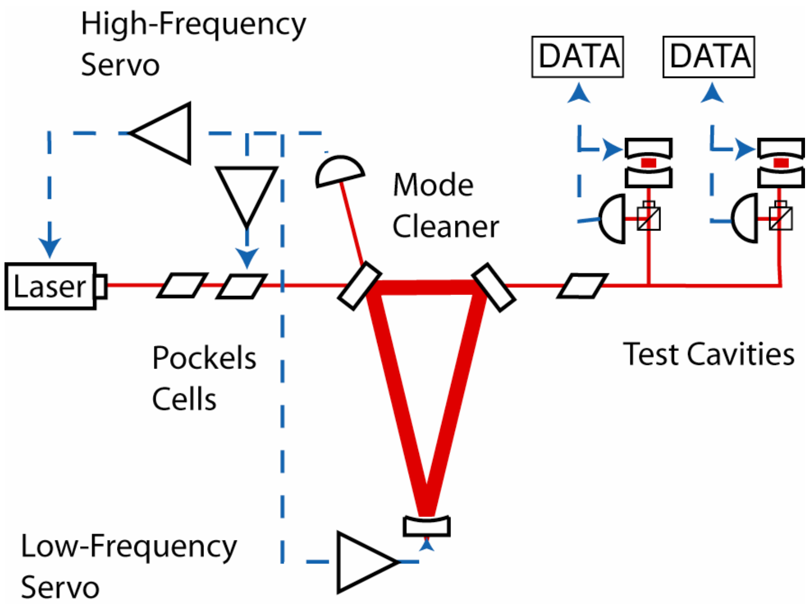
D. Coyne, T050173-00

Ring Dampers



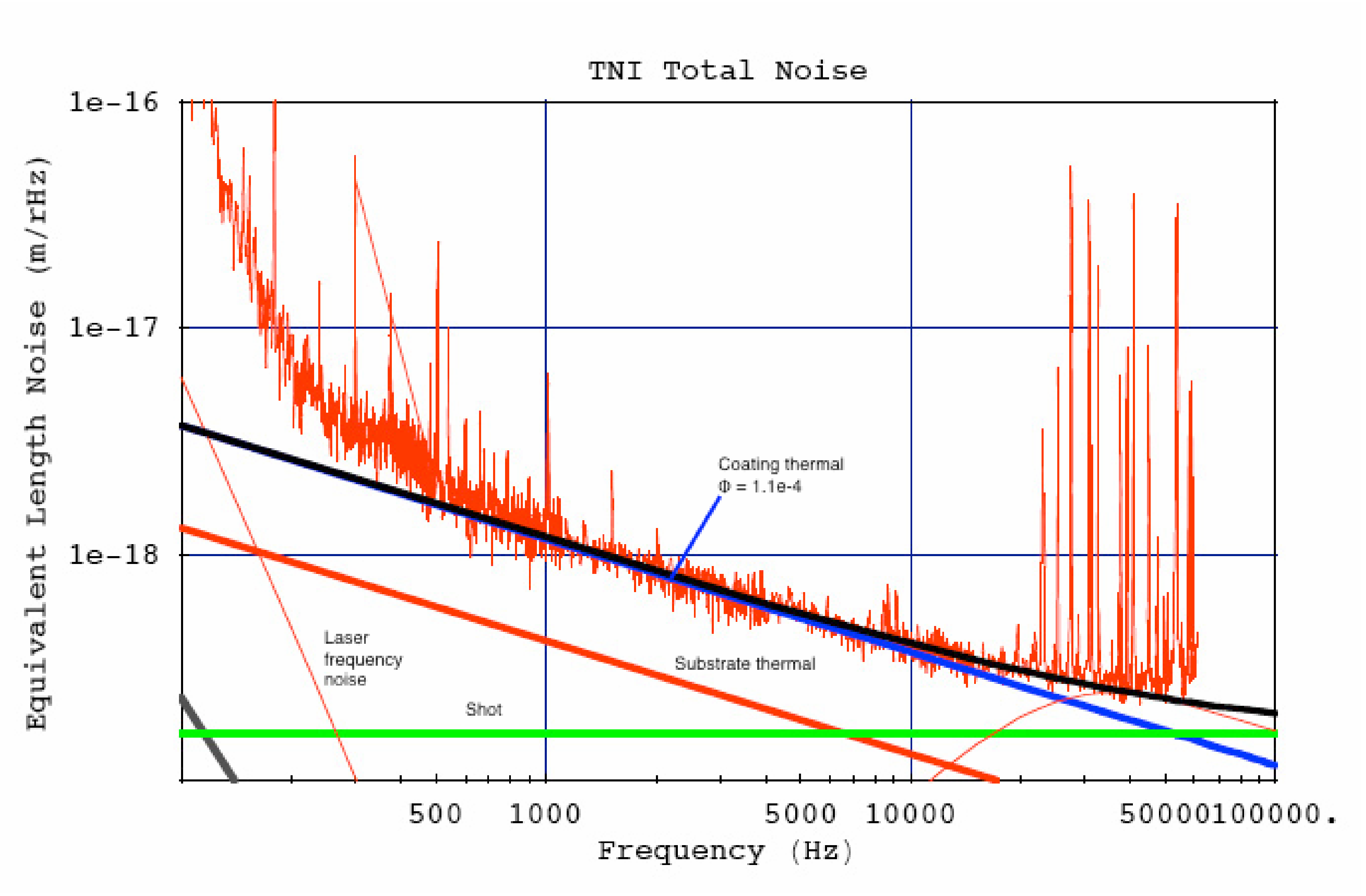
- 4”x 4” fused silica mirrors.
- Ring dampers only on SAC output mirror.
- Two ring dampers 1/8” thick located 1” on either side of the midpoint.
- Dampers are made of buna.

