Update on aLIGO PSL PMC upgrade to address contamination issues

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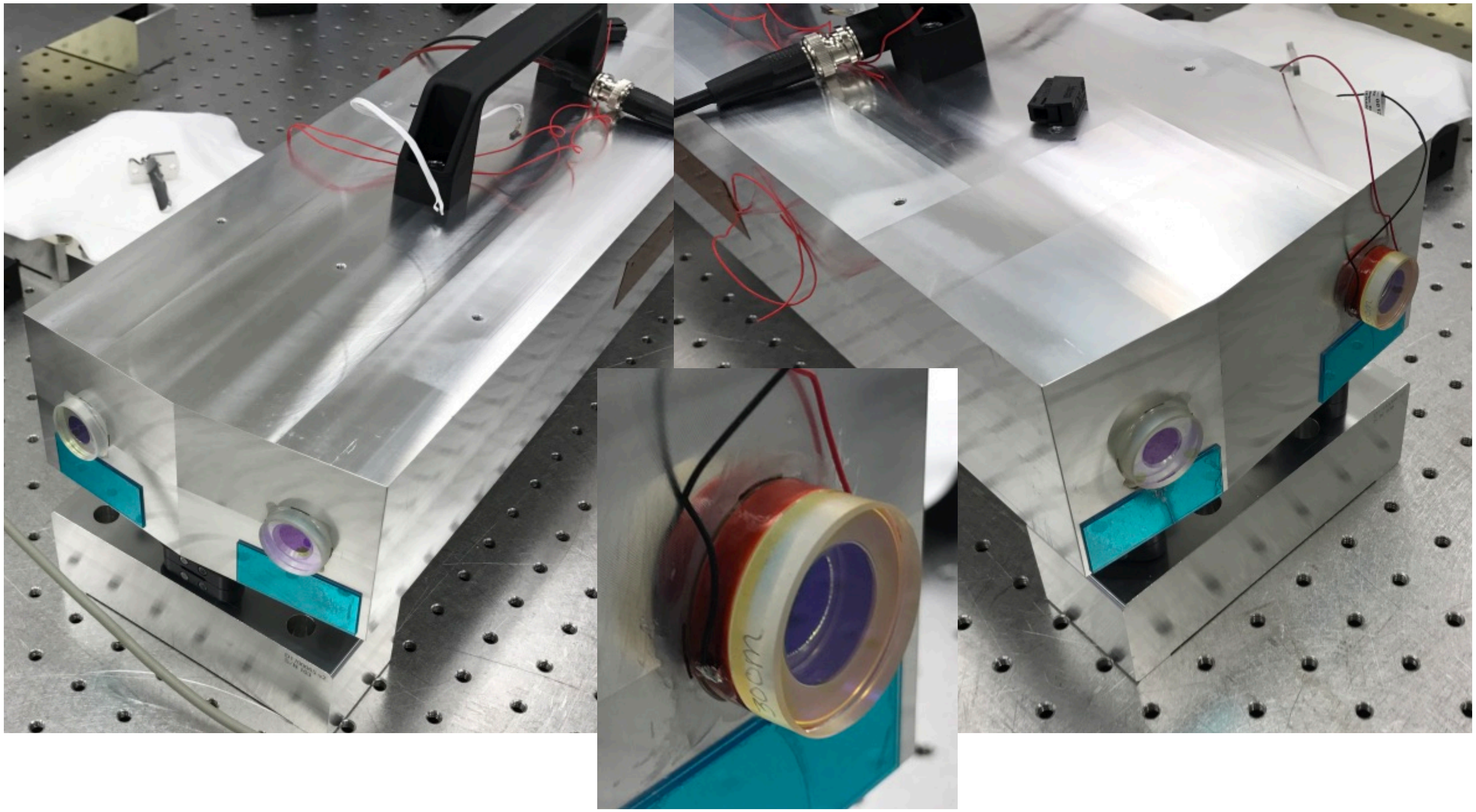
(with S. Appert, P. King, E. Sanchez, L. Zhang, et al.)

SYS telecon
Aug. 9, 2017

Original aLIGO “Glued” PMCs



History

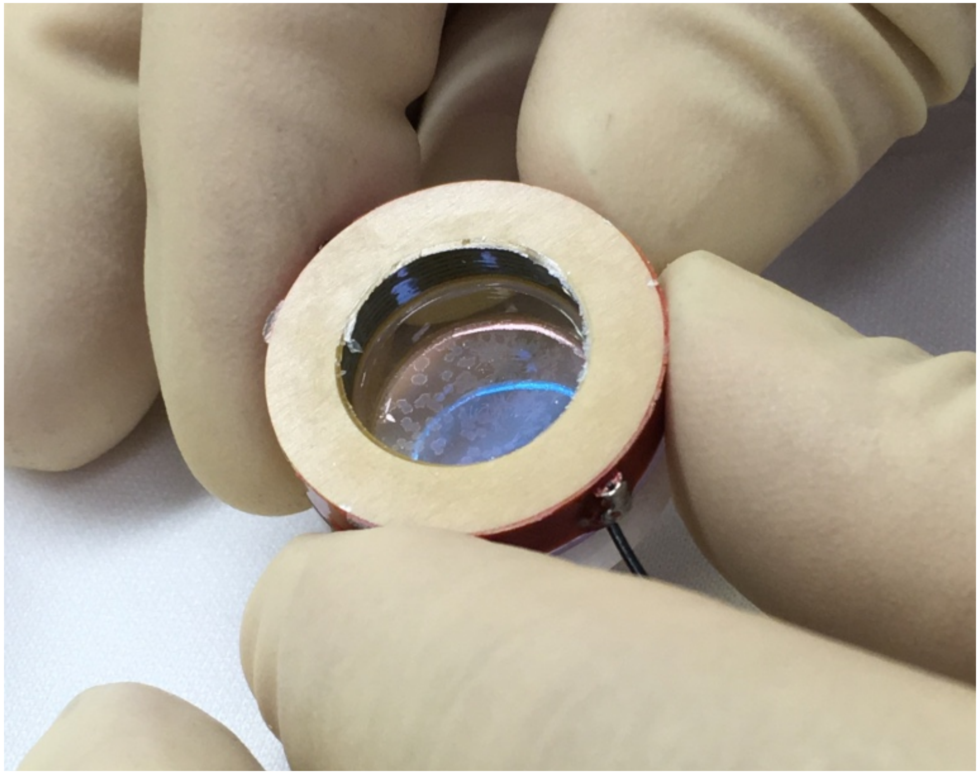
- Six PMCs delivered to aLIGO by AEI
  - » Two per interferometer – installed unit and spare
- Contamination of PMC tank windows observed (excess scattered light, power loss)
  - » Tank windows cleaned and lids removed to enable outgassing
- One PMC replaced due to glitchy PZT (repaired at LHO)
- Two more replacements due to excessive losses
- Current status (average losses per mirror):
  - S/N 08 before repair: 50 ppm; after PZT replacement 60 ppm
  - S/N 09: 46 ppm
  - S/N 10: 1375 ppm
  - S/N 11: 1461 ppm

Contaminant identified: non-UHV PZT contaminating M4

Mirror removed from lossy PMC removed from operation at LLO

Attribution to PZT verified by analysis carried out by JPL (Calum, Garilynn, et al.)

Not seen (at least visually) on other cavity mirrors



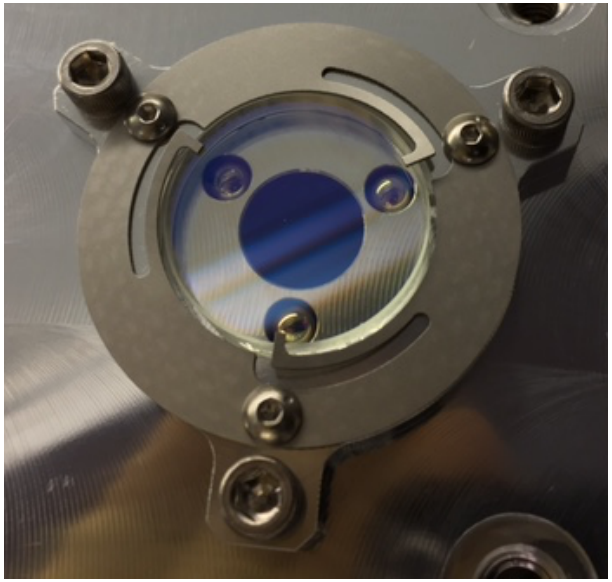
LIGO

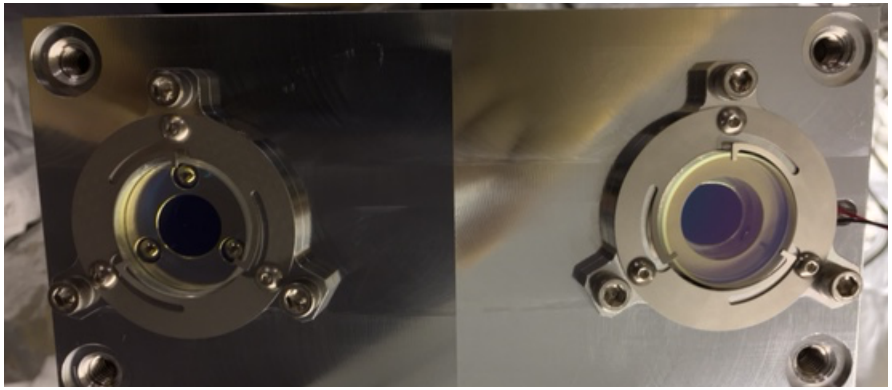
Solution pursued

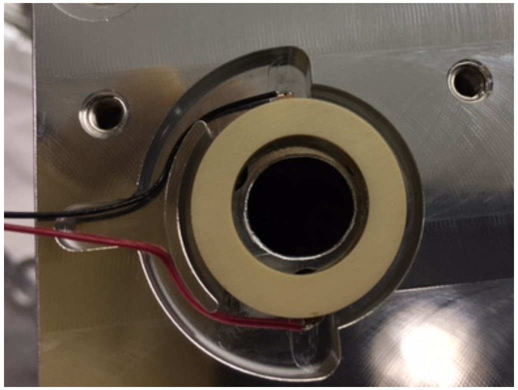
- Procure UHV PZTs with same dimensions and performance (m/V) from same vendor (PI)
- Procure new PMC mirrors from ATF (flats and 3m concave)
- Machine faces of aluminum spacers
  - » Investigate possibility of machining spacers with tolerances sufficient to achieve resonance by pressing optics against the surfaces of the spacer
    - – Mirrors removed from two of original six PMCs (PZT mirrors sent to JPL for analysis)
    - – PMC spacers machined by local shop (TK Machine in Richland) – 0.010” clean-up of faces – to test machining tolerances (single setup in 5-axis CNC mill)
    - – Tapped holes added to attach mirrors to spacer using off-the-shelf flexures from Newport Corp.
    - – Both cavities resonated when assembled, without alignment tweaks.
      - Losses at or below level of measurement sensitivity (< 10 ppm per mirror)
        - » See https://dcc.ligo.org/LIGO-T1600204

Fabrication of production units

- Eight PMC bodies fabricated at TK Machine (two for KAGRA)
- Mirrors and PZT held in place with flexures
  - 3-point (3/16” balls) contacts or directly contact faces of spacer (leave balls out)
- 3-point kinematic mounting to optical table
- Class A / Class B processing for all components (to minimize contamination)
  - No glue, new heaters, etc.

