Suspension Design for the 40m Interferometer

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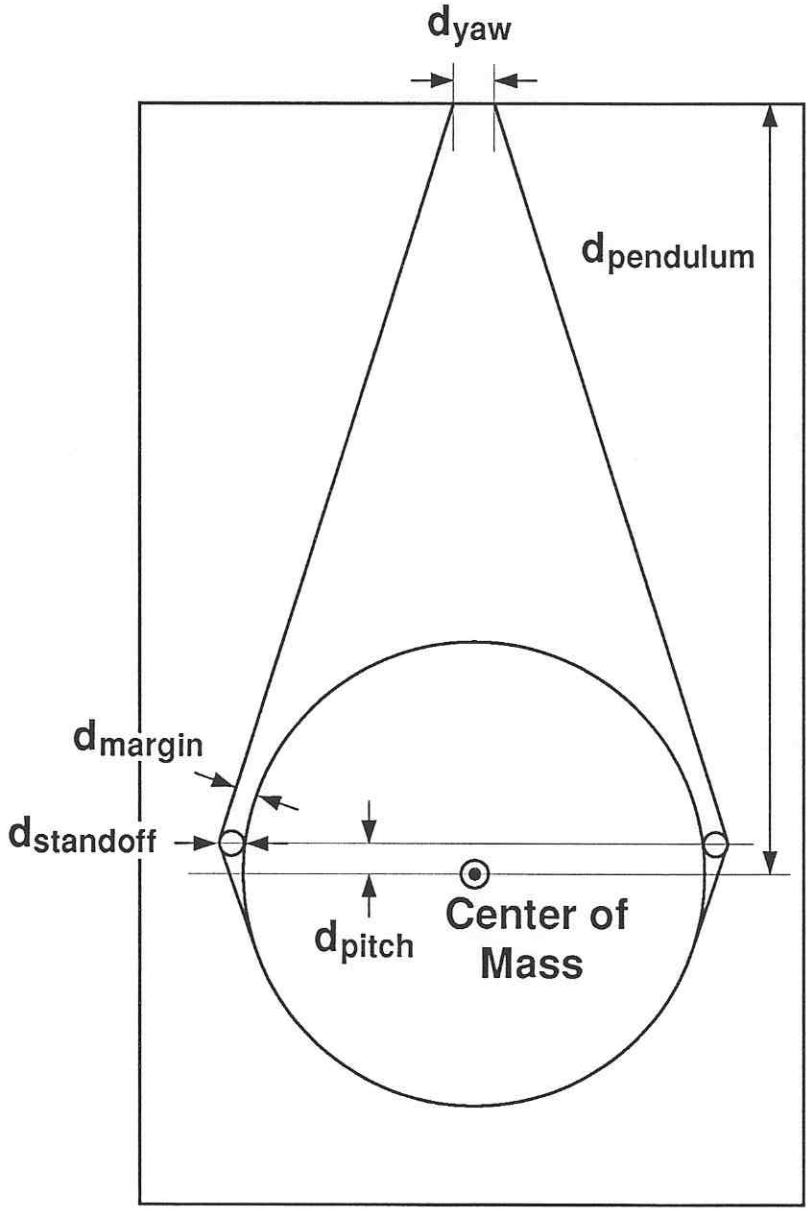
Agenda

- General Features of the design (S.K.)
- Mechanical Design (J.H.)
- Control/Electronics Design (S.K)
- Implementation (S.K.)

Features of the 40m Suspension Design

- One-body modular type suspension assembly
- Single loop of wire
- No control block
- Grooved wire standoff & guide rod
- Edge sensor
- No vane
- No active stabilization of LED intensity
- No preamplifier in the vacuum
- Cradle type safety cage
- Easy access to safety cage screw
- Low noise
- Low eddy current damping

Suspension Configuration



Physical Quantity	*40m TM*
Pendulum Frequency	0.84 Hz
Pitch Frequency	0.5 Hz
Yaw Frequency	0.5 Hz
$d_{pendulum}$	35 cm
d_{pitch}	1.3 mm
d_{yaw}	18 mm
$d_{standoff}$	1 mmD
d_{margin}	0.8 mm

