Advanced Integrated Concepts for the IlliniSat-2 Bus

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Outline

ADACS

- Problem Statement
- AD Architecture
- Kalman Filter Theory
- Simulation Results
- Conclusions

Solar Panel/Magnetorquer

- Problem Statement
- Conceptual Design
- Design Synthesis
- Manufacturing
- Integration
- Conclusions

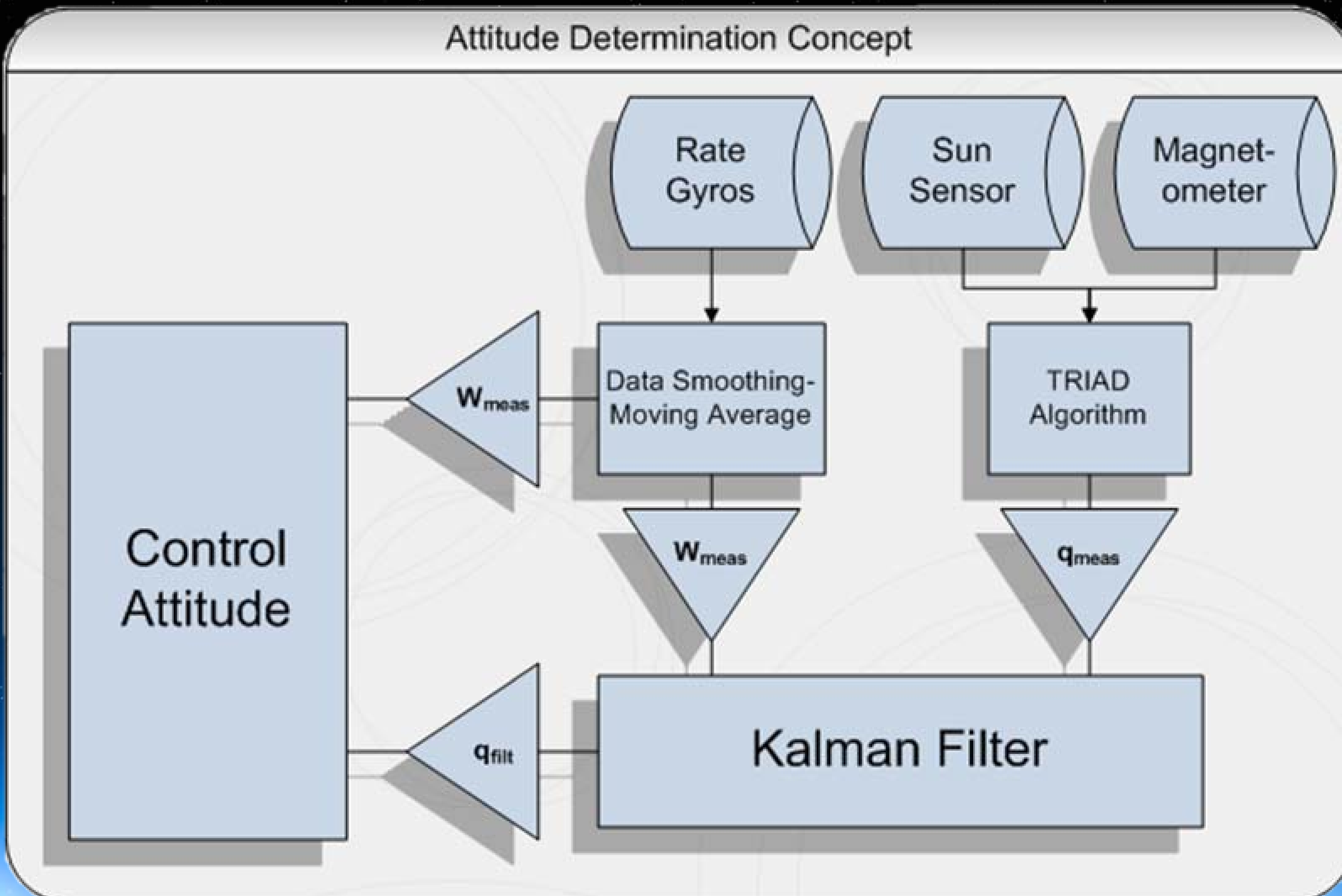
ADACS Problem

- Implementing science missions on the IlliniSat-2 bus requires precise pointing and attitude knowledge within one degree on each axis
- Limited power, mass, volume and computation make this a challenge to implement on board

Solution

- Use an array of small, cheap sensors to capture attitude knowledge
  - Magnetometer
  - Photo-diode Sun sensor
  - Rate gyros
- Use a linear Kalman filter to remove sensor noise
  - Filter only the attitude to reduce computational complexity
  - Smooth angular rate data using a moving average filter

