40m Laboratory Upgrade Progress Report

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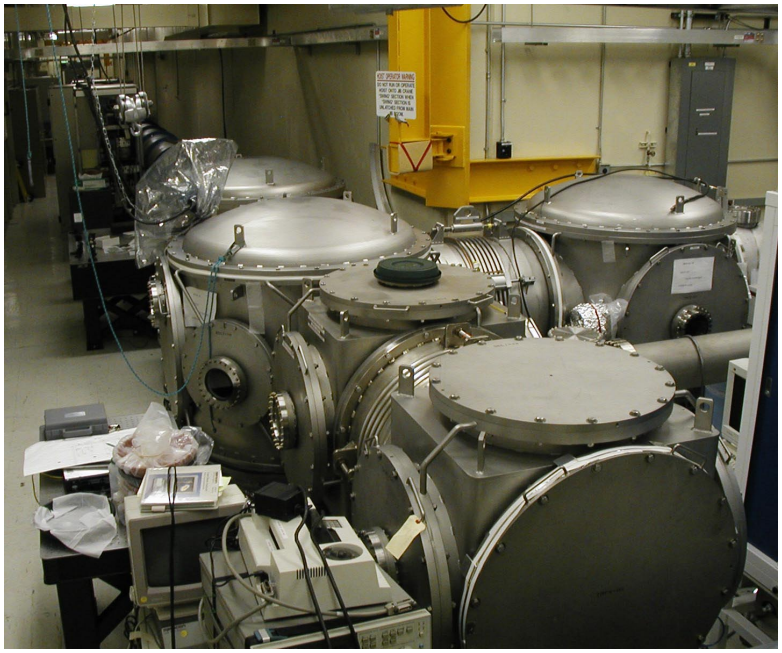
40m Technical Advisory Committee

LIGO-G030033-00-R



Primary objective: full engineering prototype of optics control scheme for a dual recycling suspended mass IFO, as close as possible to the Advanced LIGO optical configuration and control system

Advanced LIGO technical innovations tested at 40m

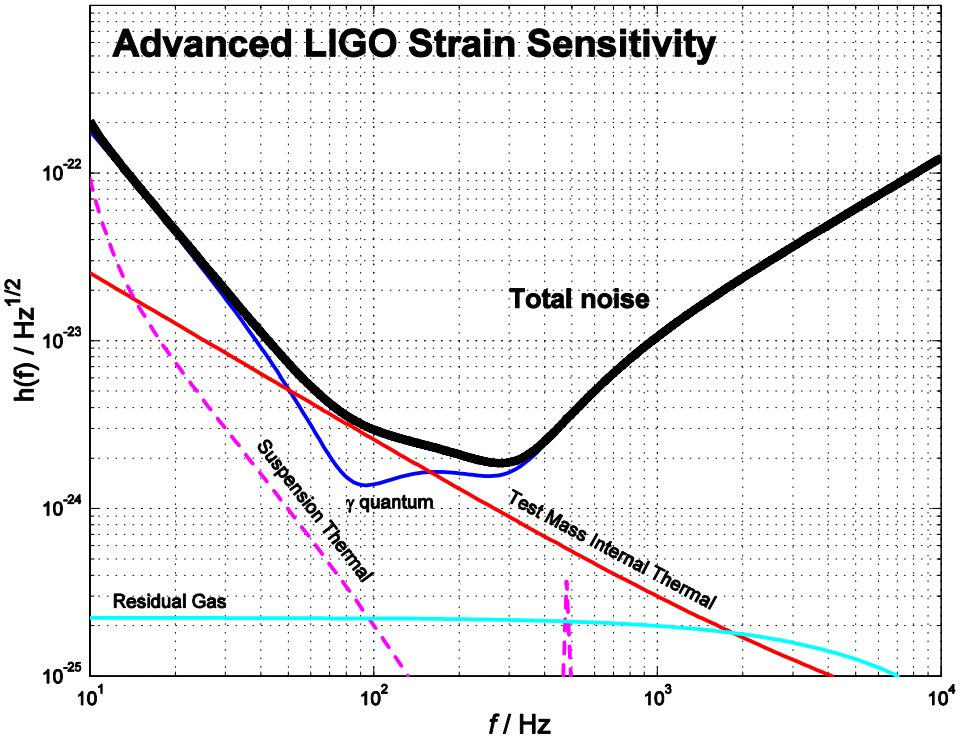
- **a seventh mirror for signal recycling**
  - » **length control goes from 4x4 to 5x5 MIMO**
- **detuned signal cavity (carrier off resonance)**
- **pair of phase-modulated RF sidebands**
  - » **frequencies made as low and as high as is practically possible**
  - » **unbalanced: only one sideband in a pair is used**
  - » **double demodulation to produce error signals**
- **short output mode cleaner**
  - » **filter out all RF sidebands and higher-order transverse modes**
- **offset-locked arms**
  - » **controlled amount of arm-filtered carrier light exits asym. port of BS**
- **DC readout of the gravitational wave signal**

