KISS Workshop

"Cubesat Optical Communications:
1.) ACS Hardware Testing at JPL (SSDT Task)
2.) Acquisition and Tracking Simulation (DSOC)"

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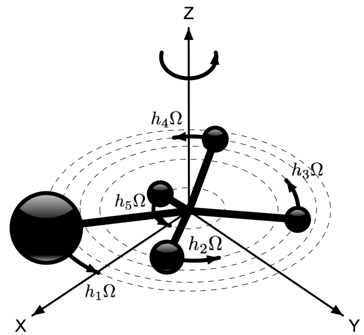
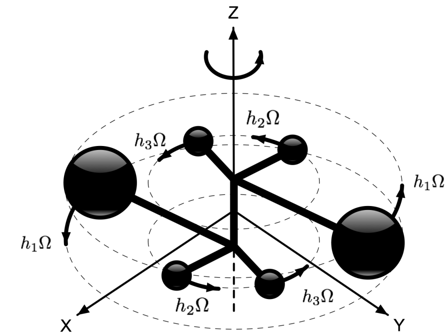
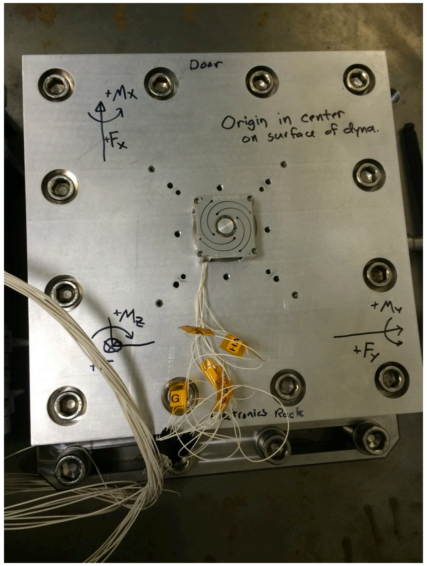
Cubesat RWA Testing at JPL

- This work was performed under the SSDT (Small Satellite Development Testbed) task at JPL.
  - Three cubesat wheels were tested using a Kistler 6 axis (Fx,Fy,Fz,Mx,My,Mz) dynamometer.
  - Exported "blocked" (first table mode was 1500 Hz) force and torque measured at high sample rates.
  - Wheels characterized out to 500 Hz and from 0 – 6450 RPM in 50 RPM increments.
  - Data used to develop harmonic models of the following form:

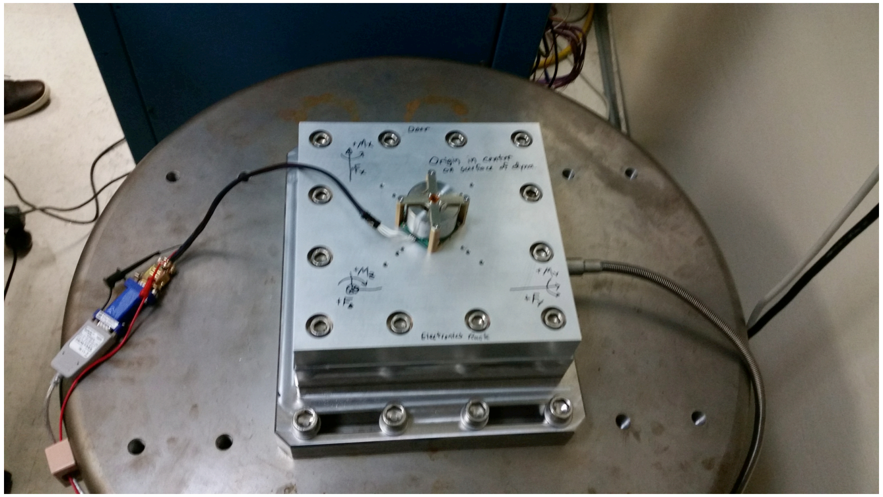
$$F_x(t) = \sum_{i=1}^{N_h} F_{x_i}(\Omega(t)) \cdot \sin(2\pi h_i \Omega(t) t + \phi_i^{F_{rad}})$$