Determination Architecture

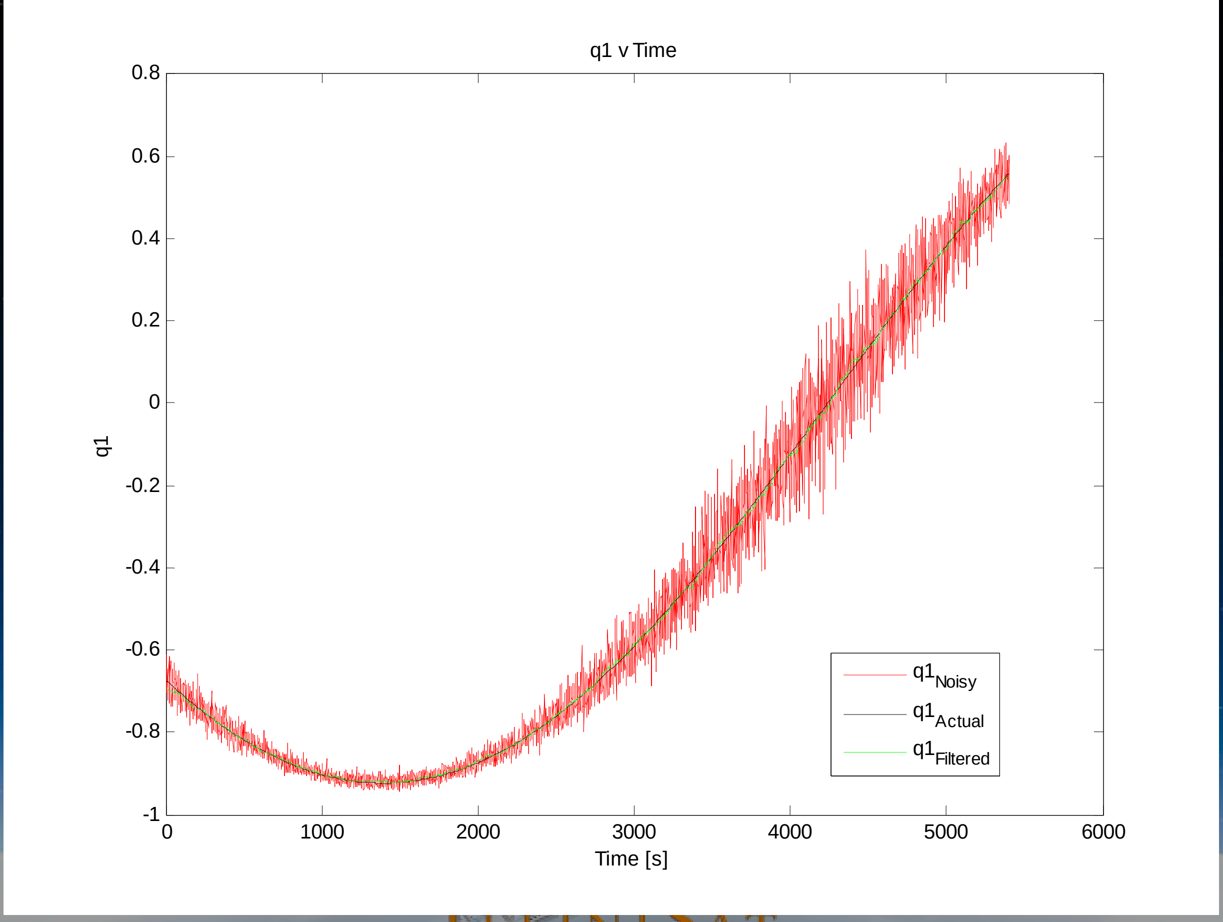


Kalman Filter Theory

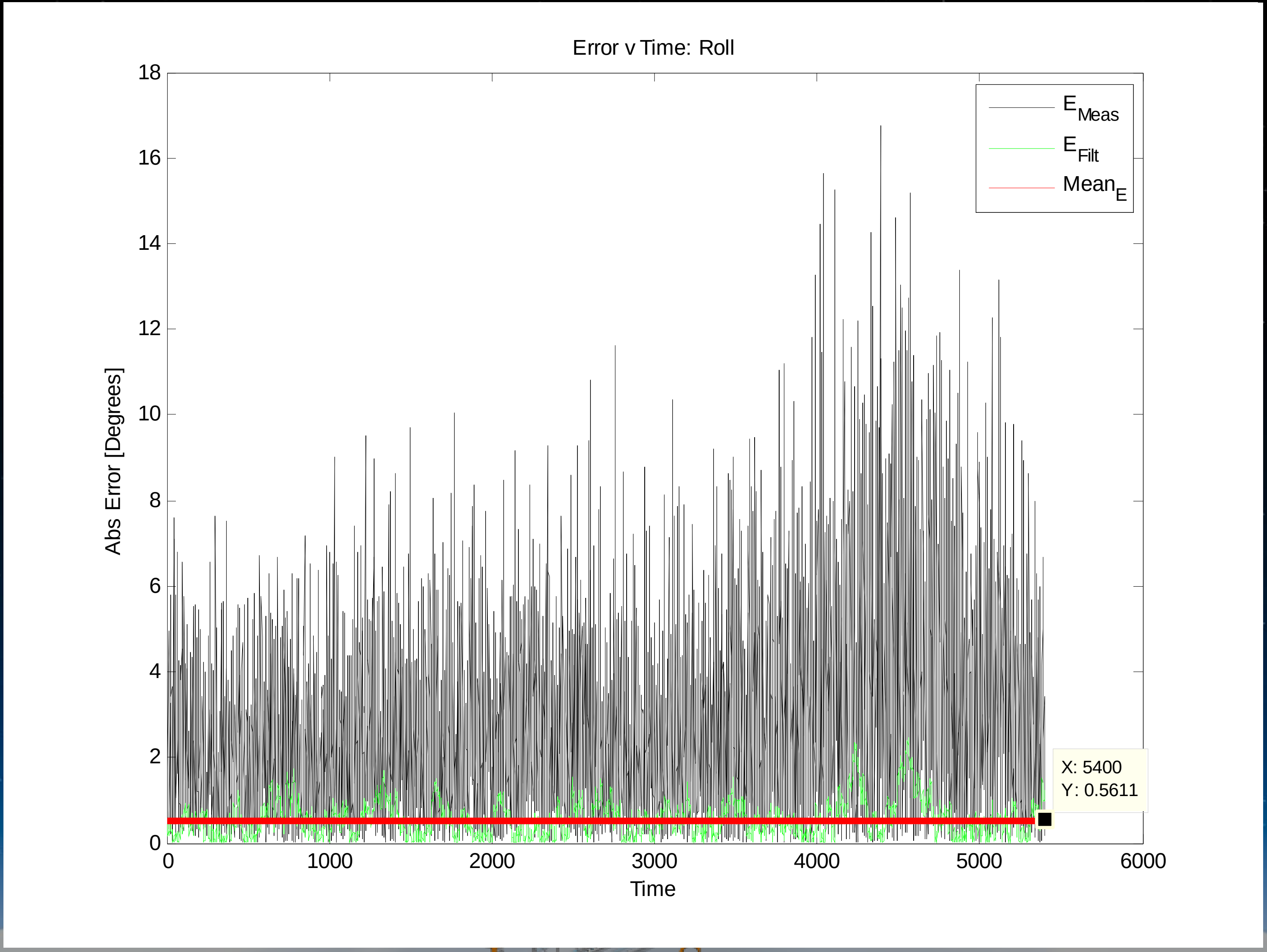
- A Kalman filter provides a minimum variance linear estimate
- States are propagated using system dynamics, then adjusted using measurement data
- Filter may be tuned to reject varying amounts of sensor noise