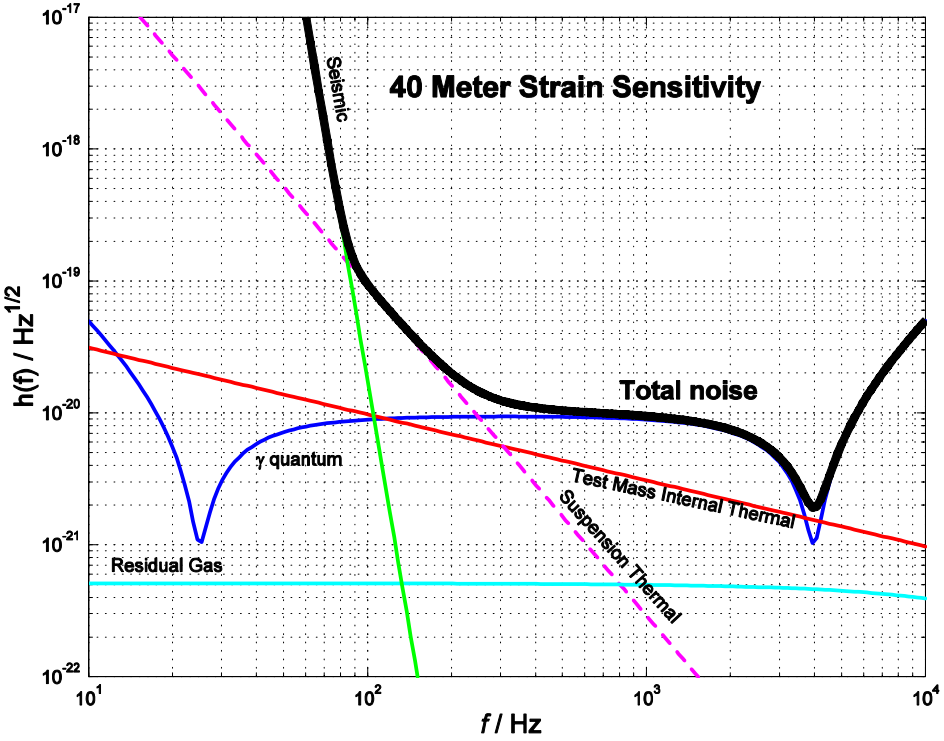
Much effort to ensure high fidelity between 40m and Adv.LIGO!

Differences between AdvLIGO and 40m prototype

- **Initially, LIGO-I single pendulum suspensions will be used**
  - » **No room for full scale AdvLIGO multiple pendulums – to be tested at LASTI**
  - » **Scaled-down versions to test controls hierarchy in 2004?**
- **Only commercial active seismic isolation**
  - » **STACIS isolators in use on all test chambers, providing ~30 dB of isolation from 1-100 Hz**
  - » **No room for anything like full AdvLIGO design – to be tested at LASTI**
- **LIGO-I 10-watt laser, negligible thermal effects**
  - » **Other facilities will test high-power laser (LASTI, Gingin)**
  - » **Thermal compensation also tested elsewhere**
- **Small (5 mm) beam spot at TM's; stable arm cavities**
  - » **AdvLIGO will have 6 cm beam spots, using less stable cavities**
  - » **40m can move to less stable arm cavities if deemed useful**
- **Arm cavity finesse at 40m chosen to be = to AdvLIGO**
  - » **Storage time is x100 shorter**
  - » **significant differences in lock acquisition dynamics, in predictable ways**
- **Control RF sidebands are 33/166 MHz instead of 9/180 MHz**
  - » **Due to shorter PRC length**
  - » **Less contrast between PRC and SRC signals**

