Feed-forward vibration isolation and reduction of Newtonian noise

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1. Newtonian noise
2. Feed-forward (FF) control
3. Some demonstrations of FF vibration isolation
4. Our plan

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Newtonian noise

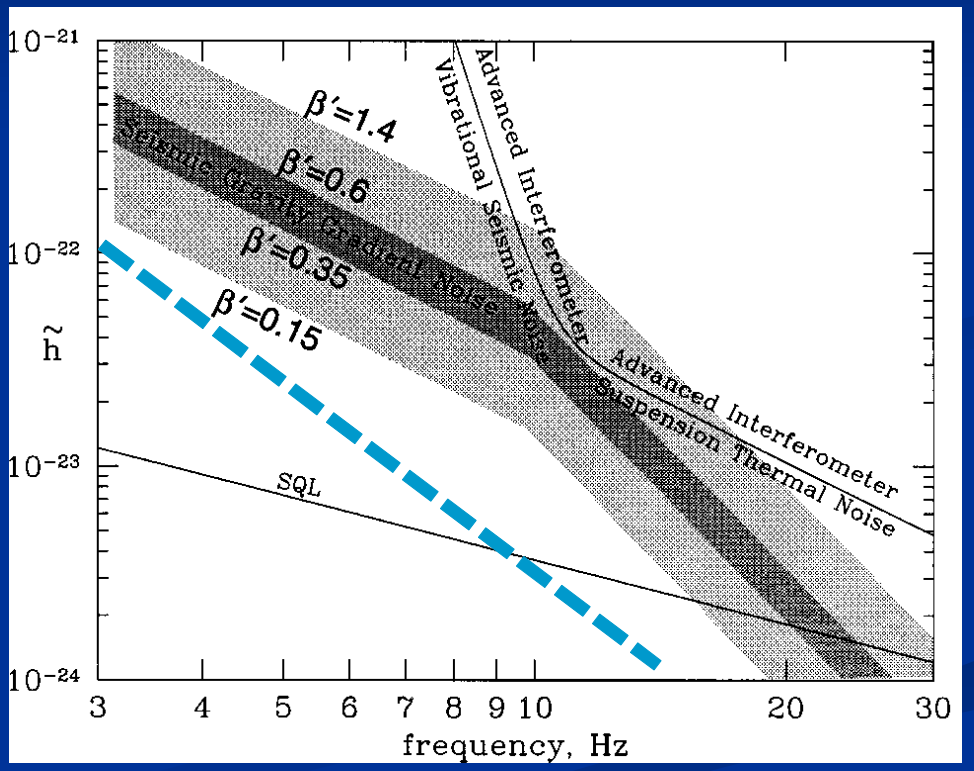
Ambient seismic waves induce density perturbations, which produce fluctuating gravitational forces.

- Naïve estimation

$$\tilde{x} \approx \frac{4\pi G\rho}{(2\pi f)^2}\beta' W$$

$$W = 1\times 10^{-9}\,\mathrm{m}/\sqrt{\mathrm{Hz}}\left(\frac{1\mathrm{Hz}}{f}\right)^2$$

- Generally this noise is smaller in underground.
- Large amount of moving water due to melted snow may make effective noise in spring around Kamioka.

