Seismic Attenuation System (SAS)
for
Gravitational Wave Detectors I

Akiteru Takamori
University of Tokyo

22 September, 2000
JPS Meeting Niigata

LIGO doc#: G000304-00-R

0. Authors

SAS

University of Tokyo

M. Ando

K. Numata

K. Somiya

A. Takamori

K. Tsubono

T. Yoda

NAOJ

M. Fukushima

S. Kawamura

R. Takahashi

Caltech

R. DeSalvo

Sz. Márka

V. Sannibale

H. Yamamoto

C. Wang

Universita' di Pisa

A. Bertolini

G. Cella

Florida Tech.

H. Tariq

INSA de Lyon

N. Viboud

0. Overview

SAS

1. Introduction
- Objectives
- TAMA SAS Mechanics
- TAMA SAS Control

2. IP Control
- System Diagonalization

3. Experiments
- Sensor Diagonalization
- Closed Loop Operation

4. Conclusion

1. Introduction

SAS

1. 1. Objective of the Project

Expansion of Detection Band to Low Frequencies

Reliable / Robust Operation of the Interferometers

- Ultra Low Frequency (10 mHz ~) Pre-Isolation Stage

Attenuation of Micro Seismic Peak

Small Residual Velocity of Test Mass : Ease Locking Acquisition

Platform for Controls

Controls with Small Energy Consumption

- Low Frequency (100 mHz ~) Attenuation Chain

Passive Isolation in All Dof

Specs Overkilling against Spurious Degeneration

(Cross-Coupling, Internal Resonances)

- Active Controls

Digital Control : High Flexibility

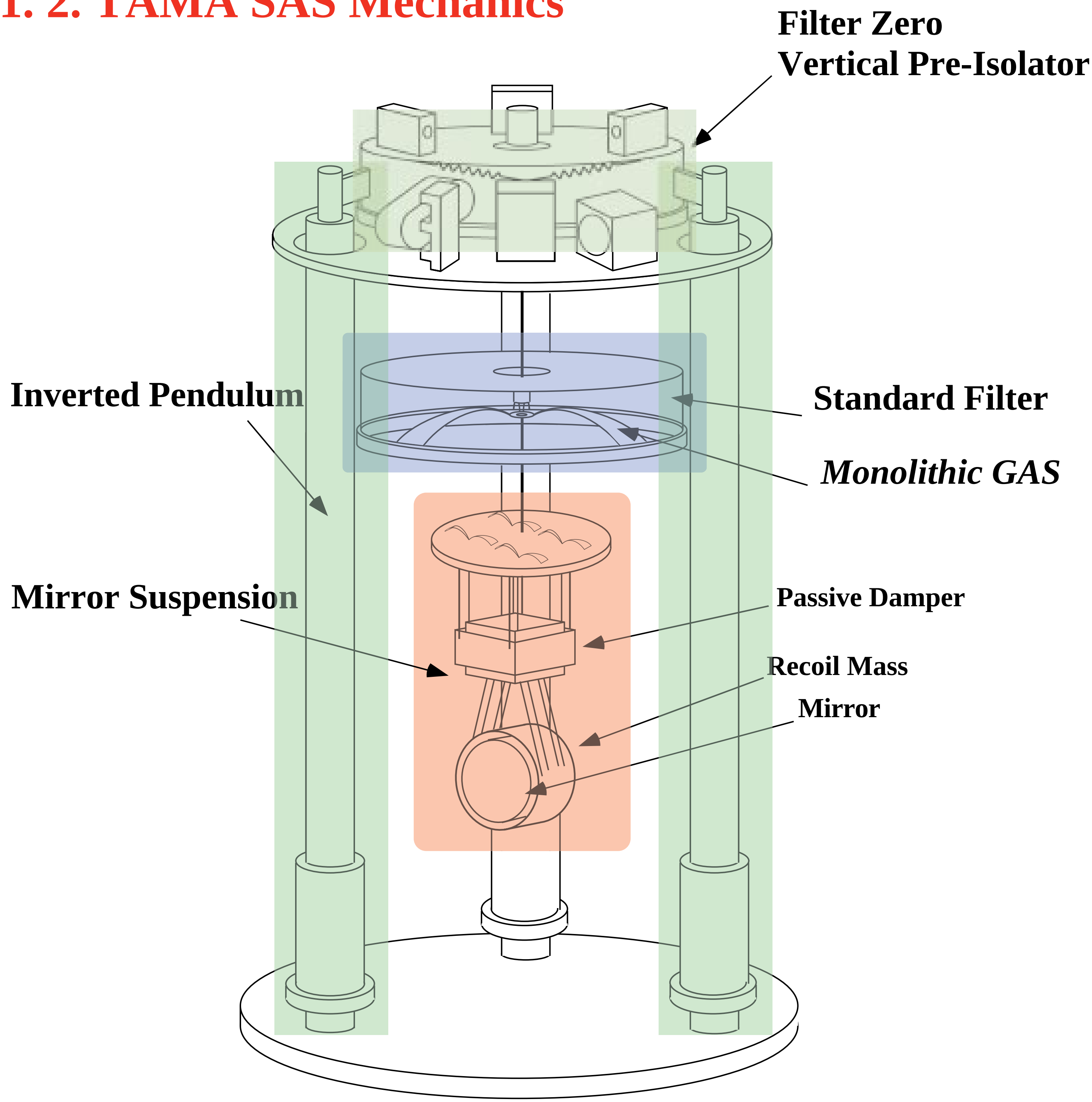
Out of GW Detection Band

Inertial Damping to Suppress Residual r.m.s. Displacement

Local / Global Position Control

1. Introduction

1. 2. TAMA SAS Mechanics



Pre-Isolation Stage	Passive Isolation Stage	Mirror Suspension
< 100 mHz	< 1 Hz	1 Hz <

1. 3. TAMA SAS Control

Local Control

- Position Control (< as low freq. as possible)

Positioning of SAS Subsystems
Damping for Lock Acquisition
Using LVDT
Coil-Magnet Pairs, Stepping Motors

- Inertial Damping (low freq. ~ 10 Hz)

Suppresses r.m.s. Displacement of SAS Subsystems
Using Accelerometer Signal
Coil-Magnet Pairs

