LISA

Beyond Einstein: From the Big Bang to Black Holes

Frequency-Tunable Pre-stabilized lasers for LISA via Sideband Locking

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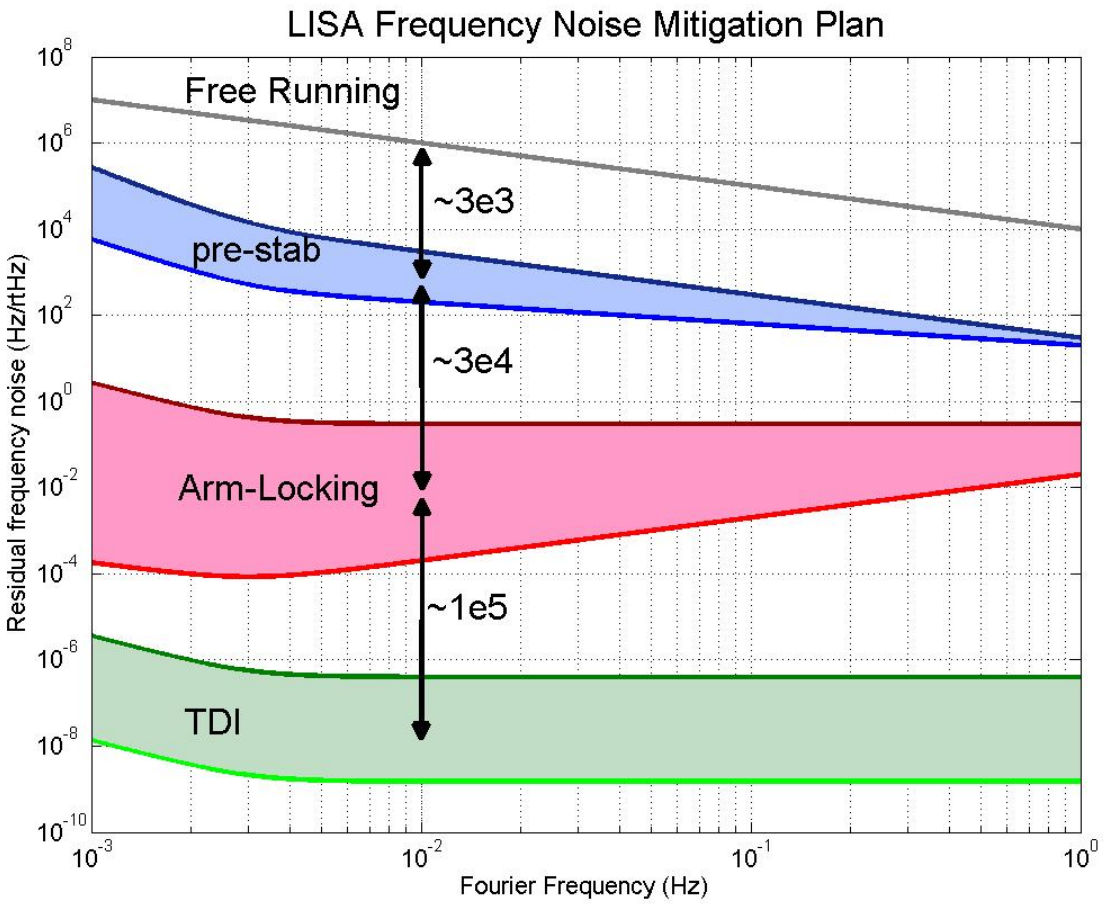
Motivation

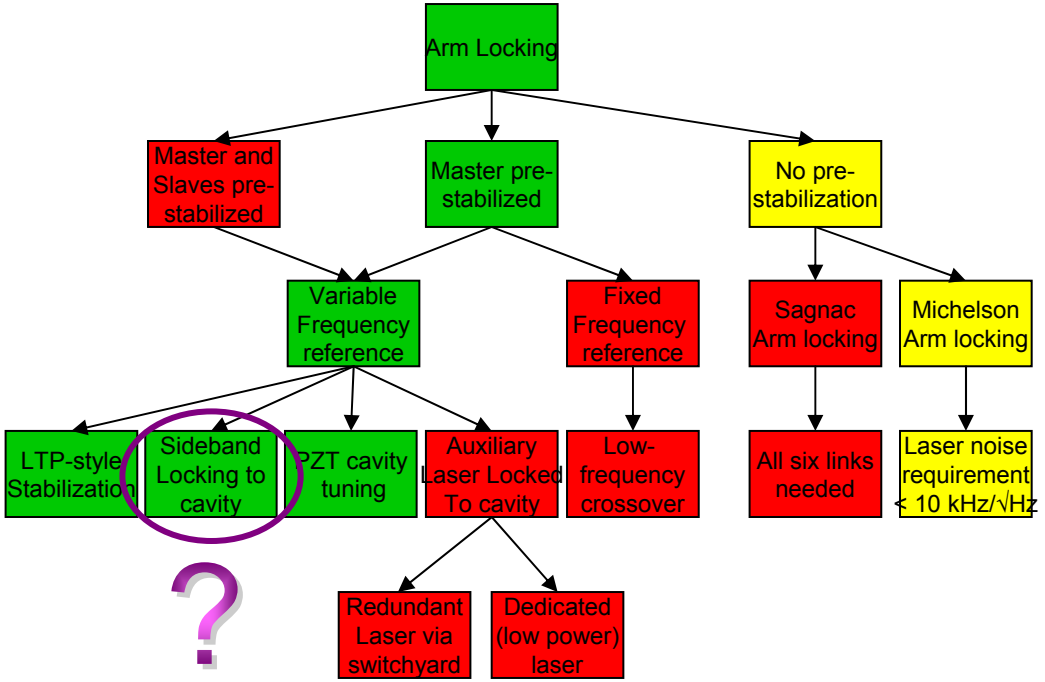
Laser frequency noise is a major potential noise source for LISA

- Three-stage system (two active one passive) to achieve overall suppression of ~10^{13}
- Running pre-stabilization and arm-locking in series reduces gain (bandwidth) requirements on arm-locking.
- Serial arrangement *requires frequency-tunable pre-stabilization* because cavity lock point drifts with respect to arm-locking lock point.