Thermal Noise Interferometer

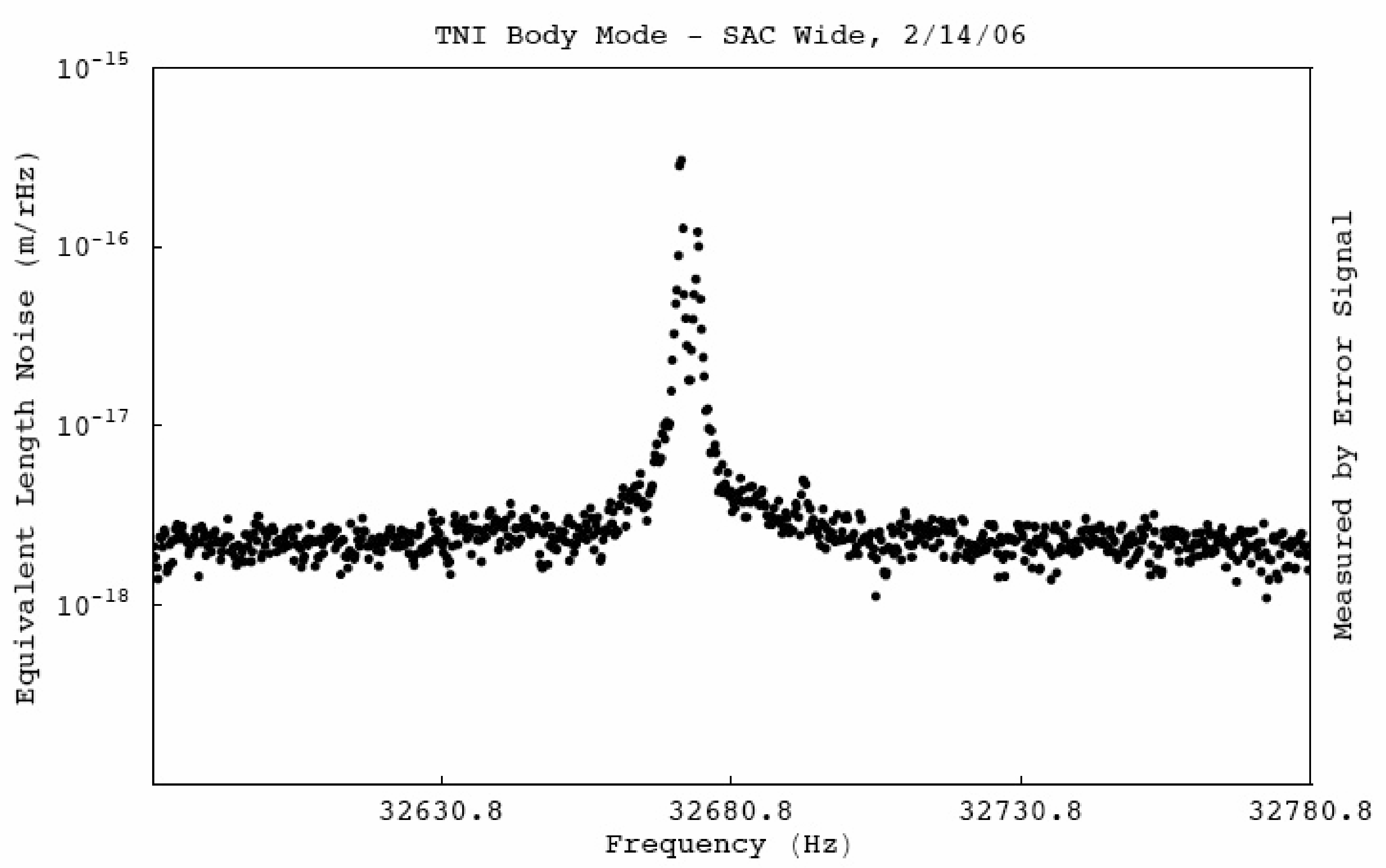


- Fundamental-noise limited interferometer (thermal and shot).
- Test Cavities:
  - Fused silica substrates
  - Titanium doped silica tantala coatings
  - Ring dampers around SAC output
- Measurement made as relevant to AdLIGO as possible in a small interferometer.
  - Lowest noise levels practical
  - Low-mechanical-loss substrates
  - Largest practical spot size

