Adv. LIGO Arm Length Stabilisation

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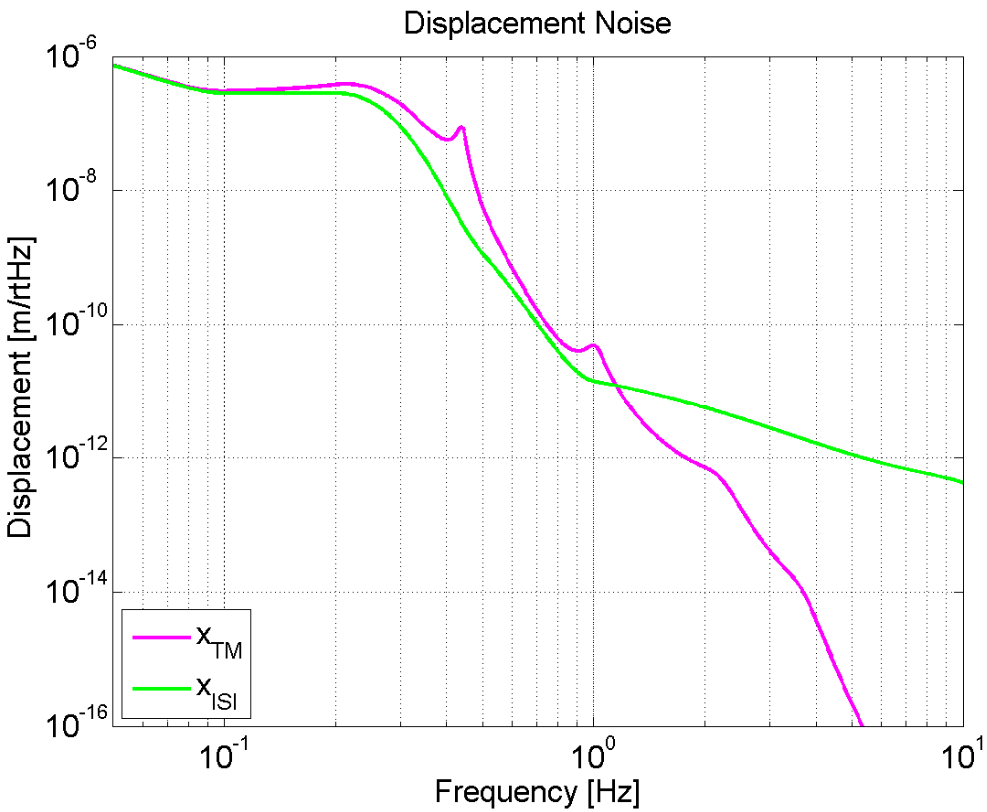
Adv LIGO Arm Cavity Lock Acquisition Challenges

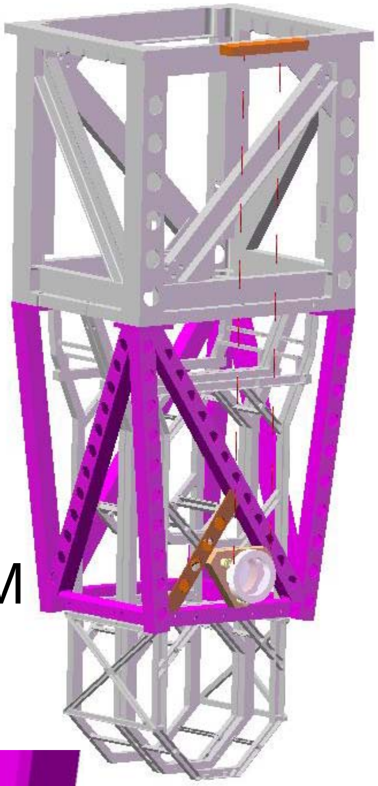
- IFO acquisition procedure
  - Stabilise the arm cavity length, with offset wrt. PSL(preventing swinging through resonance).
  - Bring recycling cavities into resonance (central IFO).
  - Reduce arm cavity offset, to bring arm cavities on resonant with PSL.
- Stabilise the arm cavity length fluctuations to within arm cavity linewidth (equivalent ~1 nm).
  - The test mass motion below 0.5 Hz is ~0.1 μm/rtHz.



