Methodology for Determining the Sensing and Actuation Matrices of the Test Masses

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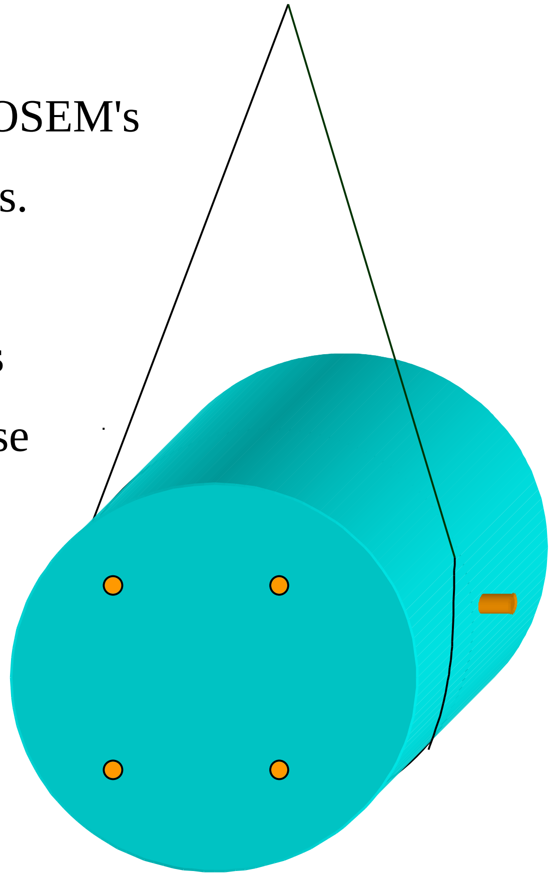
Test Mass Eigenmodes



- Test Masses have the OSEM, sensor/actuator system. OSEM's susceptible to small misalignments and inefficiencies.
- Sensing matrix converts the sensor signals to the optic's position/orientation. Actuation matrix converts these position signals into an actuator input signal.
- These matrices should be tuned for efficiency.
- Side Sensor information (?)
- Optic's position is referenced to it's eigenmodes and/or to the optical levers (P & Y)

Calculating the Sensing Matrix

We define the detector signals, D, and the Position signals in "lab" coordinates by, M,

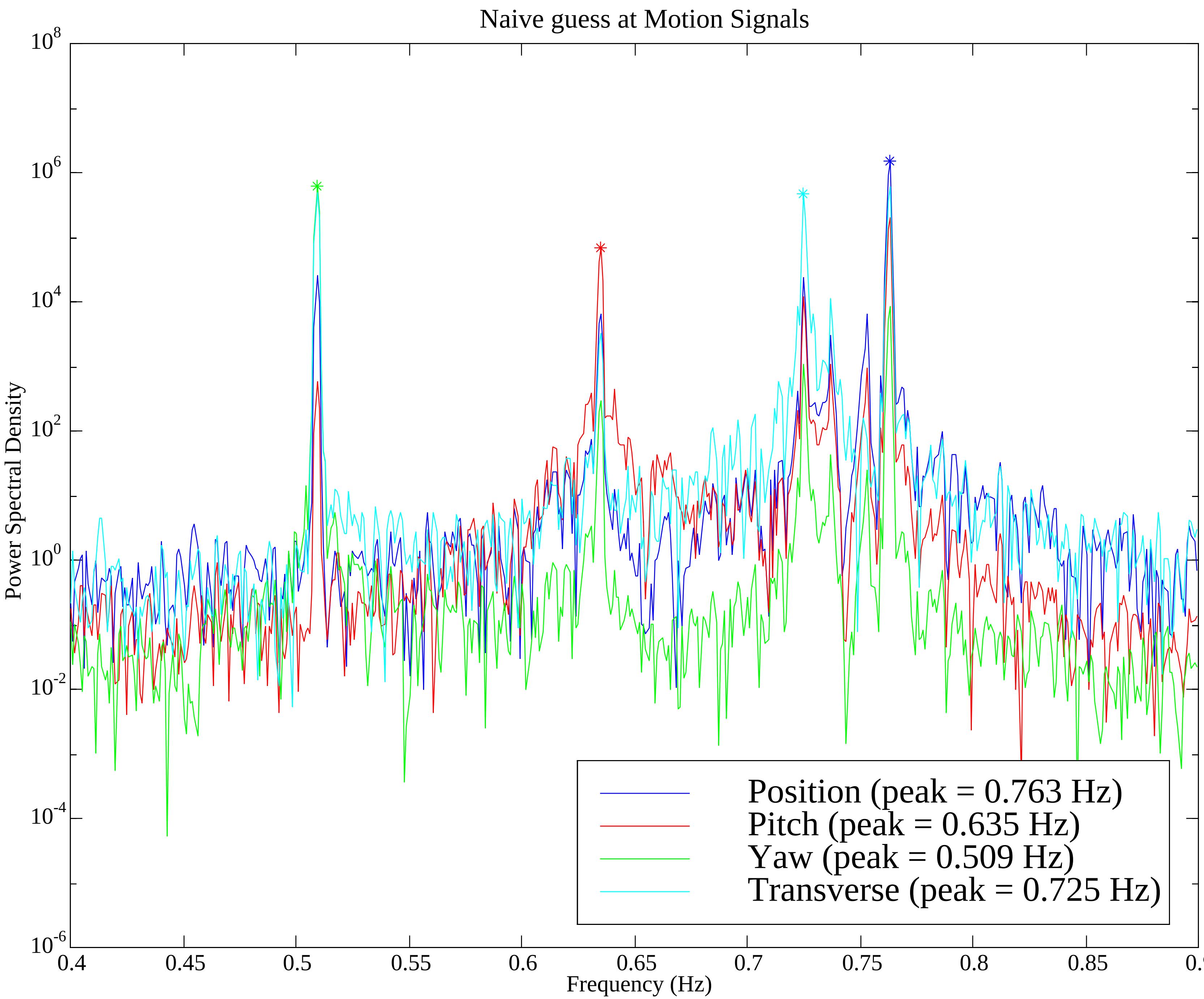
$$D = \begin{bmatrix} UL \\ LL \\ UR \\ LR \\ S \end{bmatrix} = \begin{bmatrix} UL(t_1) & \dots & UL(t_N) \\ LL(t_1) & \dots & LL(t_N) \\ UR(t_1) & \dots & UR(t_N) \\ LR(t_1) & \dots & LR(t_N) \\ S(t_1) & \dots & S(t_N) \end{bmatrix} \qquad M = \begin{bmatrix} X \\ P \\ Y \\ T \end{bmatrix} = \begin{bmatrix} X(t_1) & \dots & X(t_N) \\ P(t_1) & \dots & P(t_N) \\ Y(t_1) & \dots & Y(t_N) \\ T(t_1) & \dots & T(t_N) \end{bmatrix}$$

