Modeling of AdLIGO arm lock acquisition using E2E time domain simulation

Osamu Miyakawa
Hiroaki Yamamoto

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Introduction

- Is it possible to acquire lock FP arms of AdLIGO?
  - » Complicated Quad-suspension
  - » Weak actuation force ~100μN due to Electro Static Drive (ESD)
  - » High finesse ~1200
  - » Radiation pressure due to high power (0.8MW)
- First fringe lock for arm is a minimum requirement for full 5DOFs lock of RSE according to the 40m's experiment.

Parameters in this simulation

- 4km single arm cavity
- AdLIGO Quad suspension
  - » Local damping (6 DOFs on Top Mass)
  - » Maximum actuation force: 200mN for UIM, 20mN for PM, 100μN for TM
  - » LSC UGF: 8Hz for UIM, 40Hz for PM, 180Hz for TM
- Error signal from reflected RFPD.
- Feedback to test mass only during lock acquisition, then feedback to lower 3 masses after locked.
- Higher order mode up to TEM01, 10 implemented

For maximum mirror speed test

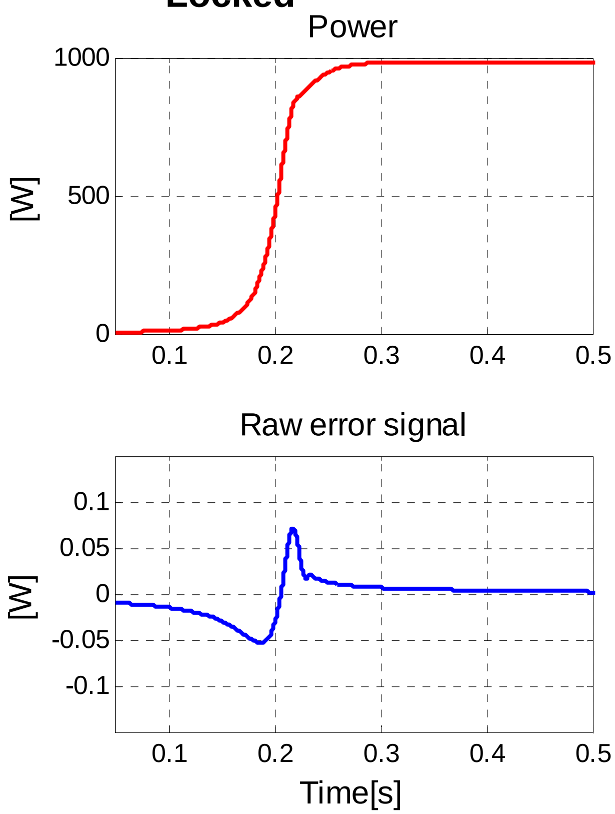
- No seismic motion
- Very low power ~1kW stored in arm to avoid radiation pressure
- Initial given mirror speed at TM

There might be better parameters because it's a big parameter space.

