Research activities at the Caltech 40m prototype

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LIGO-G1101178

Outline

- Targets of the 40m prototype
- Length Sensing & Control
- Simulated Plant
- Active noise cancellation

The 40m prototype

- Facility located on the campus of Caltech

- A fully instrumented engineering and control prototype of the aLIGO IFOs
  i.e. vac chambers, suspensions, MC and full IFO

- Current mission:
  To promote and accelerate commissioning of aLIGO

- Two main thrust areas:
  Optical configuration
  Control issues of the IFO

Staus

- **Previous configruation (~2009):**
  - **Detuned RSE**
  - -> Lock Acquisition, Length Control, Noise coupling
  - **Detailed in Rob Ward's thesis (LIGO Doc P1000018)**

- **Upgrade of the 40m**
  - **Increase the resemblance to aLIGO**
  - **Upgrade installation**
  - -> started on Feb 2010, completed on Dec 2010

- **Achieved milestones**
  - **ALS (a.k.a. Green locking) demonstrated for an arm**
  - **Lock of the DRMI**

New optical configuration

Dual Recycled Michelson with Fabry-Perot arms

- Length Sensing & Control: greater resemblance to aLIGO

Dichroic TMs & 532nm beam injection for Arm Length Stabilization

Mimicking aLIGO : F(1064nm) = ~450, F(532nm) = ~100

Small Schnupp asymmetry: Δl = ~3cm

Similar to the aLIGO's 5cm

Adjusted such that the 55MHz sidebands reach the dark port

Longer power and signal recycling cavities (PRC, SRC)

PRC =6.8m, SRC=5.4m

Folded by ANU Tip-Tilt suspensions

Primarily "no detuning"

Smaller test masses with SOS suspensions

3 inch dia. x 1 inch thick.

Same DC radiation pressure effect as in aLIGO

mass 0.25kg/40kg vs power 3kW/850kW

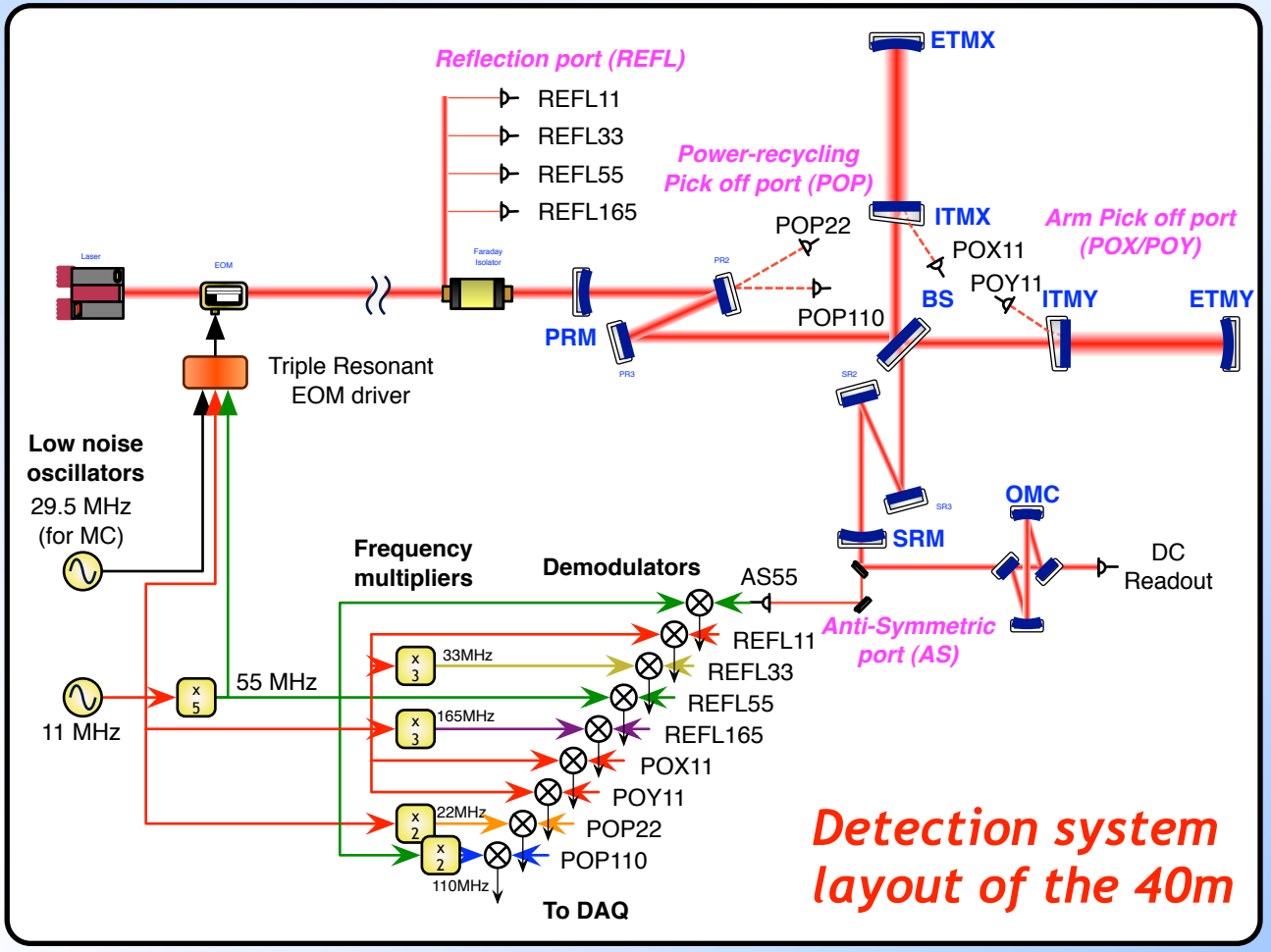
Length Sensing and Control

2 phase mod. (no MZ) and demods at harmonic freqs

- 11MHz and 55MHz modulation sidebands

3rd harmonic demod. for robust extraction of the signals

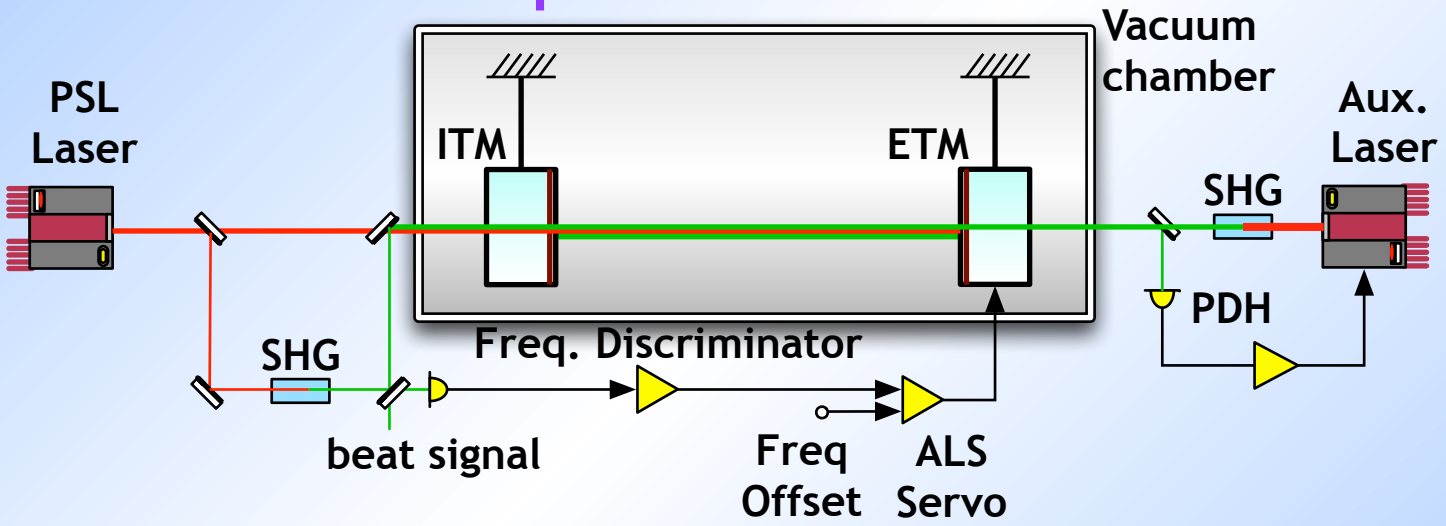
2nd harmonic demod. for sideband power monitor