Target sensitivity of AdvLIGO and 40m prototype





Milestones Achieved as of Spring LSC Meeting

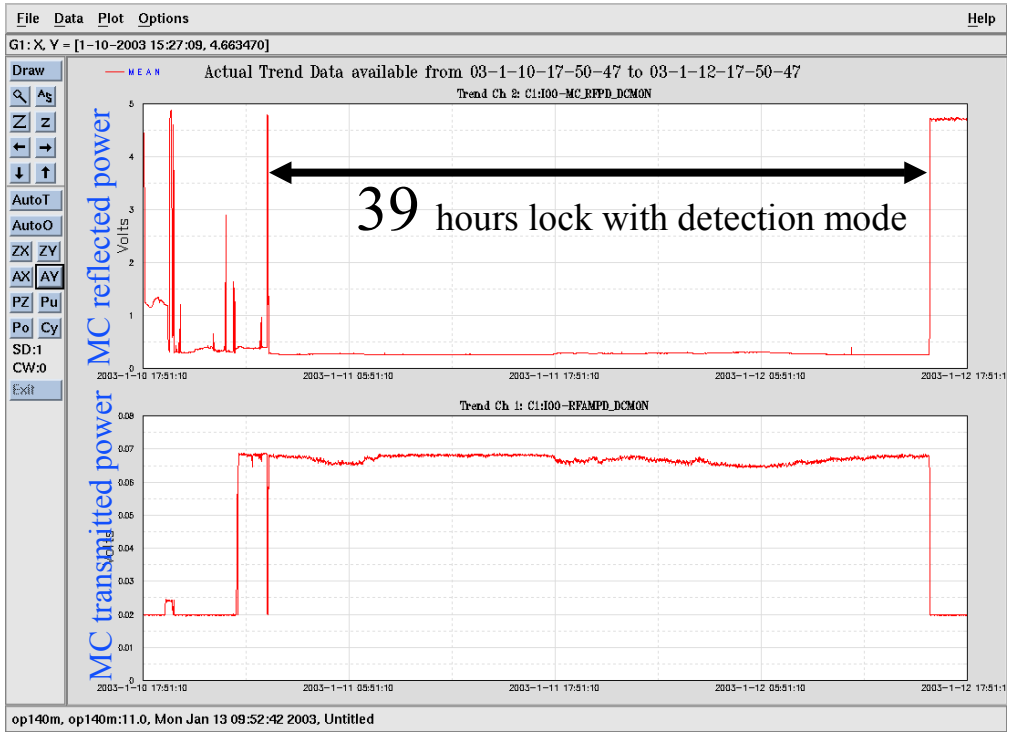
- The characterization of the mode cleaner performance, and its interaction with the pre-stabilized laser system, occupied much of fall 2002. By the end of December 2002, the noise performance of the system met specifications.
- The intensity stabilization system (ISS) for the pre-stabilized laser continues to be developed and installed.
- The Global Diagnostics System (GDS), including DTT, AWG, and DMT have been installed, and DTT/AWG is in use.
- Five new temperature-controlled vacuum bake ovens were commissioned in the South Annex of the laboratory, and many bake jobs were completed and qualified.
- 8 of 10 digital suspension controllers for suspended optics were completed by the end of calendar 2002. ETM$_x$ and ETMy remain to be completed.
- All 10 core optics were produced, polished, and coated, and their optical properties measured by LIGO engineers, by August 2002.
- All of the mechanical suspensions for the core optics for the main dual recycled interferometer were designed, fabricated, cleaned and baked.

Milestones Achieved as of Spring LSC Meeting

- Sensor/actuators (OSEMs) for the all the suspended optics were assembled, cleaned and baked, tested, and prepared for installation.
- Three core optics (Beamsplitter, ITMx, and ITMy) were suspended and damped in February 2003. Four remain to be suspended by the summer 2003.
- Remaining optical sensing equipments of AP, SP & MC, ITMx, ITMy, TRx, TRy were assembled and installed on the optical tables in February 2003.
- Several key auxiliary systems (the in-vacuum Faraday isolator, the in-vacuum mode matching telescope with off-axis parabolic mirrors, the in-vacuum PZT steering mirror system, and the optical lever zoom telescope system) were designed, and components procured, by the end of 2002. They are now being assembled.