Simulation Results

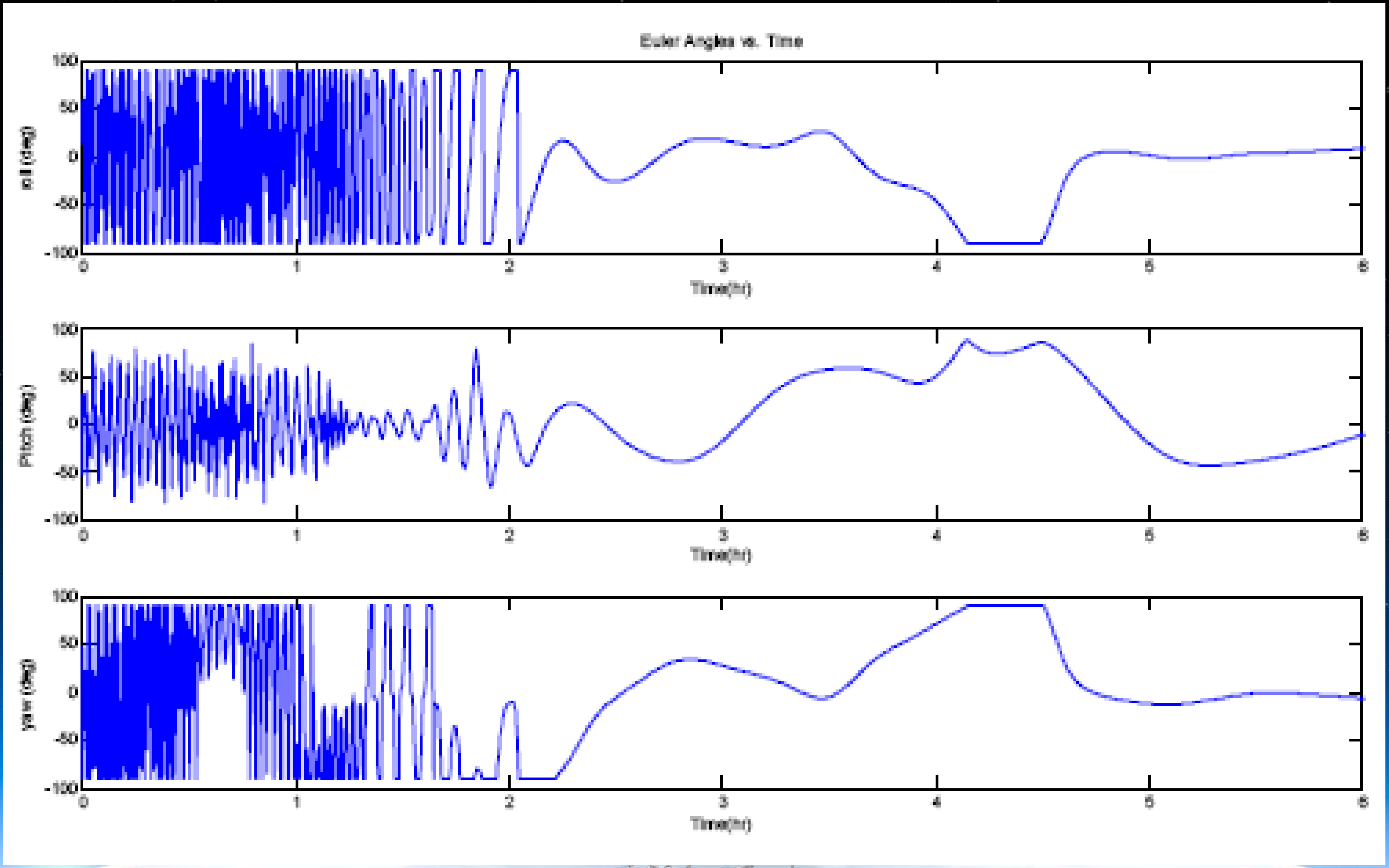
- Nadir point scenario modeled using reasonable sensor noise estimates



Simulation Results Cont.