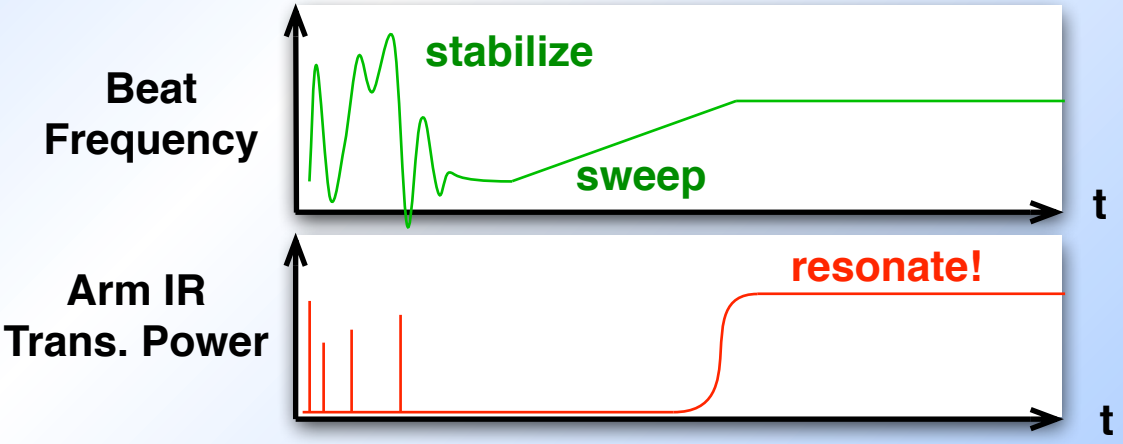


Arm Length Stabilization (ALS)

Stabilizes the arm lengths before the lock

- Utizing beat notes between 532nm beams
- Stabilizes arm fluctuation: from ~1um (~10MHz) to ~100pm (~1kHz)
- For deterministic lock acquisition

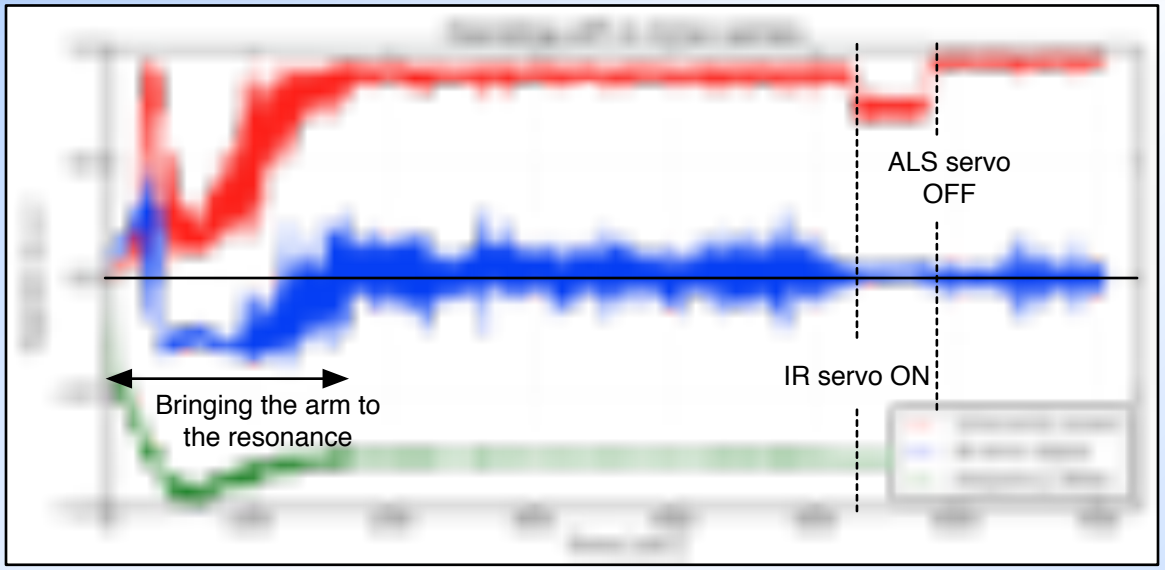




ALS: Demonstration

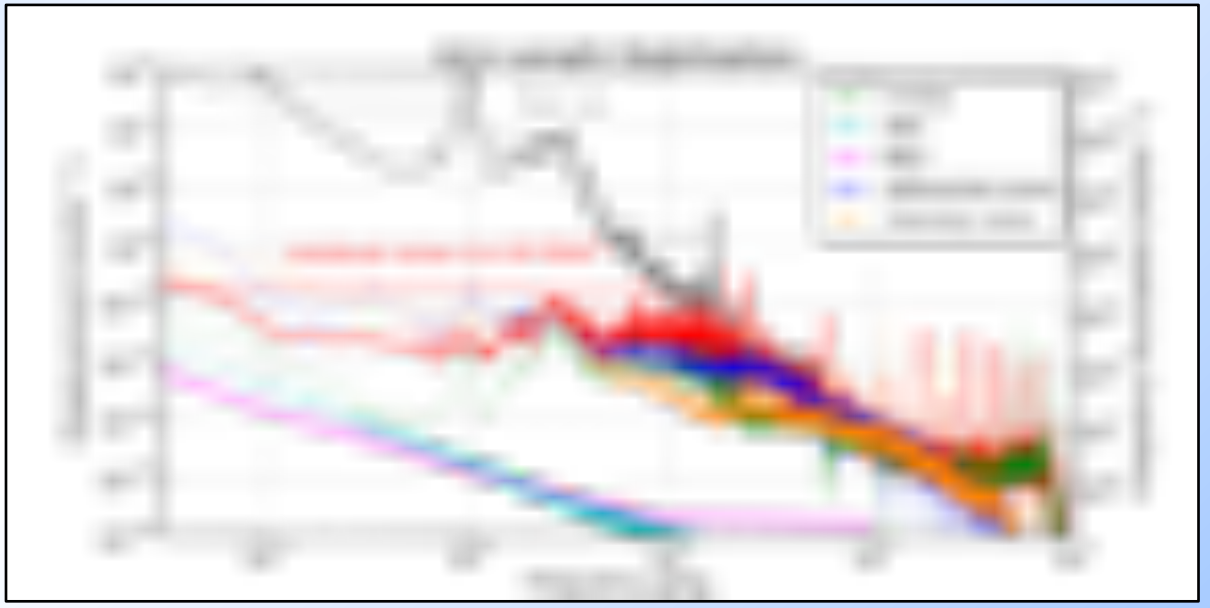
Beat freq sweep

The transmission (red) is kept at the top of the resonance without locking with the IR beam (100s-520s)