Global Control

- Position Control

Positioning of Mirrors
Using IFO Signal

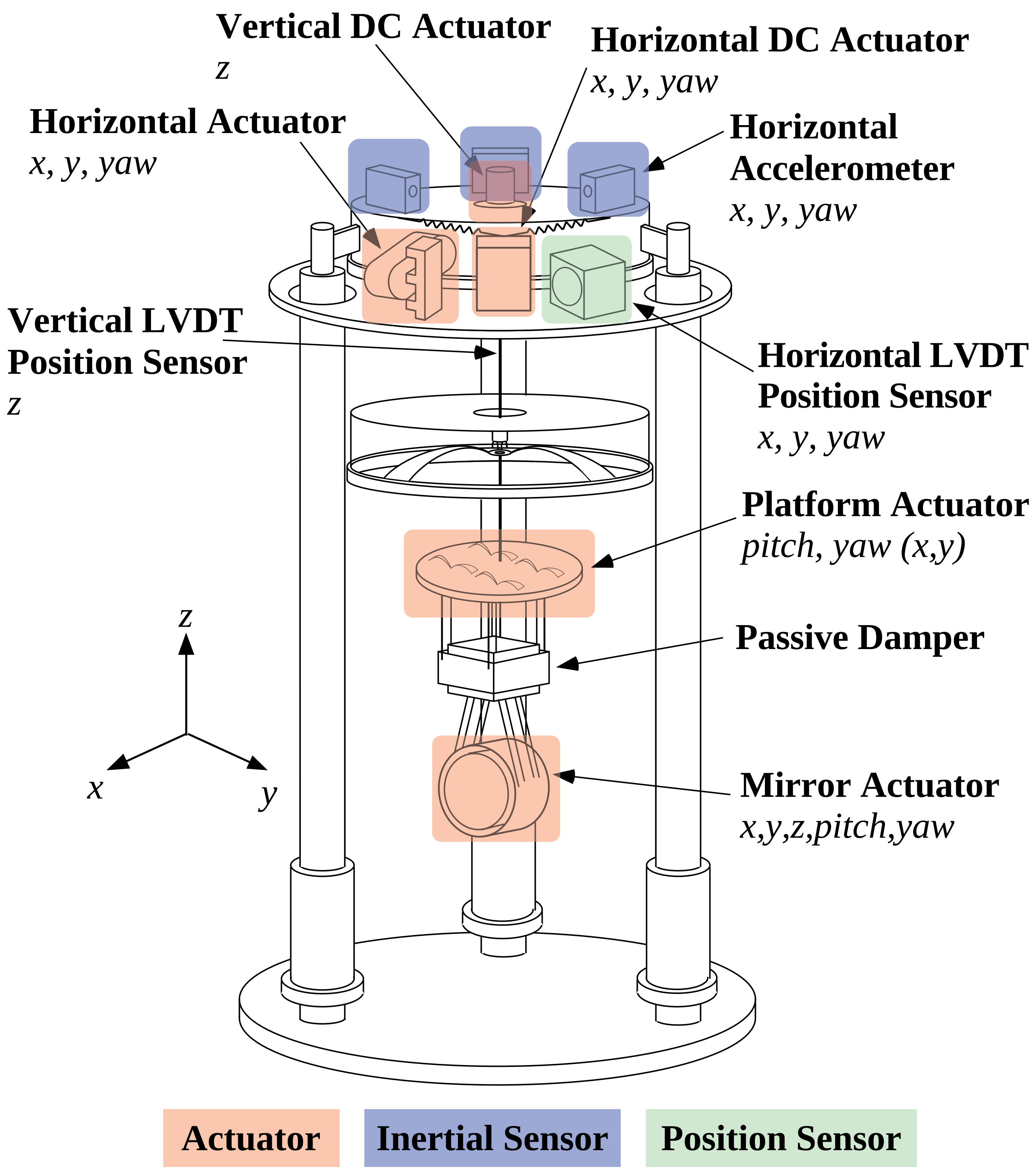
Hierarchical Scheme

- Distributing Adequate Range of Control Authority

Allows Minimum Noise Injection from Control

1. 3. TAMA SAS Control

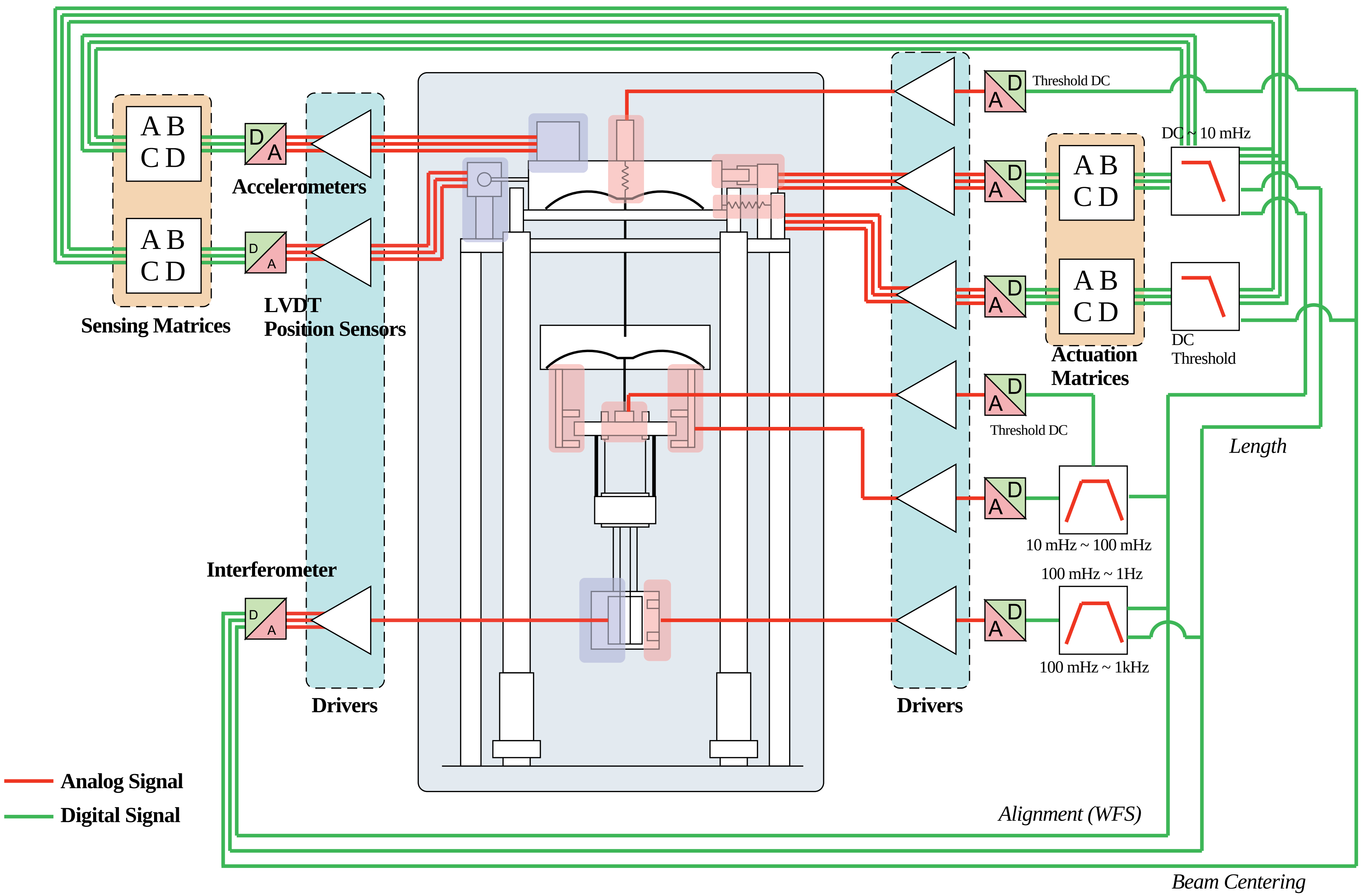
Hardware