The sensing matrix, A, is given by $M = A \cdot D$.

Make an initial guess for the sensing matrix, A_0, where

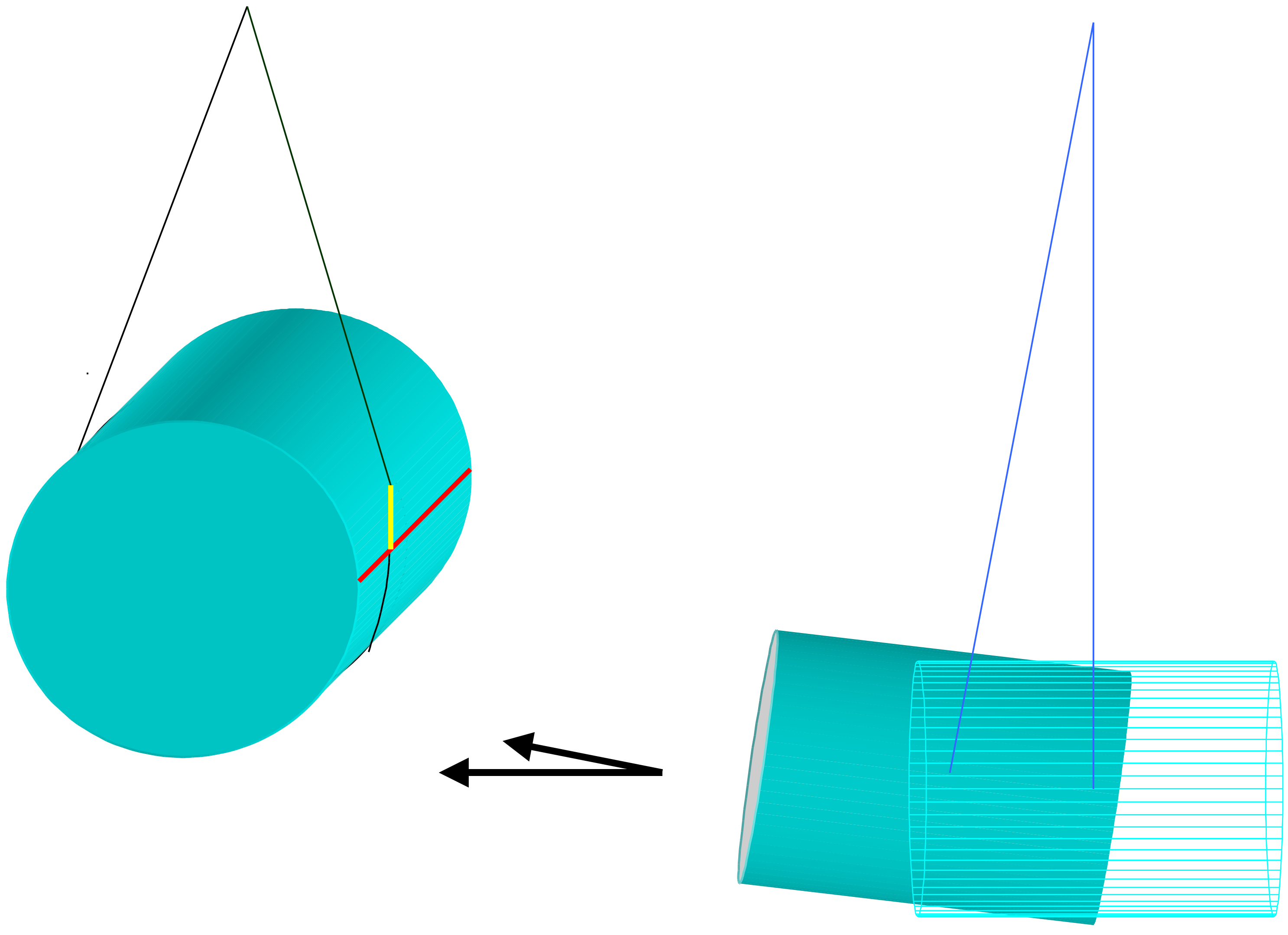
$$A_0 = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 \\ 1 & -1 & 1 & -1 & 0 \\ 1 & 1 & -1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