Dimensions (I)

40 M SUSPENSION	*DIMENSIONS*	
PARTS	*millimeters*	*inches*
TEST MASS:		
diameter	101.6 r=50.8	4.00
thickness	88.9	3.50
MAGNET:		
diameter	1.905 r=.9525	.075
length	3.175	.125
STANDOFF:		
diameter	1.016 r=.508	.040
length	2.032	.080
dpendulum	350	
dpitch	1.3	
dyaw	18	
dstandoff (WIRE STANDOFF dia)	1.0 r=.5	.039
WIRE STANDOFF length	4.8	.19

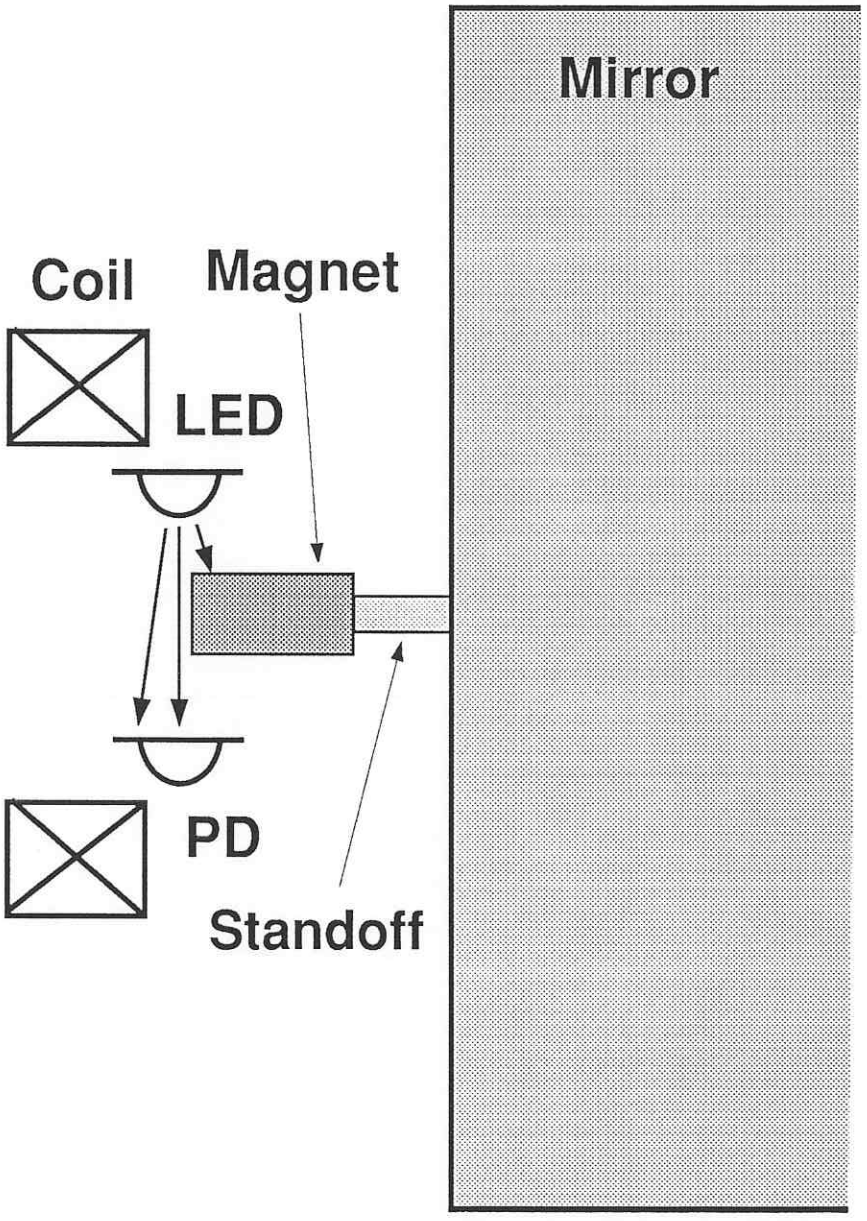
Dimensions (II)