Tunable Reference Concepts for Fabry-Perot Cavities

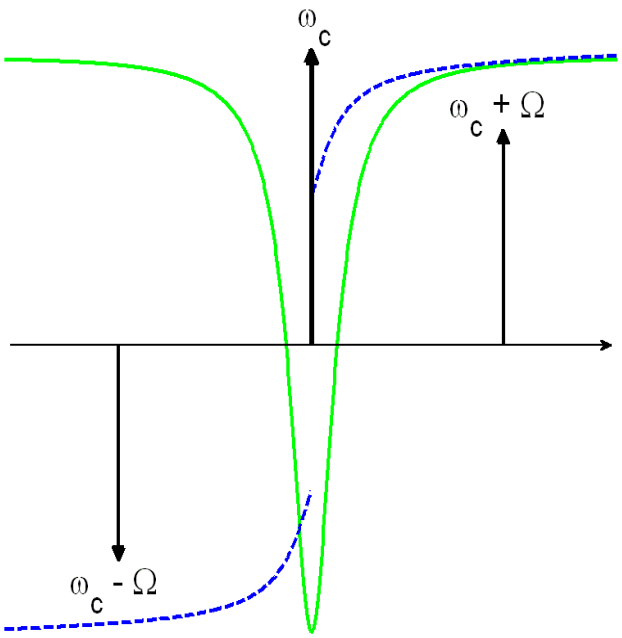
- Tunable Cavity
  - Adjust length of cavity spacer
  - "Standard" method
  - Likely reduces cavity stability
- Offset Phase-Lock Loop
  - Lock master laser to cavity, PLL slave with adjustable offset
  - No modification to cavity
  - Requires additional laser
- Offset Sideband Locking
  - Use EOM as frequency actuator
  - EOM already present for PDH
  - No modification to cavity
  - Increased noise?



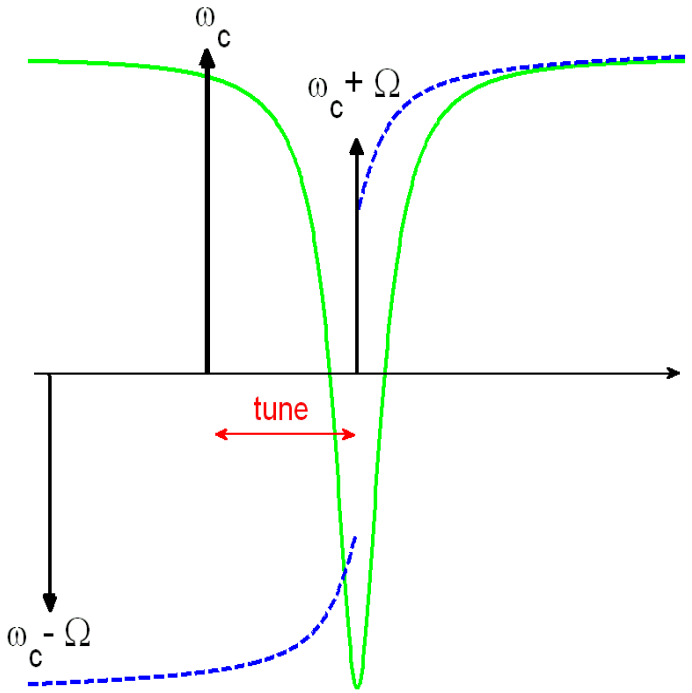
Offset Sideband Locking

Concept: Lock phase-modulation sidebands to cavity resonance and tune central frequency by adjusting modulation frequency.

Normal Pound-Drever-Hall Lock

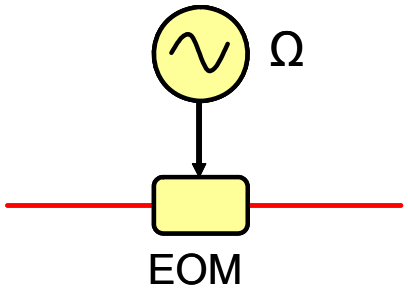


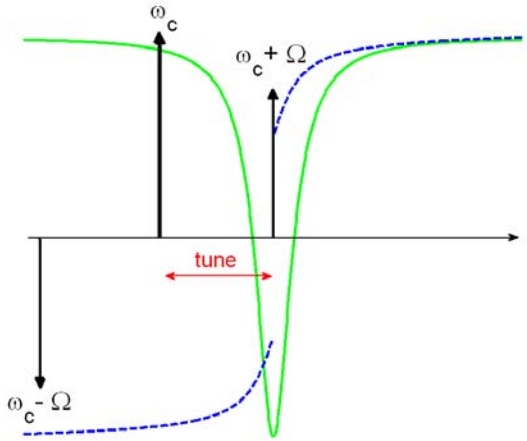
Sideband Lock



Three Flavors of Sideband Locking

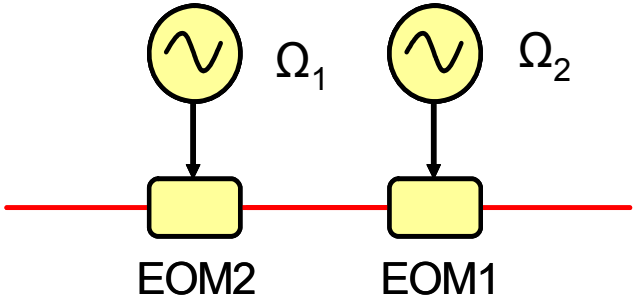
Single Sideband (SSB)

