Time domain simulation for a FP cavity with AdLIGO parameters on E2E

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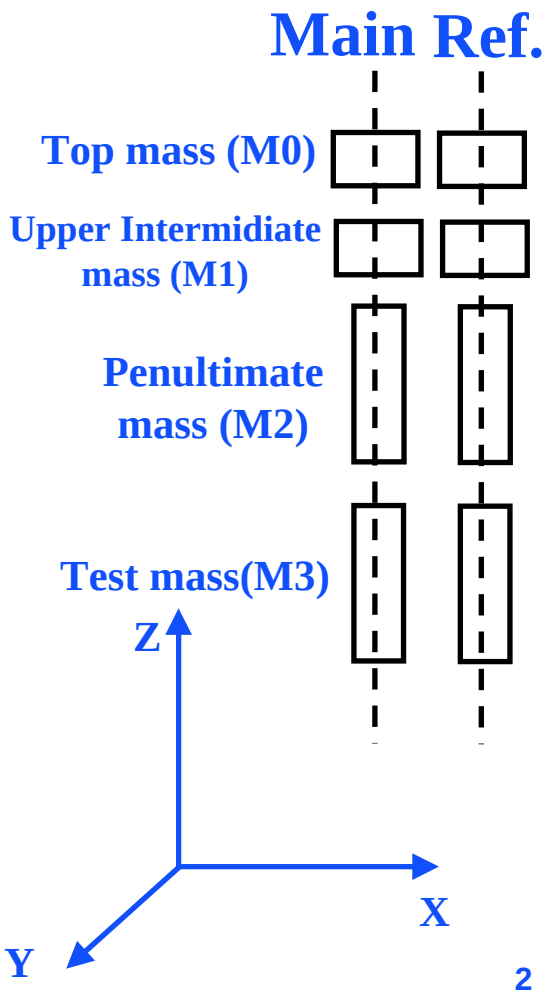
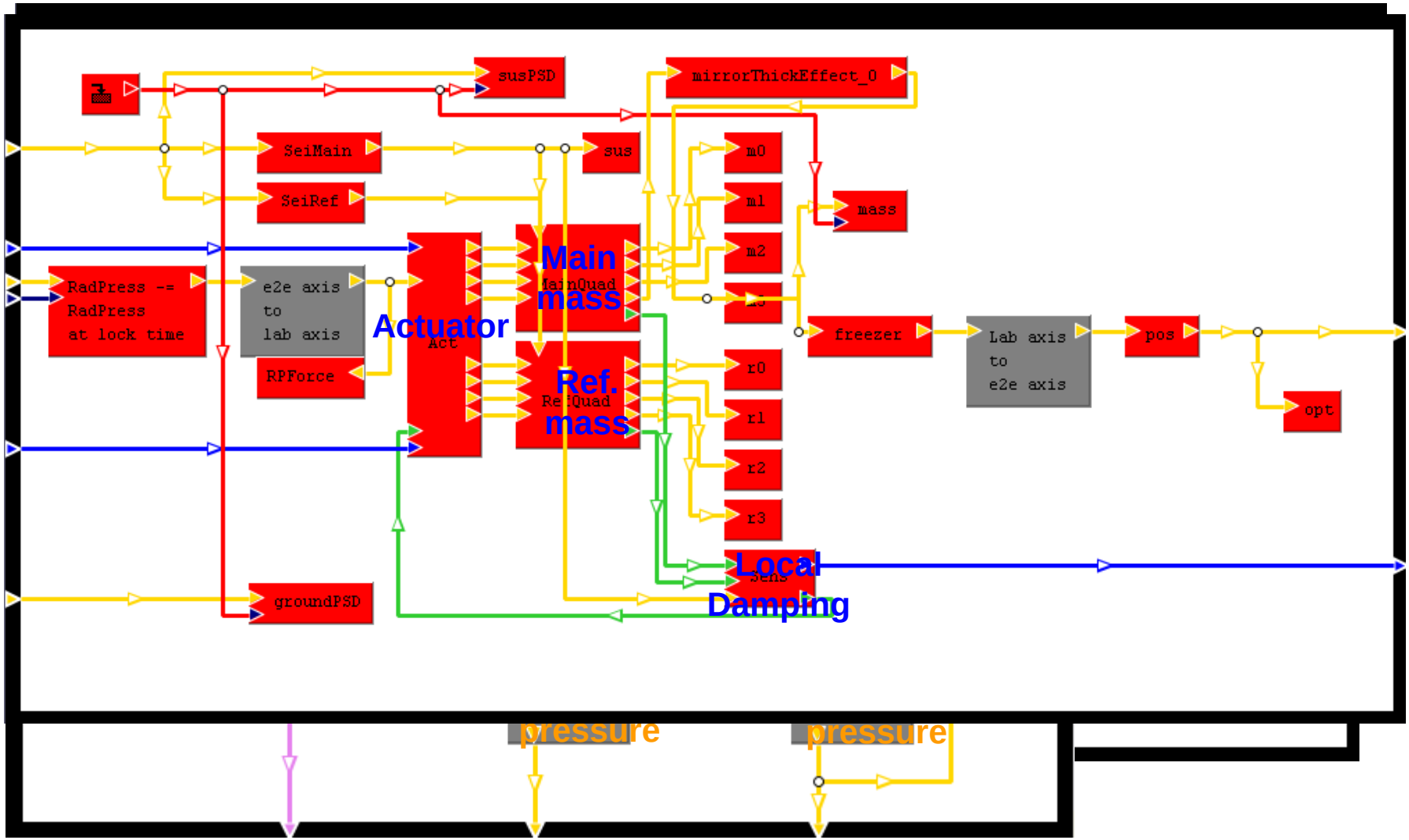
- **Is it possible to acquire lock with radiation pressure?**
- **Is it possible to control alignment with radiation pressure?**
- **Optical spring in ASC?**
- **Do we need test mass actuator for ASC? both ETM and ITM?**
- **Is the actuator dynamic range enough?**
- **Noise performance?**

What implemented

- AdLIGO Quad suspension (Mark's model 03/31/2006)
- Local damping (6 DOFs of M0)
- Seismic motion and optical table motion on X,Y, tY and tZ (length, side, pitch and yaw)
- 3995m FP single cavity with AdLIGO parameters
  - » ROC = 2076m for both ITM, ETM test mass
  - » Full laser power inside cavity = 0.73MW
- Radiation pressure force on length and alignment
- Shot noise and radiation pressure noise
- Length control for M3 through M1, M2, M3
- M3 alignment control through M2 using WFS
- Electronic noise of WFS PD

