KAGRA 4th External Review

Control and tuning of suspension

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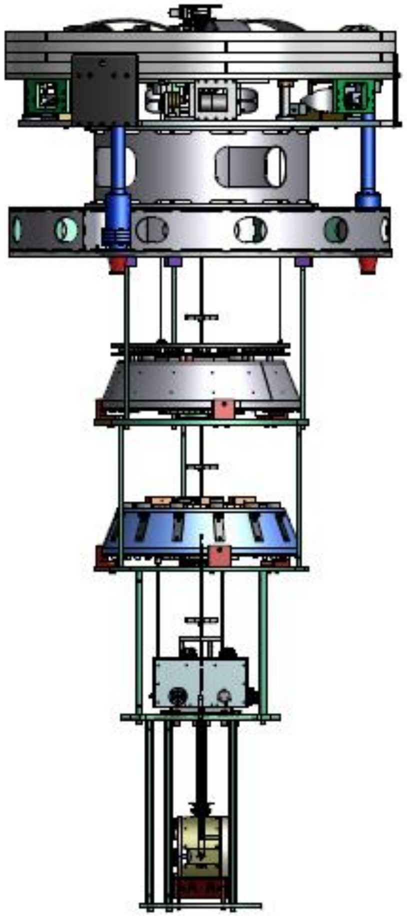
Contents

- Overview of suspension control systems
- Control design (for type-B SAS)
- Implementation of digital control system in prototype SAS

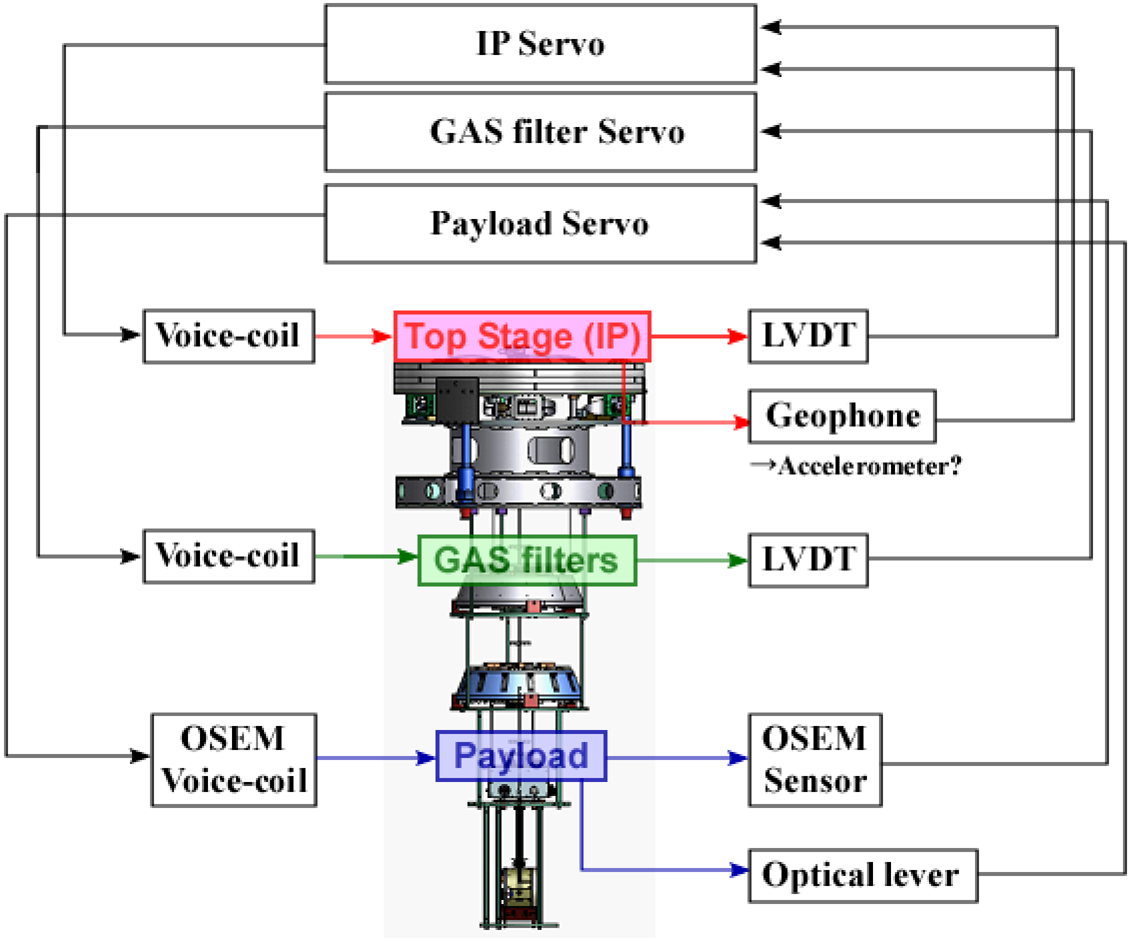
Local controls for SAS

Purpose

- Compensate the **DC drift** of low-frequency oscillators.
- Damp the **mechanical resonances** after earthquakes.
- Reduce the mirror **RMS velocity** for quick lock acquisition.