1. Introduction

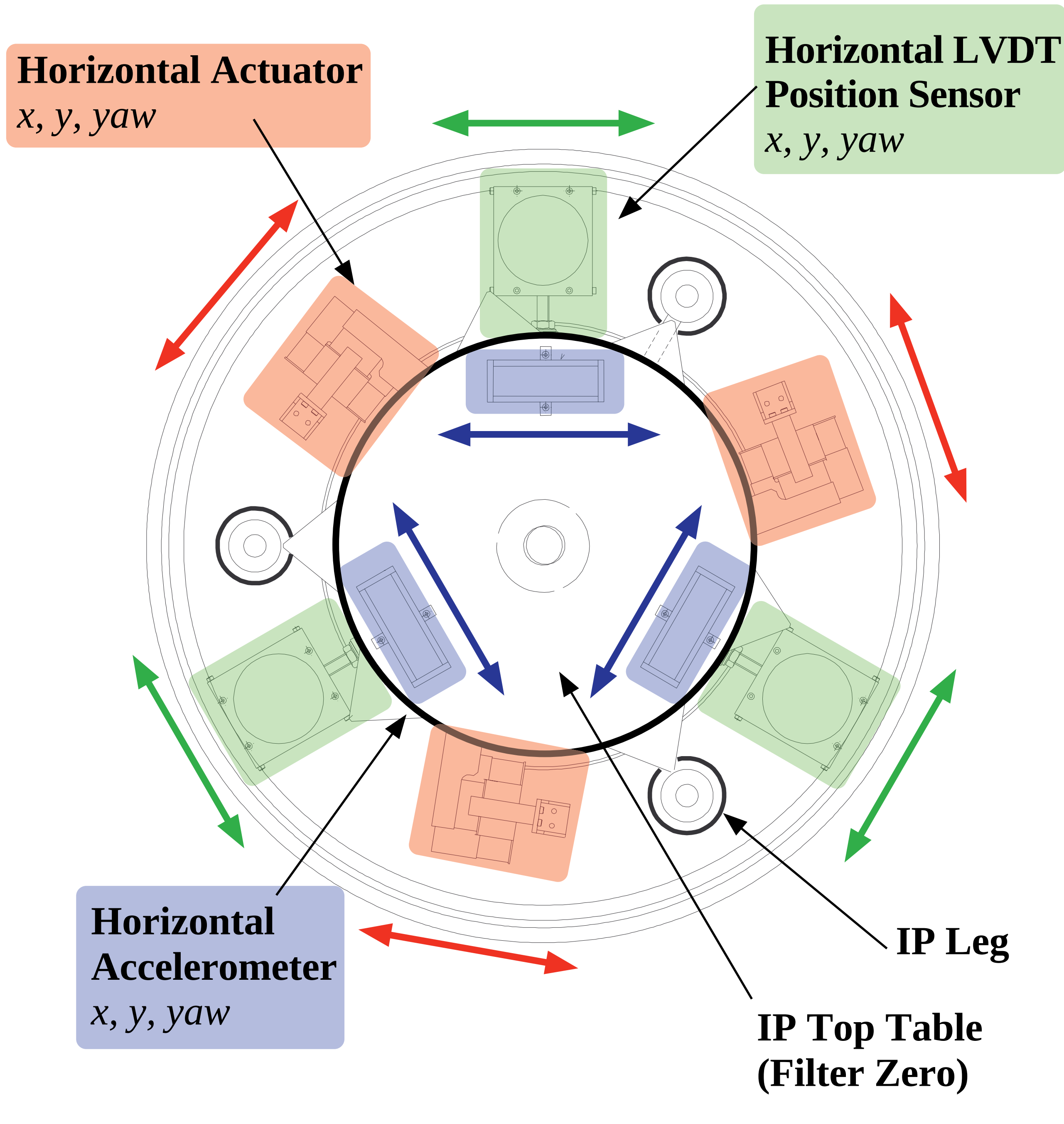
TAMA SAS

1. 3. TAMA SAS Control



2. IP Local Control

2. 1. IP Control Components



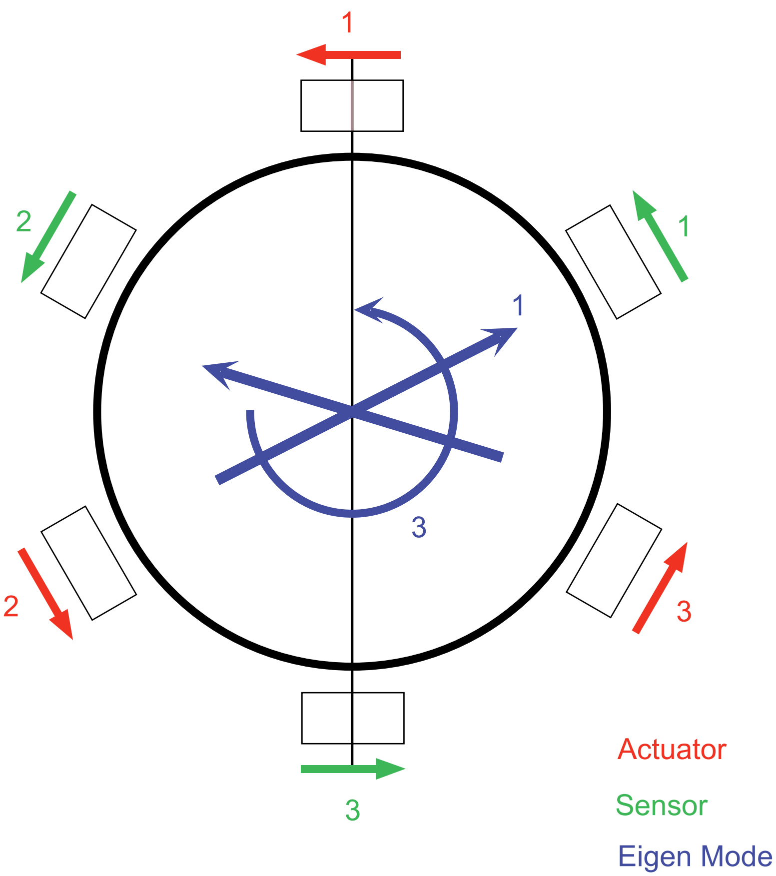
Main Sensors / Actuators on IP Top

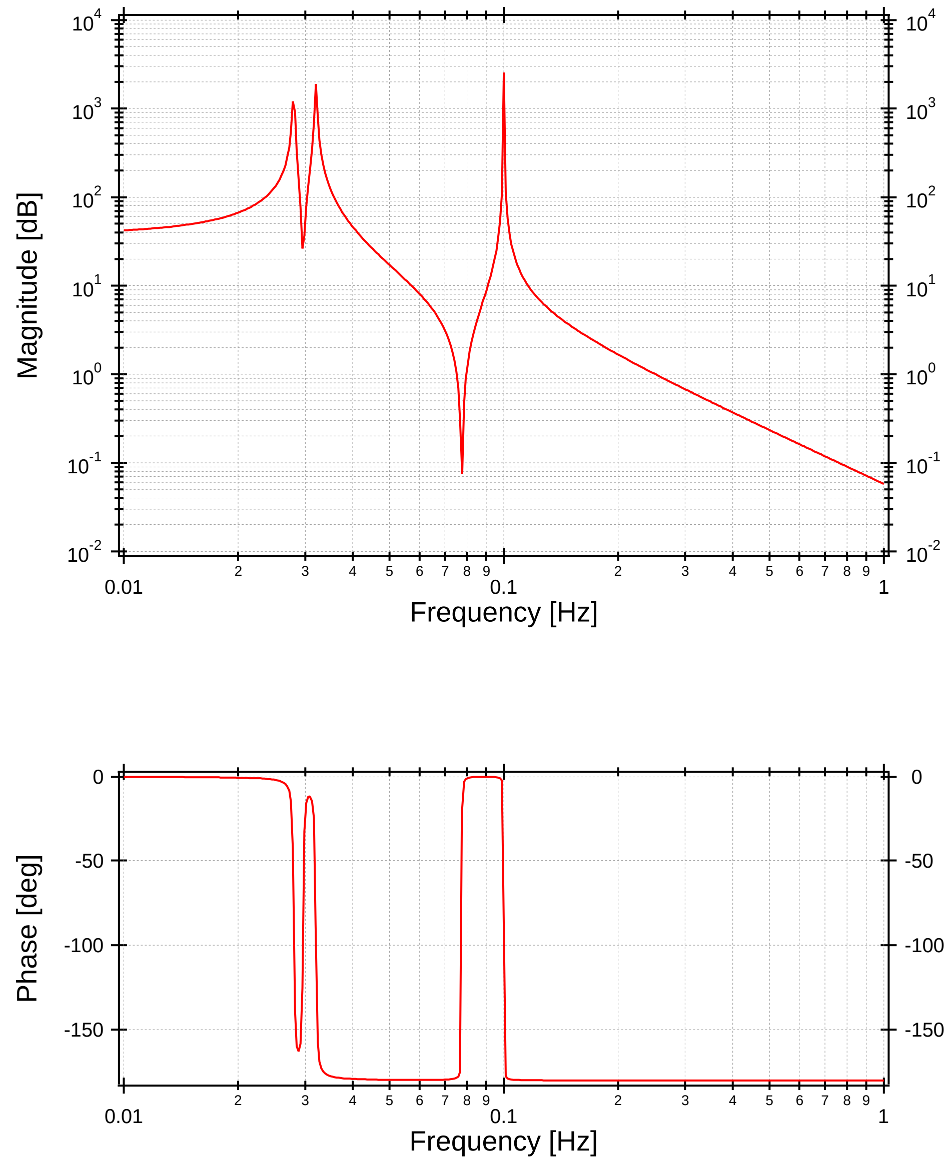
2. IP Local Control

2. 2. Signal Diagonalization

- Signal Mixing

Due to System Geometry
/Asymmetry





2. IP Local Control

2. 2. Signal Diagonalization

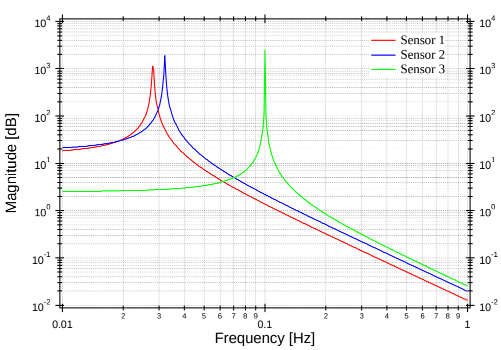
Resolves Signal Mixture by:

- Linear Combination of *Real* Sensor Signals
  = *Virtual* Sensor Signals
- Linear Combination of *Virtual* Actuator Signals
  = *Real* Actuator Signals

