TNI Progress and Status

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LSC Meeting

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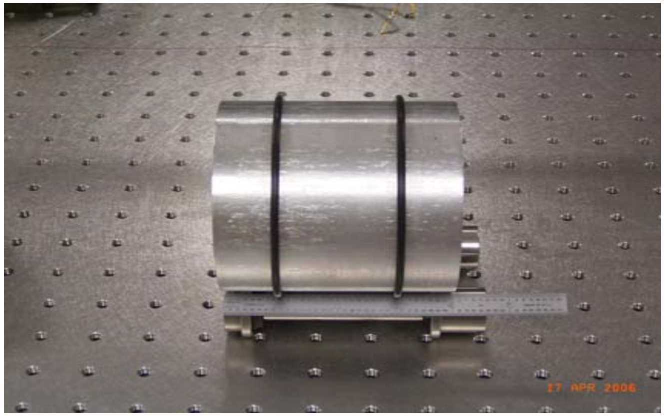
LIGO-G070107-00-Z

Current Areas of Activity

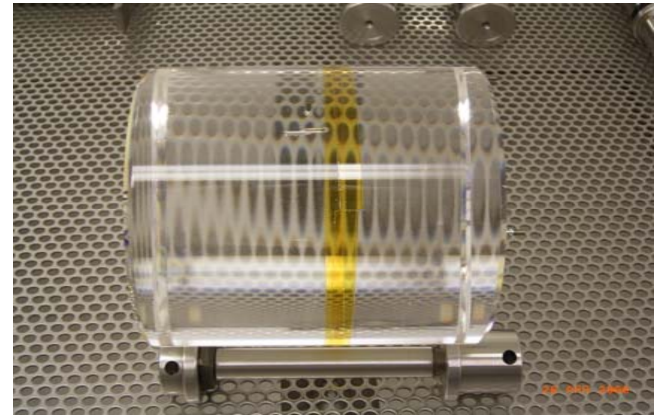
- Parametric Instability Damping
- Improved Calibration / Spot Size Measurement
- Aperiodic Coating