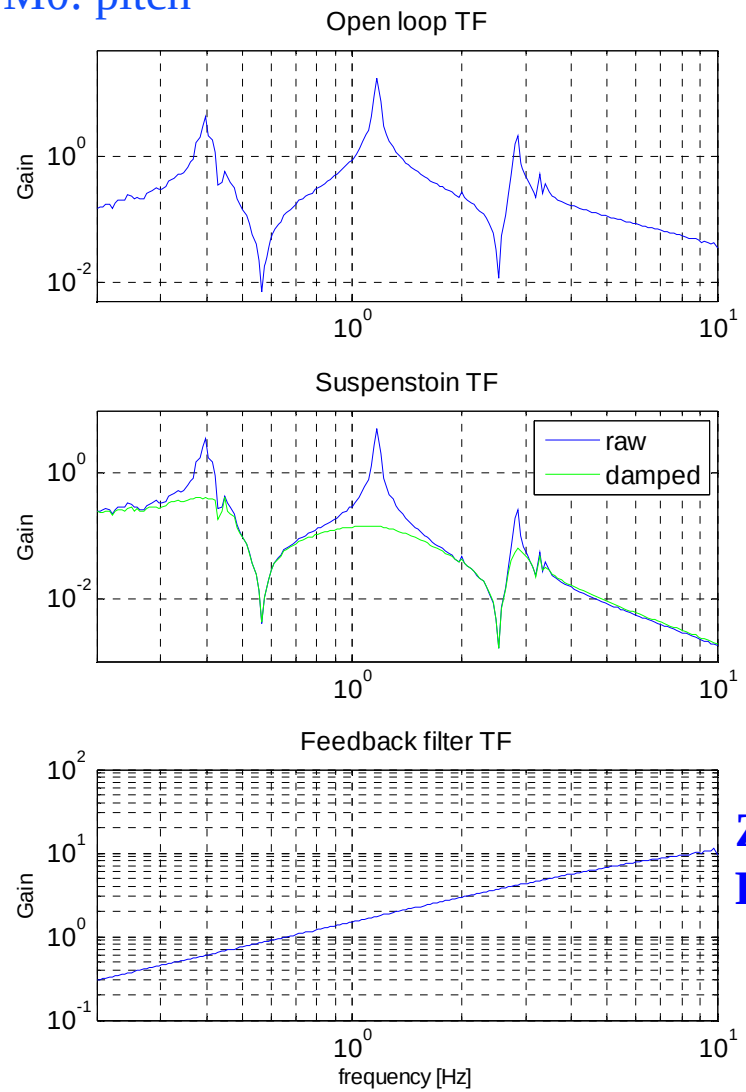


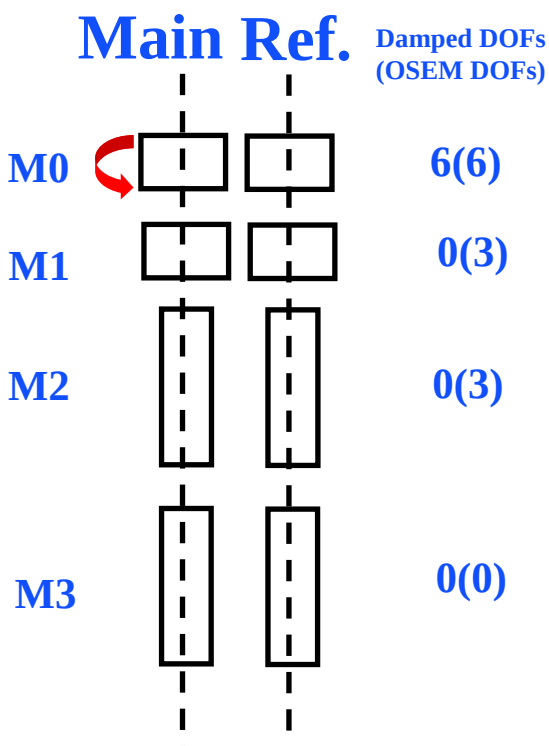
E2E


susPSD
mirrorThickEffect_0
SeiMain
sus
m0
m1
m2
m3
mass
SeiRef
RadPress -=
RadPress
at lock time
e2e axis
to
lab axis
RPForce
Act
Actuator
Main
mass
MainQuad
Ref.
mass
RefQuad
r0
r1
r2
r3
freezer
Lab axis
to
e2e axis
pos
opt
Local
Damping
groundPSD
pressure
pressure