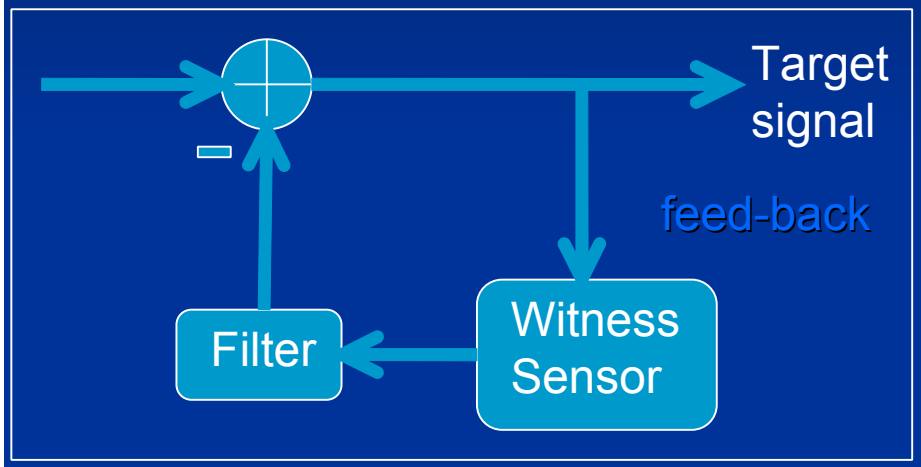


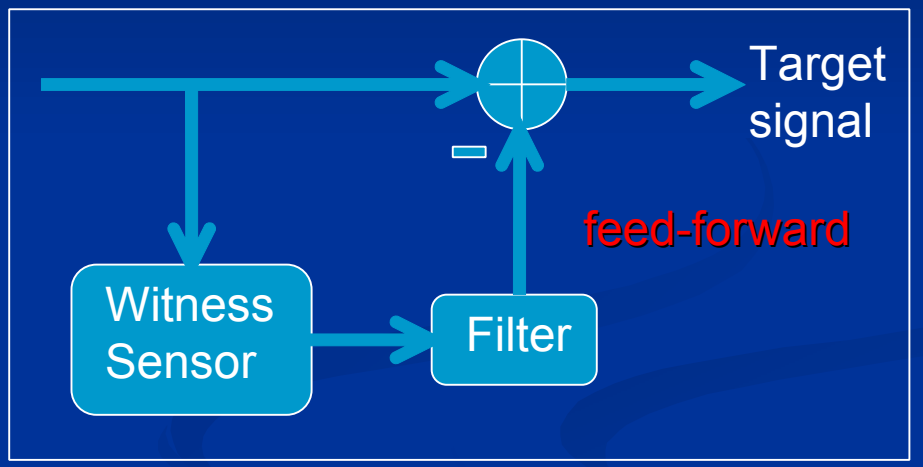
Estimated Newtonian noise in LIGO (Hughes and Thorne, PRD 58 122002)

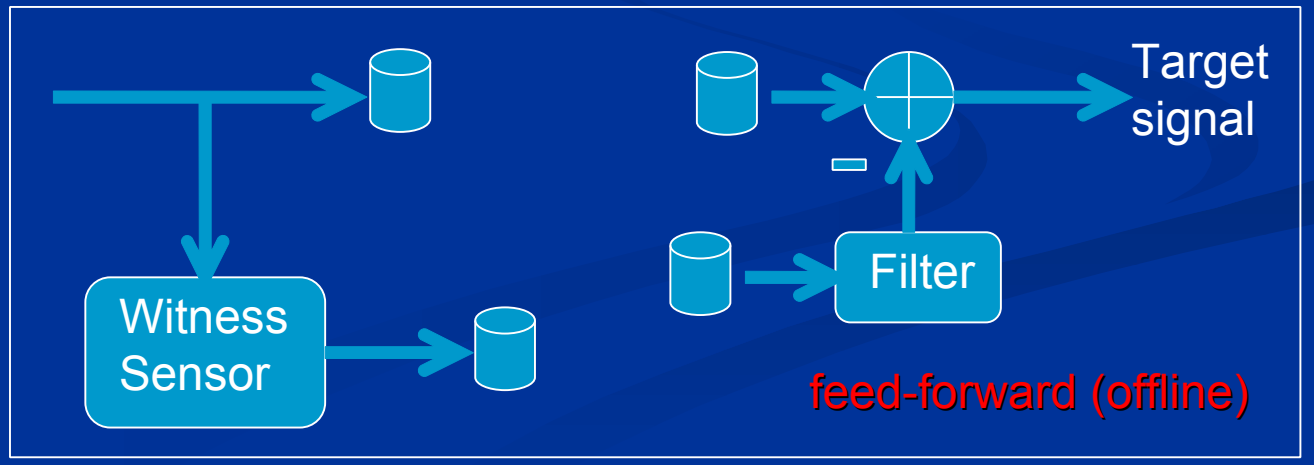
Feed-forward control

Comparison with feed-back control

- Witness sensor is effected by the feed-back control.
- Witness sensor is NOT effected by the feed-forward control.