SAS Local control overview



IP servo:

- DC position (X,Y) control
- Thermal drift control
- Pendulum mode damping

GAS filter servo:

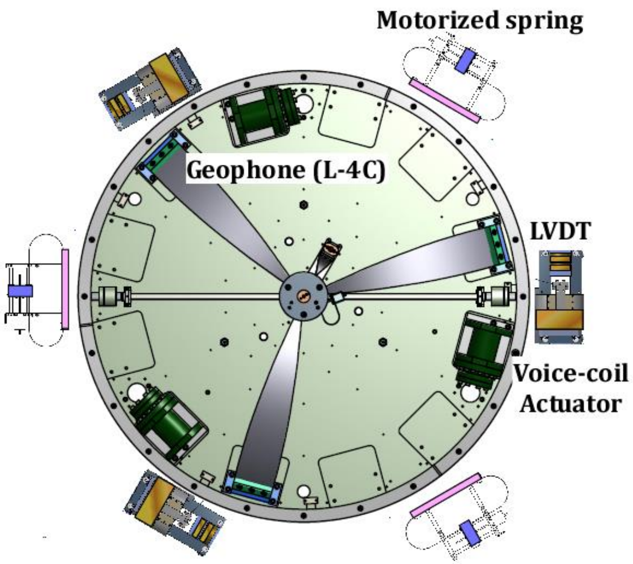
- DC position (Z) control
- Thermal drift control
- GAS filter mode damping

Payload servo:

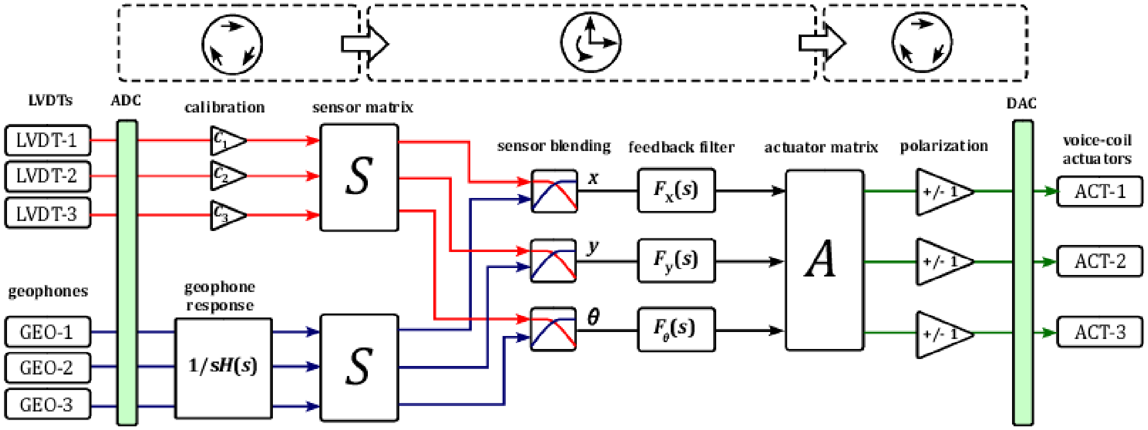
- DC alignment control
- Pendulum/rotation mode damping

