QB50 CubeSat PDR
Team: STAR

Satellite Testbed for Attitude Response

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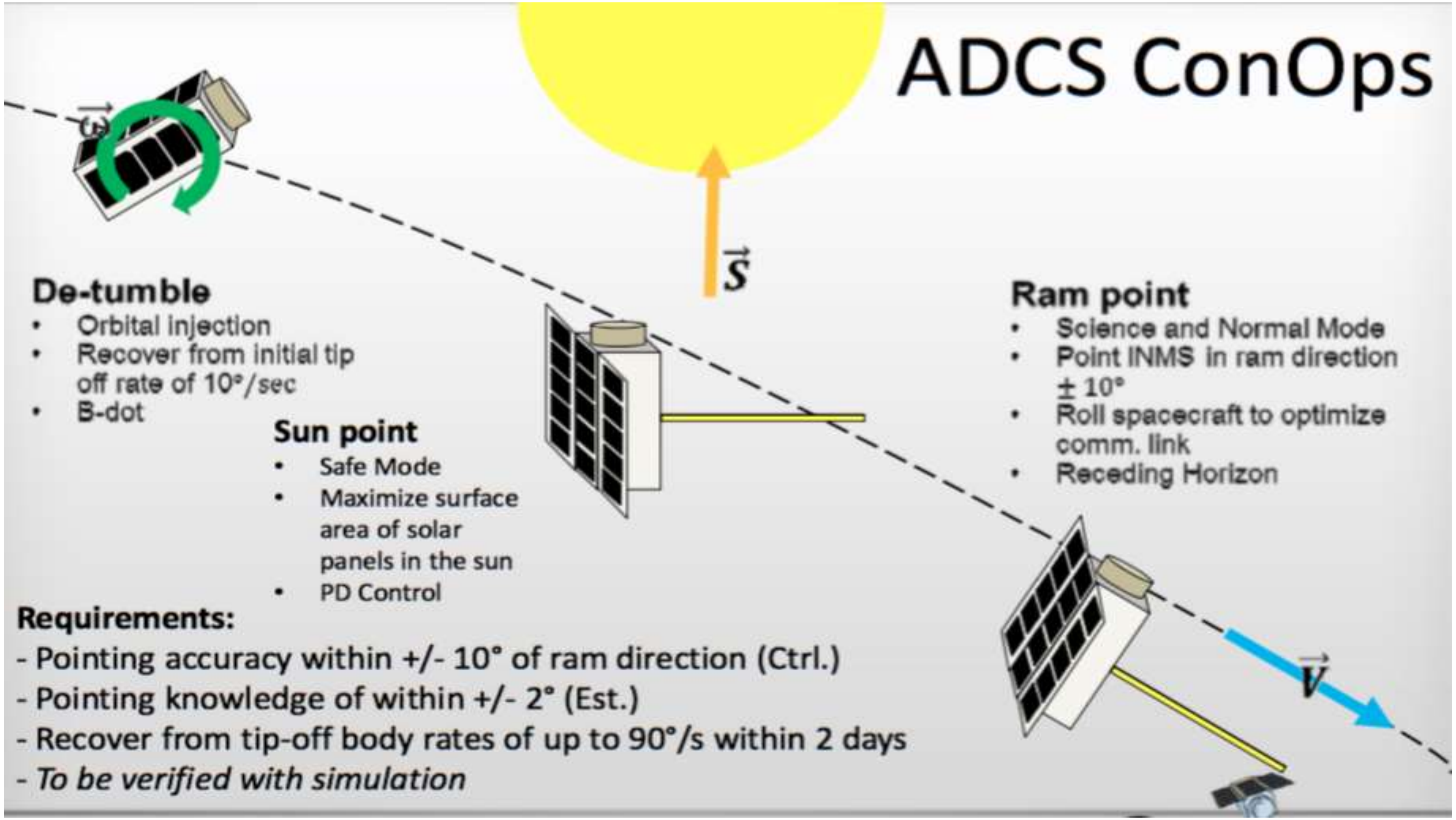
Presentation Outline

- Mission Introduction
- Project Description
- Feasibility – Interface Board
- Feasibility – Sun Sensor Table
- Feasibility – Helmholtz Cage Test
- Status Summary
- Backup Slides

Mission Introduction

QB50 Satellite – Attitude Determination and Control System (ADCS)

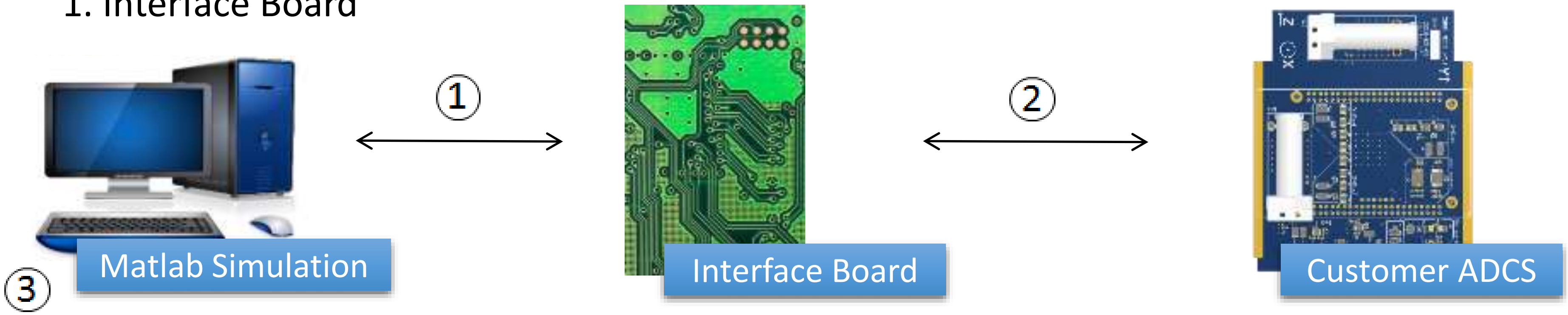


- One of 50 CubeSats
- 400 km orbit
- ~ 8 month mission
- Provide in situ thermosphere measurements

Project Description

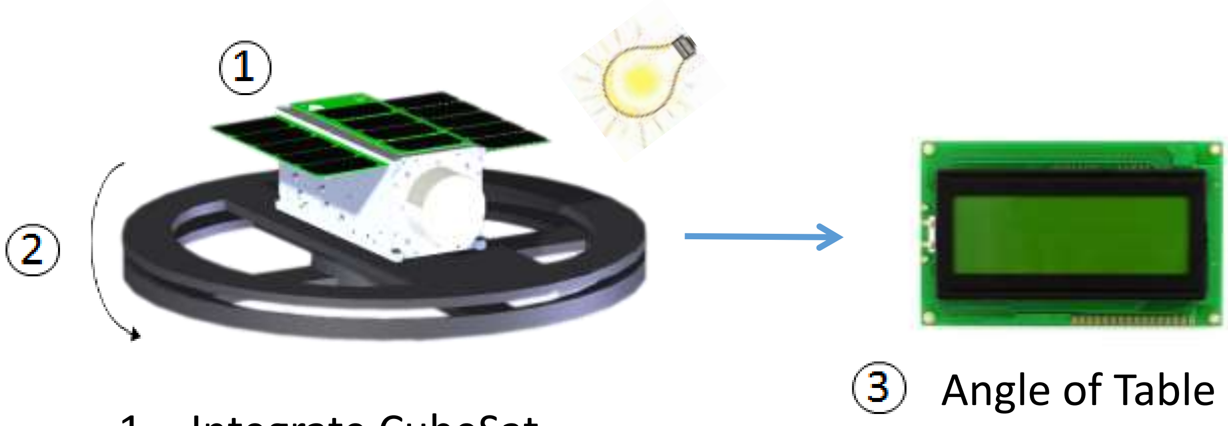
ADCS Verification ConOps

1. Interface Board



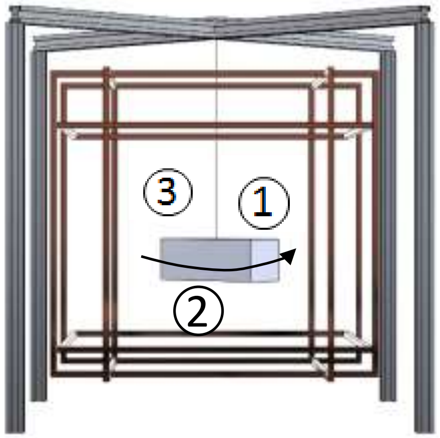
1. USB from simulation to interface board
2. Connect interface to ADCS
3. Run Simulation

2. Sun Sensor Calibration Table



1. Integrate CubeSat
2. Rotate Table to desired angle
3. Compare angle of table to angle reported by satellite

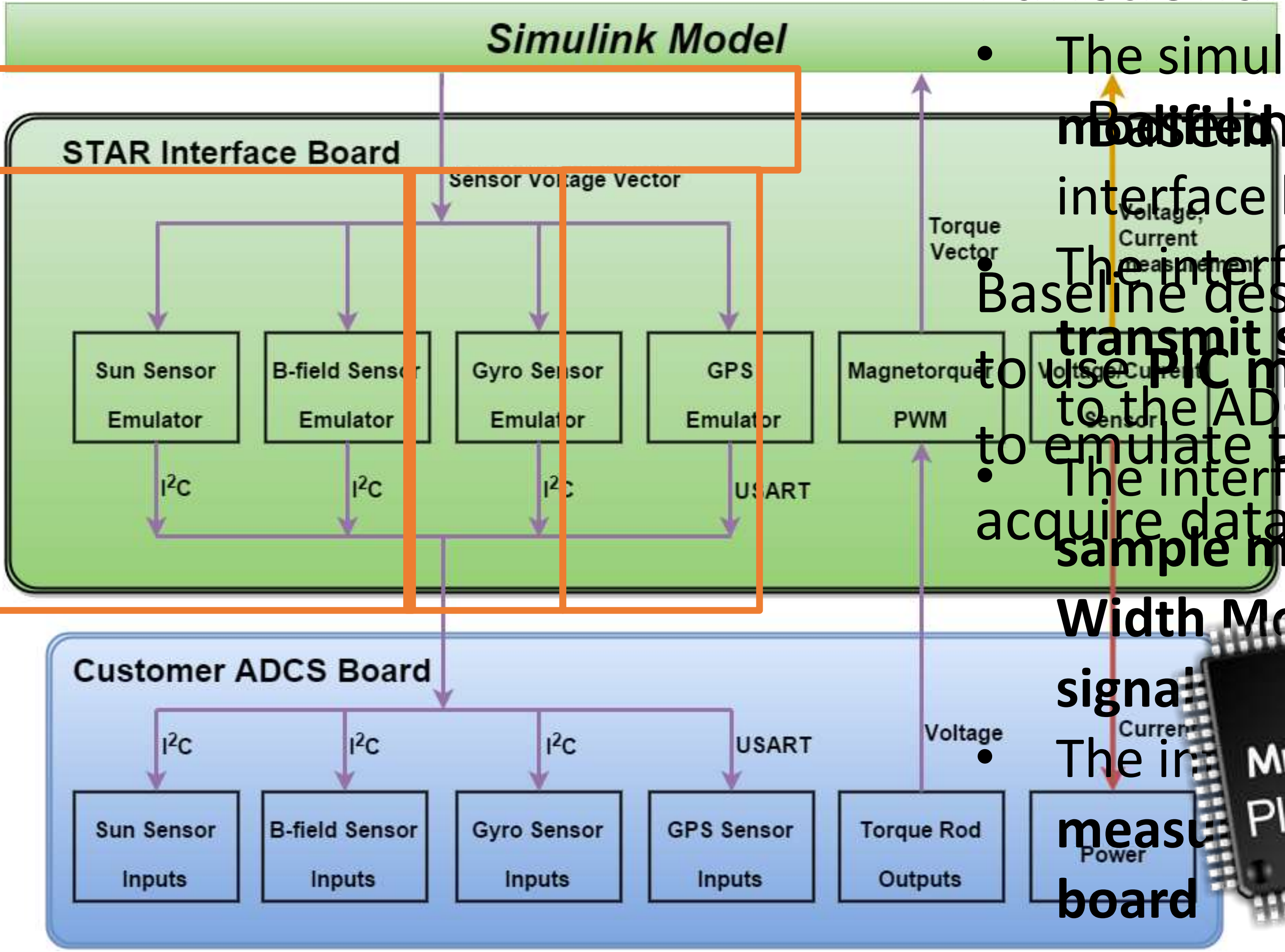
3. Helmholtz Hanging Apparatus



1. Integrate CubeSat
2. Fire Magnetorquer
3. Satellite rotates to verify functionality

Interface Board – Block Diagram

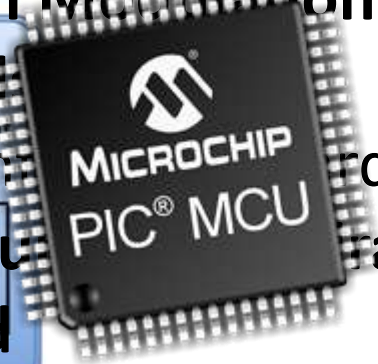
Baseline Design



Functional Requirements

- The simulation shall be **modified to communicate** with interface board
- The interface board shall **transmit simulated sensor data** to the ADCS board
- The interface board shall **sample magnetorquer Pulse Width Modulation (PWM) signal**
- The in… rd shall **measu… raw of ADCS board**

Baseline design decision is to use **PIC microcontrollers** to emulate the sensors and acquire data



ADCS Verification ConOps

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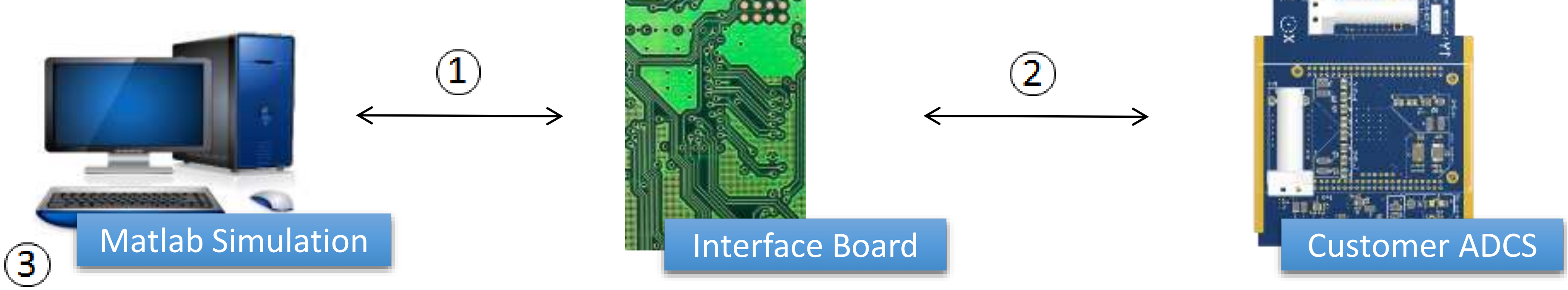

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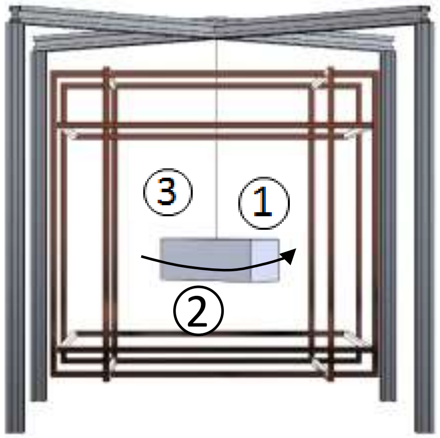

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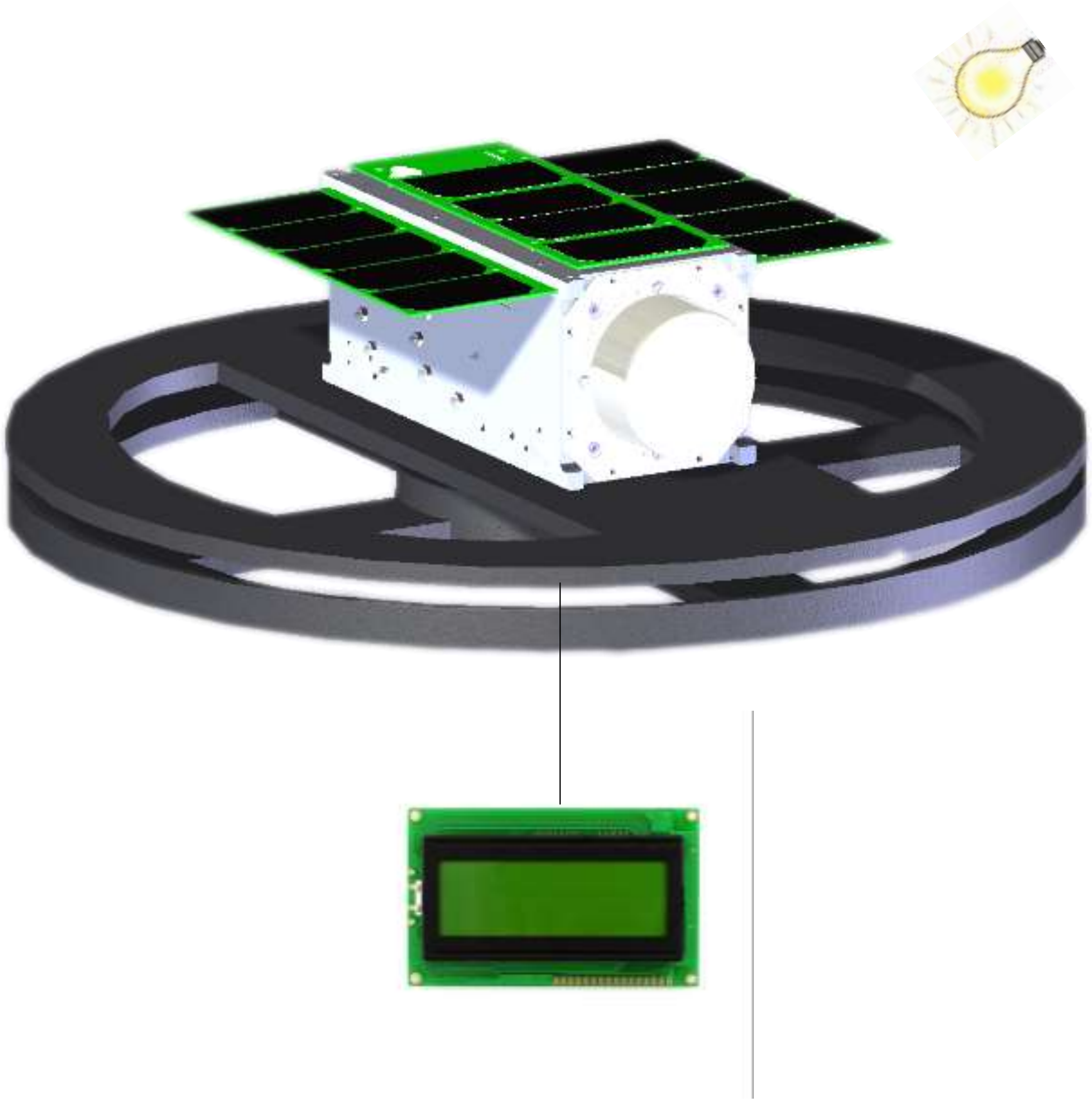
Sun Sensor Calibration Table – Baseline Design



Functional Requirements

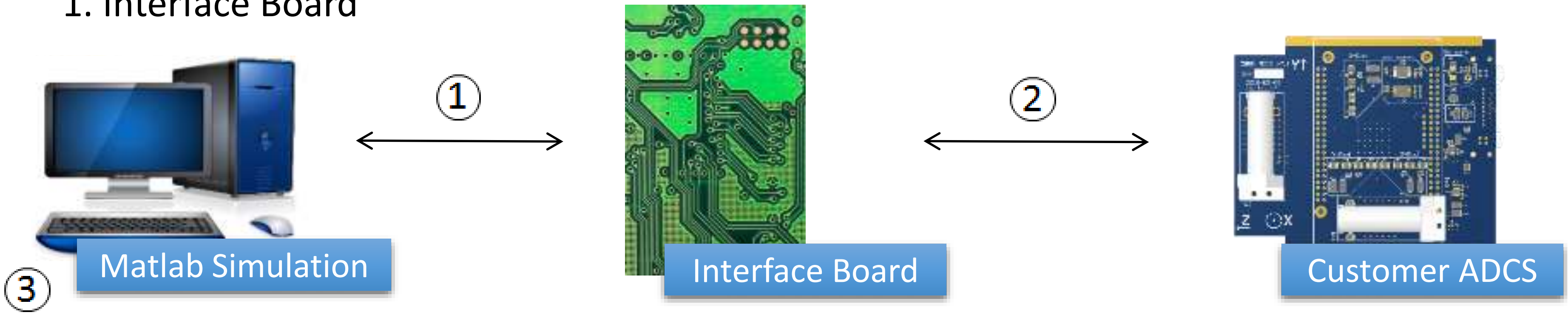
- The turn table shall be **turned to desired angle**
- The turn table shall have a **resolution of 1° with ±0.5° accuracy**

Baseline Design

Baseline design decision is to **manually** rotate turn table and use a **magnetic encoder** to display position on an LCD display

ADCS Verification ConOps

1. Interface Board



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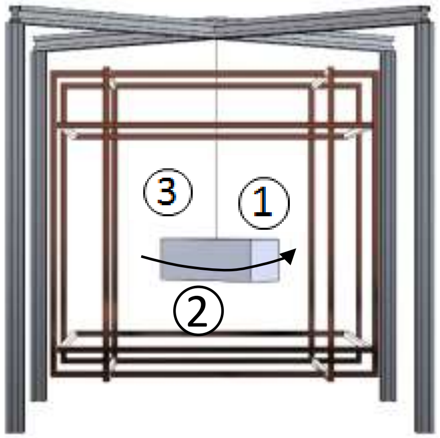