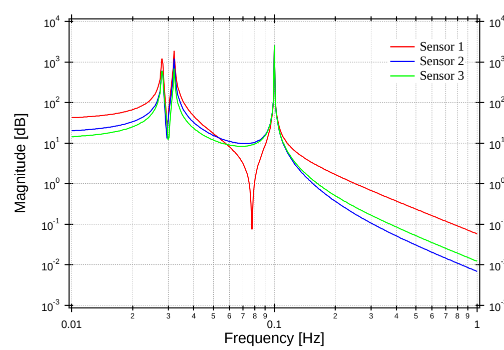
Simplifies Control Design

MIMO to SISO

Sensing / Driving Matrix

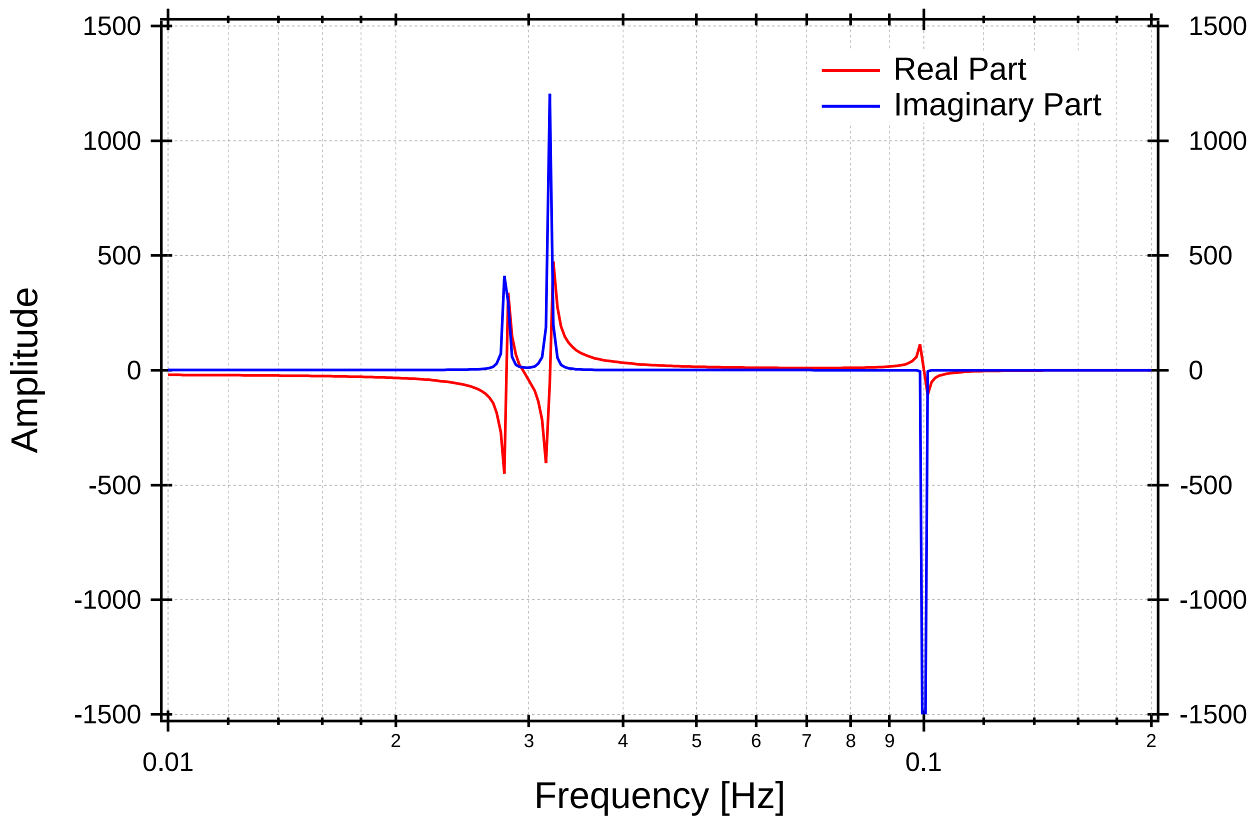


$$= \left[\quad S \quad \right]$$



Sensing Matrix

2. IP Local Control



At Resonance:

Single Mode is excited.

Imaginary part of the TRF carries information.

Amplitude and Sign

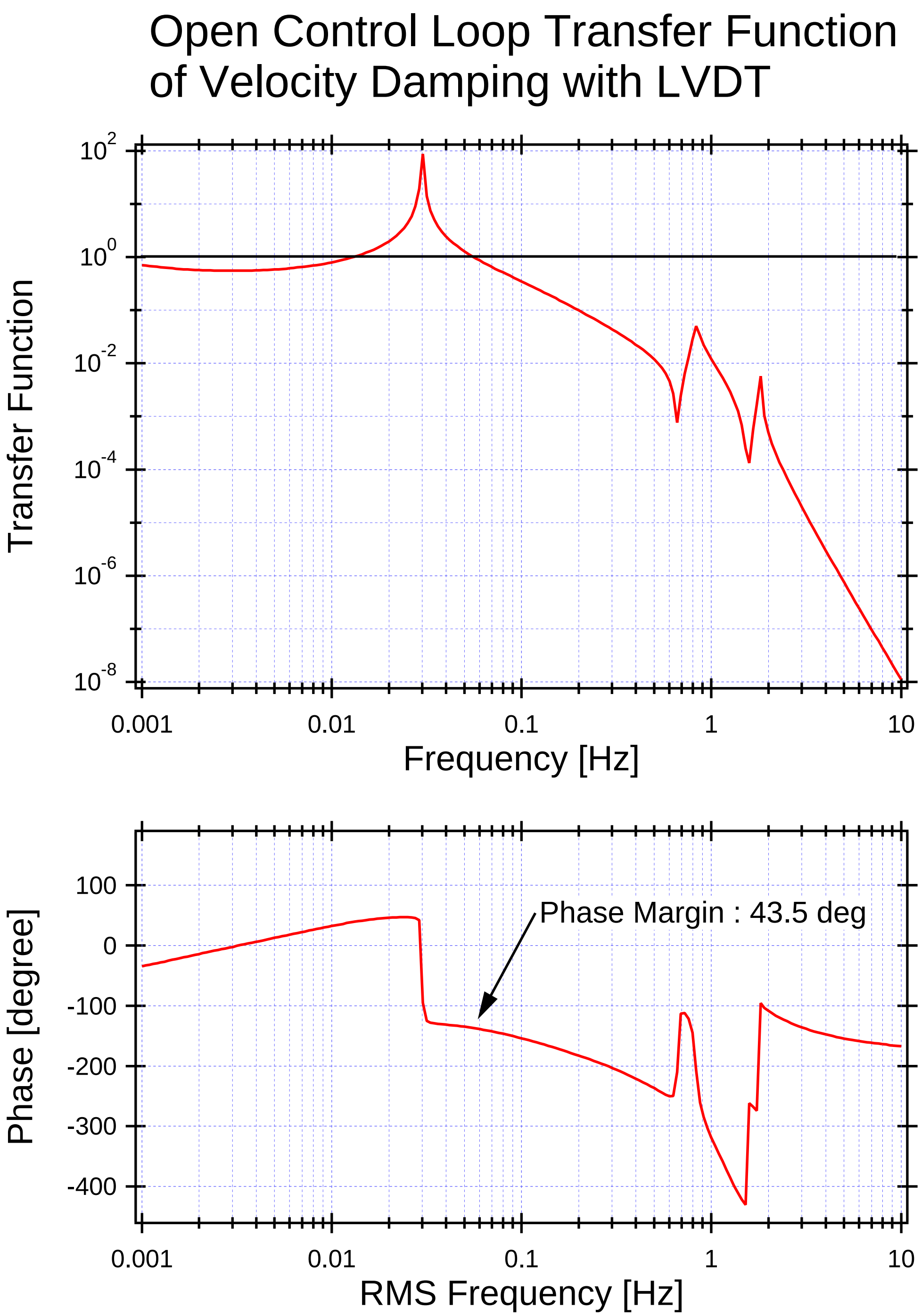
Example

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} \quad S^{-1} \quad \end{bmatrix} \begin{bmatrix} v_1 \\ 0 \\ 0 \end{bmatrix}$$