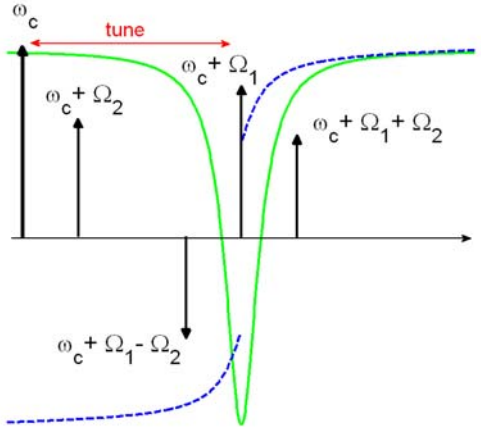




- Simplest to implement
- Some noise coupling due to asymmetry

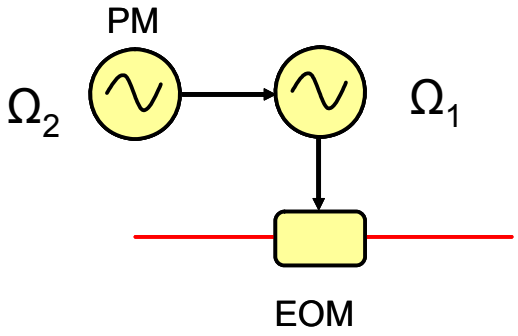
Dual Sideband (DSB)

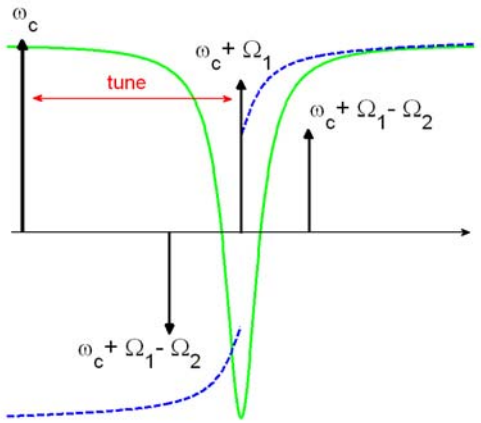




- Restores PDH symmetry
- Complex modulation pattern

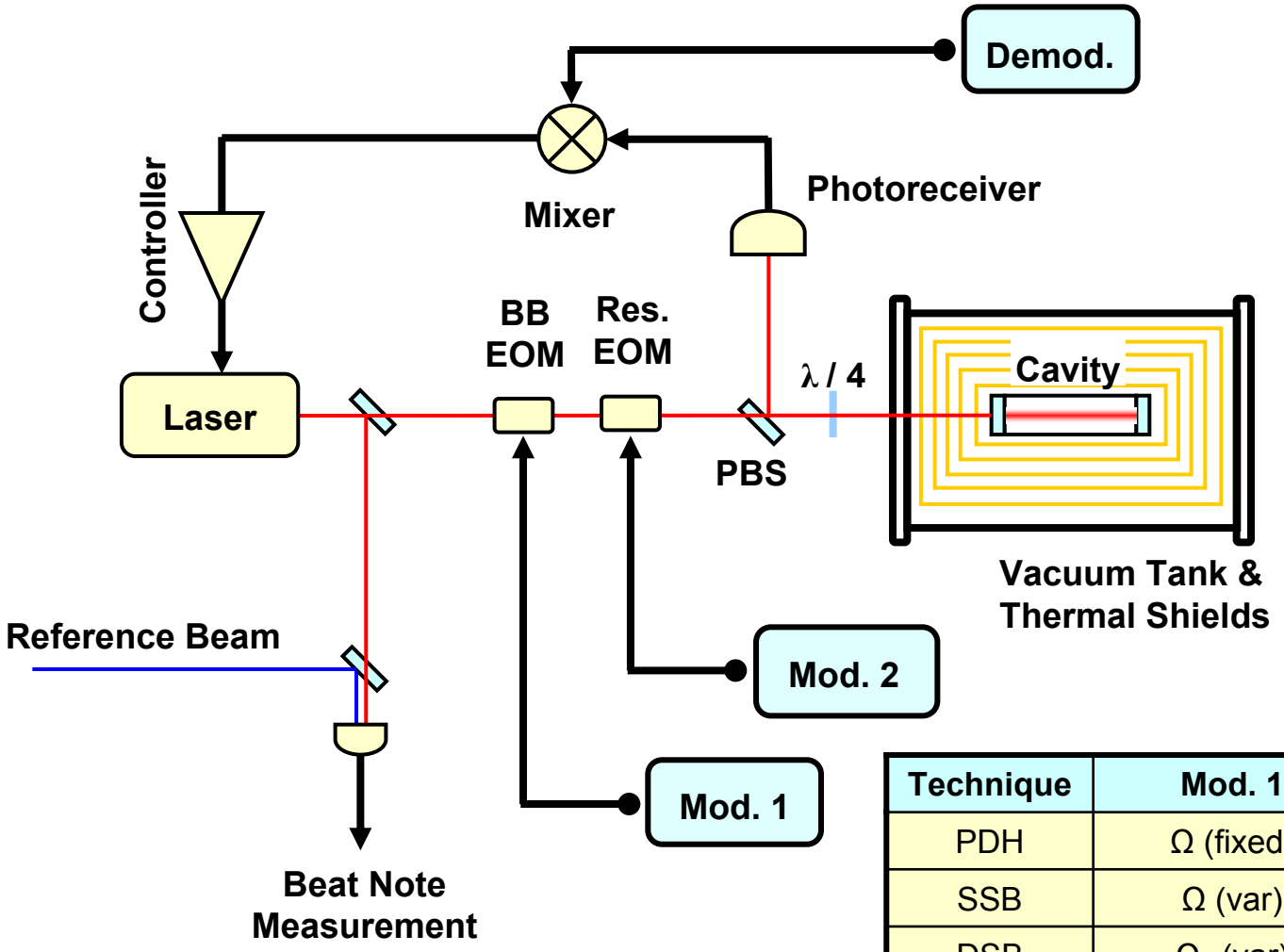
Electronic Sideband (ESB)





- Simple, symmetric modulation pattern
- Requires phase modulation capability on LO