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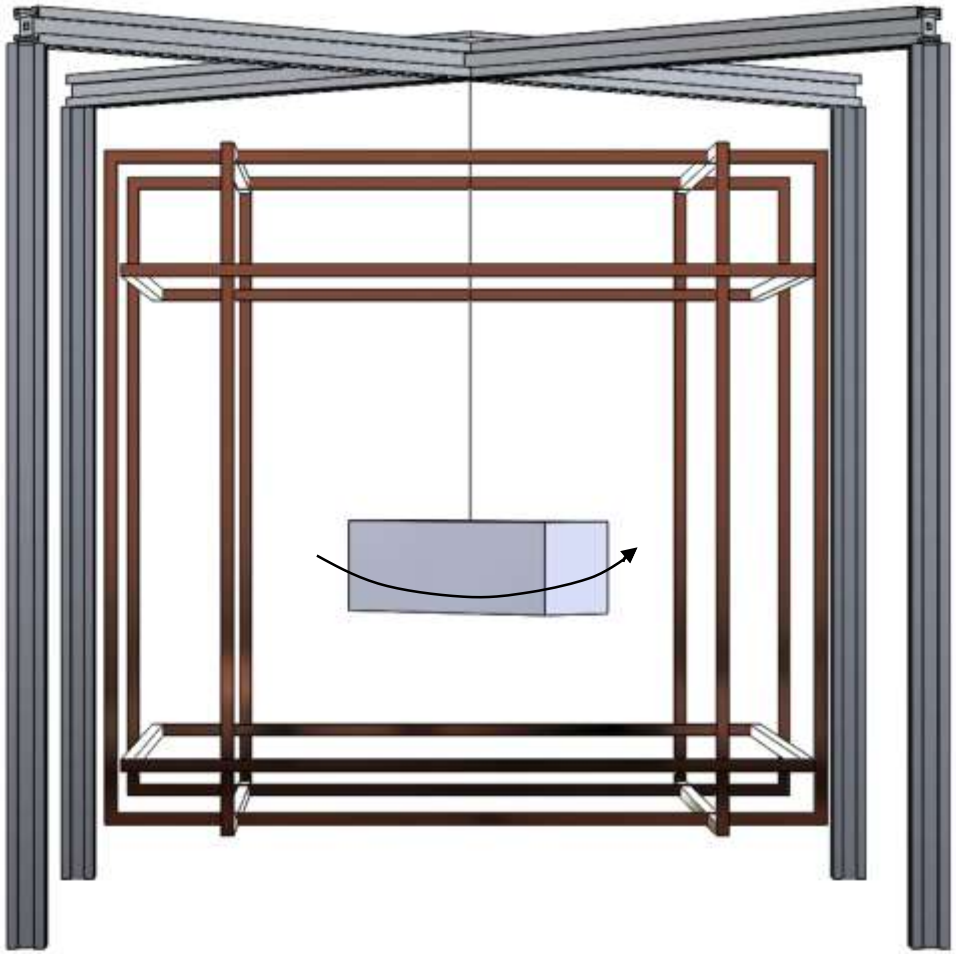
Helmholtz Cage – Baseline Design



Functional Requirements

Baseline Design

- The CubeSat shall be **suspended in the HelmHoltz Cage**

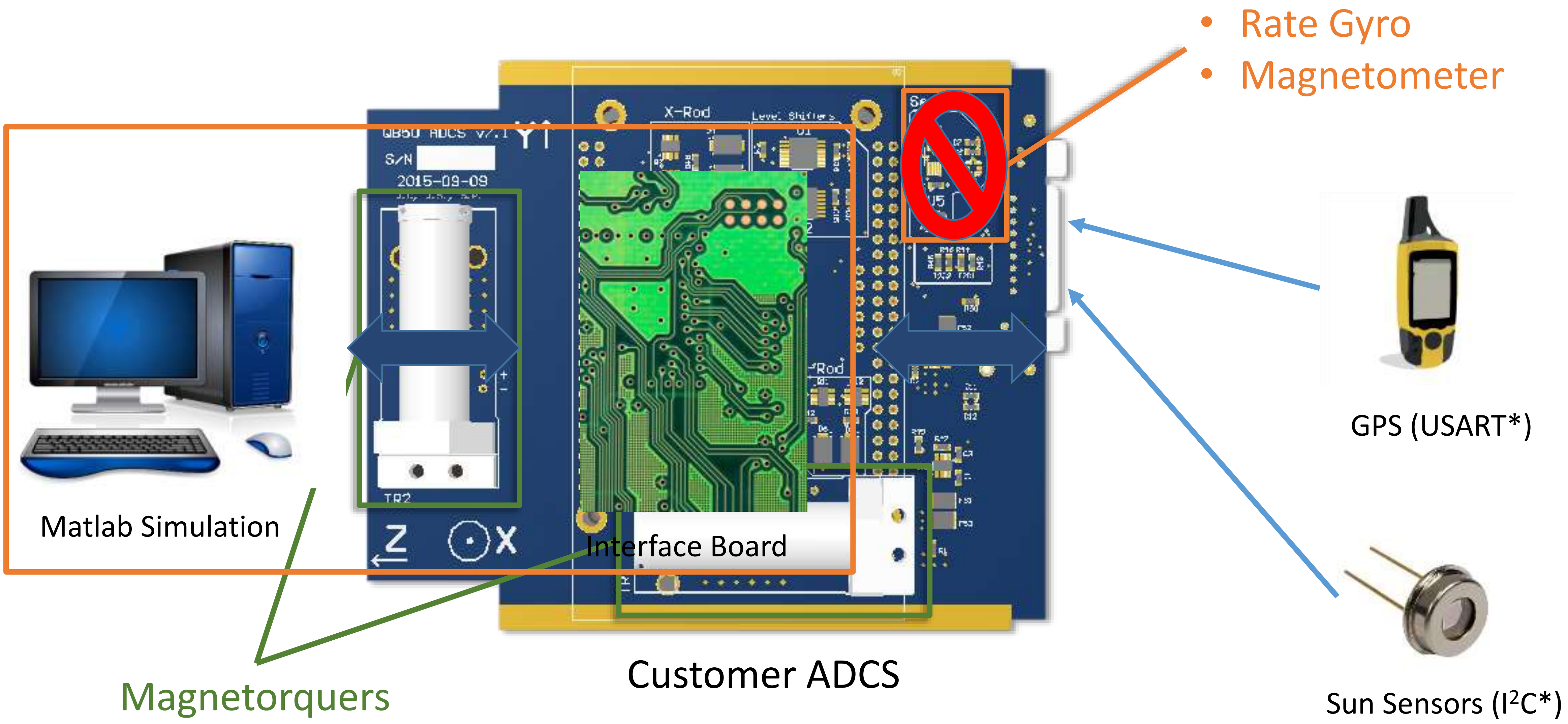
  Baseline design decision is to **hang** the CubeSat with a **line**

- The CubeSat shall **rotate with 1 degree of freedom(DoF)**

Baseline Feasibility

Interface Board

Interface Board - Feasibility



*I^2C = *Inter-Integrated Communication*

*USART = *Universal Synchronous Asynchronous Receiver/Transmitter*

Simulation to Interface Board - Feasibility

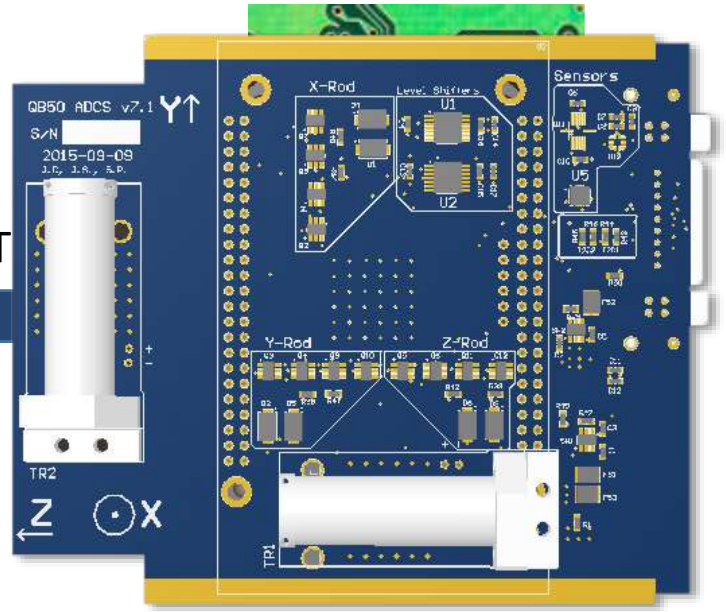
**UART = Universal Synchronous Receiver/Transmitter*
**USB = Universal Serial Bus*

Matlab Simulation

USB

FTDI USB* to UART*

UART

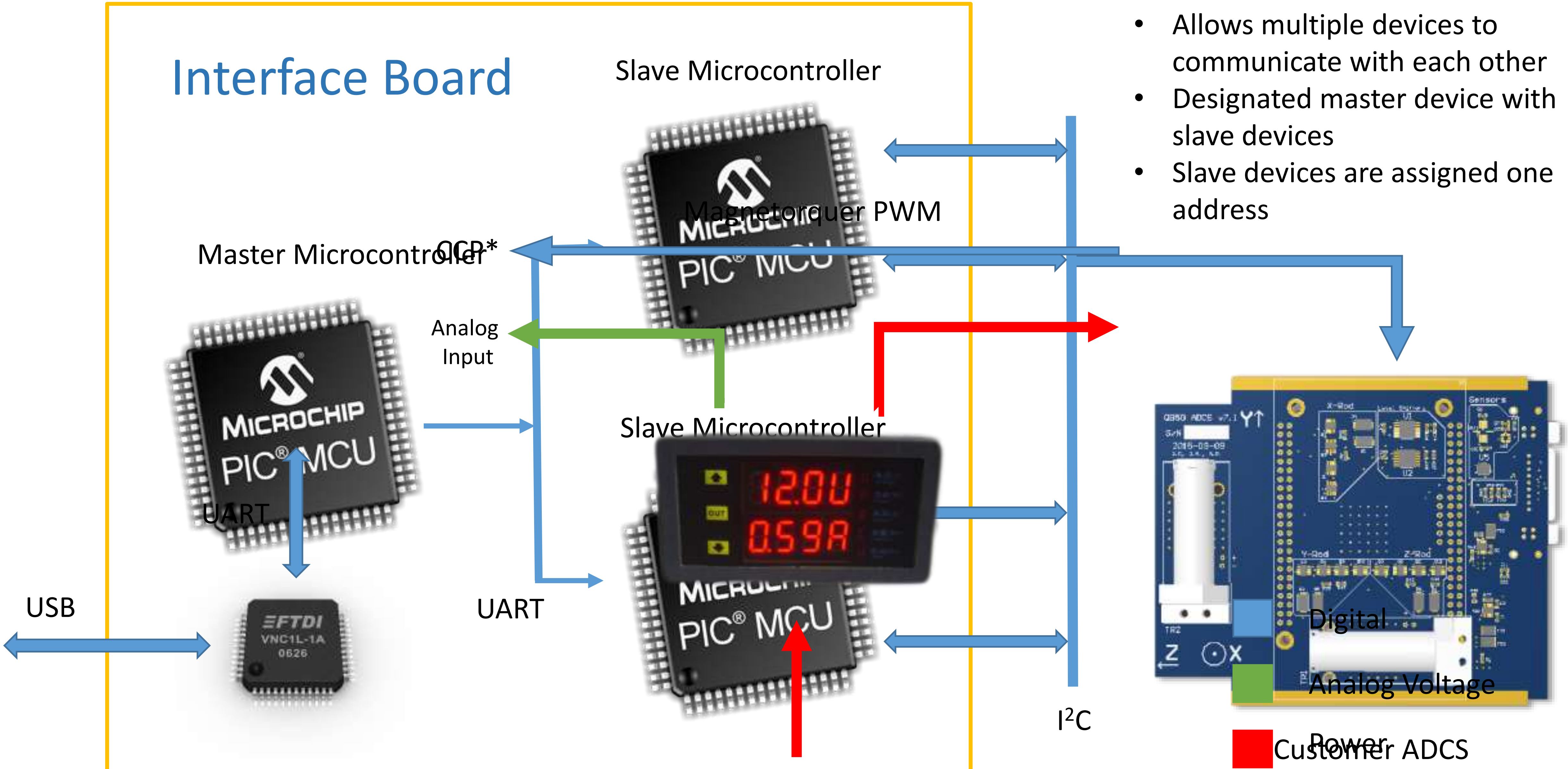


Customer ADCS

- **Compatible with Matlab** using included drivers from FTDI
- Converts USB into a common communication protocol used by microcontrollers

Interface Board to ADCS - Feasibility

I^2C Bus
- Allows multiple devices to communicate with each other
- Designated master device with slave devices
- Slave devices are assigned one address

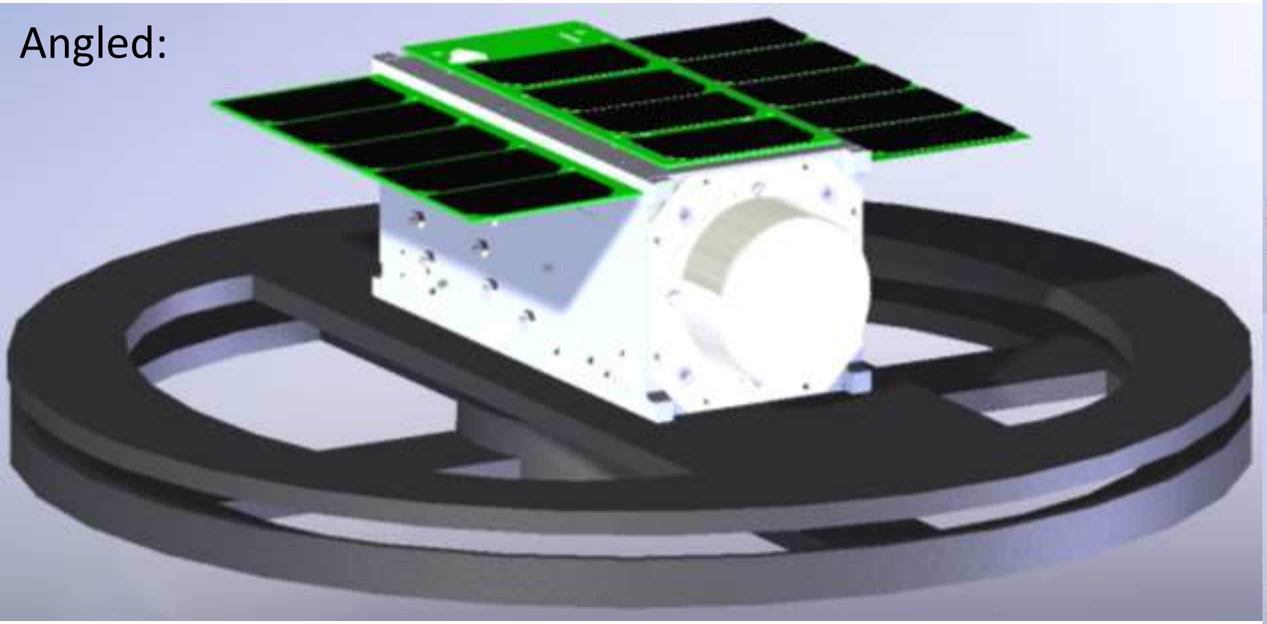


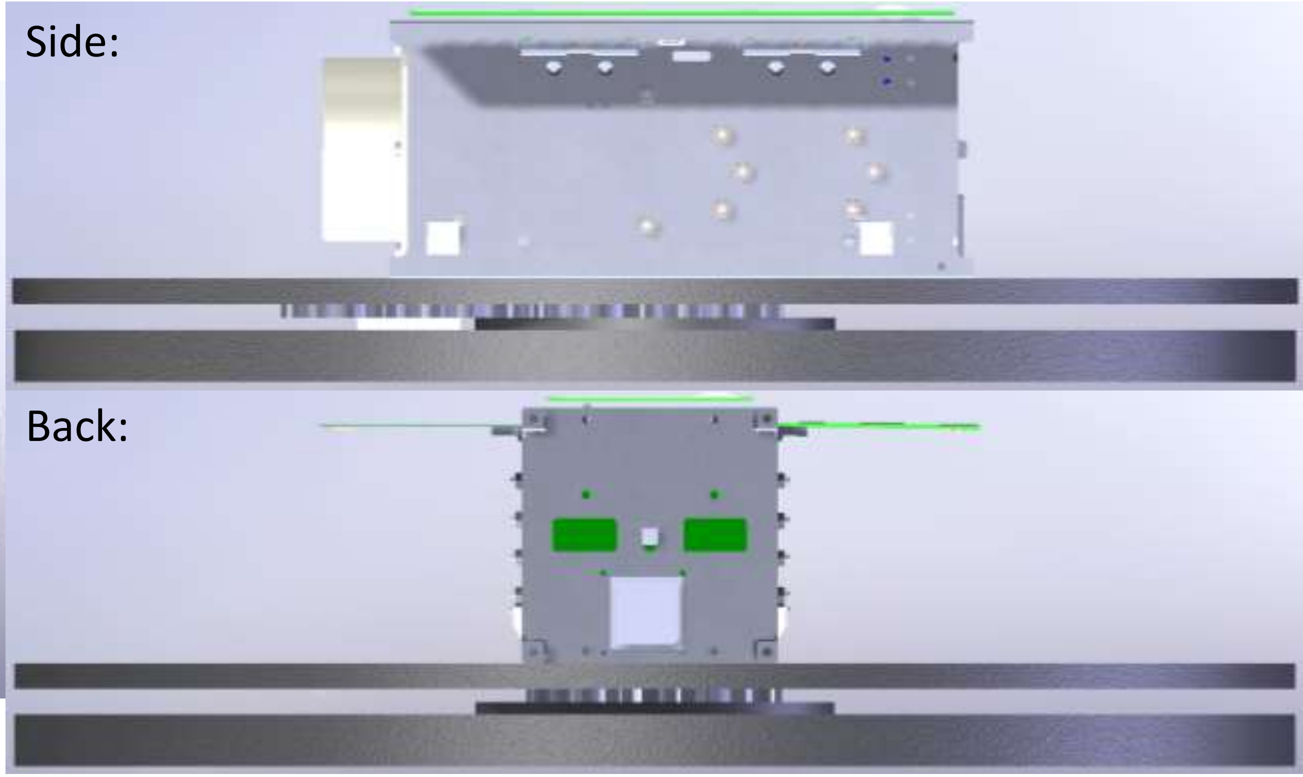
*CCP = Capture/Compare/PWM

Baseline Feasibility

Sun Sensor Calibration Table

Sun Sensor Calibration Table - Feasibility





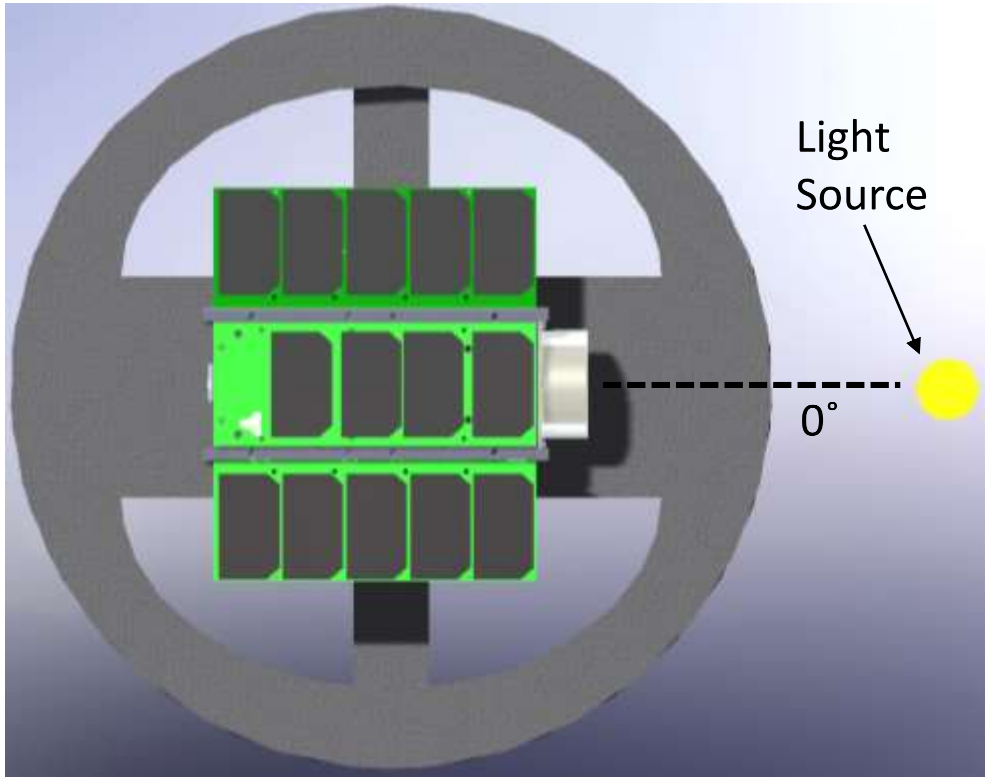
Diameter = 50 cm
Height = 4 cm

Supports 1U, 2U, and 3U CubeSats in all orientations

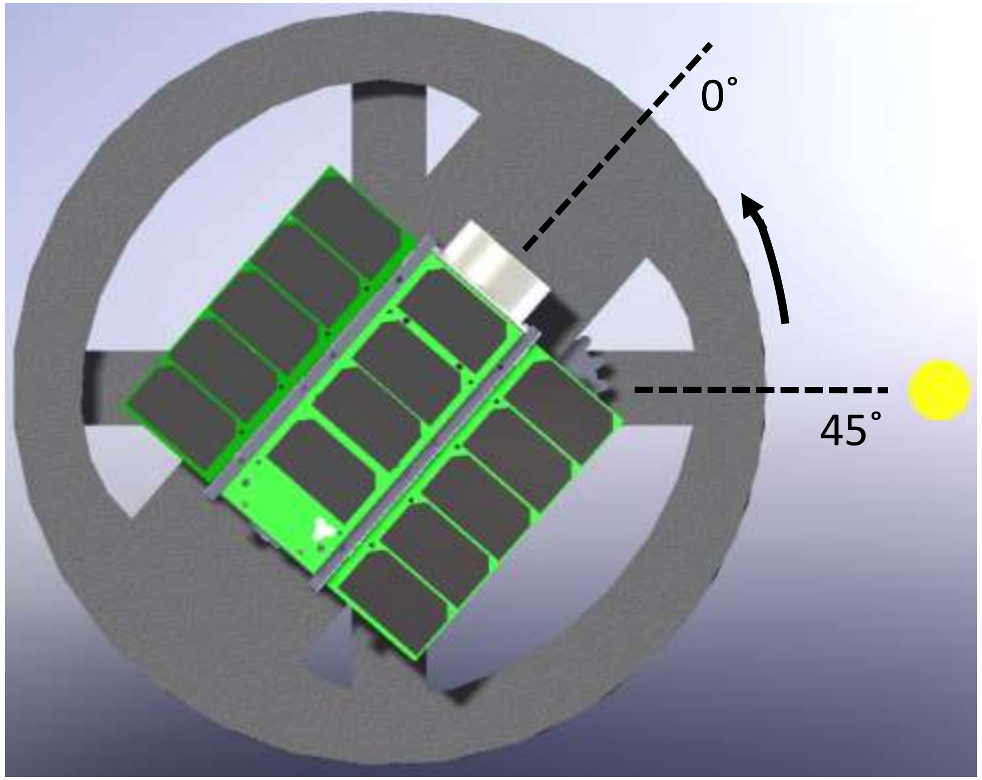
Sun Sensor Calibration Table - Usage

Rotation types:

1) Manual – rotate to desired angle
2) Motor – to be implemented by customer

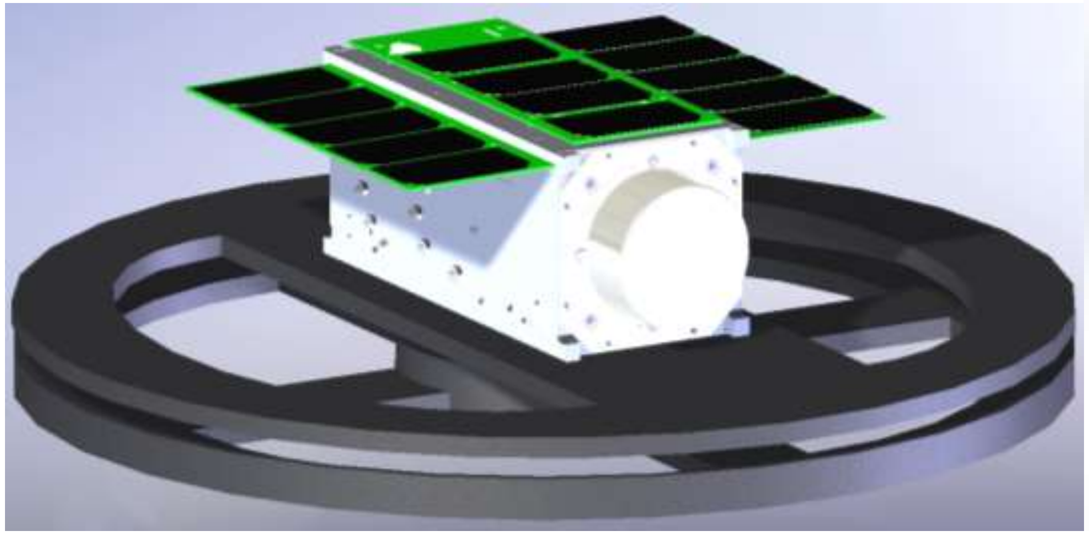


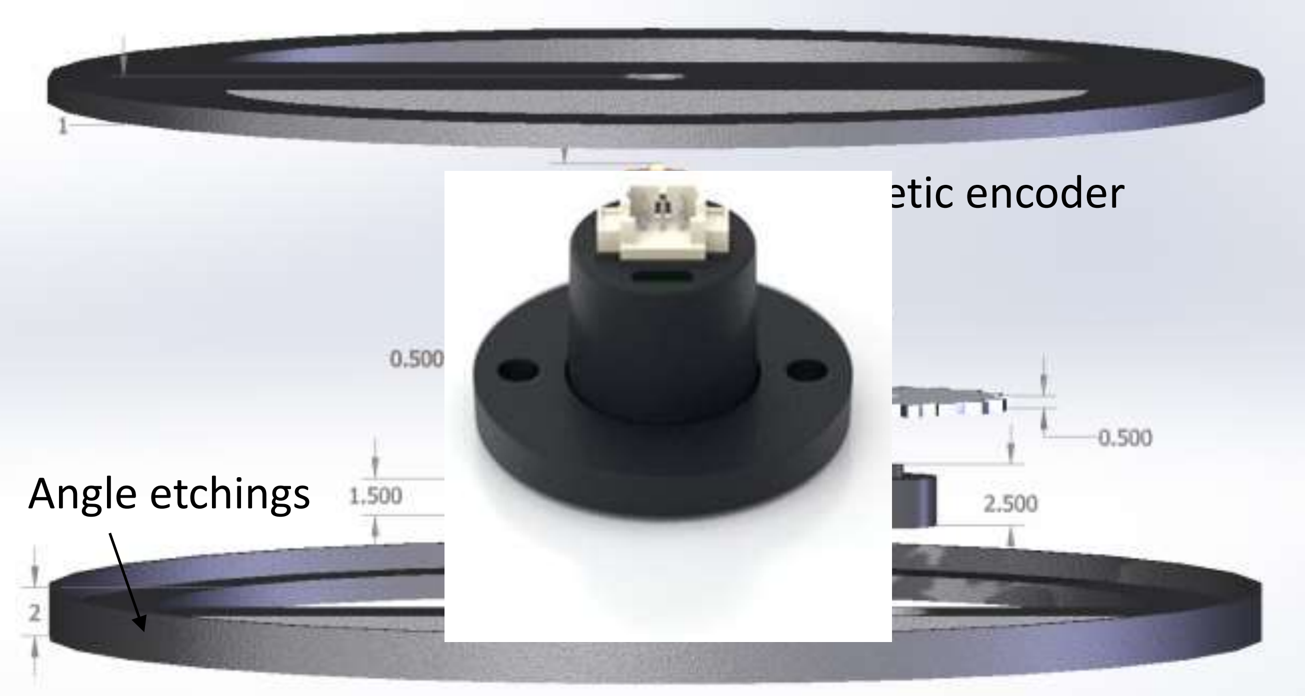
Rotation



Sun Sensor Calibration Table - Feasibility

1. Rotate with resolution of 1˚ with ±0.5˚ accuracy
   - 10 bit rotary encoder
     - Resolution = $360^\circ/2^{10}$ = 0.352˚ per bit < 1˚
   - Angle etchings
     - Physical – electronics redundancy
     - Board diameter = 50 cm = 19.685”
     - Arc length spacing = circumference/360˚ = 0.172”/degree

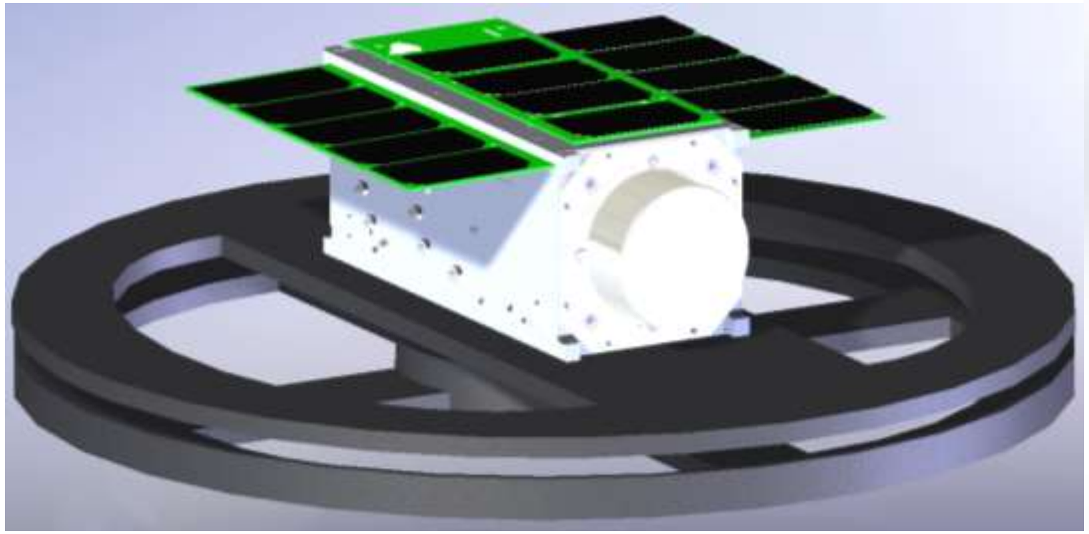


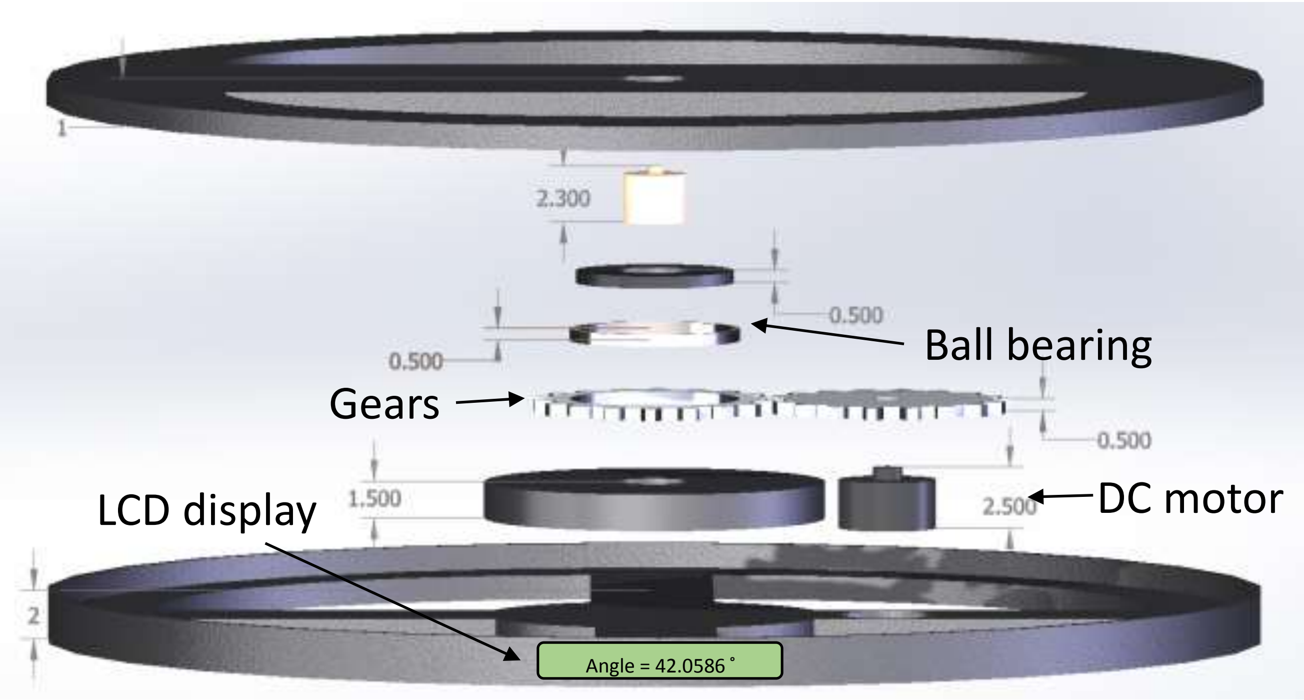


All measurements in centimeters

Sun Sensor Calibration Table - Feasibility

2. Display angular position to user
   - LCD display output
3. Manually operated with potential to be automated
   - 10 Hz Sun sensor, RPM of< 5/3
   - Torque required = 0.0746 N*m





Baseline Feasibility

Helmholtz Cage Test

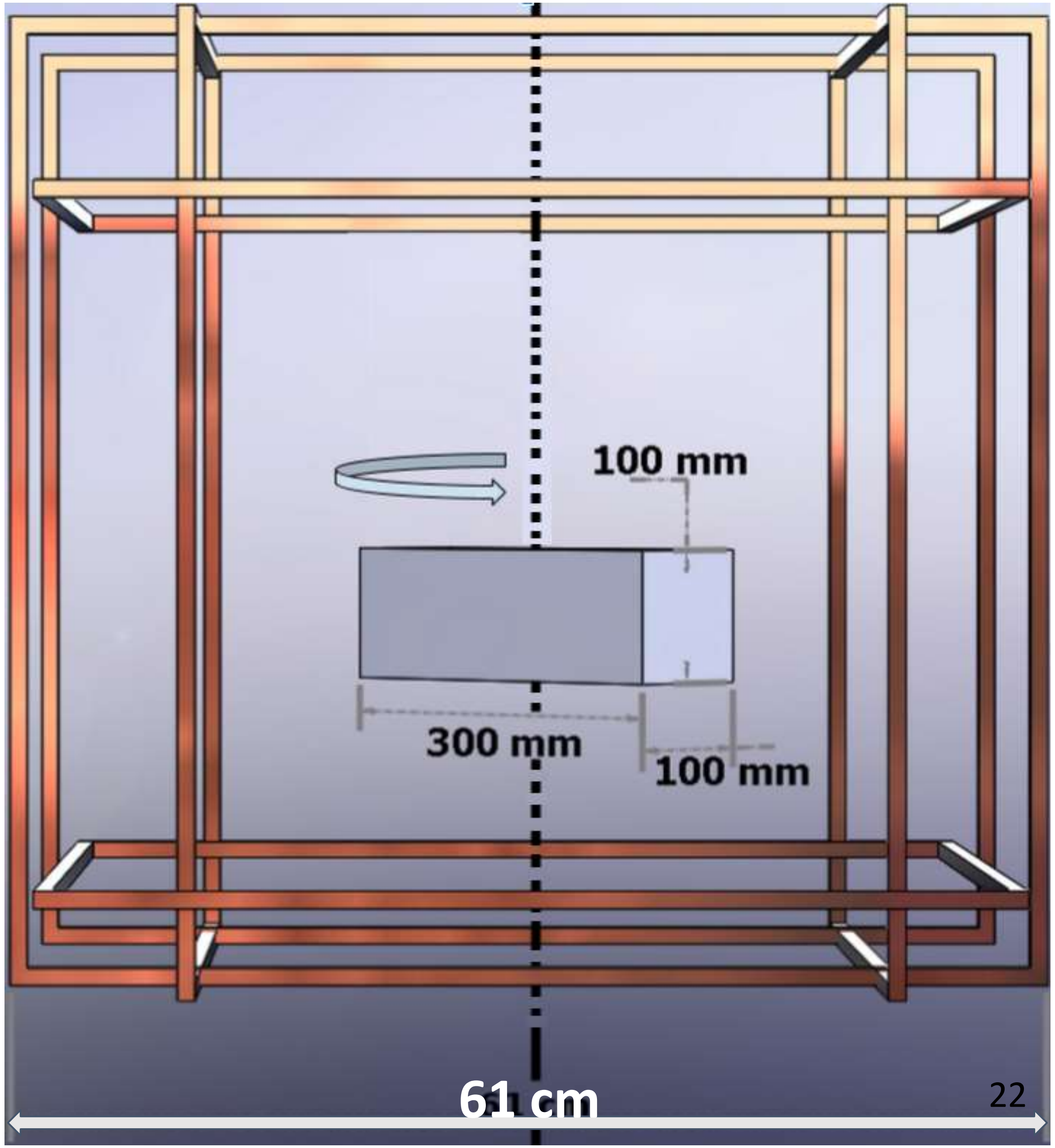
Helmholtz Cage Structure Feasibility

TEST:

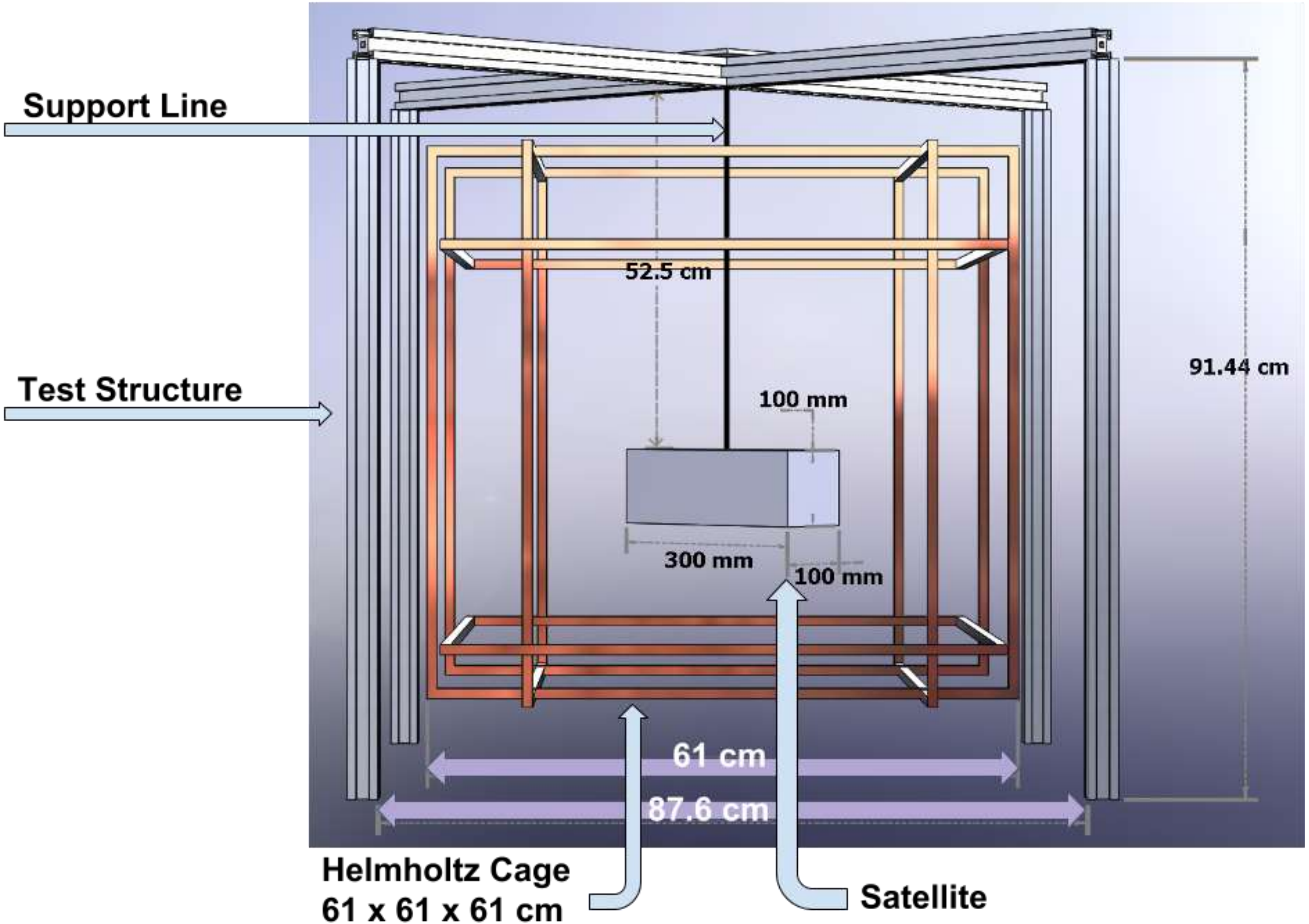
- The QB50 will sense attitude and make necessary adjustments using its magnetorquers