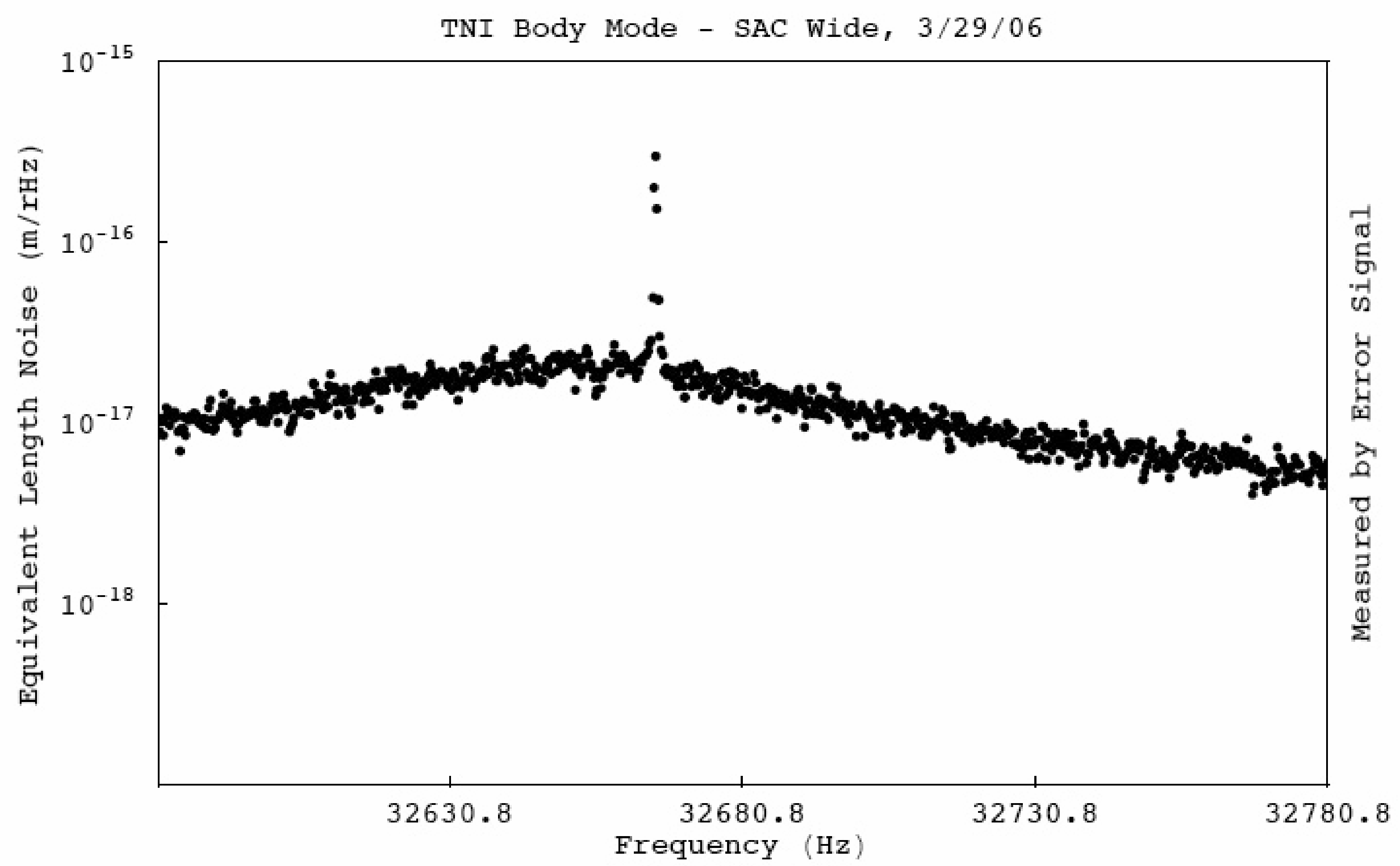
TNI Total Noise



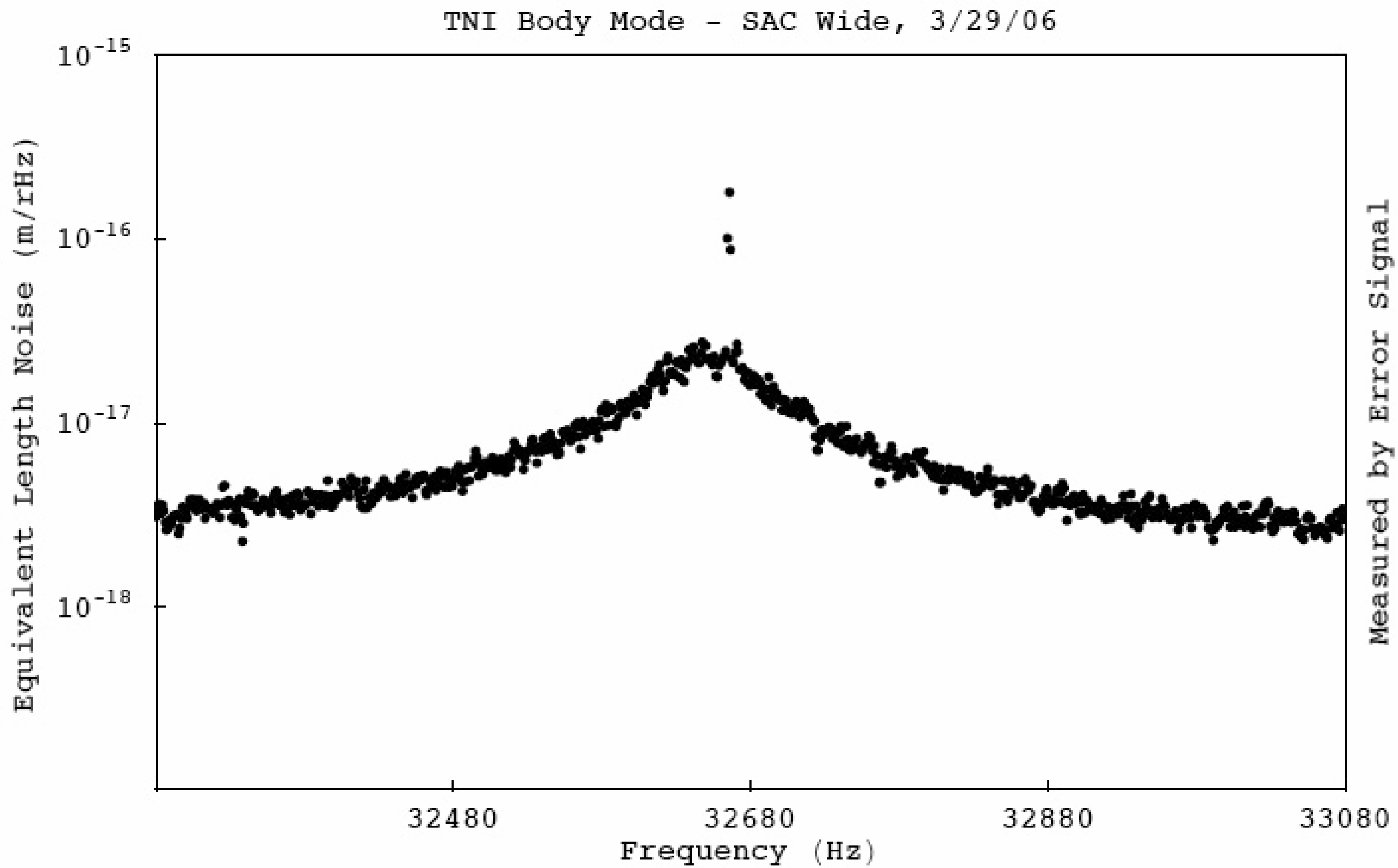
Effect of damper on Q's