Local damping

Example M0: pitch

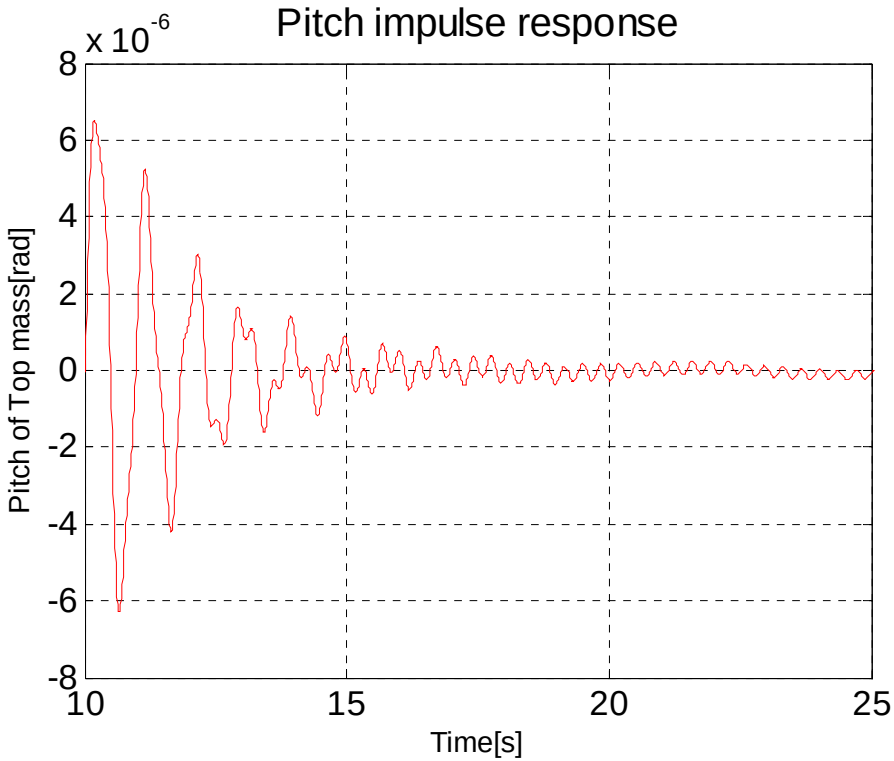




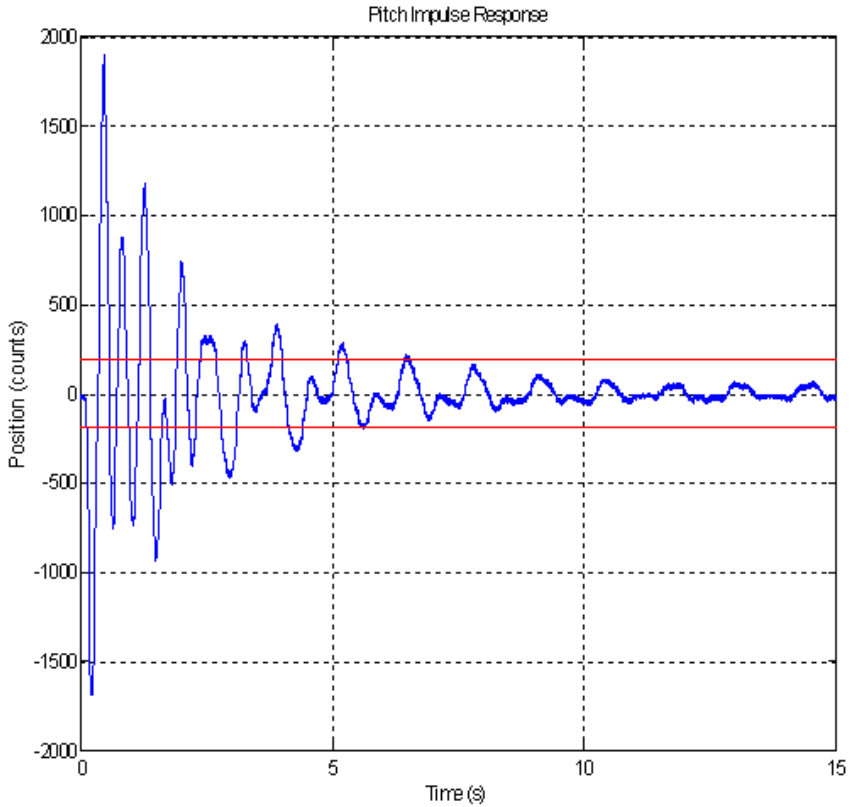
Zero @ 0Hz
Pole @ 10,10Hz

Local damping: impulse response

Example M0: pitch

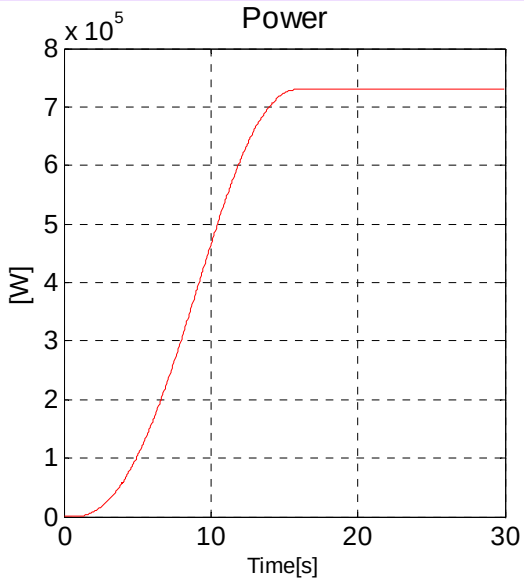


E2E simulation

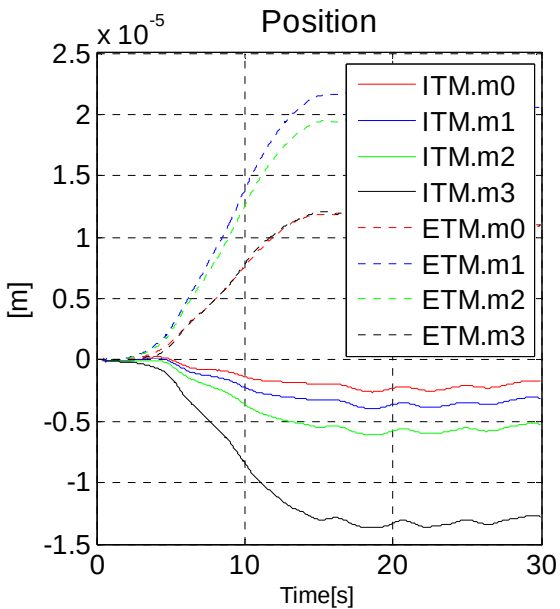


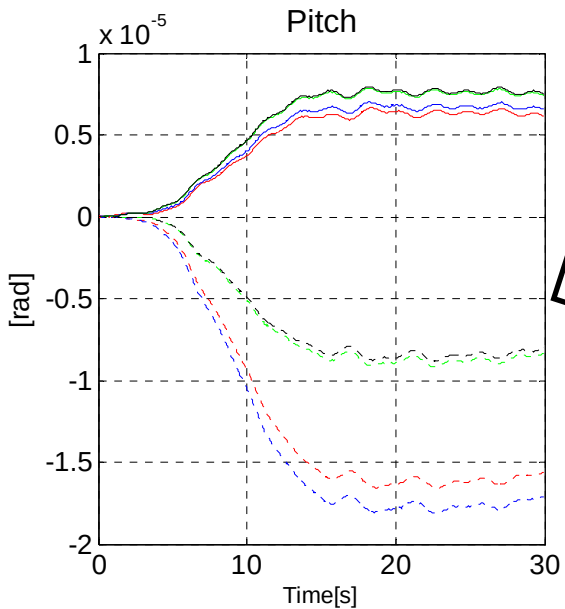
Measured data

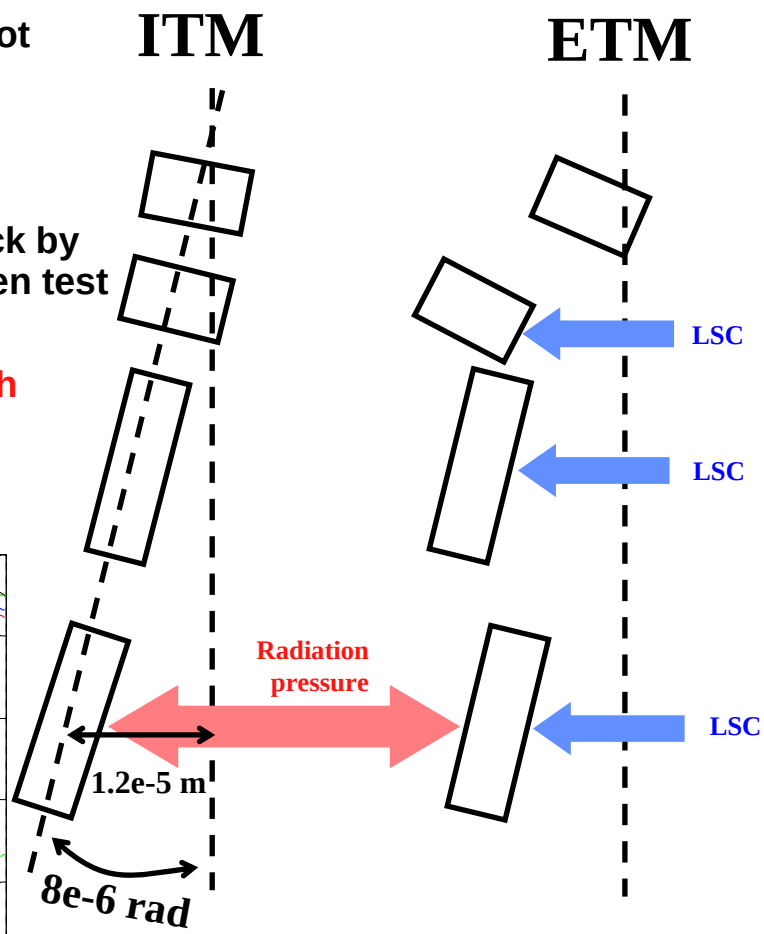
Quad suspension with radiation pressure (length)



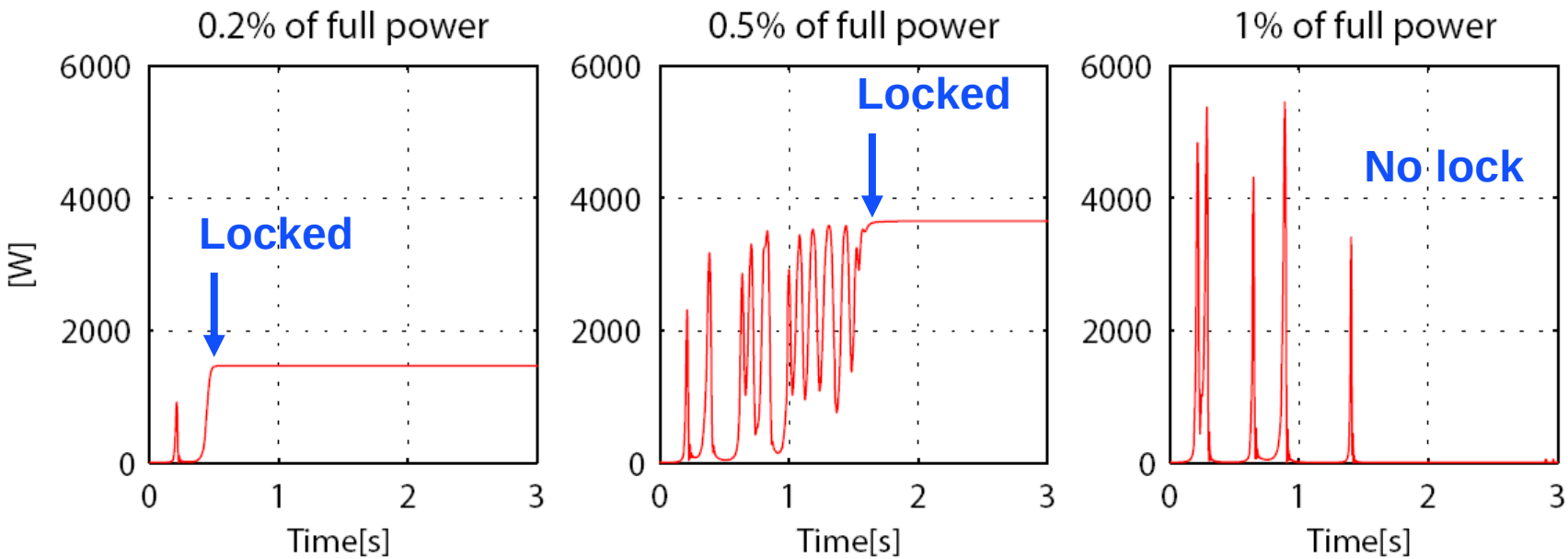
- LSC only, no ASC
- Only TEM00; misalignment not break lock
- Test masses are pushed by radiation pressure.
- ETM test mass is pushed back by LSC keeping distance between test masses.
- Position shift ~10 wave length
- Angle shift ~10μrad