Requirements

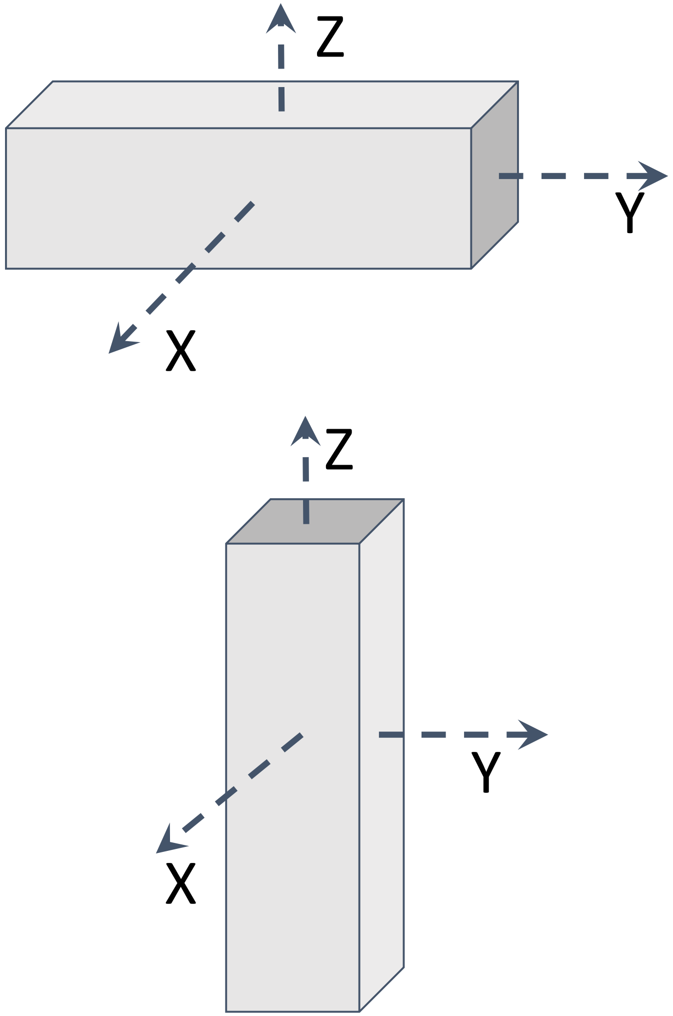
- Allow for rotation ± 360° about one axis
  - Torquing authority of 0.1 Am^2 equivalent to **5E^{-6} Nm**
  - Less than **5E^{-6} Nm** resistance to rotation
- Do not interfere with the Satellite's magnetometer readings



Helmholtz Cage Structure Feasibility



Satellite Orientations



Helmholtz Cage Testing Structure Feasibility

$$M_D = \rho*\alpha^2*t^2*h*L^4*C_D / (64)$$

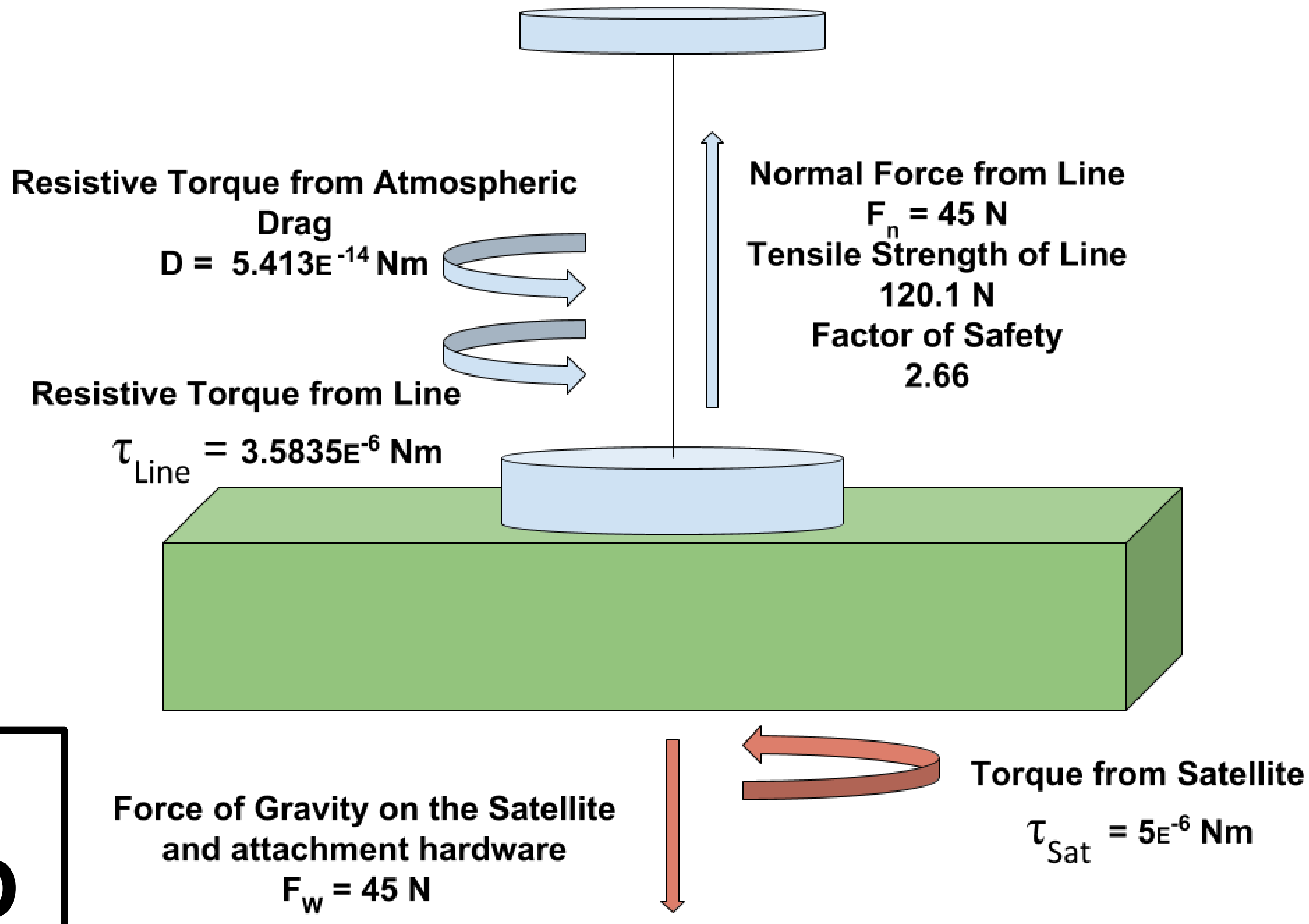
- Assume C_D = 2.05
- Assume Moment of Inertia of a hollow rectangular prism

$$\tau_{Line} = 0.5*\pi* r^4 *G*\theta*L^{-1}$$

- Assume line can be modeled as a Rod

$$\tau_{Sat} = \mu \times B$$

$$\boxed{\Rightarrow \tau_{Sat} > \tau_{Line} + M_D}$$



Helmholtz Cage Testing Structure – Feasibility
Line Resistive Torque

τ_{Line} = Resistive Torque from the line

I = mass moment of inertia of the rod

α = angular acceleration of the rod

r = cross-sectional radius of the line

θ = angular deflection = 360°

t = time for the rod to rotate θ°

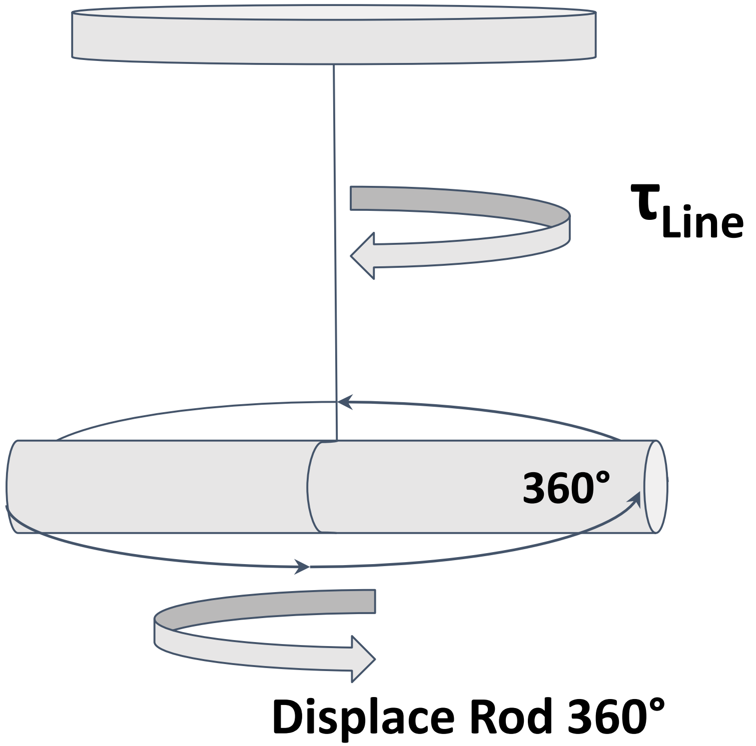
- found experimentally

$$\tau_{Line} = I * \alpha$$

$$I = m * (2 * r^2 + h^2) / 12$$

$$\alpha = 2 * \theta * t^{-2}$$

$$\tau_{Line} = 3.5835E^{-6}\ Nm$$



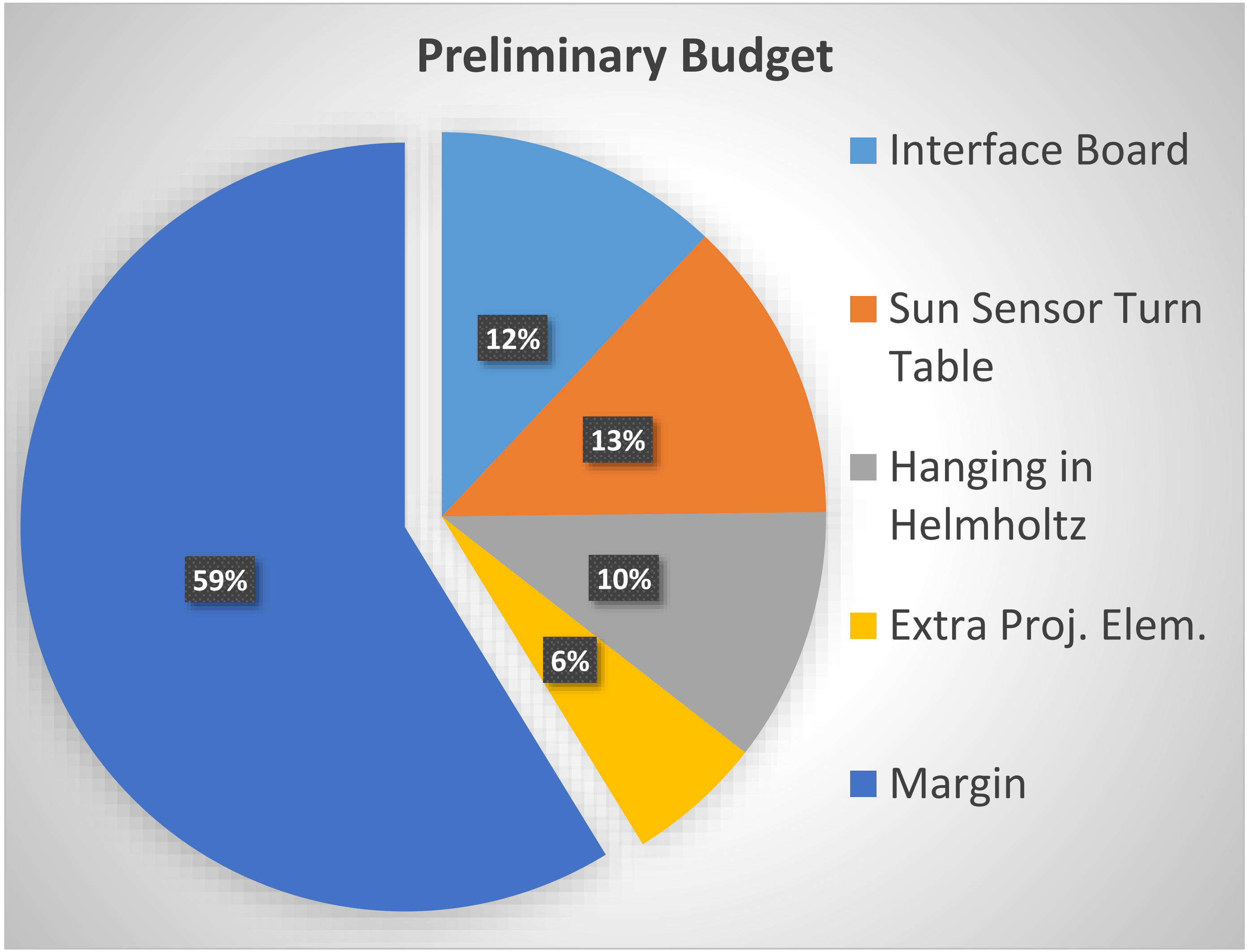
measure time (t) until rod returns to inital

Status Summary

Budget Feasibility

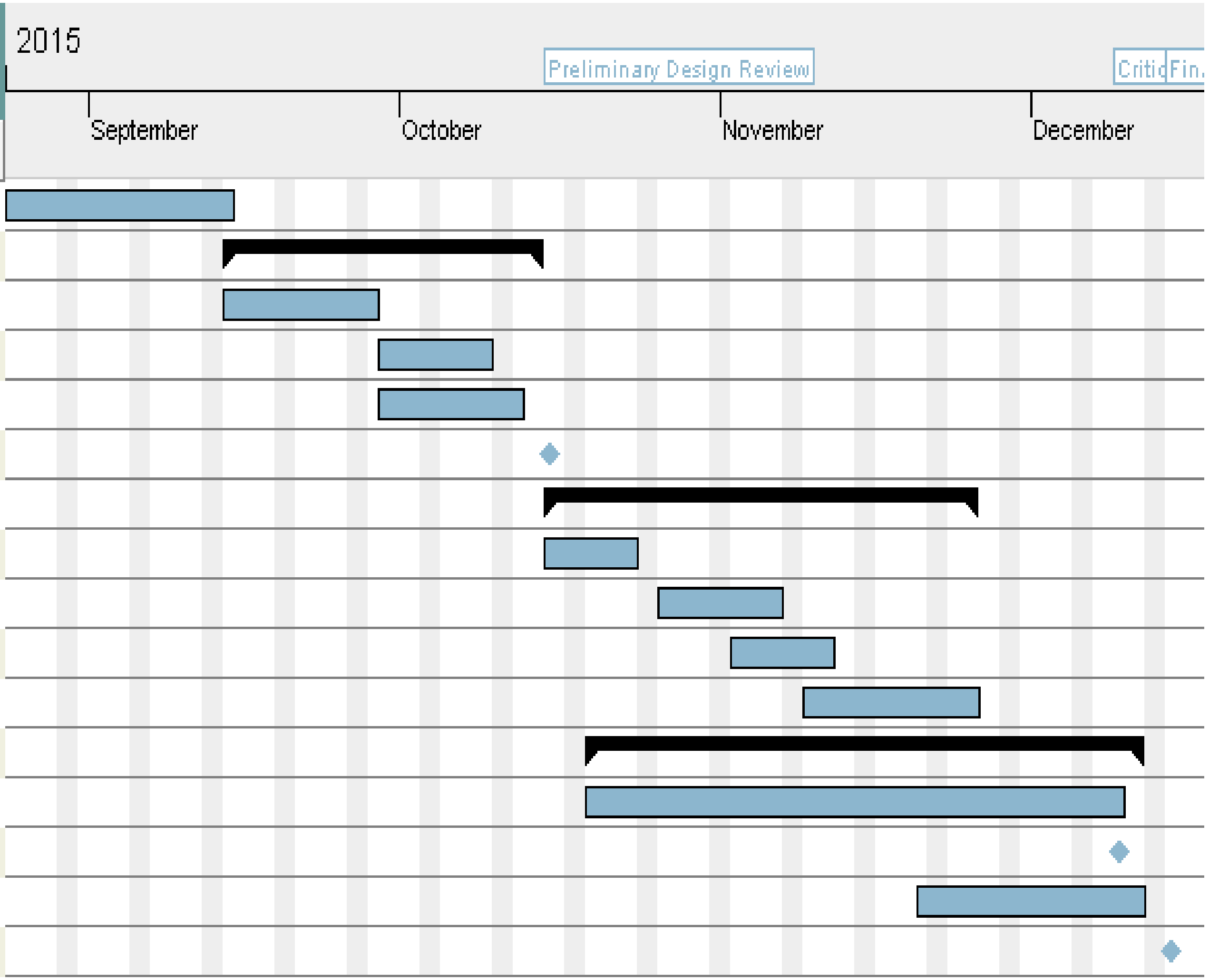
- Funding:
  - $5,000.00 CU ASEN
- Total Project Cost:
  - ~$2,000
    - 5 revisions for electronics
- Project Margin:
  - ~$3,000

*certain project elements costs are estimates/TBD



Project Schedule

Name	Begin date	End date
Project Scope and Definition	8/24/15	9/14/15
Conceptual Development and Design	9/14/15	10/14/15
Critical Design Document Due	9/14/15	9/28/15
Design Feasibility Studies	9/29/15	10/9/15
Create Preliminary Design Review Presentation	9/29/15	10/12/15
Preliminary Design Review	10/15/15	10/15/15
Testing and Design Development Phase	10/15/15	11/25/15
Create Testing Plan	10/15/15	10/25/15
Acquire Necessary Testing Materials	10/26/15	11/6/15
Assemble Testing Materials	11/2/15	11/11/15
Testing	11/9/15	11/25/15
Critical Design Development	10/19/15	12/11/15
Create Critical Design Review Presentation	10/19/15	12/9/15
Critical Design Review	12/9/15	12/9/15
Create Final Report	11/20/15	12/13/15
Final Report Due	12/14/15	12/14/15



Future Studies

- Interface Board
  - Design layout of interface board
  - Selection of precise PIC microcontrollers
- Sun Sensor Calibration Table
  - Design encoder-LCD circuit
  - Selection of gears and gear ratio
- Helmholtz Cage Test
  - Further testing of hanging lines for margin
- Software
  - Increase of simulation accuracy

Questions?

Backup Slides

- Interface Board
- Simulation
- Sun Sensor Calibration Table
- Helmholtz Cage Test
- Logistics

Interface Board

Interface Board: Requirements

- Interface board shall output digital sun sensor, rate gyro, magnetometer, and GPS data at 10Hz or greater.
- Interface board shall sample the 3 magnetorquer PWM outputs
- Interface board shall measure power draw of ADCS board
  - Shall measure voltage and current for 3.3V and 5V lines
  - Shall have a minimum accuracy of 5% with a desired accuracy of 1%
  - Shall sample at a rate of 20Hz or greater

Backup Slides

Functional Requirement 1

- An interface board shall provide the means for the Matlab/Simulink simulation to communicate with the QB50 ADCS board
  - DR.1 The interface board shall transmit simulated sun sensor data, via I2C, to the ADCS board at a rate of 10Hz or greater
  - DR.2 The interface board shall transmit simulated rate gyro data, via I2C, to the ADCS board at a rate of 10Hz or greater
  - DR.3 The interface board shall transmit simulated magnetometer data, via I2C, to the ADCS board at a rate of 10Hz or greater
  - DR.4 The interface board shall transmit simulated GPS data, via USART to the ADCS board at a rate of 10Hz or greater
  - DR.5 The interface board shall sample the 3 magnetorquer PWM outputs

Backup Slides

Cont.

- DR.5.1 The PWM outputs will be sampled such that the spacecraft torque generated by the magnetorquers can be calculated to an accuracy of 10% or greater
- DR.5.2 A compare, capture, and PWM (CCP) module capable of 1kHz operation shall be used to capture the PWM signals

- DR.6 The interface board shall measure the power draw of the ADCS board
  - DR.6.1 The interface board shall measure the voltage and current of the individual 5V and 3.3V lines at a rate of 1kHz or greater
  - DR.6.2 The interface board shall measure the voltage and current of the individual 5V and 3.3V lines with a desired accuracy of 1% and minimum accuracy of 5%
  - DR.6.3 The voltage and current measurements shall be sent to the computer to be logged
- DR.7 The interface and ADCS board shall operate via USB power

Backup Slides

Functional Requirement 2

- The existing Matlab/Simulink simulation shall be modified to communicate with ADCS interface board
  - DR.1 The simulation shall communicate with the interface board via USB
  - DR.2 The supporting simulation shall convert the magnetorquer signal to a torque value and maintain an accuracy of 10% or greater
    - DR.2.1 The magnetorquer torque value shall be recorded to a file at a rate of 1kHz for the entire duration of the simulation
  - DR.3 The measured voltage and current to the ADCS board shall be recorded to a file
  - DR.4 A GUI shall be added to the simulation
    - DR.4.1 The GUI shall allow the user to override sensor output to simulate sensor failure
  - DR.5 The supporting software shall feed the magnetorquer output back into the simulation to allow for closed loop testing
  - DR.6 The supporting software shall log the simulated satellite motion computed by the customer simulation

Backup Slides

Input to ADCS

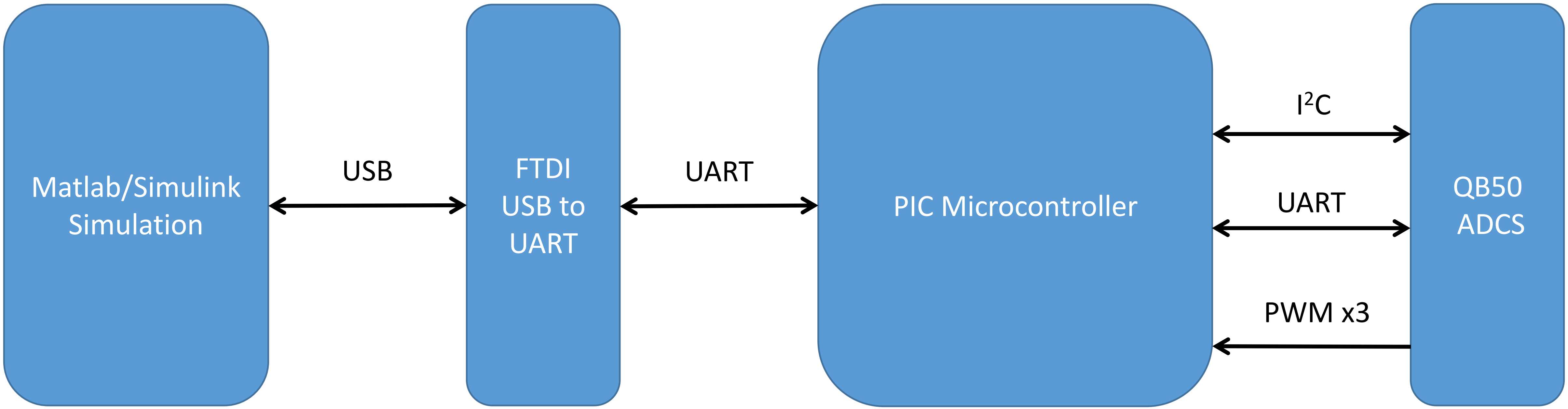
- 15 Analog Sun Sensors
  - Analog to Digital conversion takes place at the sensors
  - Communicate to the ADCS over I2C
- 3 Rate Gyros
  - Communicate over I2C
- 3 Magnetometers
  - Communicate over I2C
- 1 GPS
  - Communicates over UART