Control Simulation Results



Conclusions

- A linear Kalman filter may be used to filter attitude data
- Filter uses less complex calculations at the expense of using more sensors
- Attitude knowledge within 1 degree possible

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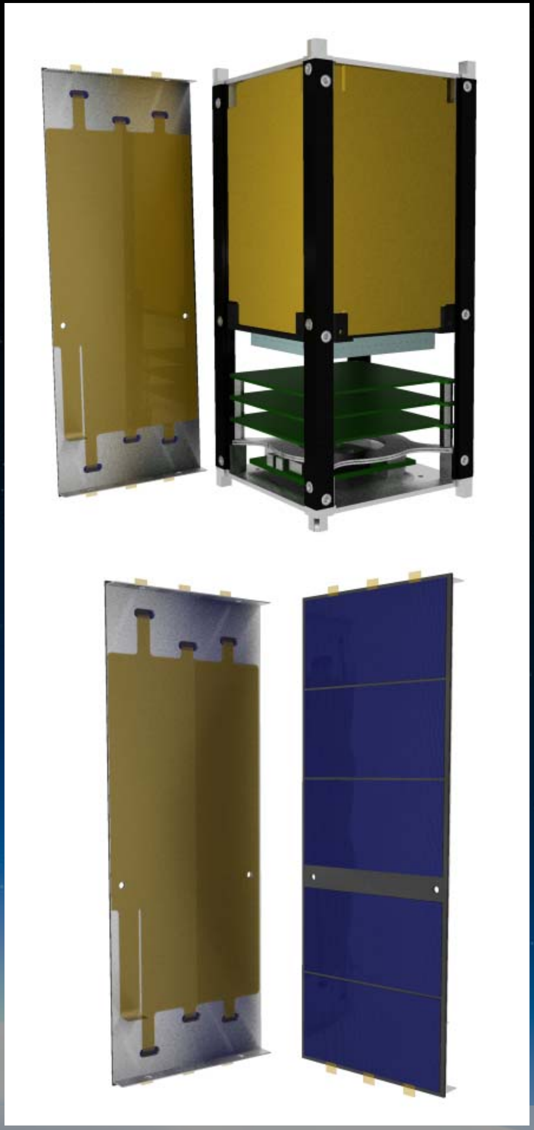
Solar Panel/Magnetorquer

- Create a strong, lightweight solar panel substrate that is easy to manufacture with reproducible quality
- Develop an integrated component to take the place of magnetorquers, and solar panel terminals

Conceptual Design

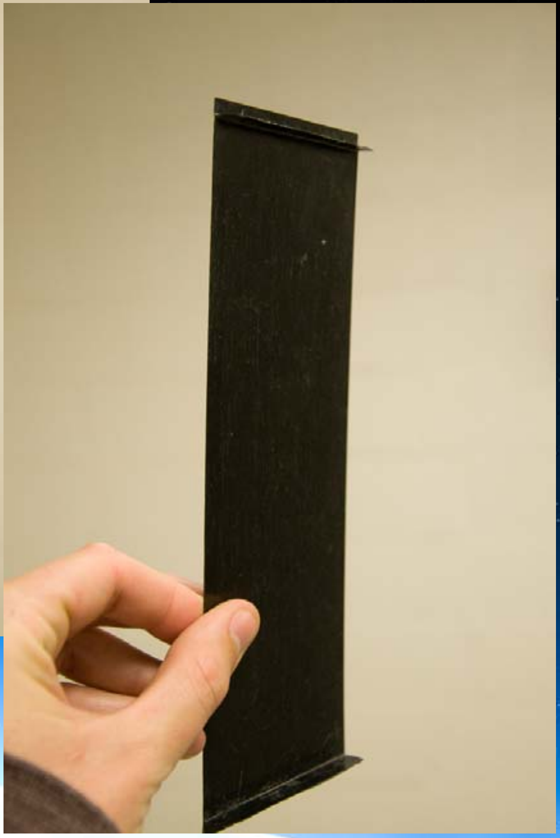
- The conceptual design consisted of:
  - Carbon fiber solar panel substrate
  - Aluminum backing
  - Flexible PCB to include magnetorquer and solar panel terminals.
- The design needs to be lightweight (<75g single panel w/ solar cells) and easy to connect



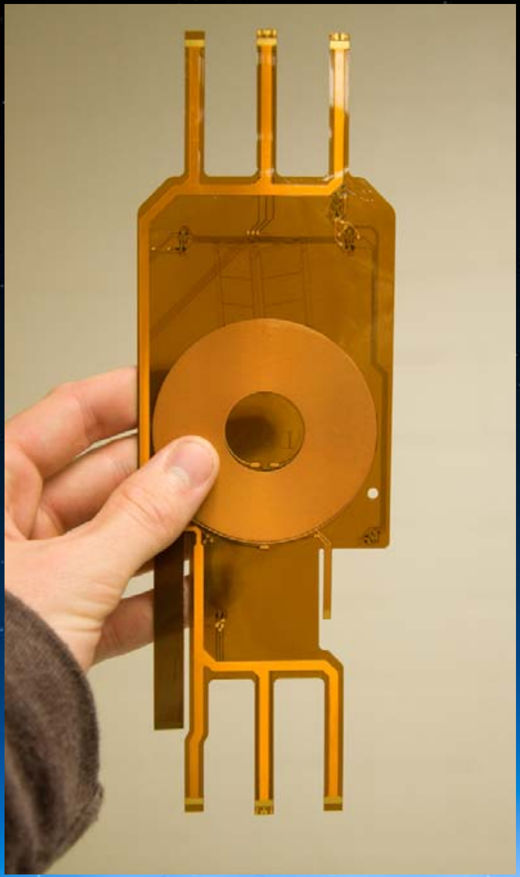
Design Synthesis

Carbon Fiber Substrate

- Constructed of unidirectional carbon fiber prepreg stacked up in an orthogonal balanced layup
- Original idea of using aluminum backing for easy machining of mechanical connections was abandoned due to warping
- After many iterations, we arrived at a balanced stack up which is currently in material testing