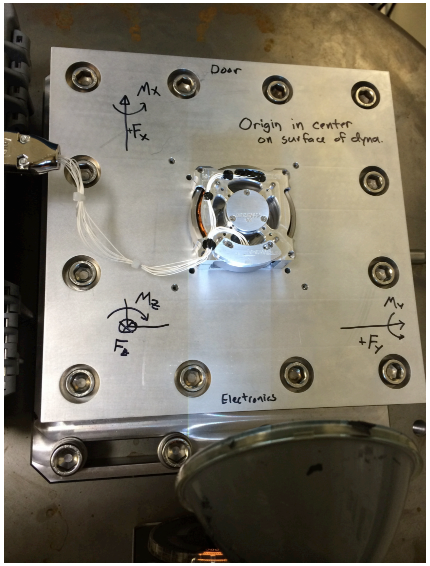




BCT 15 m-Nms RWA

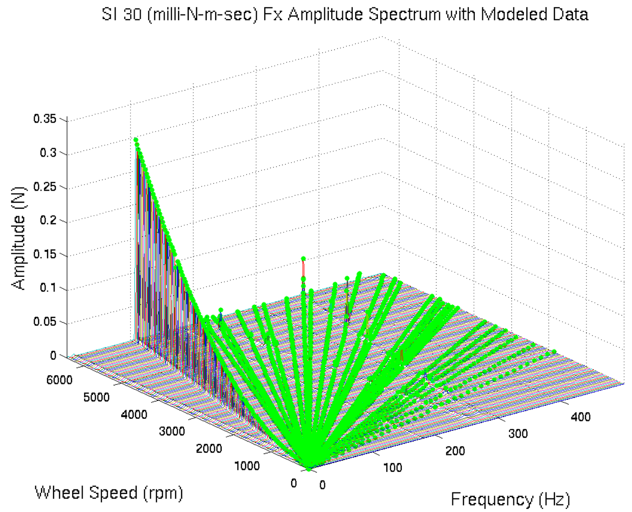


Sinclair SI 30 m-Nms RWA



BCT 100 m-Nms RWA

Cubesat RWA Testing at JPL



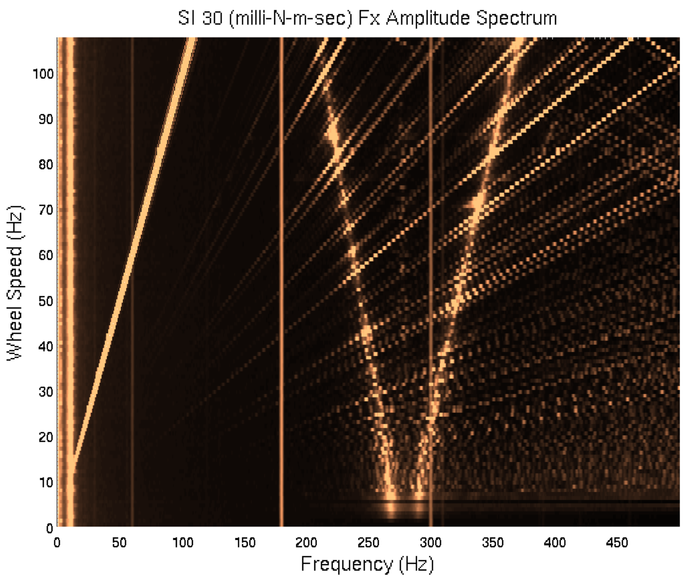


Table 1: Summary of Reaction Wheel Imbalances

Wheel	Momentum Capacity	Static Imbalance	Dynamic Imbalance
BCT 15	15 (milli-N-m-s)	0.382 (gram-mm)	27.590 (gram-mm^2)
BCT 100	100 (milli-N-m-s)	0.693 (gram-mm)	33.123 (gram-mm^2)
SI 30	30 (milli-N-m-s)	0.653 (gram-mm)	43.158 (gram-mm^2)

Table 2: Modal Summary for Reaction Wheels

Wheel	Rocking Mode	Axial Translation	Radial Translation	Number of Modeled Harmonics
BCT 15	300 Hz	380 Hz	NA	23
BCT 100	400 Hz	480 Hz	480 Hz	38
SI 30	290 Hz	NA	NA	27

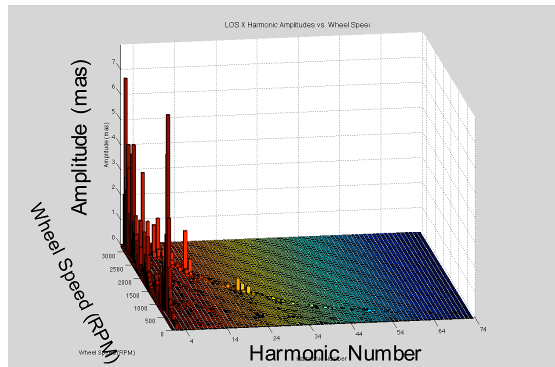
Table 3: Summary of Reaction Wheel Harmonic Coefficients

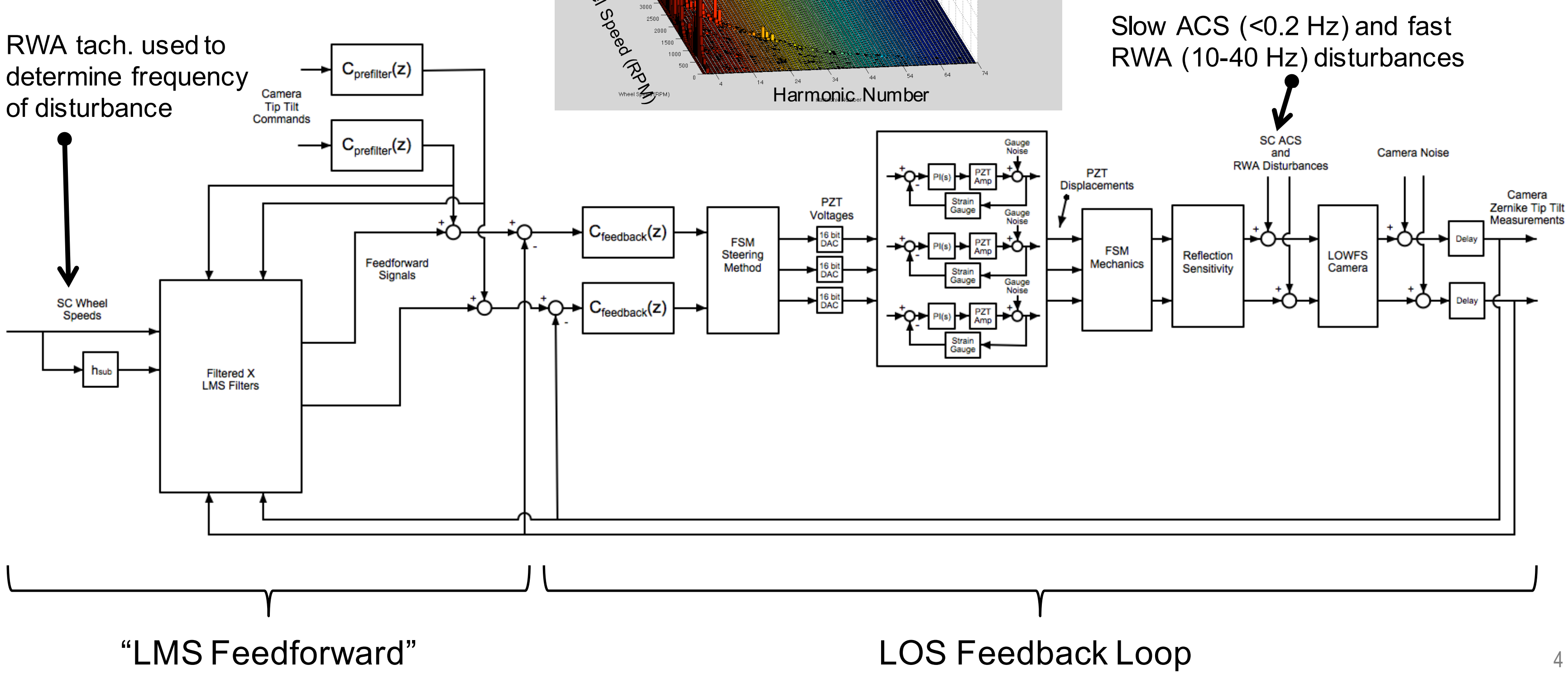
Wheel	Harmonic Coefficients: (Sorted lowest to highest)
BCT 15	0.9999 1.5457 1.9997 2.4345 2.5497 2.9953 3.0904 3.4463 3.5441 3.9978 4.0824 4.5502 4.9911 5.0923 5.4437 6.0923 6.5043 7.1050 7.9276 8.5401 10.2416 12.7994 14.8571
BCT 100	0.3605 0.7206 0.9997 1.4413 1.6381 1.8273 1.9994 2.1648 2.3165 2.5098 2.8335 2.9986 3.2235 3.4610 3.5810 3.6570 3.8342 3.9986 4.1637 4.3294 4.4687 4.6296 4.8310 4.9964 5.1580 5.6652 5.8299 5.9962 6.1332 6.4473 6.6151 6.7288 7.6659 8.6558 9.6270 10.4109 11.4971 12.4719
SI 30	1.0120 2.0240 2.1563 2.2462 2.5181 2.7652 2.9006 3.2366 3.4852 3.5992 3.9575 4.3188 4.6926 4.9254 5.0486 5.8648 6.1093 6.2523 6.45760 6.6036 6.7870 8.1606 8.8814 9.6069 10.7256 12.8661 16.1864