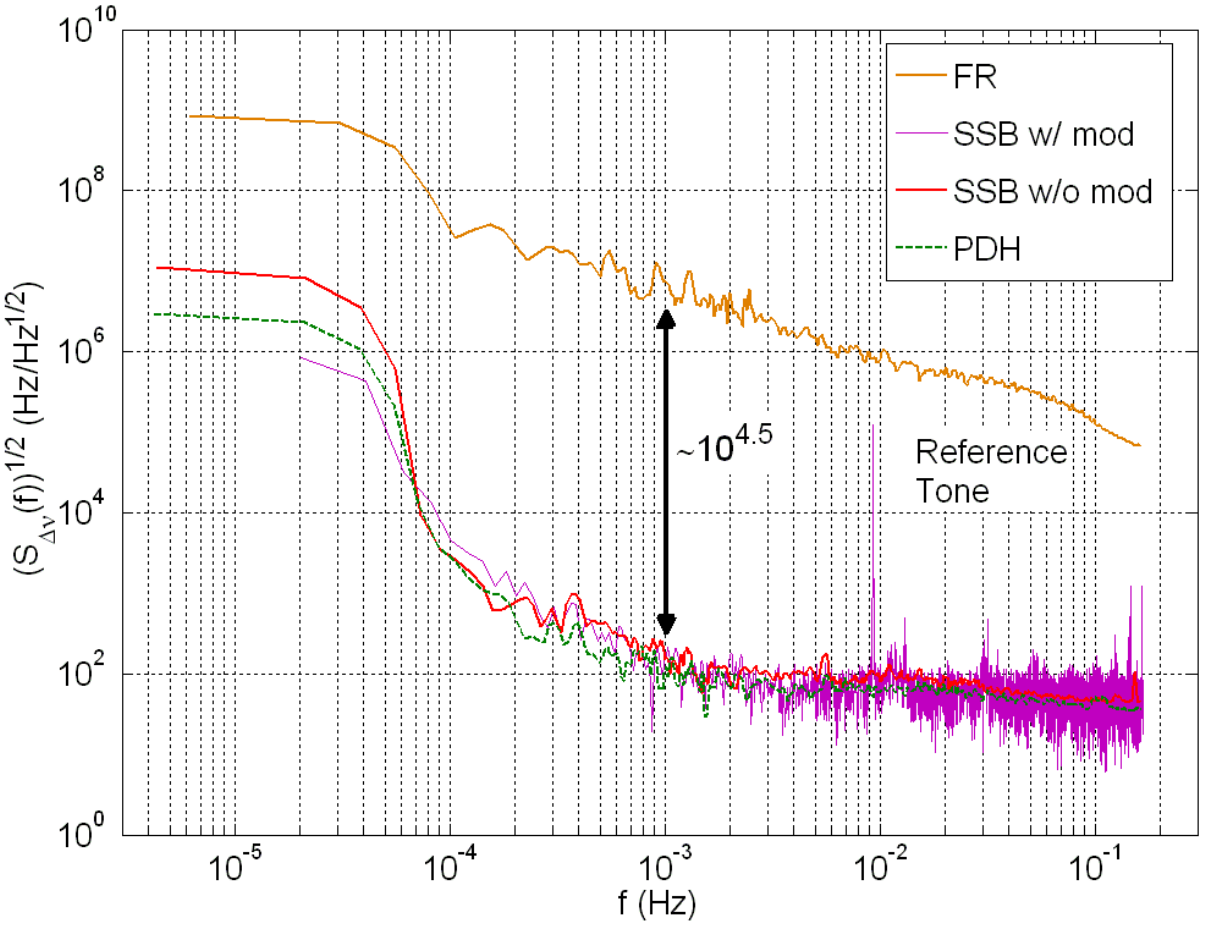
Laboratory Study



Technique	Mod. 1	Mod. 2	Demod
PDH	Ω (fixed)	N/A	Ω (fixed)
SSB	Ω (var)	N/A	Ω (var)
DSB	Ω_1 (var)	Ω_2 (fixed)	Ω_2 (fixed)
ESB	Ω_1 (var) w/ Ω_2 ϕM (fixed)	N/A	Ω_2 (fixed)

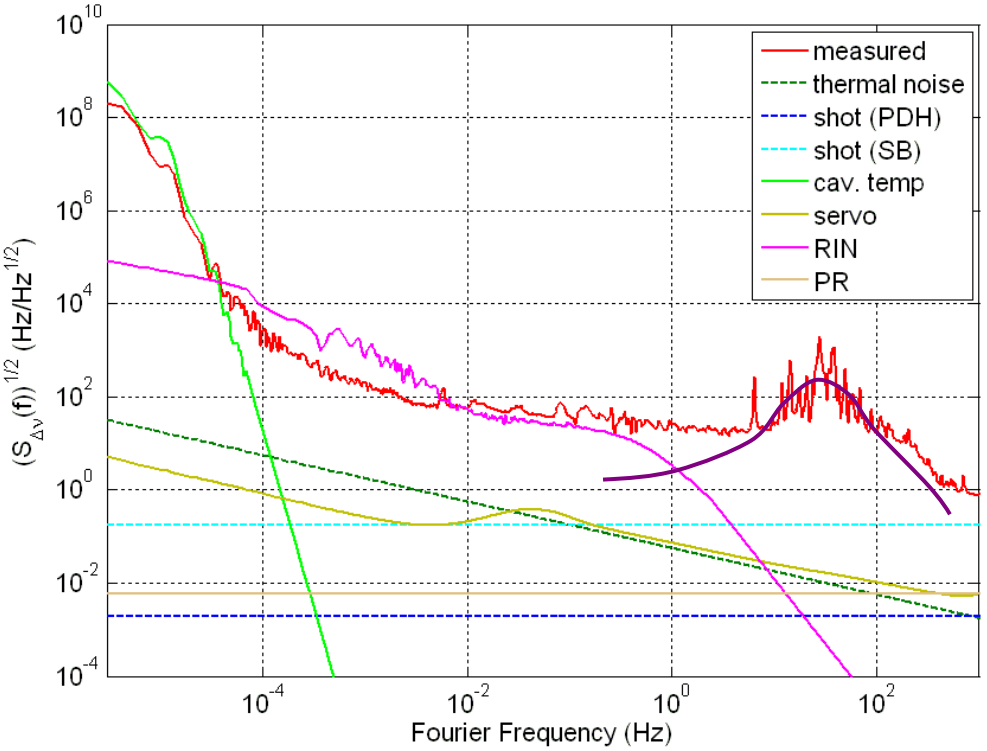
Stability Results

- Standard PDH and SSB locking have identical noise performance.
- Adding modulation tone does not disturb the noise floor.
- Similar results with other sideband locking schemes (DSB & ESB)