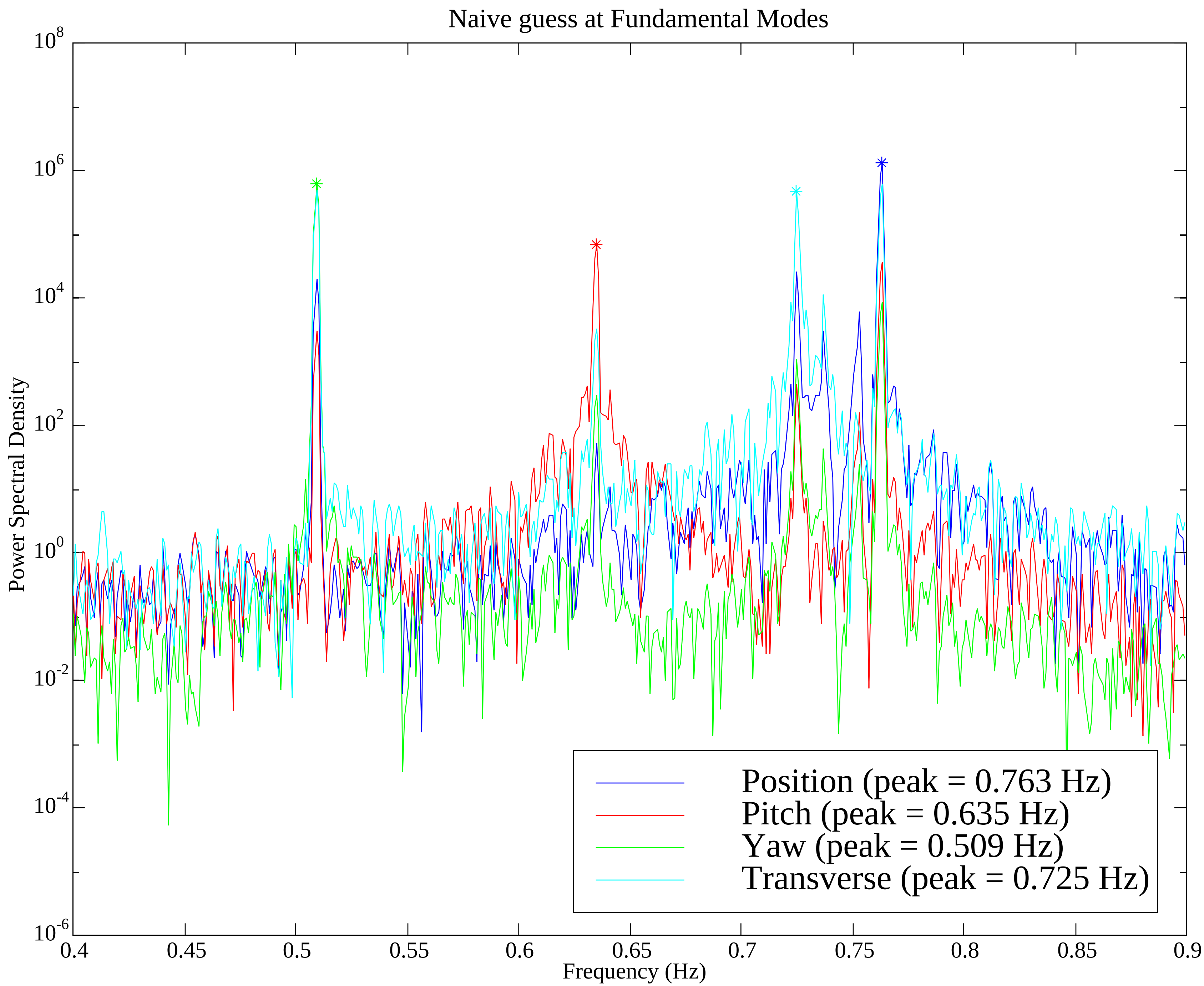
Then $M_0 = A_0 \cdot D$, is our initial guess for M .



Naive guess at Motion Signals
Power Spectral Density
Frequency (Hz)
10^8
10^6
10^4
10^2
10^0
10^-2
10^-4
10^-6
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
Position (peak = 0.763 Hz)
Pitch (peak = 0.635 Hz)
Yaw (peak = 0.509 Hz)
Transverse (peak = 0.725 Hz)

Test Mass Eigenmodes





Naive guess at Fundamental Modes
Power Spectral Density
Frequency (Hz)
10^8
10^6
10^4
10^2
10^0
10^-2
10^-4
10^-6
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
Position (peak = 0.763 Hz)
Pitch (peak = 0.635 Hz)
Yaw (peak = 0.509 Hz)
Transverse (peak = 0.725 Hz)

Filtering the EigenModes Signals

The eigenmode signals are given by $F = C\ F_0$ where

$$C^{-1} = \begin{bmatrix} 1 & \mathrm{P}_{\mathrm{X;P}}(f_P) & \mathrm{P}_{\mathrm{X;Y}}(f_Y) & \mathrm{P}_{\mathrm{X;T}}(f_T) \\ \mathrm{P}_{\mathrm{P;X}}(f_X) & 1 & \mathrm{P}_{\mathrm{P;Y}}(f_Y) & \mathrm{P}_{\mathrm{P;T}}(f_T) \\ \mathrm{P}_{\mathrm{Y;X}}(f_X) & \mathrm{P}_{\mathrm{Y;P}}(f_P) & 1 & \mathrm{P}_{\mathrm{Y;T}}(f_T) \\ \mathrm{P}_{\mathrm{T;X}}(f_X) & \mathrm{P}_{\mathrm{T;P}}(f_P) & \mathrm{P}_{\mathrm{T;Y}}(f_Y) & 1 \end{bmatrix}$$