Output from ADCS

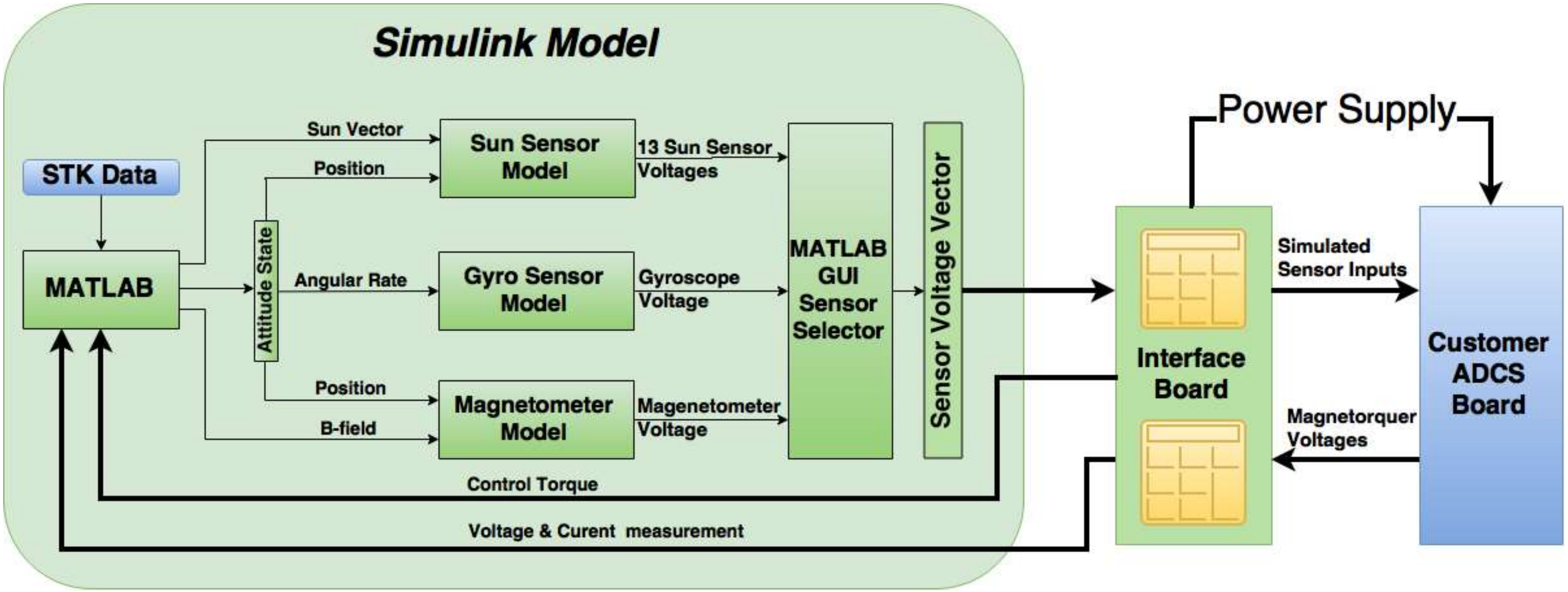
- 3 magnetorquer PWM signals
  - Operates at 1kHz
- Voltage and current measurement of 5V line to ADCS
  - Max expected current of 600mA
- Voltage and current measurement of 3.3V line to ADCS
  - Less than 20mA

Backup Slides

Interface Board



Backup Slides



[Backup Slides]

Interface Board - Components

Component	Manufacturer	Part Number	Price
Master Microcontroller	Microchip	PIC18F65J94	$3.94
Slave Microcontroller	Microchip	PIC16F18325	$1.18
USB to UART	FTDI	FT232RL	$4.50
Current Sensor	Allegro	ACS712	$4.82
Linear Voltage Regulator	STMicroelectronics	LD1117S33CTR	$0.51
Printed Circuit Board	Advanced Circuits	N/A	$33.00

Backup Slides

Interface Board – Microcontrollers

PIC18F65J94

- 4 - UART
- 2 - I2C
- 16 10/12-Bit A/D Channels
  - 500ksps @ 10-Bits
  - 200ksps @ 12-Bits
- 7 - CCP modules
  - Run at a scaled rate to oscillator

PIC16F18325

- 1 – UART
  - Allows communication to master microcontroller
- 2 - I2C
  - Allows each microprocessor to emulate 2 sensors

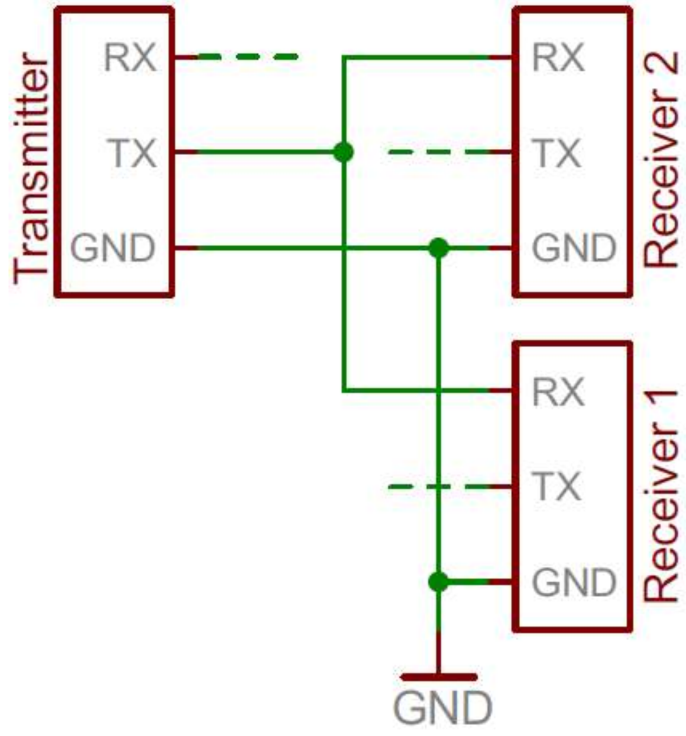
Backup Slides

UART – 1 transmitter, multiple receivers

"It can be safe to connect multiple receiving devices to a single transmitting device. Not really up to spec and probably frowned upon by a hardened engineer, but it'll work. For example, if you're connecting a serial LCD up to an Arduino, the easiest approach may be to connect the LCD module's RX line to the Arduino's TX line. The Arduino's TX is already connected to the USB programmer's RX line, but that still leaves just one device in control of the transmission line."

"Distributing a TX line like this can still be dangerous from a firmware perspective, because you can't pick and choose which device hears what transmission. The LCD will end up receiving data not meant for it, which could command it to go into an unknown state."

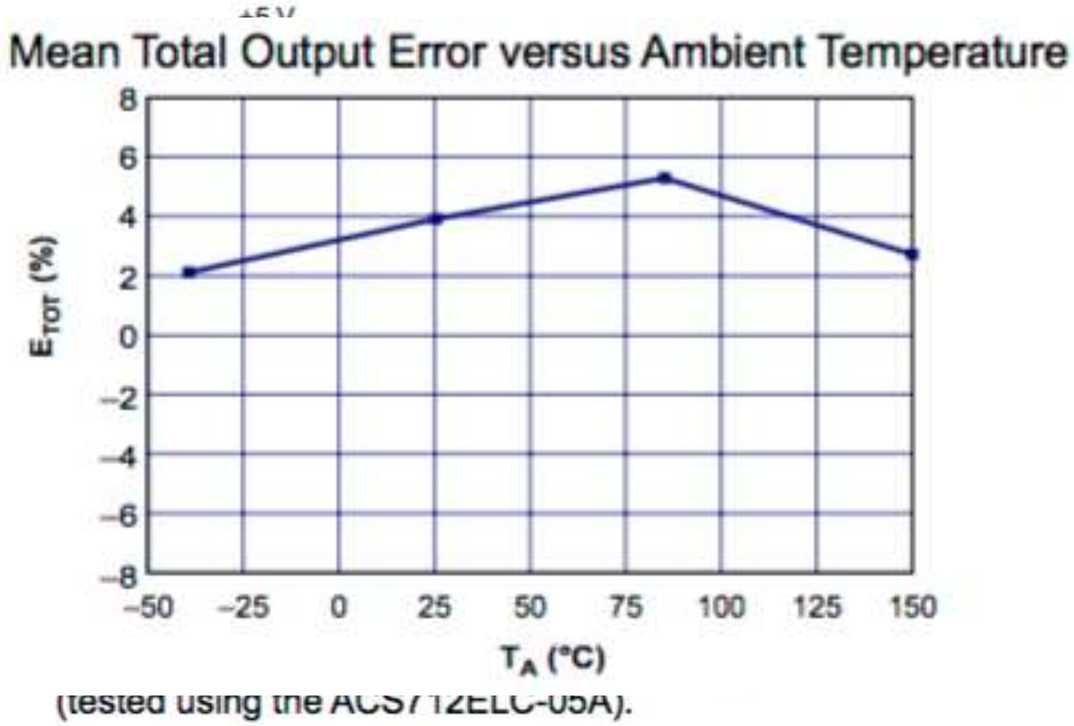
https://learn.sparkfun.com/tutorials/serial-communication



Backup Slides

Interface Board - Current Sensor

- 1.5% Typical total output error
- PIC 12-Bit ADC between 0 and 5 Volts
  - 5/(2^12) = 1.2mV resolution
- Current sensor sensitivity
  - 185mV/A base
  - 610mV/A with op-amp
- Current resolution
  - 6.5mA
  - 2.0mA



Backup Slides

Interface Board – Power Budget

Interface Board

- Microchip eXtreme Low Power
  - As low as 35uA/Mhz for 8-Bit MCU
  - 0.35mA at 10Mhz
  - <10mA for 23 MCUs
- FTDI < 25mA
- Current Sensor < 13mA

Total: ~48mA

Customer ADCS

- Beaglebone < 500mA
  - Observed ~250mA in normal operation
- Magnetorquers
  - 90 Ohms @ 5V is 56mA max
  - <167mA for 3 magnetorquers
- Sensors < 20mA

Total: ~ 437mA

Backup Slides

Current Sensor – ACS712

Selection Guide

Part Number	Packing*	T_A (°C)	Optimized Range, I_P (A)	Sensitivity, Sens (Typ) (mV/A)
ACS712ELCTR-05B-T	Tape and reel, 3000 pieces/reel	–40 to 85	±5	185
ACS712ELCTR-20A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±20	100
ACS712ELCTR-30A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±30	66

*Contact Allegro for additional packing options.

Absolute Maximum Ratings

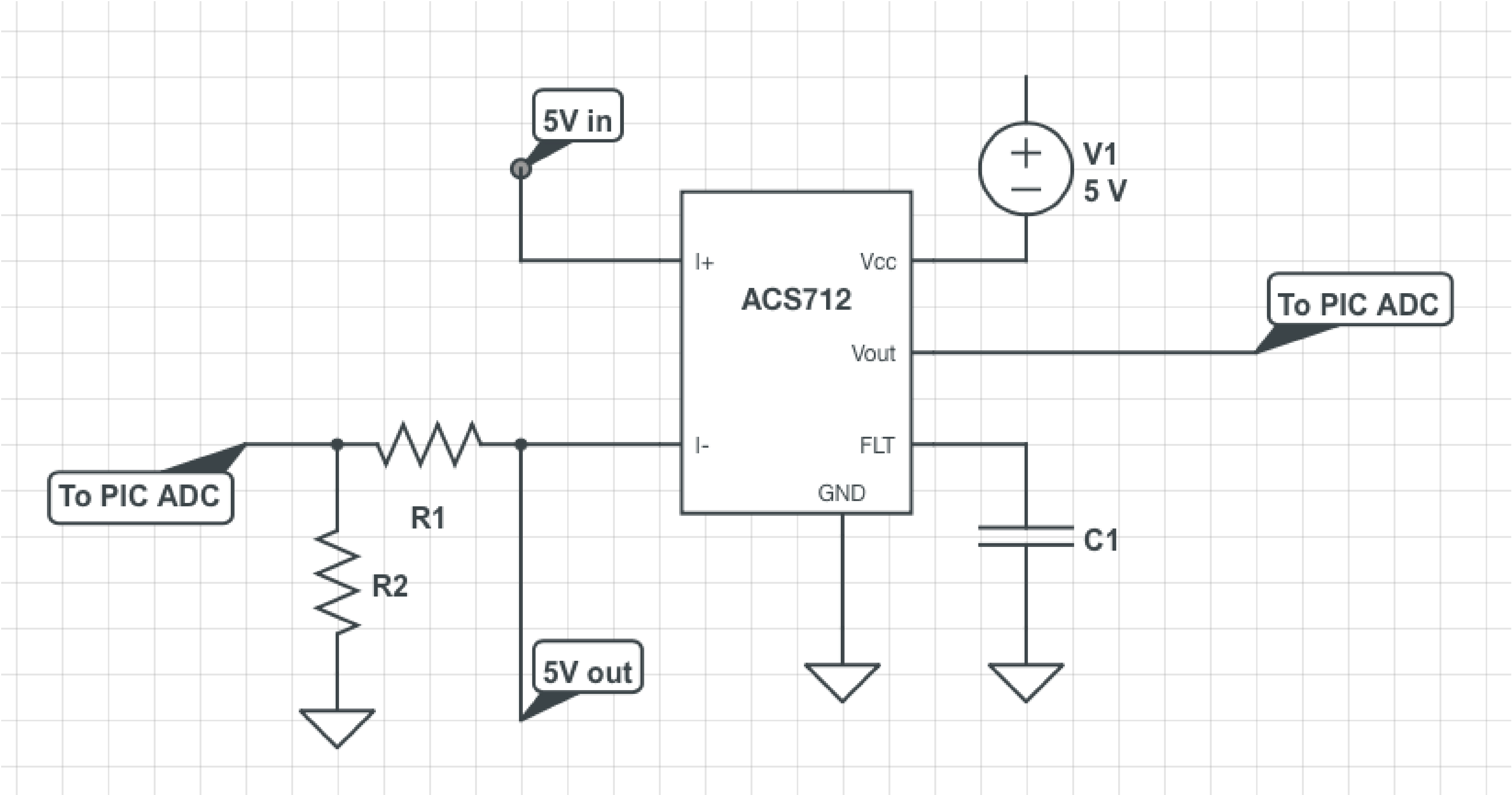
Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		8	V
Reverse Supply Voltage	V_{RCC}		–0.1	V
Output Voltage	V_{IOUT}		8	V
Reverse Output Voltage	V_{RIOUT}		–0.1	V
Reinforced Isolation Voltage	V_{ISO}	Pins 1-4 and 5-8; 60 Hz, 1 minute, T_A=25°C	2100	V
		Voltage applied to leadframe (Ip+ pins), based on IEC 60950	184	V_{peak}
Basic Isolation Voltage	$V_{ISO(bsc)}$	Pins 1-4 and 5-8; 60 Hz, 1 minute, T_A=25°C	1500	V
		Voltage applied to leadframe (Ip+ pins), based on IEC 60950	354	V_{peak}
Output Current Source	$I_{IOUT(Source)}$		3	mA
Output Current Sink	$I_{IOUT(Sink)}$		10	mA
Overcurrent Transient Tolerance	I_P	1 pulse, 100 ms	100	A
Nominal Operating Ambient Temperature	T_A	Range E	–40 to 85	ºC
Maximum Junction Temperature	T_J(max)		165	ºC
Storage Temperature	T_{stg}		–65 to 170	ºC

Features and Benefits

- Low-noise analog signal path
- Device bandwidth is set via the new FILTER pin
- 5 µs output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at T_A= 25°C
- Small footprint, low-profile SOIC8 package
- 1.2 mΩ internal conductor resistance
- 2.1 kV_{RMS} minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation
- 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis
- Ratiometric output from supply voltage

Backup Slides

Current and Voltage Measurement



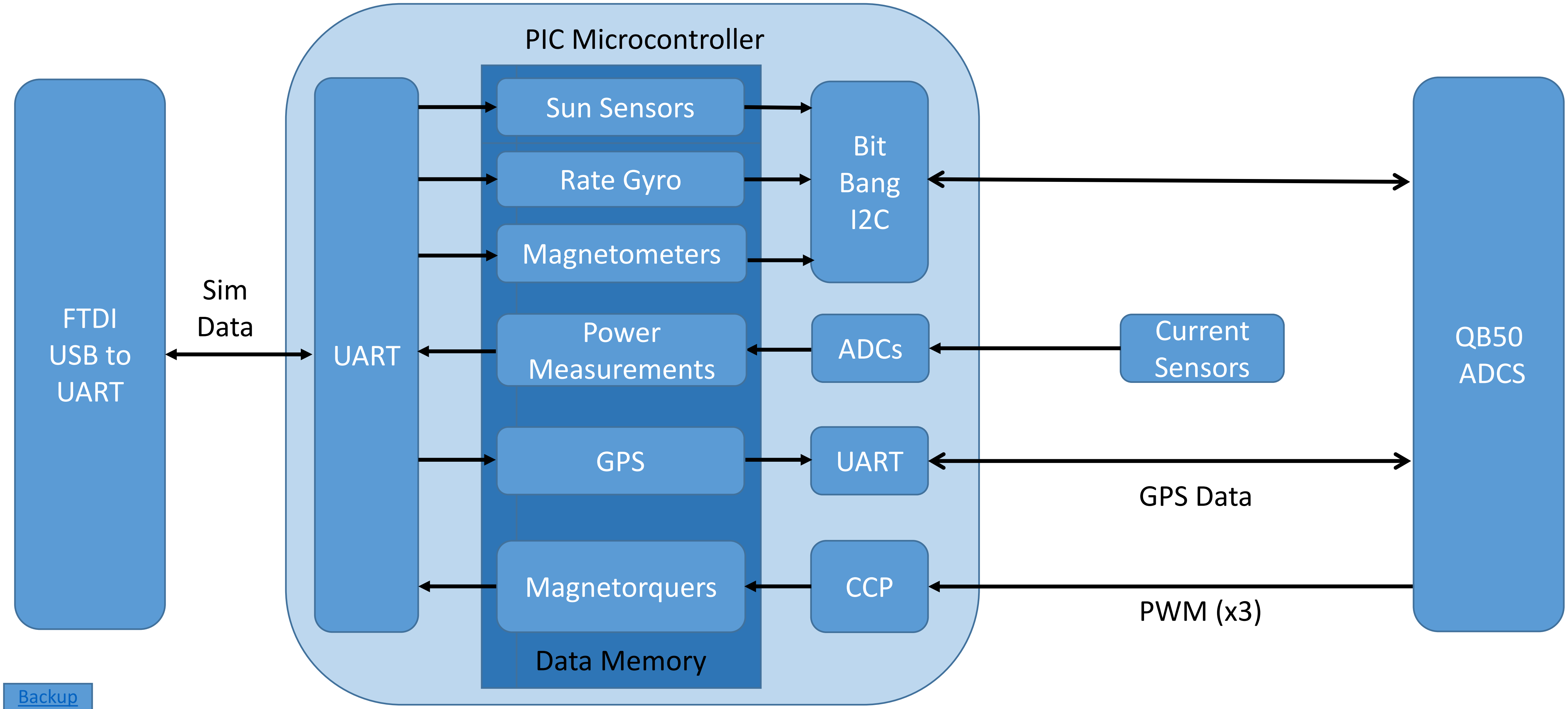
Backup Slides

Voltage Regulator – LD1117

Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
V_O	Output voltage	V_{in} = 5.3 V, I_O = 10 mA, T_J = 25 °C	3.267	3.3	3.333	V
V_O	Output voltage	I_O = 0 to 800 mA, V_{in} = 4.75 to 10 V	3.235		3.365	V
ΔV_O	Line regulation	V_{in} = 4.75 to 15 V, I_O = 0 mA		1	6	mV
ΔV_O	Load regulation	V_{in} = 4.75 V, I_O = 0 to 800 mA		1	10	mV
ΔV_O	Temperature stability			0.5		%
ΔV_O	Long term stability	1000 hrs, T_J = 125 °C		0.3		%
V_{in}	Operating input voltage	I_O = 100 mA			15	V
I_d	Quiescent current	$V_{in} \leq 15$ V		5	10	mA
I_O	Output current	V_{in} = 8.3 V, T_J = 25 °C	800	950	1300	mA
eN	Output noise voltage	B = 10 Hz to 10 kHz, T_J = 25 °C		100		µV
SVR	Supply voltage rejection	I_O = 40 mA, f = 120 Hz, T_J = 25 °C V_{in} = 6.3 V, V_{ripple} = 1 V_{PP}	60	75		dB
V_d	Dropout voltage	I_O = 100 mA		1	1.1	V
		I_O = 500 mA		1.05	1.15	
		I_O = 800 mA		1.10	1.2	
	Thermal regulation	T_a = 25 °C, 30 ms Pulse		0.01	0.1	%/W

[Backup Slides](#)