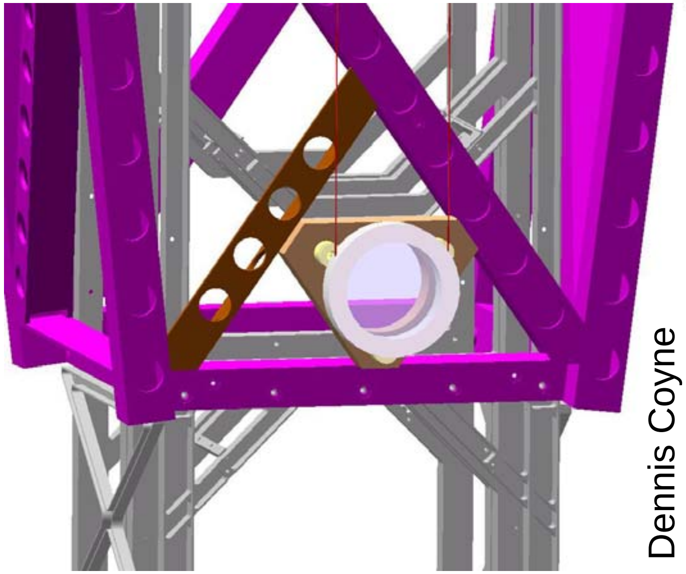
Possible Implementations

- Suspension Point Interferometer
  - Sensing motion of the Quad suspension point (ISI Platform).
  - Feedback to the Quad suspension point.
- Standard PDH reflection locking
  - Auxiliary cavity between the the masses.
  - Using 532nm laser.
  - Injection from the end-station or the corner-station.
- Digital Interferometry
  - Auxiliary sensing between the test masses using, digital interferometry.
  - Injection from the corner-station or the end-station.

Suspension Point Interferometer



- Make a second suspended cavity between the BSC ISI platform (is the Quad suspension point).
- The SPI Mirrors are lowered to be between the PM and the TM.
- The SPI Mirrors have independent actuators.
- Main feedback is to the ISI Platform.
- SPI has been discussed, and I will focus on the baseline and fallback options.



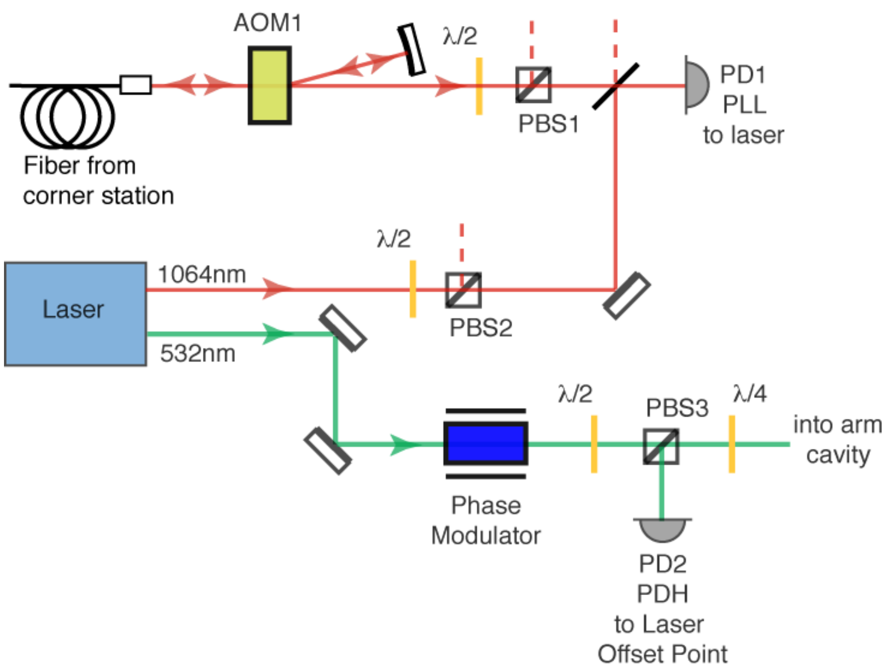
Dennis Coyne

PDH from the End-Station

- Set up a cavity between the test masses, inject from the End-Station.
  - Use 532 nm laser, this to prevent the arm cavity resonance to interact with the recycling cavities during lock acquisition.
- Use the widely used PDH technique to obtain a feedback error signal.
- To acquire lock, feedback to a frequency actuator (effectively the 532 nm laser).
  - Once locked, hand-over to the Quad-suspension actuation (PM/TM).
  - Reduce the relative test mass motion to ~1nm rms.