Lock stability of 13meter MC

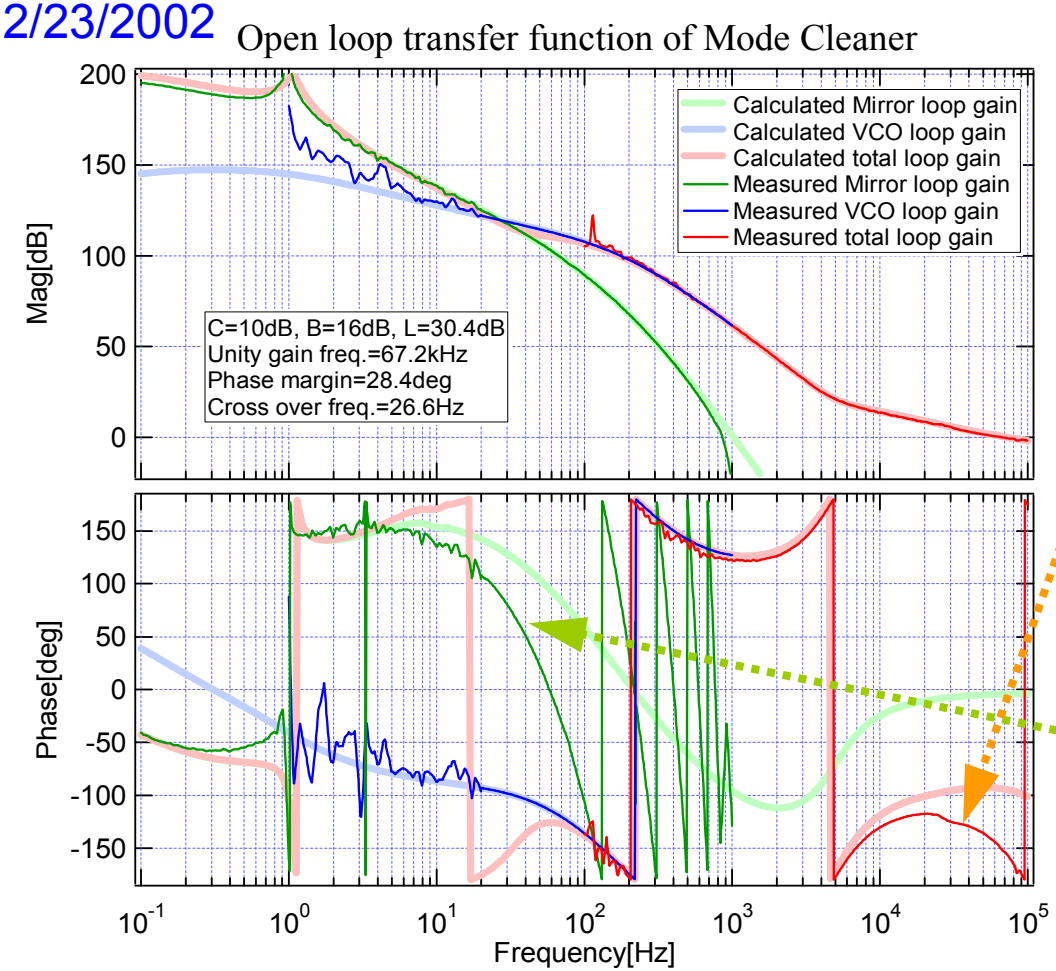
Jan.10/2003 17PM – Jan.12/2003 8AM



- Digital controlled suspensions.
- Smooth Lock acquisition (within 5sec).
- Robust lock.