ALS noise budget

200pm in RMS was achieved



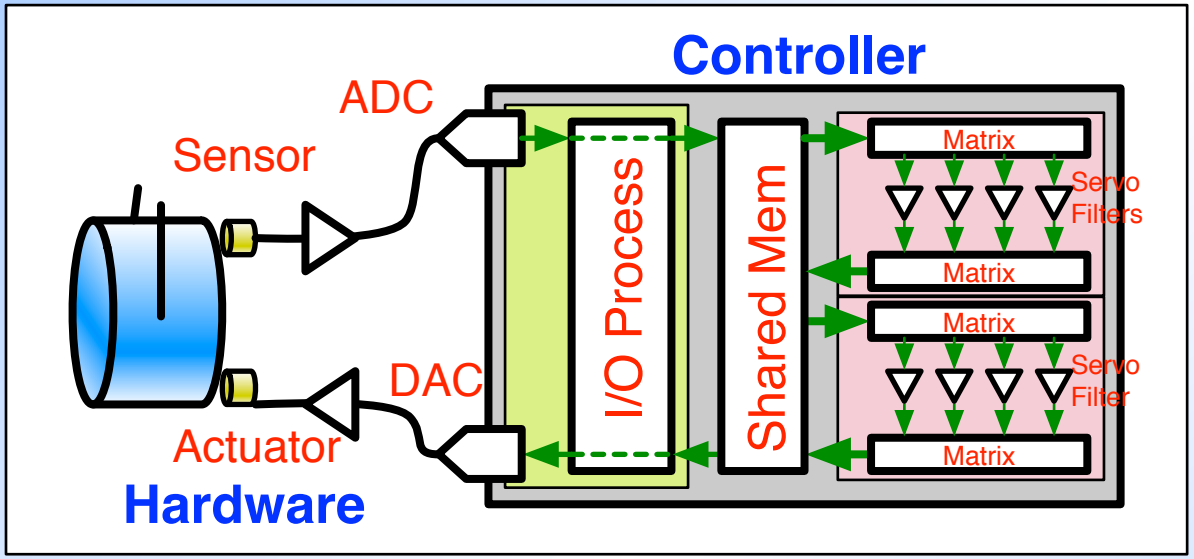
Lock Acquisition

- **Full lock acquisition sequence**
  1. Pre-stabilize the arms at an off-resonant point
  2. Lock the vertex part with the 3f-locking technique
  3. Bring the arms to their resonances
  4. Hand off the ALS servo to IR locking

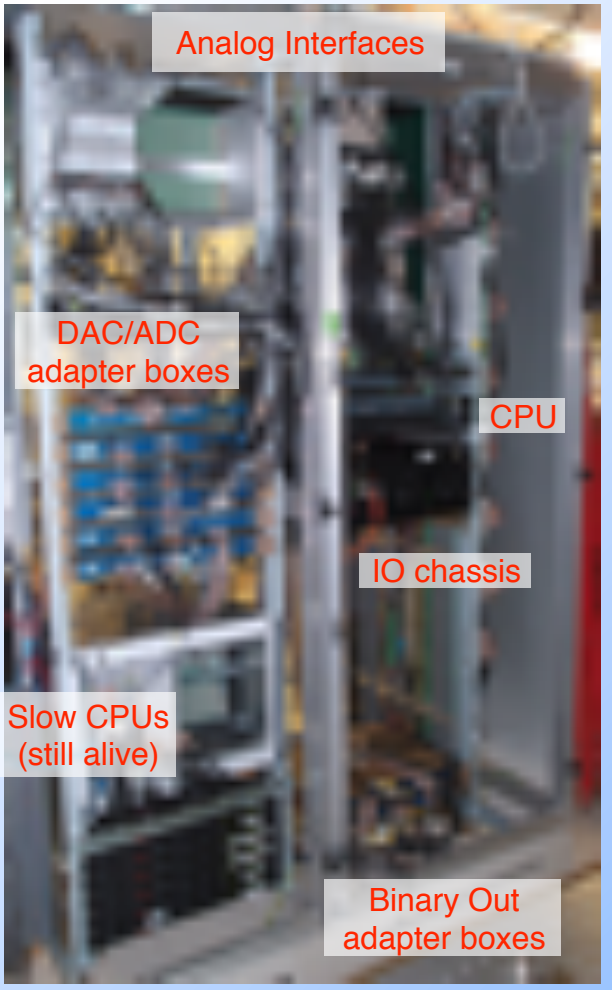
Digital control system

New aLIGO-style distributed digital control system

Replaces the old iLIGO-type hosts while keeping the analog modules



General structure of the realtime controller



Suspension controller & I/F electronics

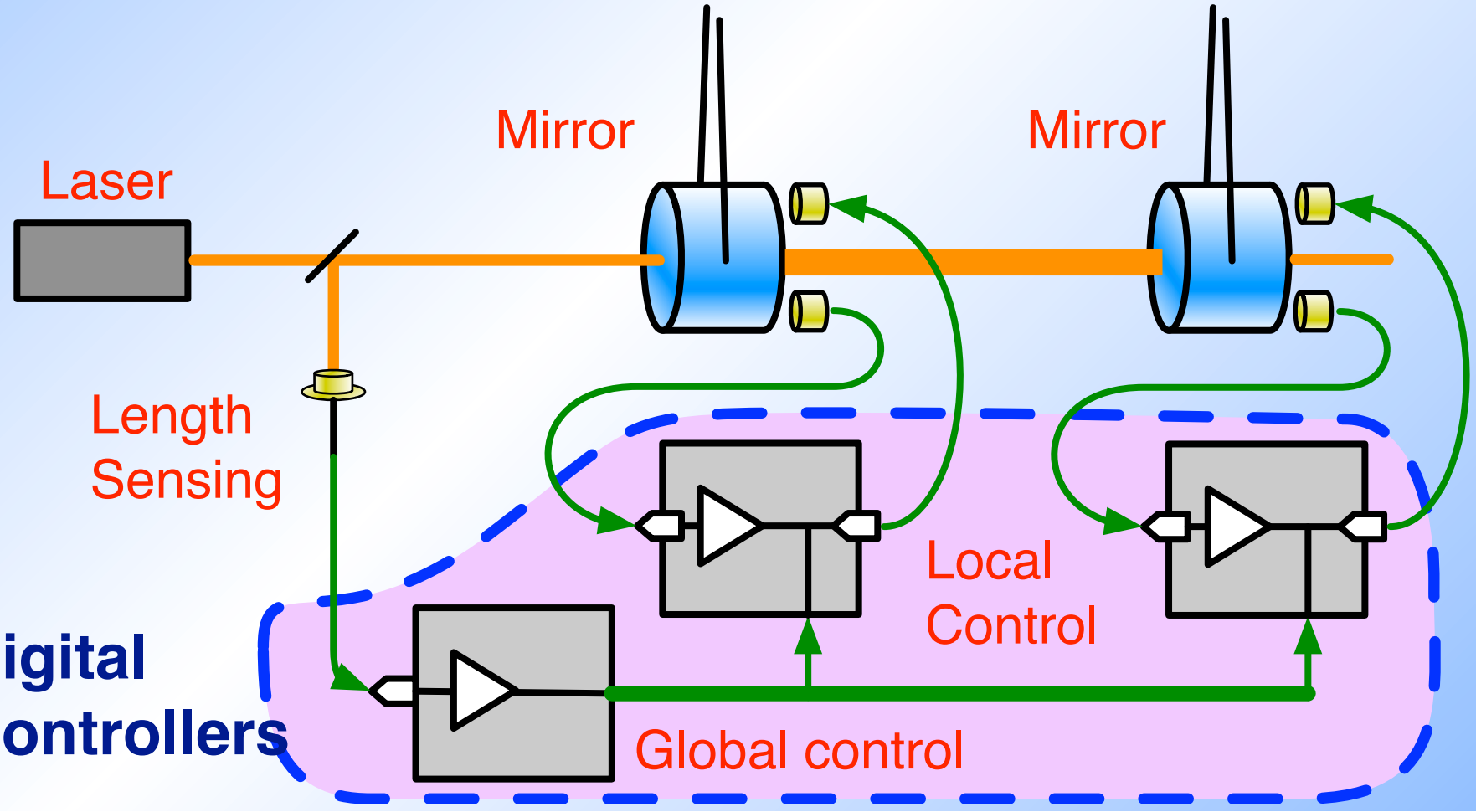
Employs 5 multicore controller hosts connected with reflective memory networks.