Interface Board – Bit Bang Method

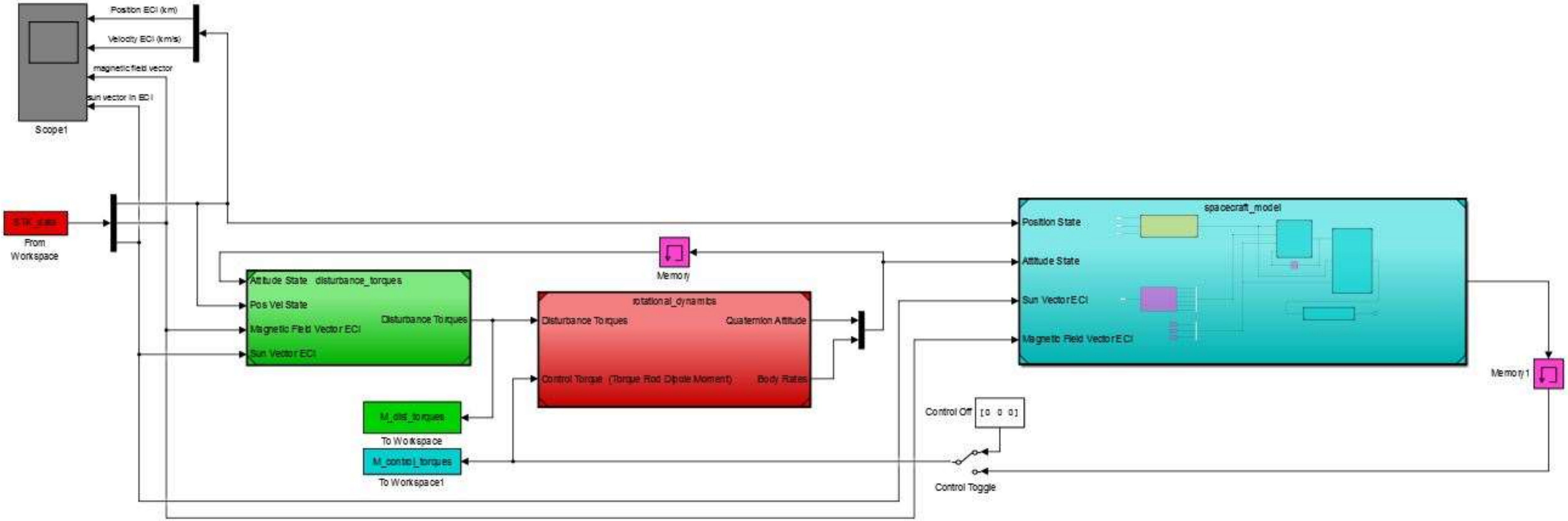


Backup Slides

Simulation

(Backup)

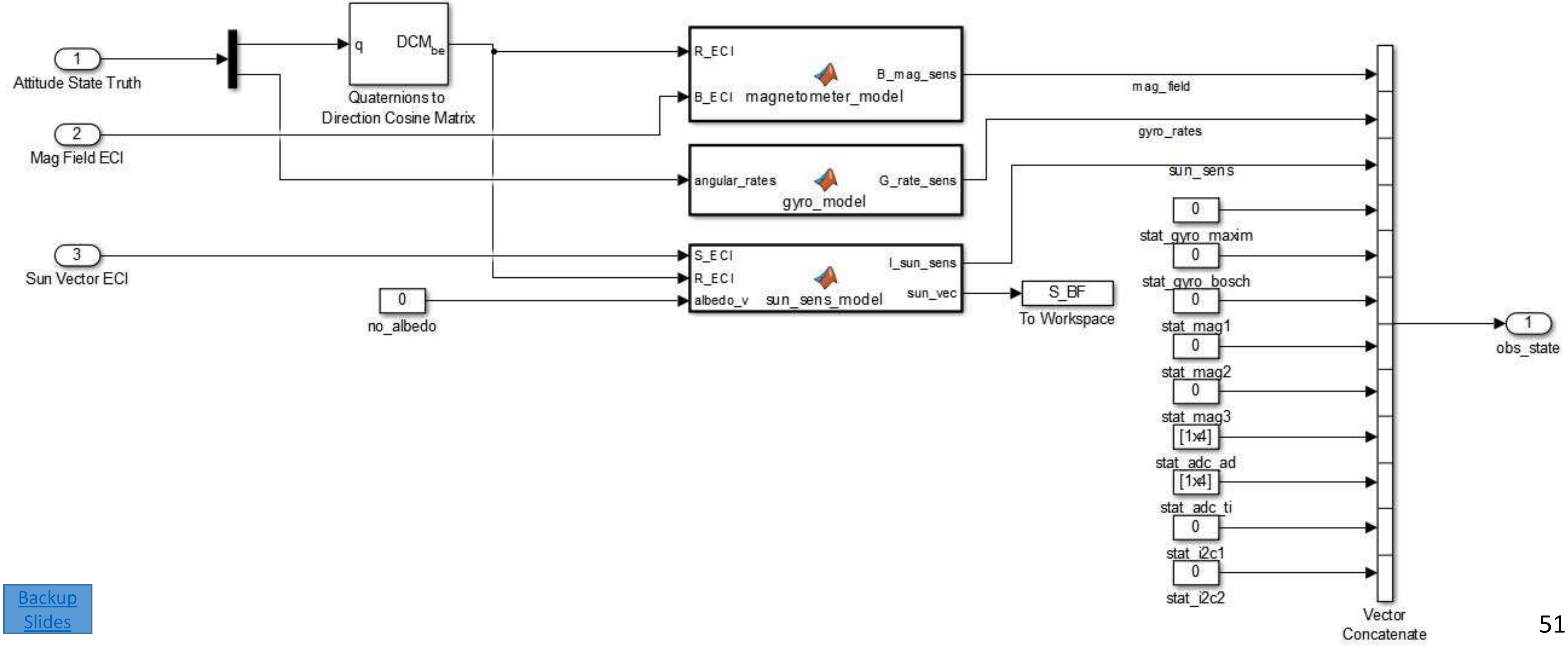
CUBESAT SIMULATION MODEL



Backup Slides

(Backup)

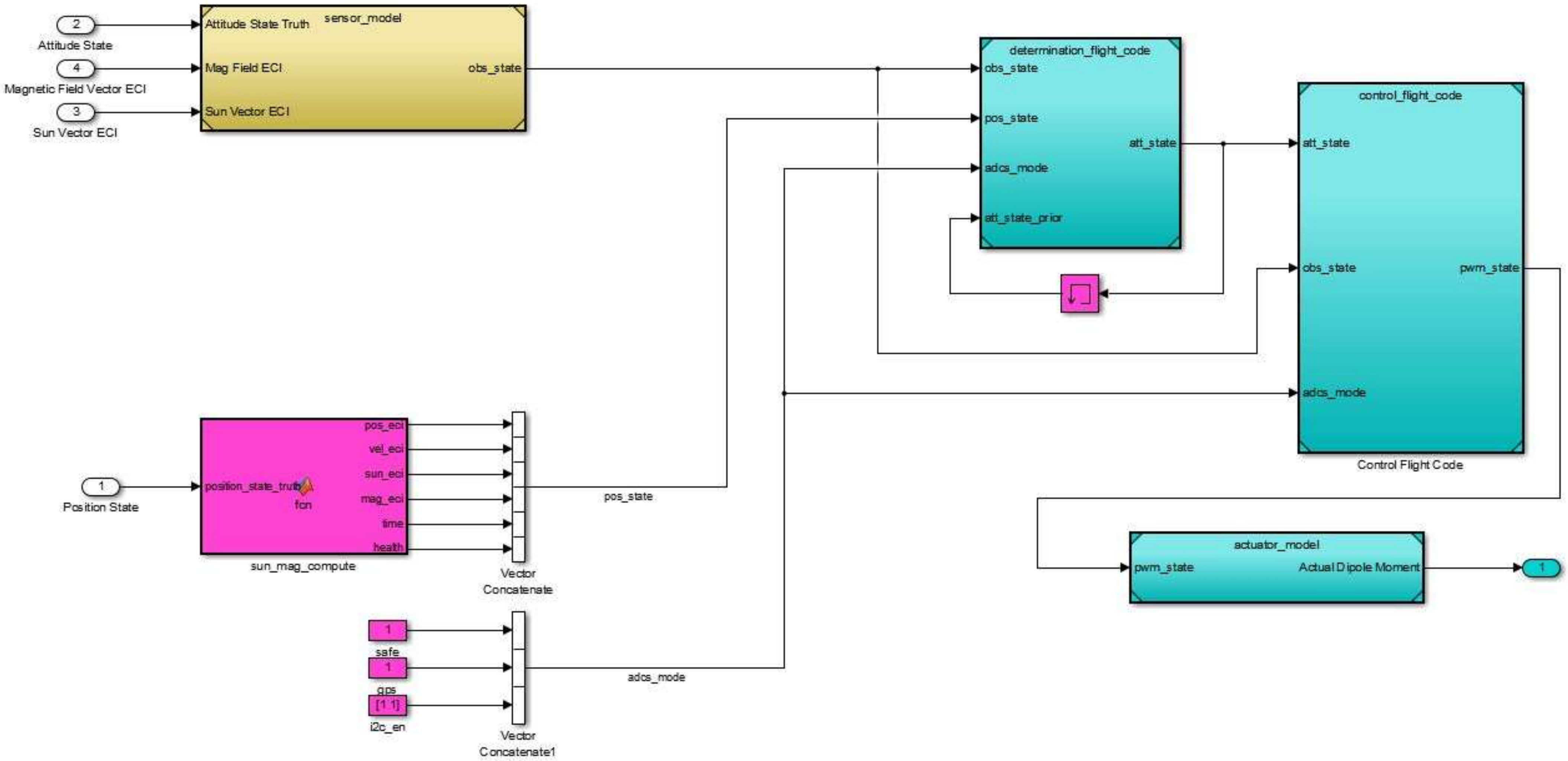
CUBESAT SIMULATION MODEL



Backup Slides

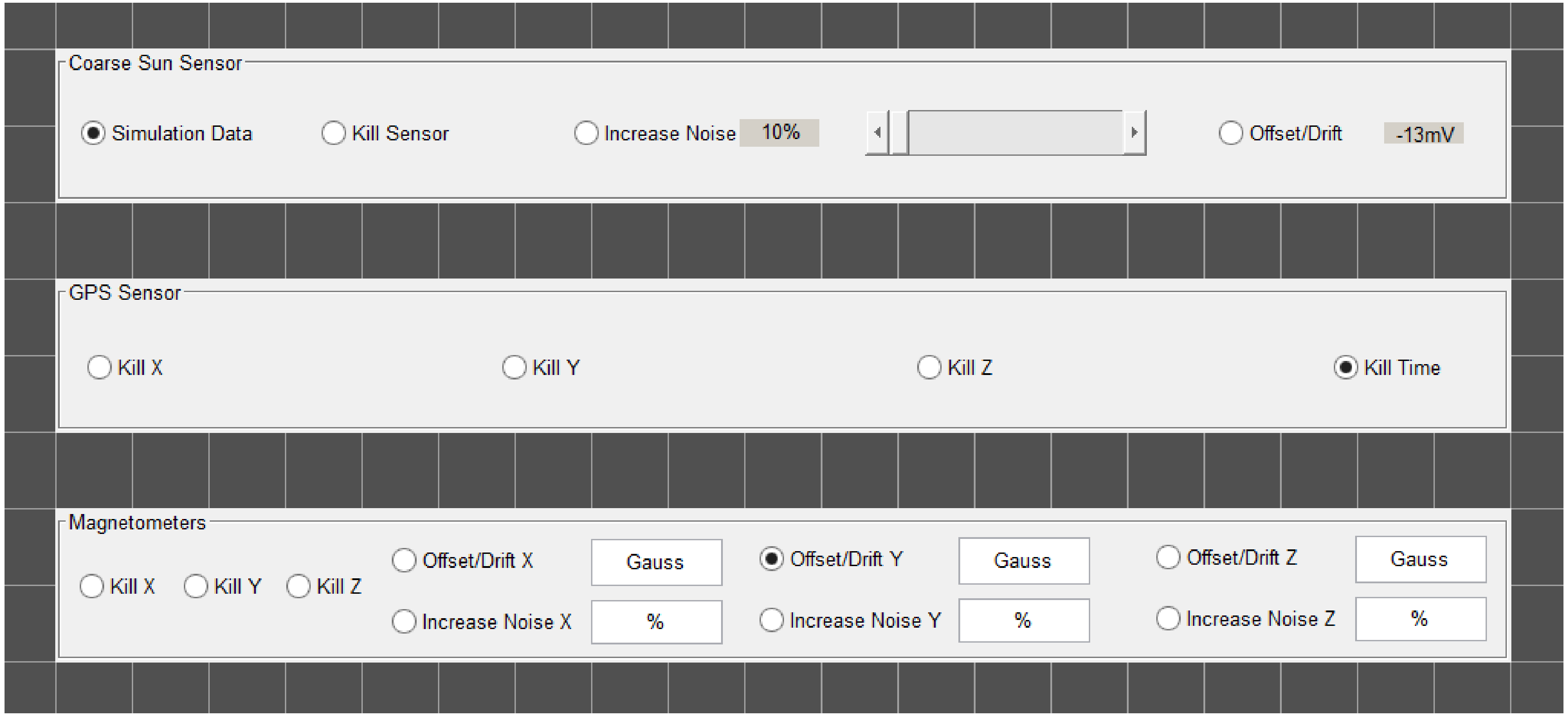
(Backup)

CUBESAT SIMULATION MODEL



Backup Slides

Sensor Override



Backup Slides

USB Power Supply

- Use External USB Battery

- Royal PB10000
- 2 USB Lines
  - 5V, 2.1 A
  - 5A, 1 A
- 10,000 mAh

Image from http://newgizmoblog.com/wp-content/uploads/2014/10/Royal-Power-1.jpg

Backup Slides

Trade Studies

Processor Weight Table

Criteria	Sub-Criteria	Percentages		Weights	
Performance	-	30%	-	0.30	-
-	Speed/Freq.	-	20%	-	0.20
-	Power	-	10%	-	0.10
Reliability	-	10%	-	0.10	-
-	Long Term	-	5%	-	0.05
-	Consistency	-	5%	-	0.15
Language	-	40%	-	0.40	-
-	Learning Curve	-	20%	-	0.20
-	Ease of Use	-	20%	-	0.20
Cost	-	10%	-	0.10	-
Support	-	10%	-	0.10	-
		100%		1.00	

Software/GUI Weight Table

Criteria	Sub-Criteria	Percentages		Weights	
License	-	5%	-	0.05	-
Learning Curve	-	35%	-	0.35	-
Ease of Use	-	25%	-	0.25	-
Compatibility	-	35%	-	0.35	-
-	Software	-	15%	-	0.15
-	Hardware	-	20%	-	0.20
		100%		1.00	

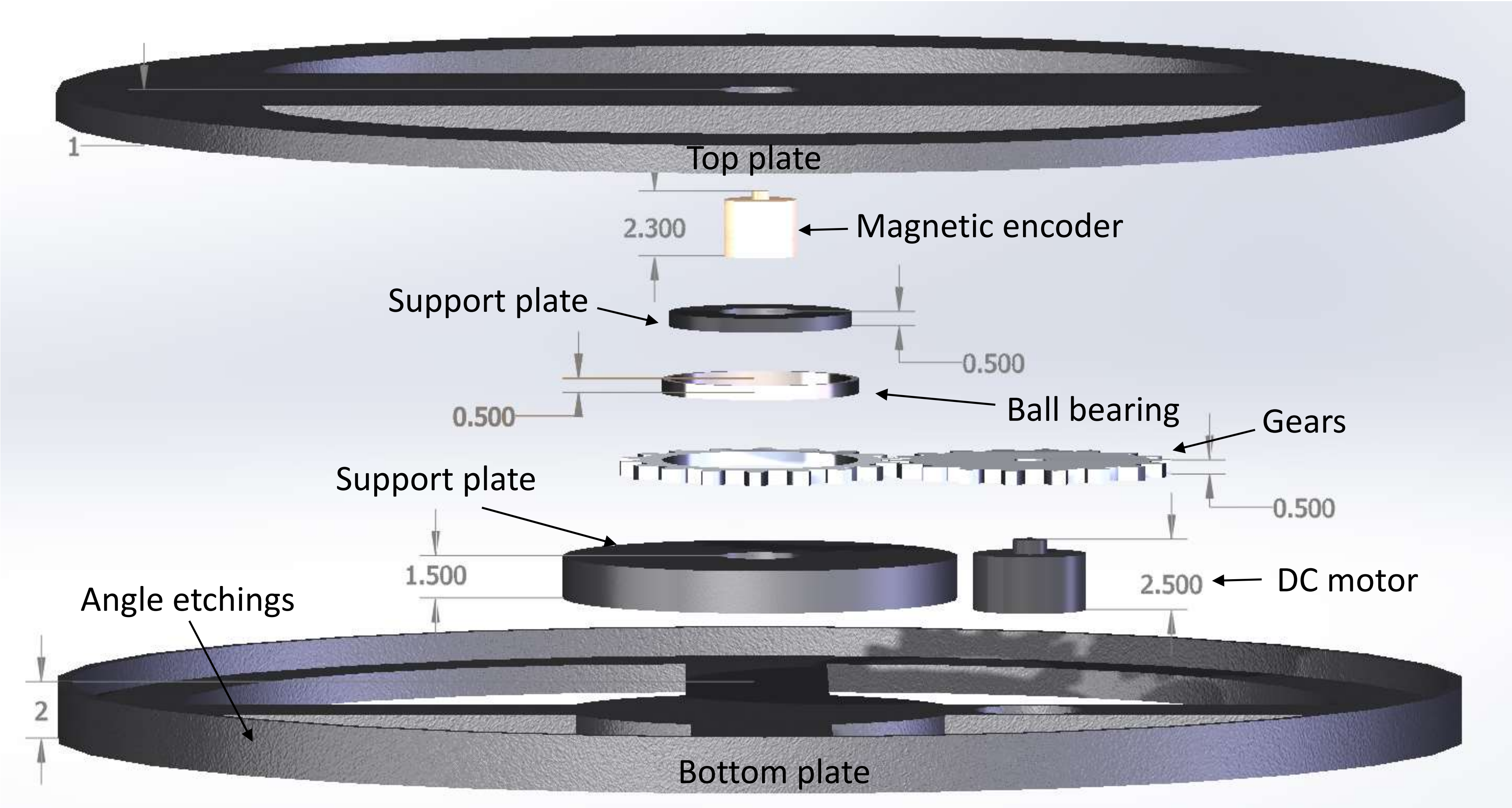
Trade Study Results

Summary Matrix			PIC		Arduino		FPGA		Ras Pi	
Criteria	Sub-Criteria	Weight	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Performance	-	30%	-	-	-	-	-	-	-	-
	Speed/Frequency	20%	3	0.60	3	0.60	5	1.00	4	0.80
	Power Use	10%	3	0.30	4	0.40	5	0.50	2	0.20
Reliability	-	10%	-	-	-	-	-	-	-	-
	Long Term Use	5%	5	0.25	5	0.25	5	0.25	5	0.25
	Consistency	5%	4	0.20	4	0.20	5	0.25	4	0.20
Language	-	40%	-	-	-	-	-	-	-	-
	Learning Curve	20%	4	0.80	4	0.80	1	0.20	3	0.60
	Ease of Use	20%	4	0.80	5	1.00	1	0.20	3	0.60
Cost	-	10%	5	0.50	4	0.40	5	0.50	4	0.40
Support	-	10%	5	0.50	4	0.40	2	0.20	3	0.30
TOTAL			-	3.95	-	4.05	-	3.10	-	3.35

Summary Matrix			Matlab		LabView		C	
Criteria	Sub-Criteria	Weight	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Weighted Score
License	-	5%	5	0.25	2	0.10	4	0.20
Learning Curve	-	35%	5	1.75	4	1.40	3	1.05
Compatibility	-	35%	-	-	-	-	-	-
-	Software	15%	5	0.75	4	0.60	3	0.45
-	Hardware	20%	4	0.80	5	1.00	3	0.60
Ease of Use	-	25%	4	1.00	4	1.00	2	0.50
TOTAL			-	4.55	-	4.10	-	2.80

Sun Sensor Calibration Table

Sun Sensor Calibration Table – Full Model



All measurements in centimeters

Backup Slides

Sun Sensor Calibration Table – Torque Calculation

τ_R = max motor torque required (N*m)

g = gravity = 9.81 m/s^2

ρ = max density of Aluminum = 2830 kg/m^3

r = radius of board = 0.25 m

t = max thickness of board = 0.03 m

m_c = max mass of CubeSat (3U) = 3.6 kg

m_t = max total mass (kg)

C_f = max bearing coefficient of friction = 0.0015

$$m_t = \rho * \pi * r^2 * t + m_c = 20.270\, kg$$
$$\tau_R = C_f * m_t * g * r \approx 0.0746\, N * m$$

*Assumes 1:1 gear ratio

Backup Slides

Sun Sensor Calibration Table – RPM Calculation

f = sampling frequency of Sun sensors = 10 Hz
n_m = number of teeth on motor gear
n_b = number of teeth on board/shaft gear

Need at least one sample per degree:

Max board RPM = 1˚*f = 10˚/second = 5/3 RPM

$$Gear\ Ratio = \frac{n_m}{n_b}$$

$$RPM_{board} = \frac{5}{3} \geq \frac{RPM_{motor}}{Gear\ Ratio}$$

Backup Slides

Sun Sensor Calibration Table – Bit Calculation

Rotate with resolution of 1˚ with ±0.5˚ accuracy

- US Digital - MAE3 Absolute Magnetic Kit Encoder
- 10-bit analog output

$$\text{Resolution} = 360^{\circ}/2^{10} = 0.352^{\circ} \text{ per bit}$$

Backup Slides

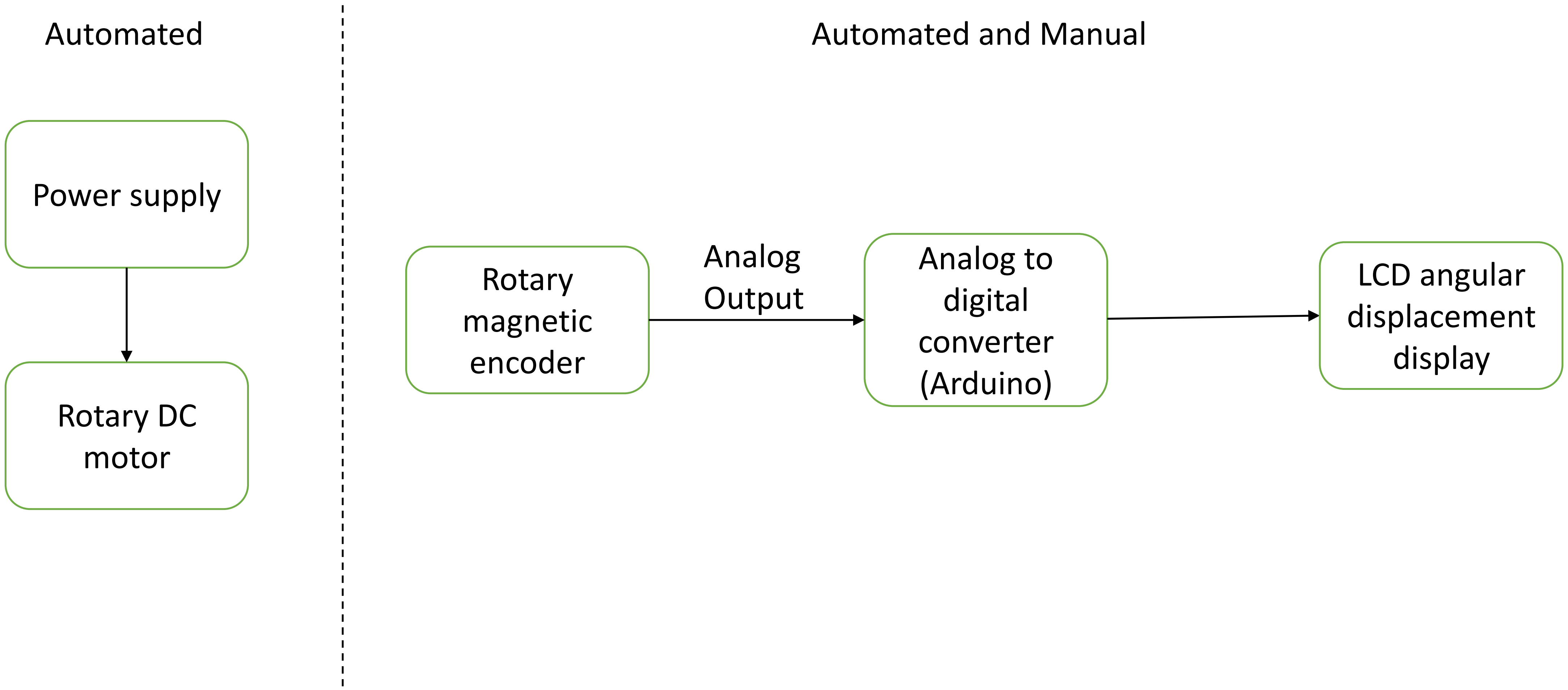
Sun Sensor Calibration Table – Reflectivity

Reflectivity less than or equal to 5% for visible wavelengths (400-700 nm)

- Avian Technologies LLC
- Avian Black-S coating has reflectance of 3.1% in visible wavelengths

Backup Slides

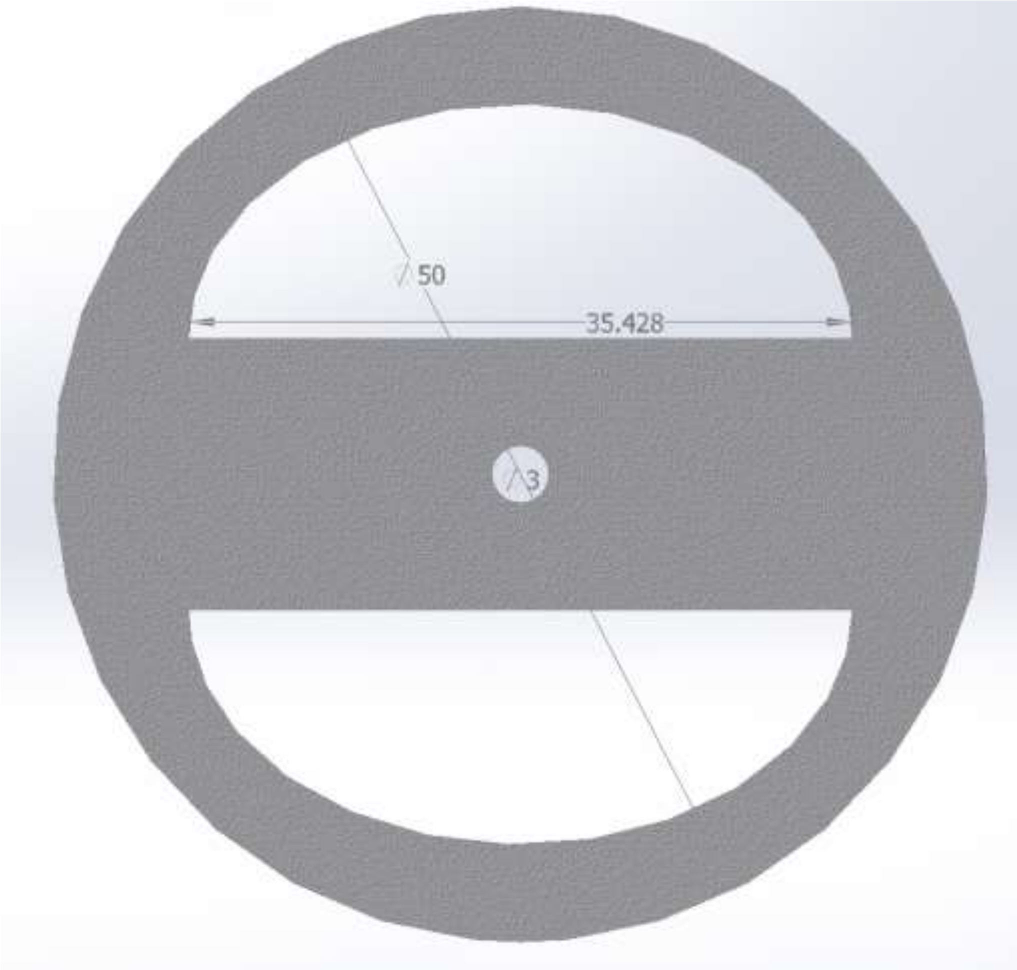
Sun Sensor Calibration Table - Flow Chart



[Backup Slides]

Sun Sensor Calibration Table – Part Model

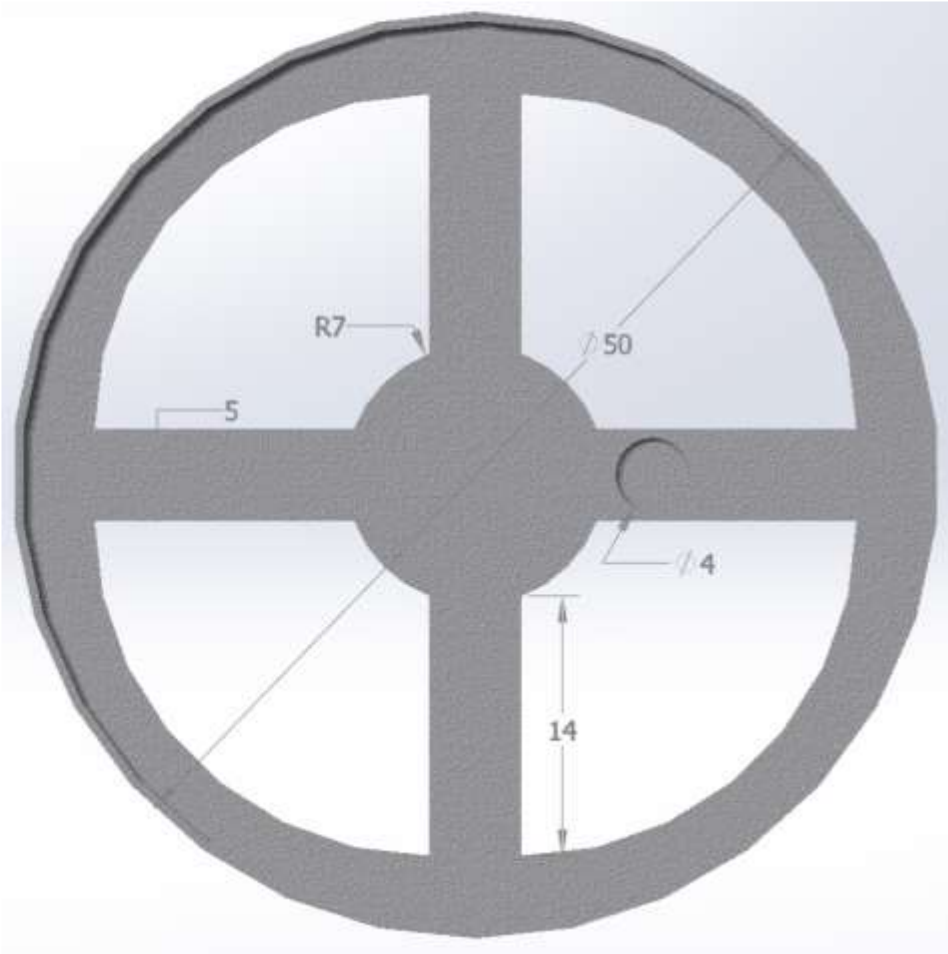
Top Platform – all measurements in centimeters

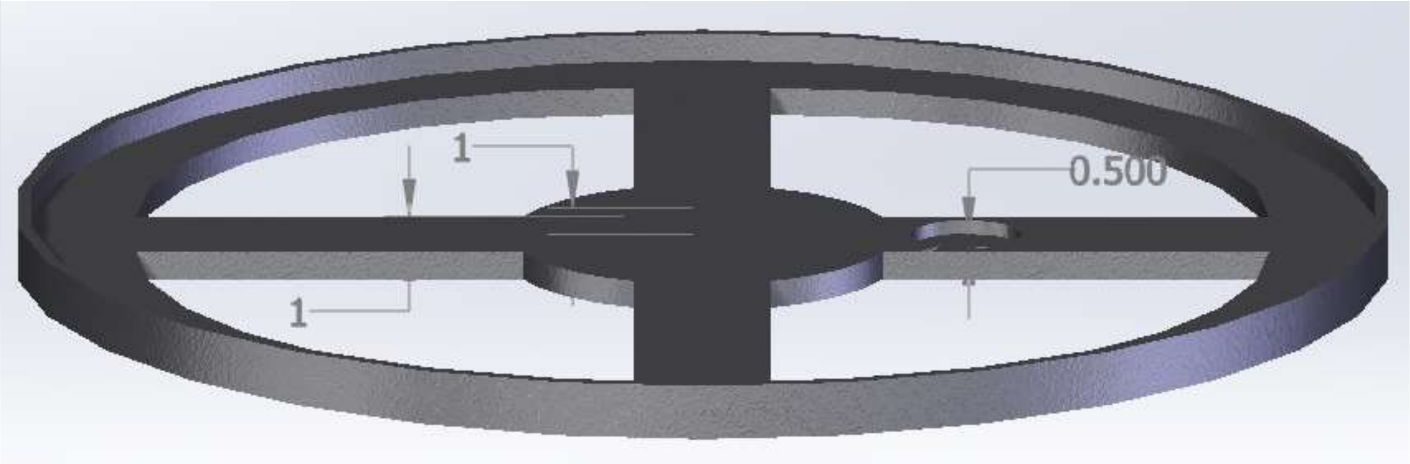


Backup Slides

Sun Sensor Calibration Table – Part Model

Bottom Platform – all measurements in centimeters





[Backup Slides]

Sun Sensor Calibration Table - Components

- 2x Aluminum disk, made from 50x50x3cm block
- 2x Aluminum gear, made from same Aluminum block
- Mechanical ball bearing
- Rotary magnetic encoder
- DC motor
- Analog to digital converter
- Digital LCD display

Backup Slides

Functional Requirement 3

- A turn table shall be delivered to the QB50 team that has resolution of 1 degree with accuracy of ±0.5°
  - DR.1 The turn table should have low reflectivity
    - DR.1.1 The table will not have an albedo exceeding 5% in the visible light spectrum
  - DR.2 The table shall sense angular position and display it to the user
  - DR.3 A stepper motor shall be used to rotate the table

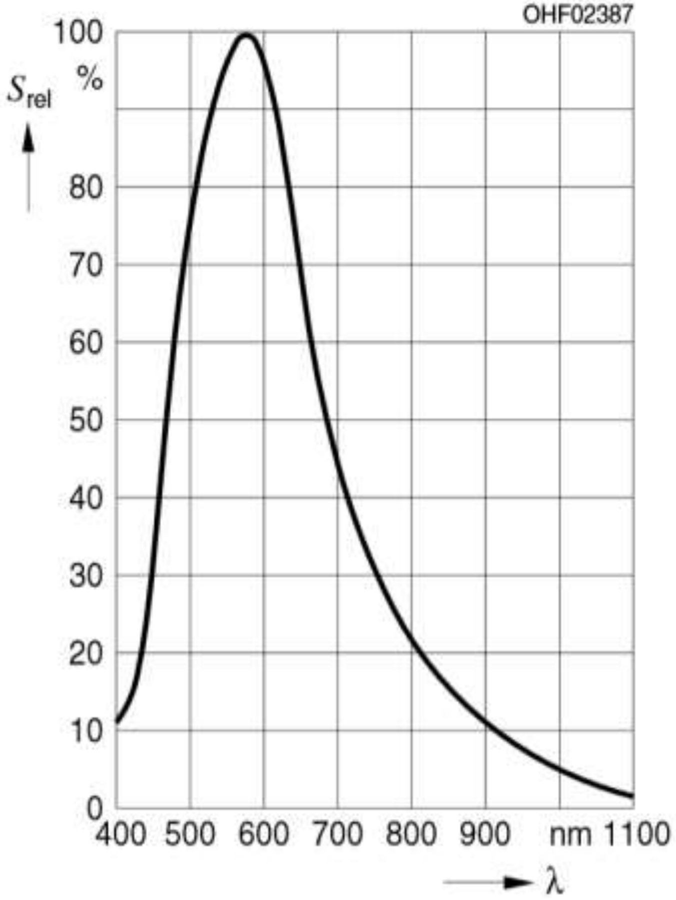
Backup Slides

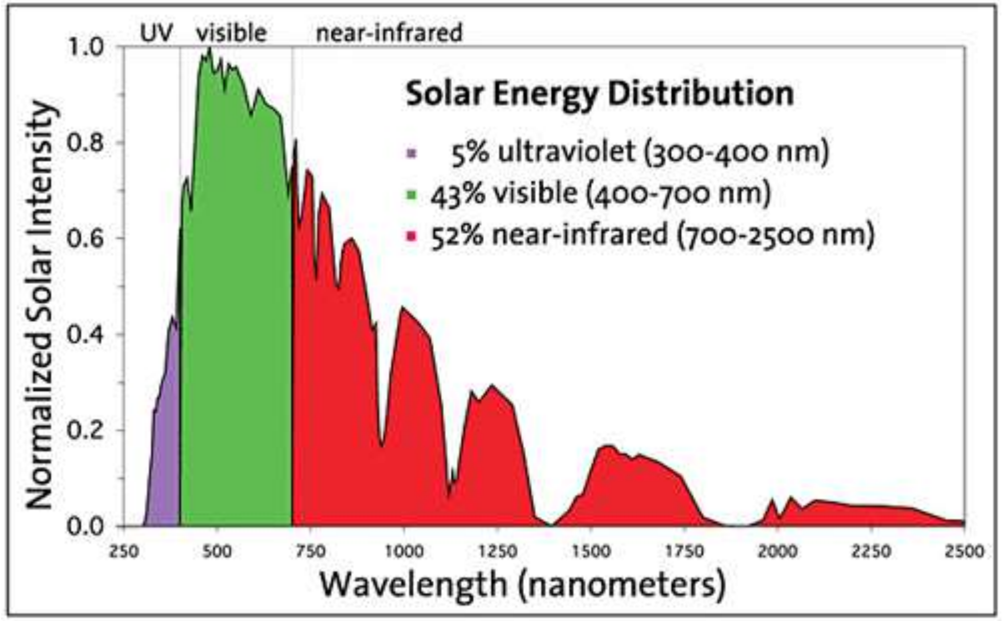
OSRAM SFH 2430 Sun Sensor

- Peak Wavelength: 570 nm
- Rise Time: 200 µs
- Fall Time: 200 µs
- Forward Current: 100 mA
- Power Dissipation: 150 mW

Backup Slides

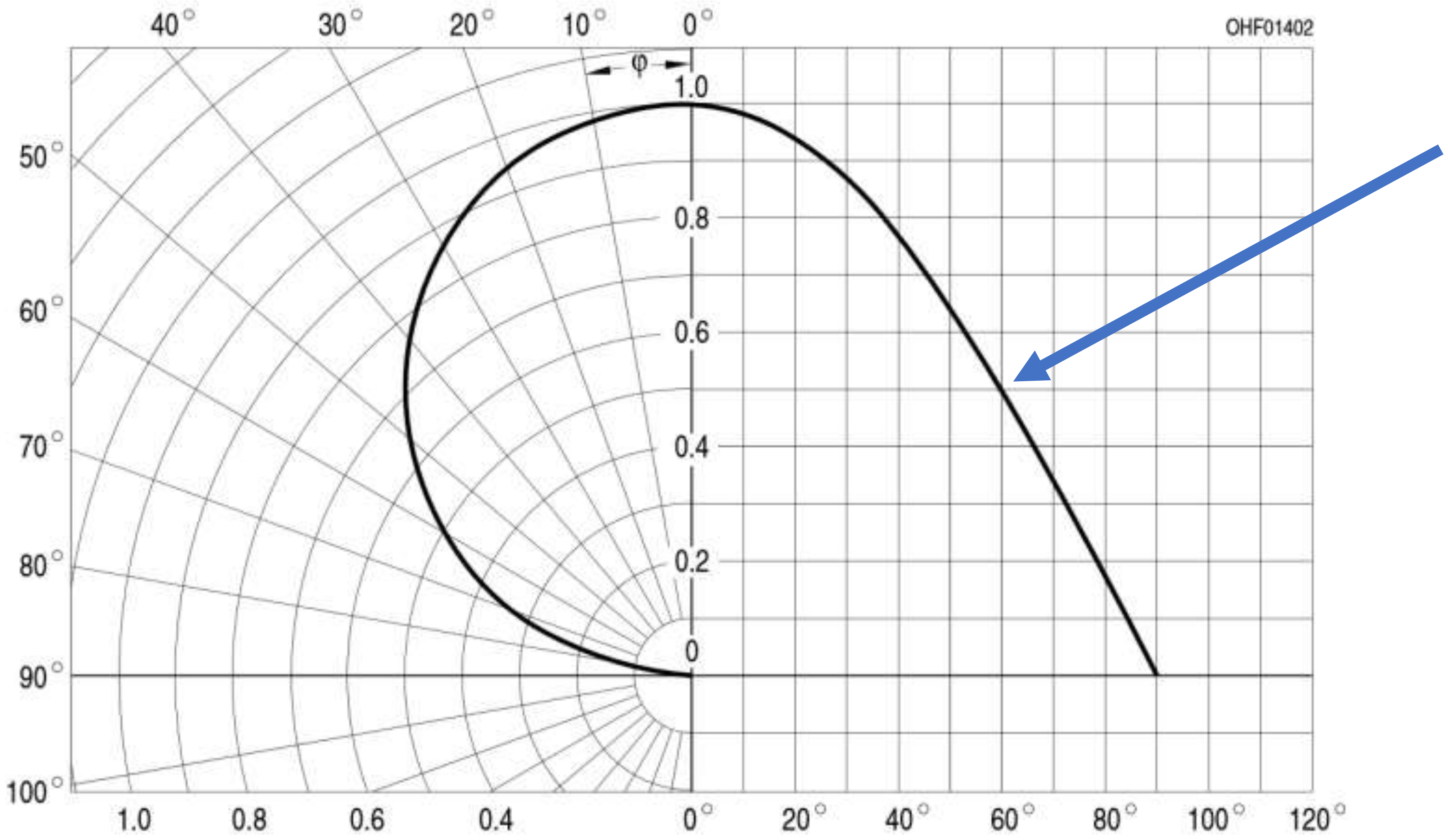
Sensor EM Spectrum vs. Solar EM Spectrum





[Backup Slides]

Directional Characteristics



- ½ angle ~ 60°
- Generally follows a cosine function until 60° angle

Backup Slides

Trade Studies

- Sun Sensor Table Weights

Criteria	Sub-Criteria	Percentages		Weights	
Time to Design	-	25%	-	0.25	-
Time to Make	-	25%	-	0.25	-
Reliability	-	20%	-	0.20	-
Ease of Use	-	20%	-	0.20	-
Cost	-	10%	-	0.10	-
		100%		1.00	

- Angular Position Sensor Weights

Criteria	Sub-Criteria	Percentages		Weights	
Accuracy	-	40%	-	0.40	-
Integration	-	25%	-	0.25	-
Life Cycle	-	5%	-	0.05	-
Ease of Use	-	10%	-	0.10	-
Cost	-	20%	-	0.20	-
		100%		1.00	