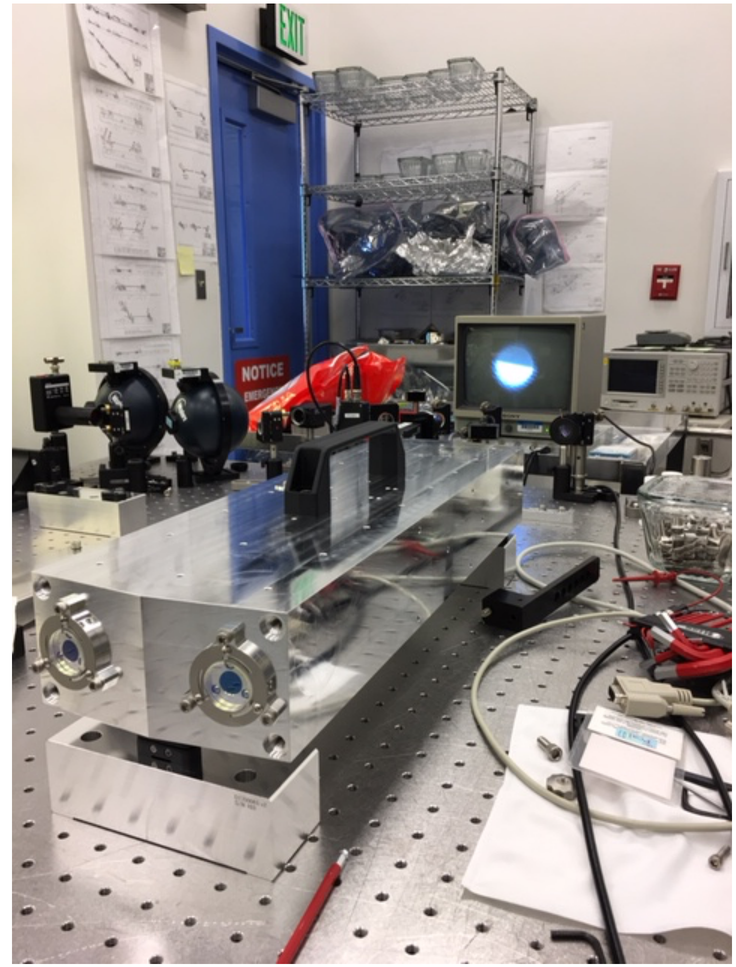






Performance of production units

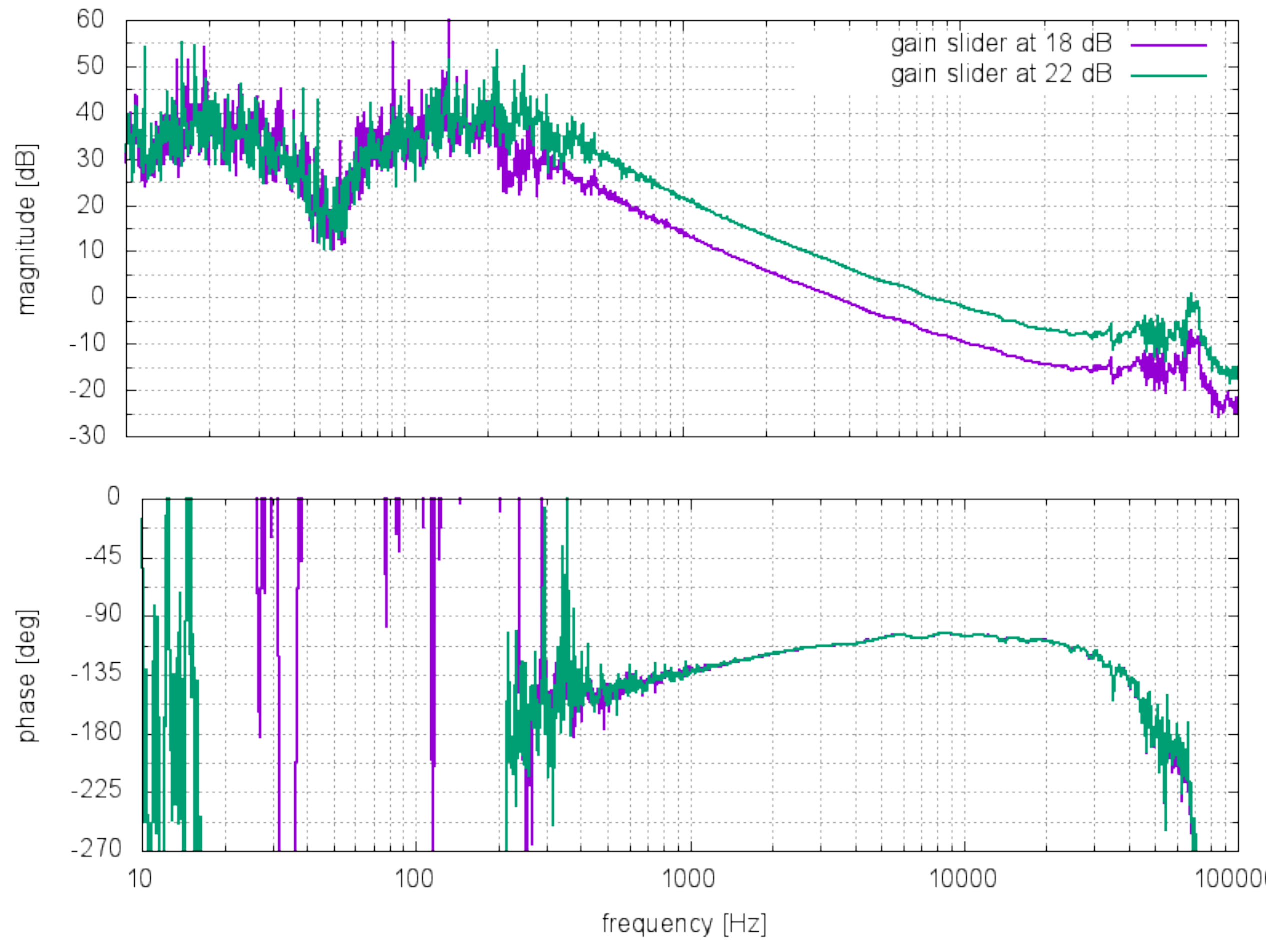
- Cavities resonate both with and without balls between PZT and body
  - » Machining accuracy is sufficient
    - – Two production cavities tested
- Finesse is close to design value (bandwidth ~1.1 MHz)
  - » New flat mirror transmissivity is as specified
- Measured losses are at or below ability to measure them
  - » Less than 10 ppm per mirror
- PZT actuator transfer function more complex than with glued configuration
  - » May impact PMC servo performance
  - » Several options for modifying PZT interfaces tested. More planned
    - – See LIGO-E1700222 for details



aLIGO PMC (H1 PSL): servo open-loop transfer function

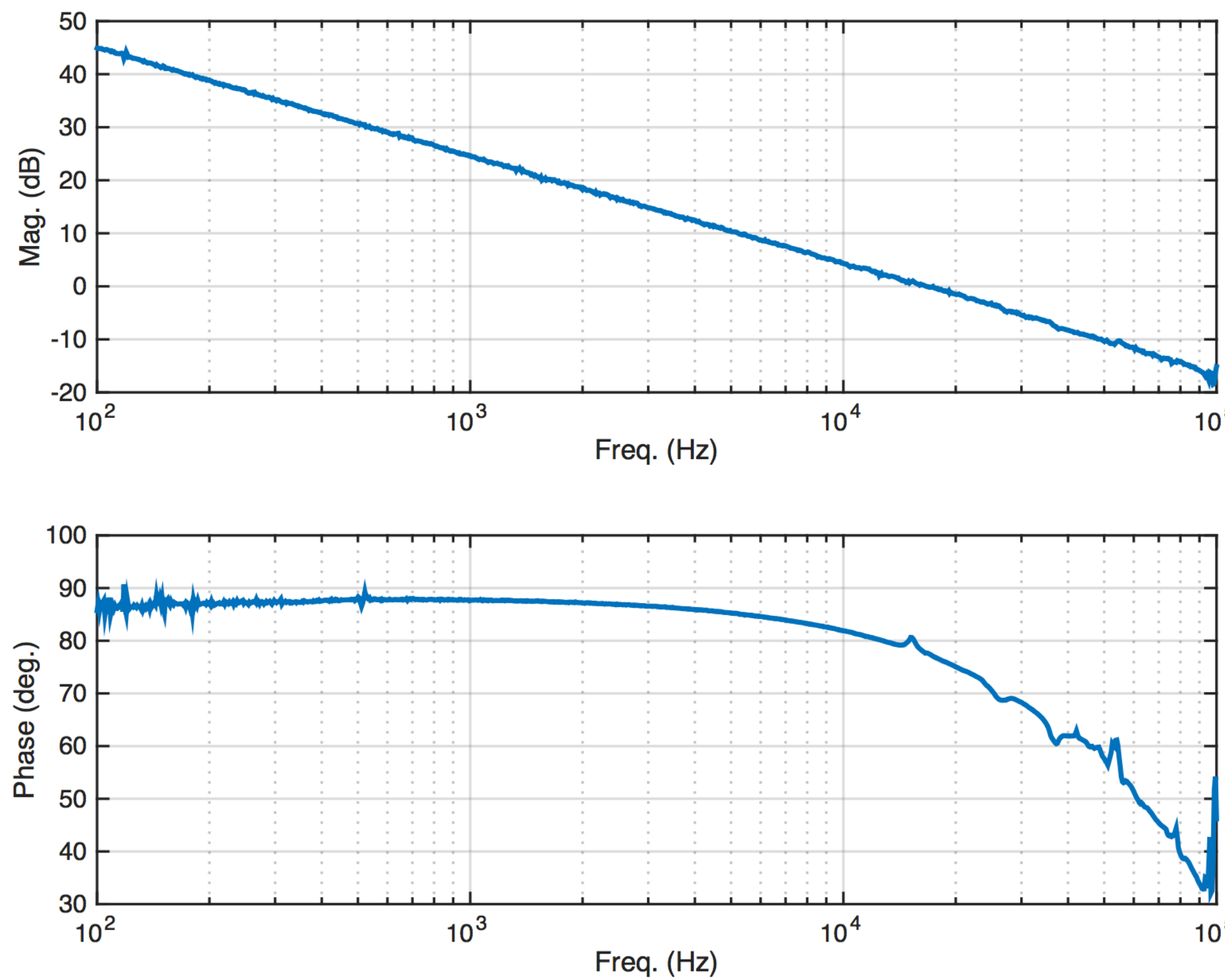
- All-glued PMC
- Servo gain set to 6dB to optimize performance
- UGF ~ 1 kHz at 6dB gain setting
- Both LLO and LHO operate with PMC servo UGF ~1kHz