Simulated Plant ~ Basic Idea

For more details
DCC G1000546-v1

Interferometer control:

Local control (suspension)
+ Global control (interferometric)



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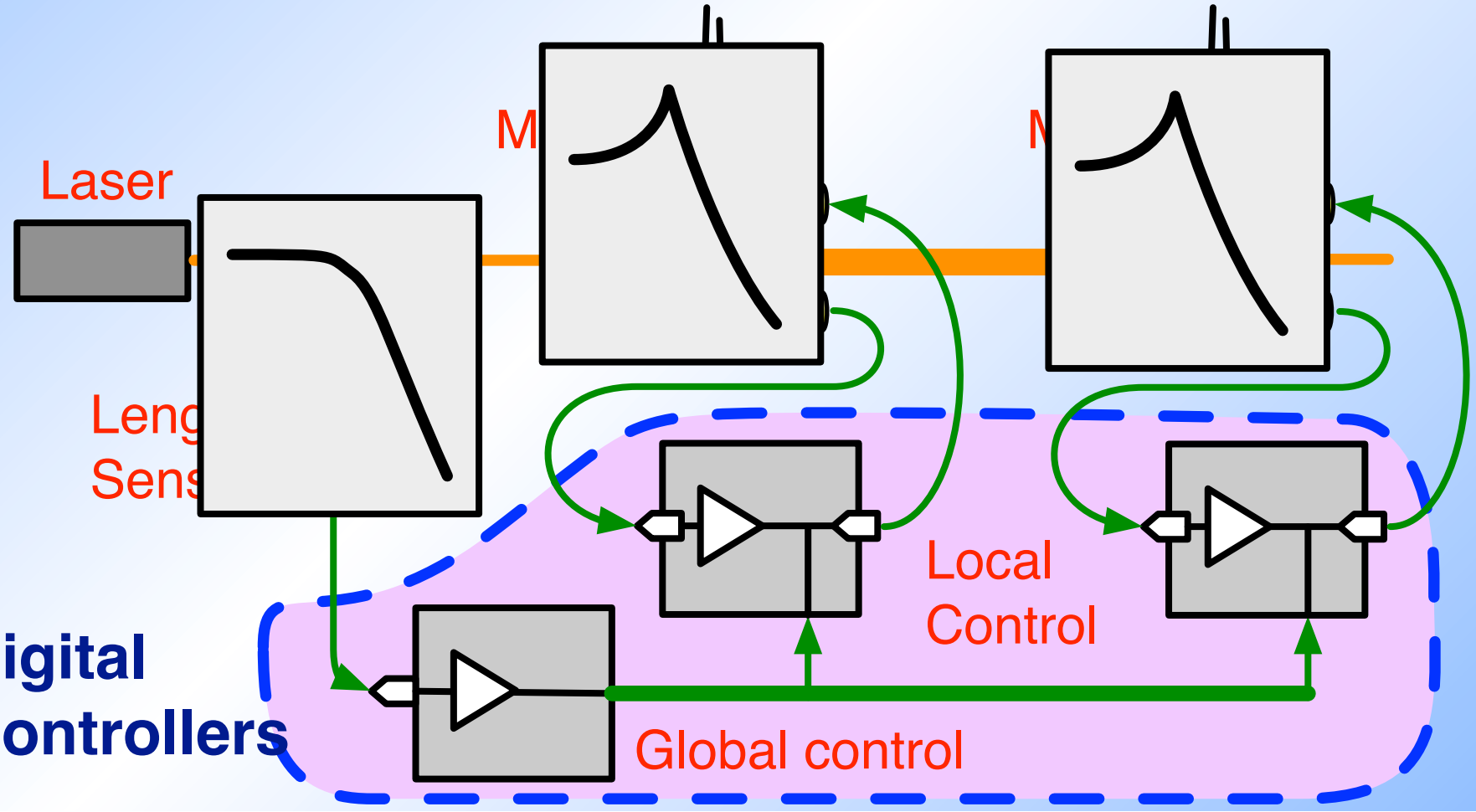