Rejecting the RWA Induced Jitter

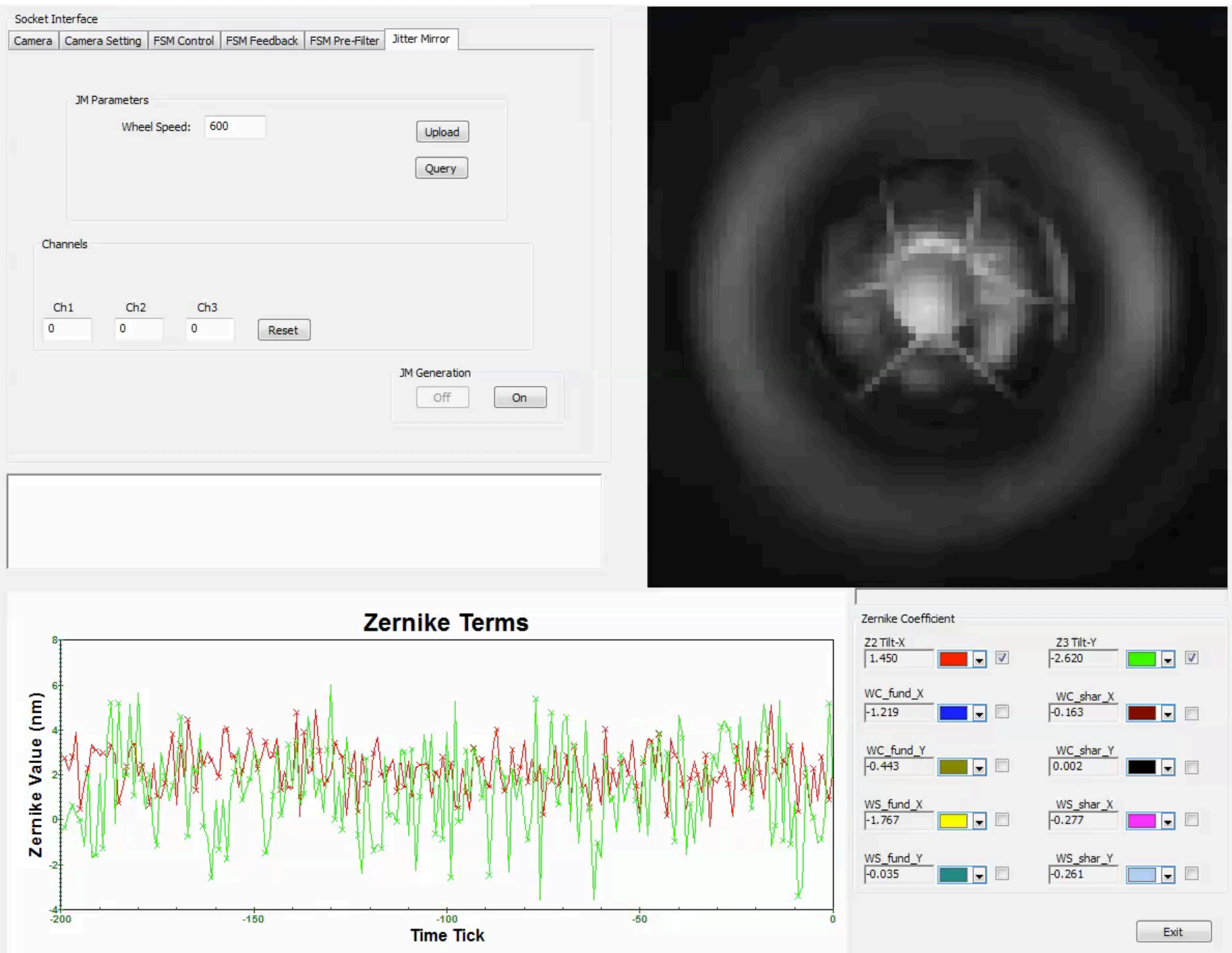
- Feedback: The LOS loop is shaped for **optimal rejection of the ACS disturbance and uplink sensor noise.** This is done by adjusting the bandwidth to minimize the RSS of both error sources.