PDH Injection

- Use a 1064/532 nm laser.
  - 1064 nm output phase lock to the PSL.
  - 532 nm for the PDH injection.
- Readout of a low finesse cavity in the arms.



ETM Coating Modification

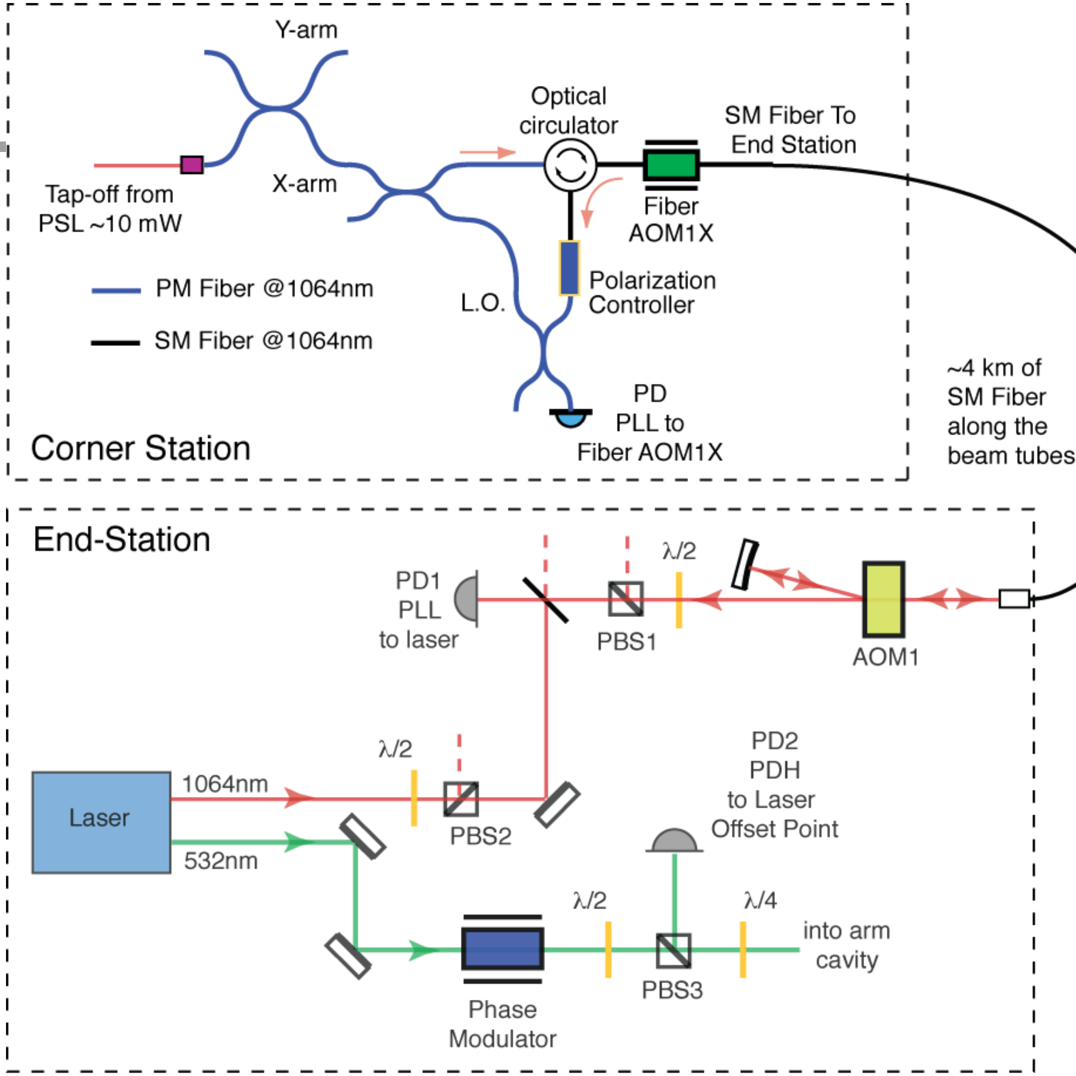
- The HR coating on the test masses are slightly modified.
  - In addition to being low loss and HR for 1064 nm, the layer thick-nesses are adjusted to create a controlled reflectivity at 532 nm.
  - The 532nm reflectivity is set to create a cavity finesse of ~30.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

- Possible coating transmission (modeled by LMA-Lyon).
  - @1064nm: 4.6 ppm
  - @532nm: 5 %
- Negligible change in coating thermal noise.