LIGO

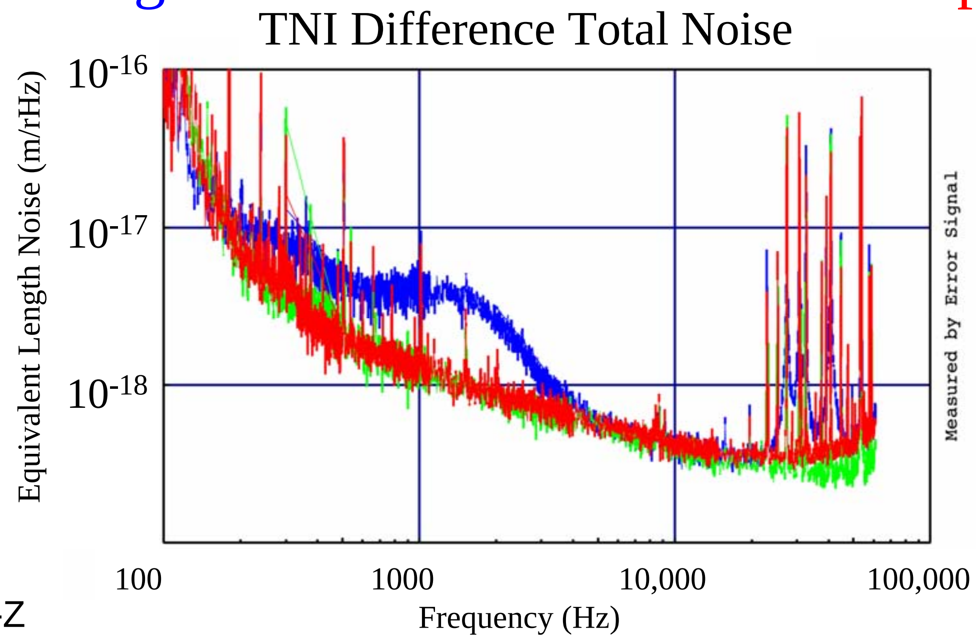
Initial Q-Suppression Ideas



Buna o-rings

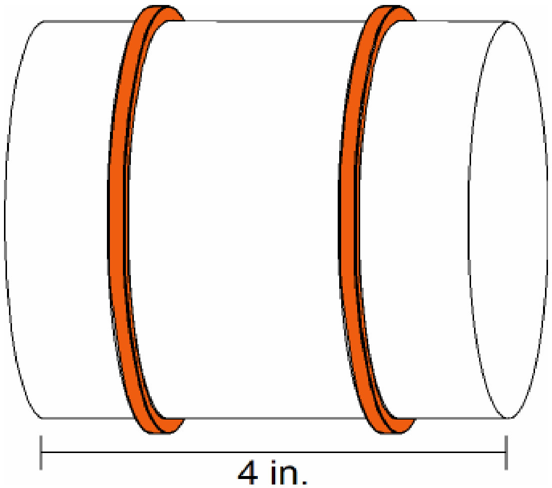


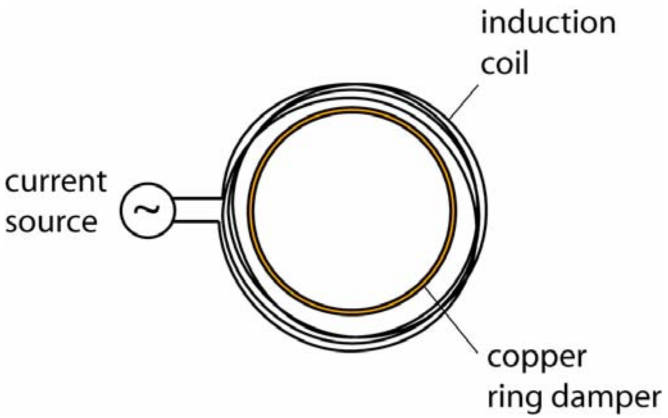
Kapton tape

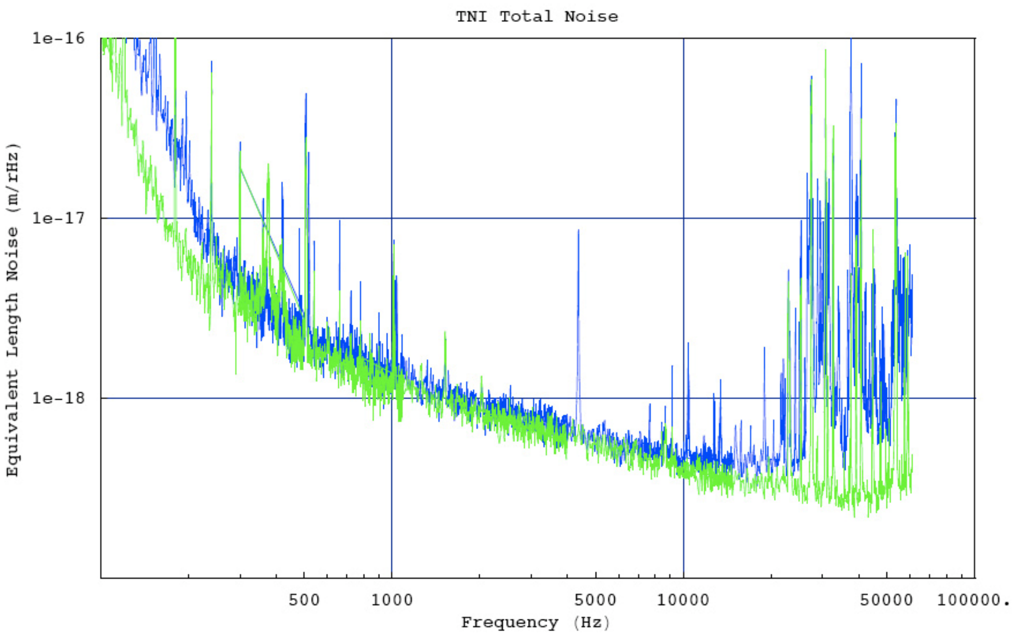


Copper Rings

- Monolithic copper rings machined undersized, heated for expansion, then placed around the barrel of the optic.
- Heating to 200°C caused rings to expand sufficiently to slip over mirrors easily, and cool with no apparent damage to the optic.
- Q reduction still good, as with buna
- Broadband noise floor nearly unaffected below ~20kHz.







Loss Angle Discrepancy

- TNI measurements of loss angle for titania-doped tantala / silica mirror coatings gave different results than those obtained from Q measurements
  - Harry et al, Class. Quantum Grav., **24** (2007) 405-415

TNI:

$$\phi_{eff} = (2.41 \pm 0.15) \times 10^{-6}$$

Q Measurements:

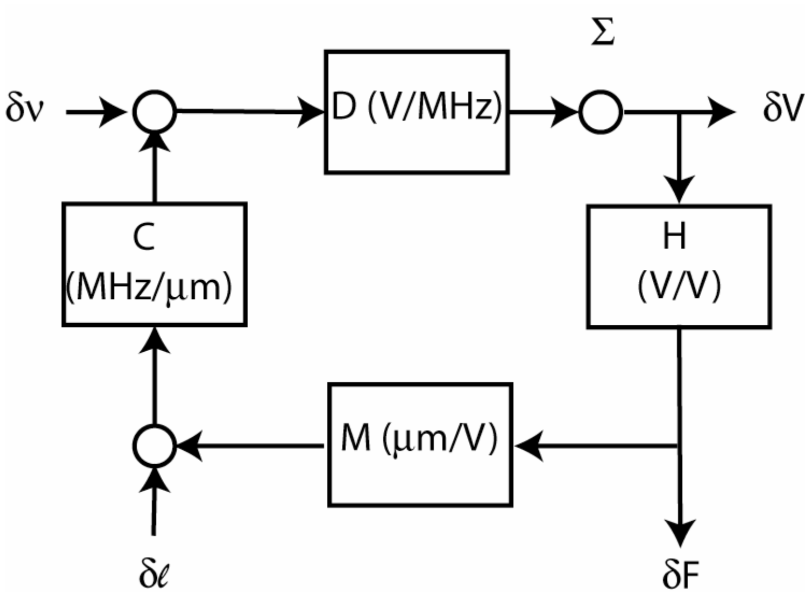
$$\phi_{eff} = (4.0 \pm 0.3) \times 10^{-6}$$

- Discrepancy ~40% is significant.

Relationship between loss angle and length noise:

$$S_x(f) = \frac{2k_B T}{\pi^{3/2} f} \frac{\left(1 - \sigma^2\right)}{wY} \phi_{eff}$$

TNI Calibration



- Extract length noise from error signal

$$\delta\ell = \frac{1 + DHMC}{DC}\delta V$$

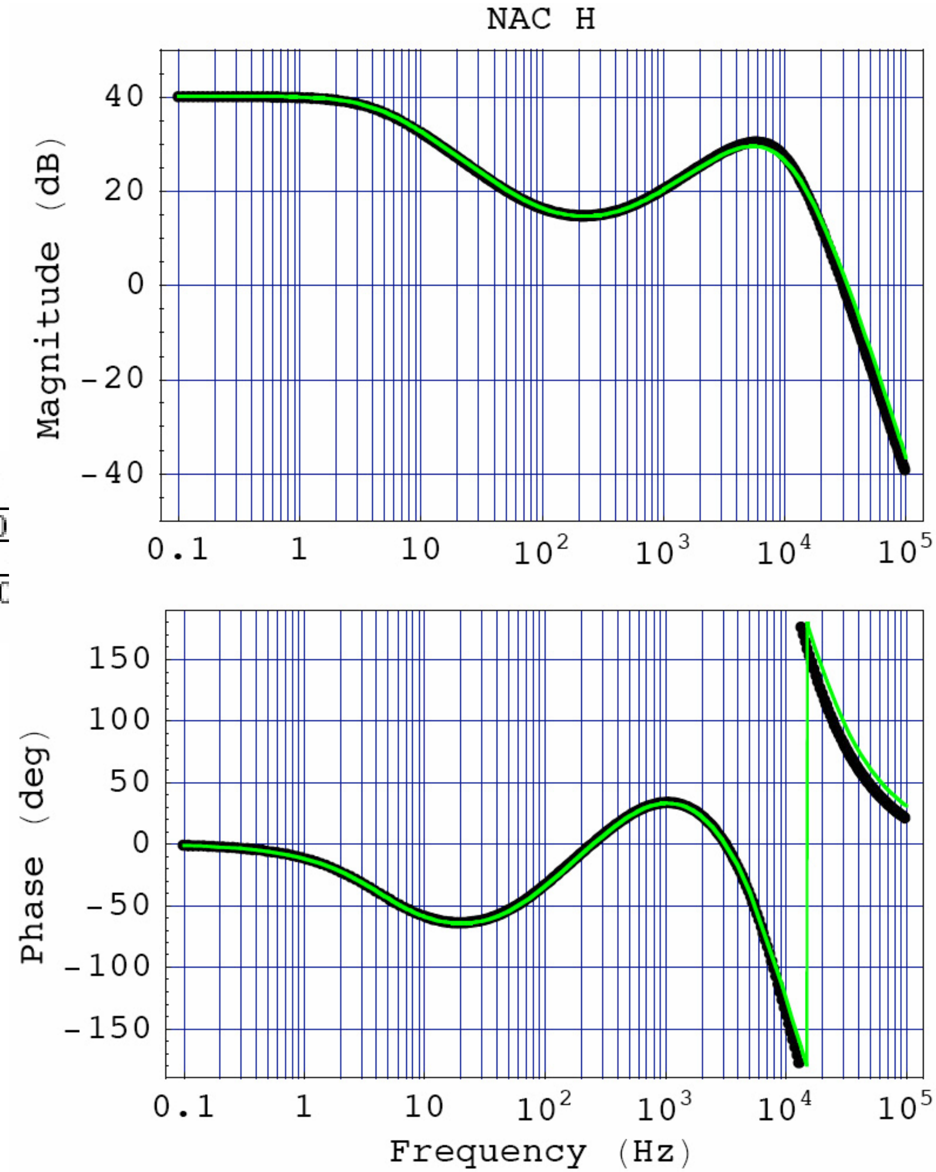
- Must know each transfer function accurately!
- Electronic transfer function *H* specified by design, verified by direct measurement.
- Conversion factor *C*