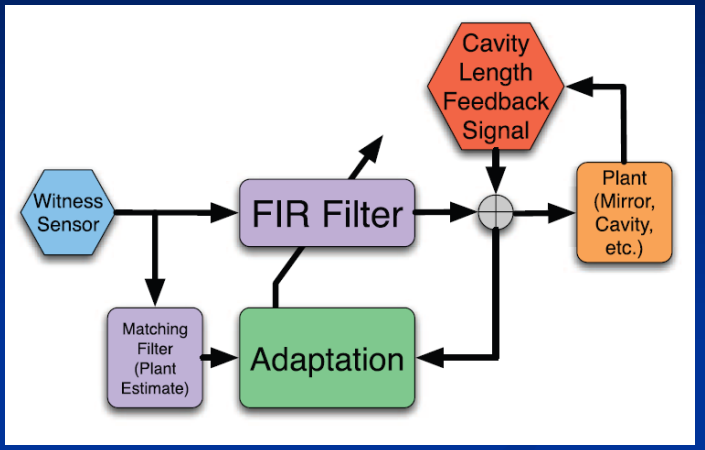


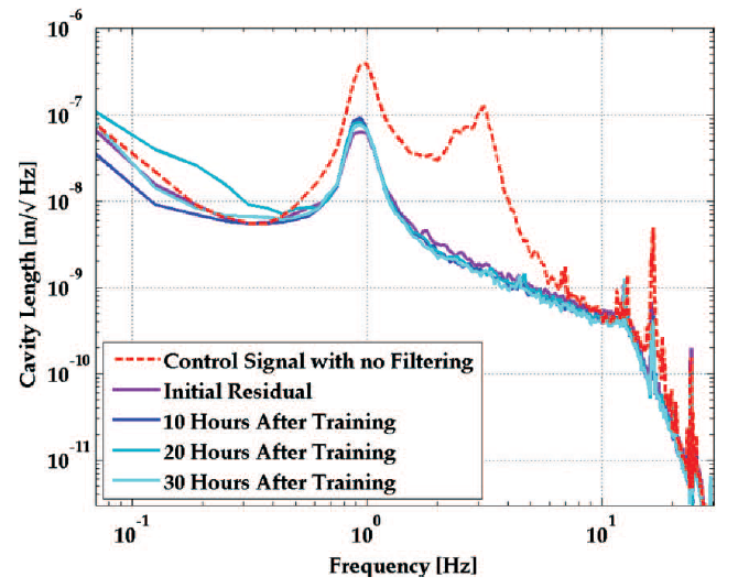
Demonstration of FF vibration isolation (1)

40m interferometer in Caltech

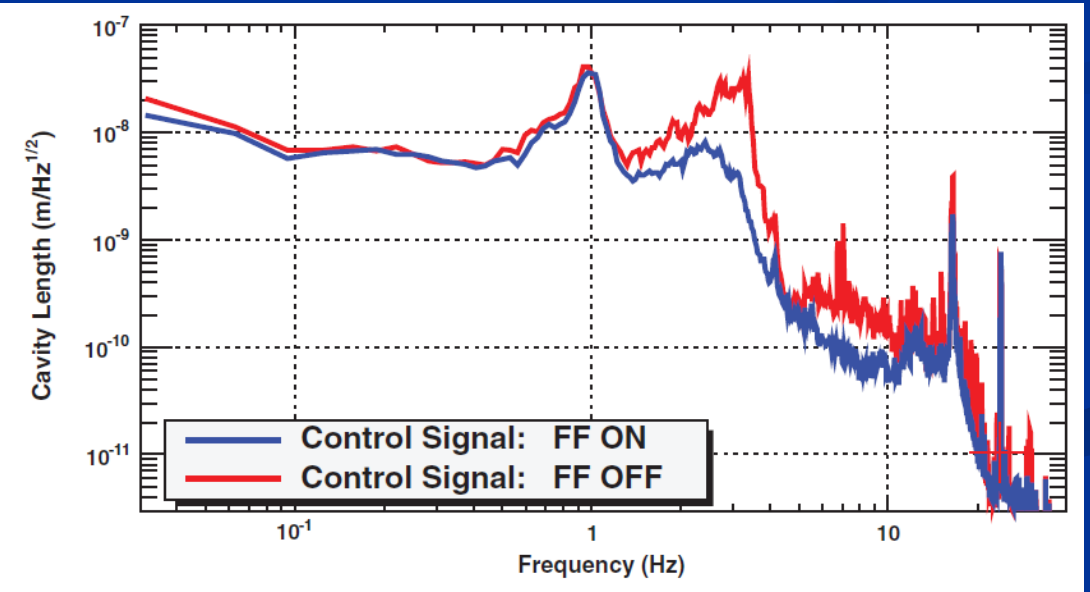
- Static Wiener filter
- Adaptive filter (least mean square algorithm)

(Driggers *et al*, RSI 83, 024501)