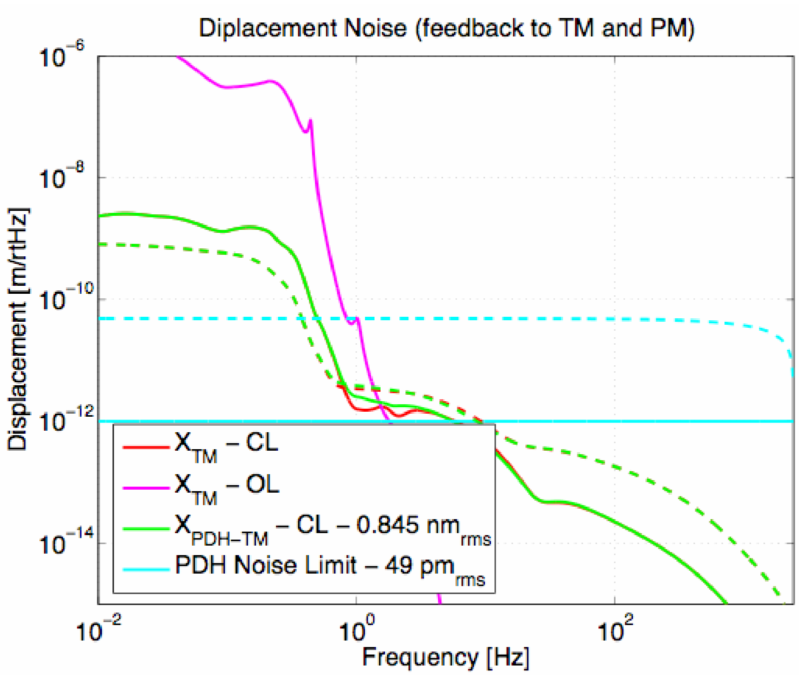
Phase Reference in the End-Station

- Use a tap-off from the PSL to inject into a fiber going to the end-stations.
- Frequency stability requirements
  - <70 Hz/rtHz @ 1Hz
  - <0.1 Hz/rtHz @ 10 Hz, not to saturate the Quad actuators.
- Implement a fiber noise cancellation scheme, to suppress the fiber induced phase noise when required.



PDH Performance

- To acquire lock, the laser is locked to the 4km long arm cavity.
- Once locked, the feedback is distributed to the Quad suspension.
  - PDH noise limit ~1 pm/rtHz.
  - Set by the fiber stabilisation (<0.1 Hz/rtHz).
  - May add a reference cavity in the end-station.