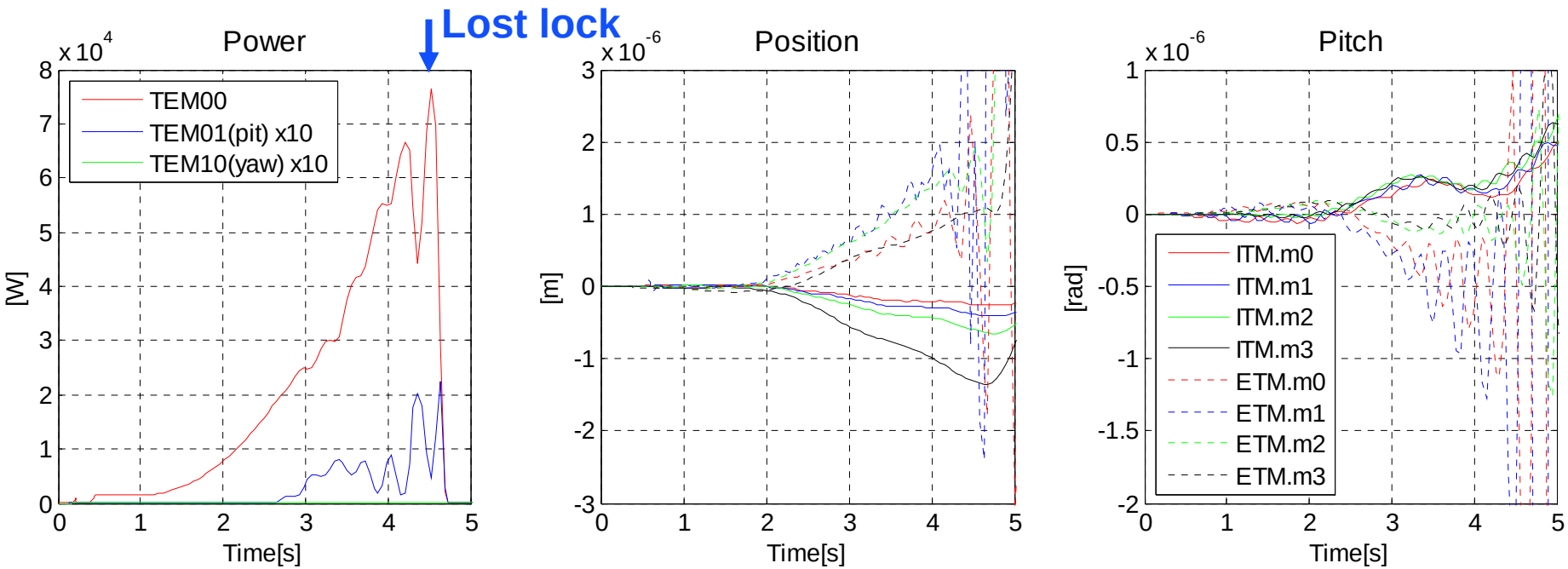


Lock acquisition with radiation pressure



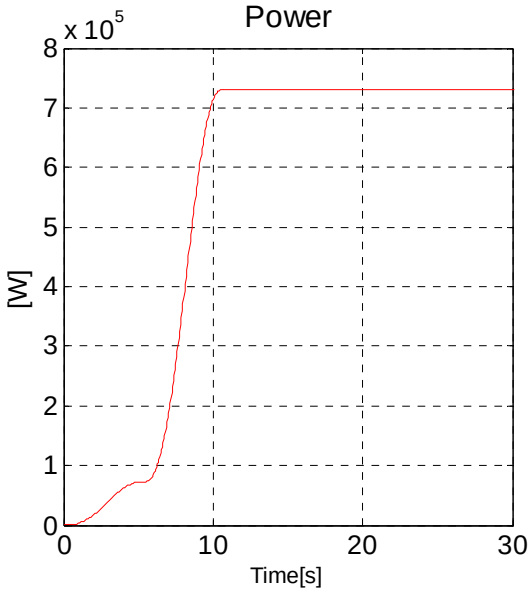
- 60nm/sec :enough slow to acquire lock for LSC by Matt Evans
- Radiation pressure and alignment incleded
- Full power : 0.7MW
- Lock can be acquired with less than few kW
  - » Is it possible such low power? Offset lock used at 40m? ->Optical spring
- Needs Monte Carlo simulation

Alignment instability with no ASC

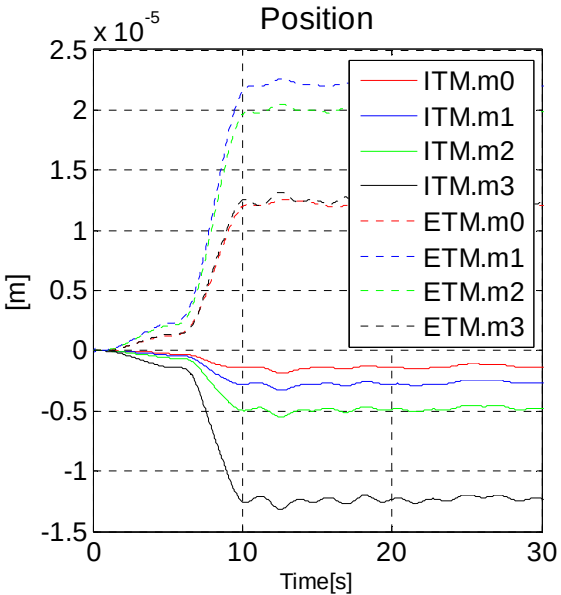


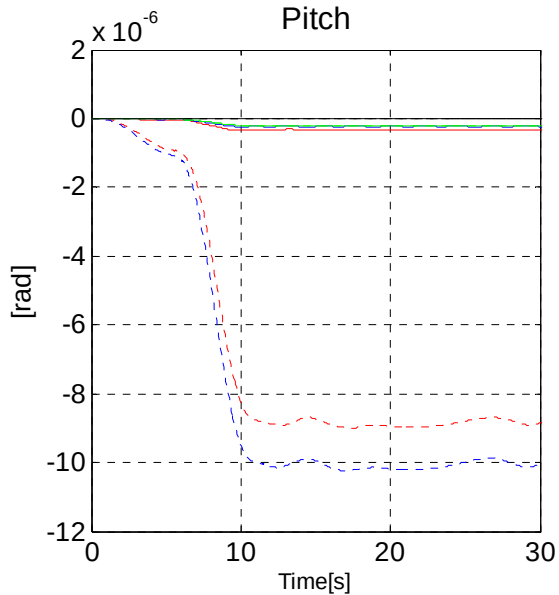
- **After lock acquisition, input power increased with no ASC.**
- **Pitch motion due to Radiation pressure breaks lock with 10%(70kW) of full power if there is no ASC**

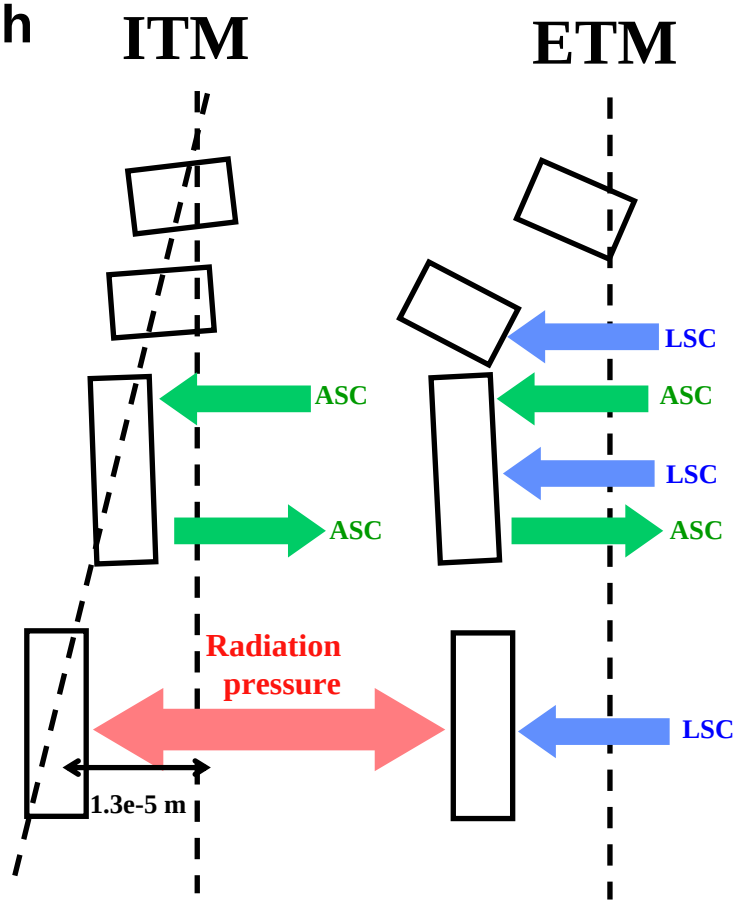
Test mass alignment control through M2 with radiation pressure