Lock acquisition using Raw error signals

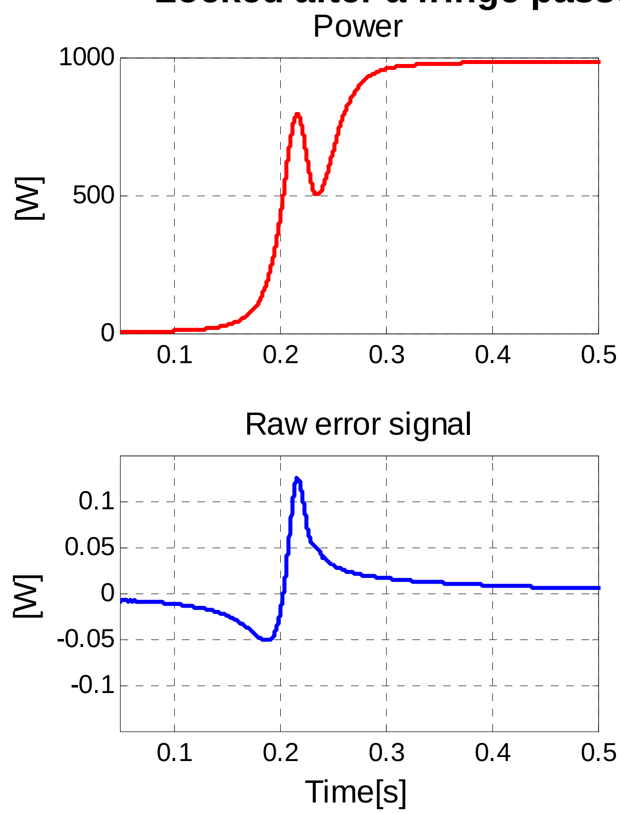
v=20nm/sec

Locked



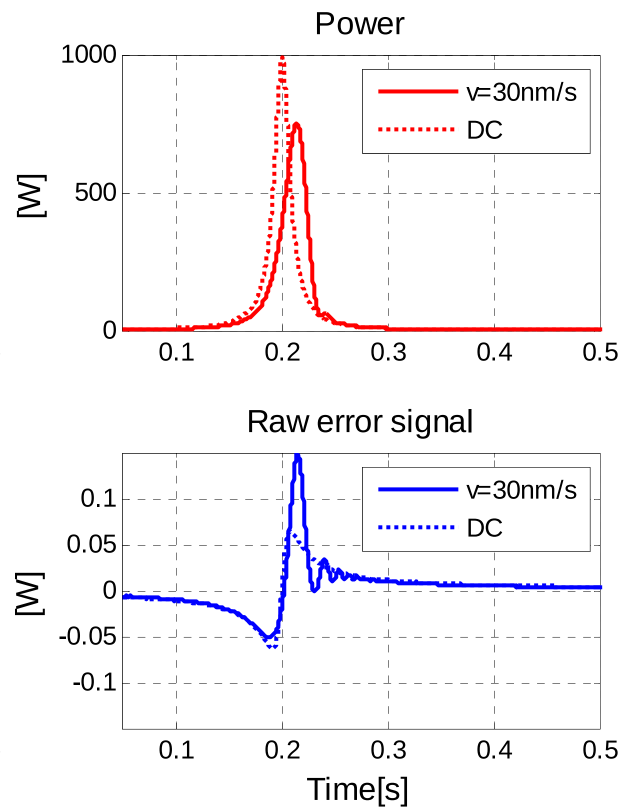
v=25nm/sec

Locked after a fringe passed



v=30nm/sec

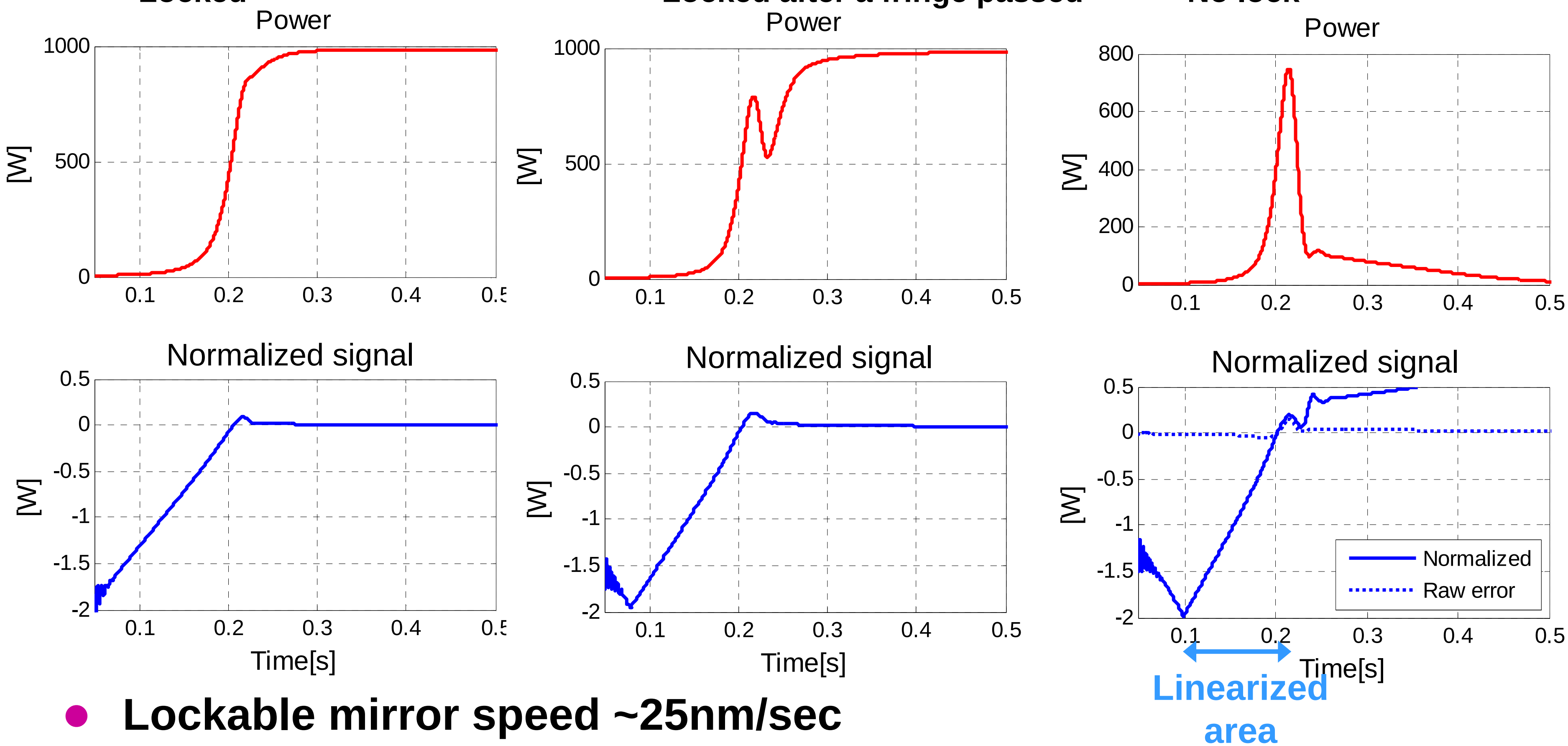
No lock



- **Lockable mirror speed ~ 25nm/sec**
- **Ringing causes no lock acquisition.**
  - » **Cavity length, Finesse, Mirror speed**