  Feedforward: RWA tones are attenuated using an LMS filter which sends commands to the feedback loop. LMS estimates the gain and phase of the disturbance. RWA tachometer signal used to determine the frequency of the disturbance.

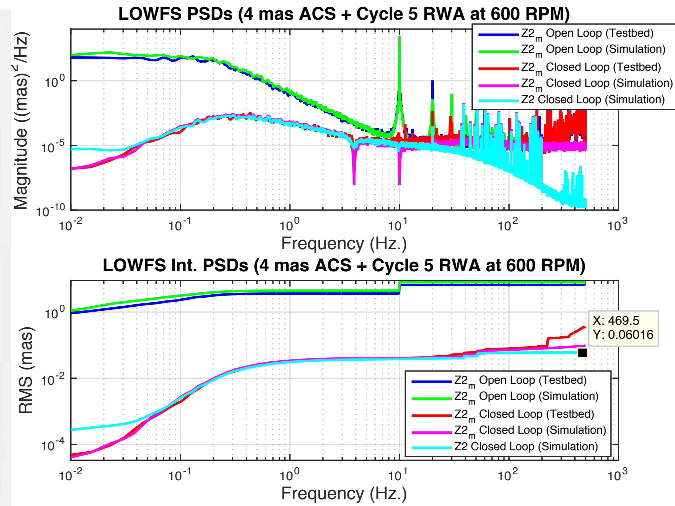




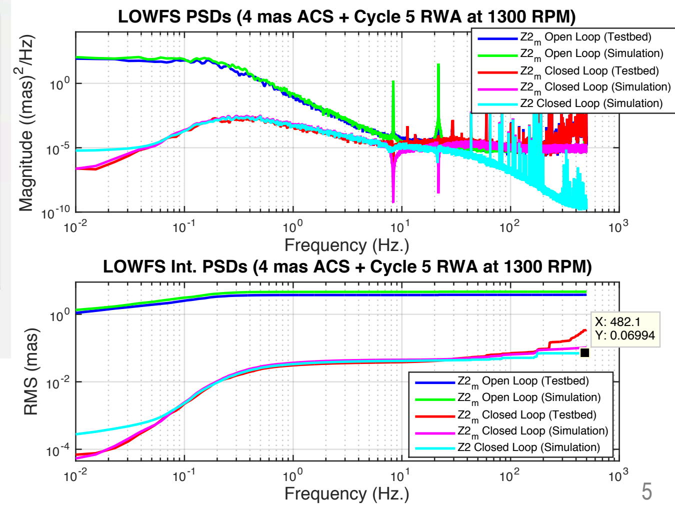
Rejecting RWA Jitter



600 RPM



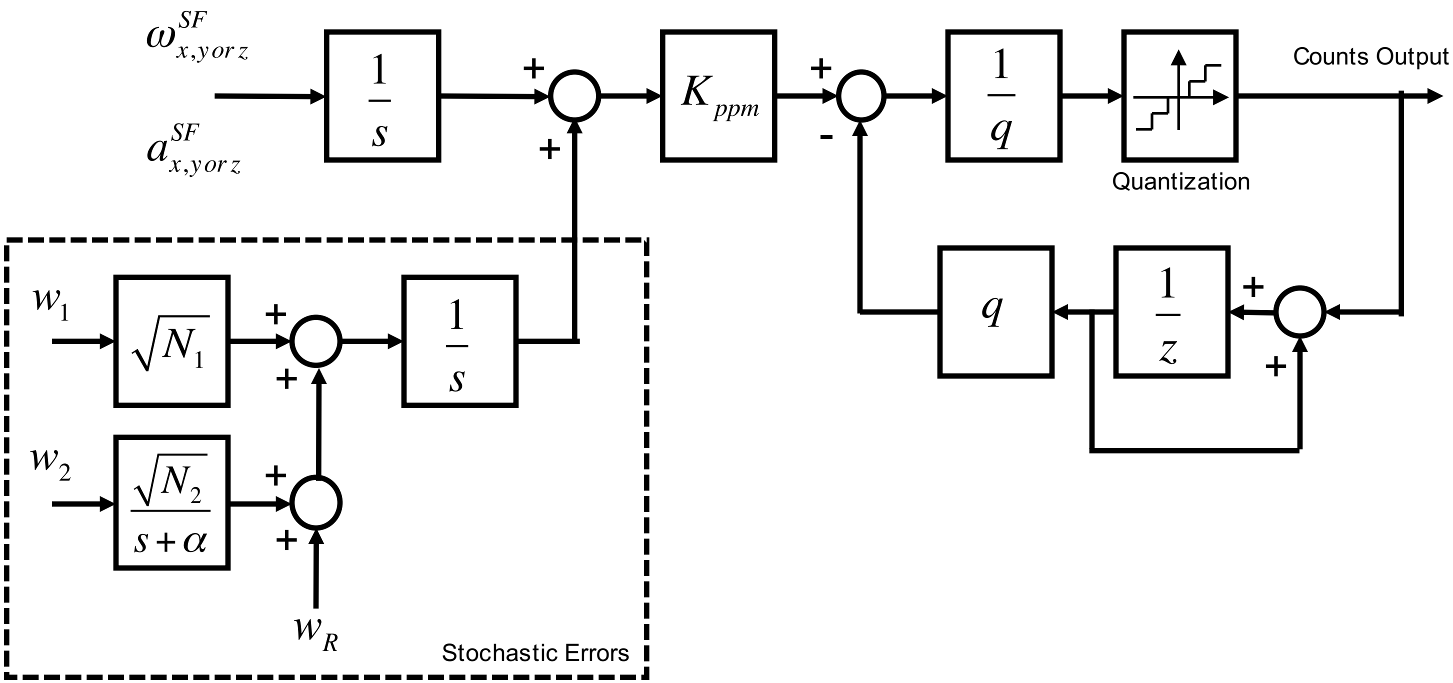
1300 RPM



Cubesat IMU Testing at JPL

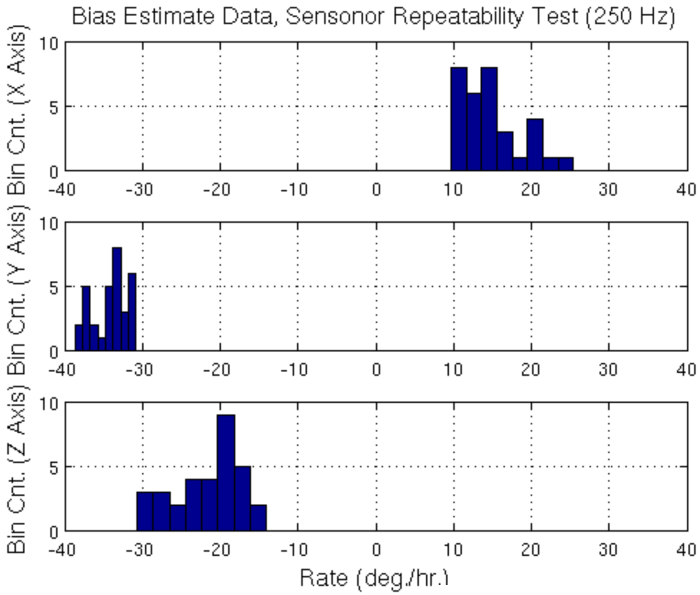
- Many Cubesat form factor gyros were tested including:
  - ADIS16488, Ellipse, Epson_IMU, KVH Gyro, KVH IMU, Sensonor, VectorNav.