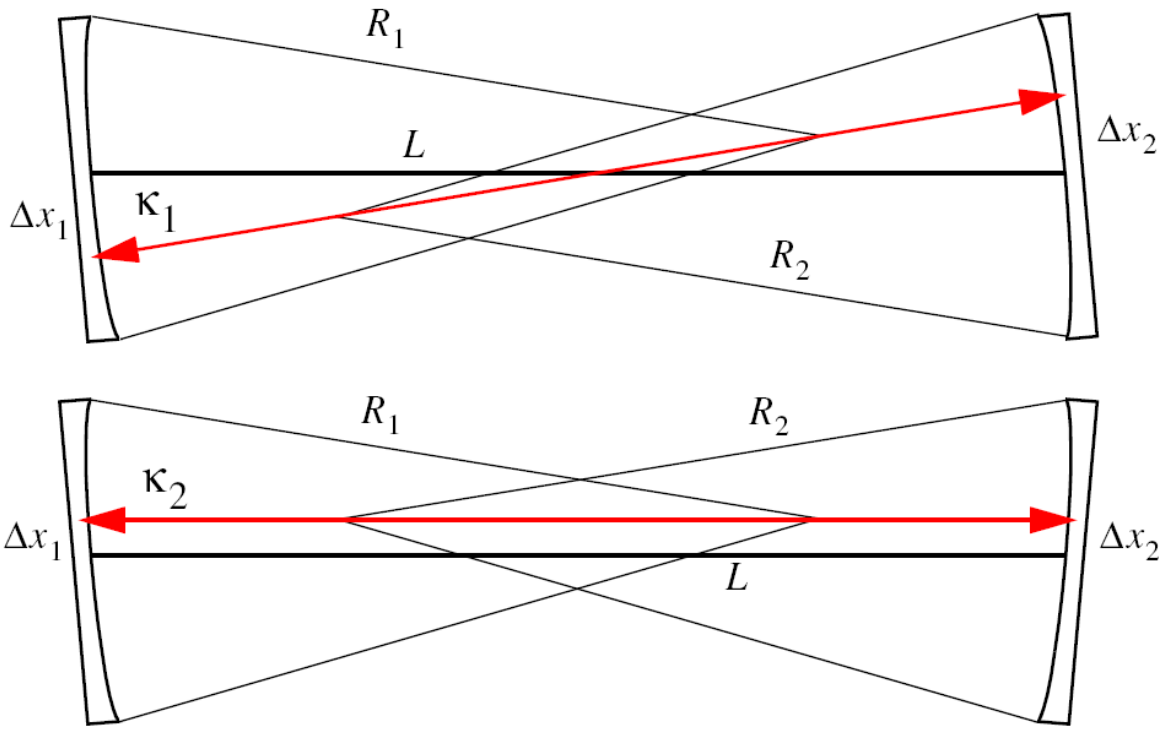
- Control M3 through M2
- f^3 filter
- Boost at 2Hz
- 10Hz control band width