Measured open loop T.F. of MC

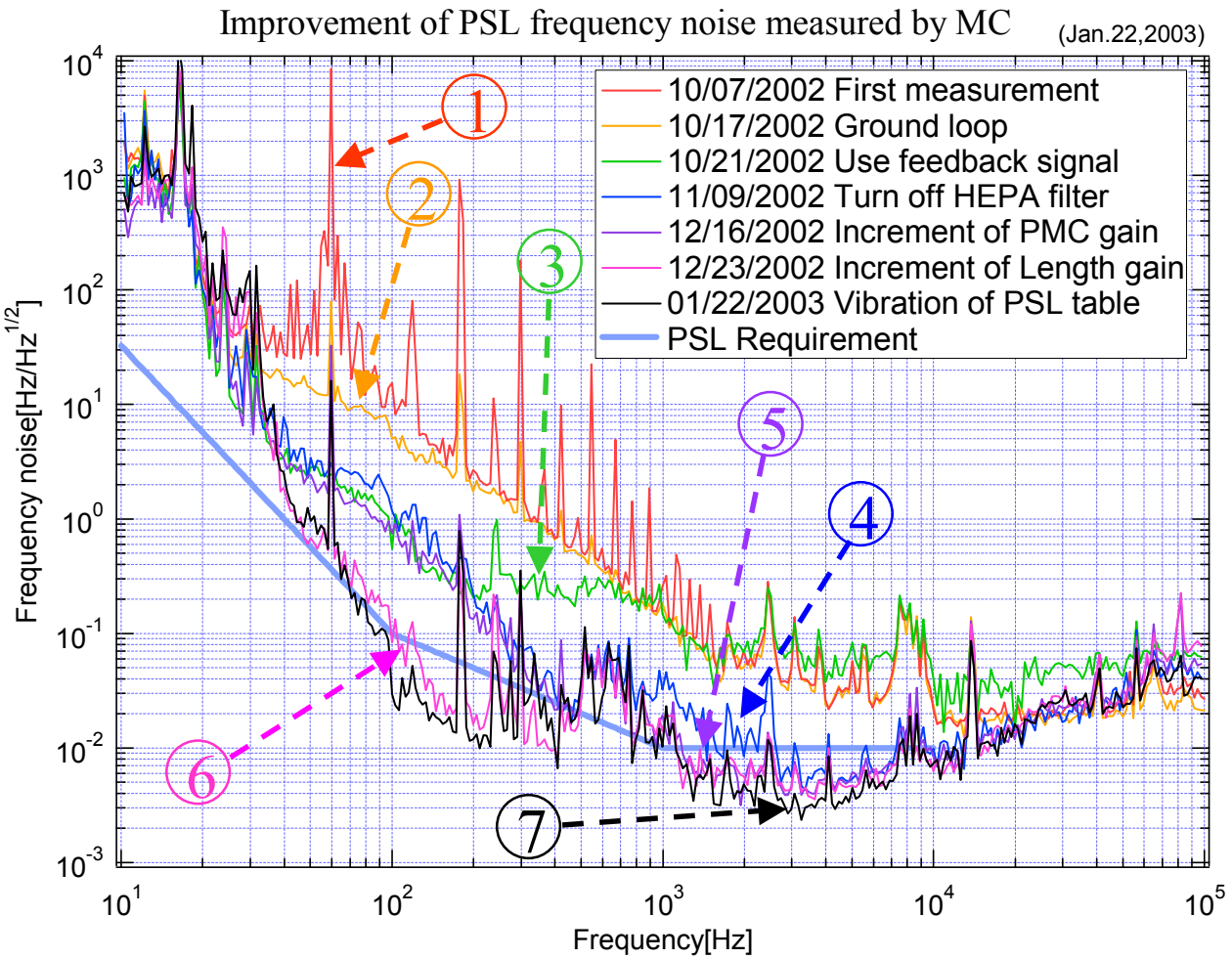
12/23/2002



- Calculated gains obtained by Rana's model on Matlab agree with measurements.
- Unity gain frequency=67.2kHz (design:over 100kHz)
- Phase margin=28.4deg
- Phase delay on total loop at high frequency limits the unity gain frequency.
- Cross over frequency=26.6Hz
- Phase delay on Mirror loop by A/D converter (ICS110B).

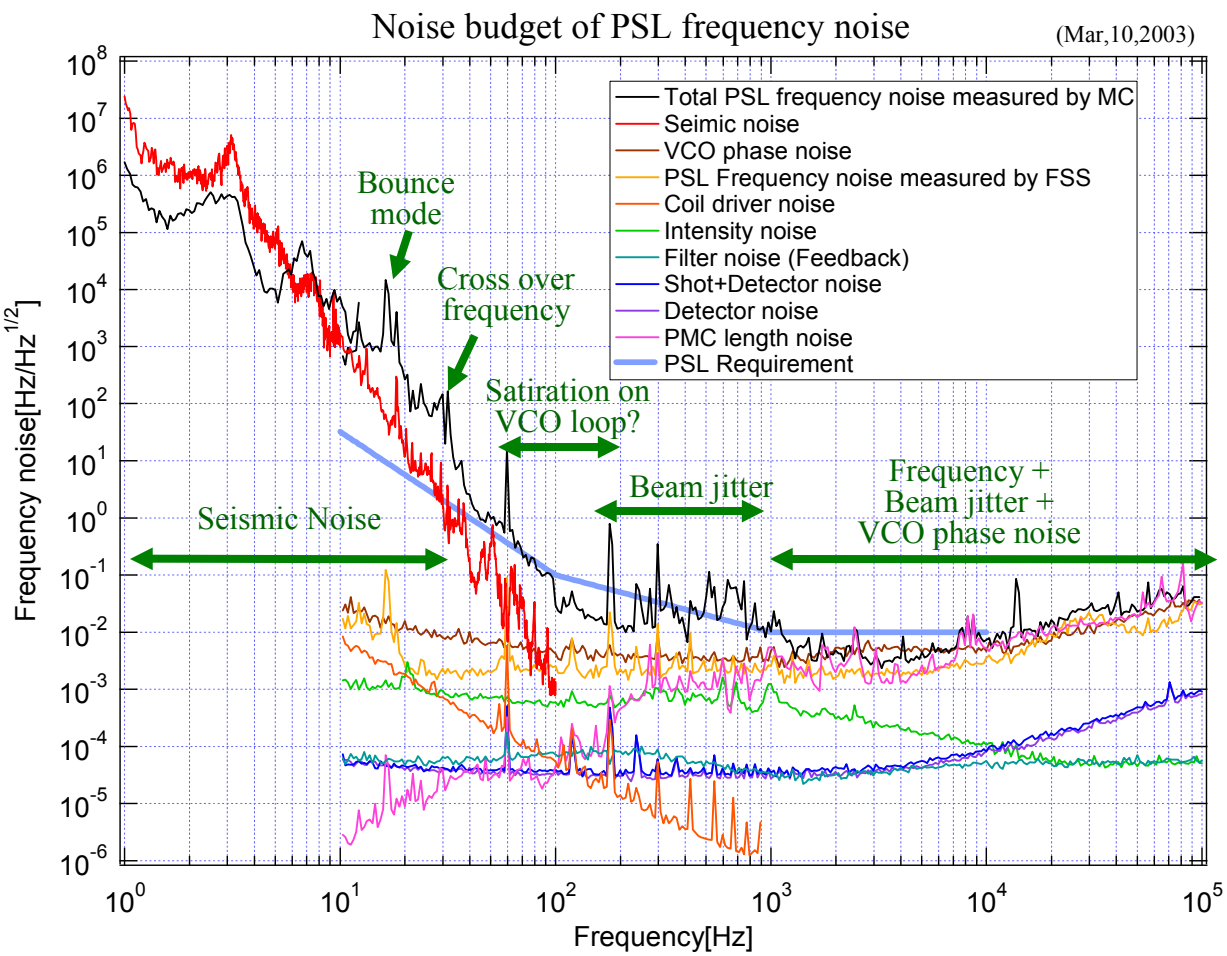
→ fixed!