- TF plot provided by P. King 7/12/17.

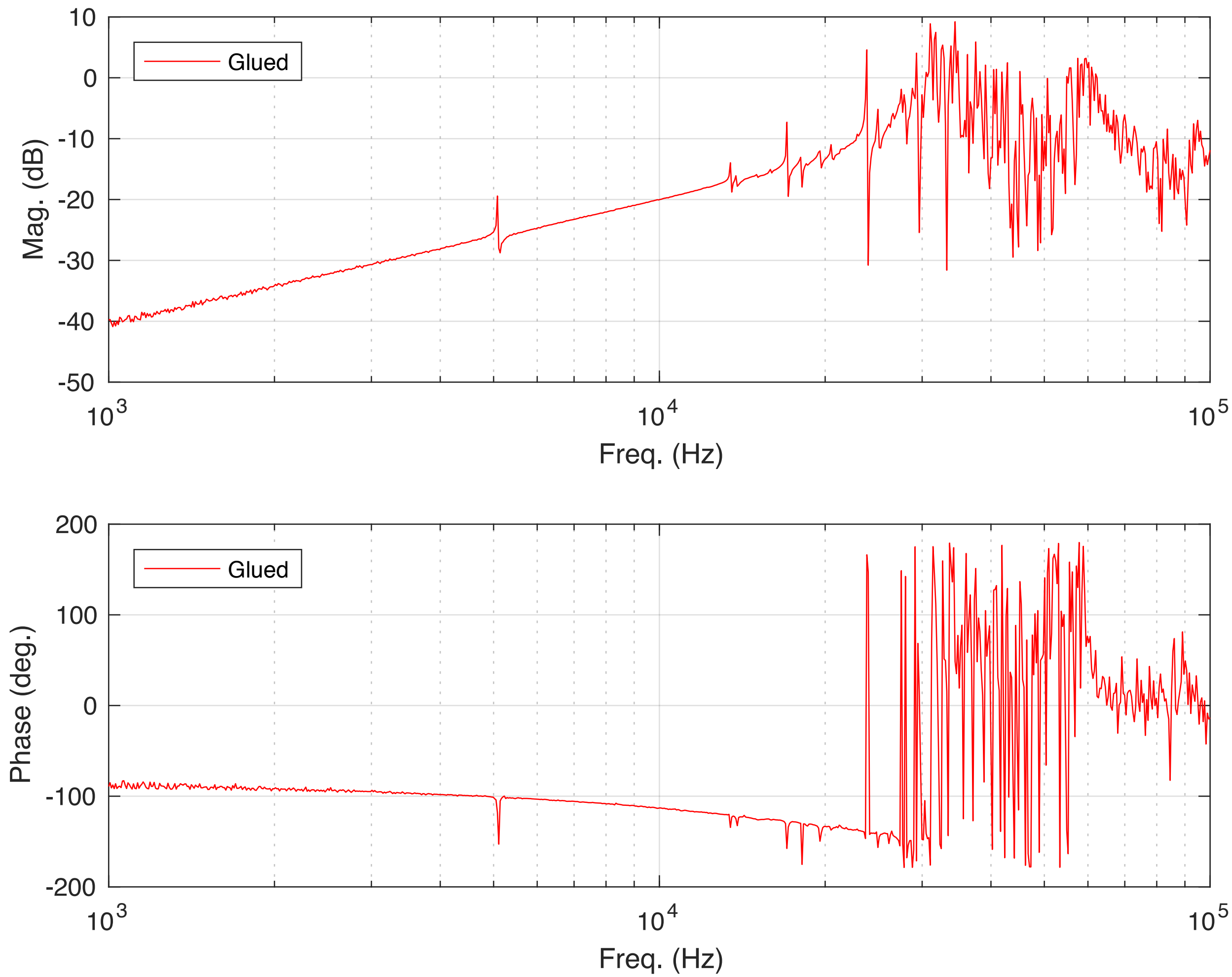


Laser frequency locking servo – open loop transfer function

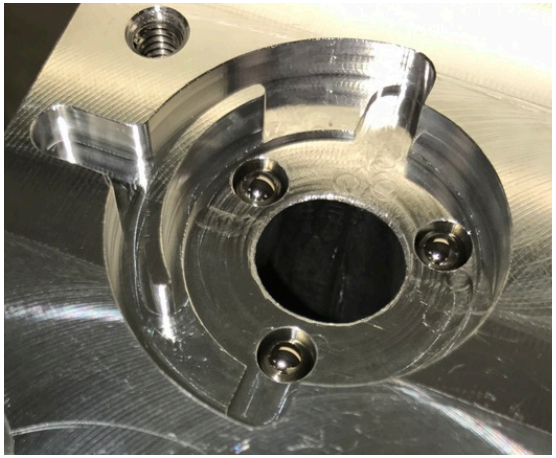
- Laser frequency locked to cavity resonance using PDH scheme.
  - » See LIGO-T1600204 for servo locking details
  - » Loop UGF ~20 kHz
- PZT actuator driven directly with dynamic signal analyzer source output (SRS up to 100 kHz, Agilent RF analyzer for higher frequencies)