40 M SUSPENSION	*DIMENSIONS*	
PARTS	*millimeters*	*inches*
GUIDE ROD:		
diameter	.64 r=.32	.025
length	3.3	.13
OSEM HEAD:		
outer diameter	25.32 r=12.66	1
length	45.9	1.807
LED		
length	4.0386	.159
width	4.2926	.169
thickness	2.9337	.1155
PHOTODIODE:		
length	7.5	.296
width	7.0	.2755
thickness	2.7432	.108

TBD
(Mechanical Design)

- Wedge consideration
- Yaw alignment gadget
- Rigidity of the suspension support structure
- Cable relay
- Aluminum coating for the sensor/actuator head and safety cage screw
- Grooved quartz rod
- Fixture for magnet/standoff assembly

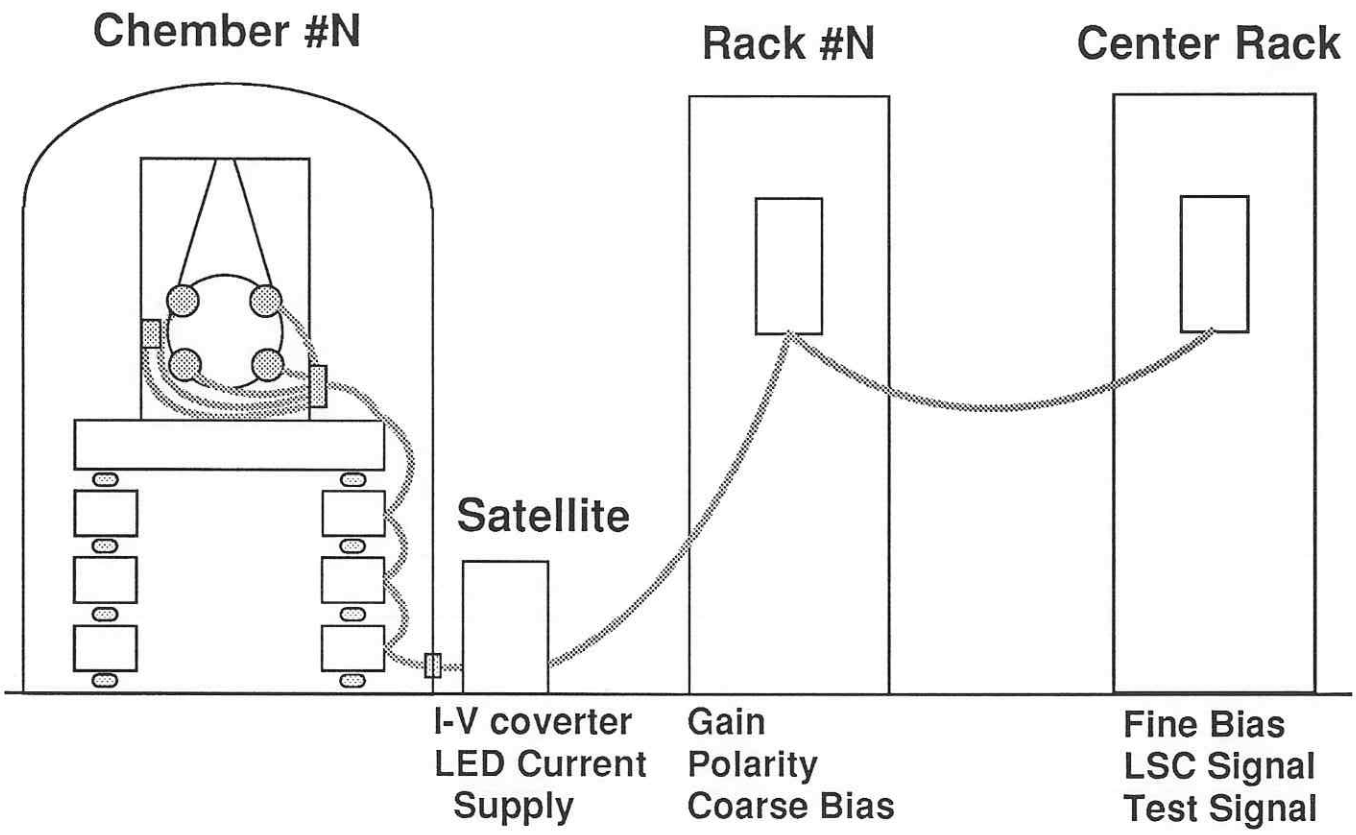
Sensor/Actuator Head



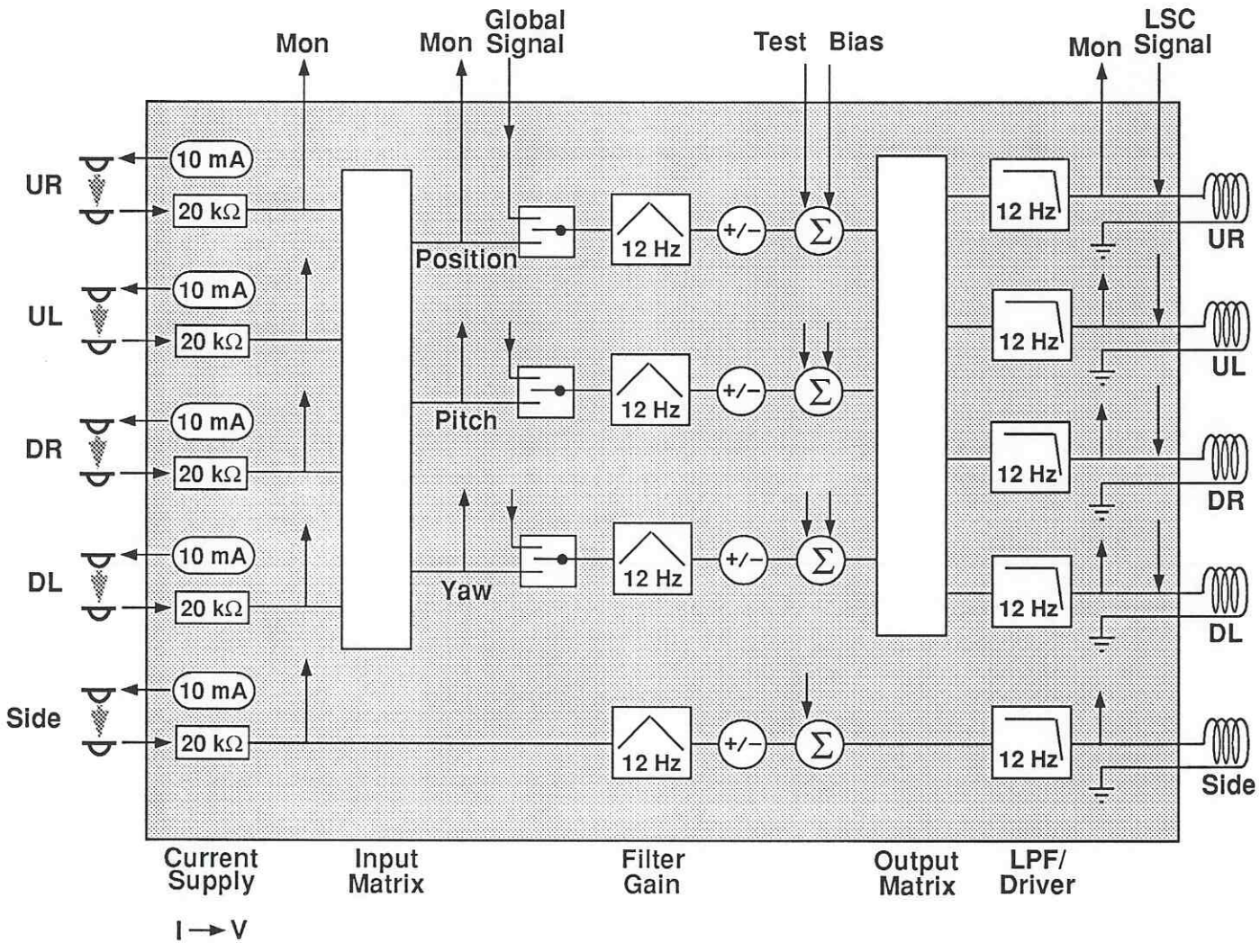
Sensor/Actuator Parameters

- Sensor
  - ››LED current: 10 mA
  - ››Distance between PD and LED: 6 mm
  - ››PD current: 100 μA_{max} (50 $\mu A_{nominal}$)
  - ››Sensitivity: 70 μA/mm per head