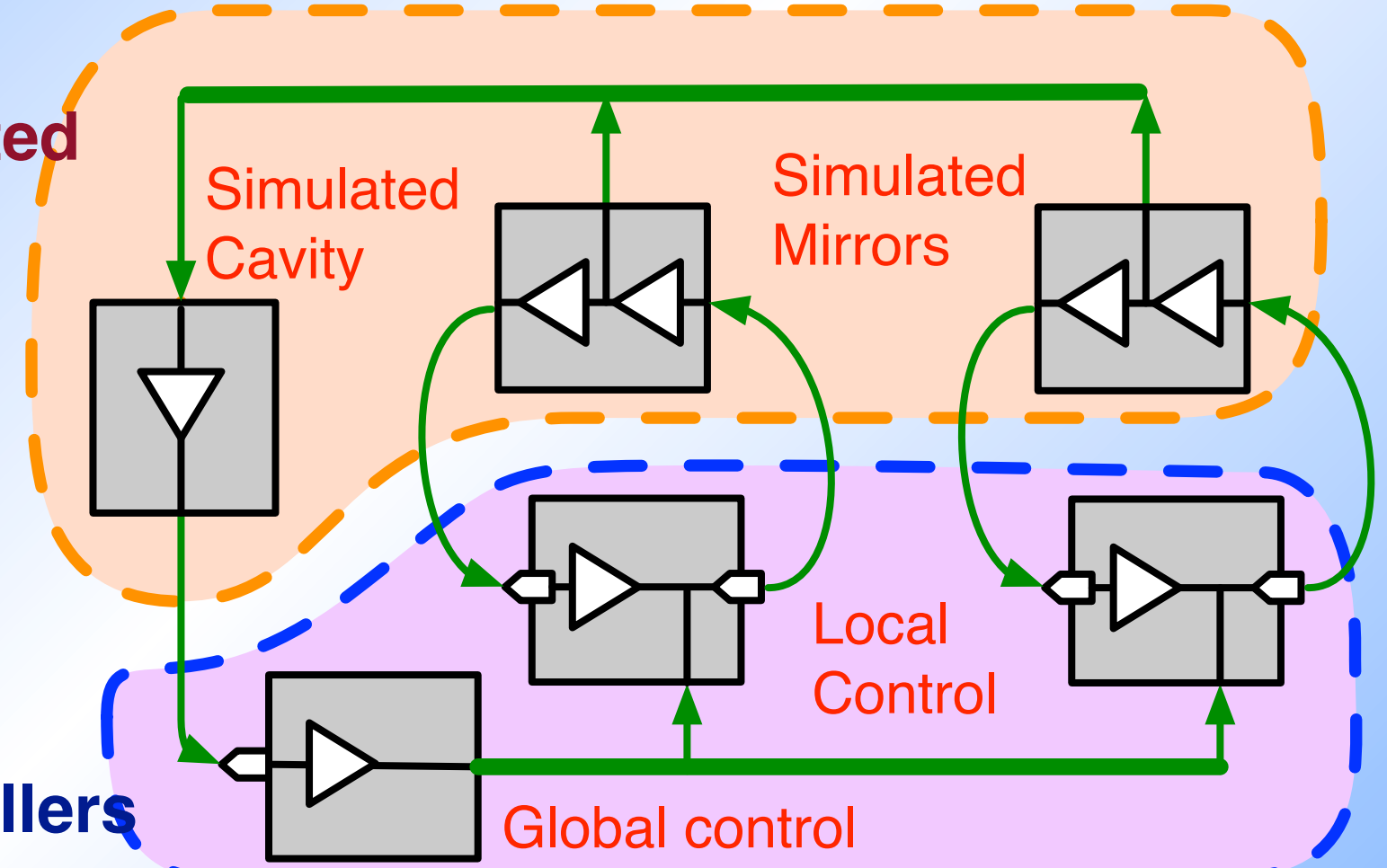
Simulated Plant ~ Basic Idea

For more details
DCC G1000546-v1

Replaced hardware responses with digital filters

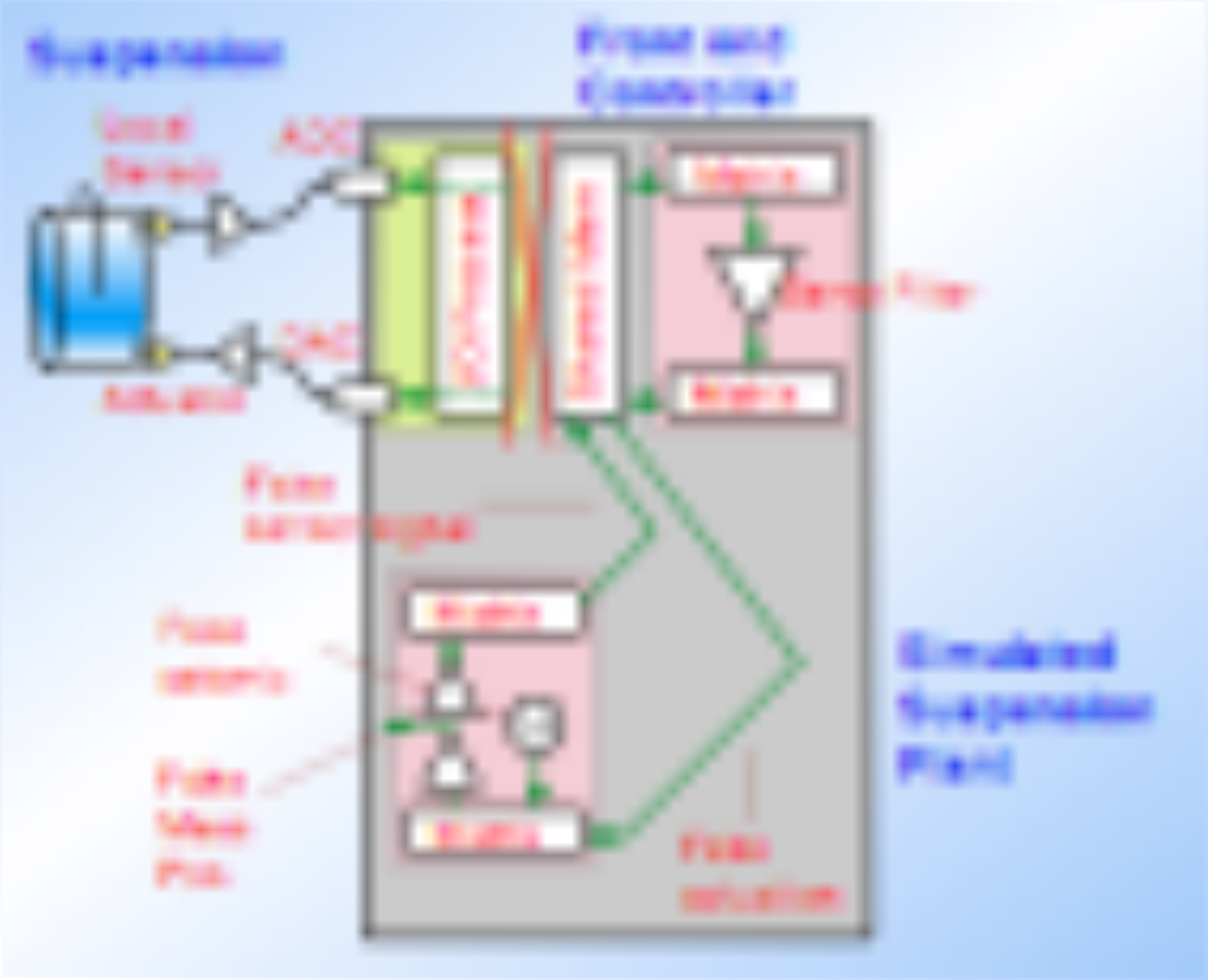
==> simulated plants

The servo loops remains stable



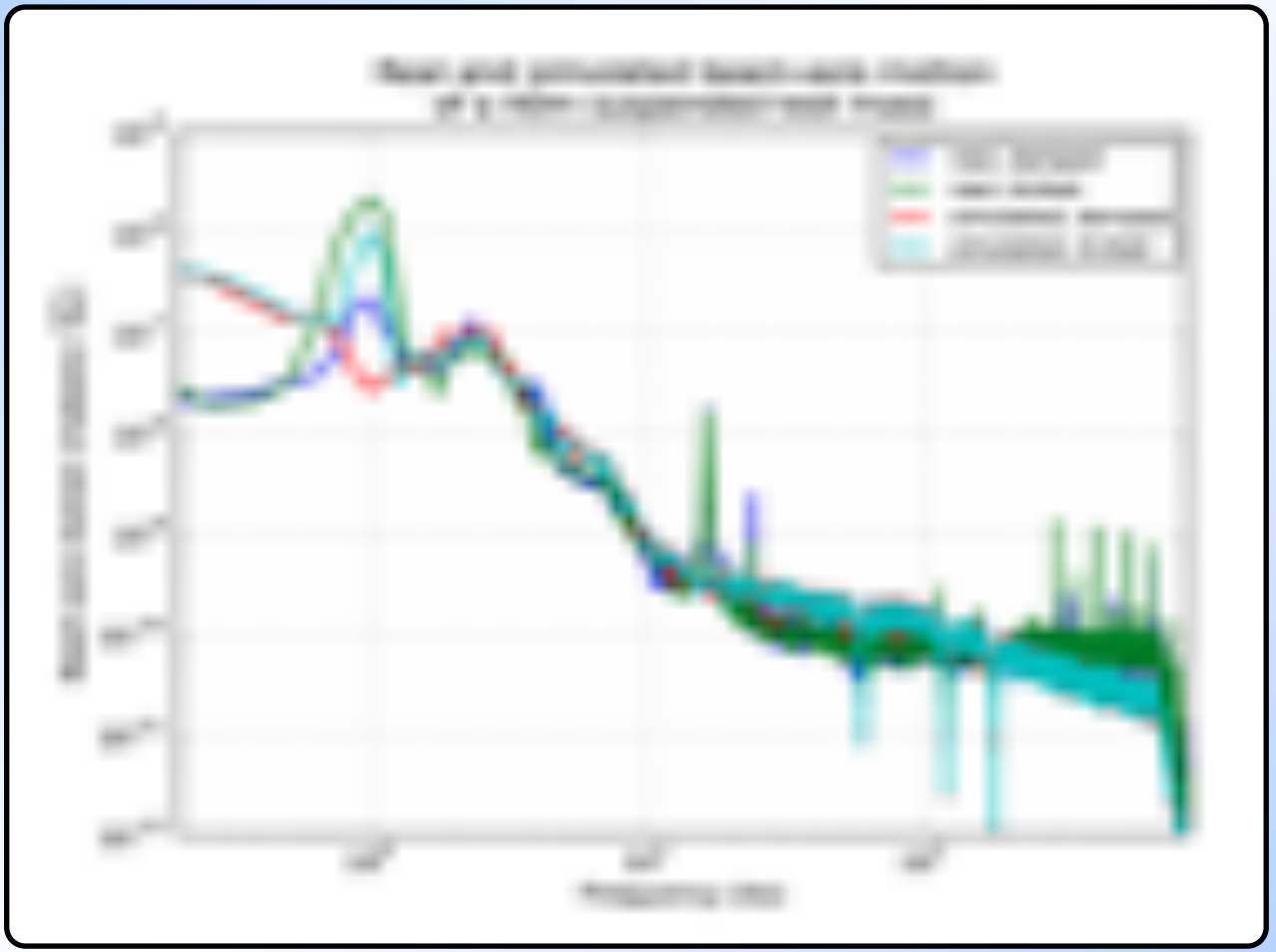
Simulated Plant ~ Realization

- Simulated Plant: Introduce fake sensor signals and obtain actuation signal via the shared mem.