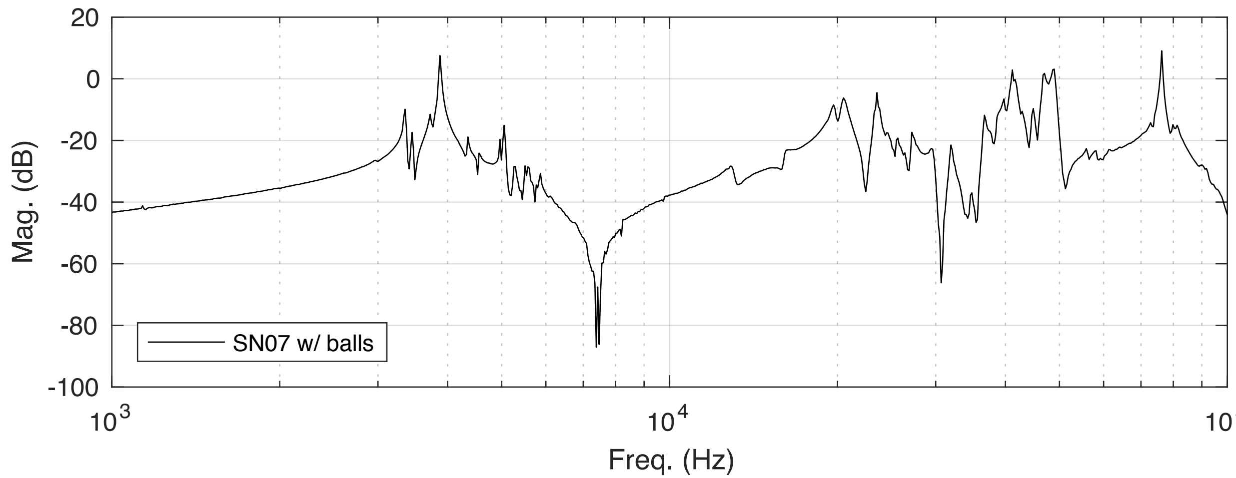


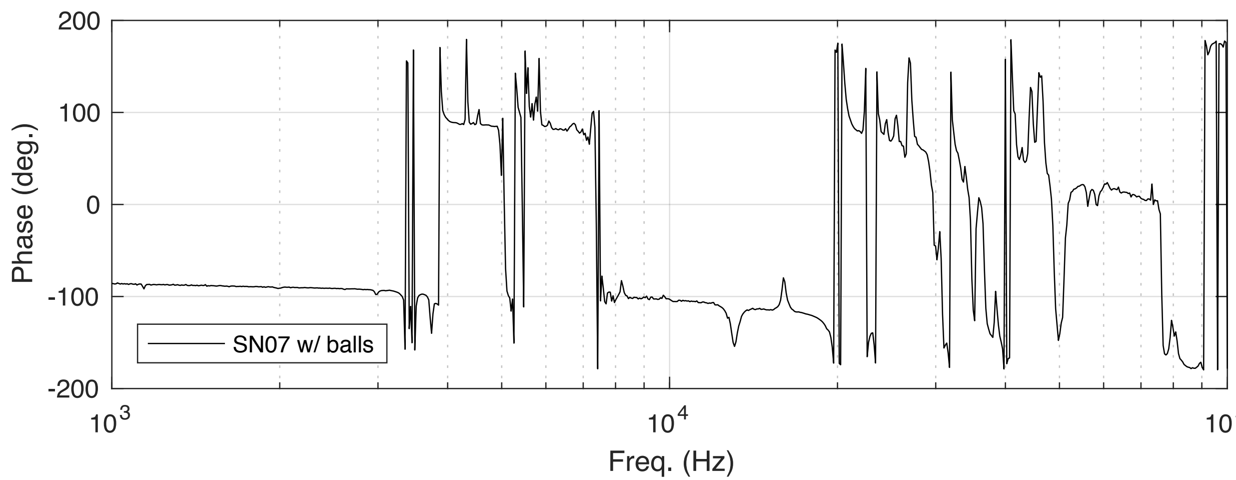
Original aLIGO "glued" PMC: 1-100 kHz



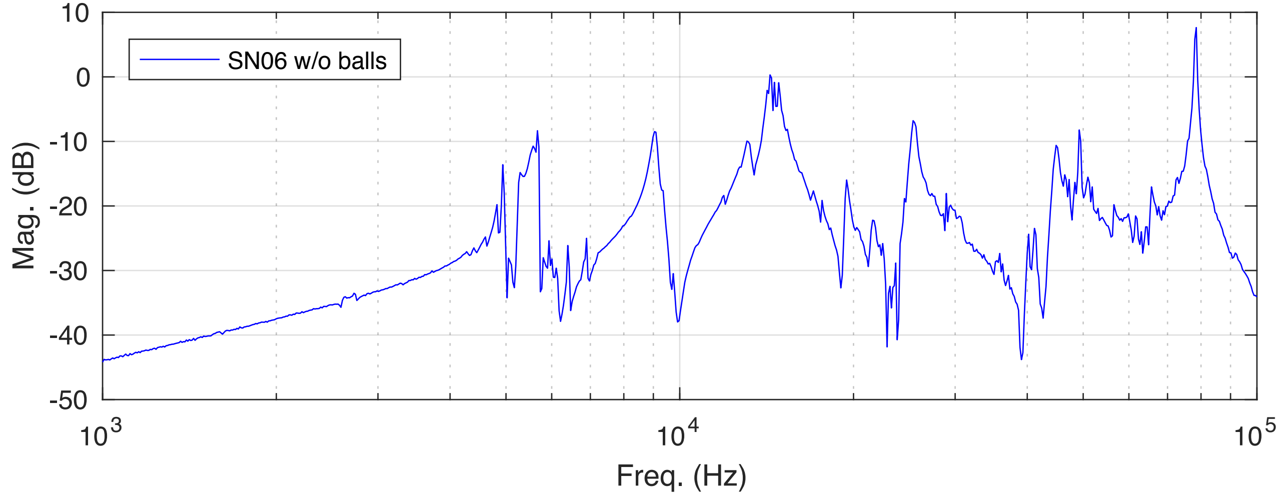
Production unit (SN07) with balls between PZT and PMC body: 1-100 kHz

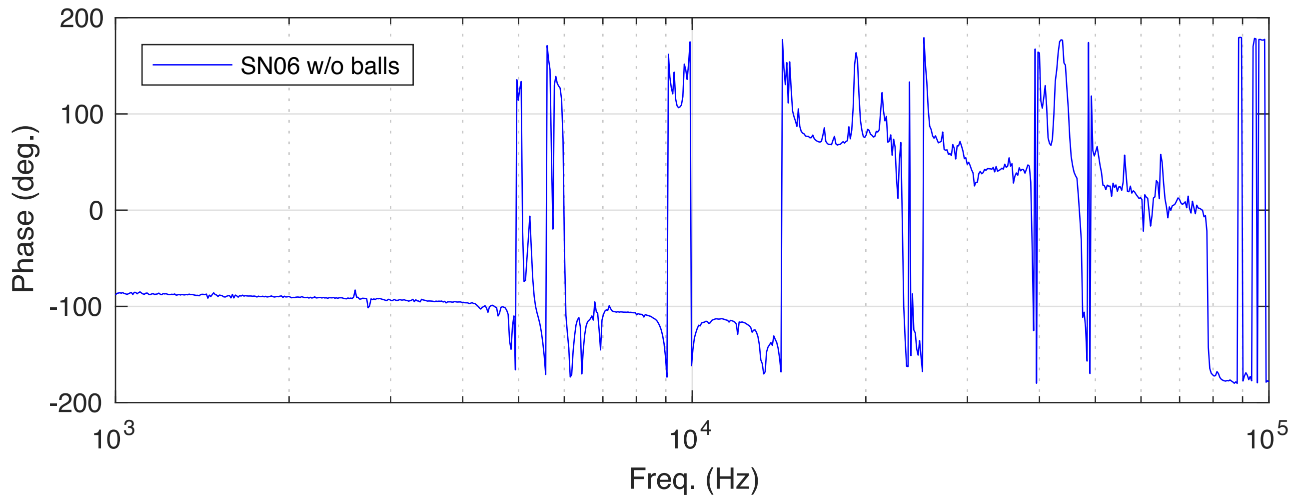




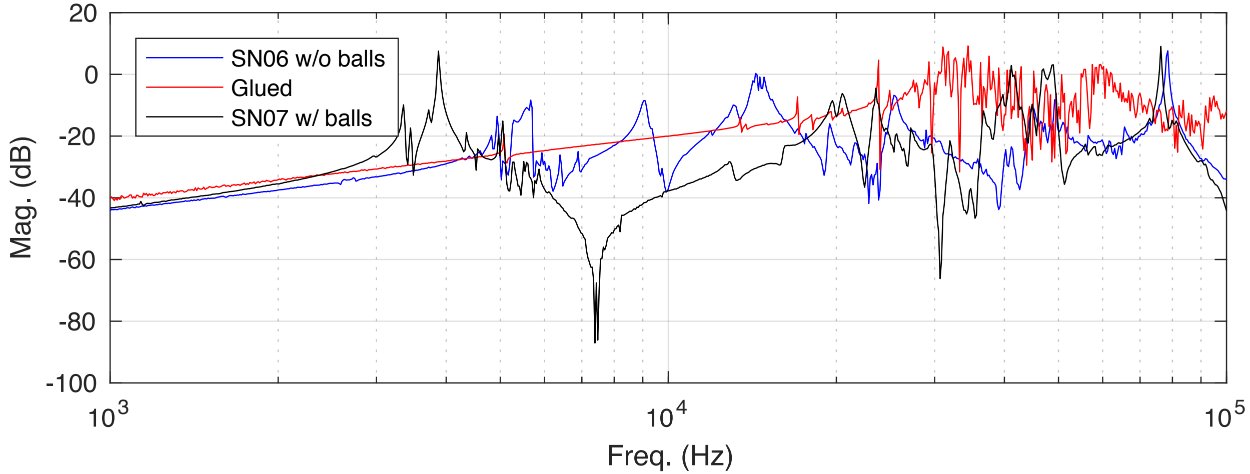


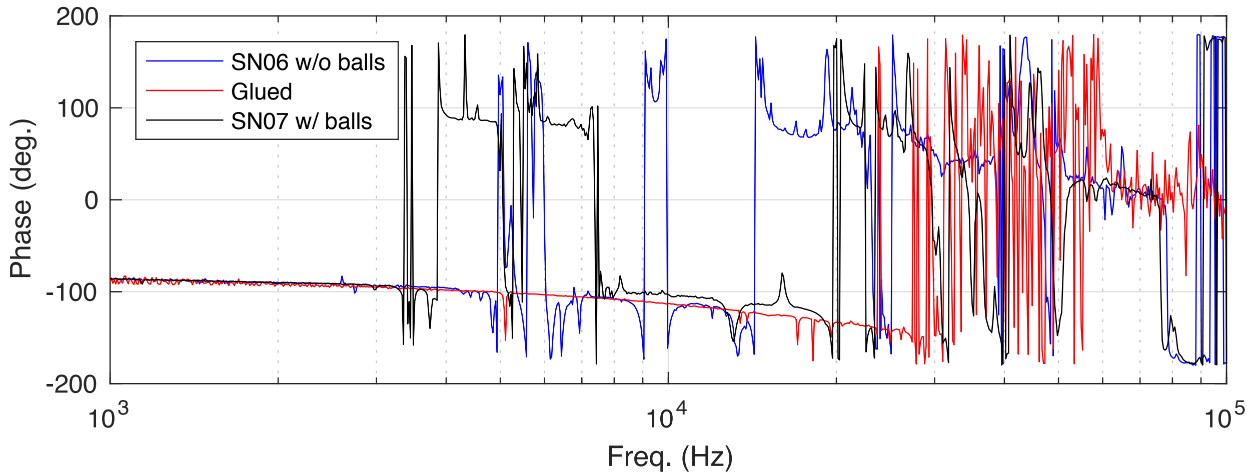
Production unit (SN06), without balls between PZT and PMC body: 1-100 kHz





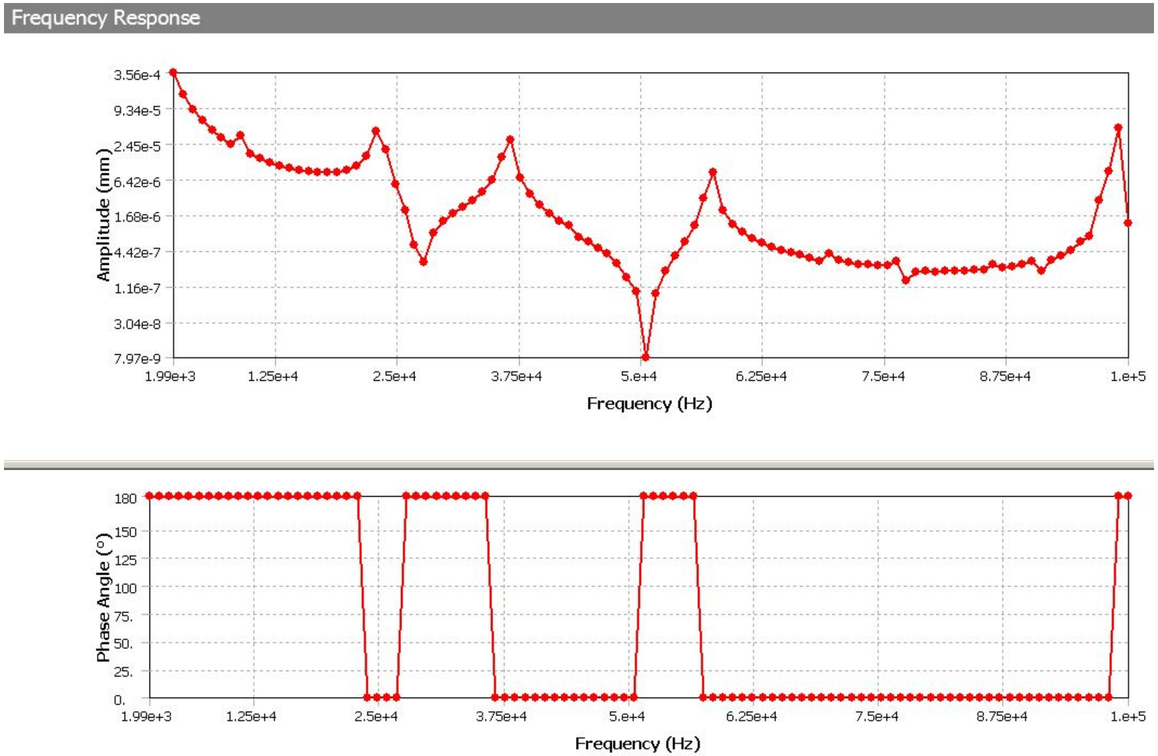
Comparison: glued, with, and without balls: 1-100 kHz