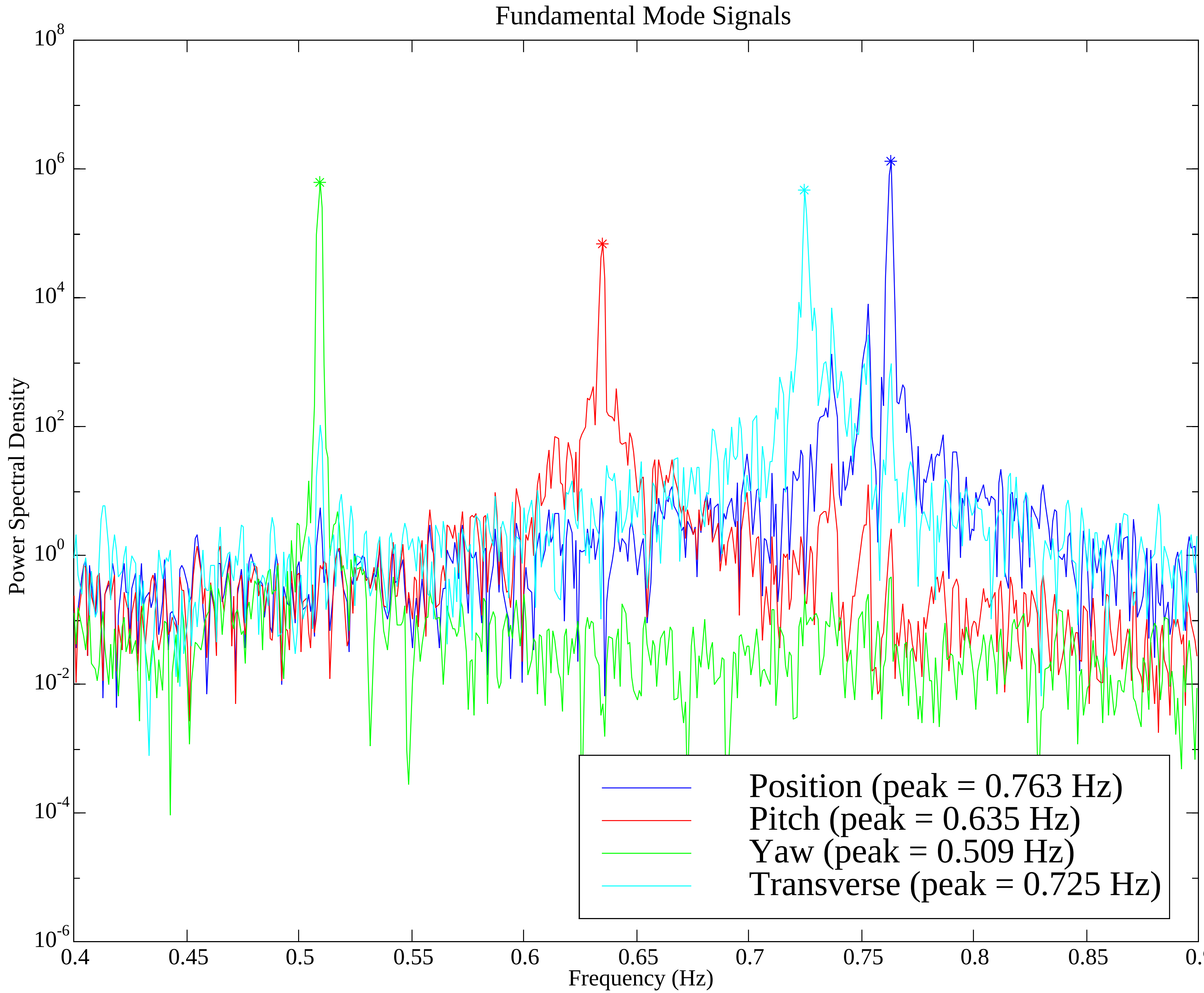
where $\mathrm{P}_{\mathrm{X;Y}}(f_Y) = \mathrm{P}_{\mathrm{X}}(f_Y) / \mathrm{P}_{\mathrm{Y}}(f_Y)\ \mathrm{sign}\left(\ \left(\mathrm{C}_{\mathrm{XY}}(f_Y)\right)\right)$,