Simulated Plant ~ Realization

- Emulation example of the suspension plant

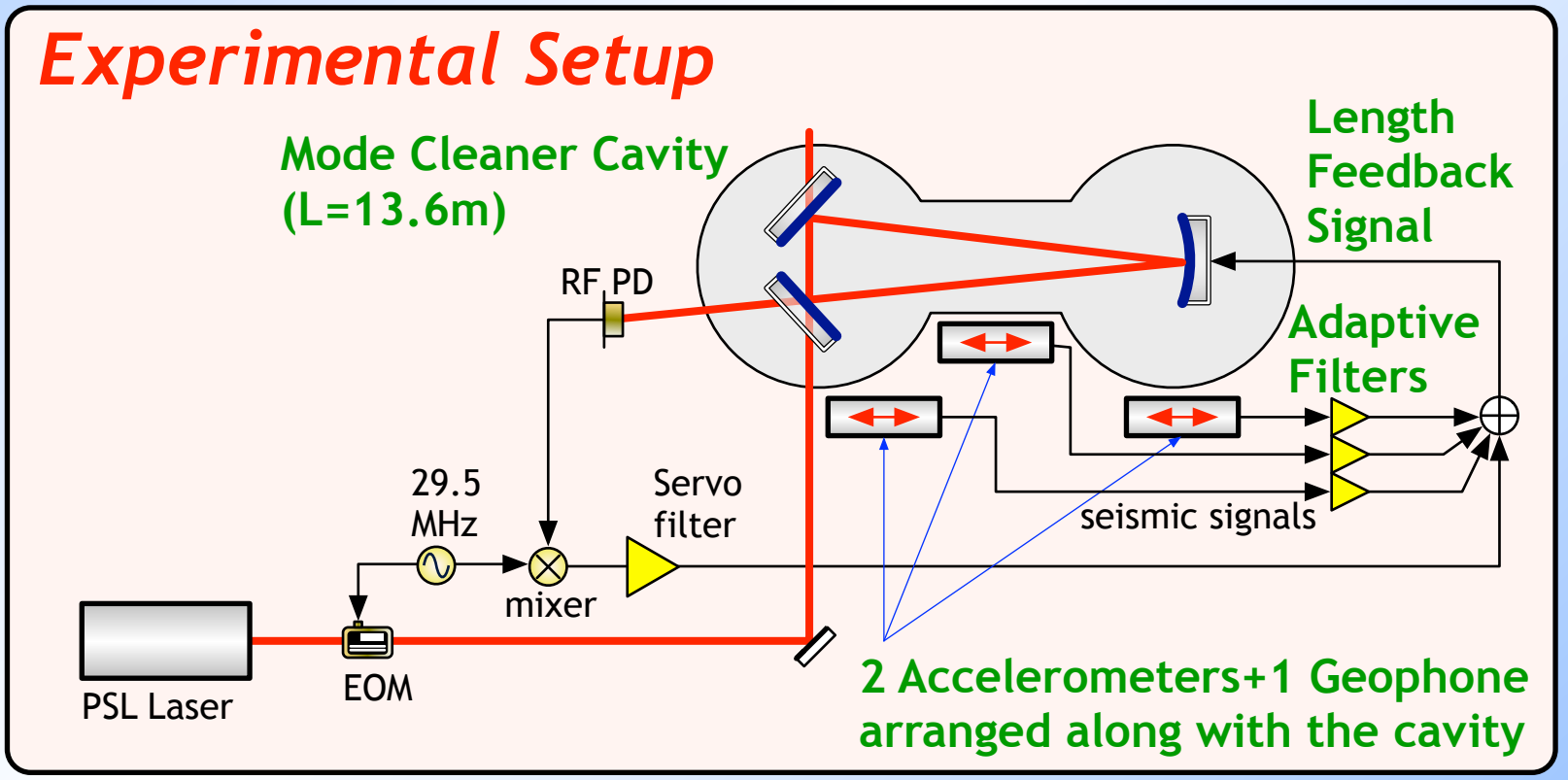


Comparison of noise levels
between the simulated and real suspensions

Adaptive noise cancellation

Feedforward to cancel coherent noise couplings

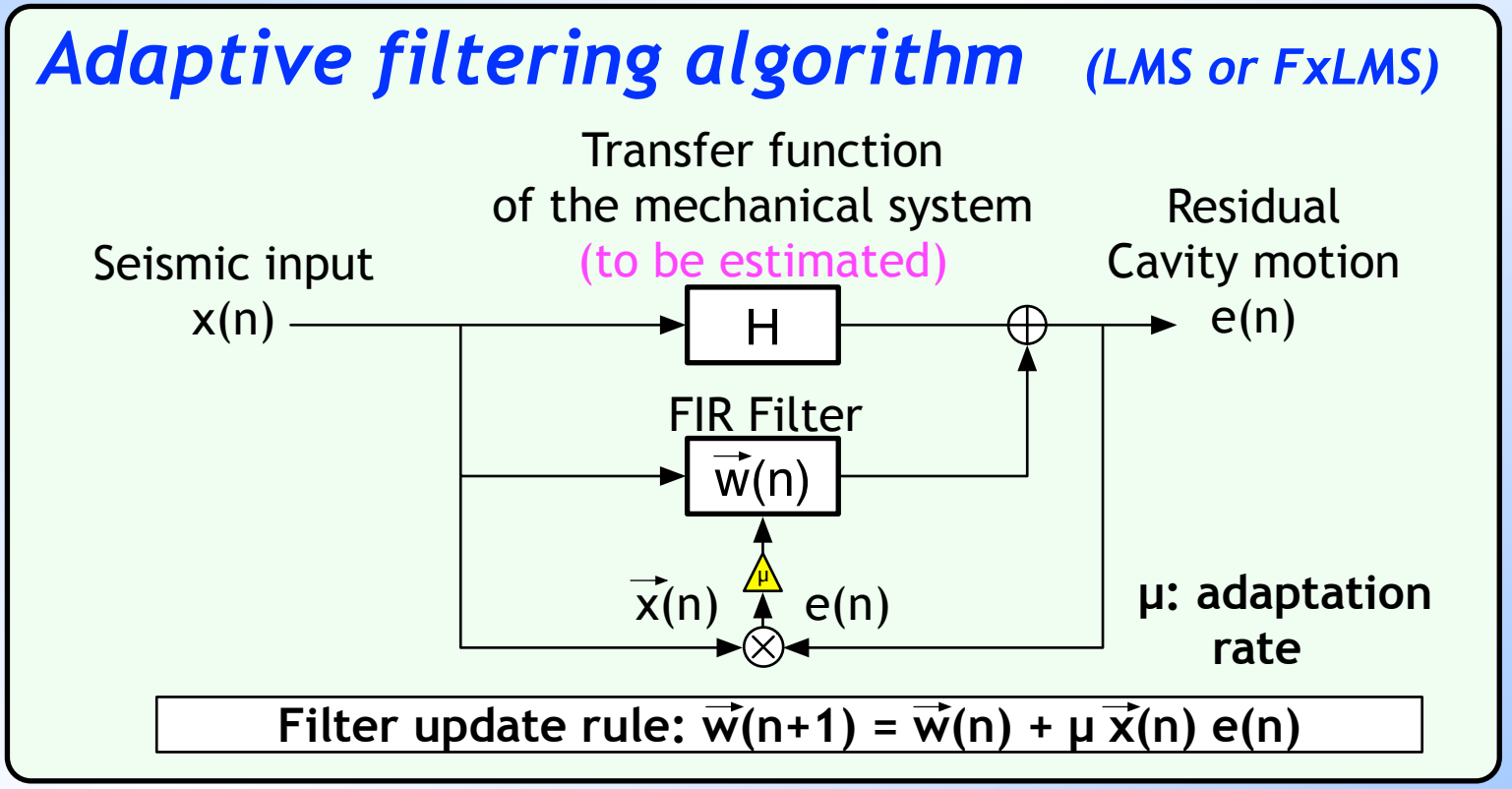
- The seismic feedforward works as an active vibration isolation
  even in the low freq band where the passive isolation is not effective
- Applicable to any noise as long as the witness and the signal are coherent. (e.g. Newtonian gravity noise, magnetic, acoustic)