Real *Virtual*

2. 3. Simulation

Control with LVDTs

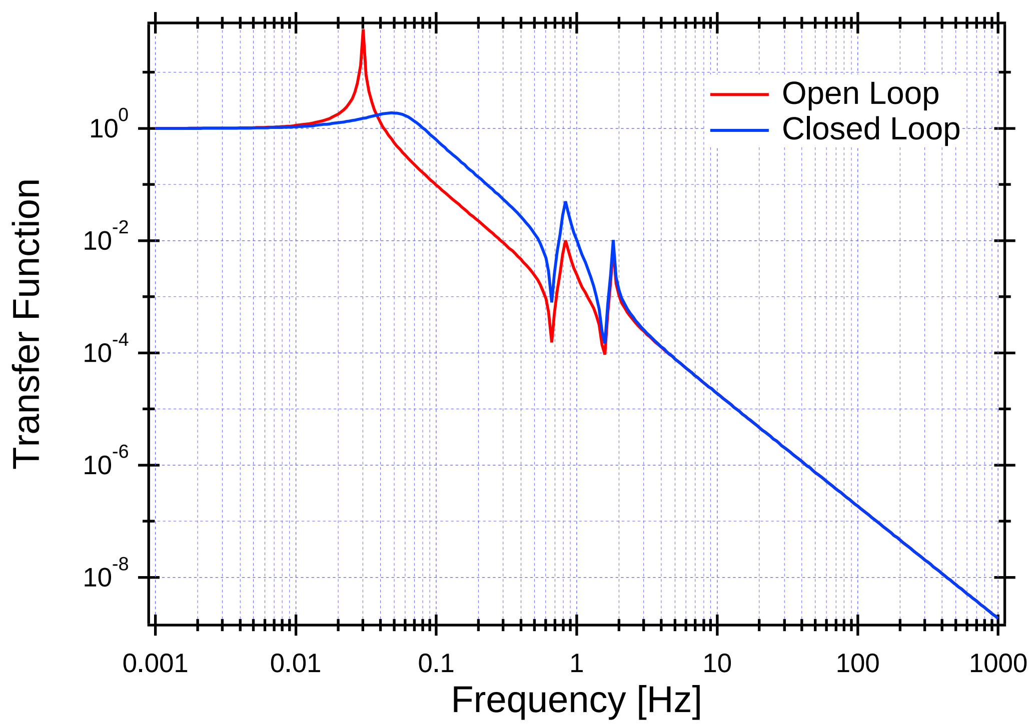


2. IP Local Control

2. 3. Simulation

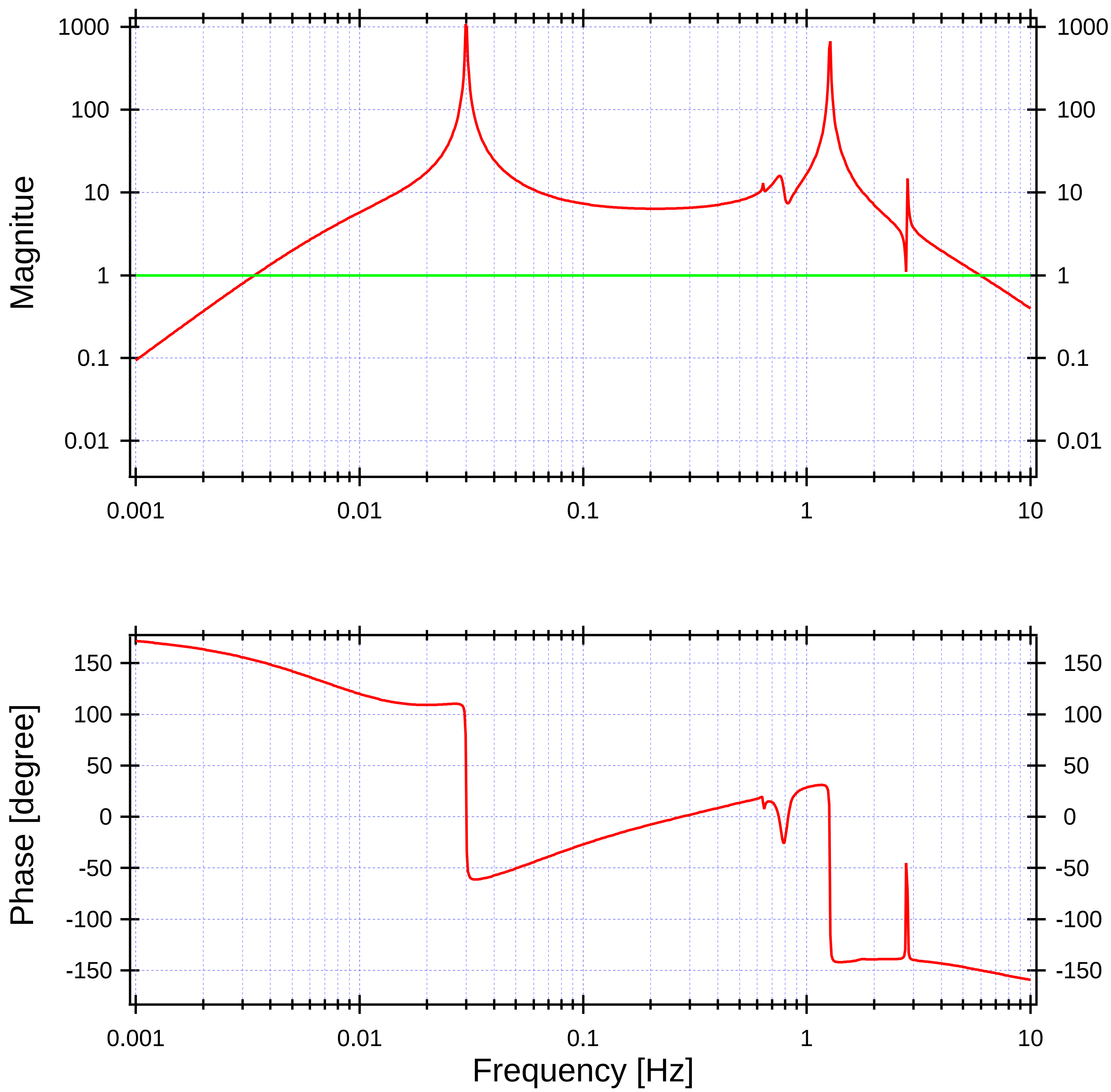
Control with LVDTs

Transfer Function of SAS (Ground to IP Top)