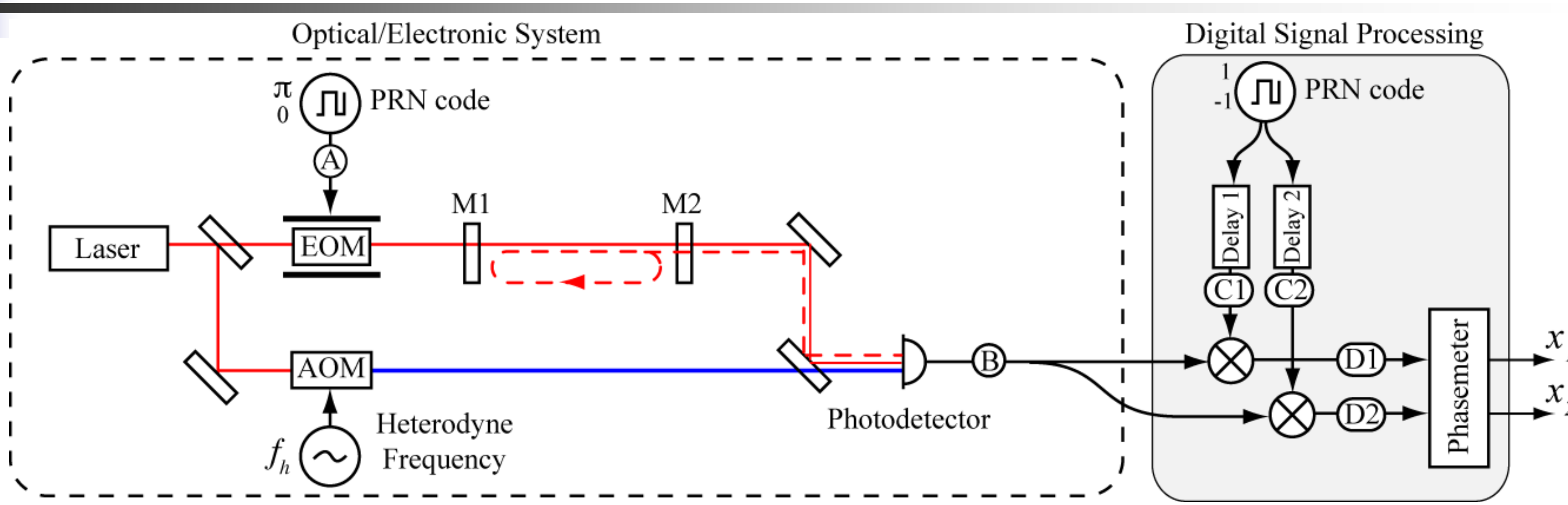


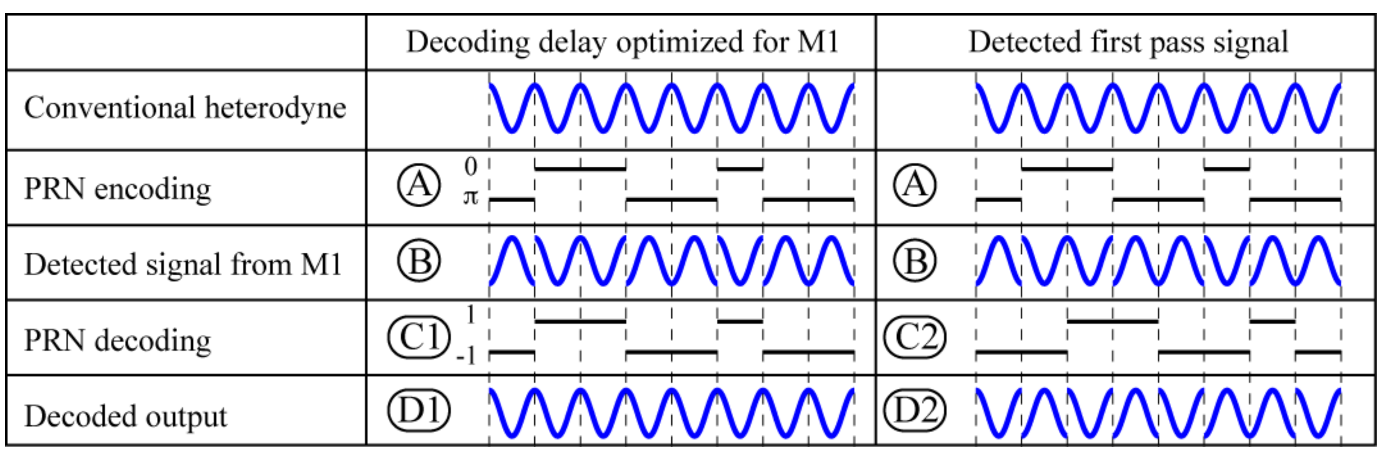
Digital Interferometry[1] - I

- Using standard heterodyne measurement, isolating individual signals with an ultra-fast waveguide phase modulator.
- The phase modulator provides a pseudo-random noise (PRN) code with a modulation depth of 100% (power spread across 'all' frequencies).
- The pseudo-random noise code enables to isolate the reflections depending on time-of-flight.
- The detected signal is demodulated with the PRN code, using the appropriate delay (depending on the time-of-flight), isolating other reflections.
- After demodulation by the PRN code, a standard heterodyne phase measurement is performed.
- The DI readout has picometer sensitivity, with larger dynamic range >> 1μm.

[1] Shaddock, '***Digitally enhanced heterodyne interferometry',*** Opt. Lett. (32), 2007