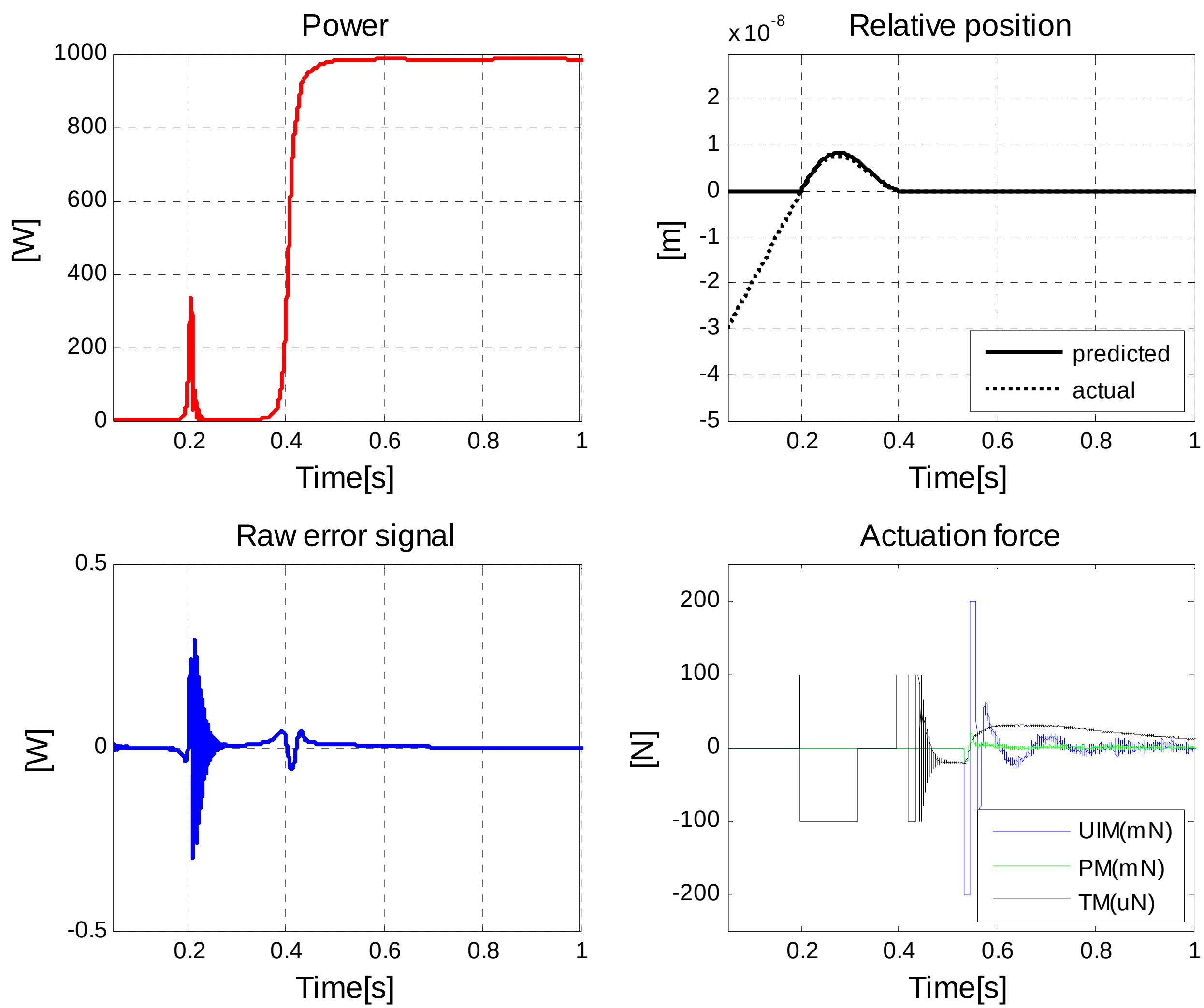
Initial LIGO algorithm
~ normalized by transmitted light

v=20nm/sec	v=25nm/sec	v=30nm/sec
Locked	**Locked after a fringe passed**	**No lock**



- **Lockable mirror speed ~25nm/sec**
- **No advantage for lock acquisition time even normalization applied.**
- **Ringing flips sign for both raw/normalized error signal.**