Design Synthesis



Flexible PCB Magnetorquer

- The design of the flexible PCB went through many iterations
- In addition to solar panel terminals at the outside edges and a magnetorquer, pyro channels were added along with data connections
- The design also allows for the magnetorquer to be separated from the circuit and used on its own for the z-axis torquer

Manufacturing

Solar Panel Substrate

- The substrate layup is done in-house and cured in-house using an autoclave
- The substrate is machined externally using a water jet
- Total mass of carbon fiber substrate 21g

Flexible PCB

- The flexible PCB was designed in-house and manufactured externally
- Total mass of flexible PCB 25g

Total Mass of Single Panel Assembly

< 65g

Integration

- Solar cells (mounted to the solar substrate) and the solar panel terminals (which is part of the flexible PCB) both need to be external to the satellite
- Therefore, a some point, one must pass through the other
- Holes are cut through the substrate to allow the fingered terminals of the flexible PCB to pass through
- The substrate/flexible PCB assembly is connected via one electrical connection to a power board, and mechanically attached to the upper and lower faces, and a center plate located near the middle of the satellite

Conclusions

- In a small package, a robust, lightweight solar panel substrate was manufactured using carbon fiber
- An integrated flexible PCB was designed and produced which includes a magnetorquer, pyro channel, solar panel terminals, and thermocouple connections
- The designs are scalable
- The two are currently under individual testing to evaluate performance for use in the IlliniSat-2 bus

Questions

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Appendix – Kalman Filter Theory