$$C = \frac{\nu}{L}$$

- Discriminant *D* and mirror response *M* each measured two different ways.
- Additional tests localize noise within the test cavities.
  - Scaling with laser power
  - Scaling with modulation depth

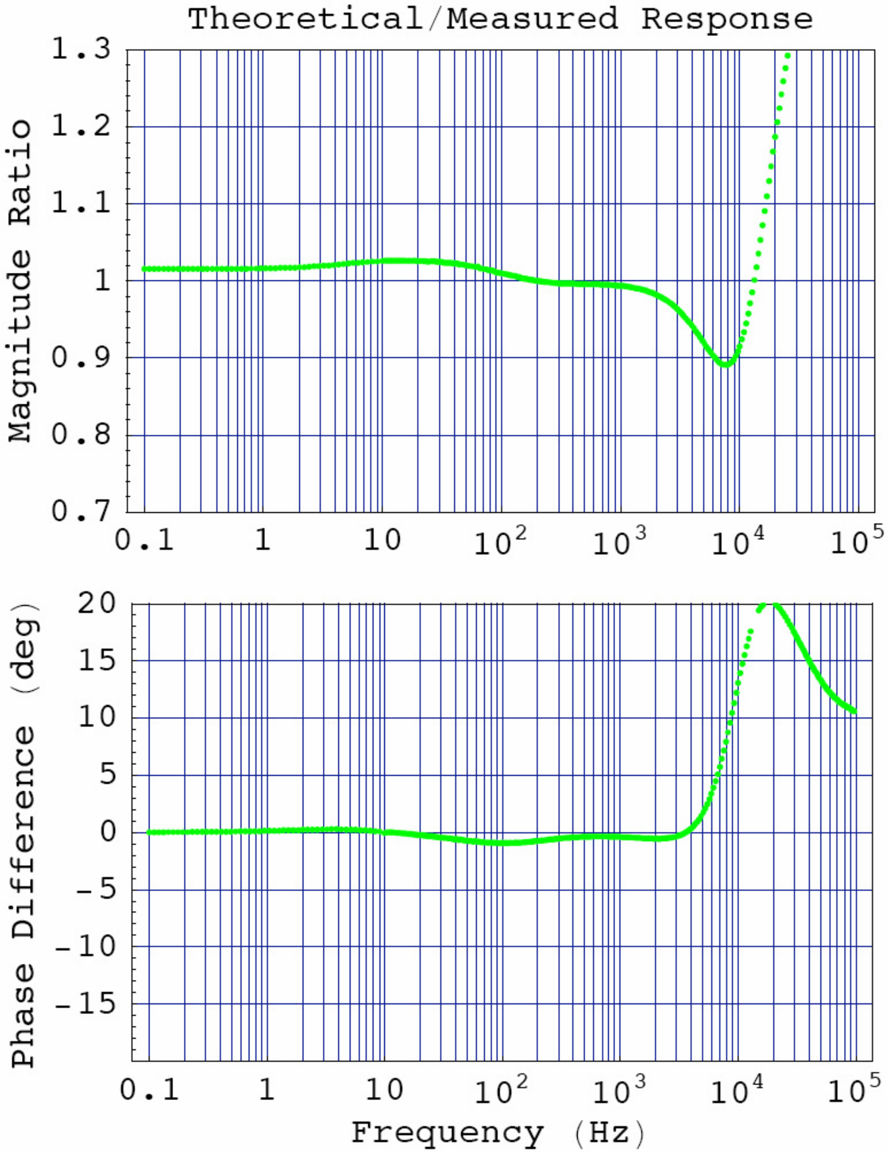
Previous Model for H, w/ Measured Parameters

$$H(f) = g_1 \times 1.7 \times 60 \times \frac{1 + i\frac{f}{105}}{1 + i\frac{f}{4.6}} \times \frac{1 + i\frac{f}{470}}{(1 + i\frac{f}{11000}}$$