IP Controller

Sensor/actuator configuration

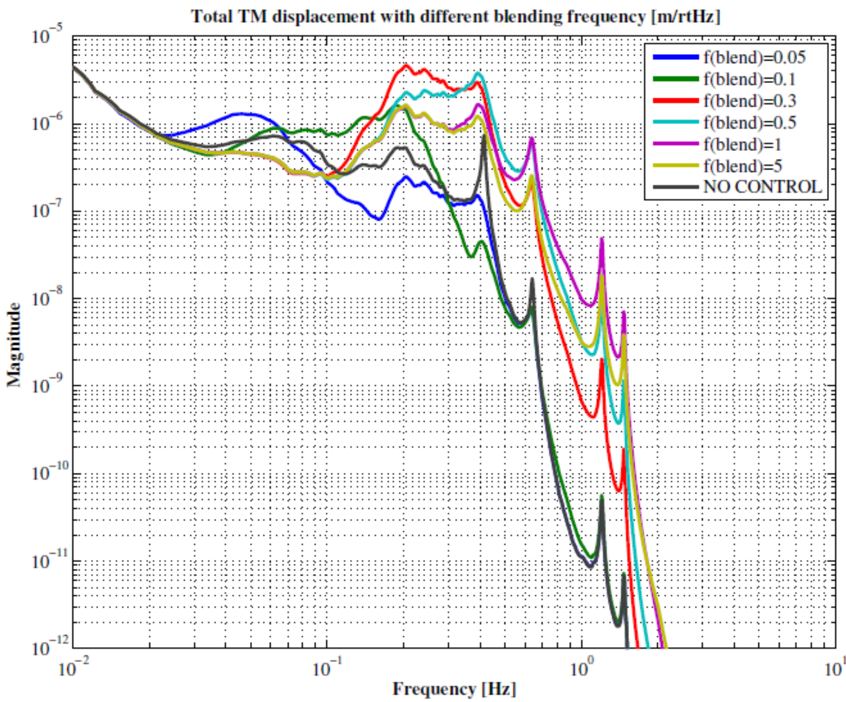


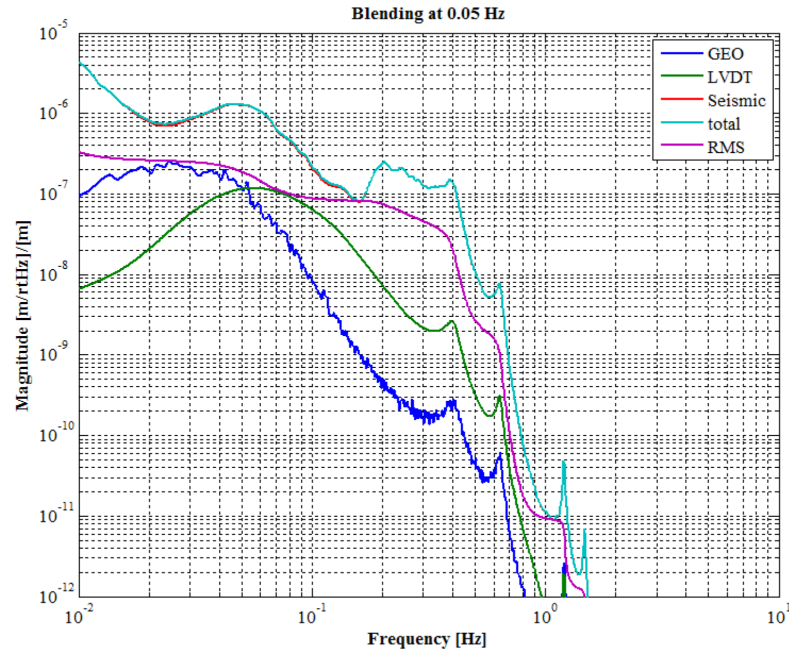
Control Servo



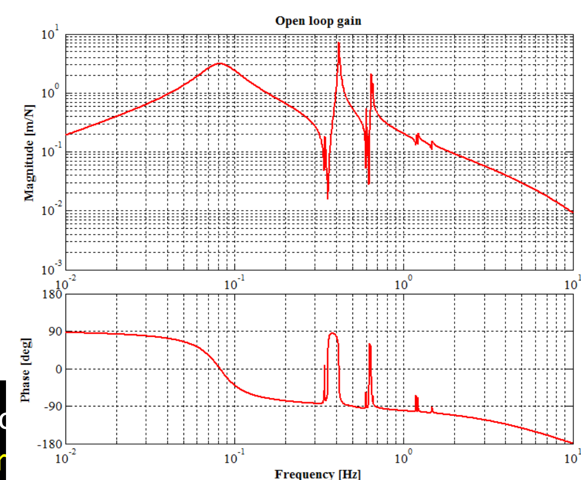
- Similar configuration as TAMA-SAS/Virgo SA
- L-4C geophones as inertial sensors
- Sensor blending + SISO servo in Euclid coordinate space

Control noise study (in Type-B SAS)



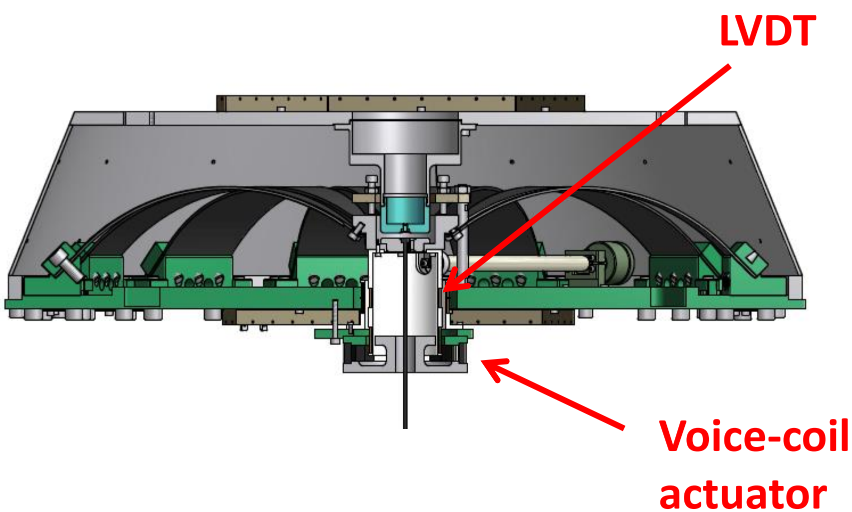


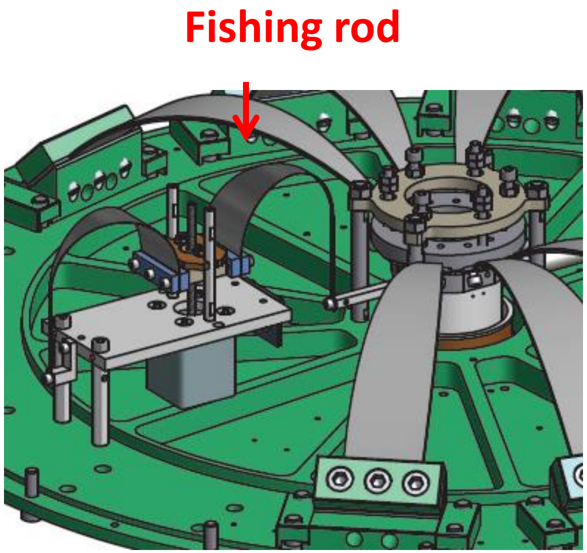
- Simple viscous-damping control with various blending frequencies
- Blending frequency should be set <100 mHz to reduce mirror RMS velocity
- Noise coupling from geophone might be a problem if we raise the control gain at low frequencies for DC control



GAS filter controller

Sensor/actuator configuration

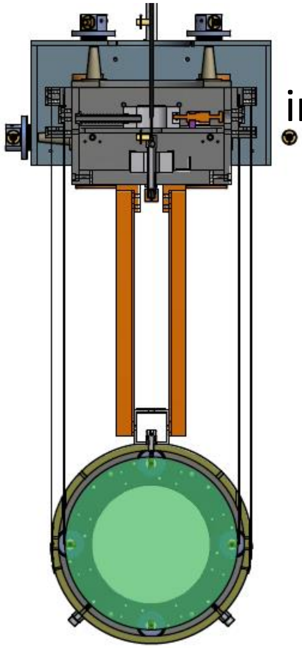




- Simple DC servo will be applied to each GAS filter to compensate the thermal drift (typically ~0.7 mm/^{o}C)
- Damping servo will not be required because of low Q(~10) of oscillation modes
- Motorized spring (fishing rod) for initial DC positioning