- Predict

$$\hat{x}_{k+1}^{\;-} = \Phi \hat{x}_k$$

$$\dot{q} = \frac{1}{2}\Omega\left(\omega\right)q$$

$$P^- = \Phi P \Phi^T + Q$$

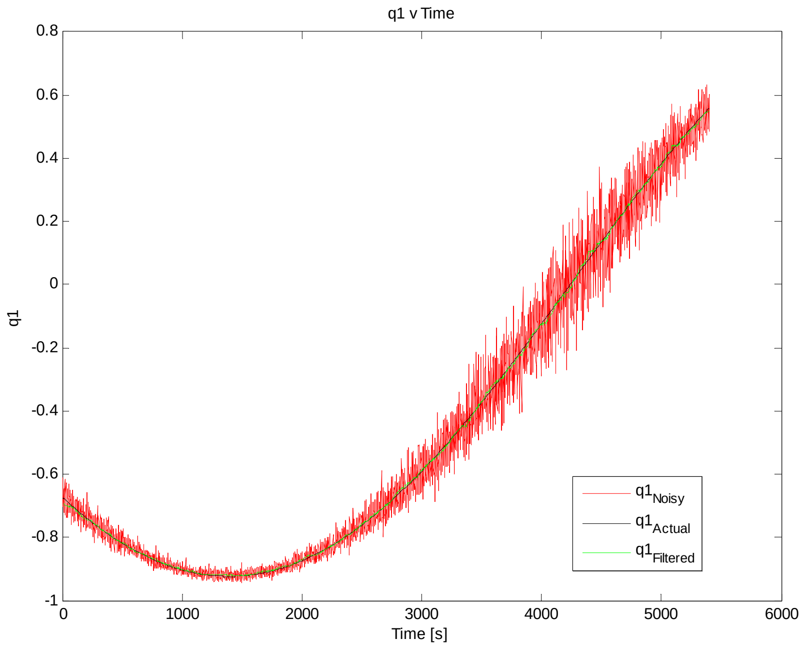
- Measurement Update

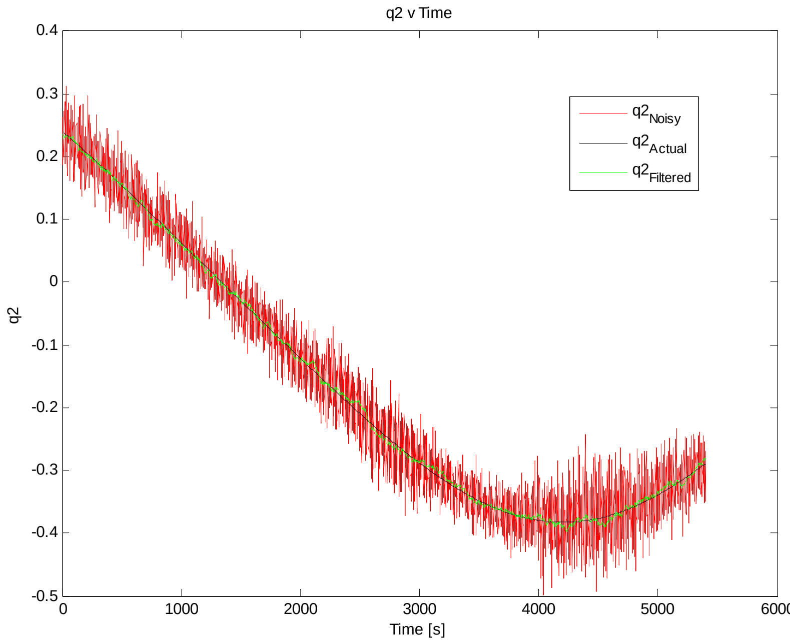
$$z_k = H x_k$$

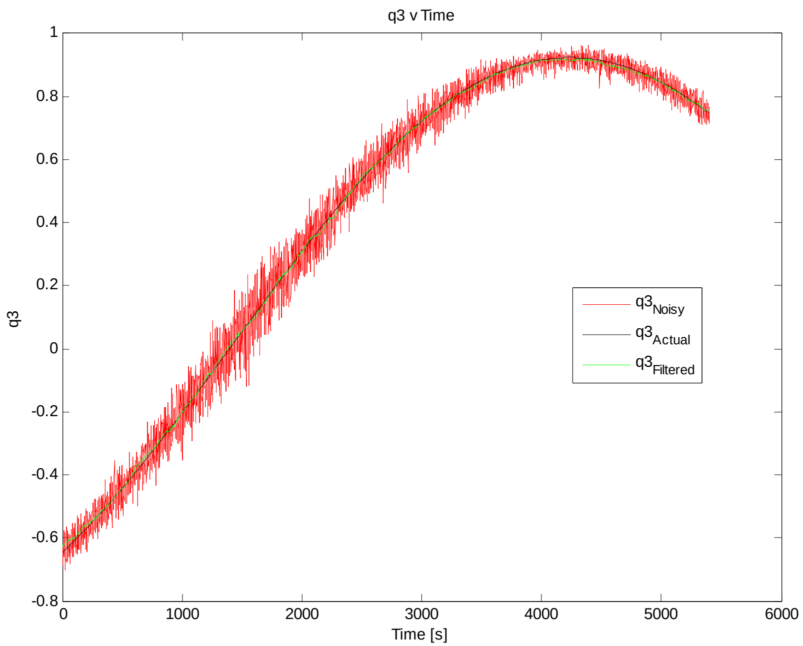
$$K = P^- H^T \left(H P^- H^T + R\right)^{-1}$$

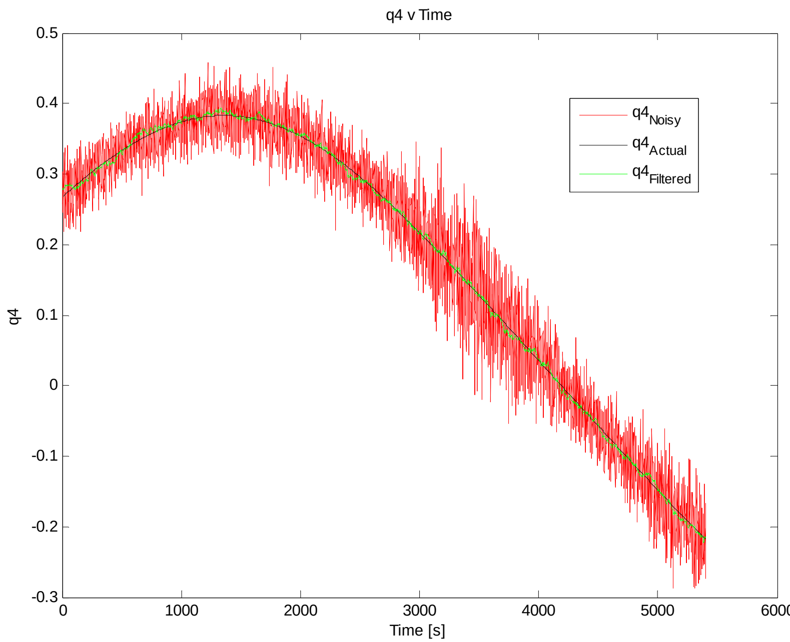
$$\hat{x} = \hat{x}^- + K\left(z - H\hat{x}^-\right)$$