Improvement of PSL frequency noise measured by 13-meter MC



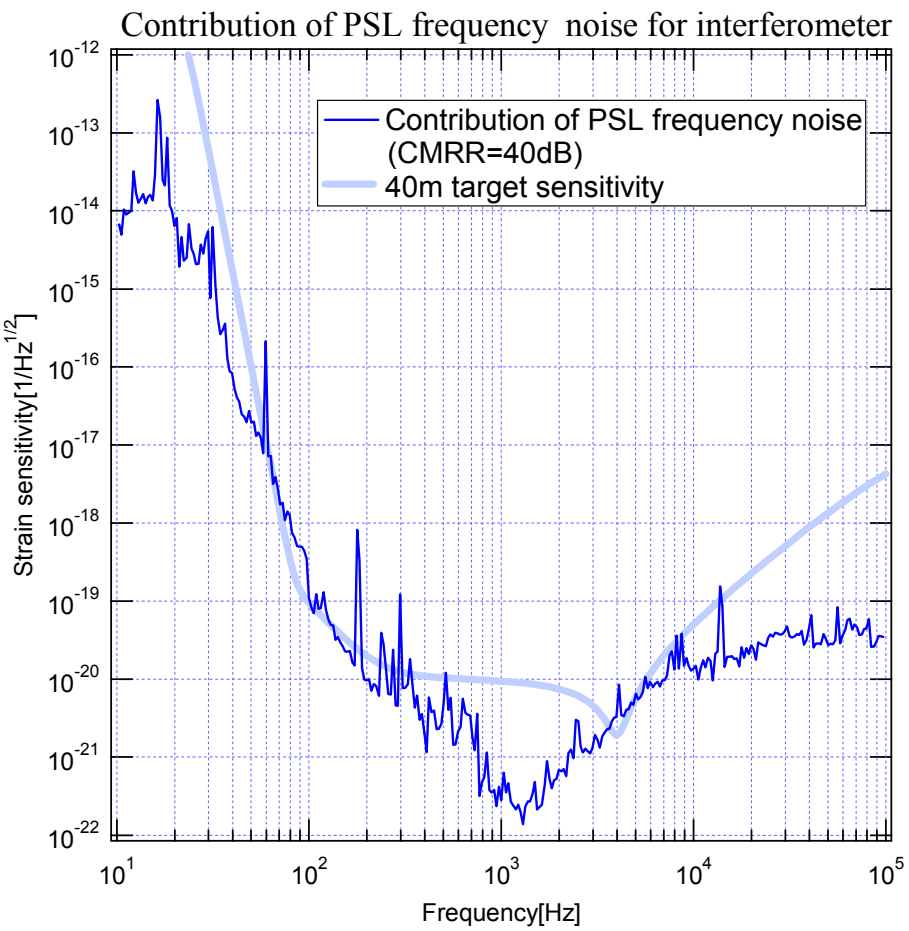
- Meets the requirement except for low frequency and bump around 600Hz.

Noise budget of PSL frequency noise measured by 13m MC



- Low frequency noise is limited by seismic noise of small stack of MC2.
- Unknown noise around 100Hz (saturation of VCO loop?).
- Beam jitter noise on PSL, Frequency noise and VCO phase noise limit the high frequency.
- Coil driver noise, Intensity noise, Feedback filter noise, Shot noise and Detector noise are lower than total noise.