Payload Controller

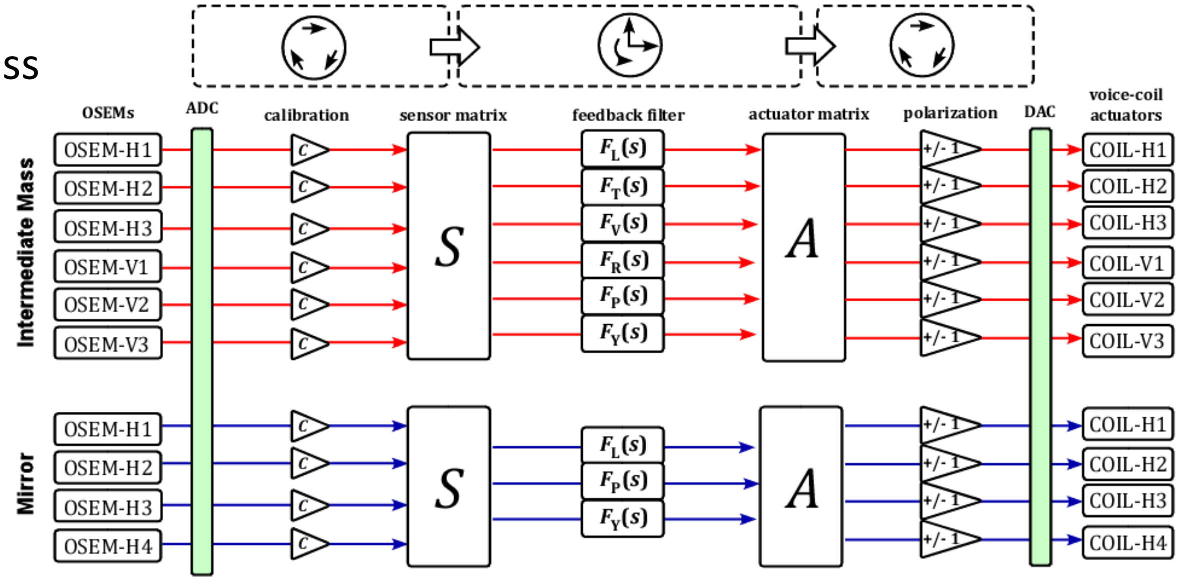
Sensor/actuator configuration



6 OSEMs on intermediate mass

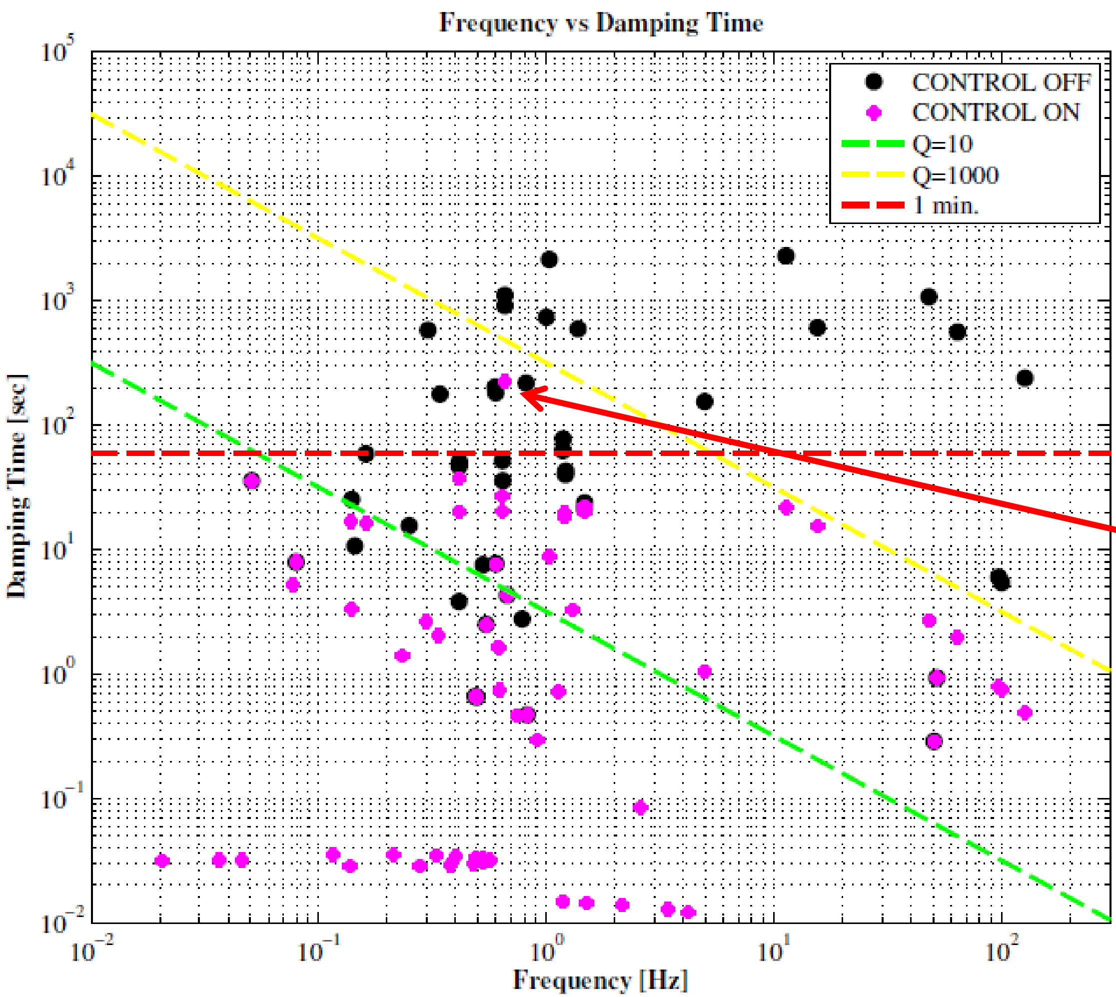
4 OSEMs on the mirror

Control system diagram (OSEM)

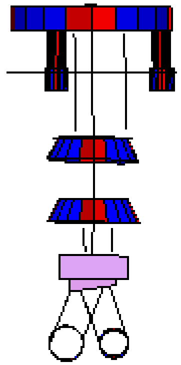


- OSEMs are used to damp the resonant modes.
- DC alignment should be set by optical lever/WFS signals.
- The intermediate mass has moving (motorized) masses to set DC tilt.