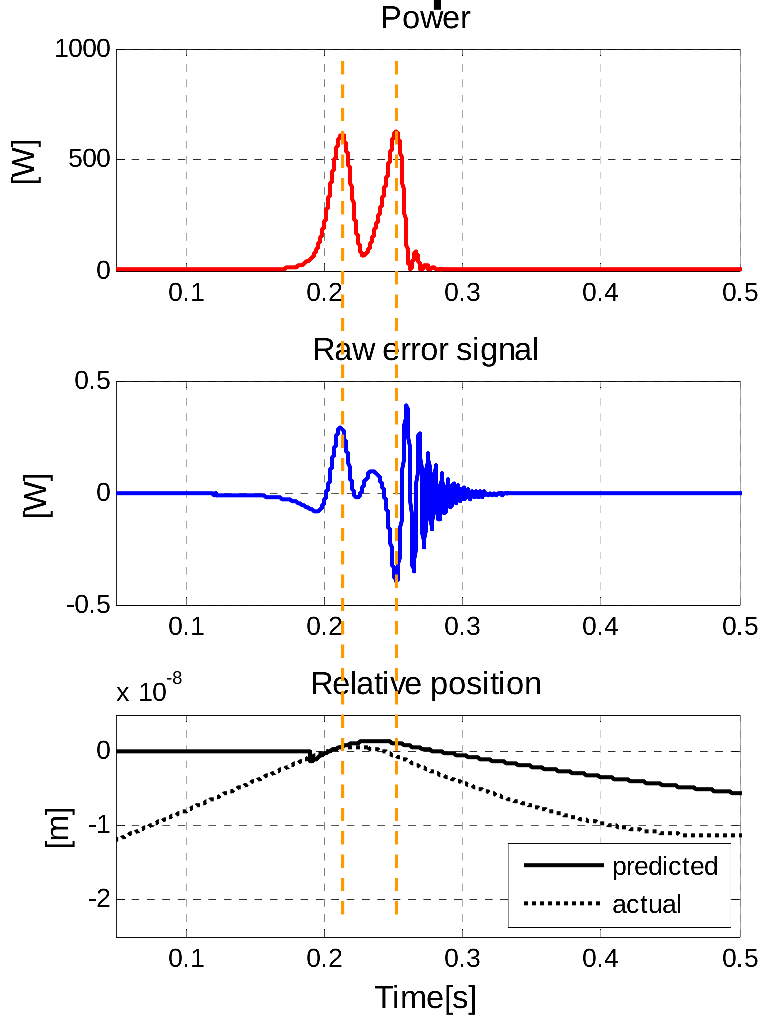
Guide lock



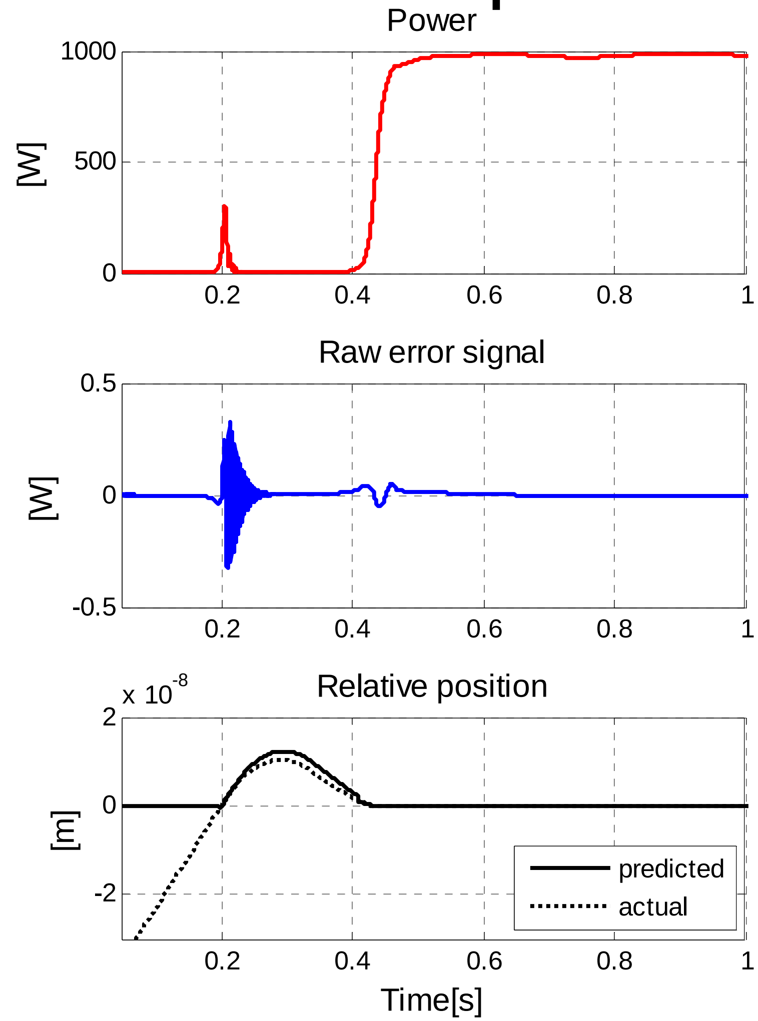
- This "guide lock" algorithm was originally proposed by Matt Evans.
- Raw error signal of first fringe at 0.2 sec is used to estimate the mirror direction and position.
- Applying maximal force to return it to the fringe at low speed where locking servo can catch it, even though the arm power is low and the demod signal is oscillating.
- Initial fringe approach speed can be maximized up to 280 nm/s (x11 times faster than the speed with raw/normalized error signal).