  - ››Range: 0.6 mm_{pp} (for 90% of maximum)
  - ››I-V resistance: 20kΩ
- Actuator
  - ››Magnet: Nd:Fe:B, 1.9 mmD x 3.2 mmL
  - ››Coil cross section: 5 mm x 5 mm
  - ››Current-force coefficient: 0.02 N/A per head
  - ››Series resistance: 1 kΩ
  - ››Voltage: +/- 15 V

Electronics & Cable Configuration

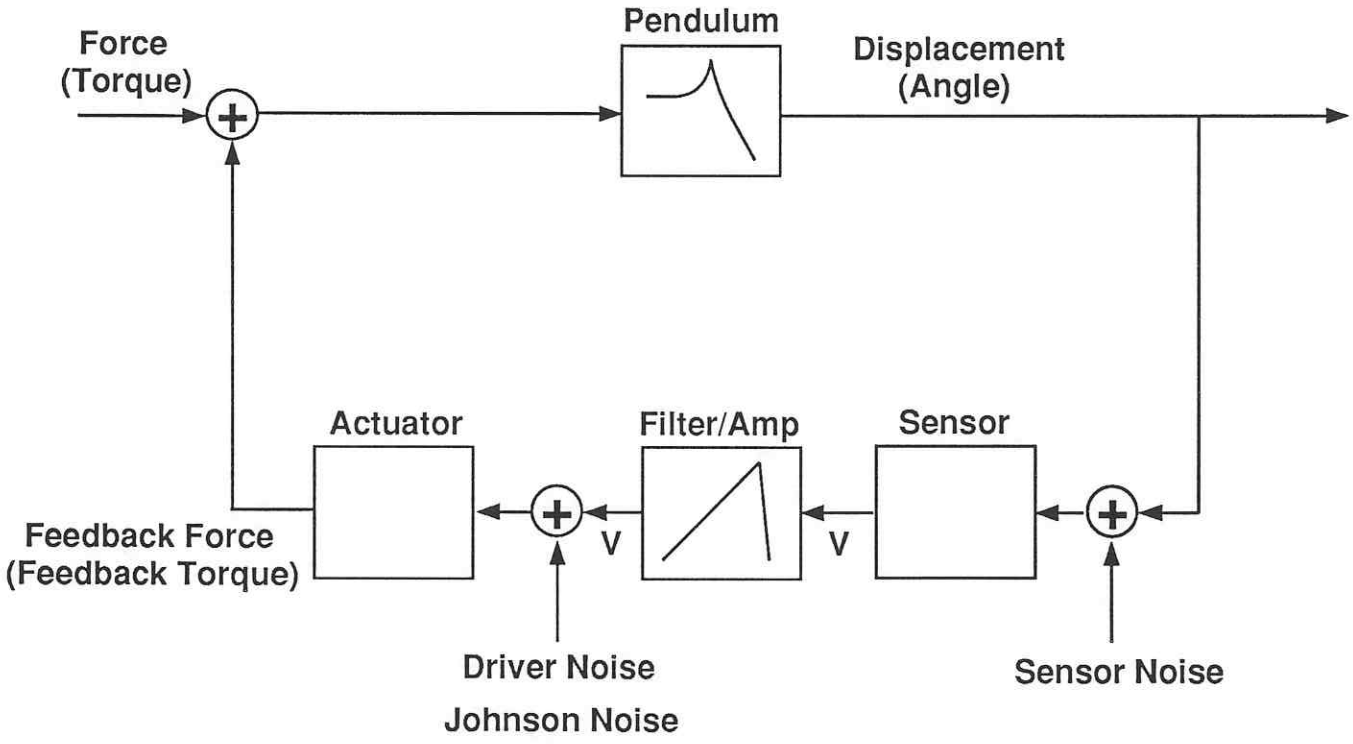


Control System



Servo Topology

- Filter:
  - ››0 Hz 1 zero
  - ››12 Hz 10 pole Cheb (1 dB)
- No bump in closed loop