Active damping performance

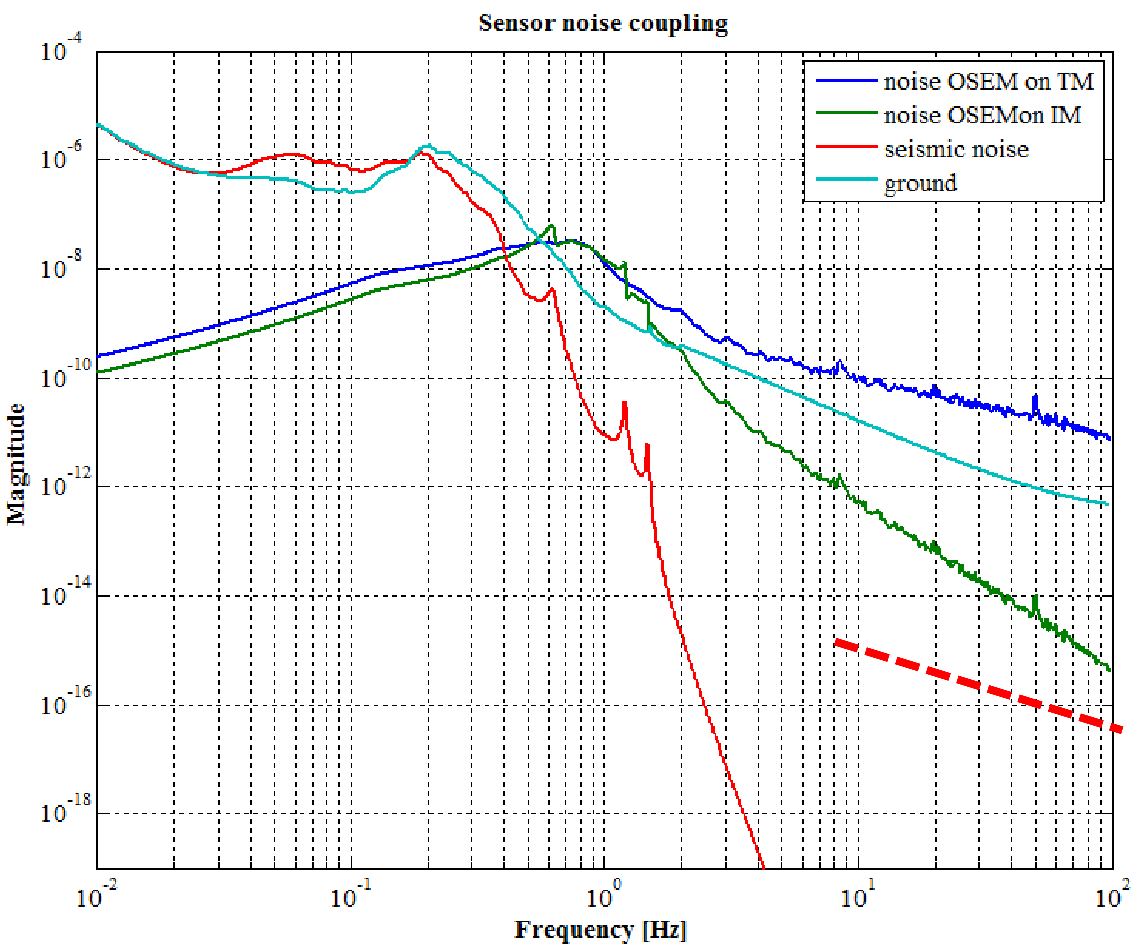


- Resonant frequency vs decay time in simulation
- 1/e decay time gets less than 1 min. for most resonant modes
- One exception: the mirror-RM lateral mode…



Sensor noise coupling

* Assuming the sensing noise measured in prototype OSEM



BS requirement in science mode

- Sensor noise coupling with strong damping by OSEMs.
- Damping servo should be turned off during science run (at least about length DoF)
- Damping servo about other DoFs might be kept on (**TBC**)

Notes

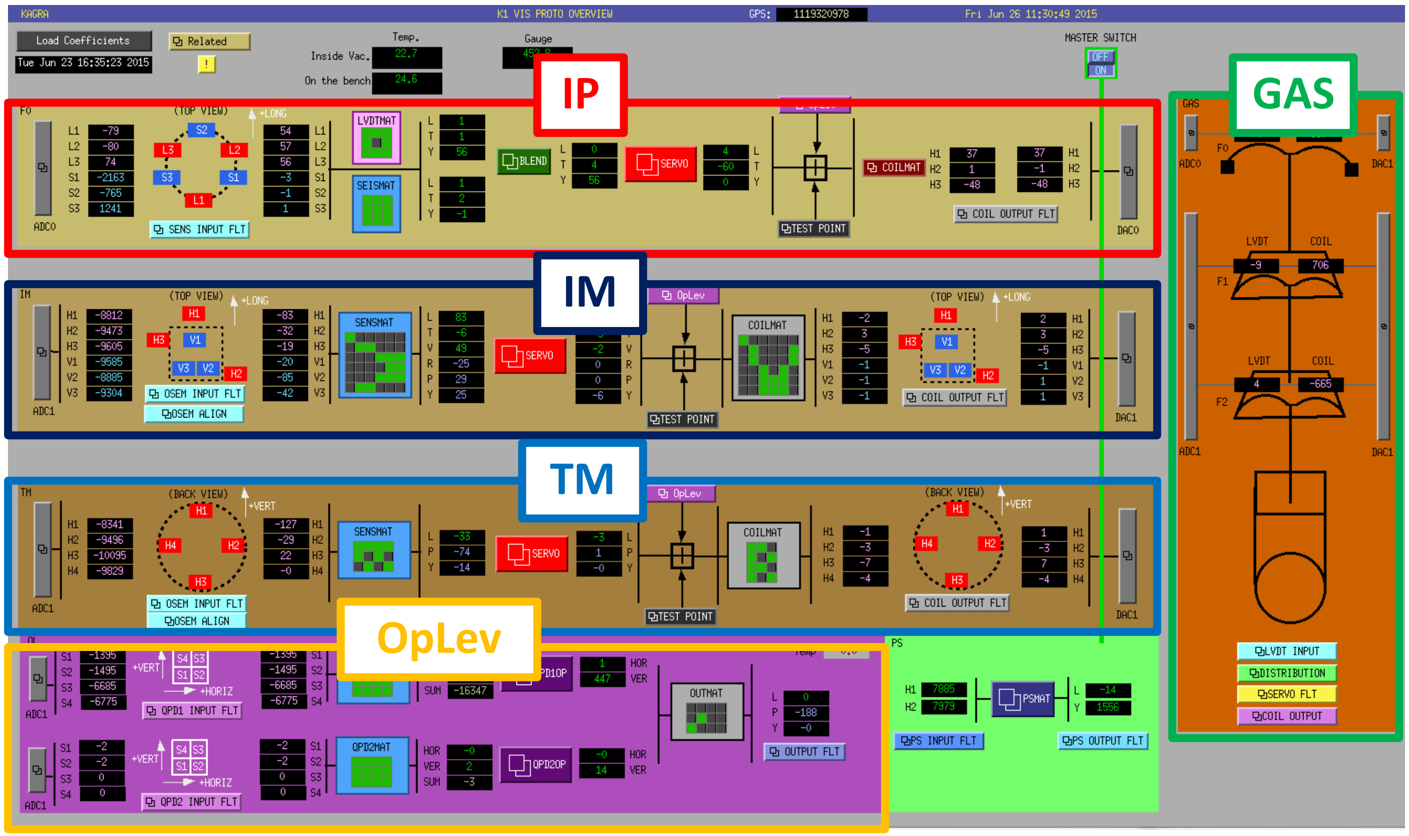
- Actuator noise couplings are studied by Y. Michimura (JGW-T1503453).