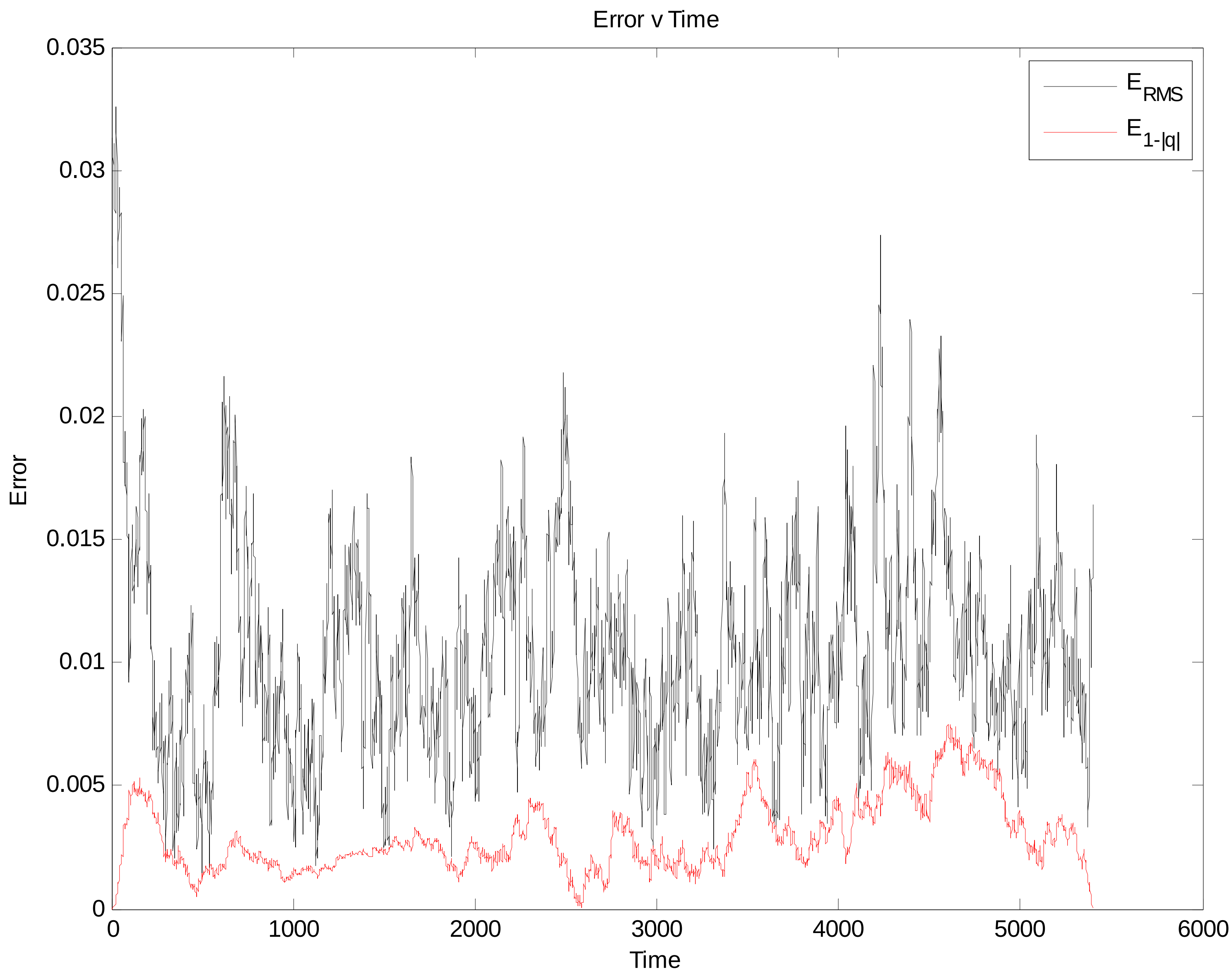
$$P = \left(I - KH\right)P^-$$


q1 v Time
q1
Time [s]
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
1000
2000
3000
4000
5000
6000
q1Noisy
q1Actual
q1Filtered


q2 v Time
q2
Time [s]
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1000
2000
3000
4000
5000
6000
q2Noisy
q2Actual
q2Filtered


q3 v Time
q3
Time [s]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
1000
2000
3000
4000
5000
6000
q3Noisy
q3Actual
q3Filtered


q4 v Time
q4
Time [s]
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
1000
2000
3000
4000
5000
6000
q4Noisy
q4Actual
q4Filtered



Error v Time
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Error
0
1000
2000
3000
4000
5000
6000
Time
E_{RMS}
$E_{1-|q|}$