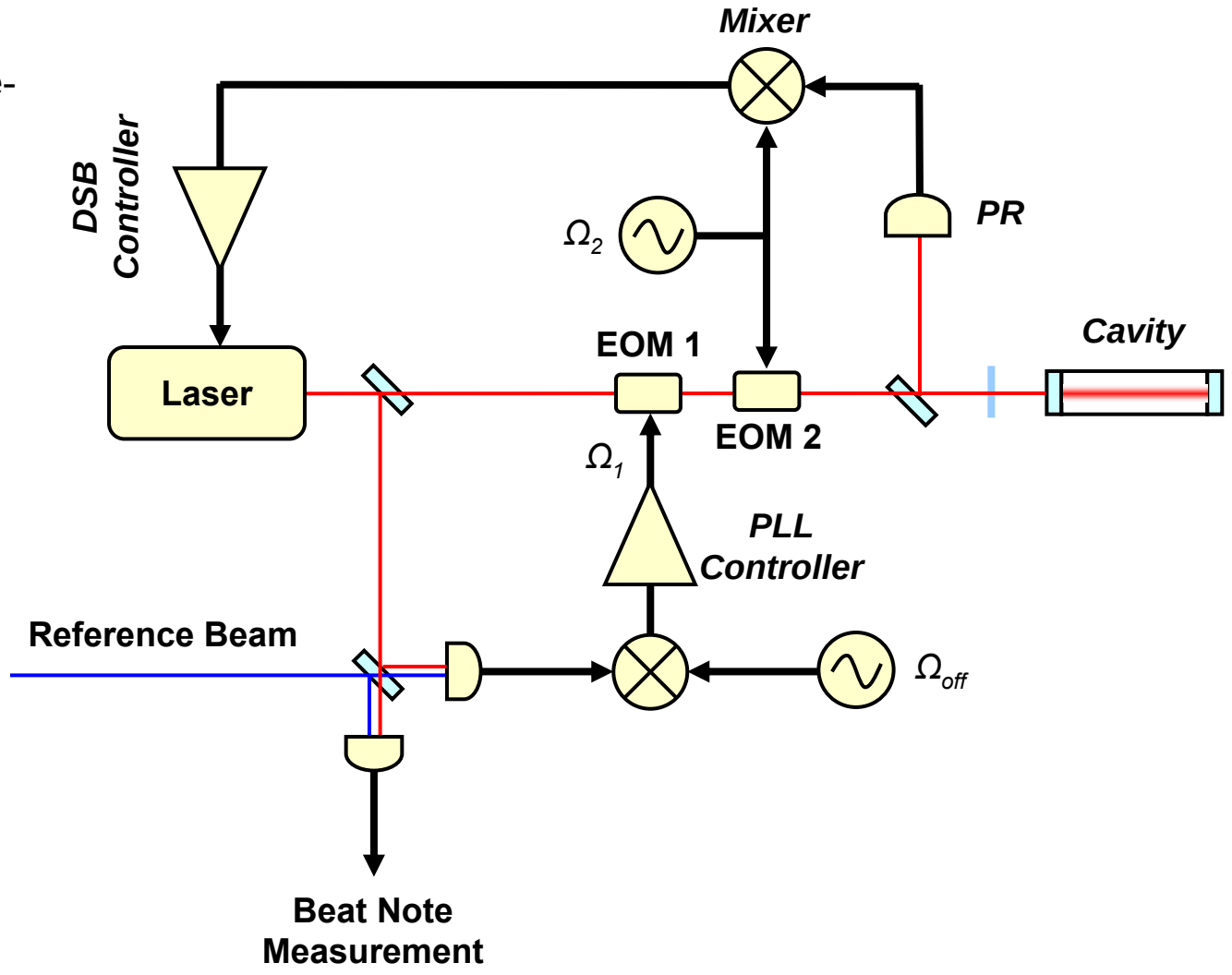
Preliminary Noise Model

- Fundamental Noise
  - Shot noise
  - Cavity thermal noise
- Technical Noise
  - Temperature Fluctuations
  - Servo Noise
  - Photoreceiver noise
  - RIN
    - via RFAM
    - via absorption
  - Vibration Noise/Acoustic
  - Pointing
  - ???