P_{X} is the power spectral density of *X*, and

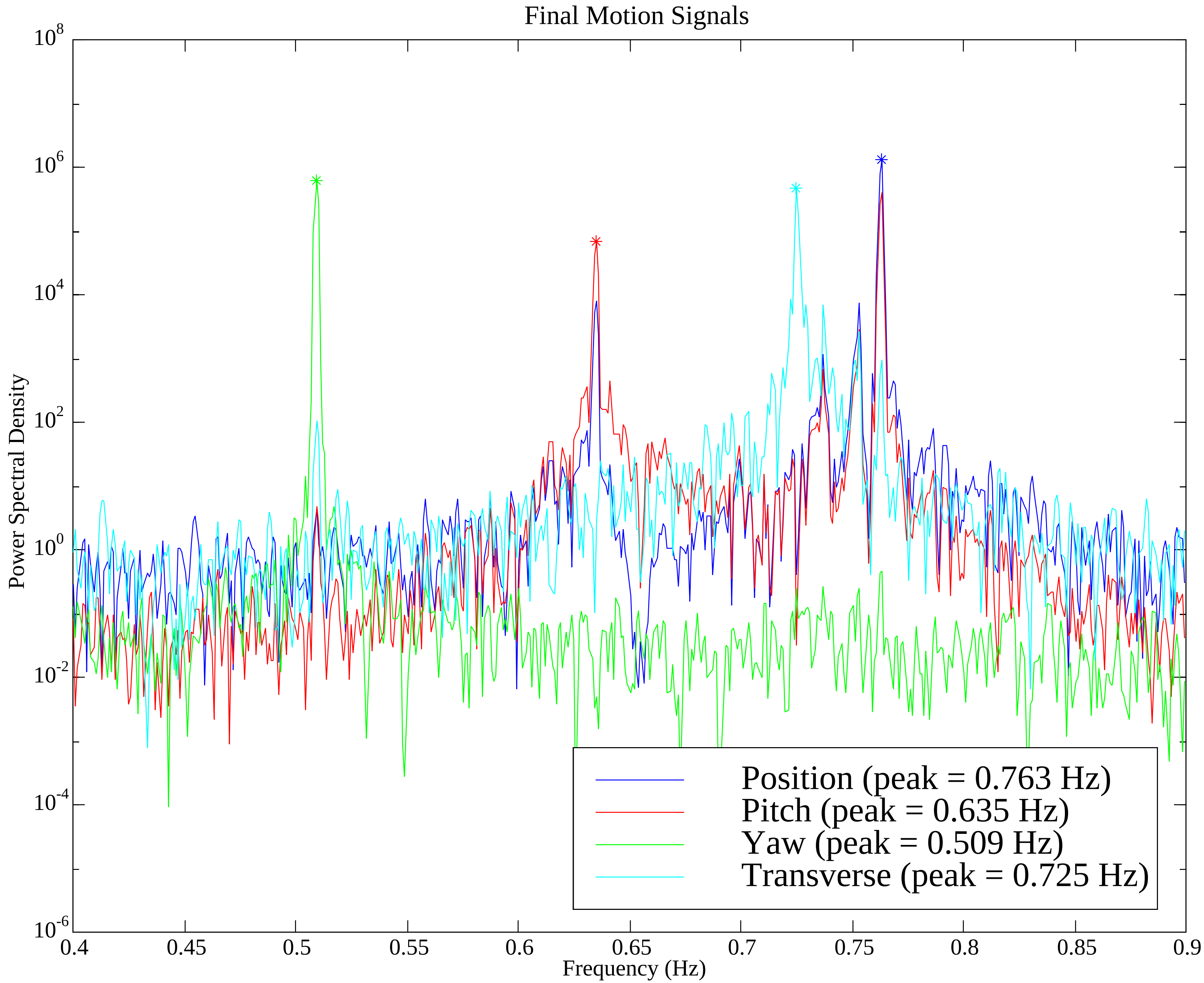
C_{XY} is the cross spectral density of *X* and *Y*.

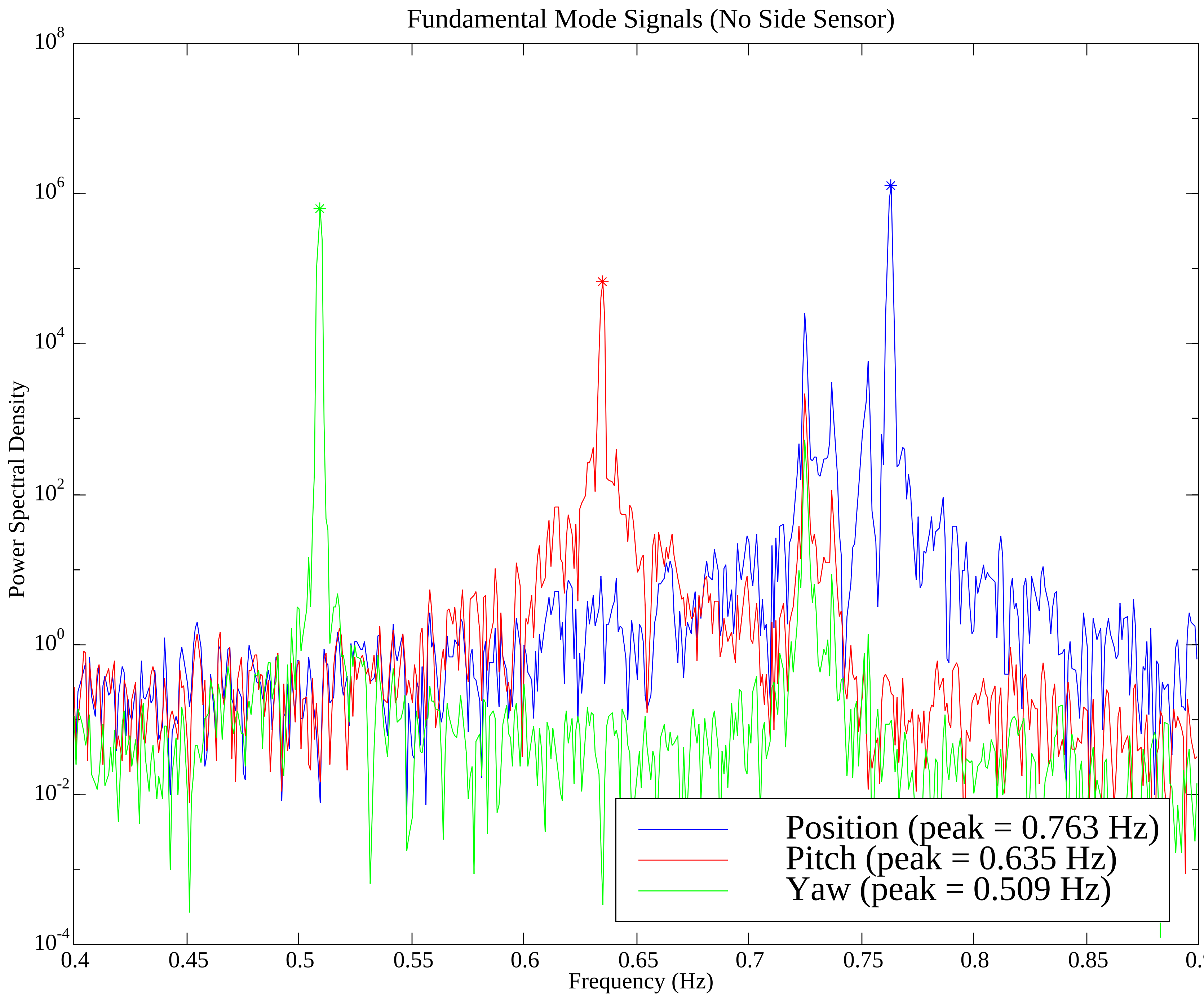
Finally, $M = R^{-1}\ F$, gives the position in the "lab" coordinate system, and