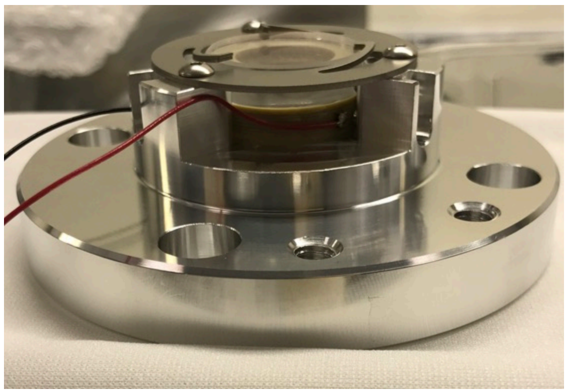
Quick look at FE analysis of PZT response
D. Coyne 6/23/17

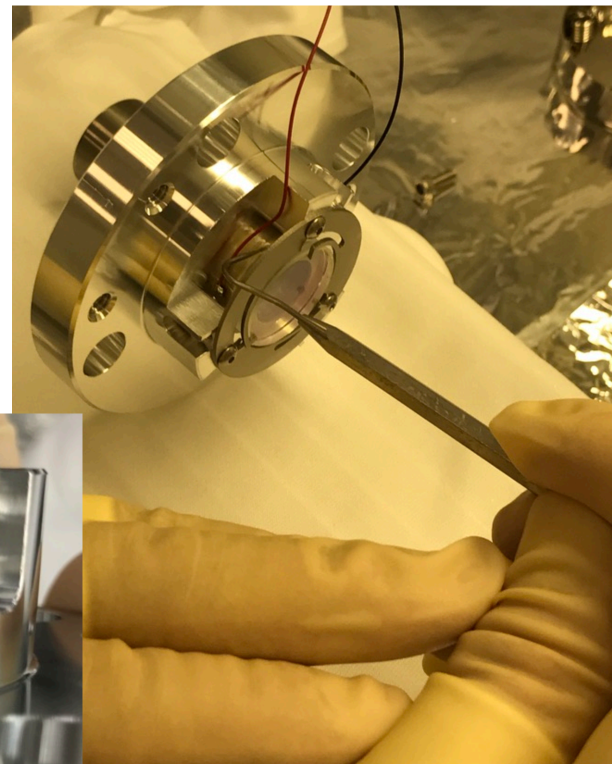
- 3-point contact with rough estimate of PZT properties
- Features (parallel resonances) similar to those seen in lab, albeit at higher frequencies.
- Seems to validate focus on mounting of PZT
- Other tests indicate PZT TF mostly dependent on PZT/M4 configuration, not other mirrors or spacer

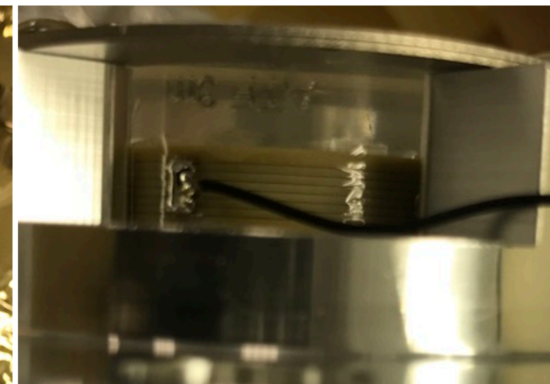


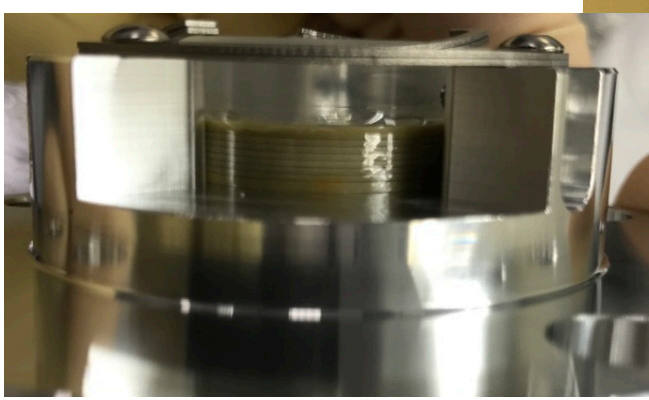
Try gluing M4 to PZT to ”stabilize” PZT

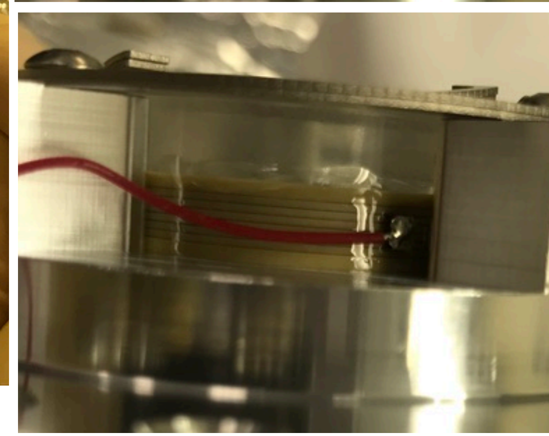
- Use gluing fixture LIGO-D1700313 and EP-30 epoxy applied around the barrel of the outer M4/PZT boundary. Cure at room temperature.









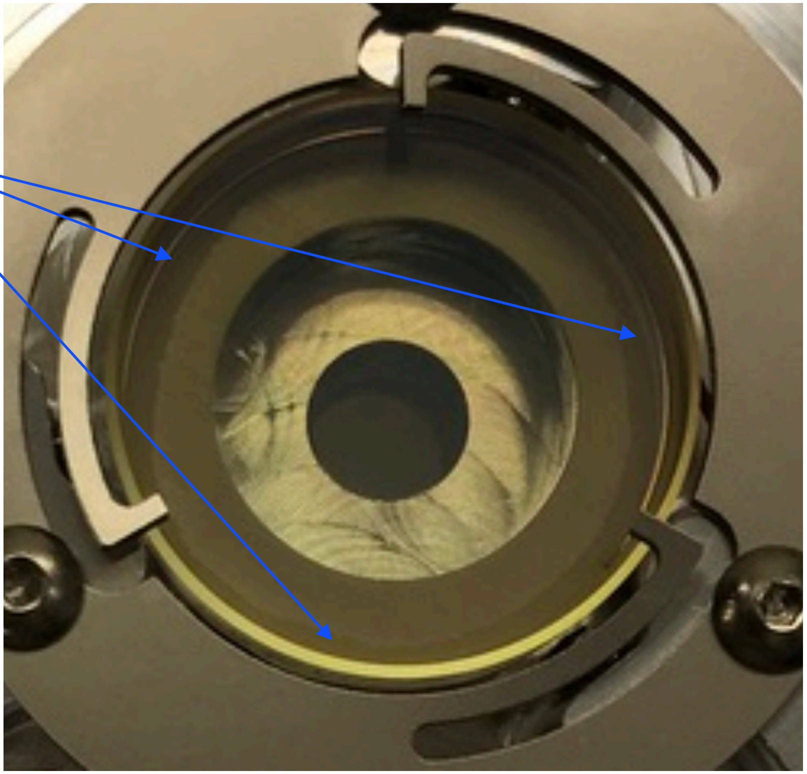


M4 to PZT gluing

Epoxy wets annular region at OD of M4/PZT assembly even though mirror is compressed against PZT with two flexures.

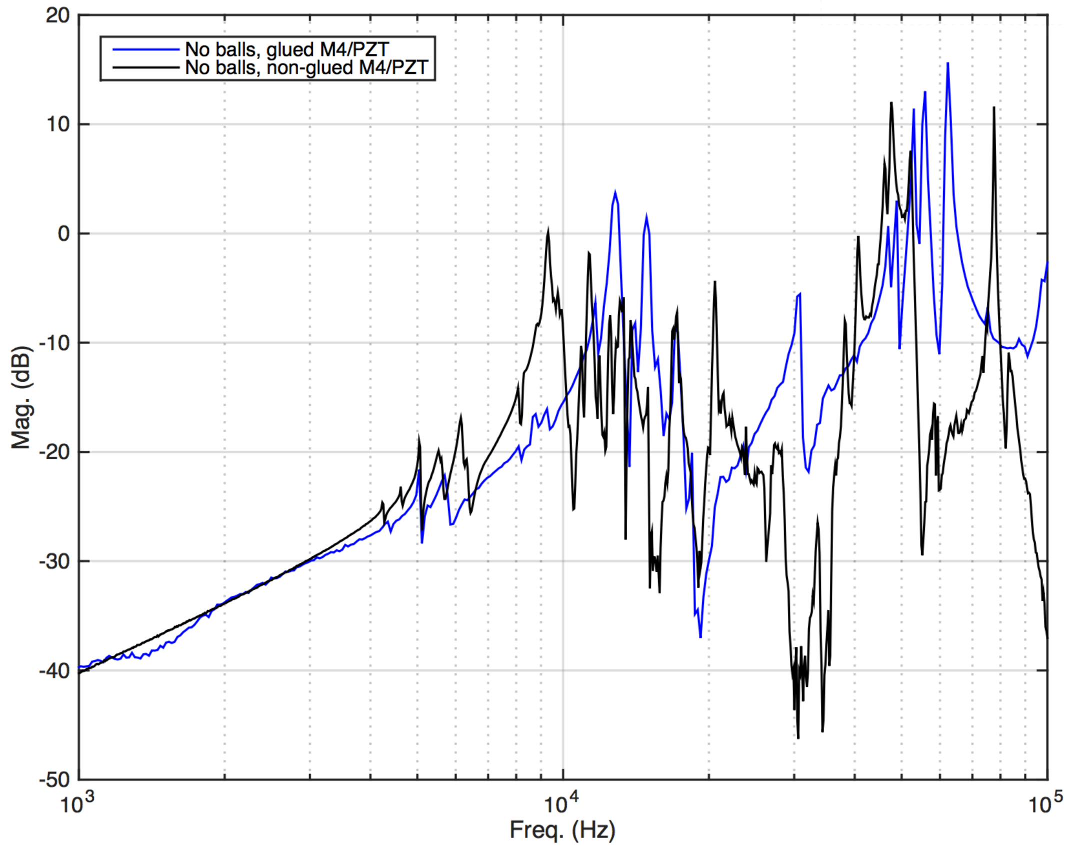
Epoxy applied only to M4/PZT boundary along OD.