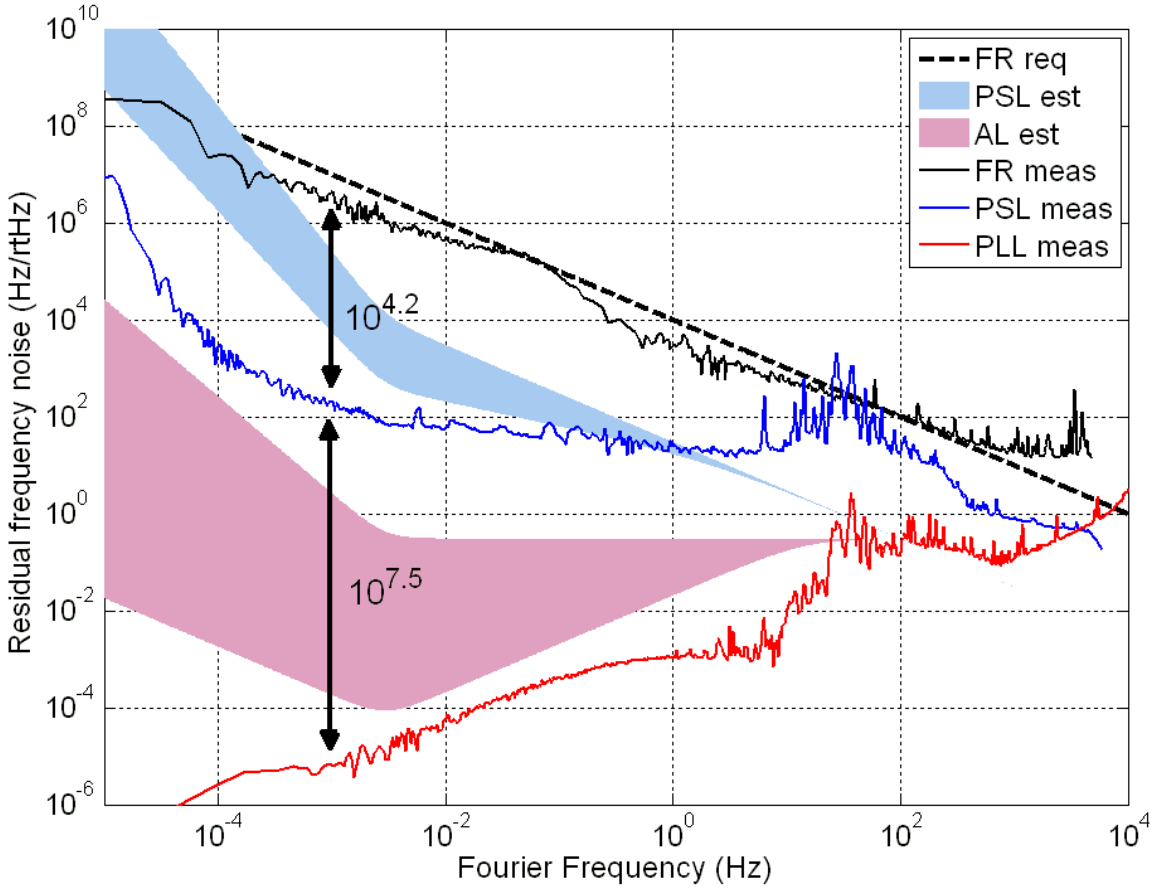
Pre-stabilized Phase-Lock Loop

- Use DSB locking as a pre-stabilization stage in a phase-lock loop
- PLL gain required to achieve given noise floor will be reduced by DSB gain.
- Demonstrates dynamic range, bandwidth, and noise of sideband locking system as an actuator.



Pre-Stabilized PLL Results

- PSL easily meets requirements below 1Hz
- PSL noise high above 1Hz, believed to be vibration/acoustics & RIN
- PLL noise floor beats arm-locking CBE, indicating actuator noise is sufficiently small for arm-locking



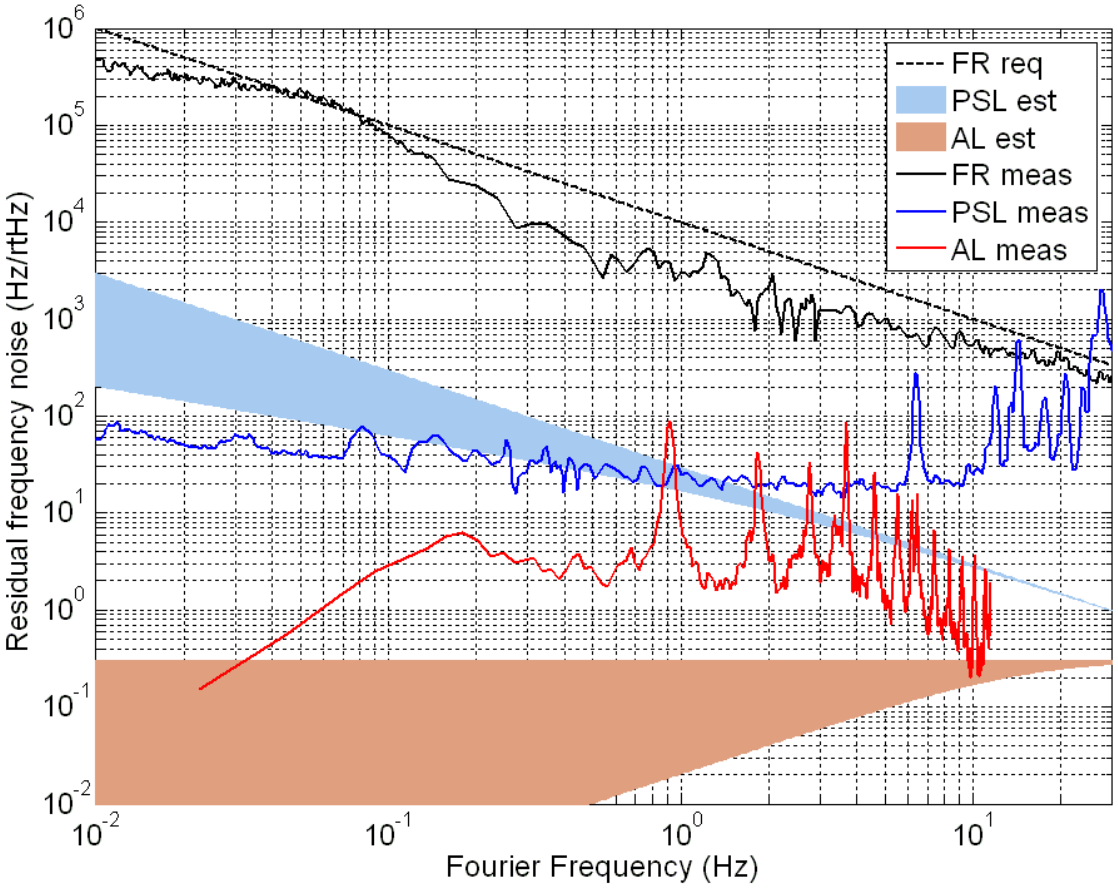
Arm-Locking Results

- Simulate 1-s long arm using EPD technique
- Perform single-arm locking in place of PLL
- Observe characteristic arm-locking noise spectrum

See V. Wand's talk

&

Y. Yu's poster



Summary

- Current LISA Frequency Noise Plan requires frequency-tunable pre-stabilization system
- Offset Sideband locking can provide frequency tuning with minimal modification to standard cavity-locking technique
- Laboratory results demonstrate that sideband locking can meet the LISA pre-stabilization requirements
- Initial demonstration of first two steps to LISA frequency noise suppression.