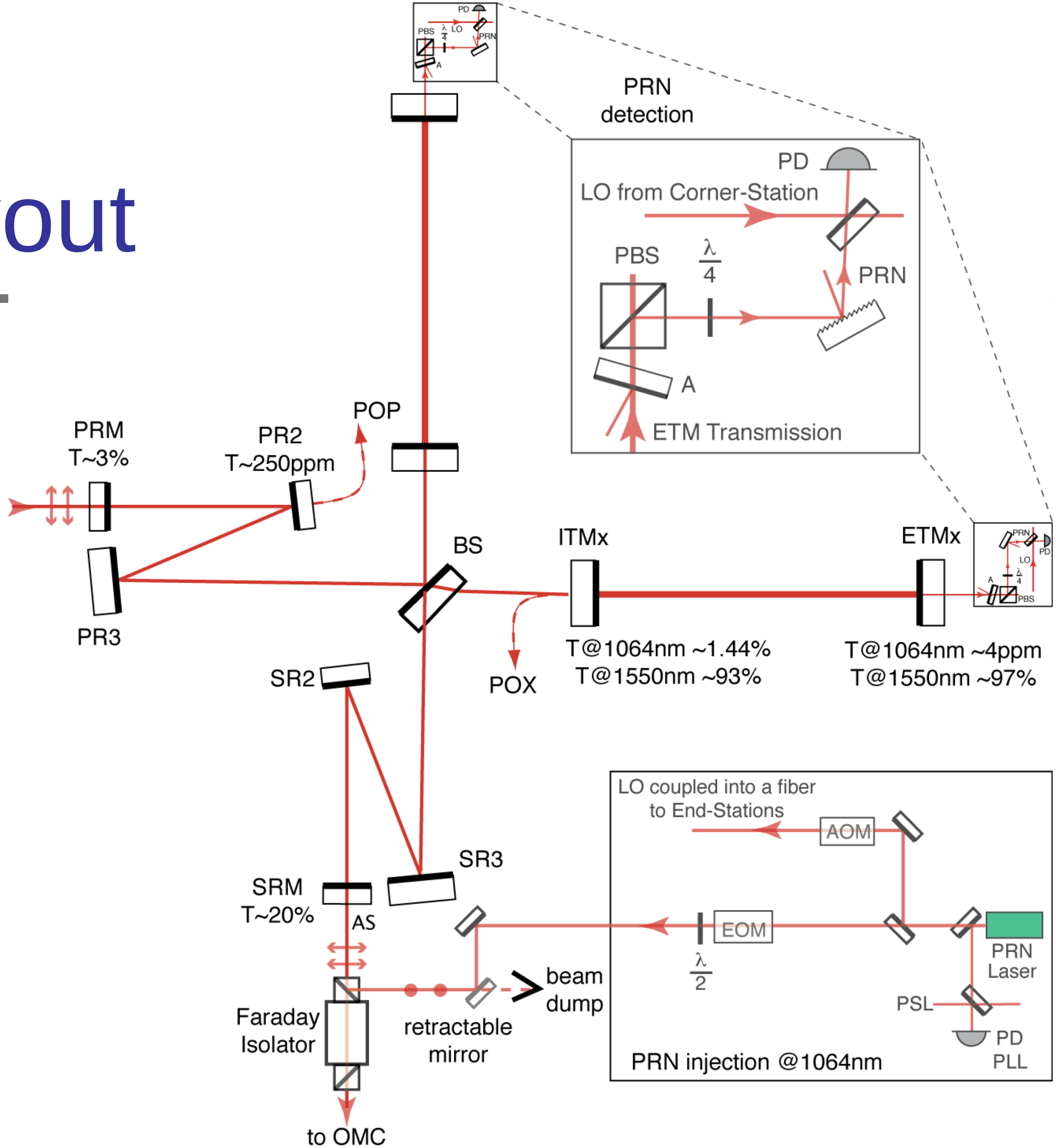
Digital Interferometry - II





De Vine et. al, in preparation

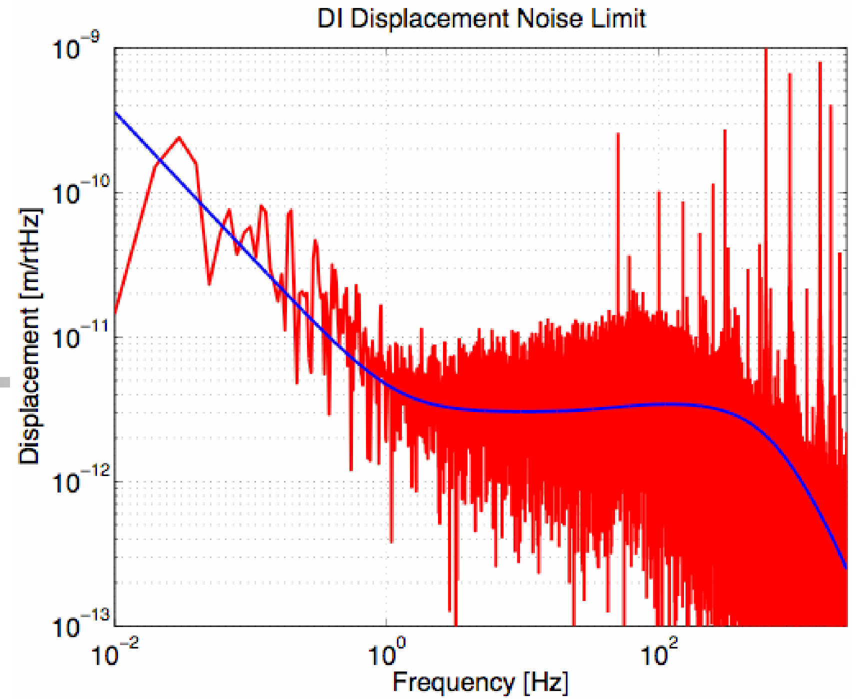
DI Layout

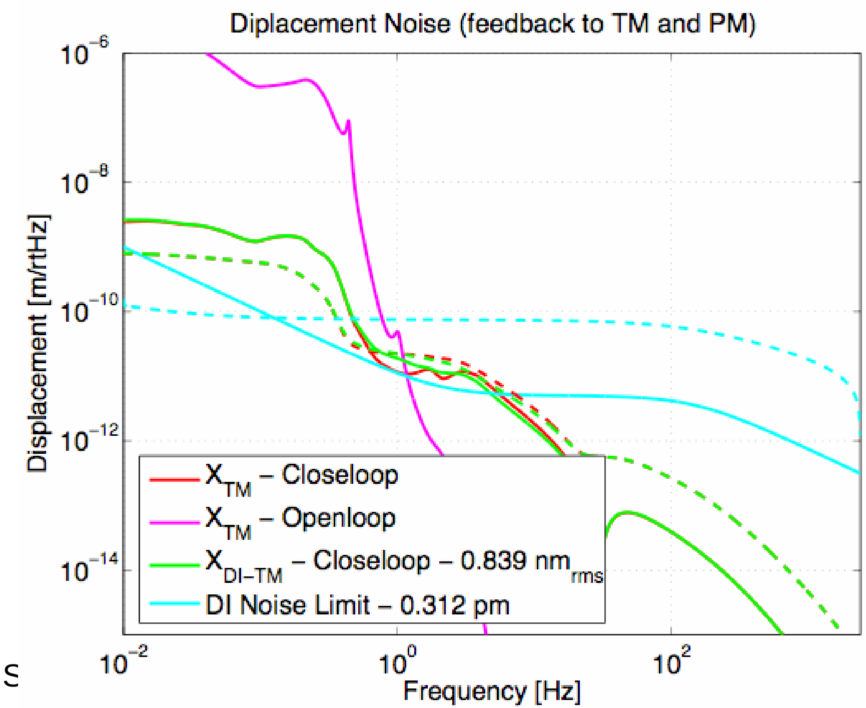


PD
PBS
LO
PRN
A
PRN
detection
PD
LO from Corner-Station
PBS
λ/4
PRN
A
ETM Transmission
POP
PRM
T~3%
PR2
T~250ppm
BS
ITMx
ETMx
PR3
T@1064nm ~1.44%
T@1550nm ~93%
T@1064nm ~4ppm
T@1550nm ~97%
SR2
POX
LO coupled into a fiber
to End-Stations
AOM
SR3
SRM
T~20%
AS
EOM
λ/2
PRN
Laser
beam
dump
PSL
Faraday
Isolator
retractable
mirror
PD
PLL
PRN injection @1064nm
to OMC

DI Performance

- The DI readout is shot noise limited, while it is performance limited by the phasemeter.
- Displacement noise level is ~ 3 pm/rtHz.
  - Rollup at lower frequencies -> polarisation drift
  - Corner at 100 Hz due to the PDH locking servo.





Conclusion

- The PDH reflection technique is chosen as the baseline.
  - Simple, familiar sensing scheme.
  - Larger signal-to-noise, assuming fiber noise can be suppressed far enough (<0.1 Hz/rtHz @10Hz).
  - 1064 nm/532 nm source preferred, this avoids the need for dual-wavelength reference cavity.
  - Possibility to implement wave-front sensing.
- Further details about injection from the end-station or the corner-station is ongoing.
- In addition, the DI is a fallback technique.
- More details can be found at: http://ilog.ligo-wa.caltech.edu:7285/advligo/Seismic_Platform_Interferometer