Offline

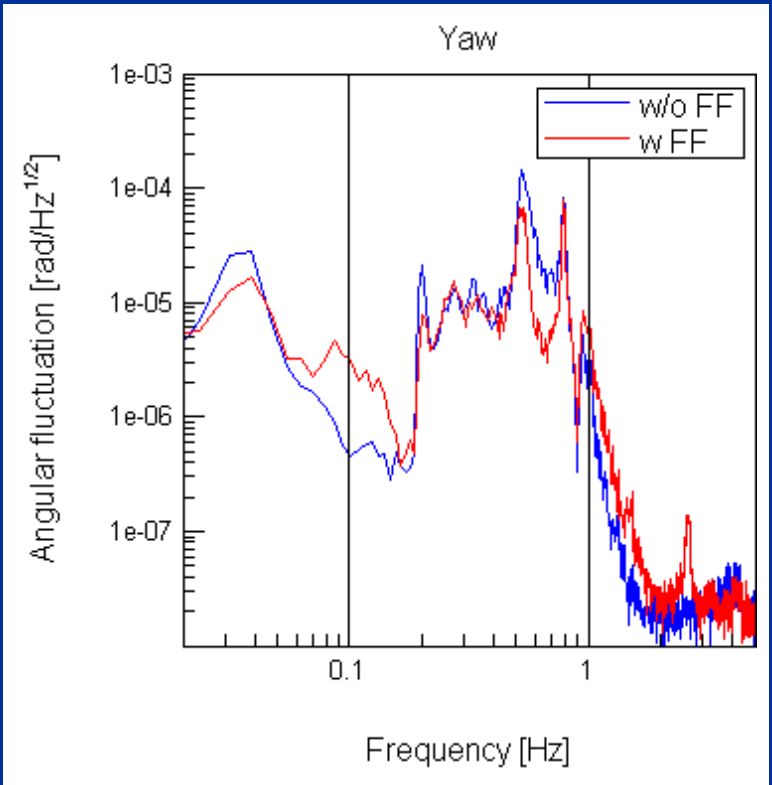


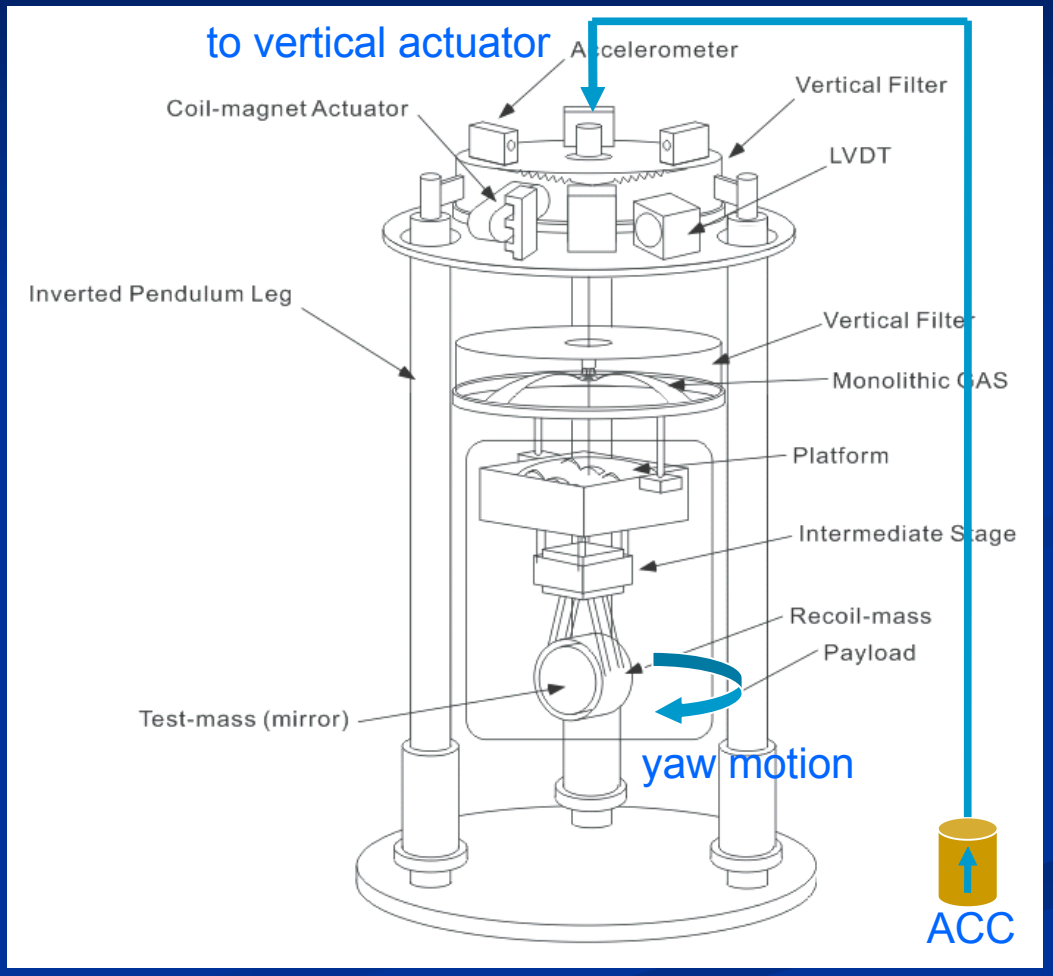
Online

Demonstration of FF vibration isolation (2)

TAMA-SAS in NAOJ

- Coupling motion (vertical to yaw)
- Filter was not optimized.