Backup Slides

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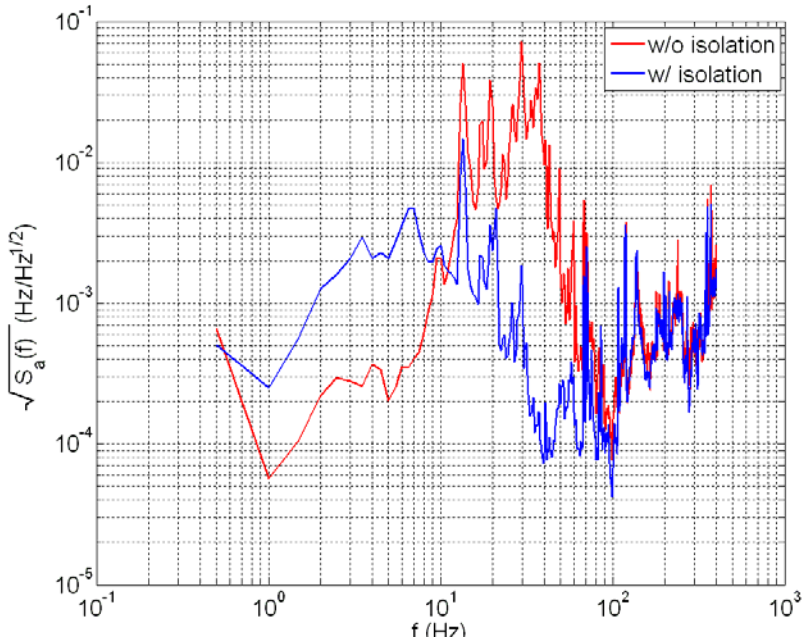
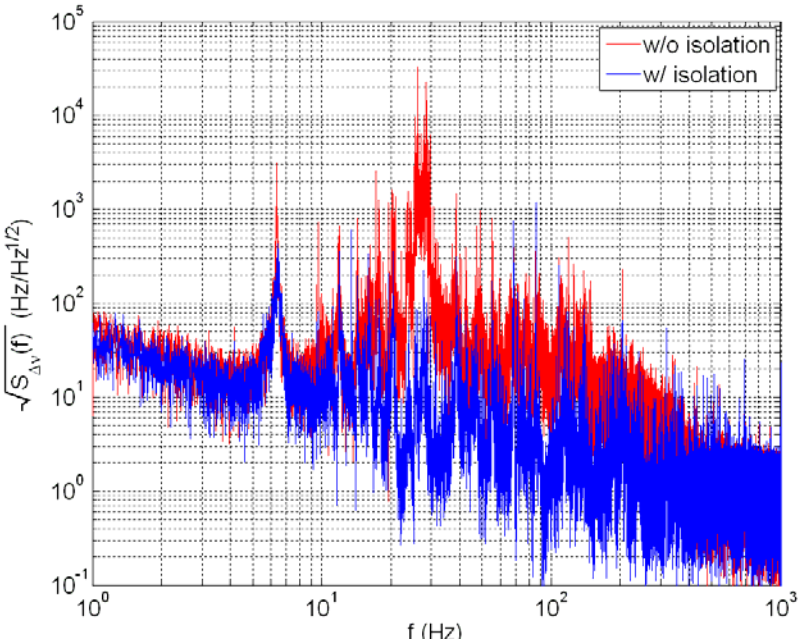
Vibration Noise