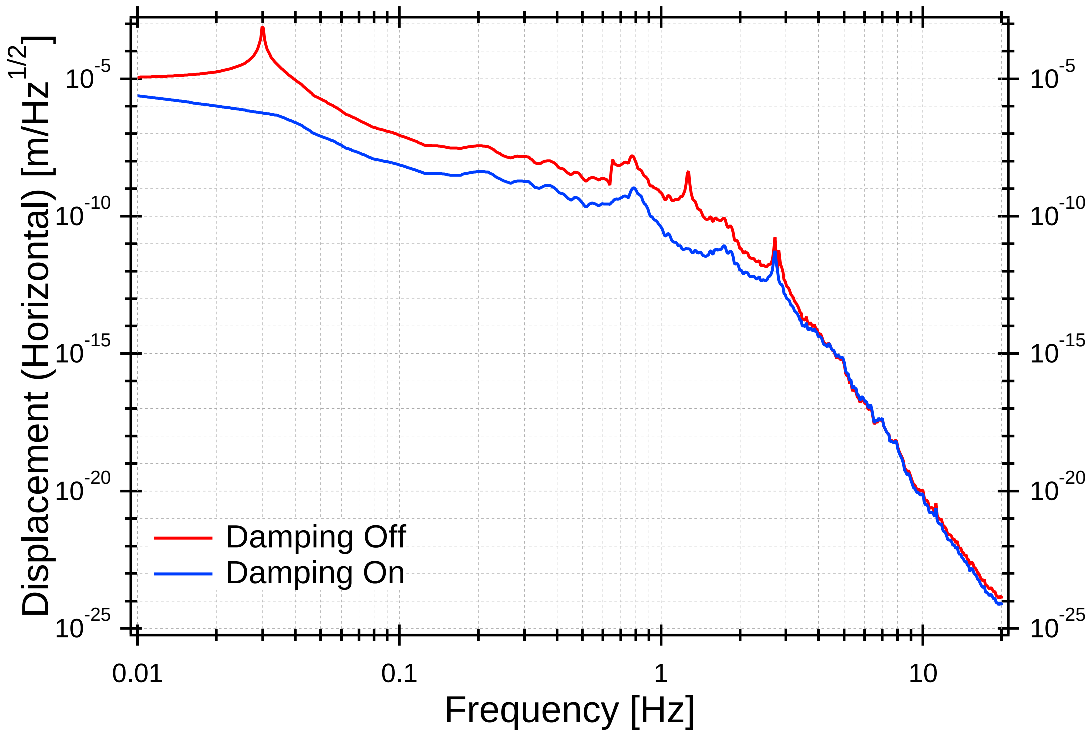
2. 3. Simulation

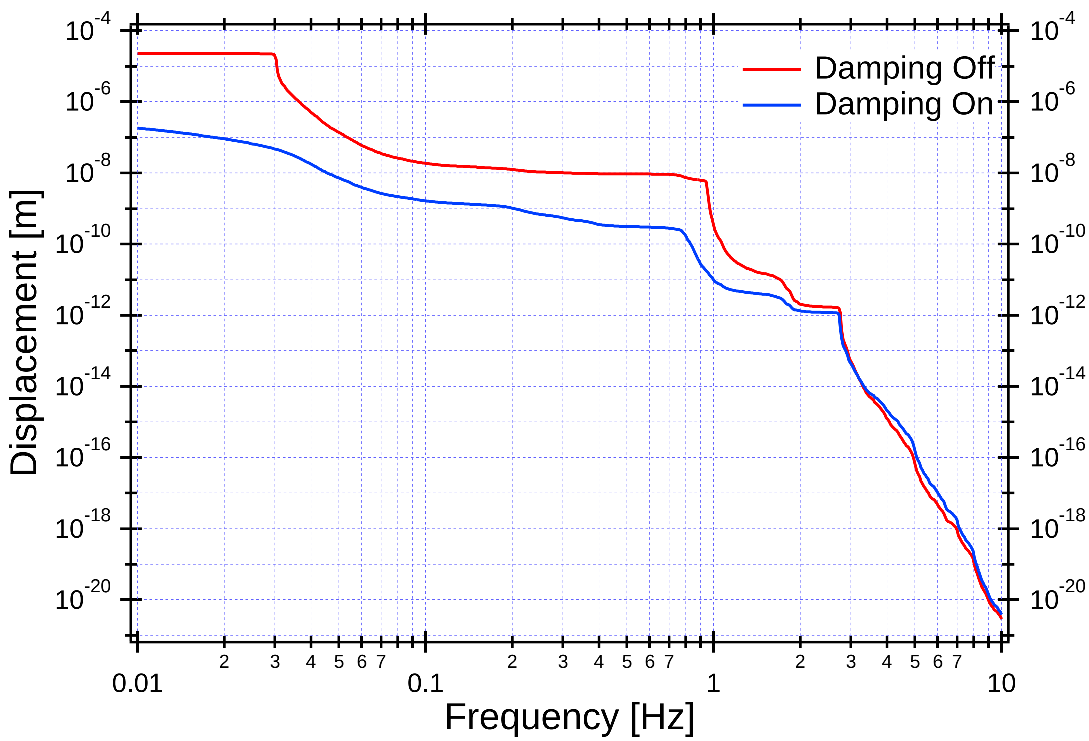
Inertial Damping



2. 3. Simulation

Inertial Damping





3. Experiment

3. 1. Scope

Confirmation/Improvement of Local Control Design

Main Issues

- **Confirmation of Virgo's Achievement**

- **Study on Unsolved Problems**
  Merging of Pos/ID Control
  Diagonalization for Global Control
  Merging with Suspension Control

- **Evaluation of System Performance**
  with Independent Sensors

3. 2. Current Advancement

Diagonalized LVDTs (topic of this talk)

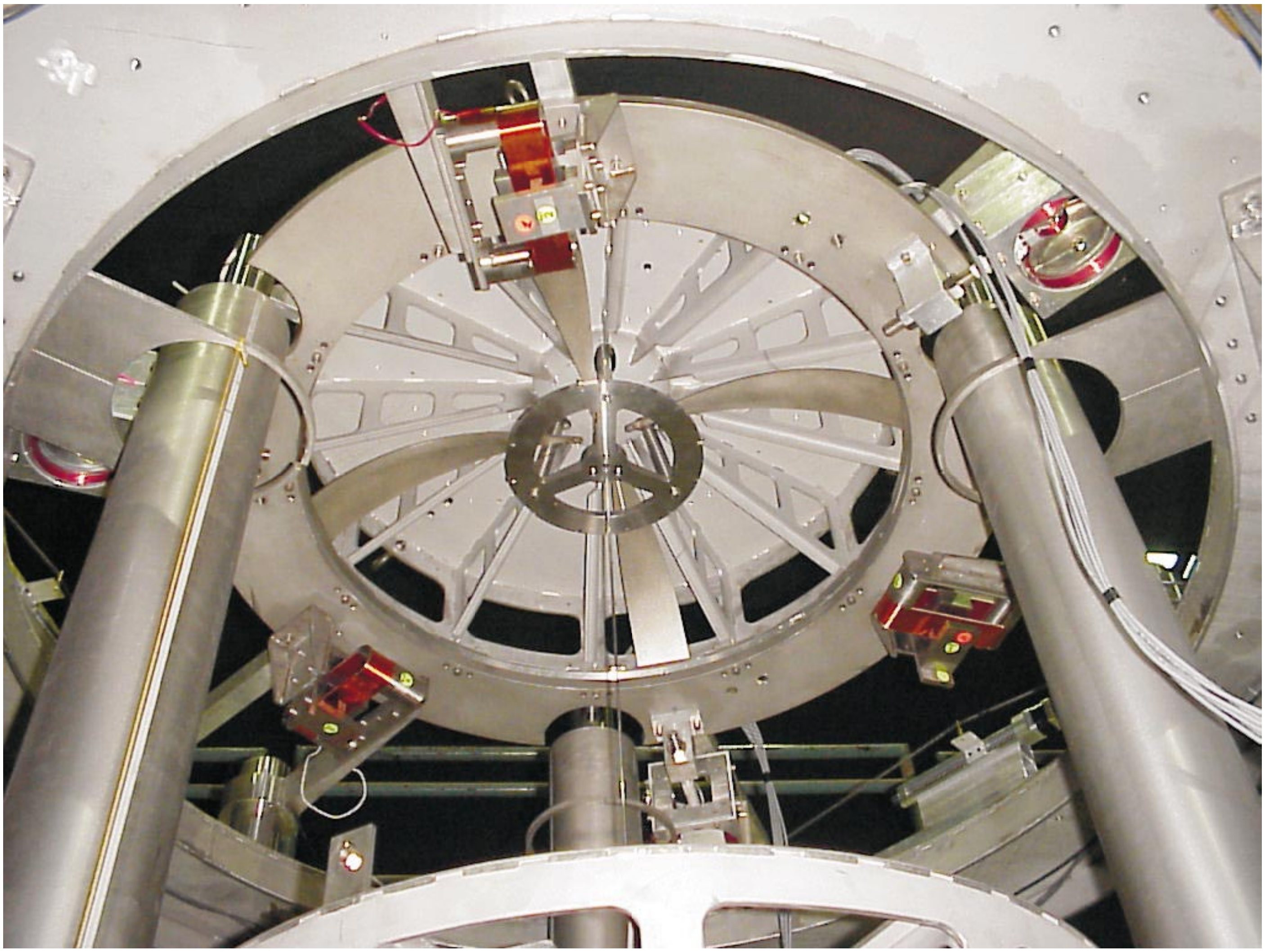
3. Experiment

3. 3. Setup

LIGO SAS Tower

- IP
- 3 GAS Filters
- Lead Block Payload
- 3 LVDTs
- 3 Virgo Accelerometers
- 3 DC Stepping Motor Actuators