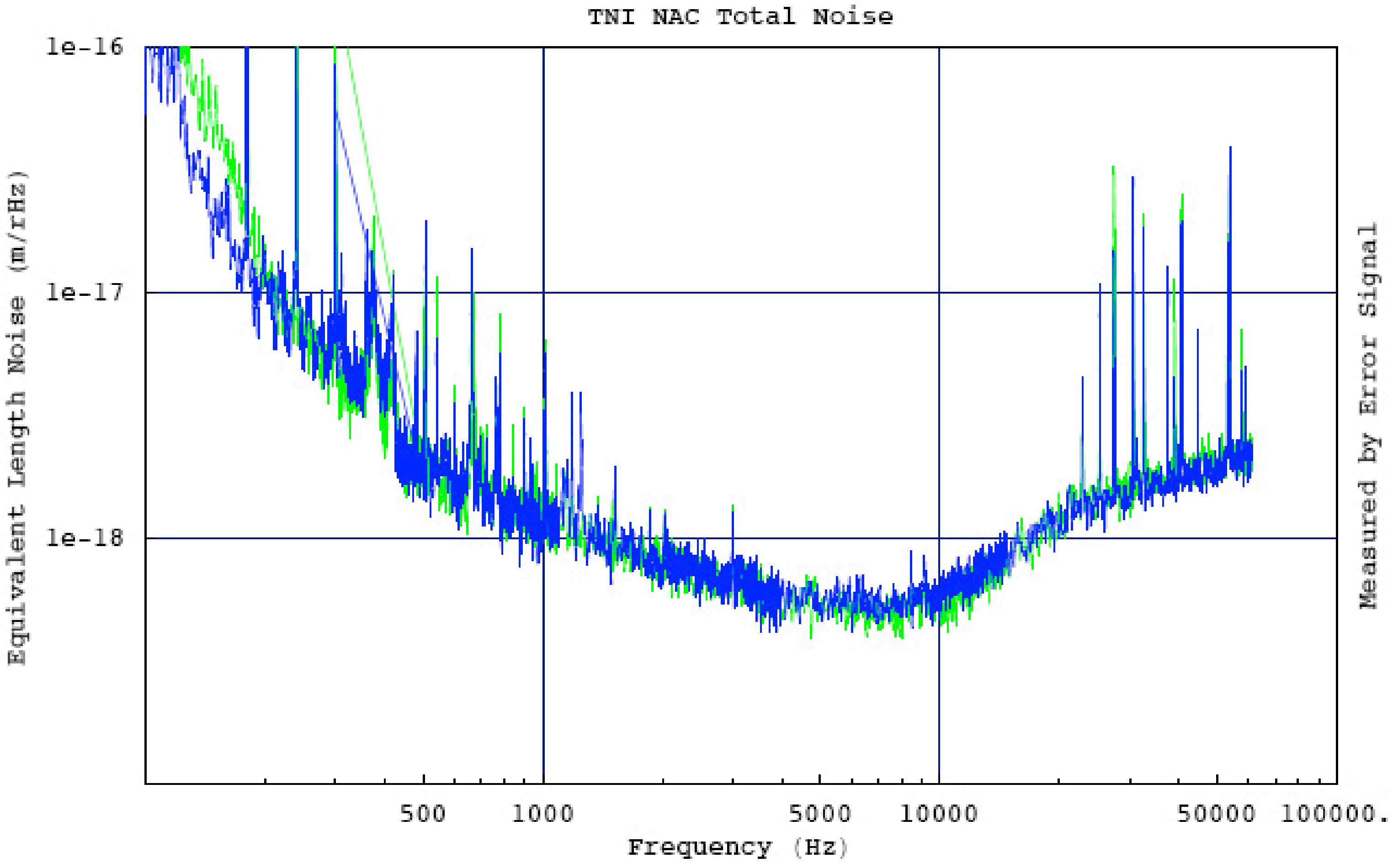
Effect of damper on Q's



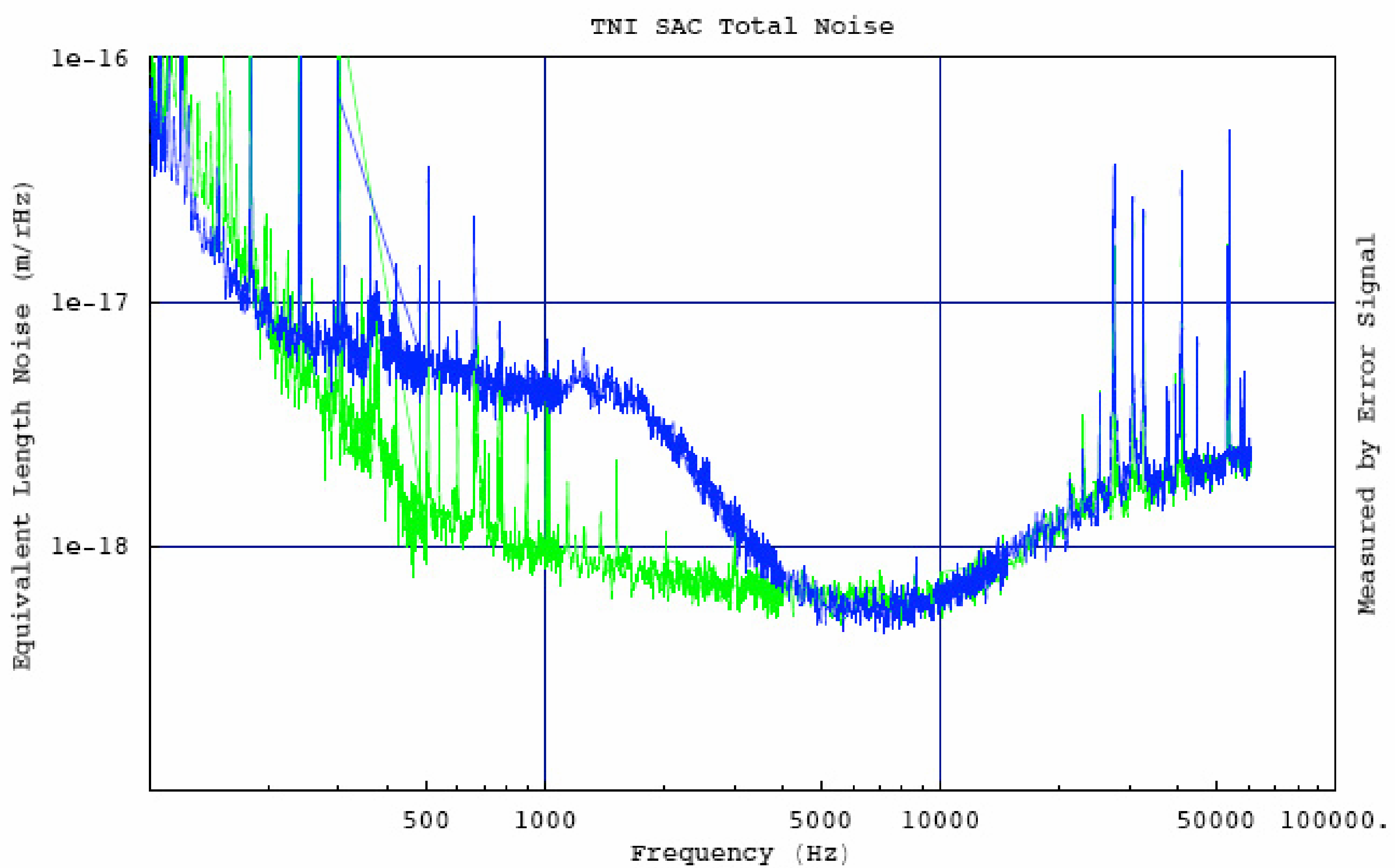