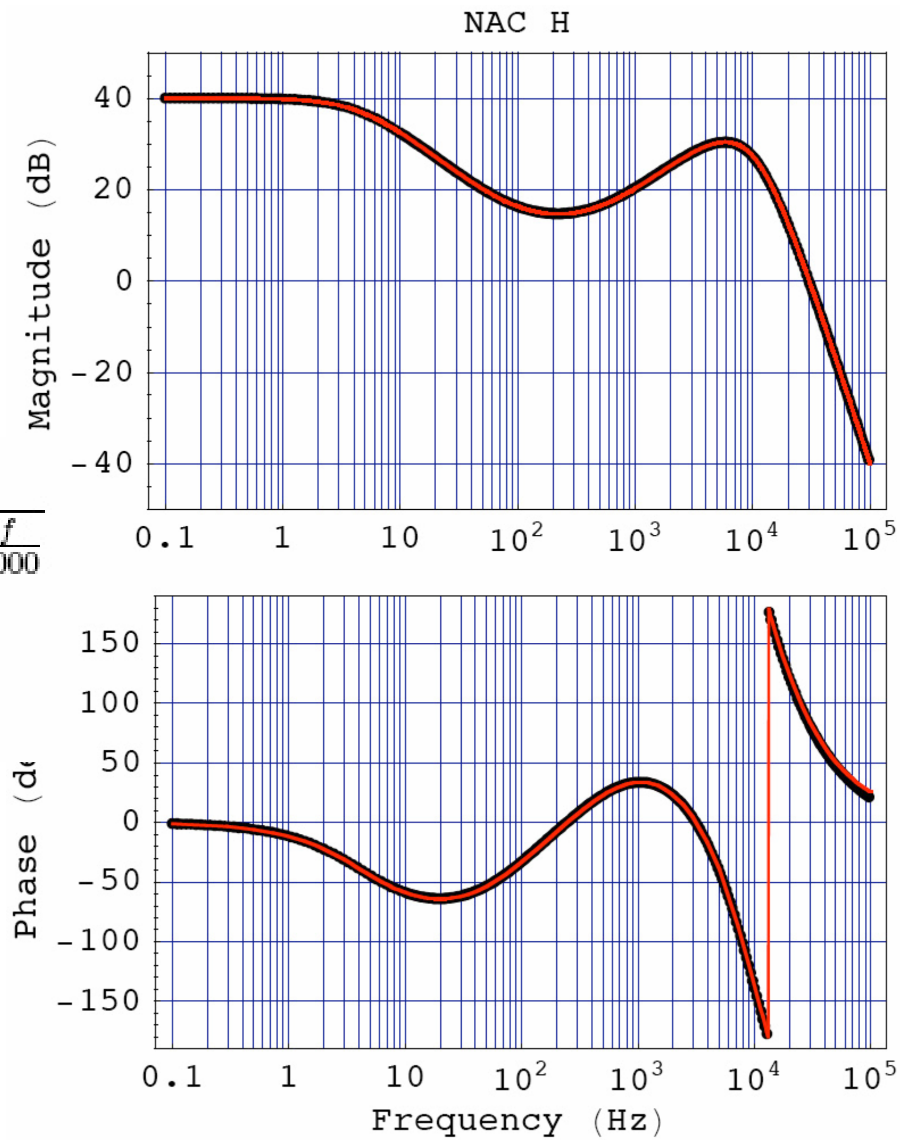


Reasonably Accurate

- Within a few percent of the measured response all the way up to 3 kHz.
- Negligible contribution to error in D.