Optimization for Guide lock parameters

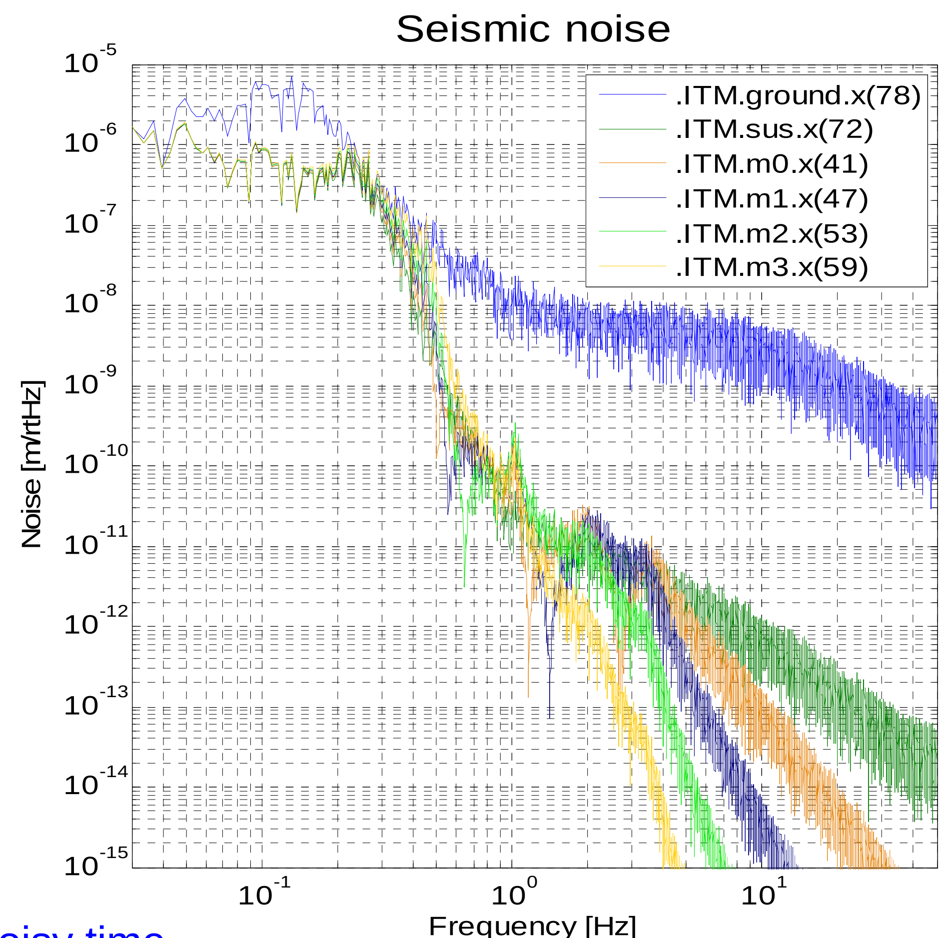
70nm/sec with no optimization



230nm/sec with optimization



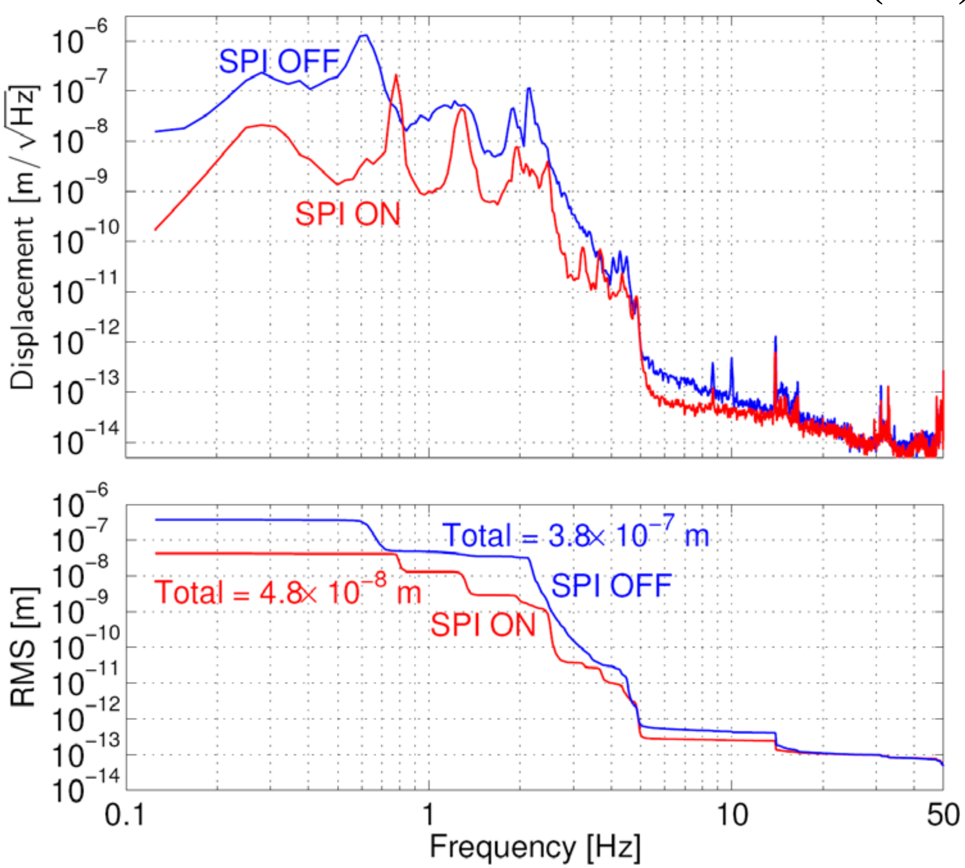
Lock acquisition limited by mirror speed due to micro seismic



- Upper 10% of noisy time
- Mirror speed is limited around 0.2-0.3Hz micro seismic.
- It produces 1e-6m/s between test masses.

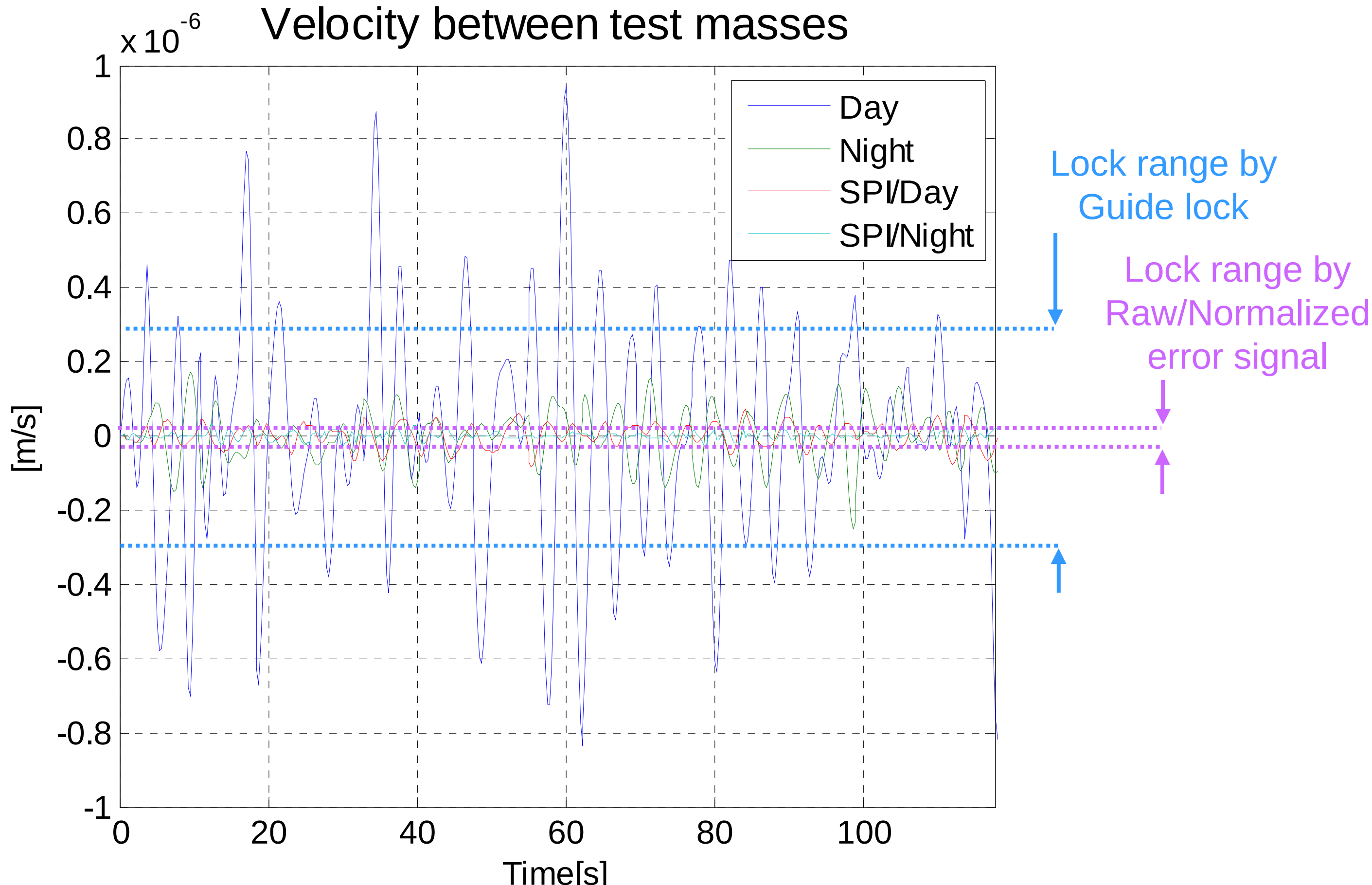
Suspension Point Interferometer (SPI)