Table Acceleration Noise
Measured via Accelerometer

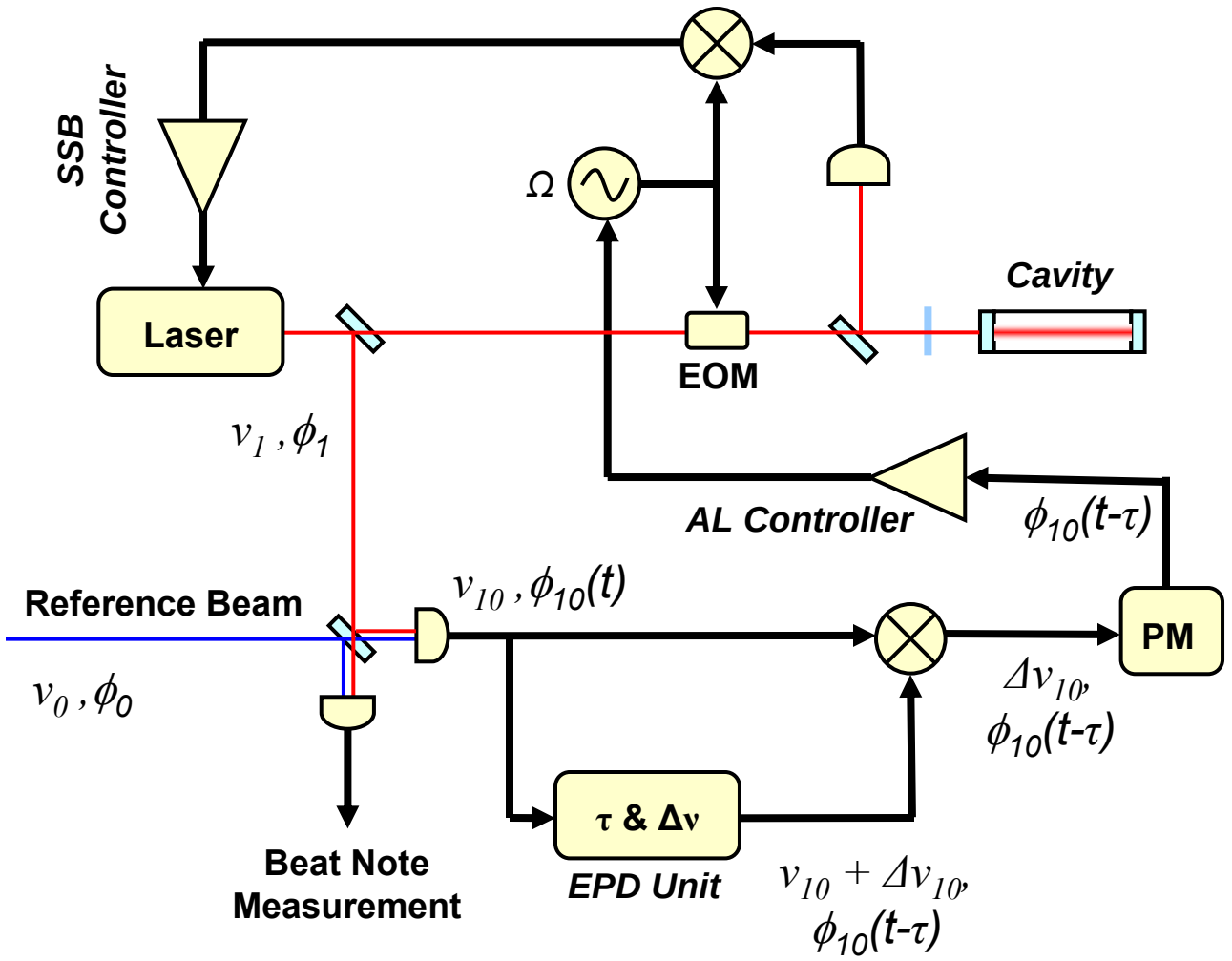


Frequency Noise measured
via phasemeter



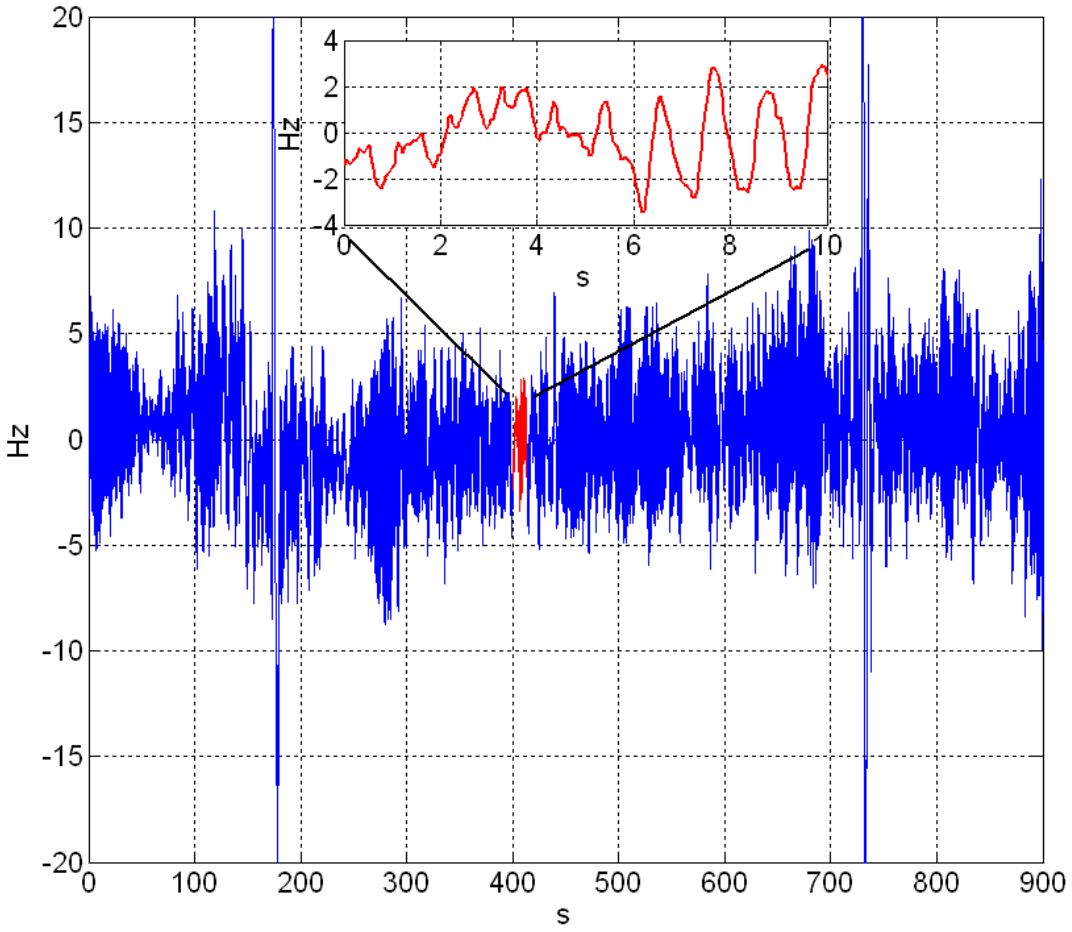
Hardware arm-locking model

- Extension of PLL example utilizing Electronic Phase Delay (EPD) technique to mimic arm-locking error signal.
- Simulates single-arm locking
- ~1s round-trip delay
- Fixed Doppler shift
- Utilized SSB locking for first test.



Arm-Locking Timeseries

- 1 s delay gives noise at 1 Hz multiples
- Pre-stabilization noise is non-stationary, glitches excite arm-locking transients



Arm-Locking Transfer Function

- Measured noise suppression matches expectations
- ~40dB at 100mHz