New Formula - Verified by Measurement

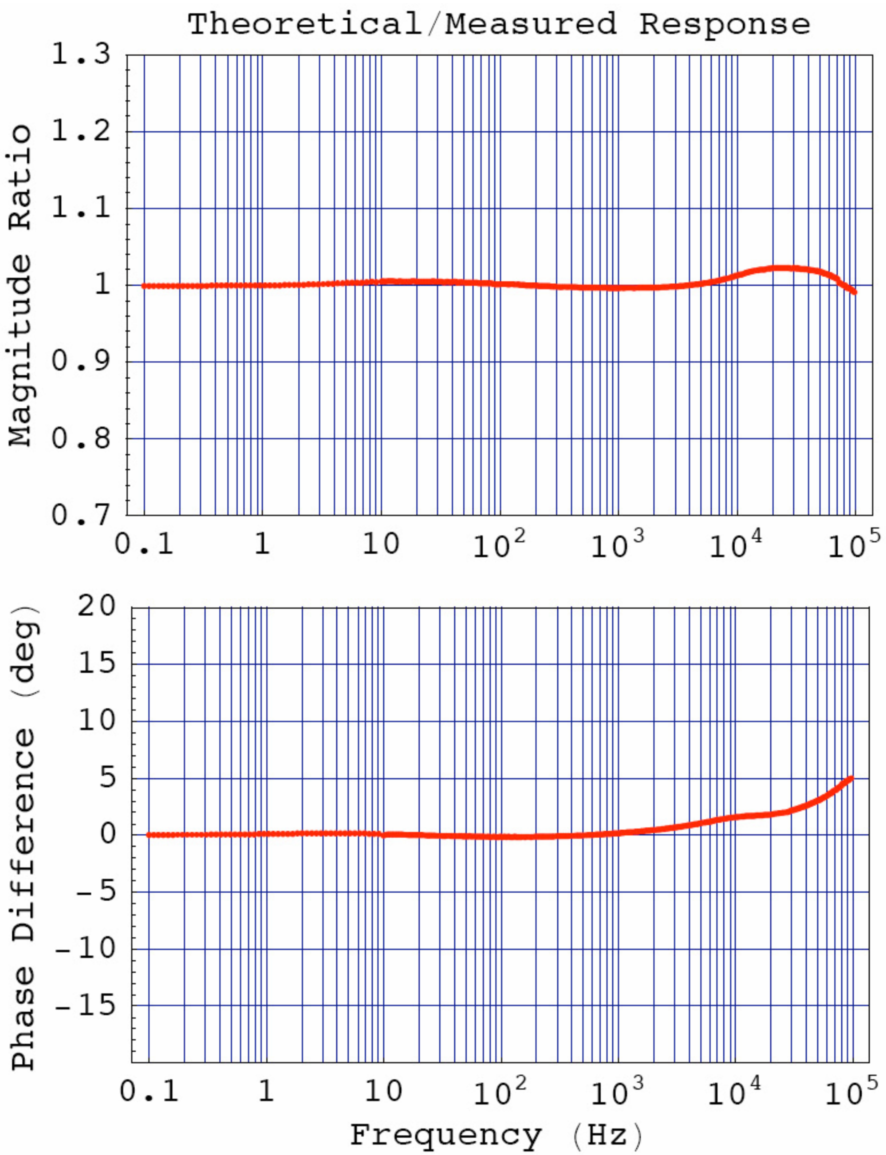


$$H(f) = g_1 \; 98.7 \; \frac{1}{1 + i\frac{f}{10400}} \times \frac{1}{1 - (\frac{f}{10300})^2 + i\frac{f}{7000}}$$

$$\times \frac{1 + i\frac{f}{102}}{1 + i\frac{f}{10600}} \times \frac{1 + i\frac{f}{475}}{1 - (\frac{f}{204})^2 + i\frac{f}{4.57}}$$

Very Accurate

- Within 1% of measured response up to about 10 kHz
- Negligible contribution to error.
- Using to reanalyze the undoped and doped coating noise data along with a more accurate value for C.