Control Parameters

- Control parameters for pseudo-critical damping

Degree of Freedom	*Pendulum*		*Sensor (V/m or V/rad)*	*Filter/ Amp Gain$_{elec}$ @ 1Hz*	*Actuator (N/V or Nm/V)*
	f_0(Hz)	*(m/N or rad/Nm) @ DC*			
Position	0.84	2×10^{-2}	6×10^{3}	100	8×10^{-5}
Side	0.84	2×10^{-2}	2×10^{3}	1600	2×10^{-5}
Pitch	0.50	60	200	60	3×10^{-6}
Yaw	0.50	60	200	60	3×10^{-6}

- Pendulum (@ DC) x Sensor x Filter/Amp (@ f_0) x Actuator = 1

Sensor Noise

Degree of Freedom	*Sensor Noise (m/rHz or rad/rHz)*	*Loop Gain @ 40 Hz*	*Coupling*	*Displace-ment Noise @ 40 Hz (m/rHz)*
Position	3×10^{-11}	7×10^{-10}	1	2×10^{-20}
Side	6×10^{-11}	7×10^{-10}	< 0.1	$< 4 \times 10^{-21}$
Pitch	8×10^{-10}	4×10^{-10}	< 3 mm	$< 1 \times 10^{-21}$
Yaw	8×10^{-10}	4×10^{-10}	< 3 mm	$< 1 \times 10^{-21}$

- Displacement Noise = Sensor Noise
  x Loop Gain
  x Coupling

Driver Noise (Including Johnson Noise)

Degree of Freedom	*Effective Driver Noise (V/rHz)*	*Actuator/ Pendulum @ 40 Hz (m/V or rad/V)*	*Coupling*	*Displace-ment Noise @ 40 Hz (m/rHz)*
Position	3×10^{-9}	7×10^{-10}	1	2×10^{-18}
Side	6×10^{-9}	2×10^{-10}	< 0.1	$< 1 \times 10^{-19}$
Pitch	3×10^{-9}	3×10^{-8}	< 3 mm	$< 3 \times 10^{-19}$
Yaw	3×10^{-9}	3×10^{-8}	< 3 mm	$< 3 \times 10^{-19}$

- Displacement Noise = Effective Driver Noise
  x Actuator/Pendulum
  x Coupling

Range of Actuator

Degree of Freedom	*Driver Voltage$_{pp}$ (V)*	*Actuator (N/V or Nm/V)*	*Pendulum @ DC (m/N or rad/Nm)*	*Range @ DC (m_{pp} or rad_{pp})*
Position	30	8×10^{-5}	2×10^{-2}	5×10^{-5}
Side	30	2×10^{-5}	2×10^{-2}	1×10^{-5}
Pitch	30	3×10^{-6}	60	5×10^{-3}
Yaw	30	3×10^{-6}	60	5×10^{-3}

- Range = Driver Voltage
  x Actuator
  x Pendulum

Thermal Noise (Internal Mode)