Photo taken approximately 30 minutes after applying epoxy

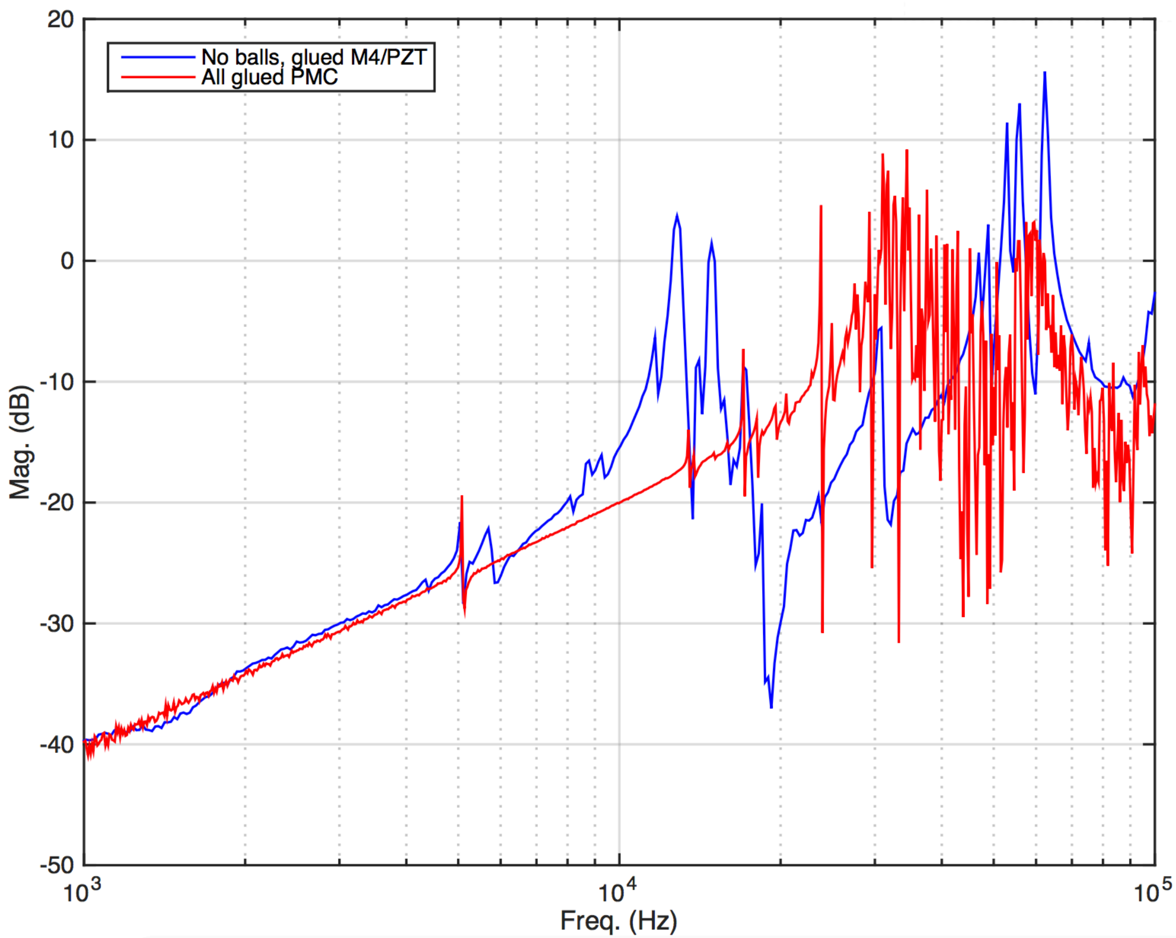


Glued M4/PZT assembly (SN02) compare glued and non-glued

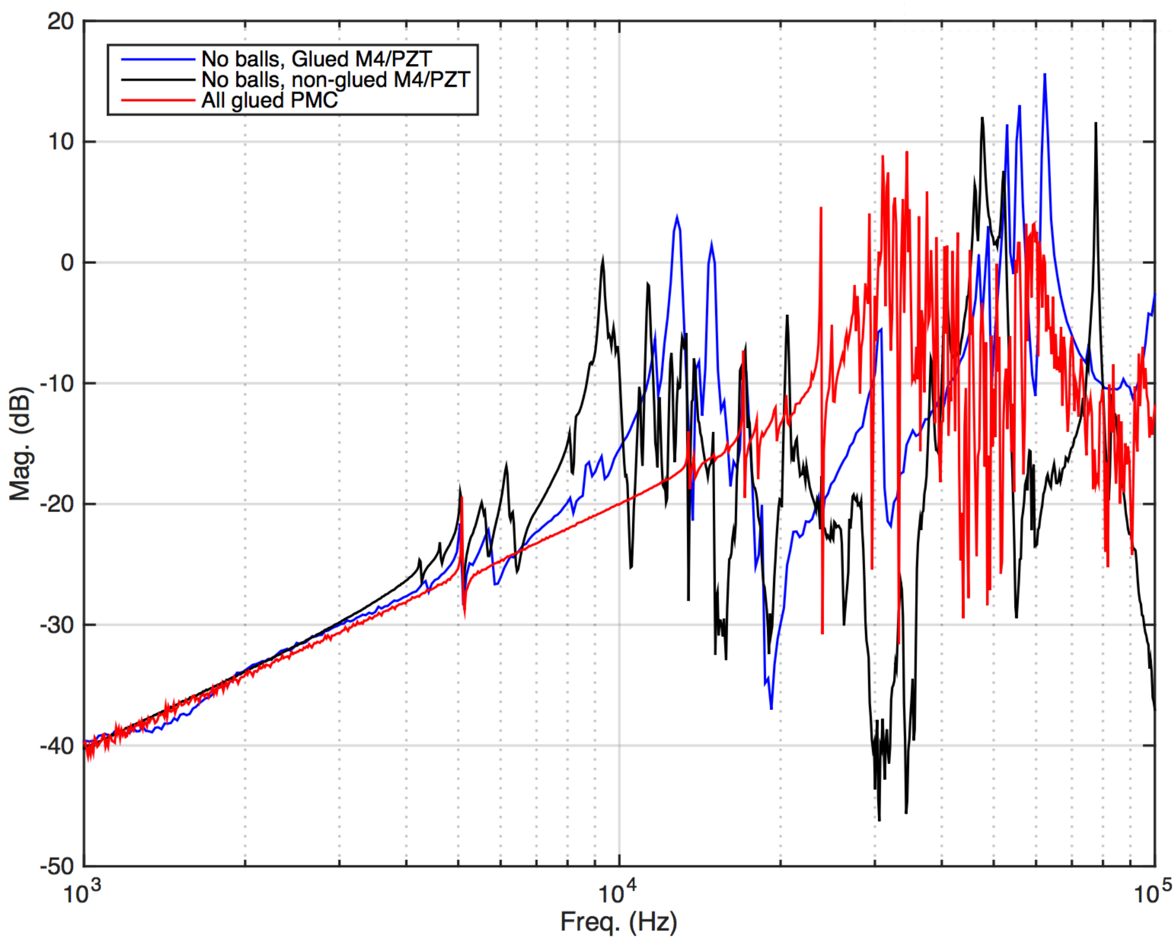
- Glued M4/PZT assembly (SN02) on 1st Aug.
- Measured the parallelism before gluing.