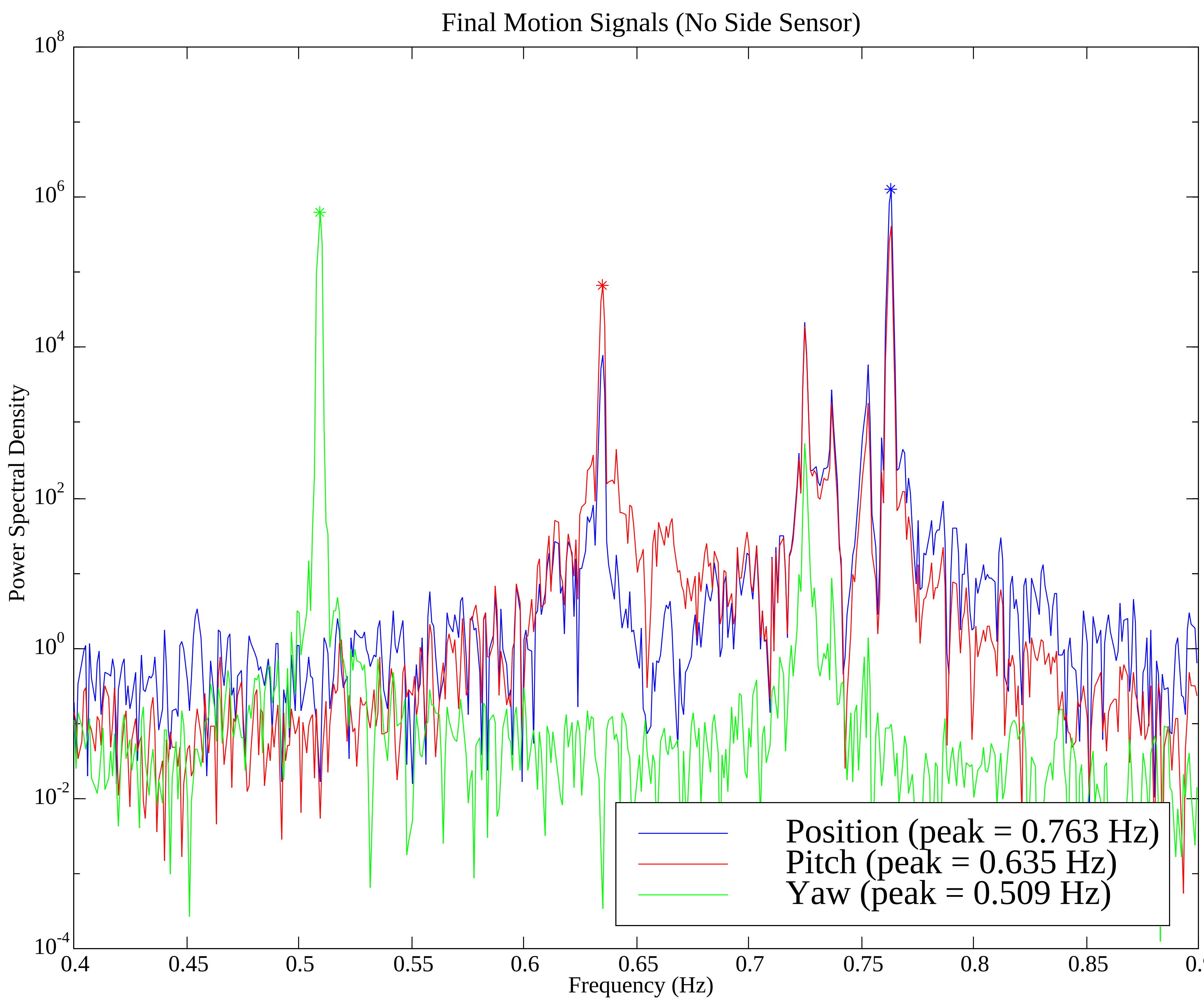
$$\boxed{A = R^{-1}\ C\ R\ A_0}$$



Fundamental Mode Signals
Power Spectral Density
Frequency (Hz)
10^8
10^6
10^4
10^2
10^0
10^-2
10^-4
10^-6
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
Position (peak = 0.763 Hz)
Pitch (peak = 0.635 Hz)
Yaw (peak = 0.509 Hz)
Transverse (peak = 0.725 Hz)