Y. Aso Ph.D thesis (2006)



• SPI reduces displacement noise at least 10 times at low frequency advancedligo

Cavity velocity



- Day: upper 10% of noisy time
- Night: 1/5 motion of the day time
- SPI: reduce mirror speed 10times at low frequency (0.1Hz zero and 1Hz pole)

Arm LSC Summary

- **Possibility of lock acquisition when mirrors pass through a resonant point**

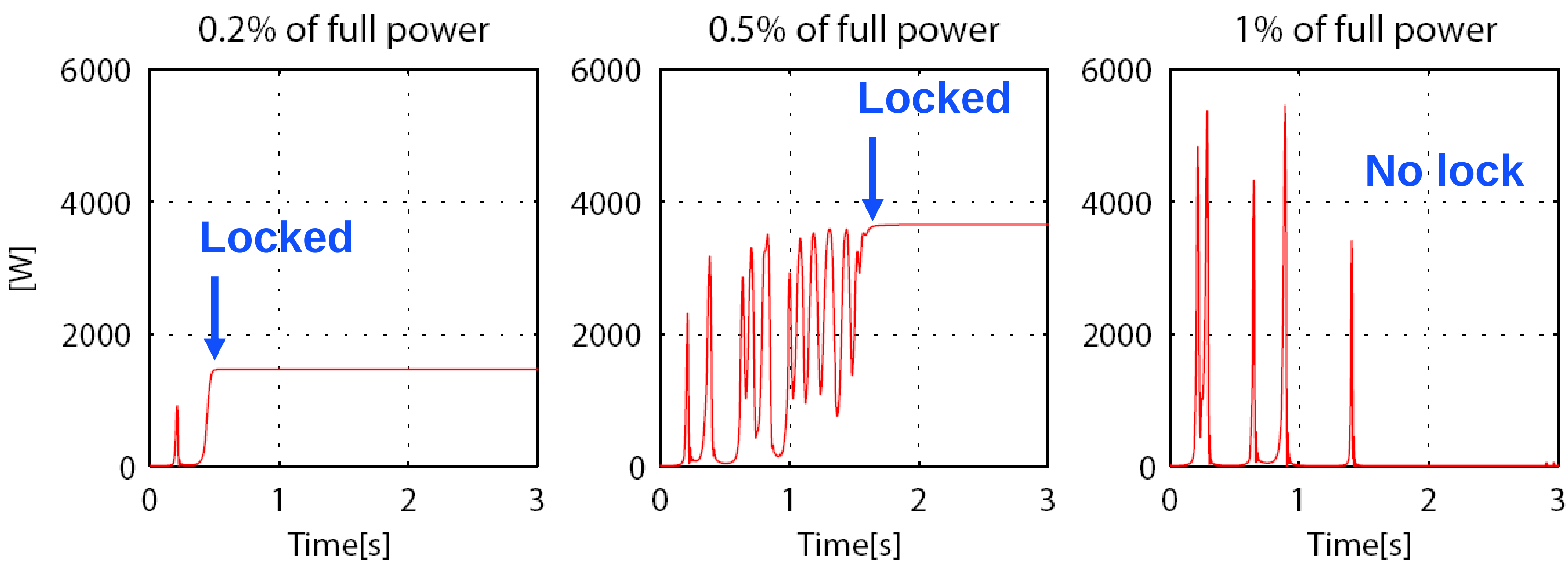
	Lockable mirror speed	Day	Night	SPI/Day	SPI/Night
Raw error	25nm/sec	9.5%	32%	56%	98%
Normalized	25nm/sec	9.5%	32%	56%	98%
Guide lock	280nm/sec	68%	99%	100%	100%

- **Guide lock can replace SPI.**
  - » **Can lock arm but not easy to lock full 5DOF in the day time with one of the guidelock or SPI.**
  - » **May lock full 5DOFs in the night with one of the guidelock or SPI**
  - » **May lock full 5DOFs in all day with guidelock and SPI.**

Difficulty

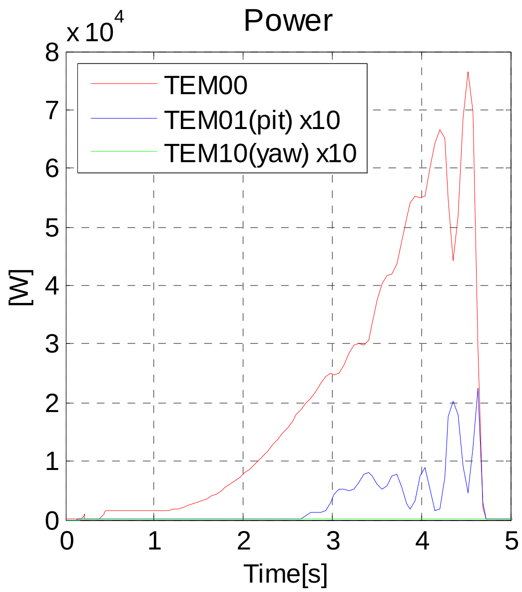
- Bias of alignment was assumed to be zero, and mode matching was assumed to be perfect
  - » Causes mistriggering guide lock in real experiment
- Peak does not corresponds to the real resonant point. Peak is delayed due to the limit of the speed of light.
- Mirror should be pushed to cross the resonant point if the seismic noise is too small, but should not be too fast.
  - » If you take 20sec to cross resonant point, mirror speed will be about 50nm/sec, enough slow.