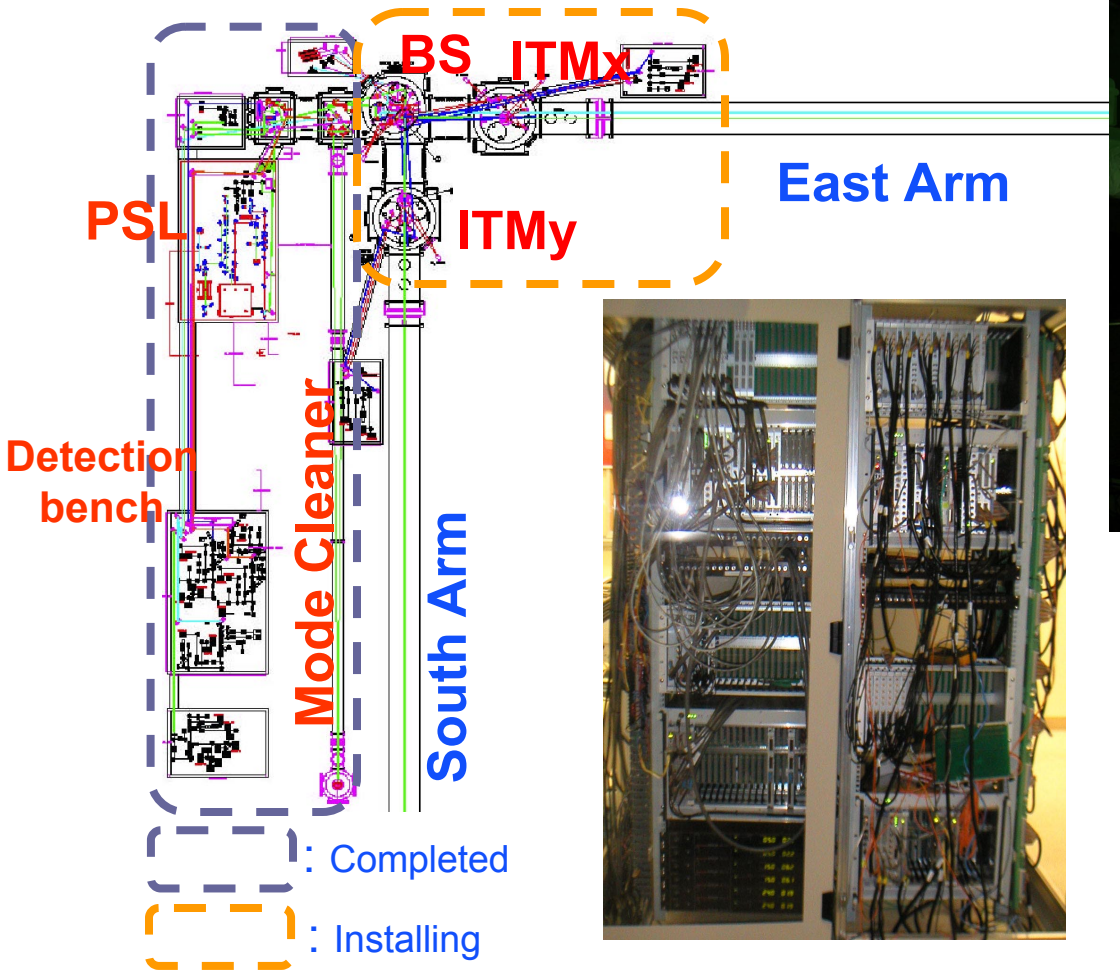
Estimation of PSL frequency noise for 40m interferometer

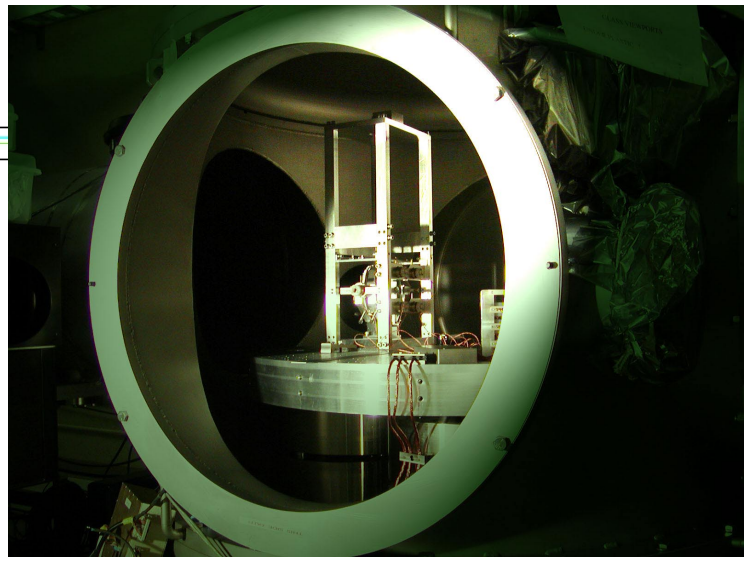


- -40dB Common Mode Rejection Ratio (CMRR) is assumed.
- Measured residual frequency noise of MC and measured OLTF of MC are used.
- Need more CMRR or more OLTF to reach the target sensitivity.

>>Actual estimation will be performed by single arm cavity later.