Glued PMC/PZT VS All glued PMC

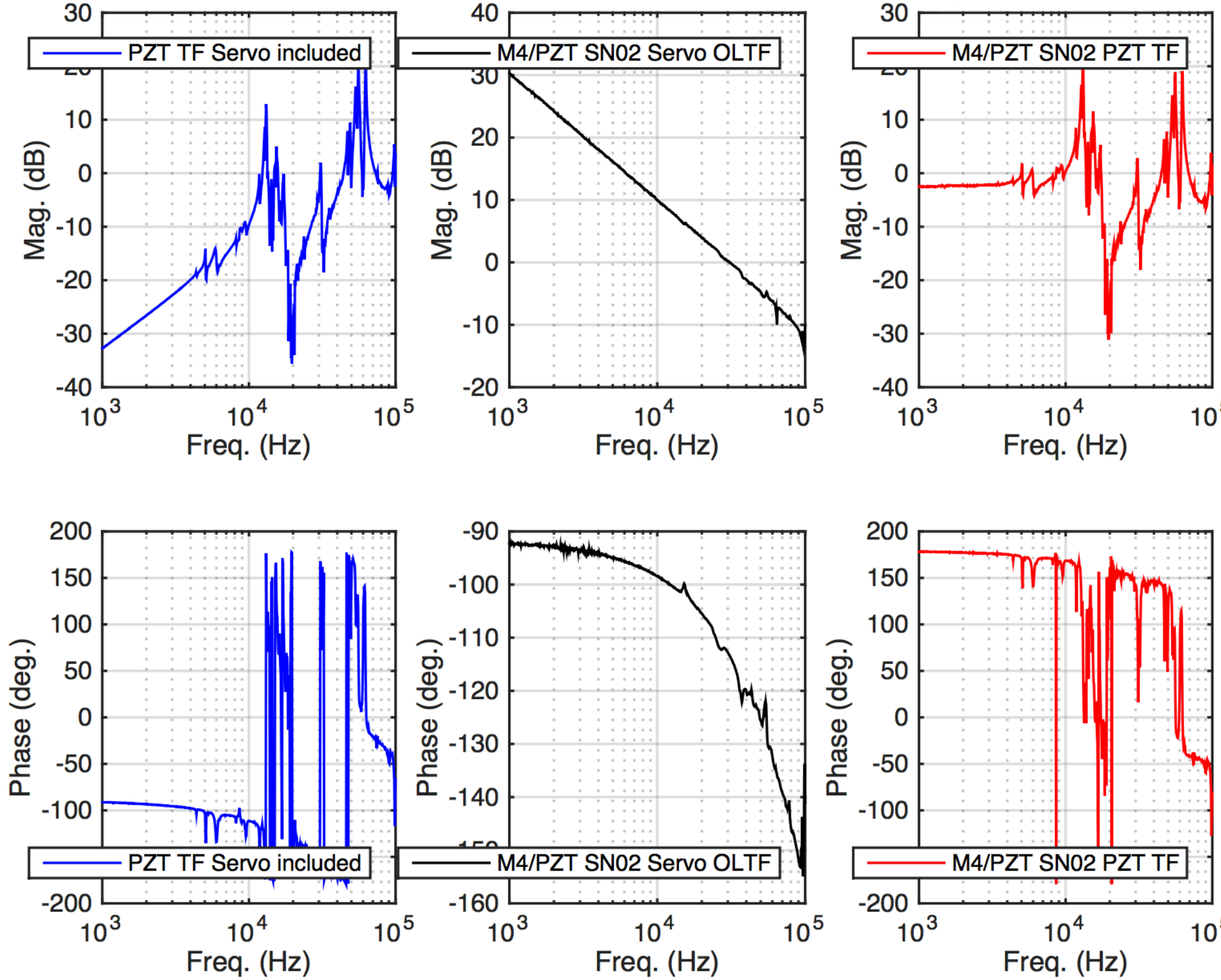


Glued PMC/PZT vs. non-glued vs. all-glued PMC

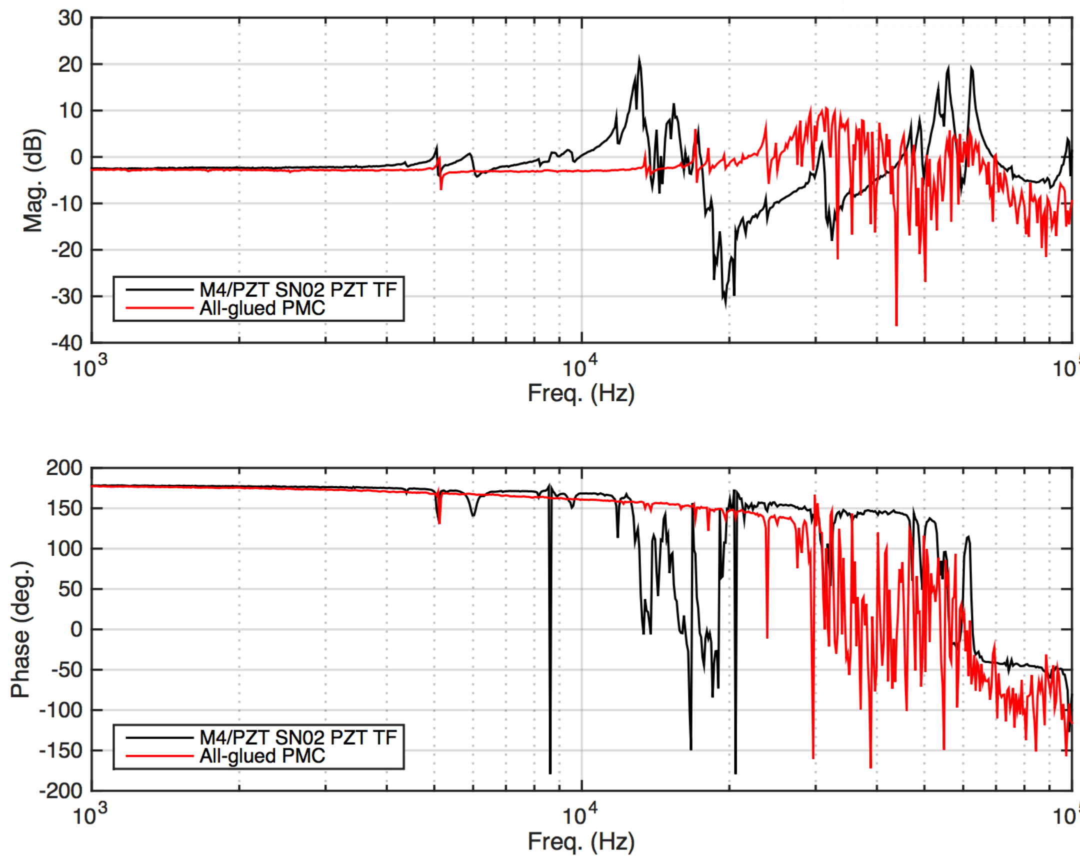


PZT actuator transfer functions correcting for impact of servo

- Laser frequency locked to cavity resonance using PDH scheme.
  - » See LIGO-T1600204 for servo locking details
- PZT actuator driven directly with dynamic signal analyzer source output (SRS up to 100 kHz, Agilent RF analyser for higher frequencies)