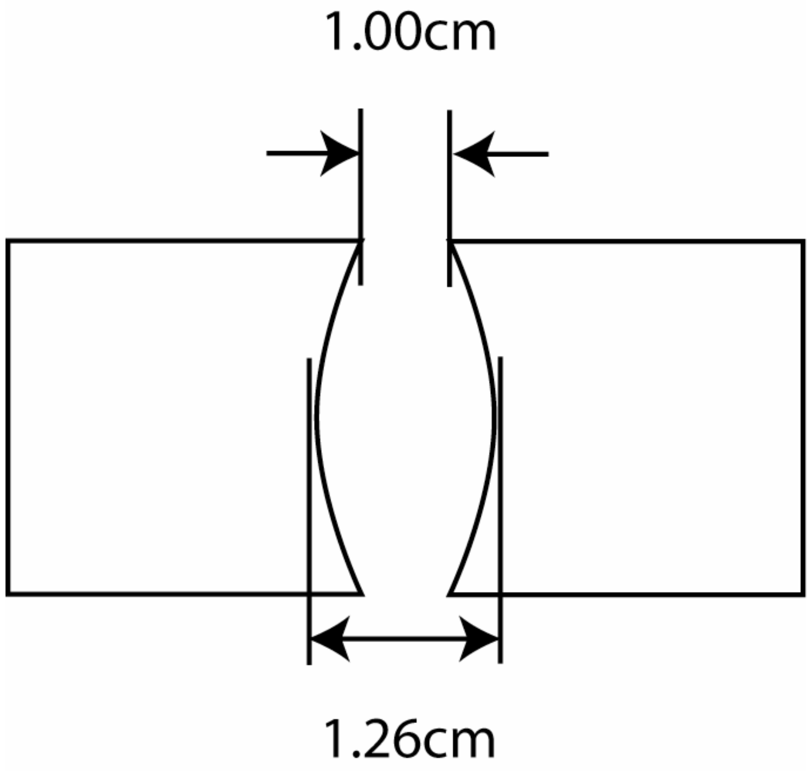
Spot Size and Coating Thickness

- Need to know both spot size and coating thickness to extract loss angle
- Had been using w = 160 μm
- Optical, physical measurements give w = 163 +/- 10 μm (still being refined)
  - Leads to expected ~4% increase in phi (denominator has w^2)
- Had been using d = 4.26 μm (REO): Undoped coating thickness
- Actual value is d = 4.515 μm (LMA): Doped coating thickness
  - Leads to a 6% reduction in phi
- Net effect is a change in phi which is on the order of the uncertainty in this number.

$$S_x(f) \approx \frac{2k_B T}{\pi^{3/2} f} \frac{(1-\sigma^2)}{wY} \left\{ \phi_{sub} + \frac{2}{\sqrt{\pi}} \frac{d}{w} \left(\frac{1-2\sigma_c}{1-\sigma_c} \right) \phi_{coat} \right\}$$

Cavity Length L

- Mirror radius of curvature had been neglected!
- Increases cavity length by 26%.
- Taking center of mass shift into account gives a suspended cavity length of 1.24cm.
- This would give a spot size of 163.6μm, in agreement with optical measurement.
- This change decreases C, raising the equivalent length noise
- Still working numbers, but this is the right order of magnitude to account for loss angle discrepancy



$$C = \frac{\nu}{L} \qquad \delta\ell \approx \frac{\delta V}{DC} \qquad S_x(f) = \frac{2k_B T}{\pi^{3/2} f} \frac{(1-\sigma^2)}{wY} \phi_{eff}$$

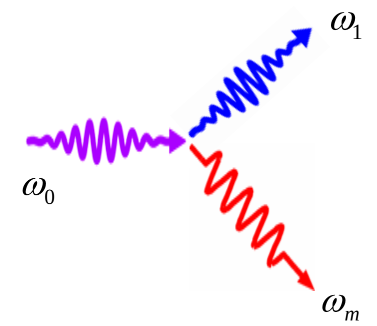
Aperiodic Coatings

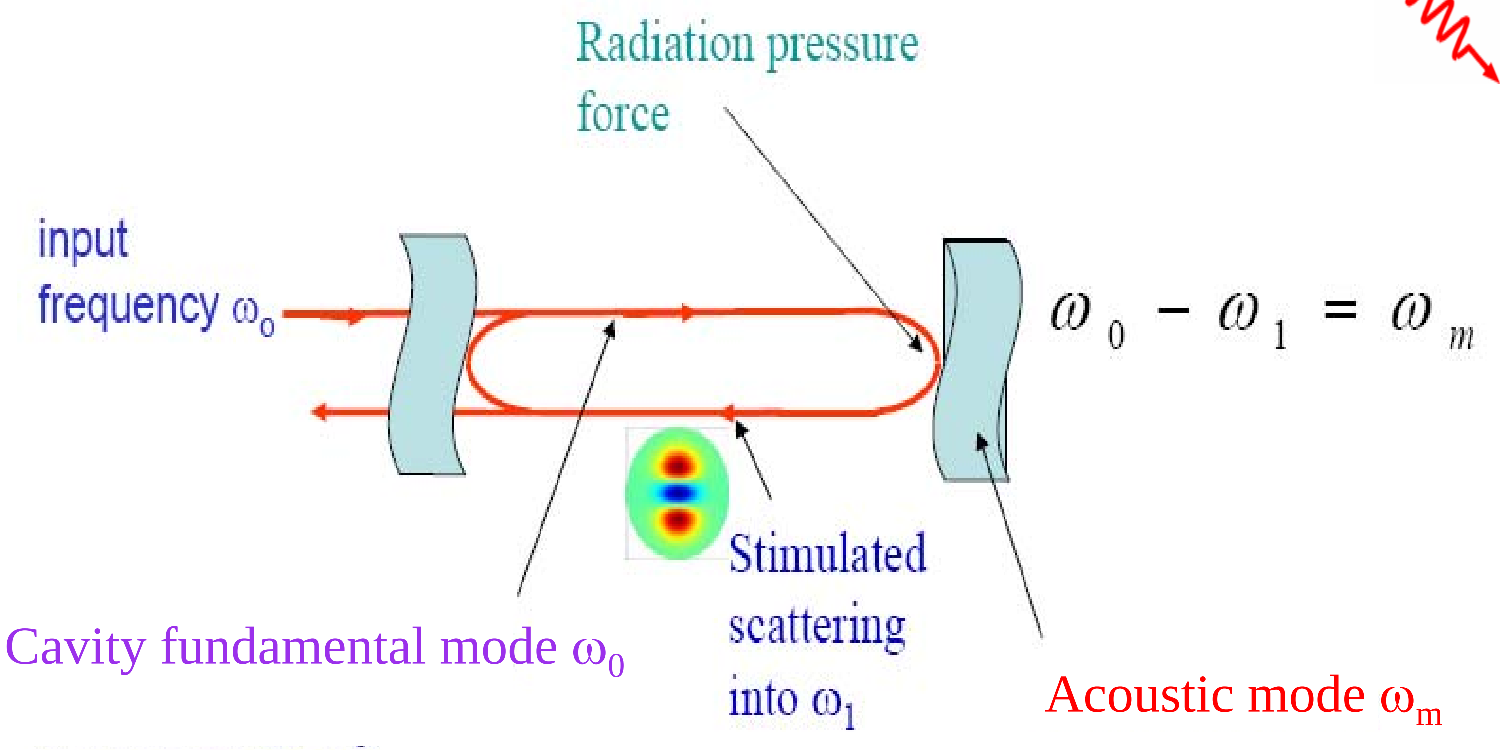
- Goal: reduce high-loss material in HR coating by varying layer thickness, while preserving phase relationship for reflection
- Collaboration with
  - Vincenzo Galdi and Innocenzo Pinto at Benevento (coating design),
  - LMA at Lyon (fabrication and loss measurements), and
  - Sheila Rowan at Glasgow (loss measurements)
- We have a design for an aperiodic coating using silica and UN-doped tantala.
- Currently waiting on fabrication by LMA - as soon as we get new coatings, we will measure actual noise at TNI.
- There have been issues with fabrication. LMA is working on resolution.