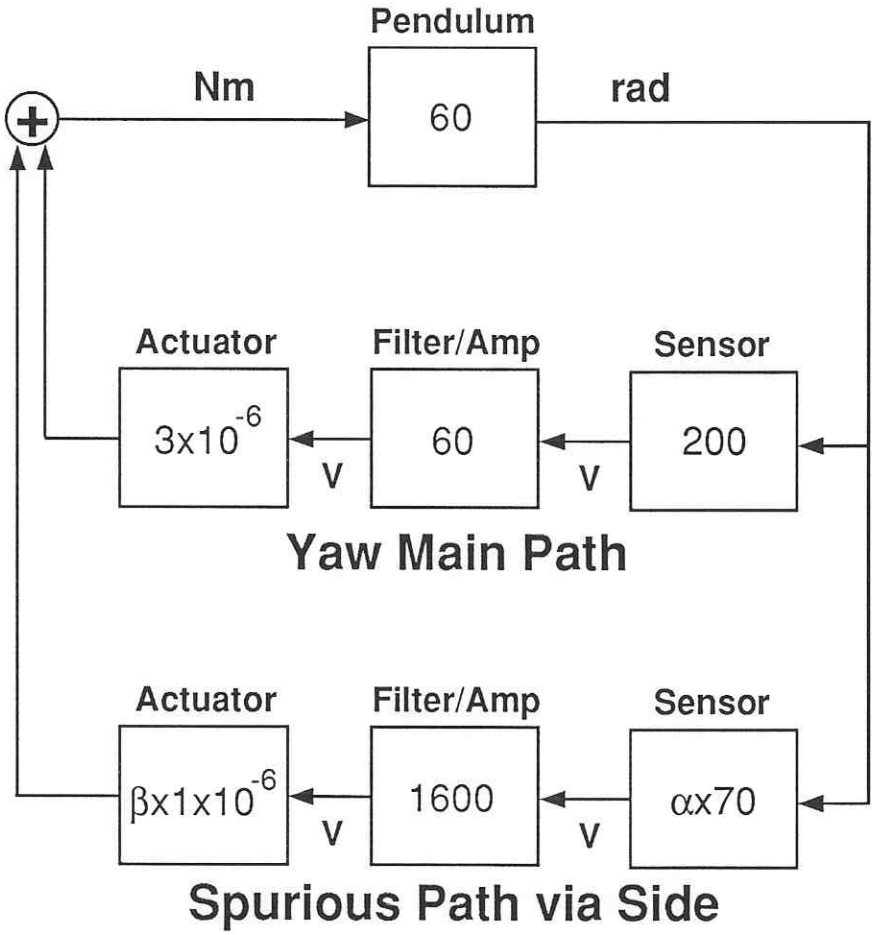
- Current 40m
  - ››Magnet: Nd:Fe:B, 3.2 mmD x 4.5 mmL
  - ››Standoff: aluminum, 1.6 mmD x 3.2 mmD
  - ››Q: 300,000 with 2 magnet/standoff assembly
  - ››Thermal Noise: $2 \times 10^{-19} \mathrm{m}/\sqrt{\mathrm{Hz}}$ at 100 Hz with 2 masses
- New Design
  - ››Magnet: Nd:Fe:B, 1.9 mmD x 3.2 mmL (35% in S, 25% in V)
  - ››Standoff: aluminum, 1.0 mmD x 2.0 mmD (39% in S, 24% in V)
  - ››Q: 340,000 (if 1/S, 5) - 600,000 (if 1/V, 4) ??? with 5 magnet/standoff assembly --- to be measured
  - ››Thermal Noise: $2.7 \times 10^{-19} \mathrm{m}/\sqrt{\mathrm{Hz}}$ - $2.0 \times 10^{-19} \mathrm{m}/\sqrt{\mathrm{Hz}}$??? at 100 Hz with 4 masses
  - ››Effect of wire standoff and guide rod: negligible

Thermal Noise (Pendulum Mode)

- Current 40m
  - ››Wire: 2 loops, steel, 0.003"D, 25 cm
  - ››Thermal noise: $3 \times 10^{-19} \mathrm{m}/\sqrt{\mathrm{Hz}}$ at 100 Hz
- New design
  - ››Wire: 1 loop, steel, 0.0036"D, 35 cm
  - ››Thermal noise: $2 \times 10^{-19} \mathrm{m}/\sqrt{\mathrm{Hz}}$ at 100 Hz ???
  - ››Effect of groove on wire standoff: negligible

Cross-coupling

- e.g. Side to Yaw
  - ›› α: Sensor coupling, β: Actuator coupling
  - ›› a x b << 0.3 is required!



TBD
(Electronics)

- LSC signal injection
- Clean-up of the circuit diagram
- System design of electronics

Implementation

- Design (- Jun. 95)
- Fabrication (Jun. 95 - Nov. 95)
- Test on bench (Nov. 95)
- Installation and characterization (Dec. 95 - Jan.96)
- Modification and design of the BS suspension (Feb. 96 - Mar. 96)
- Fabrication (Apr. 96 - Jul. 96)
- Test/preparation (Aug. 96)
- Installation (Sep. 96)