- MATLAB codes and Simulink models for suspension control simulation: JGW-T1503606

Implementation, Control Test in Prototype SAS

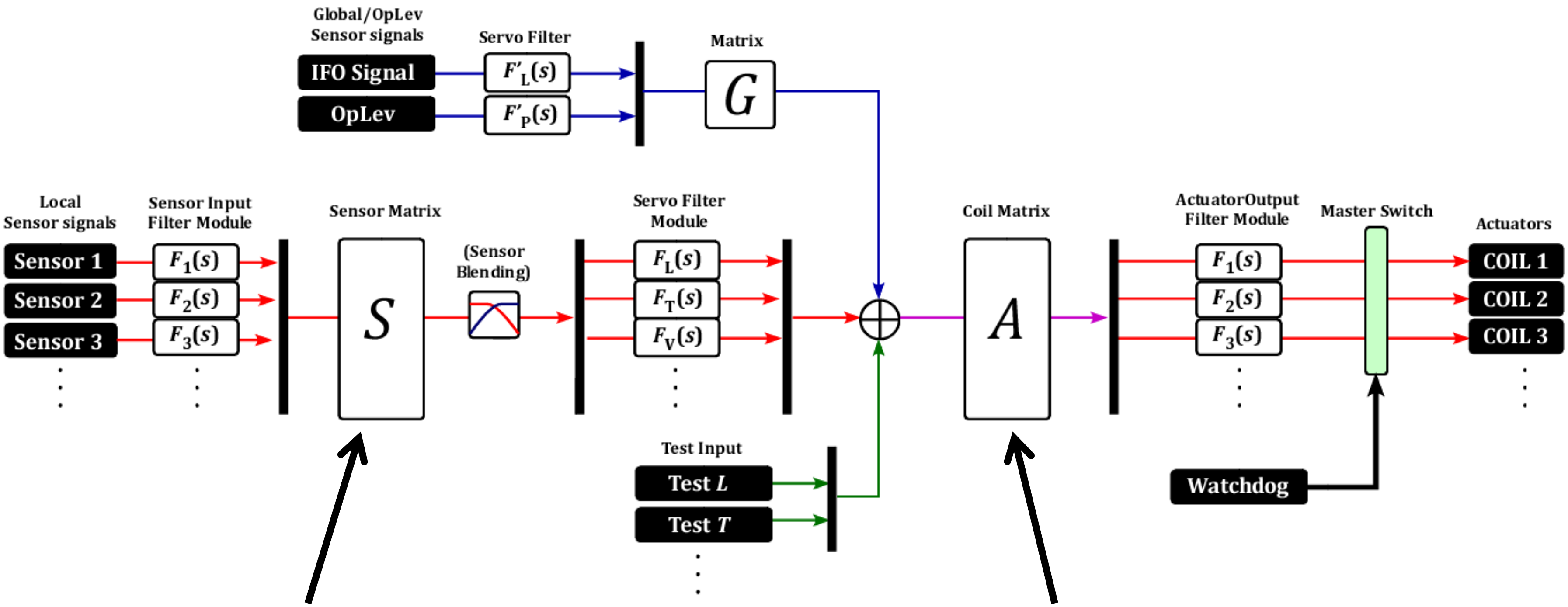
Digital control system for prototype SAS

User interface (MEDM) for prototype SAS control



Digital control system for prototype SAS

Signal flow in each system:



Sensing matrix is determined from sensor layout geometry

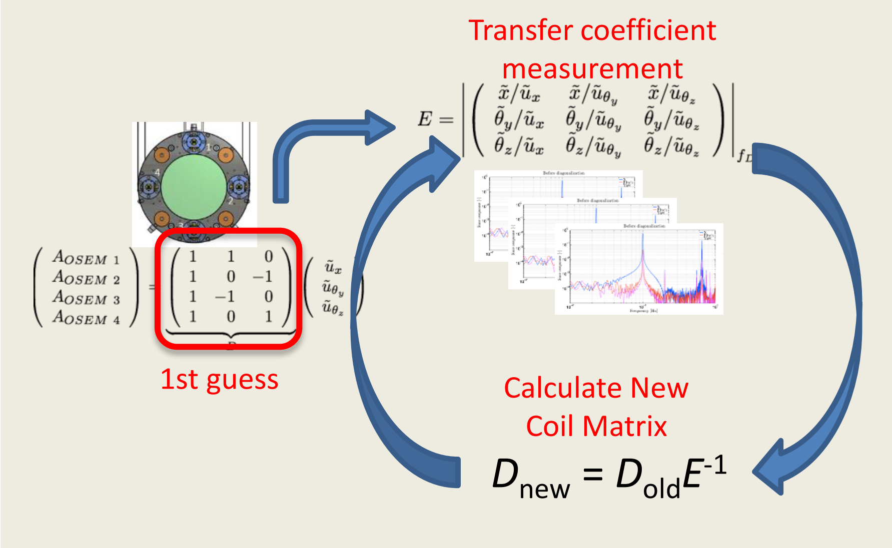
Coil matrix is set from the measurement so that it diagonalizes virtual actuators.