Effect of damper on Q's



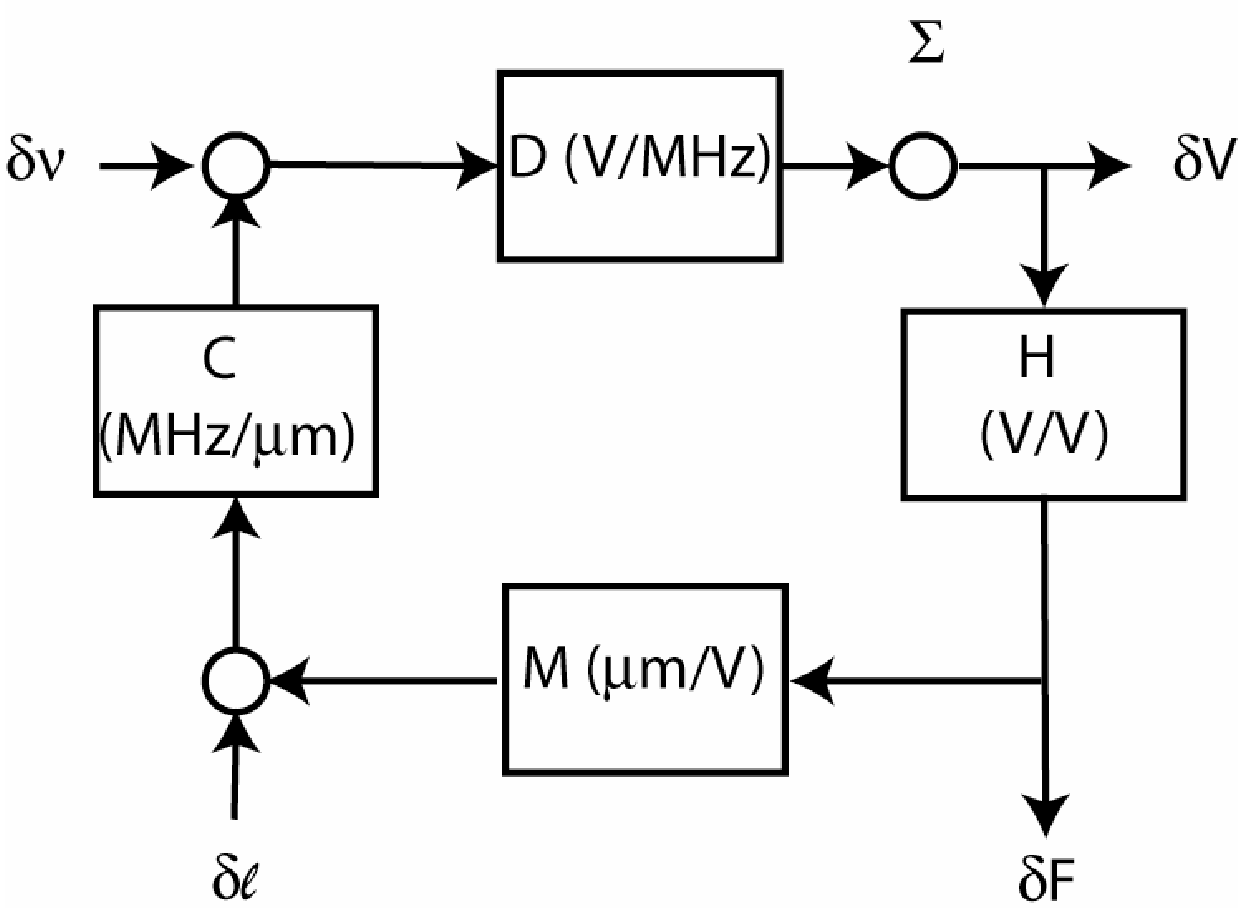
Effect on Broadband Thermal Noise (NAC)