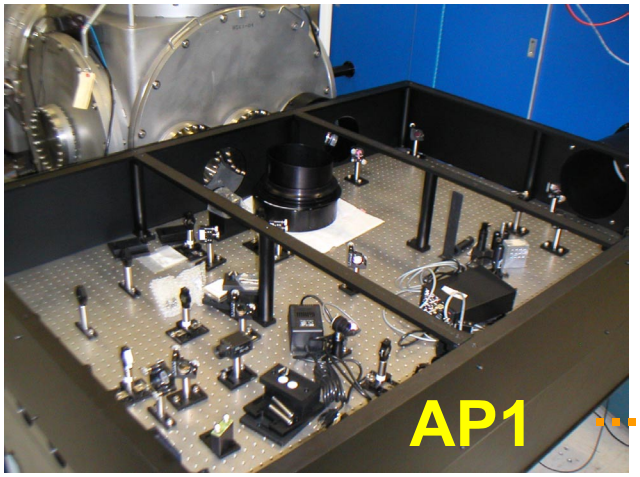
Core optics

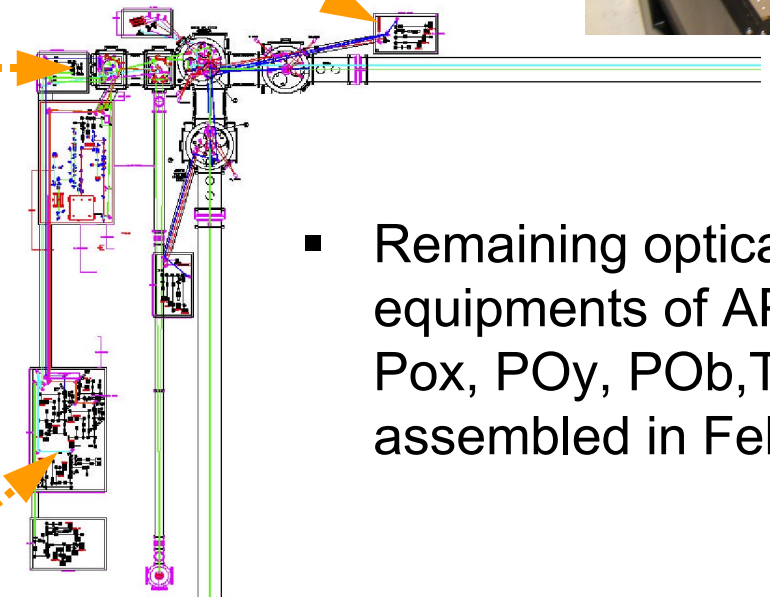




- ITMx, ITMy, BS optics hung, balanced, installed, damped in February 2003
- Begin commissioning of the interferometer with 1 degree-of-freedom, short Michelson

Further Infrastructure





- Remaining optical sensing equipments of AP1, SP & MC, Pox, POy, POb,TRx, TRy were assembled in February 2003.

Next 9 months

- Redesign of digital suspension controller using PCs for filtering.
- Assemble, hang, and install the four core suspended optics (PRM, SRM, ETMx, ETMy) by 2Q 2003, and have them damped by the controller system.
- Begin commissioning of the interferometer in stages, with 1 degree-of-freedom systems (short Michelson, Fabry-Perot arms) by 2Q 2003, even before a digital length control system is installed.
- Fabricate and install auxiliary optics systems: scattered light control, initial alignment system, optical levers, video monitoring.
- Fabricate and install LIGO I-like length sensing and control system.
- Fabricate and install the alignment sensing and control system.
- First experiments in dual recycled configuration response, lock acquisition, and control are expected to take at least a year.

Milestones revisited

- **2Q 2002:**
  - **All in-vacuum cables, feedthroughs, viewports, seismic stacks installed.** Done
  - **13m input MC optics and suspensions, and suspension controllers.** Done
- **3Q 2002:**
  - **Begin commissioning of 13m input mode cleaner.** Done
  - **Acquisition of most of CDS, ISC, LSC, ASC.** Done
- **4Q 2002:**
  - **Core optics (early) and suspensions ready. Ten Suspension controllers. Some ISC.** Done
  - **Glasgow 10m experiment informs 40m program** In progress
  - **Control system finalized** In progress
- **2Q 2003:**
  - **Core optics (late) and suspensions ready.** In progress
  - **auxiliary optics, IFO sensing and control systems assembled.** In progress
- **3Q 2003: Core subsystems commissioned, begin experiments**
  - **Lock acquisition with all 5 length dof's, 2x6 angular dof's**
  - **measure transfer functions, noise**
  - **Inform CDS of required modifications**
- **3Q 2004: Next round of experiments.**
  - **DC readout. Multiple pendulum suspensions?**
  - **Final report to LIGO Lab.**

(Some) outstanding issues and action items (40m, AdvLIGO)

- **Any significant changes in people's thinking re: optical configuration, controls, CDS architecture??**
- **166 MHz PD's for WFS, LSC. Double demodulation(166 ⊕ 33 MHz).**
- **Design servo filters for LSC, ASC**
- **Detailed noise model (RSENOISE, Jim Mason)**
- **Lock acquisition studies with E2E/DRLIGO. Develop lock acquisition algorithms, software.**
- **Triple-check thermal effects (Melody) – negligible?**
- **Output mode cleaner – will PSL-PMC-like device be adequate? (For 40m, for AdvLIGO). Suspended?**
- **Offset-lock arms - algorithms, software.**
- **DC GW PD – in vacuum? Suspended?**

We expect that LSC members, as well as students,
will participate in this most interesting phase of the project.