  - One purpose of this testing was to develop models of the gyro output and to verify the stated specifications.
  - Two axis rate table used to perform 1.) scale factor experiments, 2.) repeatability experiments, and 3.) stochastic experiments. These experiments were sufficient to characterize the error terms in the block diagram below.

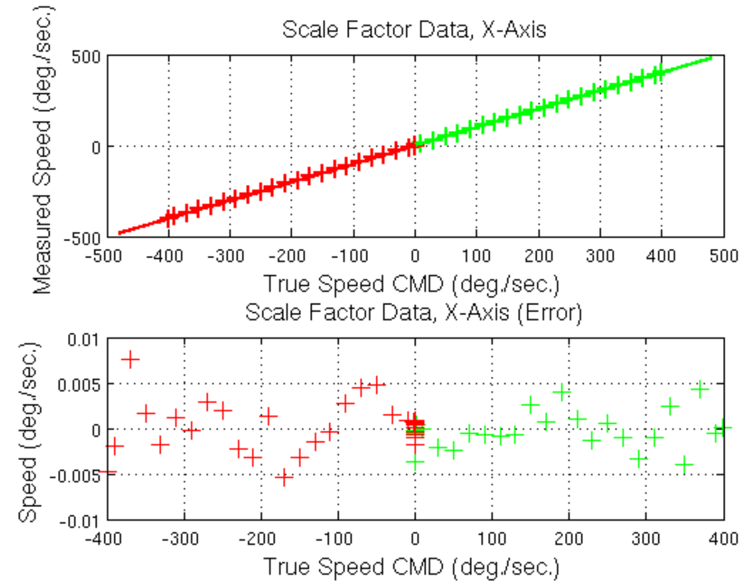
Block diagram for gyro model in delta theta mode. (Angle white noise error omitted)

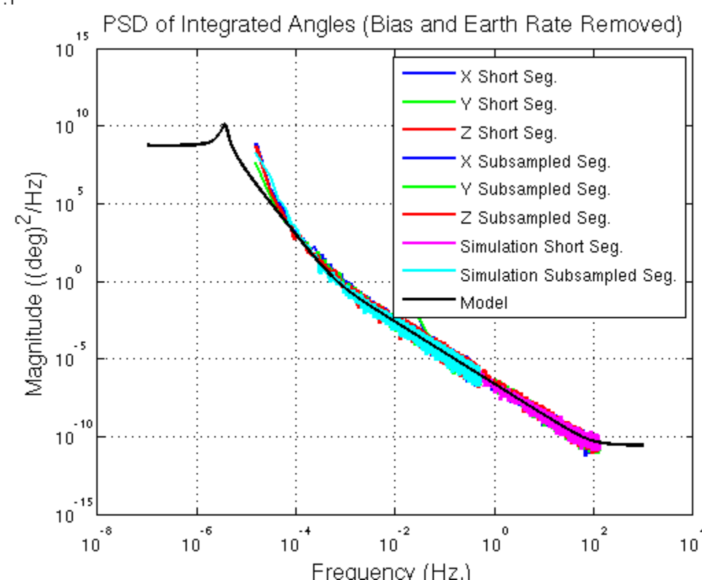


Cubesat IMU Testing at JPL

- Results for Sensonor gyro: Gyro operated in integrated angle mode (deg.) at 250 Hz.