Final Motion Signals
Power Spectral Density
Frequency (Hz)
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
Position (peak = 0.763 Hz)
Pitch (peak = 0.635 Hz)
Yaw (peak = 0.509 Hz)
Transverse (peak = 0.725 Hz)


Fundamental Mode Signals (No Side Sensor)
Power Spectral Density
Frequency (Hz)
10^8
10^6
10^4
10^2
10^0
10^-2
10^-4
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
Position (peak = 0.763 Hz)
Pitch (peak = 0.635 Hz)
Yaw (peak = 0.509 Hz)



Final Motion Signals (No Side Sensor)
Power Spectral Density
Frequency (Hz)
10^8
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
0.4
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0.8
0.85
0.9
Position (peak = 0.763 Hz)
Pitch (peak = 0.635 Hz)
Yaw (peak = 0.509 Hz)

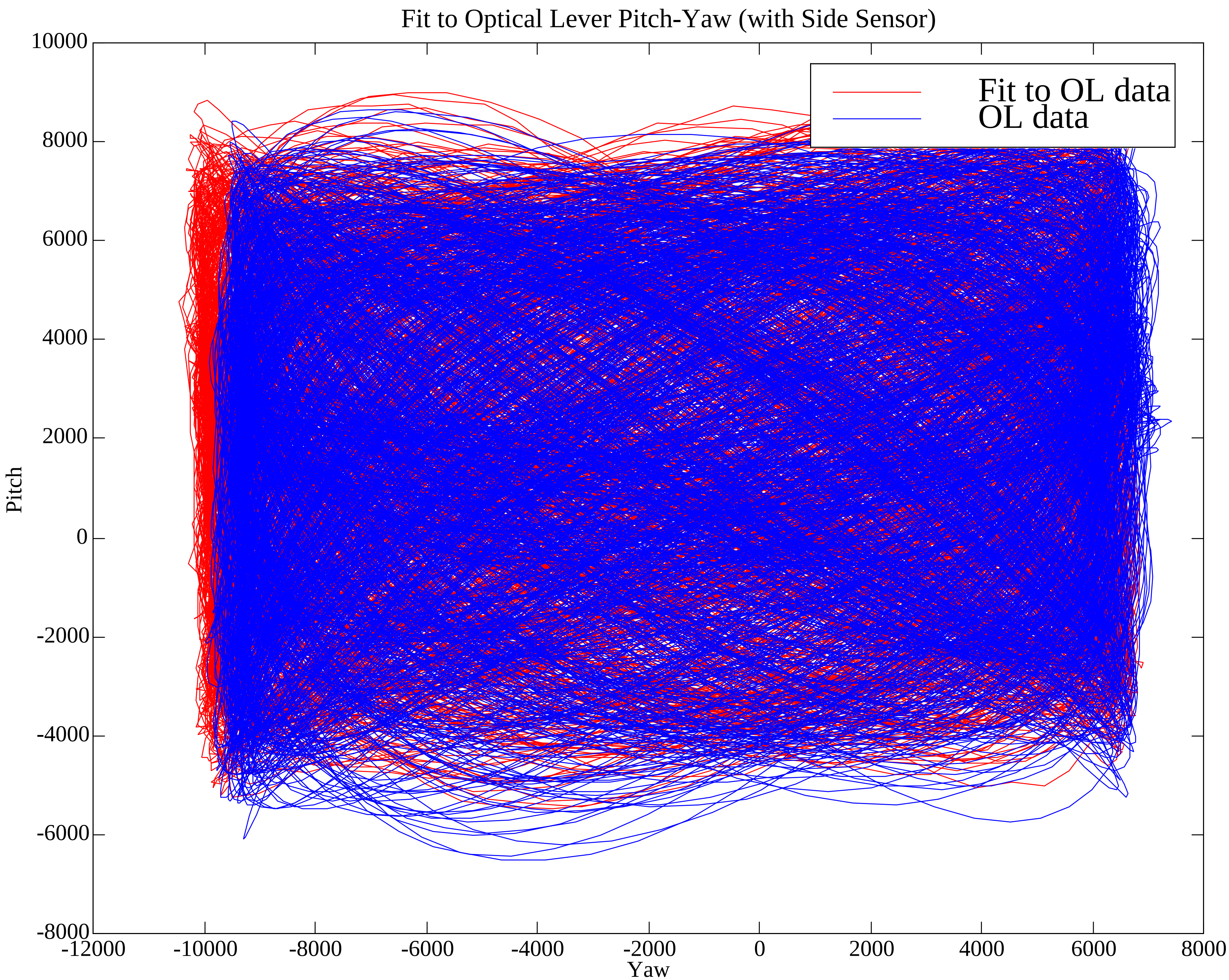
[Pitch, Yaw] Accuracy Check

- The optical levers use a laser reflected from the optic surface to monitor the pitch and yaw relative to the beam tube coordinate system.