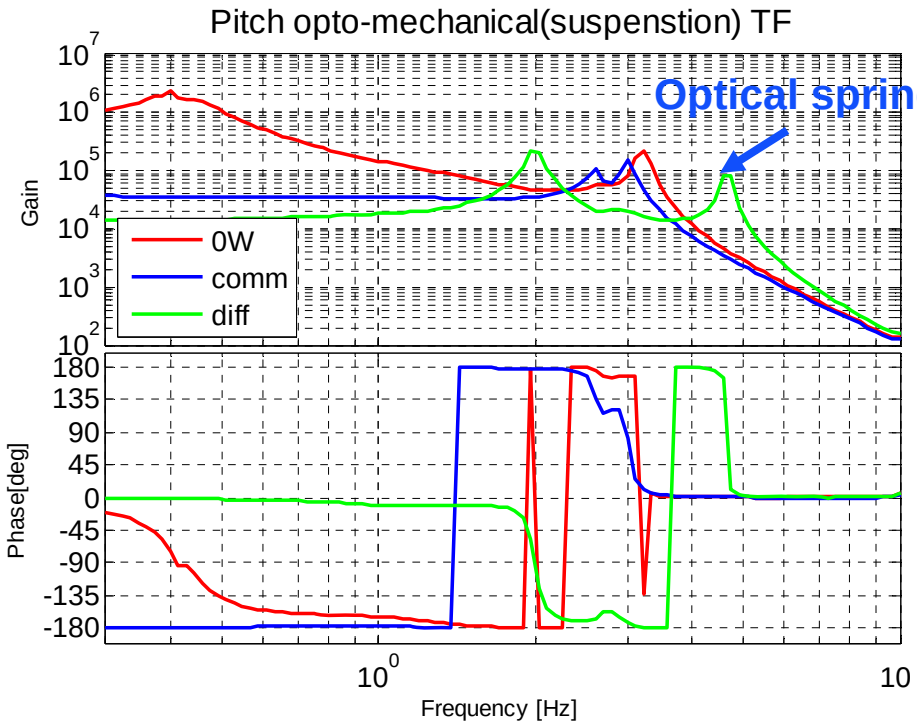
Two modes of optical instability

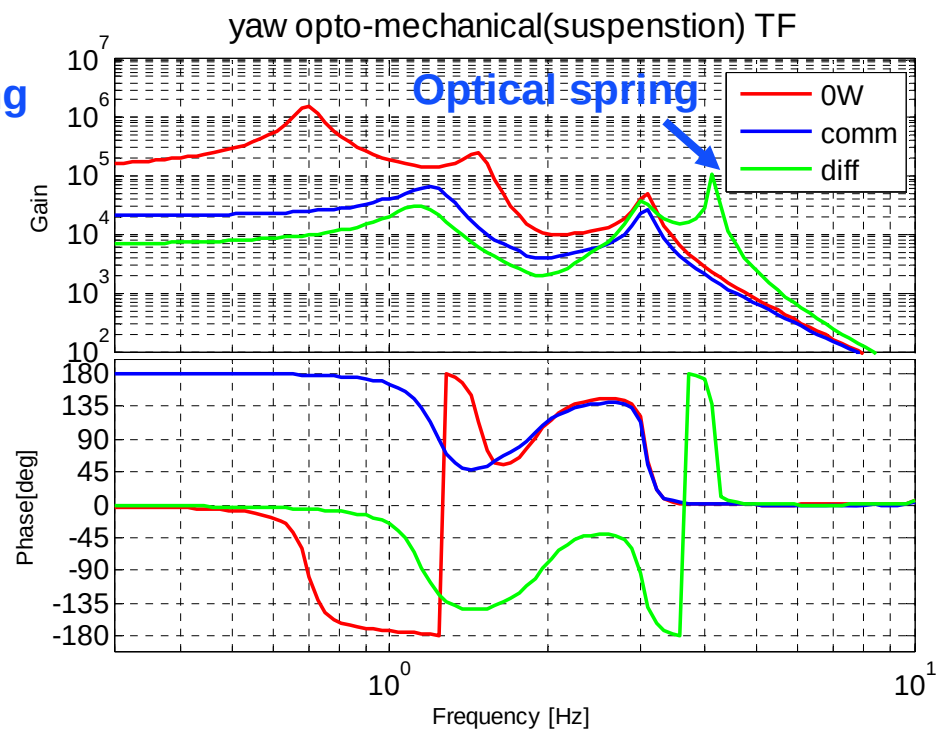


Differential : stable -> spring

Common : unstable -> no spring

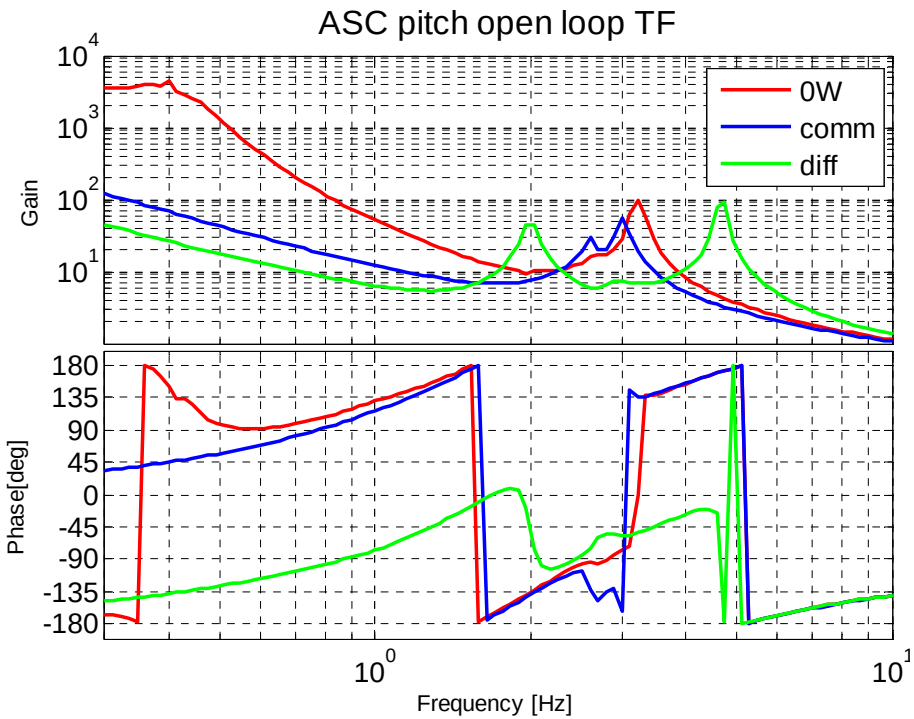
Opt-mechanical (suspension) TF

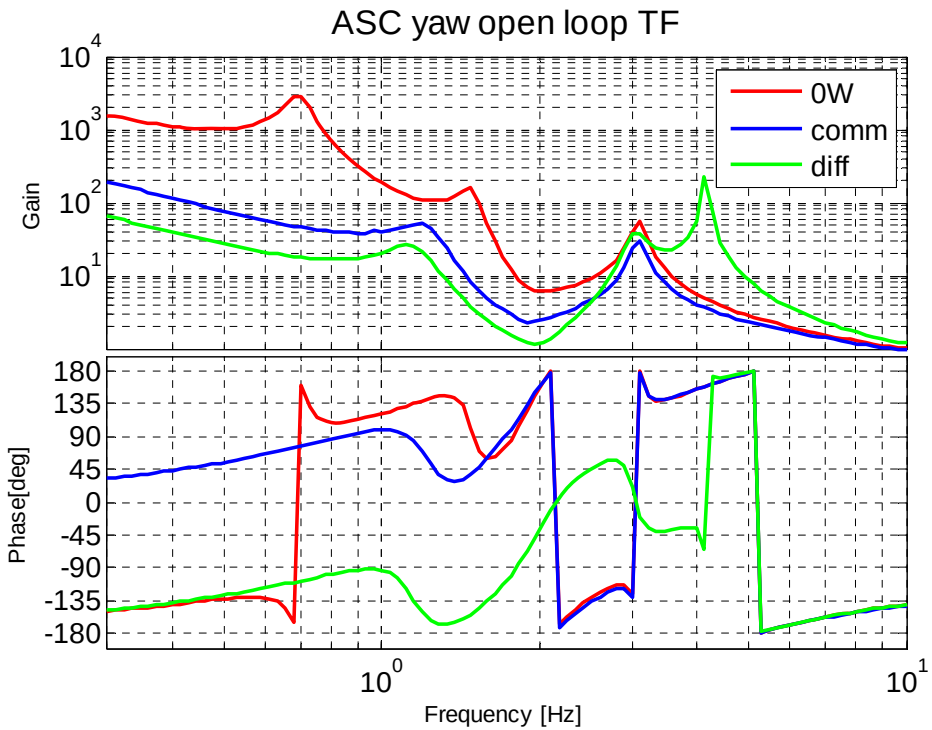




- **TF from M2 actuator to WFS error signal, simulated in time domain.**
- **Low frequency gain and peak are suppressed.**
  - » **Needs compensating gain for full power**
- **Optical spring in differential mode at 4.5Hz for pitch and 4.1Hz for yaw.**
- **Control BW must be higher than optical spring frequency.**

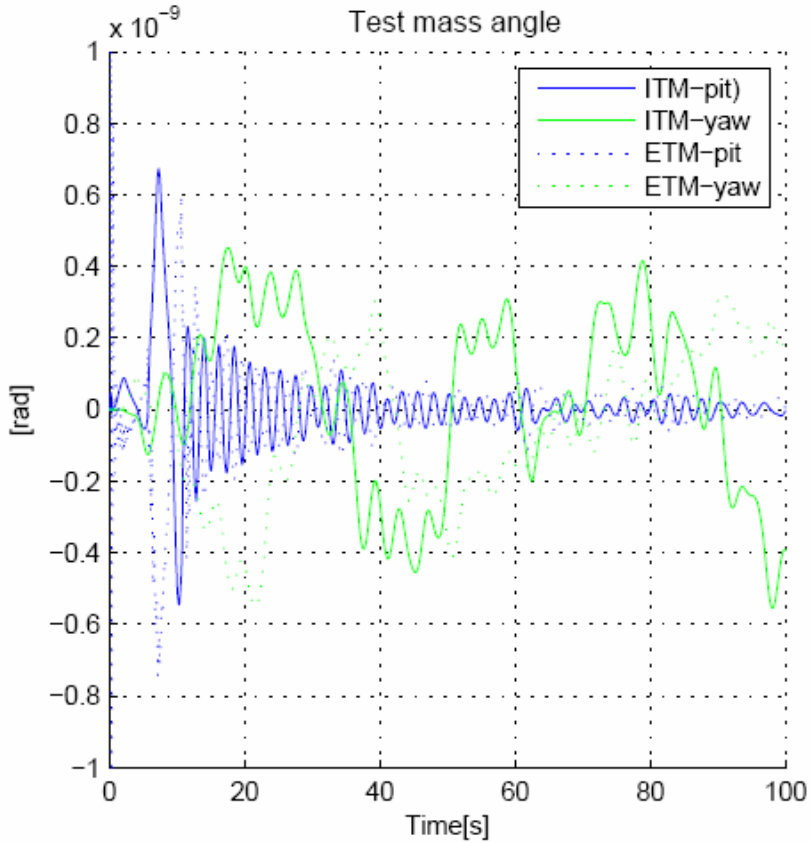
Open loop TF of ASC

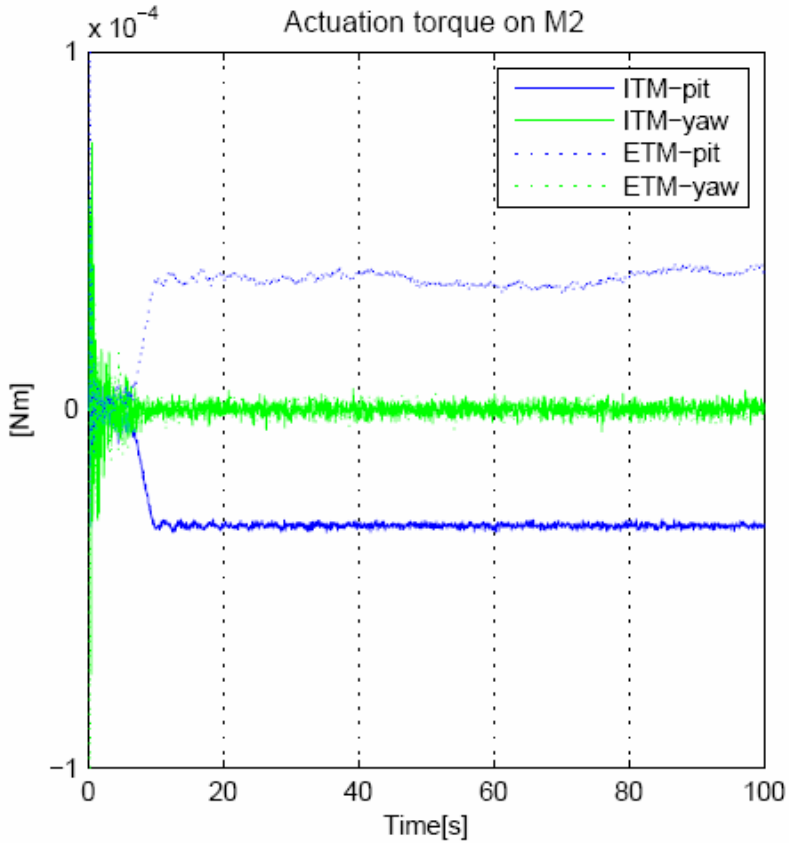




- **10Hz control band width**
- **Gain in low frequency is suppressed a lot by radiation pressure**