Adaptive noise cancellation

Algorithm: train the FIR filter with the product of the witness signal and the residual error

The FIR filter asymptotically get close to the wiener filter

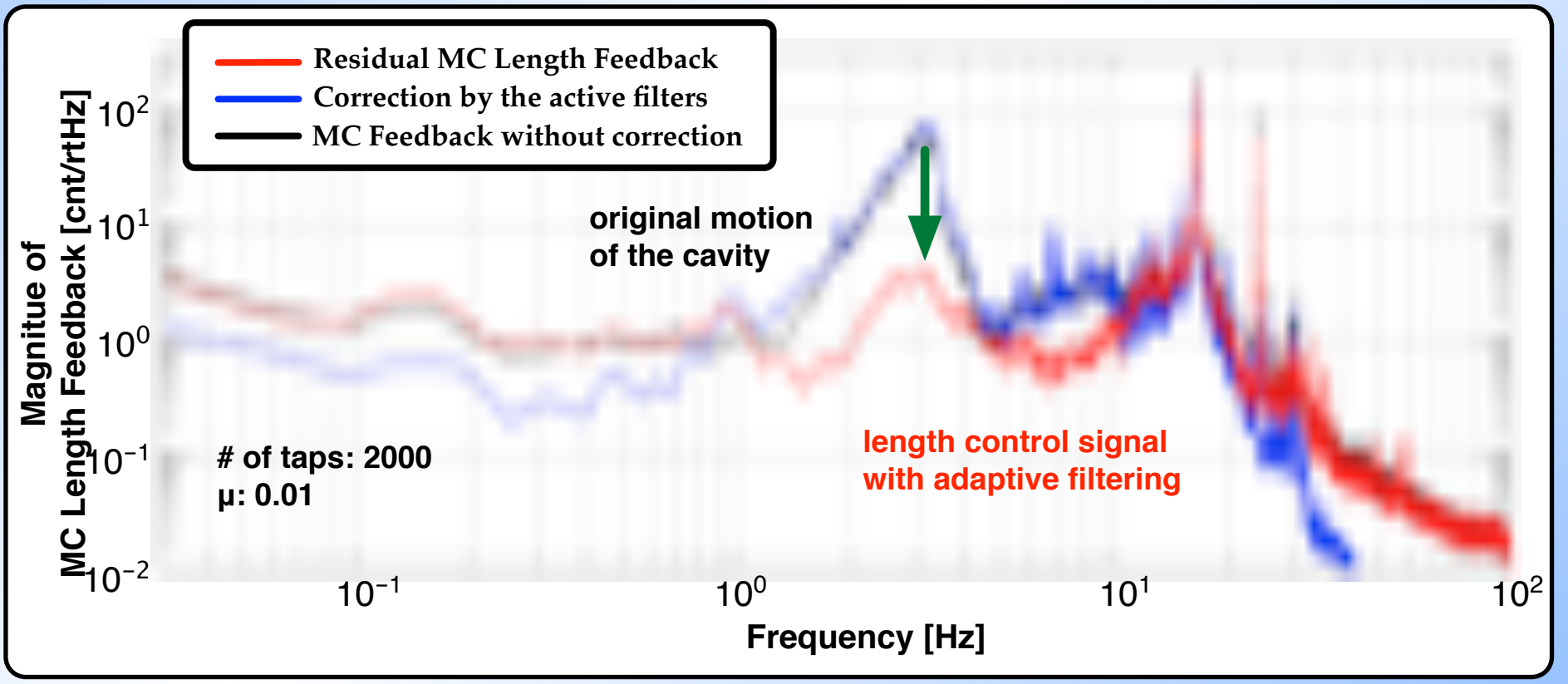


Adaptive noise cancellation

- **Demonstrated reduction of the MC motion**

  three sensor signals are used as the witness channels

  Reduction by a factor of 17 at 3Hz



Summary and Plans for 2011

- **Interferometer sensing and control:**

- Two arms are locked with 532nm and 1064nm beams
- Arm length stabilization of 200pm$_{RMS}$ has been realized
  with auxiliary 532nm laser injection from one of the arm end
- Dual-recycled Michelson is regularly locked and is operating

=> Plan: Characterization of DRMI
Demonstration of full lock with Arm Length Stabilization

- **Digital control system**

- Controllers for the suspensions and length control were implemented
- Simulated plant: suspensions and a simple cavity have been modeled

=> Plan: Expansion of the simulated models for full IFO

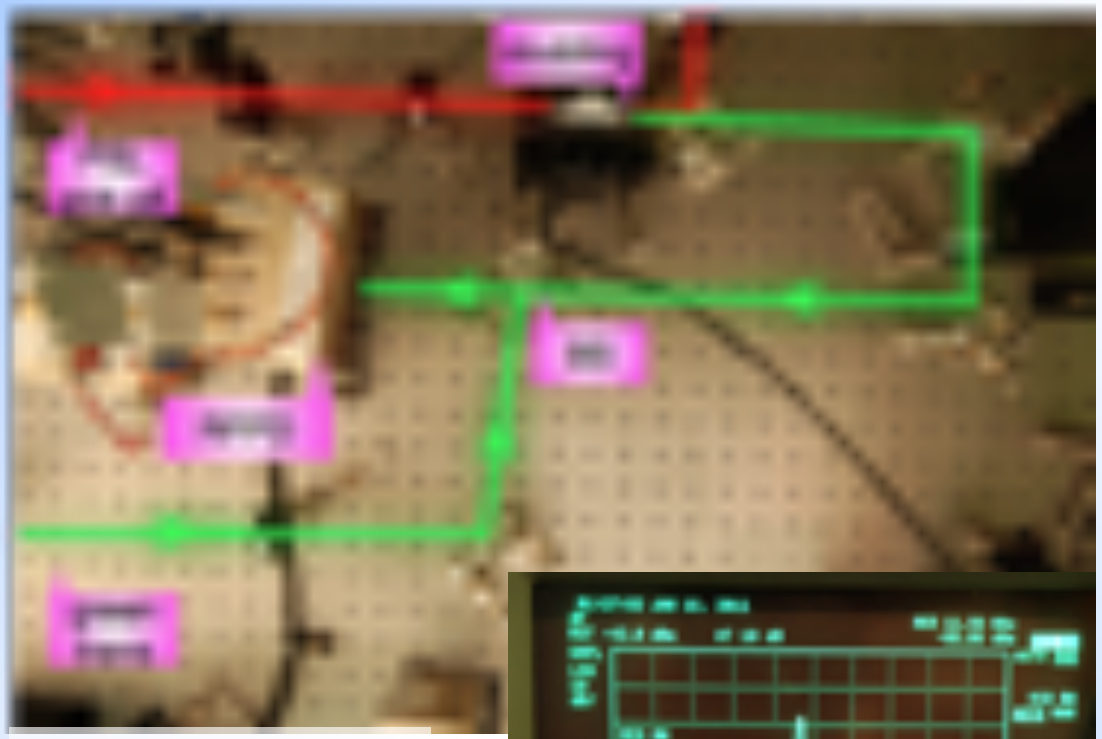
- **Adaptive seismic noise cancellation**