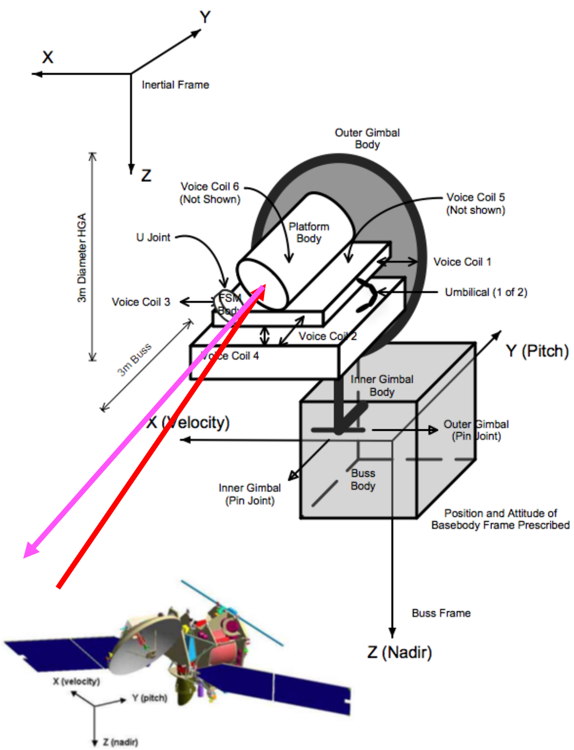


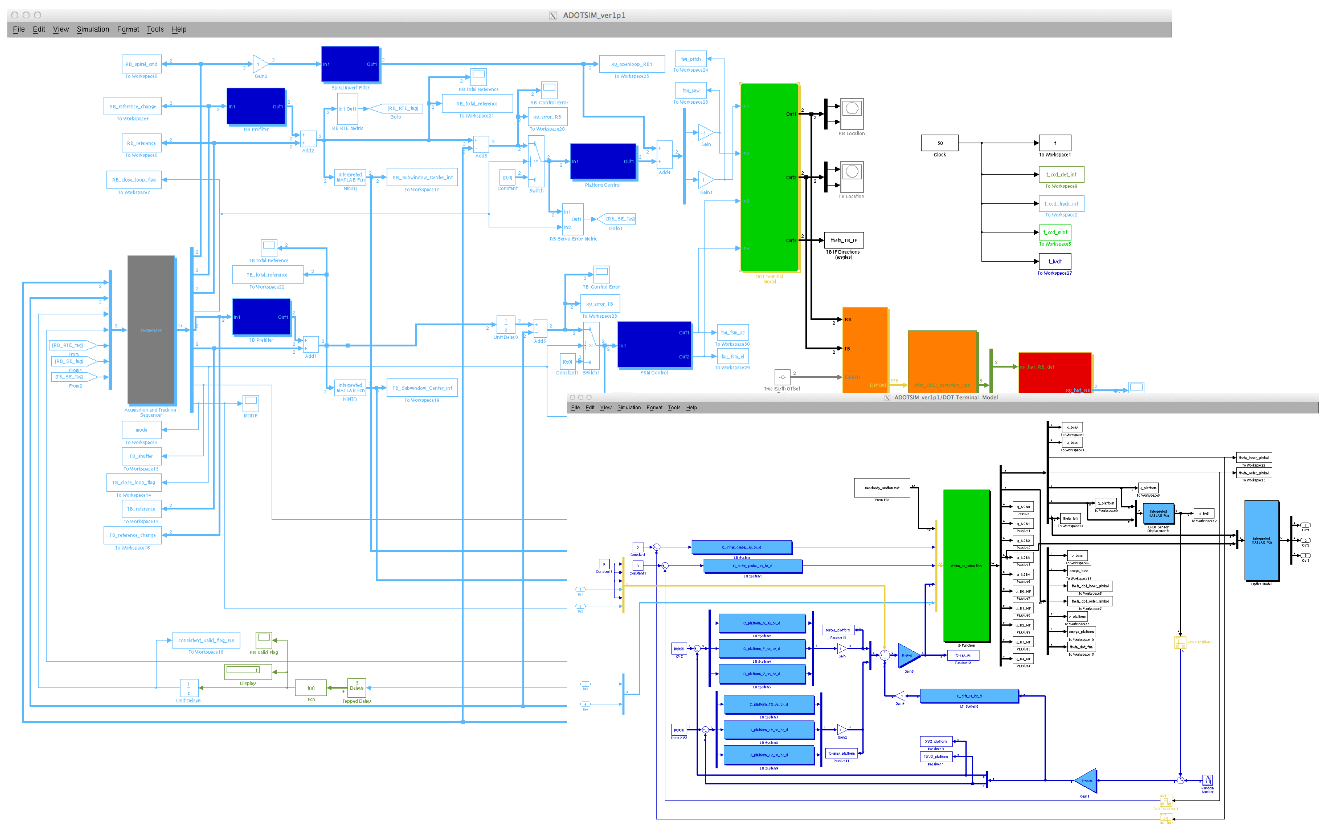




DSOC Optical Comm. Acquisition and Tracking Simulation

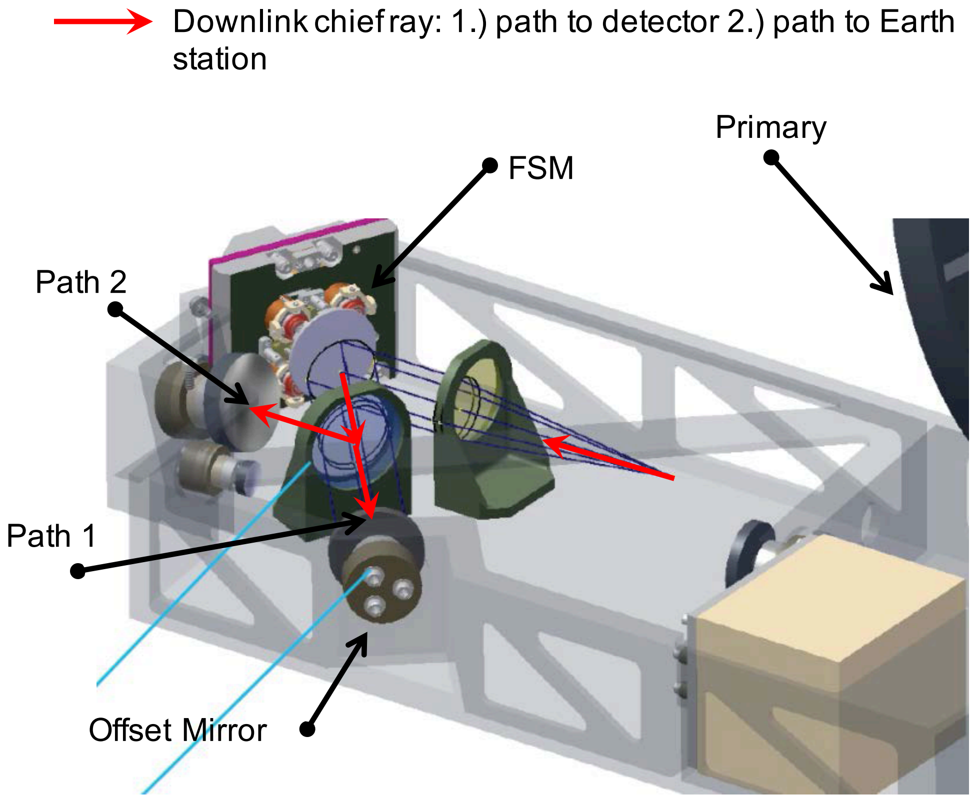
- Simulation includes models for the 1.) rigid body dynamics including gimbal, FSM, and voice coil platform 2.) basebody motion 3.) optical sensitivities 4.) detector 5.) link budget/flux levels with scintillation 6.) detection, estimation and control functions.