3. 3. Setup



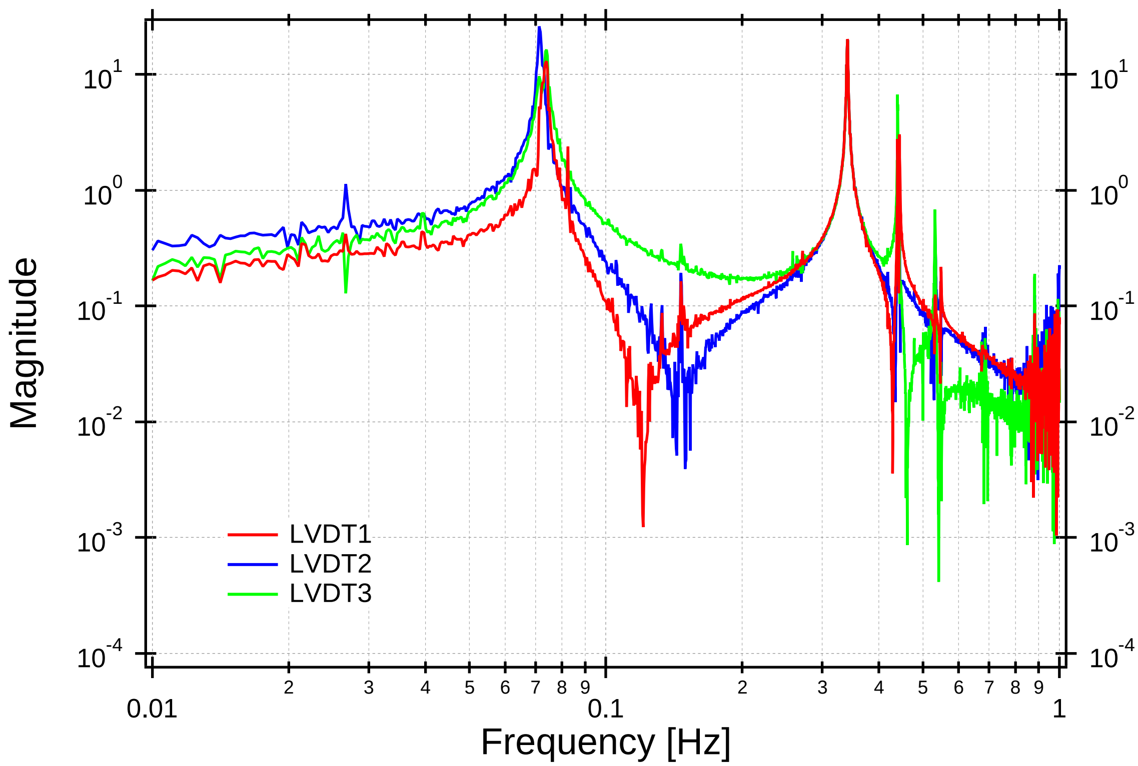
3. Experiment

SAS

3. 4. Results

LVDT Diagonalization

- Measurement of Transfer Function
from *Real* Actuator to *Real* LVDTs



3 Separated Modes

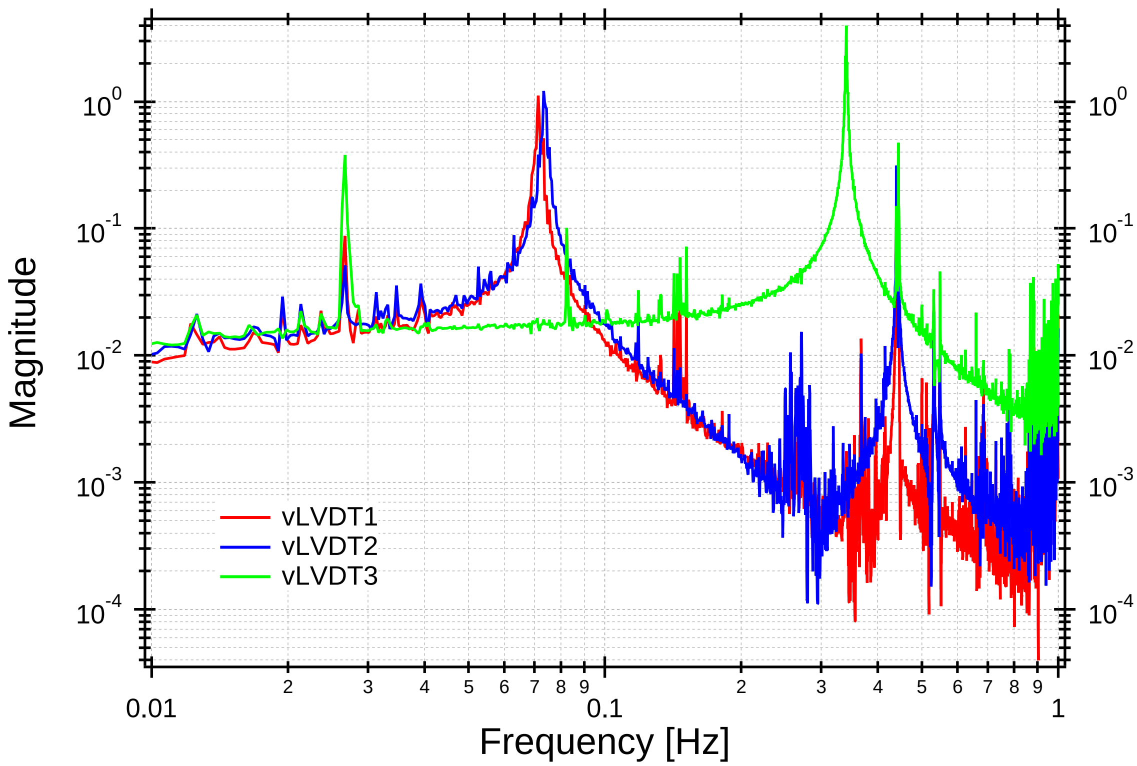
at Resonant Freq. : Only single mode is excited.

3. Experiment

SAS

3. 4. Results

Transfer Function of Virtual LVDTs



Each Virtual LVDT is sensitive to just one mode.

4. Conclusion

4. 1. Status

Designed SAS Control

Estimated SAS Performance

Confirmed Sensor Diagonalizing Procedure with LIGO SAS Prototype

working Effectively

4. 2. Works to be done

Experiment of Control with TAMA SAS Prototype

- **Passive characteristics of each components has been studied.**
- **Active components are ready.**
- **Launch Experiment without Suspension.**