- The [P,Y] of optic may be mapped to the [P,Y] of the optical lever to obtain the scale, offset, and rotation of the two coordinate systems

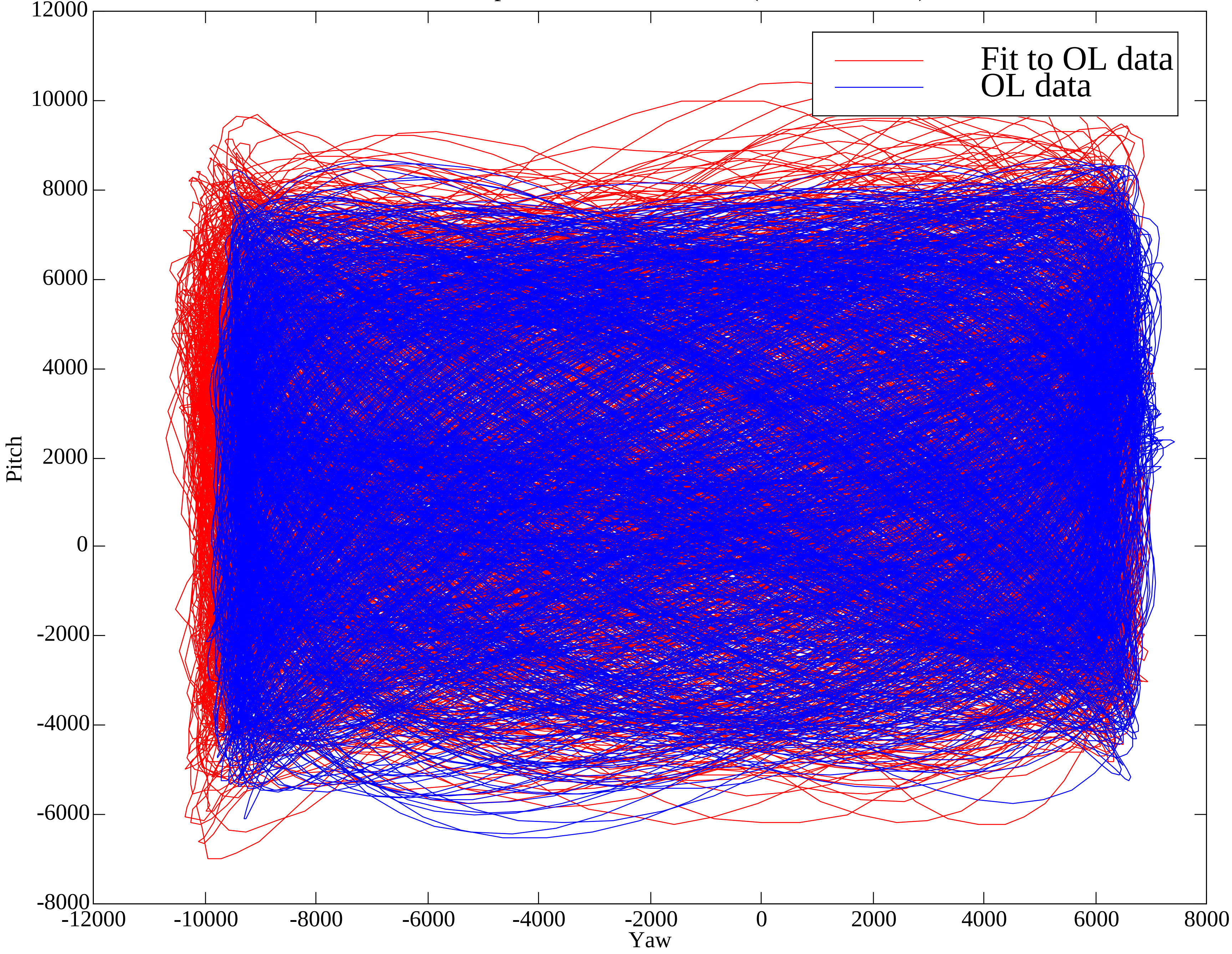
- For ITMY

  OL_Pitch,Yaw = R(0.024 rad) * [(4.38e+02, 1.93e+03) .* OSEM_Pitch,Yaw
  + (7.45e+02, -1.75e+03)]



Fit to Optical Lever Pitch-Yaw (with Side Sensor)
Fit to OL data
OL data
Pitch
Yaw
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-12000
-10000
-8000
-6000
-4000
-2000
0
2000
4000
6000
8000

Fit to Optical Lever Pitch-Yaw (no Side Sensor)



Actuation Matrix

- In development is a method for the actuation matrix which parallels the method for the sensing matrices.

- We can input a Signal to the actuators to drive motion in a given direction. We then read out the actual motion from the sensors using the sensing matrix. We perform this routine for an actuation input signal in all four coordinates. This will give us a measure for the cross-coupling. We can then tune out the cross-coupling as we did with the sensing matrix and output the tuned actuation matrix.

Conclusions

- Currently programs written by us (SP, GG, & MB) exist at the site for tuning the matrices. This process should be more refined to integrate the data acquisition, the matrix input to the system, and some measure of the improvement.

- We have shown the need to include the side sensor information in order to fully describe the test mass matrices. The amplifier boards used for forming position and actuation signals are being upgraded to include the side sensor.