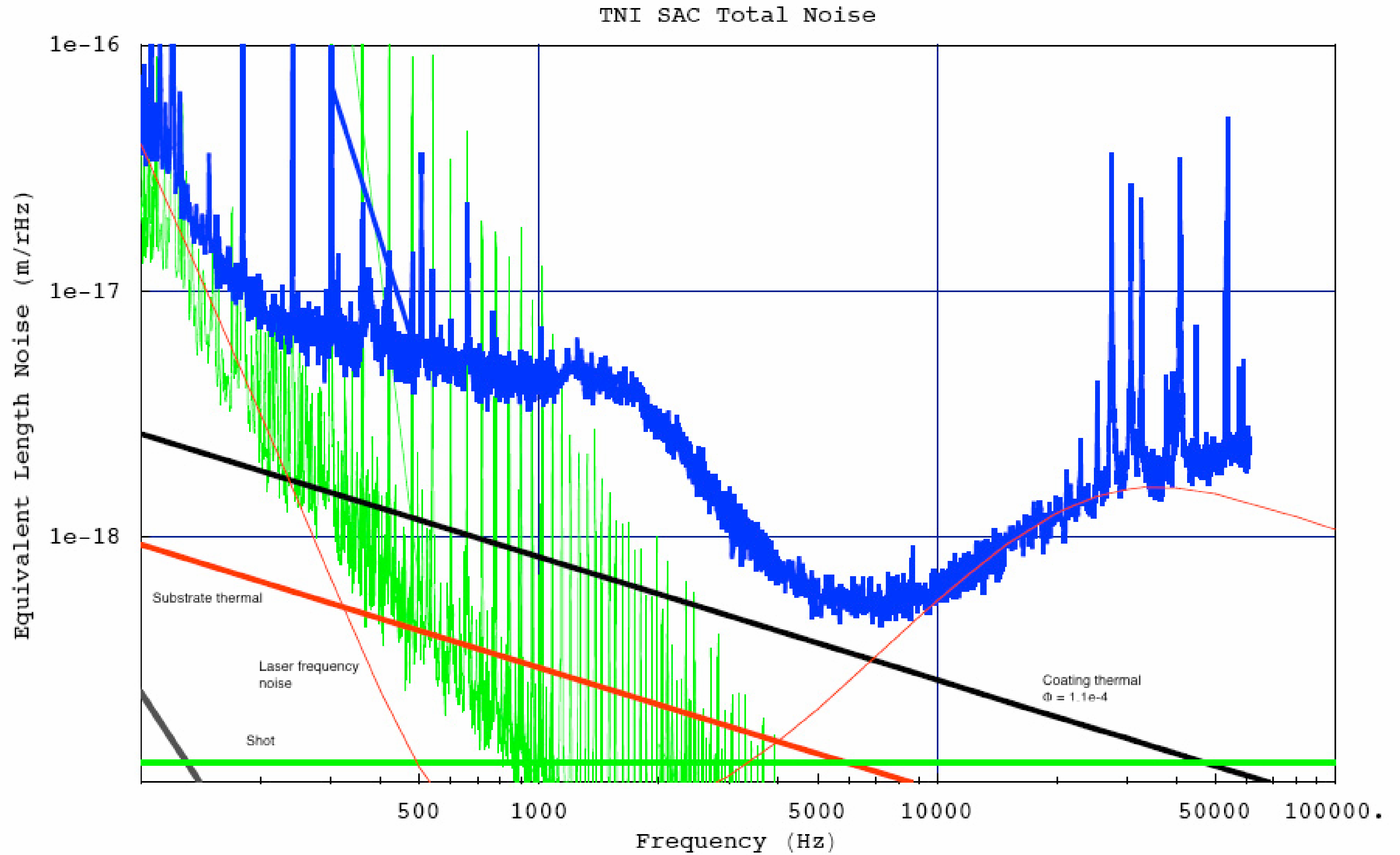
Effect on Broadband Thermal Noise (SAC)