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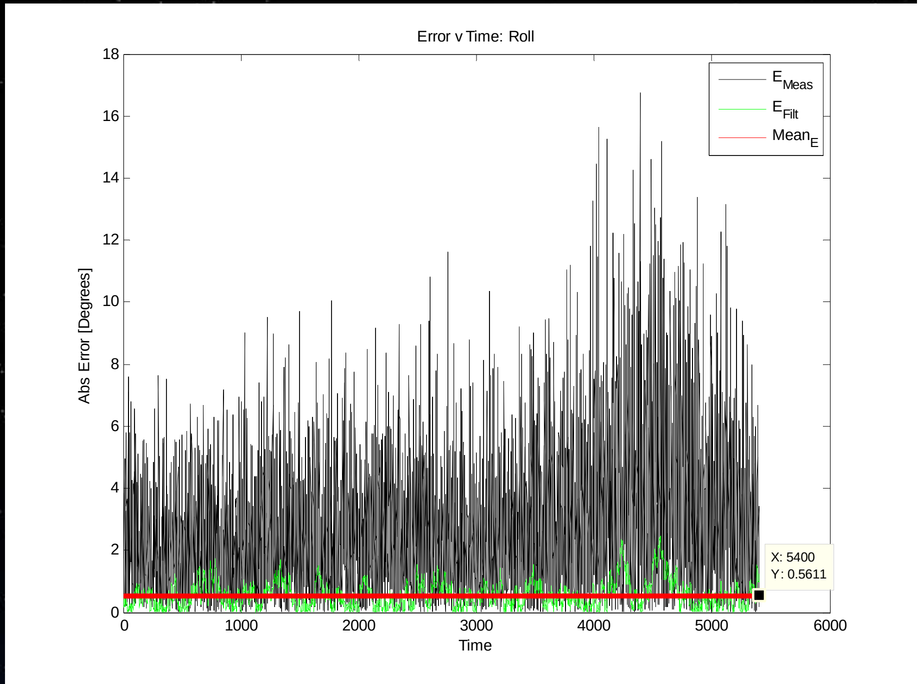
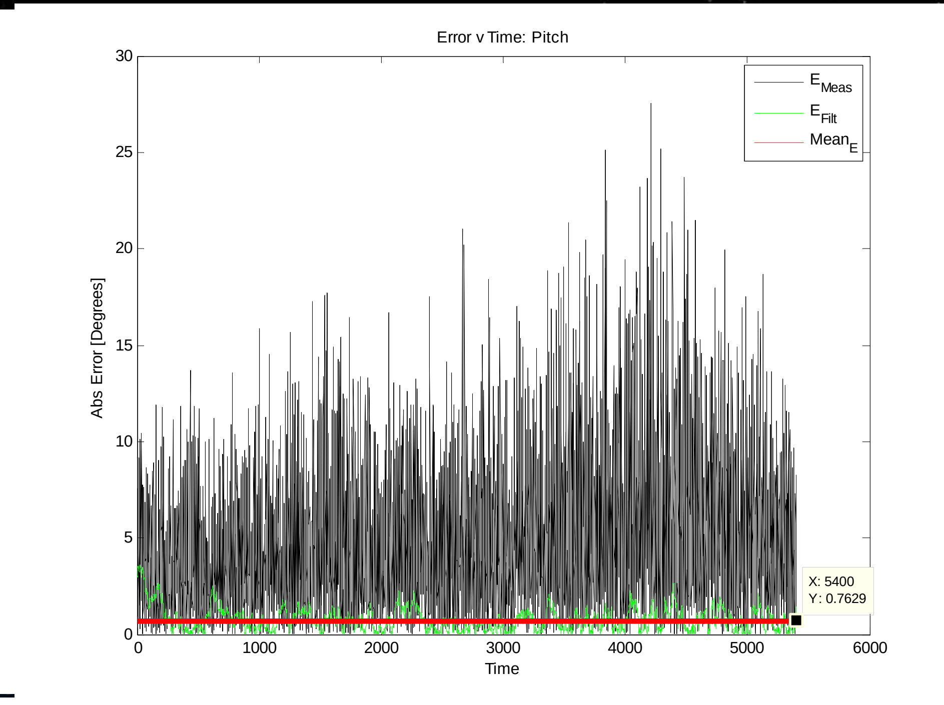
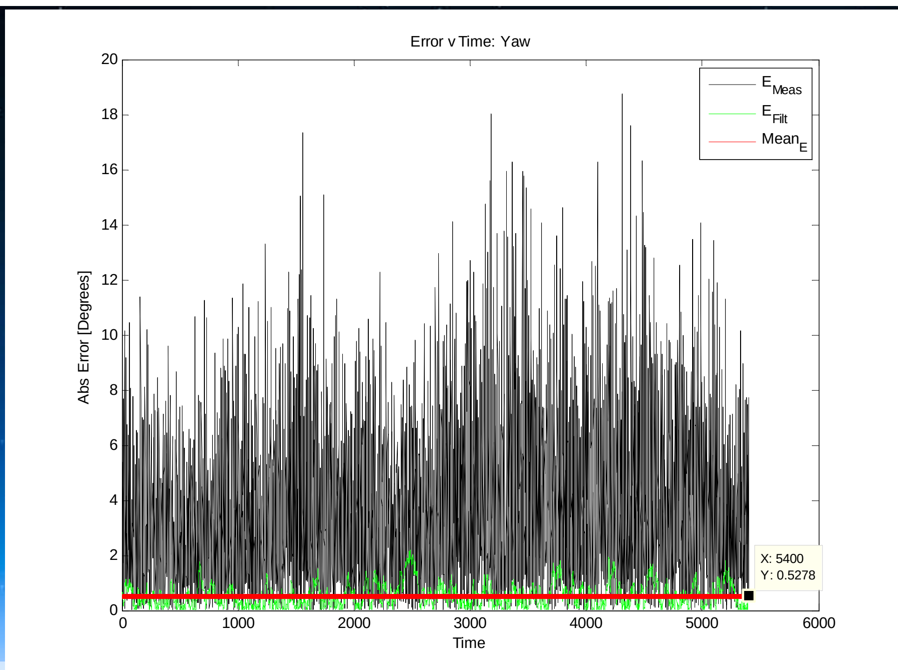

Error v Time: Roll
E_{Meas}
E_{Filt}
$Mean_E$
X: 5400
Y: 0.5611
Abs Error [Degrees]
Time


Error v Time: Pitch
E_{Meas}
E_{Filt}
$Mean_E$
X: 5400
Y: 0.7629
Abs Error [Degrees]
Time


Error v Time: Yaw
E_{Meas}
E_{Filt}
$Mean_E$
X: 5400
Y: 0.5278
Abs Error [Degrees]
Time

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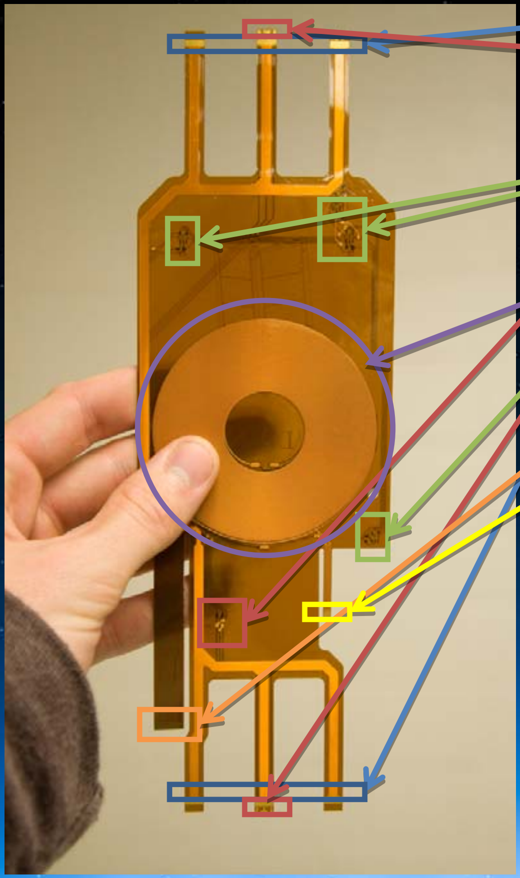
Appendix – Assembly

Appendix – Flex Cable Functionality



- 6 Solar Panel terminals
- 3 Pyro channels
- 4 surface mount data terminals
- Magnetorquer
- Primary data and power connection
- Torque-only secondary tail

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