Lock acquisition with radiation pressure

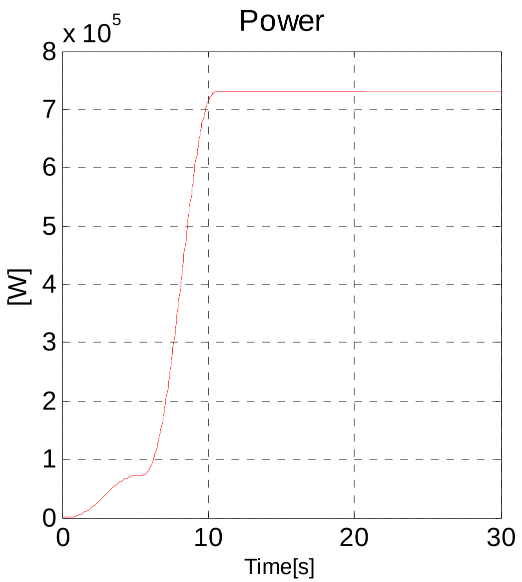


- Radiation pressure causes a disturbance of lock acquisition
- 60nm/sec :enough slow to acquire lock for LSC
- Full power : 0.7MW
- Lock can be acquired with less than few kW
- Following 40m method: ~30% input light makes 1kW inside arm with CARM offset
  - » 125W x 0.3 x 0.5(BS) x 0.07(T_{PRM}) x 770(FP) = 1kW

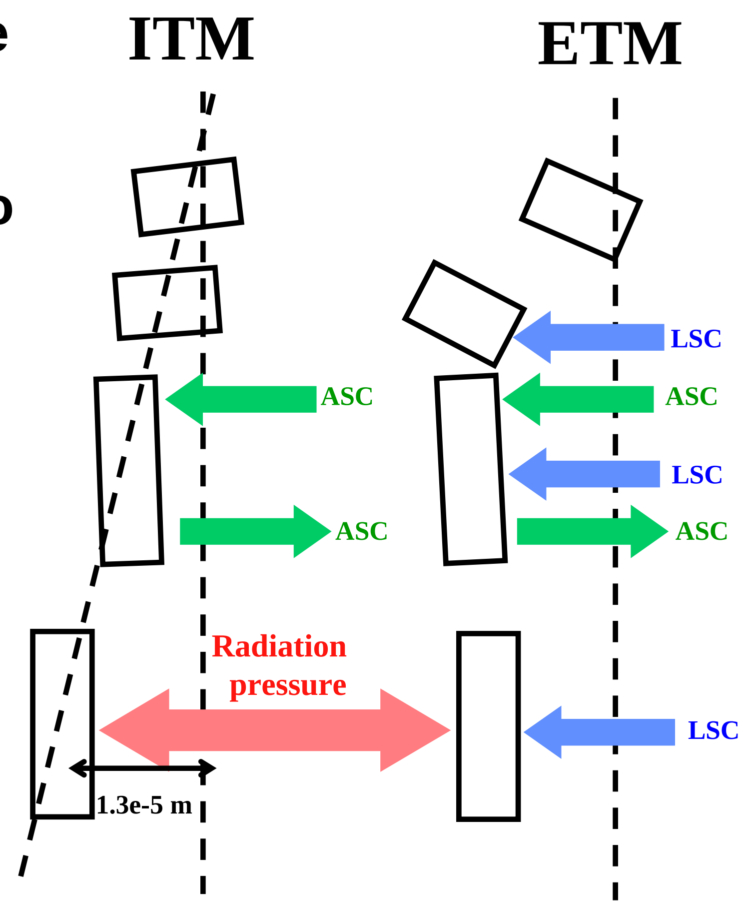
Angle stability with/without ASC due to radiation pressure



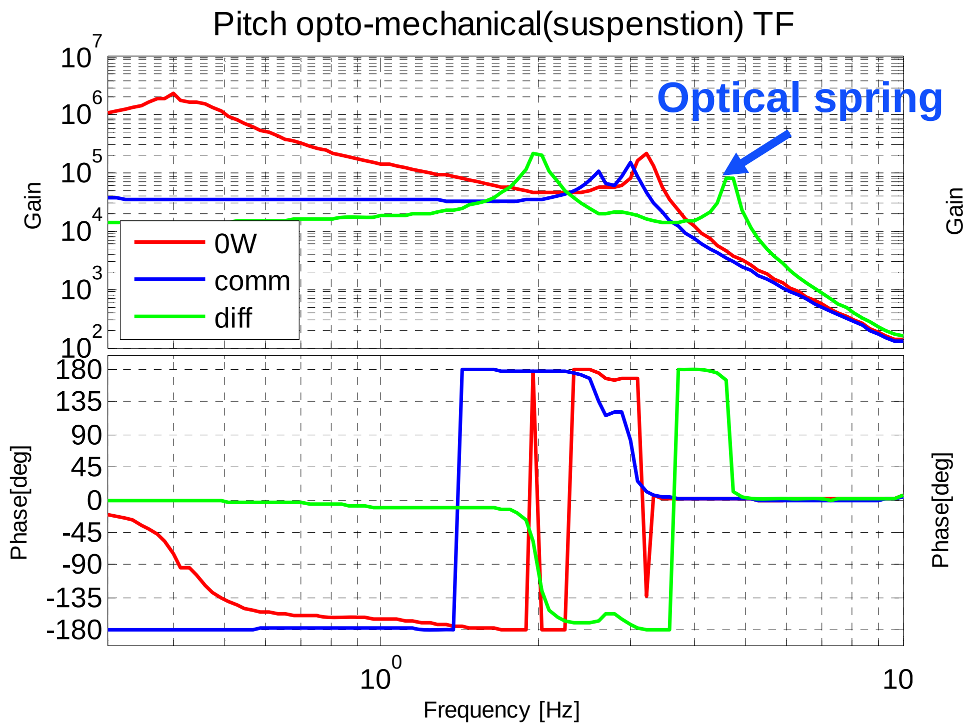
- Pitch motion due to Radiation pressure breaks lock with 10%(70kW) of full power if there is no ASC