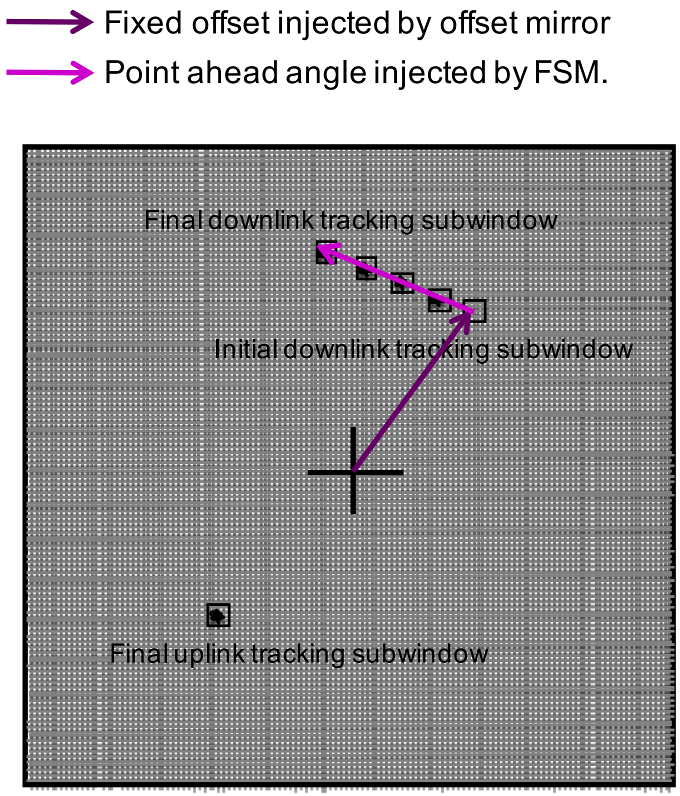




DSOC Optical Comm. Acquisition and Tracking Simulation

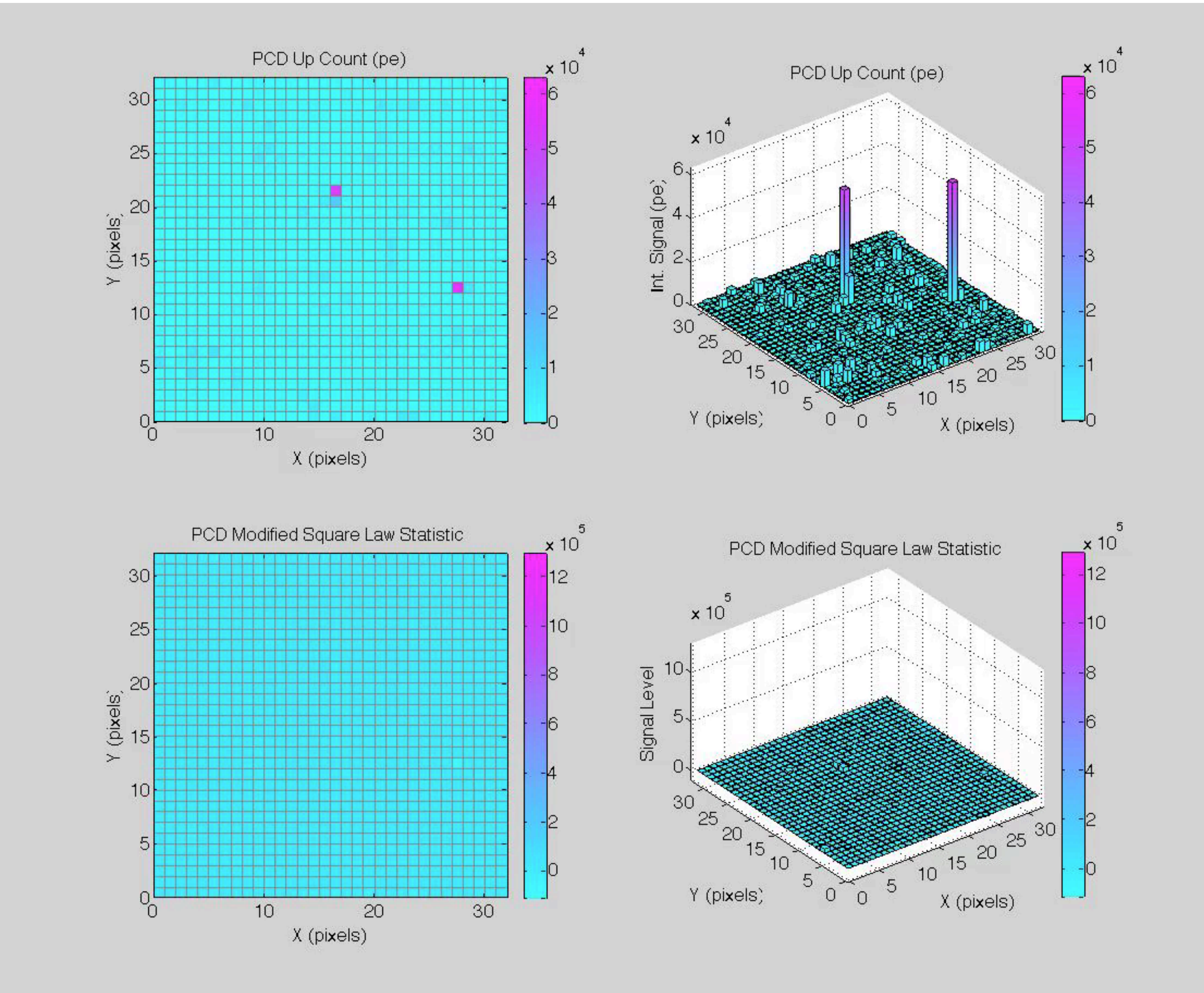
- Uplink beam is steered with by moving the entire platform with voice coils.
- Direction of the downlink beam is controlled with the FSM. FSM has no effect on the uplink beam.
- FSM is used to implement downlink beam point ahead angle.
- **BOTH** the motion of the downlink beam on the detector focal plane and its inertial direction are modeled.