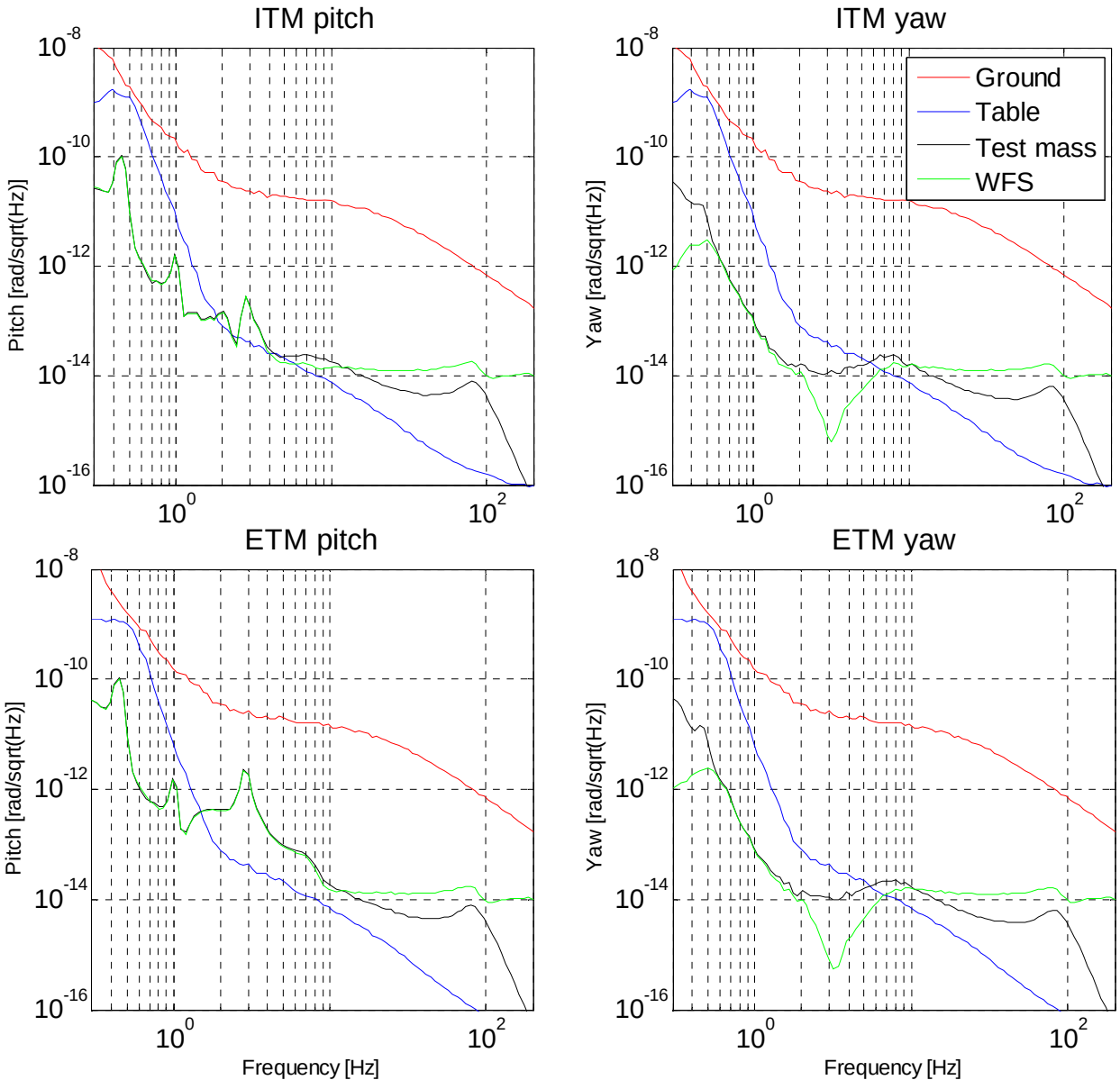
Noise performance





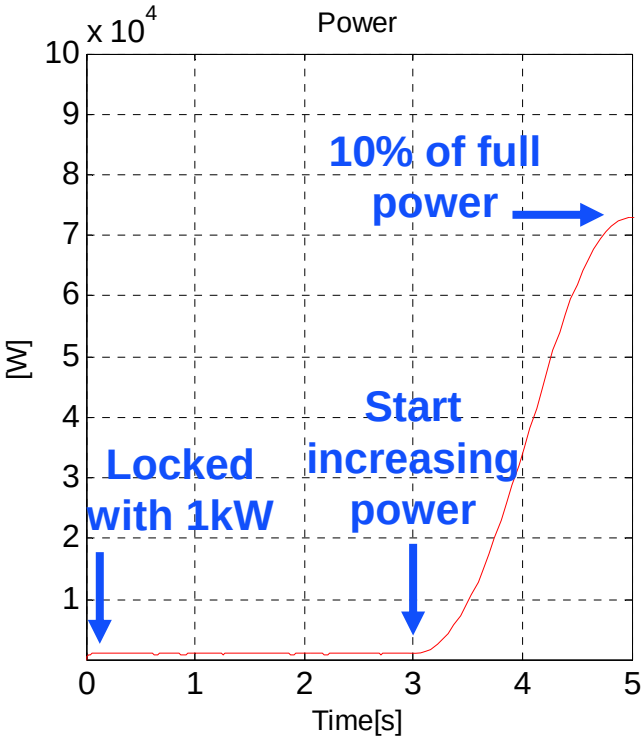
- **Residual RMS: <10^{-9} rad (depends on servo) of 10^{-9}rad requirement**
- **Actuation torque(force): 3x10^{-5} Nm (1x10^{-4} N) on M2 OSEM (max 20mN)**

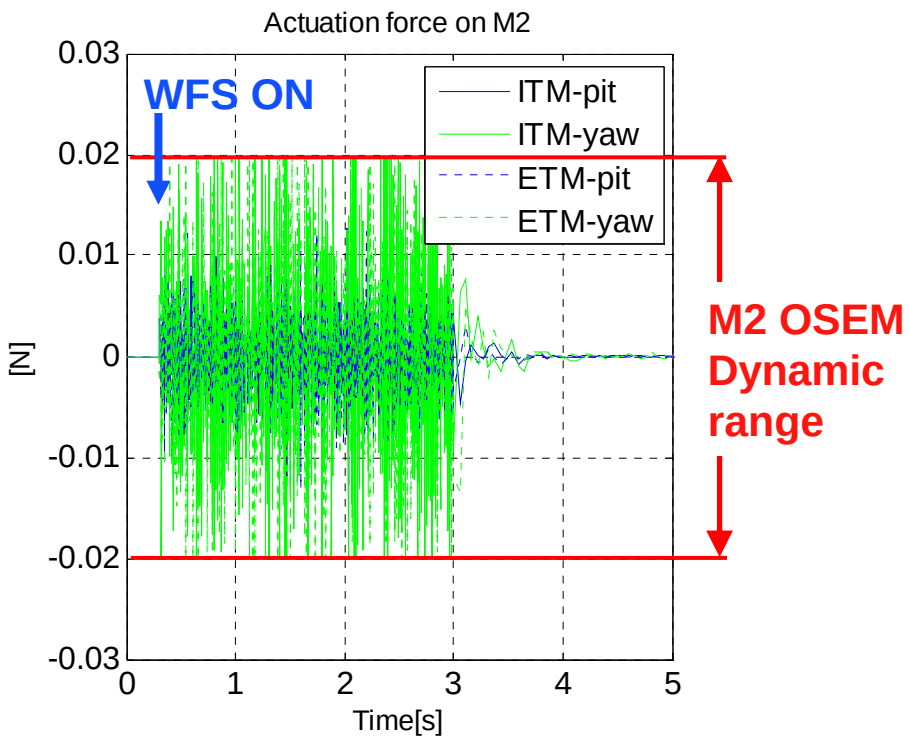
Noise performance in spectra



- **Spectrum depends on seismic noise model.**
- **Length to pitch coupling is not ignorable, but can be avoided using unbalance of OSEM.**
- **High frequency is limited by shotnoise at 10^{-14} rad/rHz with 100mW input(25mW for each quadrant).**