Summary

- Parametric instability
  - Copper rings reduce mechanical Q with small noise floor increase
- Calibration of instrument
  - Improved electronic transfer function
  - Precise measurements of cavity length and spot size are in progress
  - Corrected cavity length value for transfer function, should significantly reduce discrepancy in TiO_2-doped Ta_2O_5 coating loss angle measurements
- Aperiodic coatings
  - Currently in fabrication

Parametric Instability





Ju, et al. G050325-00

Condition for Instability

Mechanical Q

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

Stokes Mode

Anti-Stokes mode

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

Optical Measurement of w_0

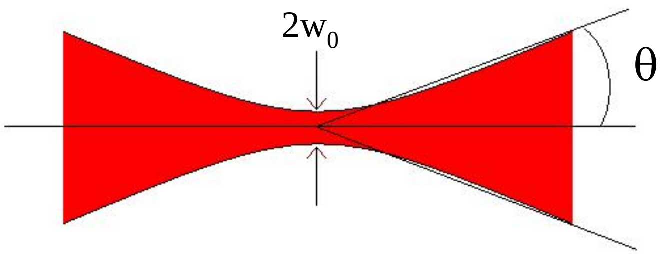
- Gaussian beam waist size is equivalent to spreading angle:

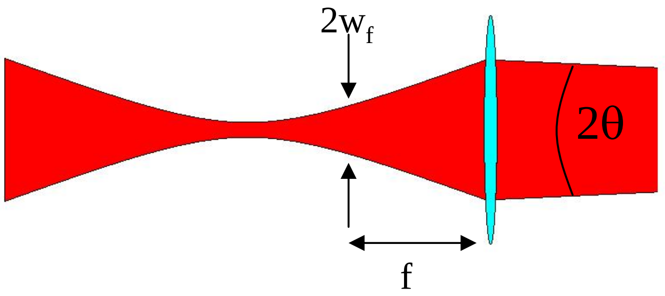
$$\theta = \frac{\pi w_0^2}{\lambda}$$

- ISO standard (11146-1) for measuring spreading angle (using a lens of focal length f):

$$\theta = \frac{w_f}{f}$$

- Preliminary results: w = 163 +/- 10 μm
- Large error due to issues measuring focal length of lens, will be resolved soon.





Direct Measurement of L

- Performed direct measurement of mirror separation at edges using calipers
- Faces were slightly tilted, but geometrically deduce separation at center to be ~1.216 cm
- This corresponds to a beam waist of 162.3 μm - consistent with other results