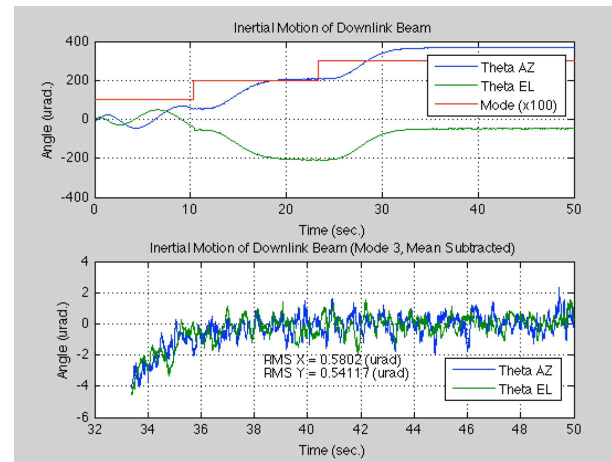




DSOC Optical Comm. Acquisition and Tracking Simulation

- Simulation run with MRO orbital basebody disturbance. Used 8 beam scintillation case with 1e5 (pe/sec).)





RMS X = 0.5802 (urad)
RMS Y = 0.5412 (urad)

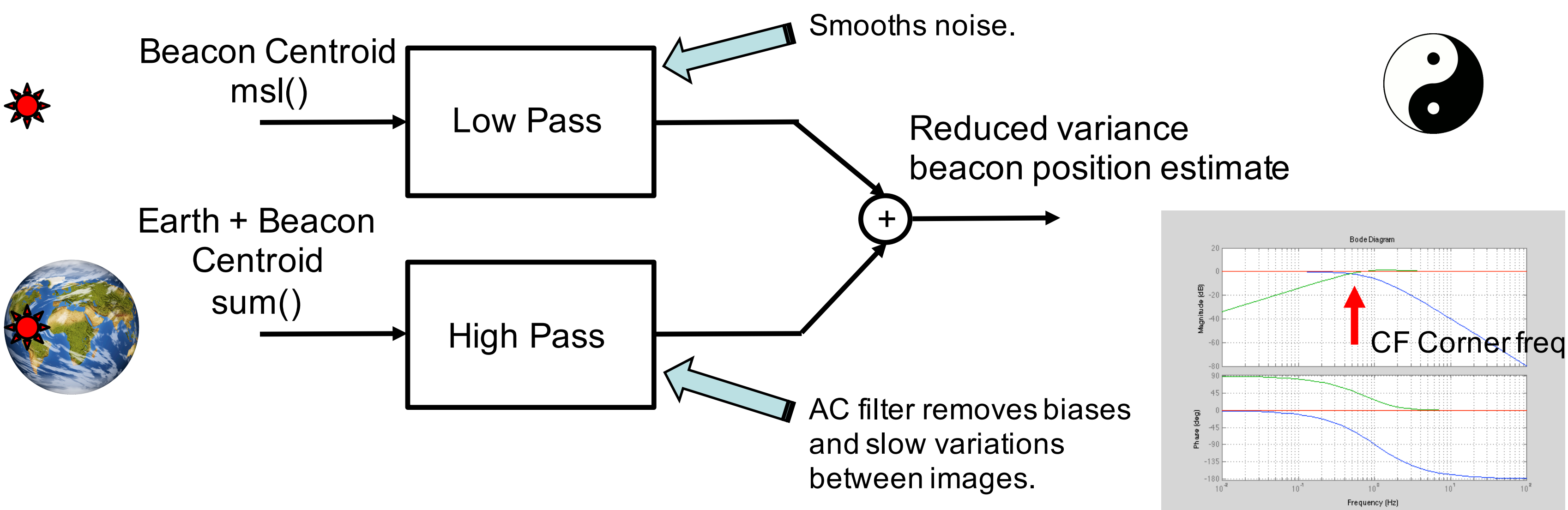
Poor Mans Kalman Filter: Complementary Filter

- The idea is to make use of **all** the uplink photons that are collected instead of just the beacon flux.

- This technique reduces the platform jitter and subsequently the **downlink jitter**, but could also be used:
  1.) To compensate for a deficient quantum efficiency
  2.) To reduce the aperture of the telescope.

- Beacon MSL centroid is the one you want to position, but it is noisy relative to the SUM centroid because the beacon image has fewer photons and its centroid results from a squared statistic.

- SUM centroid is *smoother* but has a *bias* due to the likely offset between the beacon image and Earth image. CF mixes these two measurements making a net estimate that incorporates the best features of each.



Optical Comm. System Engineering Tool

- ARM “goto” mission trajectory. KECK ground station used.