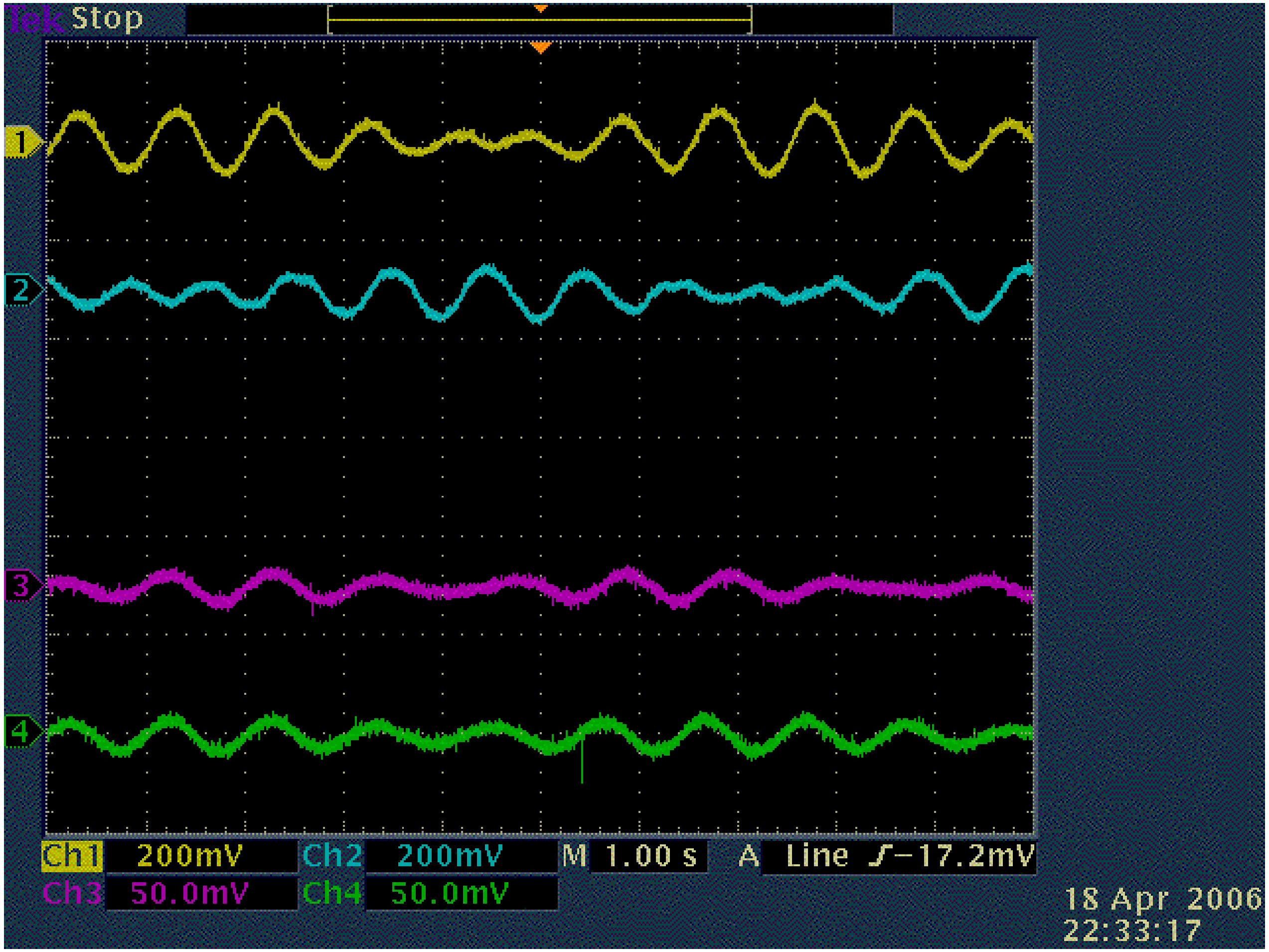
Servo Block Diagram



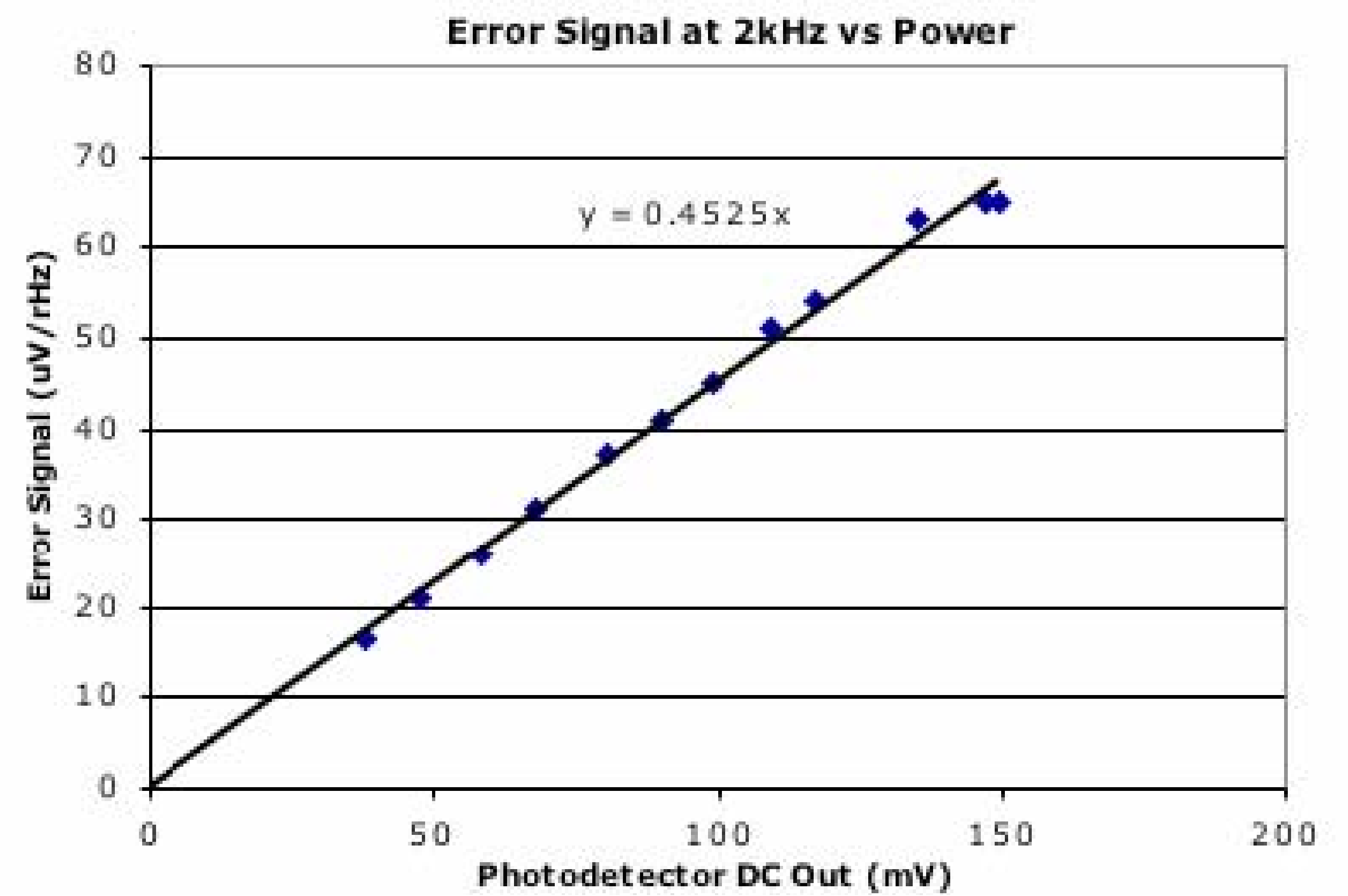
Noise Breakdown



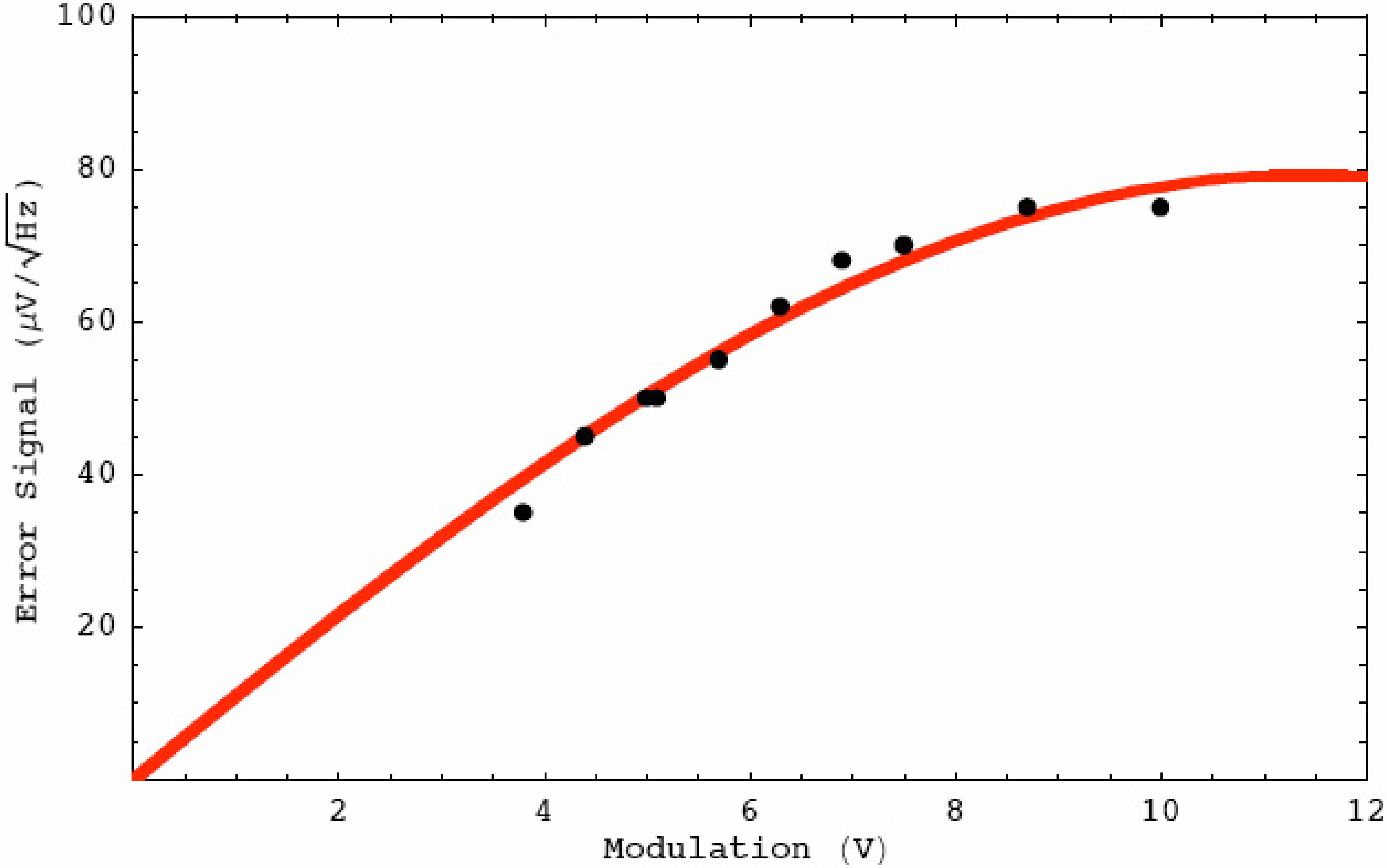
Mirror Floats Freely



Error Signal Scales with Power



Error Signal Scales with Modulation Depth



What can be said about the bump?

- It is only in SAC.
- It is not due to:
  - servo electronic noise.
  - laser frequency noise.
  - pendulum thermal noise.
  - shot noise.
  - contact of mirror with barn.
- It scales with power and modulation depth in a way that is consistent with length noise.
- It is stable and reproducible.

What Next?

- A model that accounts for the change in the broadband noise and indicates how to avoid it.

Conclusion

- Parametric instabilities are expected to be a problem for AdLIGO.
- Ring dampers have been proposed to avoid them.
- Ring dampers were installed at the TNI.
- Observed a drastic reduction in Q's.
- Observed an increase in broadband thermal noise.
- Need a model that explains what was observed.