Demonstration of FF vibration isolation (3)

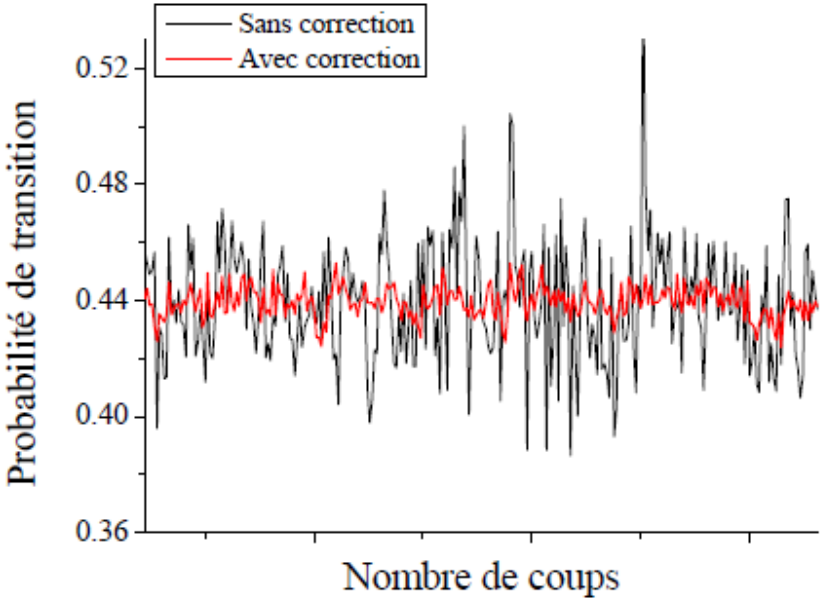
Atom interferometry in Myongji Univ.

Seismometer → PC → $k_{eff}gT^2$

$v(t) \rightarrow \phi_{vib}^{S}$

Interferometer $k_{eff}gT^2 + \phi_{vib}^{S}$

Post correction



Typical sensitivity

Without correction (day) : 8 10^{-8}g @ 1 s

With correction (night) : 5 10^{-8}g @ 1 s

With correction : 2-3 10^{-8}g @ 1 s

→ Gain ~ 3

Best result

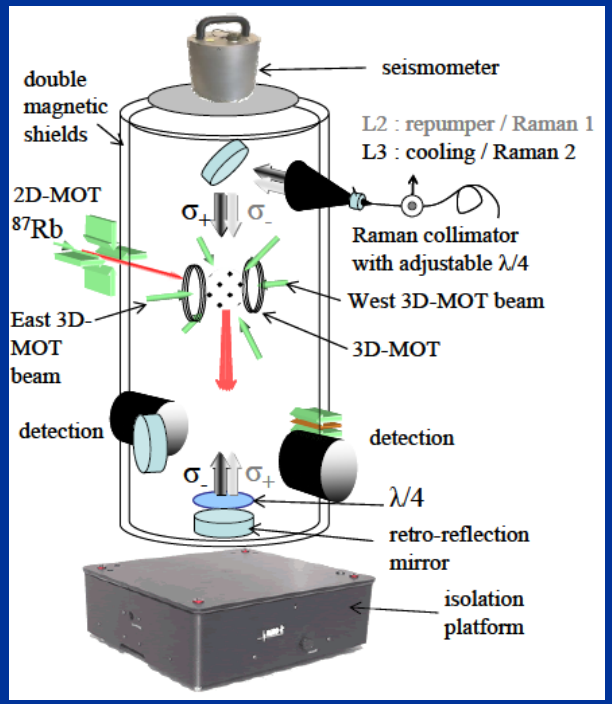
Night – Air conditioning OFF

With correction : 1.4 10^{-8}g @ 1 s

by Jaewan Kim

Our Plan

1. FF vibration isolation for the Atom gravimeter and KAGRA
2. Reduction of Newtonian noise using FF technique with gravity gradiometer in KAGRA



Atom gravimeter by Jaewan Kim

x2 ⇒ Gradiometer

R&D

- Establishment of FF algorithm
- Improvement of repetition cycle of gravity measurements