Actuator diagonalization

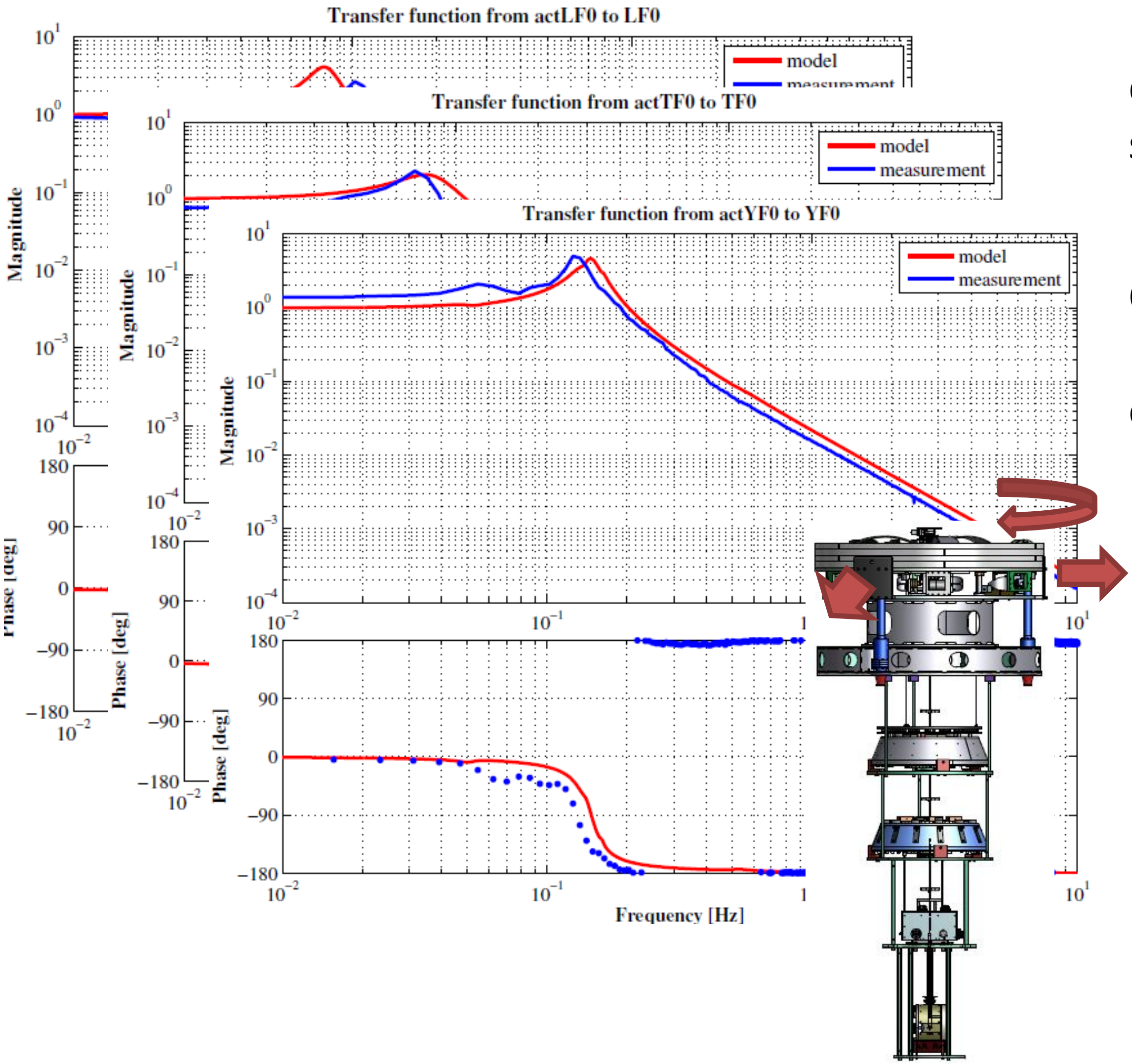
1. Coil matrix elements are set arbitrary (roughly set from actuator layout).
2. Measuring the coupling from virtual actuators to virtual (local) sensors by actuating in different DoFs separately at a certain frequency (10-100 mHz).
3. Calculating a new coil matrix from the measured coupling coefficients.
4. Repeat the procedure 2 and 3 for several times.

Procedure

- We diagonalize actuators with local sensors in DC (at low freq.)
- Simple, but time consuming!
- Now writing a script to automatize it…



Transfer function measurement



Measuring transfer functions from diagonalized actuators to virtual sensors

Comparing with models
→ Check if any fricting/broken part exists

Watchdog

- **After large excitation:**
  - Geophone signals saturate and the control gets crazy.
  - Optical lever beam spot goes away from QPD.
  - Actuator signals saturate and no AC control is applied.
  - …

- **We need a system automatically turns off the control / switch it to more robust one.**

- Now we are designing software watchdog system (firstly aimed for long-term measurement of prototype SAS)