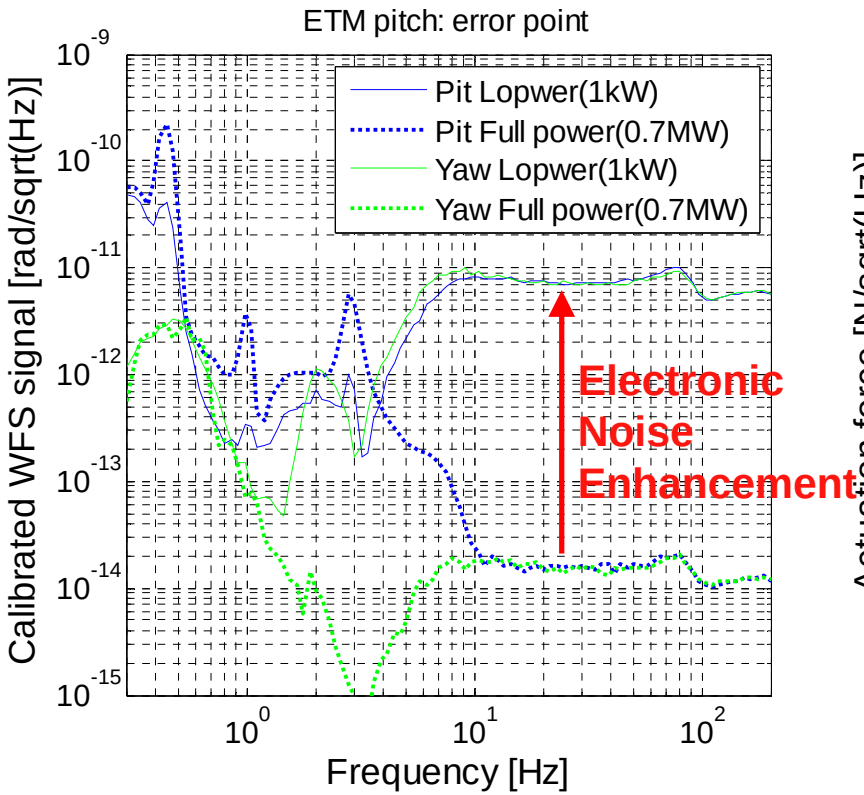
Electronic noise with low power

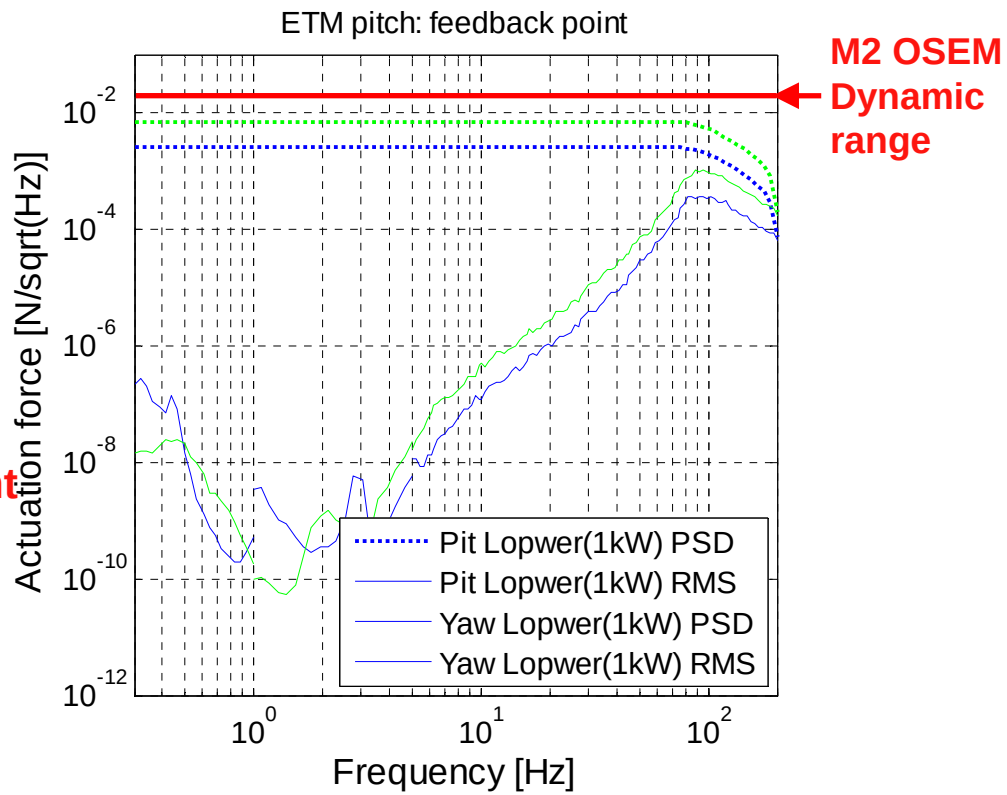




- **Full power: 0.7MW with electronic noise of 10^{-6}rad/V, 100mVmax, 10nV/rHz**
  - » **10^{-14}rad/rHz (same level as shotnoise), force: $3\times10^{-4}N_{p\text{-}p}$ (maximum:20mN)**
- **Low power: 1kW for lock acquisition, 7×10^{-4}rad/V, 100mVmax, 10nV/rHz**
  - » **7×10^{-12}rad/rHz, force: $20mN_{p\text{-}p}$(maximum:20mN) -> OSEM saturation**

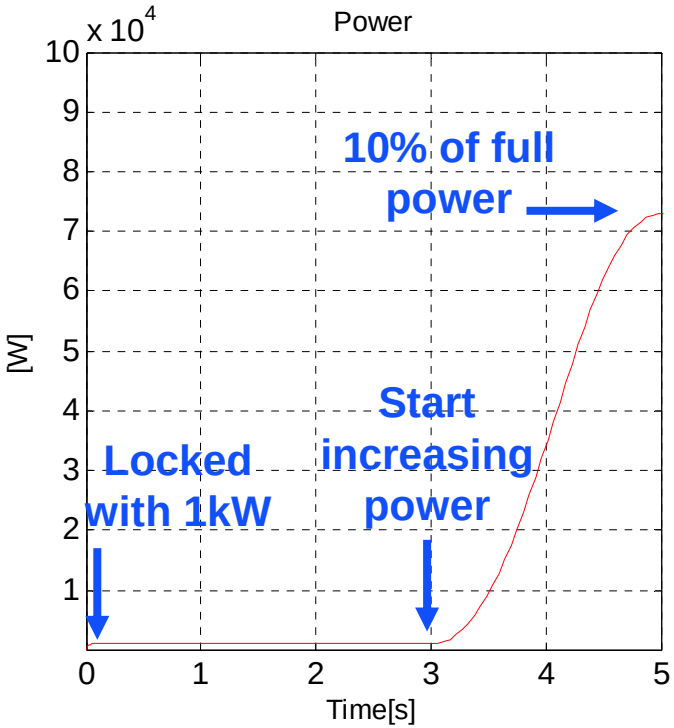
Electronic noise with low power

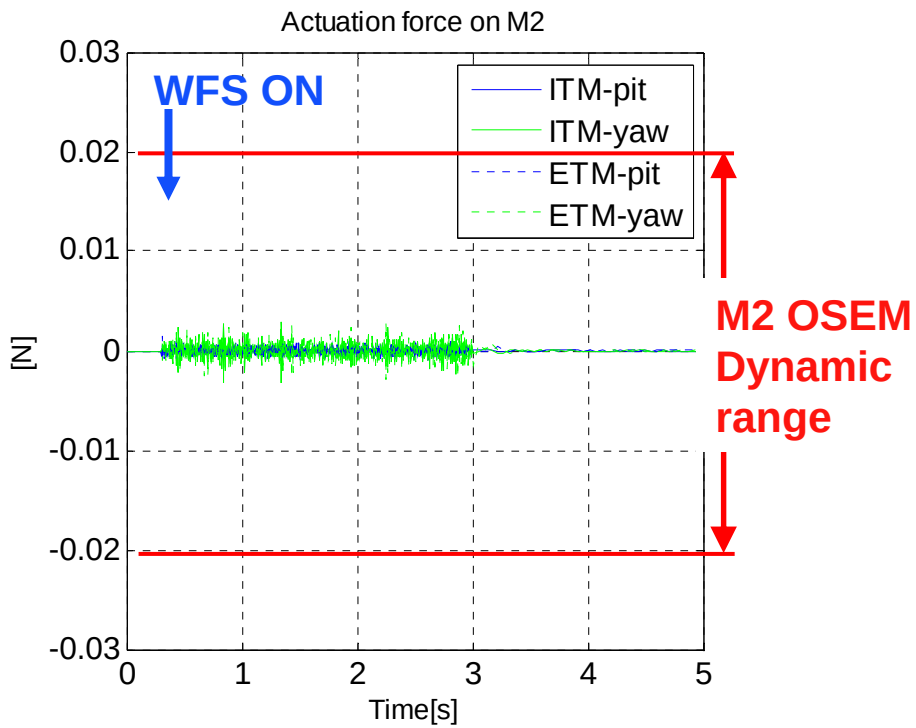




- **Feedback Penultimate mass(M2) and test mass(M3) for both ITM and ETM?**
- **Low/High gain WFS?**
- **Variable transimpedance of factor sqrt(700)?**
  - » **Same level as shotnoise of low power case**
- **Pole around 30Hz?**

2-pole at 30Hz





- **Seems stable**

Conclusion

- **Is it possible to acquire lock with radiation pressure?**
  - *Yes, with less than few kW*
- **Is it possible to control alignment with radiation pressure?**
  - *Yes, with 10Hz control band-width*
- **Optical spring in ASC?**
  - *Yes, 4-5Hz*
- **Do we need test mass actuator for ASC? both ETM and ITM?**
  - *No for full power, penultimate mass actuator enough, but might be necessary for low power*
- **Is the actuator dynamic range enough?**
  - *Yes for full power: 1mN of 20mN, but No for low power: 20mN of 20mN -> low-pass filter around 30Hz*
- **Noise performance?**
  - **< 10^{-9} rad**

Next step

- Unbalance on OSEM
- Miss-centering
- Another g-factor
- Monte-Carlo lock acquisition test

- Lock acquisition for full DRFPMI case
  - » simulation time : real time = 10 : 1 for single FP cavity
    = 200 : 1 for DRFPMI with LSC only
    = 400000 : 1 for DRFPMI with ASC
    ->needs summation DRMI for alignment