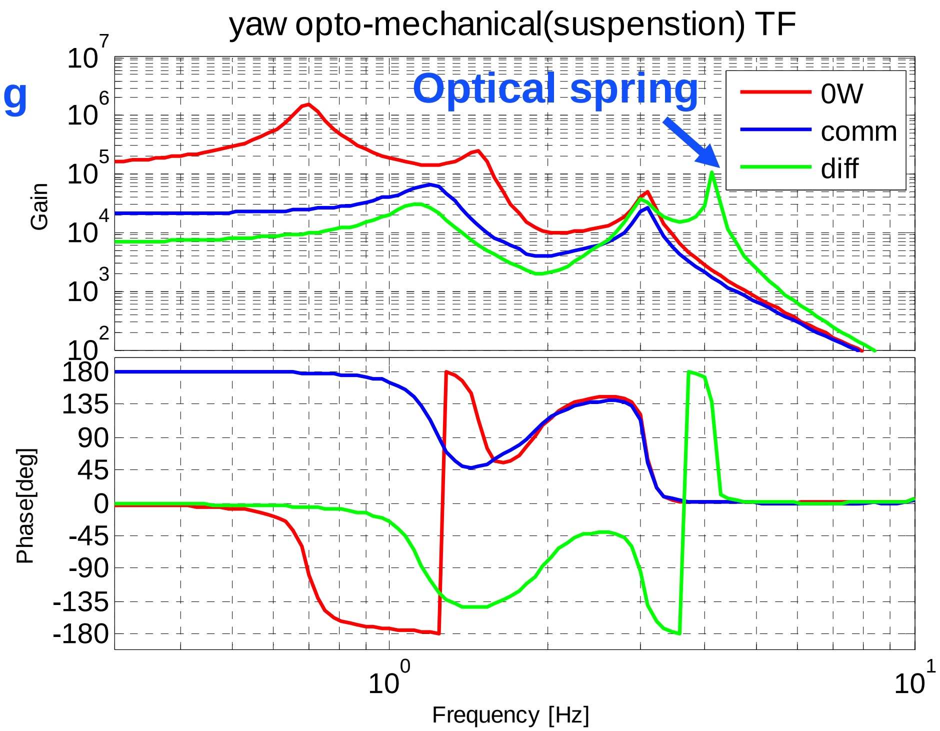


- Controlling M3 through M2 leads full power(0.7MW)
- f^3 filter
- Boost at 2Hz
- 10Hz control band width



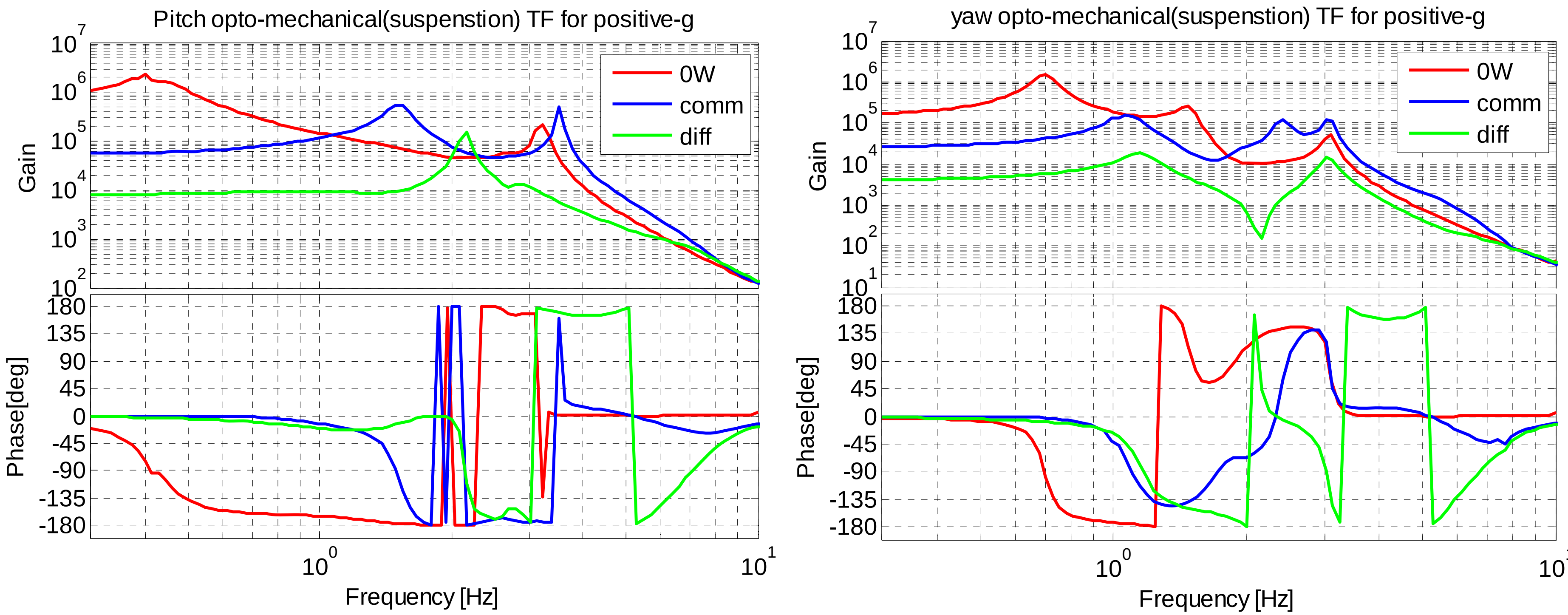
Opt-mechanical (suspension) TF





- **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.**

Positive g factor
Opt-mechanical (suspension) TF



- **Transfer function from penultimate mass actuator to WFS error signal.**
- **ITM ROC = ETM ROC = 55.4km, g1 = g2 = +0.927 (see P030055-B) instead of ITM ROC = ETM ROC = 2.076km , g1 = g2 = -0.927**
- **A dip exists in yaw-differential mode.**
- **Phase has more delay than negative g factor case.**

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Conclusion and Next step

- At least, there is a path to acquire arm lock with current design parameters, but real world is more difficult than simulation world.
- The next major step: lock acquisition for full DRFPMI
  - » simulation time : real time = 10 : 1 for single FP cavity

    = 200 : 1 for DRFPMI with length motion

    = 400000 : 1 for DRFPMI with length/angle motion
- First trial; 40m method, with radiation pressure, no angle motion
  1. Lock 3DOFs of central part (MICH, PRC, SRC)
  2. Lock 2DOFs of arms with CARM offset to keep arm power low
  3. ASC on
  4. Reduce CARM offset
  5. Full RSE
- Noise study (electronic noise, vacuum noise)
- Future plan; includes FFT results
  - » thermal, mirror surface, loss distribution

AdLIGO on E2E