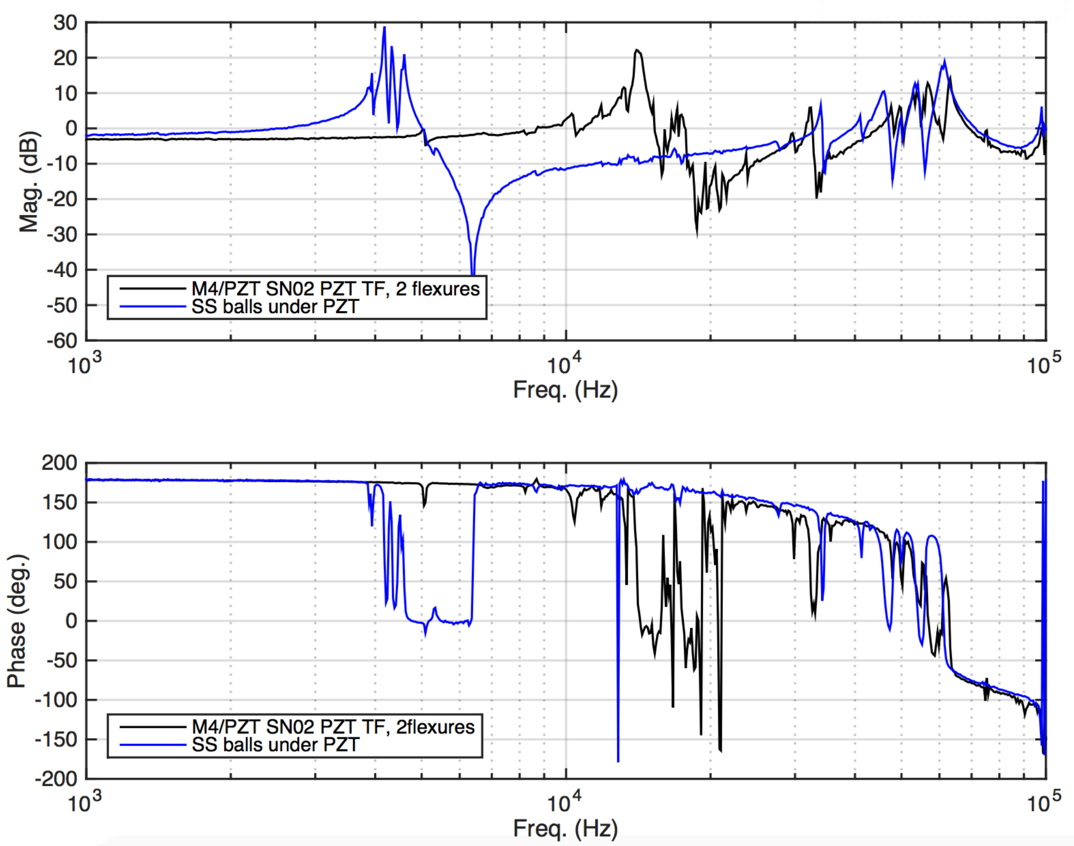


Glued M4/PZT assembly vs. all-glued PMC

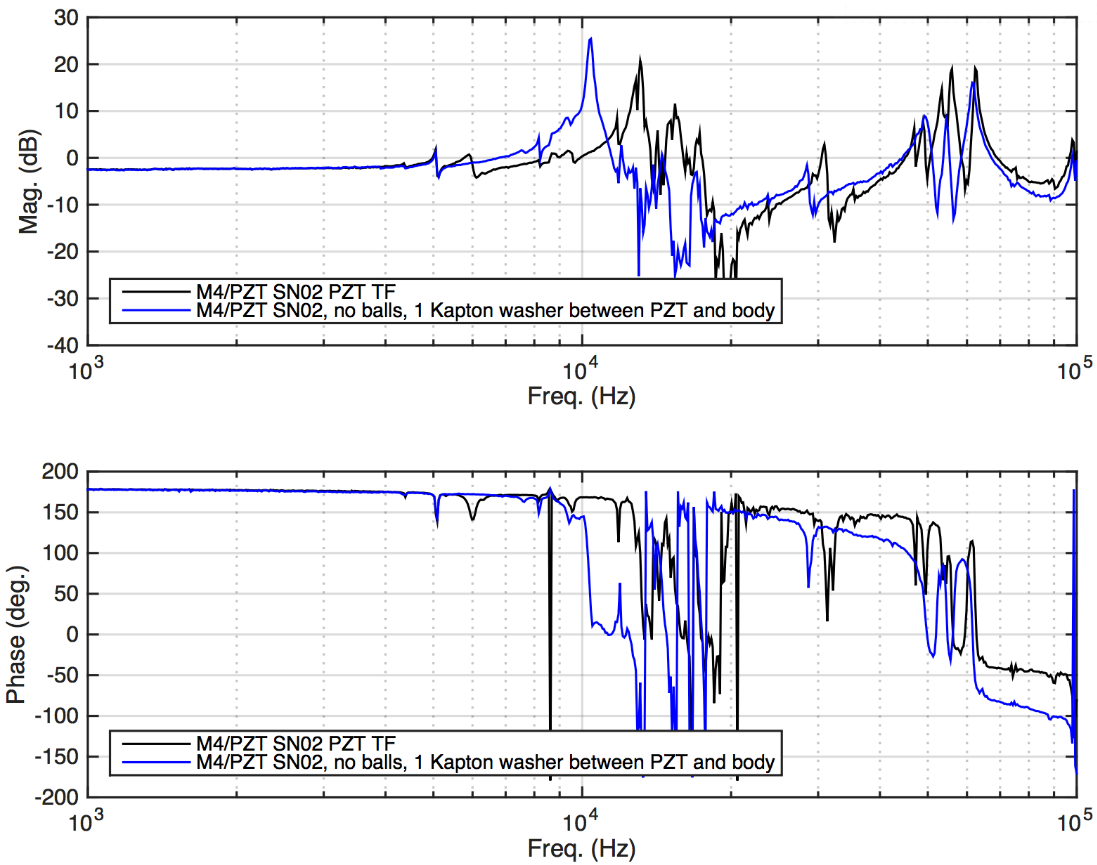


LIGO

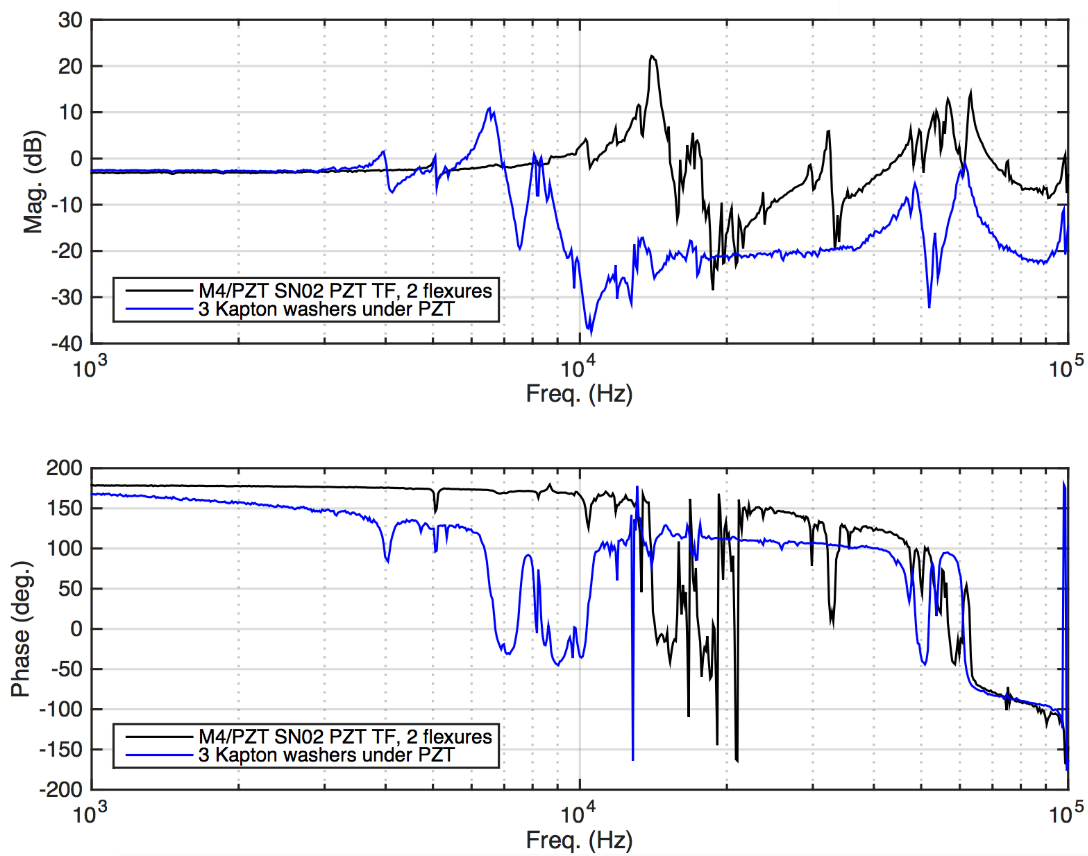
M4/PZT on balls



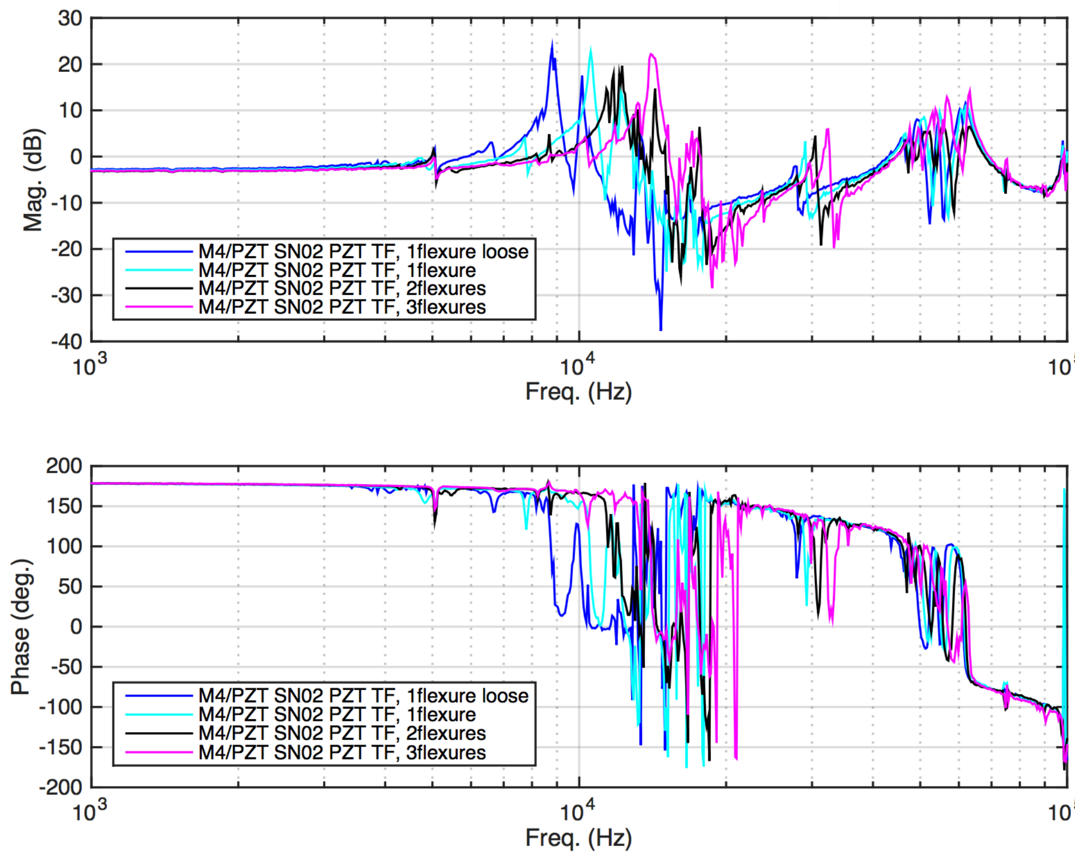
0.010” thick kapton washer between body and PZT



3 Kapton washers under the PZT

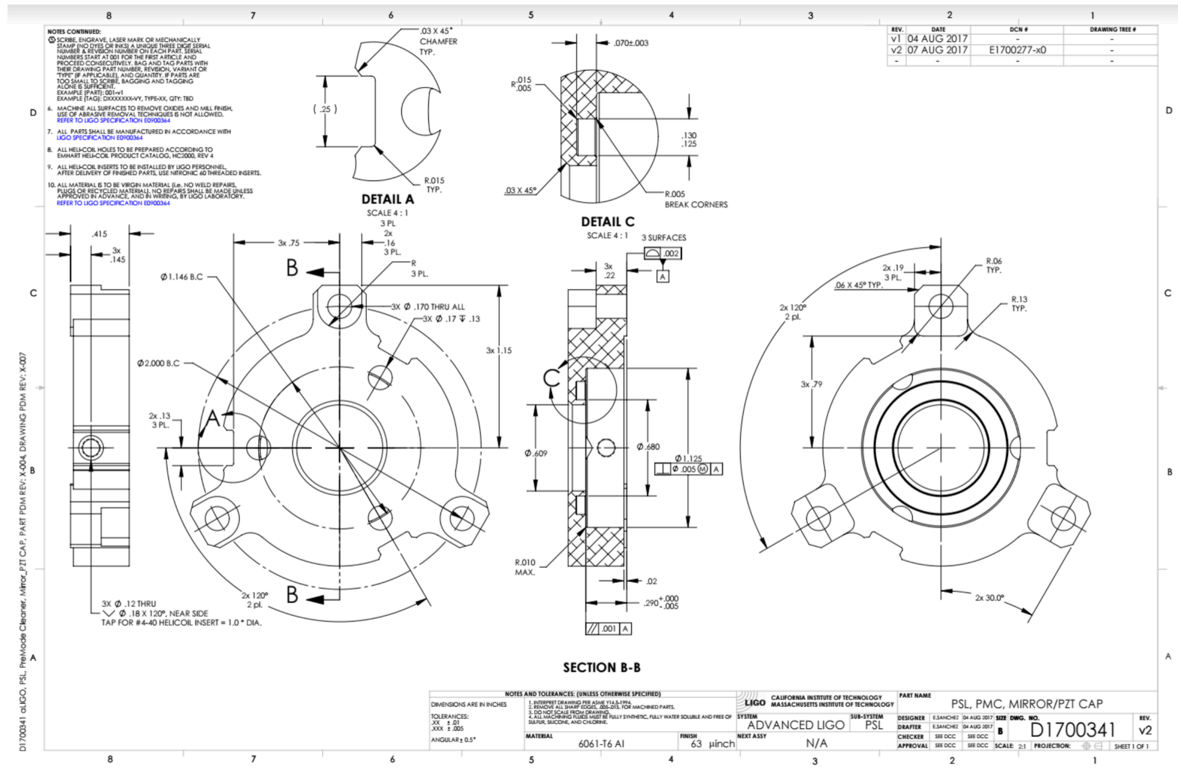


½, 1, 2, or 3 flexures?
(no balls, no washers)



Next tests

- viton balls for damping (3/16” diameter).
- viton washers under flexures (1.062” OD x 0.490” ID x 0.062” thick).
- Increase spring pressure by adding flexures.
- PZT mirror cap with viton o-ring for damping
- Glue PZT to body
- Servo amplifier loop shaping, filtering
  - Loop locks with 1-2 kHz UGF but little gain margin



- 0.103 in. cross section viton o-ring.
- 0.010 in. compression (no balls, no washers).
- 0.020 in. and 0.030 in. compression with 1 or 2 kapton washers.