- Achieved reduction of the MC length change

=> Plan: Implementation of the technique
to the main arm cavities

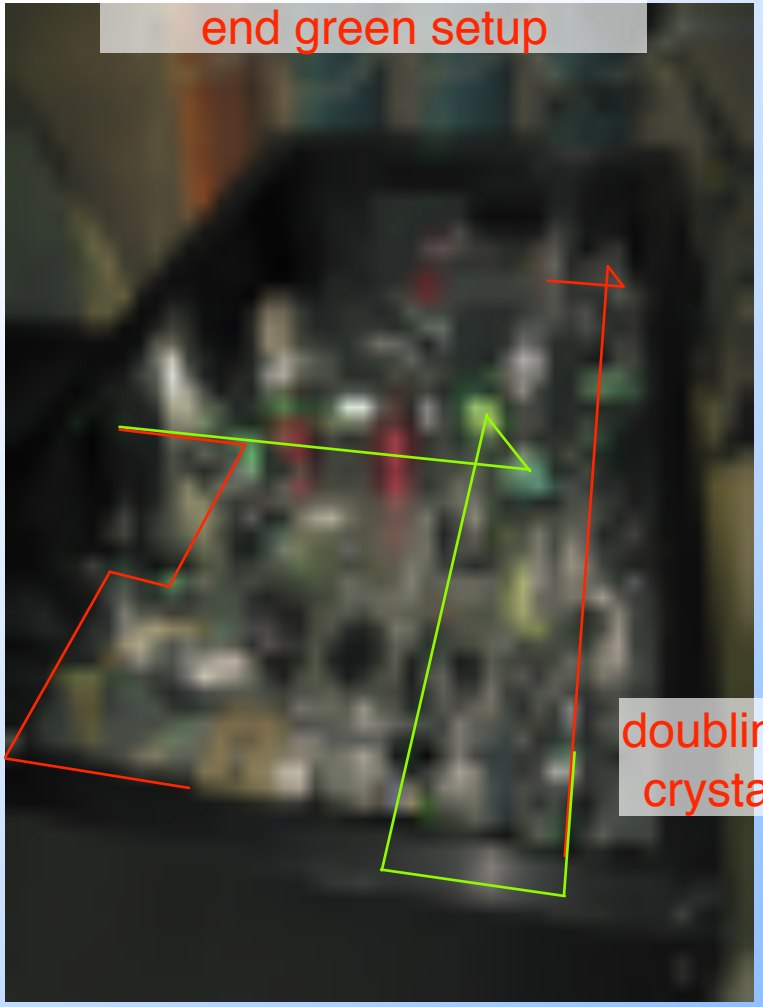
ALS: Setup

- both arms locked with green
- beat note at the vertex obained and stabilized
- beat freq sweep / differential freq noise



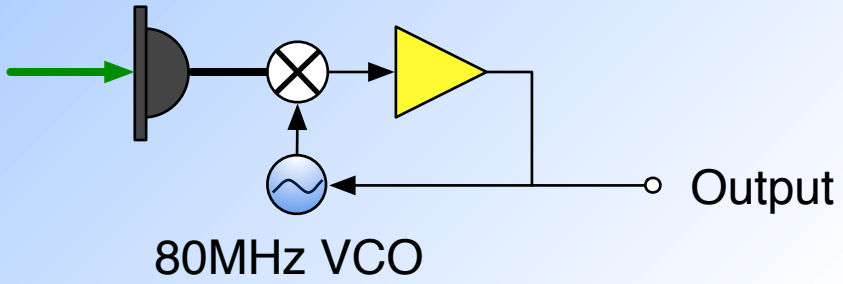
vertex beat detection setup

beat note

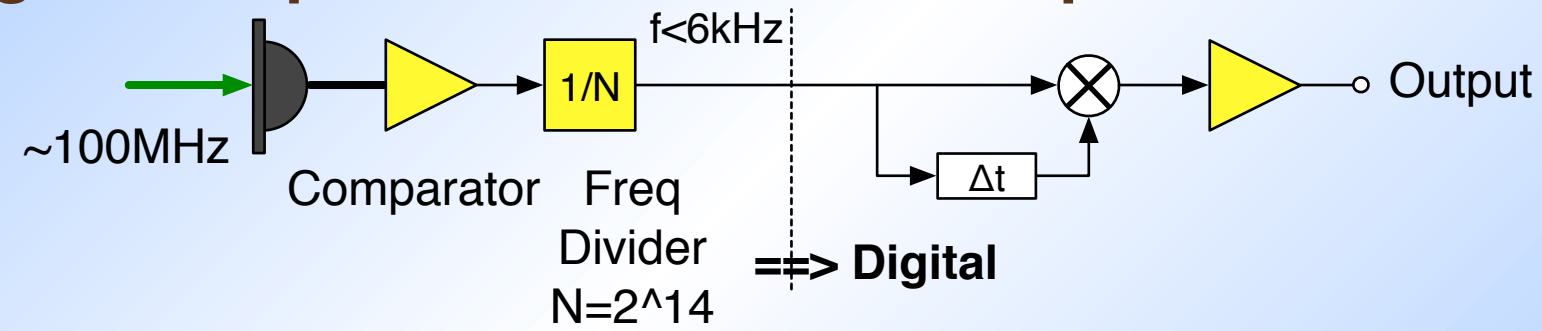


ALS: 3 options for freq discrimination

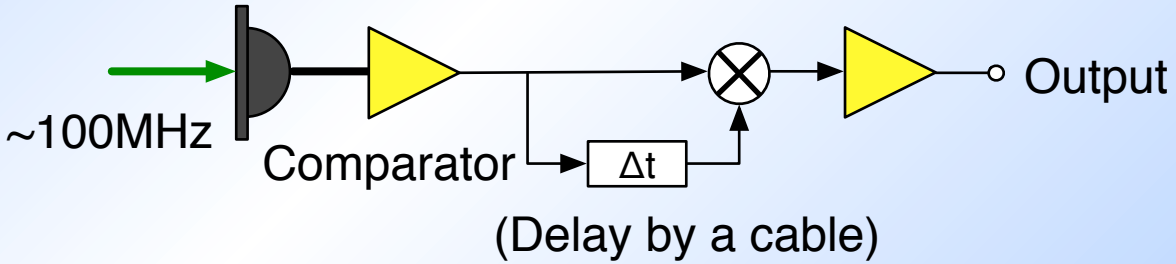
- PLL with VCO



- Digital Freq Discriminator with freq divider



- Mixer Freq Discriminator



Another option is the phase frequency discriminator which is being considered for aLIGO

https://awiki.ligo-wa.caltech.edu/aLIGO/PhaseFrequencyDiscriminator

ALS: Mixer Frequency Discriminator (MFD)

Basic idea:

Delay: Δt ⇒ $\phi(f)$

Mixer: $\phi(f)$ ⇒ Voltage