Summary

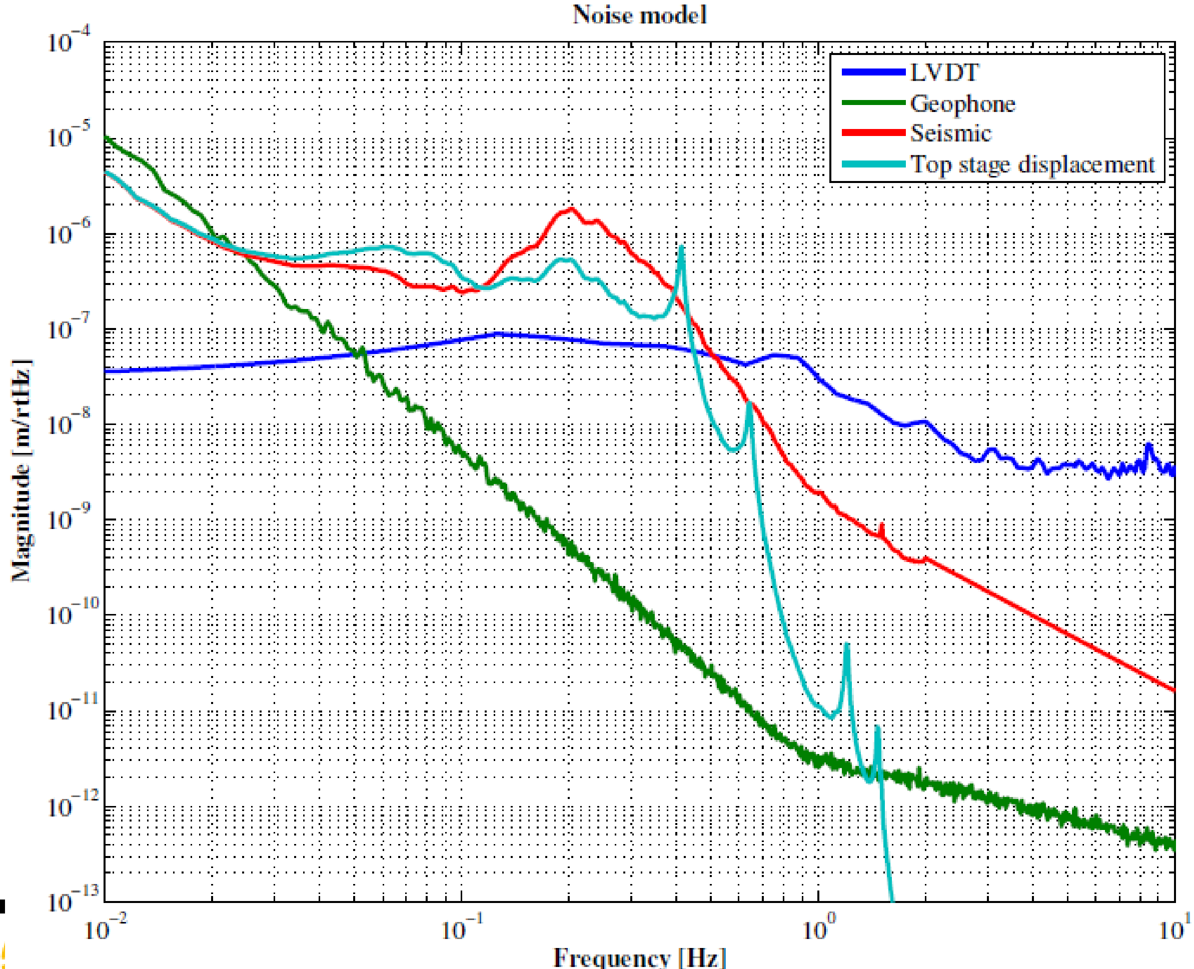
- We are developing local control system with control noise taken into account.
- Active damping works well, while one un-damped mechanical mode is found.
- Need to make control strategy: switching controls after lock acquisition?

- Control digital system is implemented for SAS prototype and now is working.
- Efficient way of actuator diagonalization and watchdog system are to be developed.

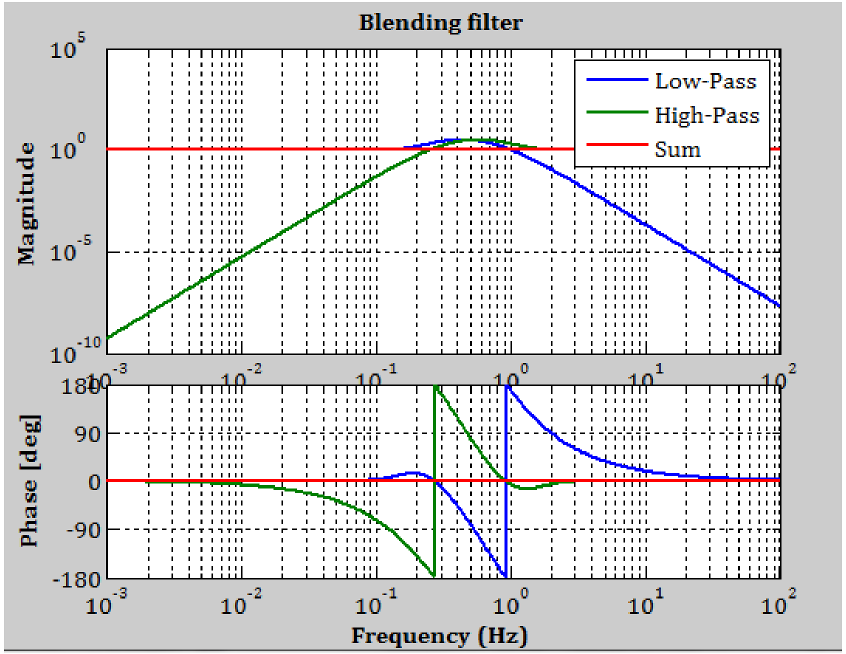
Appendix

Sensor/seismic noise model

- LVDT: measured noise
- Geophone: measured preamp noise
- Seismic: (<2 Hz) 90% percentile data of 1.5 year measurement in CLIO site, (>2 Hz) $1/f^2$ interpolation



Blending filter



- Geophone noise raises at low frequency by ~$f^{-3.5}$
- Steeper high-pass is required to avoid noise coupling
- Blending filter with 7th order polynominal

$$H_{HP}(s) = \frac{s^7 + 7s_0 s^6 + 21 s_0^2 s^5 + 35 s_0^3 s^4}{(s+s_0)^7},$$

$$H_{LP}(s) = \frac{35 s_0^4 s^3 + 21 s_0^5 s^2 + 7 s_0^6 s + s_0^7}{(s+s_0)^7}$$