Trade Study Results

Summary Matrix		Manual		Semi-Manual		PC	
Criteria	Weight	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Time to Design	25%	5	1.25	3	0.75	2	0.50
Time to Make	25%	4	1.00	3	0.75	1	0.25
Reliability	20%	5	1.00	4	0.80	2	0.40
Ease of Use	20%	2	0.40	4	0.80	5	1.00
Cost	10%	5	0.50	3	0.30	2	0.20
TOTAL		-	4.15	-	3.40	-	2.35

Summary Matrix		Potentiometer		Optical Encoder	
Criteria	Weight	Raw Score	Weighted Score	Raw Score	Weighted Score
Accuracy	40%	4	1.60	4	1.60
Integration	25%	3	0.75	5	1.25
Life Cycle	5%	3	0.15	5	0.25
Ease of Use	10%	3	0.30	5	0.50
Cost	20%	5	1.00	3	0.60
TOTAL		-	3.80	-	4.20

Helmholtz Cage Test

Helmholtz Cage Testing Structure: Backup Calculations - Torque from Satellite

Turning Authority (Ta) = 0.1 Am2 = 0.1 J/T

Magnetic Field Strength (B) = 0.5 Gs = 5_E^{-5} T

Maximum Torqe = B * Ta = 5_E^{-6} Nm

Backup Slides

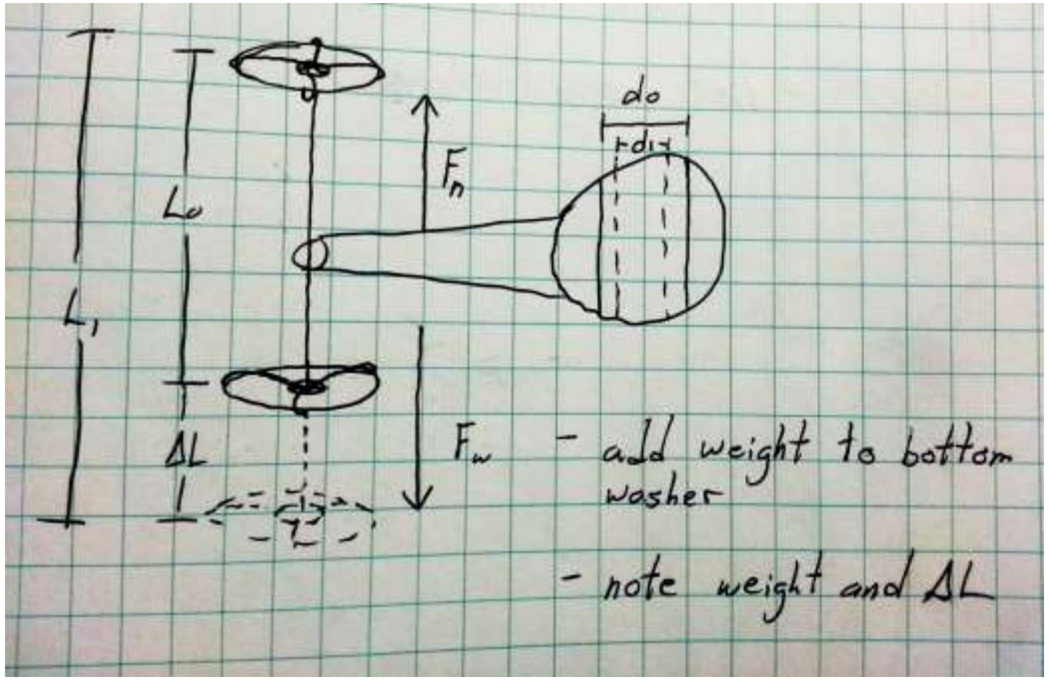
Helmholtz Cage Testing Structure: Backup Calculations - Modulus of Rigidity Test

L_0 = initial length of line
d = diameter of line
G = modulus of rigidity
E = modulus of elasticity
v = Poisson's Ratio
σ = Normal Stress
ε = Strain
F = load on line
A_{CS} = cross-sectional area of line

$\mathbf{E = \sigma / \varepsilon_y}$ $\mathbf{\sigma = F / A_{CS}}$ $\mathbf{\varepsilon_y = (L_1 - L_0) / L_0}$

$\mathbf{v = \varepsilon_x / \varepsilon_y}$ $\mathbf{\varepsilon_x = (D_1 - D_0) / D_0}$

$\mathbf{G = ½ * E * (1\text{-}v)^{-1}}$



[Backup Slides](#)

Helmholtz Cage Testing Structure: Backup Calculations - Modulus of Rigidity Test

		E test [mm]				E test [N]				V test [mm]			
Line Type	**Line Capacity**	L_0	L_1	L_2	L_3	F_0	F_1	F_2	F_3	d_0	d_1	d_2	d_3
Braided	**50 lbs**	**257**	**7.254**	**15.03**	**21.75**	**0**	**42**	**67**	**92**	**0.81**	**.608**	**.58**	**.569**
Braided	**27 lbs**	**225**	**47.52**	**15.28**	**21.28**	**0**	**30**	**42**	**57**	**.57**	**.46**	**.42**	**.41**
Steelon	**45 lbs**	**346**	**35.0**	**35.5**	**36.0**	**0**	**90**	**290**	**362**	**.682**	**.682**	**.673**	**.673**
Steelon	**20 lbs**	**253**	**5.00**	**9.76**	**12.02**	**0**	**15**	**76**	**126**	**.66**	**.51**	**.5**	**.5**
Nanofil	**17 lbs**	**316**	**32.2**	**32.6**	**33.2**	**0**	**14**	**43**	**76**	**.282**	**.29**	**.268**	**.263**

Backup Slides

Helmholtz Cage Testing Structure: Backup Calculations - Line Resistive Torque

$\boldsymbol{\tau_{Line}}$ **=** Resistive Torque from the line
$\boldsymbol{\tau_{Sat}}$ **=** Torque from satellite = 5E^{-6} Nm
L = length of line = 30 cm (half of the cage height)
J = polar moment of inertia
G = modulus of rigidity
θ = angular deflection = 360° (requirement from customer)
r = cross-sectional radius of the line

Alternative Calculation

$G_{max} = 2*L*\boldsymbol{\tau_{Sat}}*r^{-4}*\theta^{-1}*\pi^{-1}$

$= 0.5$ GPa

Compare to other materials

$G_{Aluminum}$ = 27 GPa

$G_{Polycarbonate}$ = 2.3 GPa

$G_{Polyethelene}$ = 0.12 GPa

Assume line has smaller G than polyethelene

Backup Slides

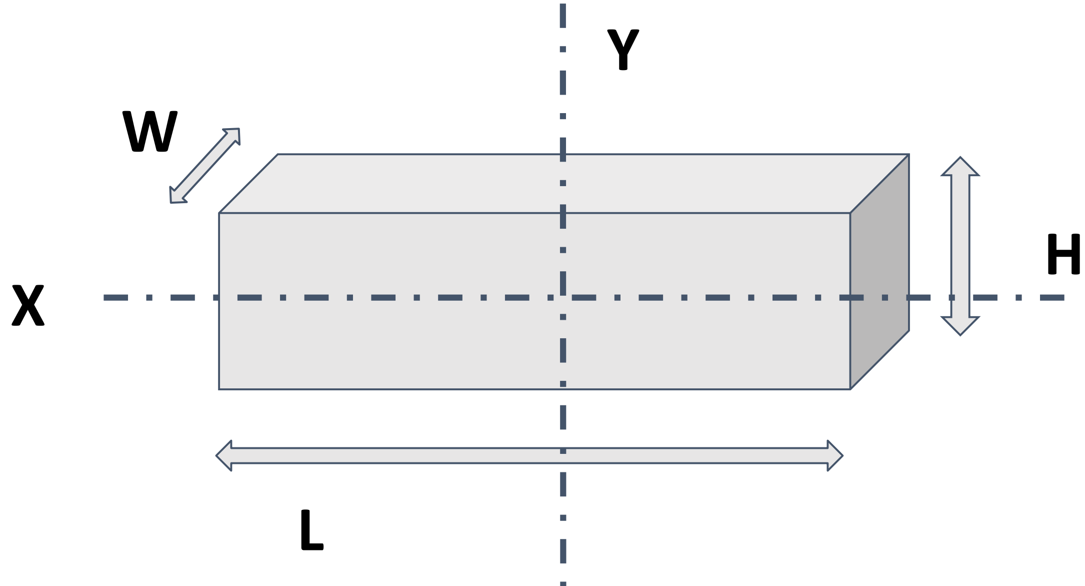
Helmholtz Cage Testing Structure: Backup Calculations - Satellite Acceleration

τ_{Sat} = Torque from satellite = 5E^{-6} Nm
I = mass moment of inertia about y axis
α = angular acceleration of satellite
ω = angular velocity of satellite
t = time satellite is accelerating
L = length of satellite = 30 cm
W = width of satellite = 10 cm
H = Height of satellite = 10 cm
m = mass of satellite = 3.6 kg
V = velocity of satellite edge

$$\tau_{Sat} = I * \alpha \longrightarrow \alpha = \tau_{Sat} / I$$

$$I = (m/12 * W^2_{outer} + m/3 * L^2_{outer}) - (m/12 * W^2_{inner} + m/3 * L^2_{inner})$$

$$V = \alpha * t * L * \tfrac{1}{2}$$



Backup Slides

Helmholtz Cage Testing Structure: Backup Calculations - Moment From Drag

D = Drag Force
C_D = Drag Coefficient of flat plate = 1.05 to 2.05
- assumed to be 2.05 to be conservative

ρ = density = 1.05 kg/m-3
- assumed to be standard atmosphere at 1500 m (5000 ft)

V = velocity of outermost satellite edge
A = Area of satellite side
M_D = Moment caused by Drag

$D = ½ * \rho * V^2 * C_D * A$

- V and A vary from the center to the edge of the satellite

$M_D = \rho * \alpha^2 * t^2 * h * L^4 * C_D / (64)$

- Drag was integrated over half of the satellite length

Backup Slides

Helmholtz Cage Testing Structure: Backup Calculations - Moment From Drag

D = Drag Force
C_D = Drag Coefficient of flat plate = 1.05 to 2.05

- assumed to be 2.05 to be conservative

ρ = density = 1.05 kg/m-3

- assumed to be standard atmosphere at 1500 m (5000 ft)

V = velocity of outermost satellite edge
A = Area of satellite side
M_D = Moment caused by Drag

$D = ½ * \rho * V^2 * C_D * A$

- V and A vary from the center to the edge of the satellite

$F_{equivalent} = D * L / 4$

- Drag approximated by distributed load

$d = ⅔ * r$

$M_D = 2 * F_{equivalent} * d$

Backup Slides

Helmholtz Cage Testing Structure: Backup Calculations - Moment From Drag

$D = \frac{1}{2} * \rho * V^2 * C_D * A$

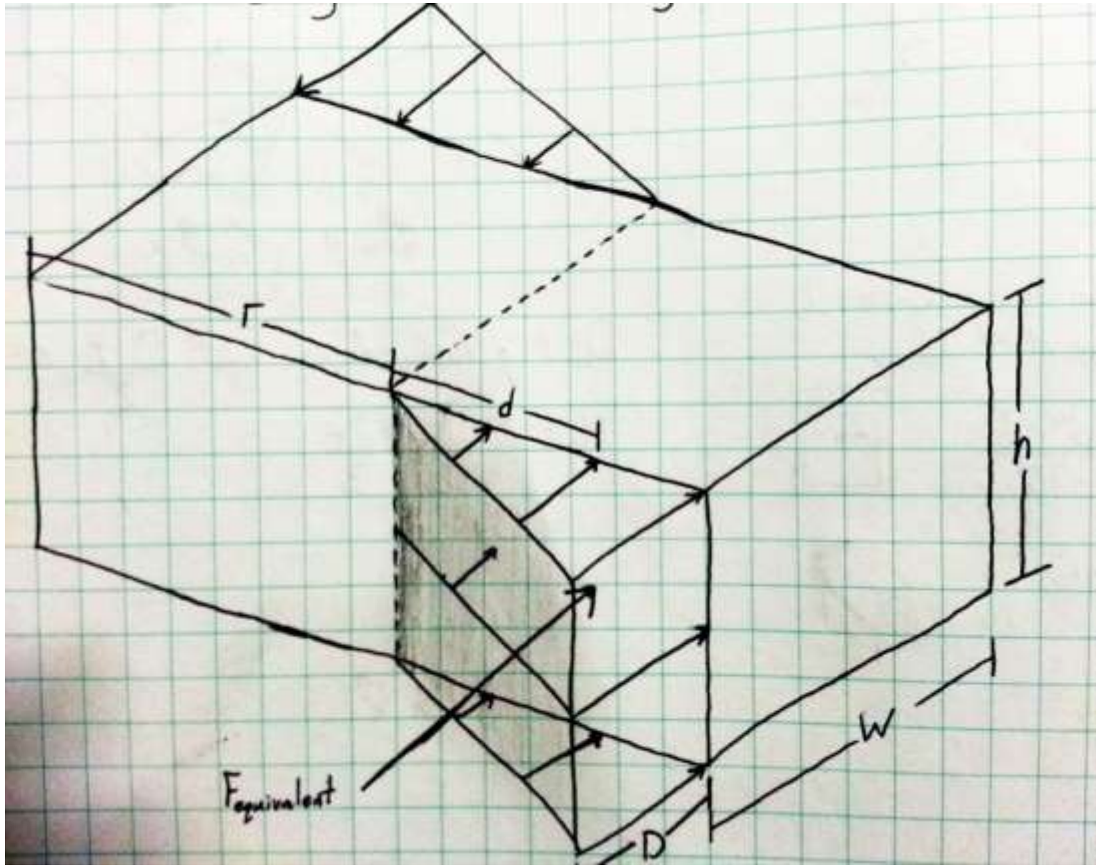
- V and A vary from the center to the edge of the satellite

$F_{equivalent} = D * L / 4$

- Drag approximated by distributed load

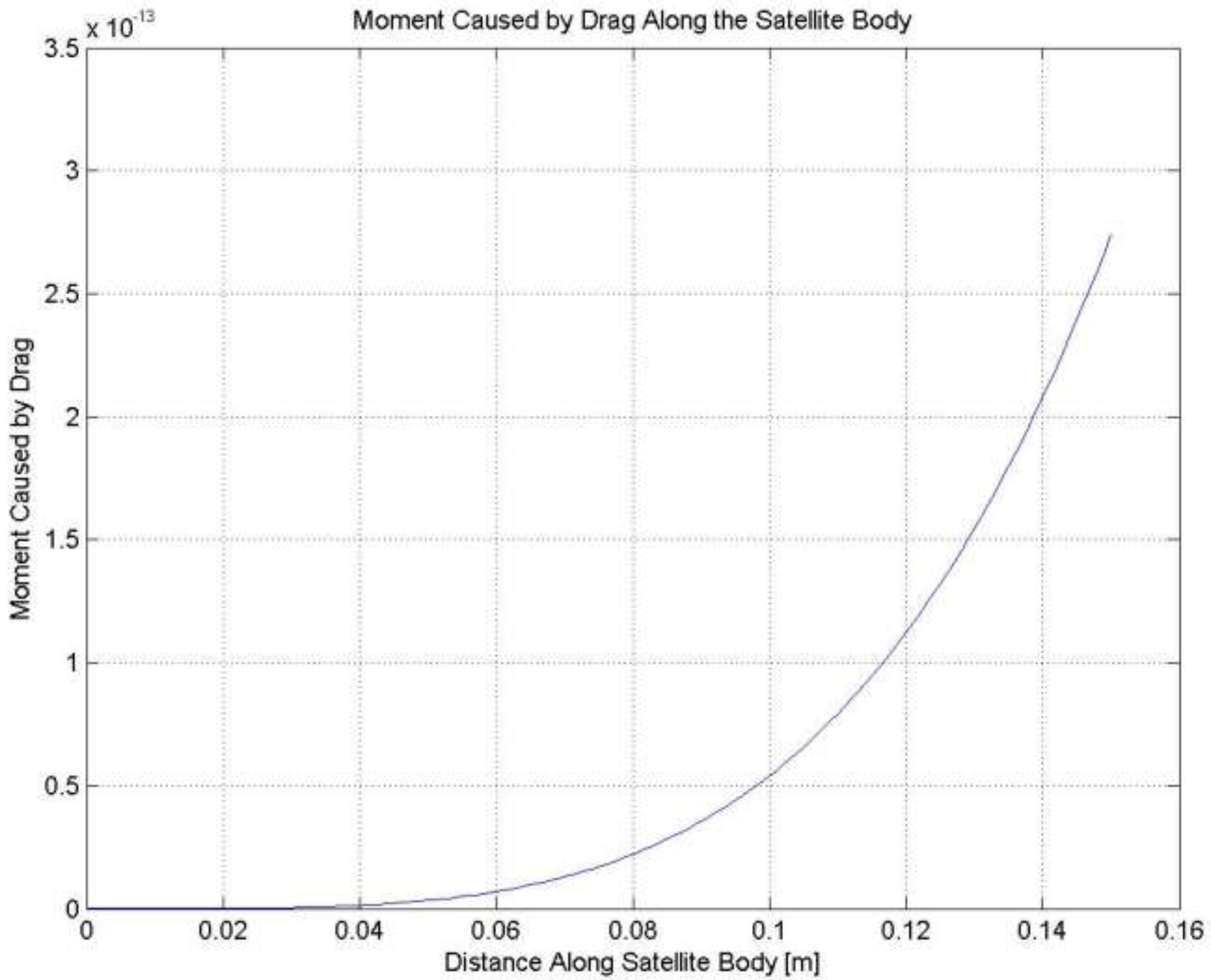
$d = \frac{2}{3} * r$

$M_D = 2 * F_{equivalent} * d$



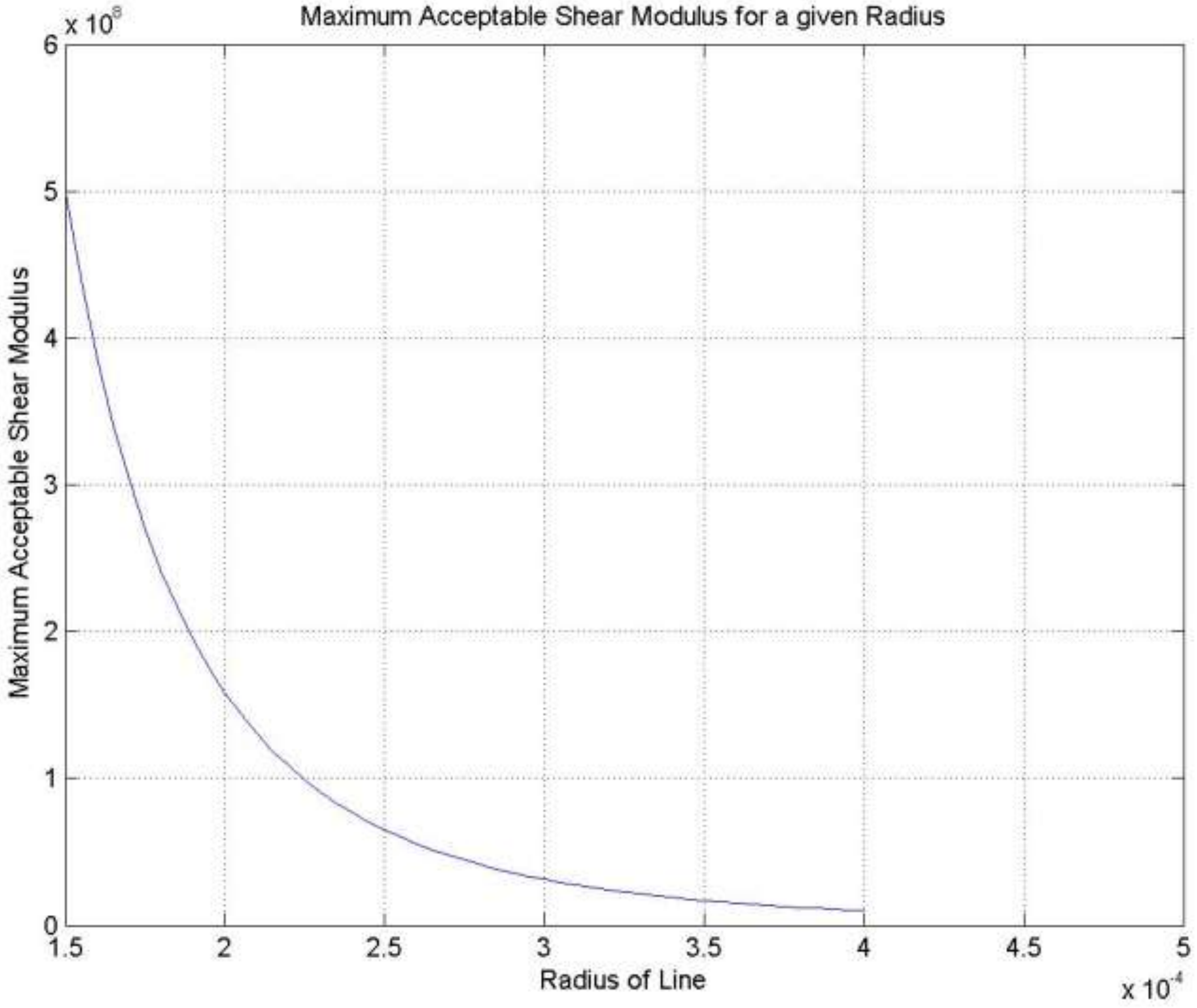
Backup Slides

Helmholtz Cage Testing Structure: Backup Calculations - Moment From Drag



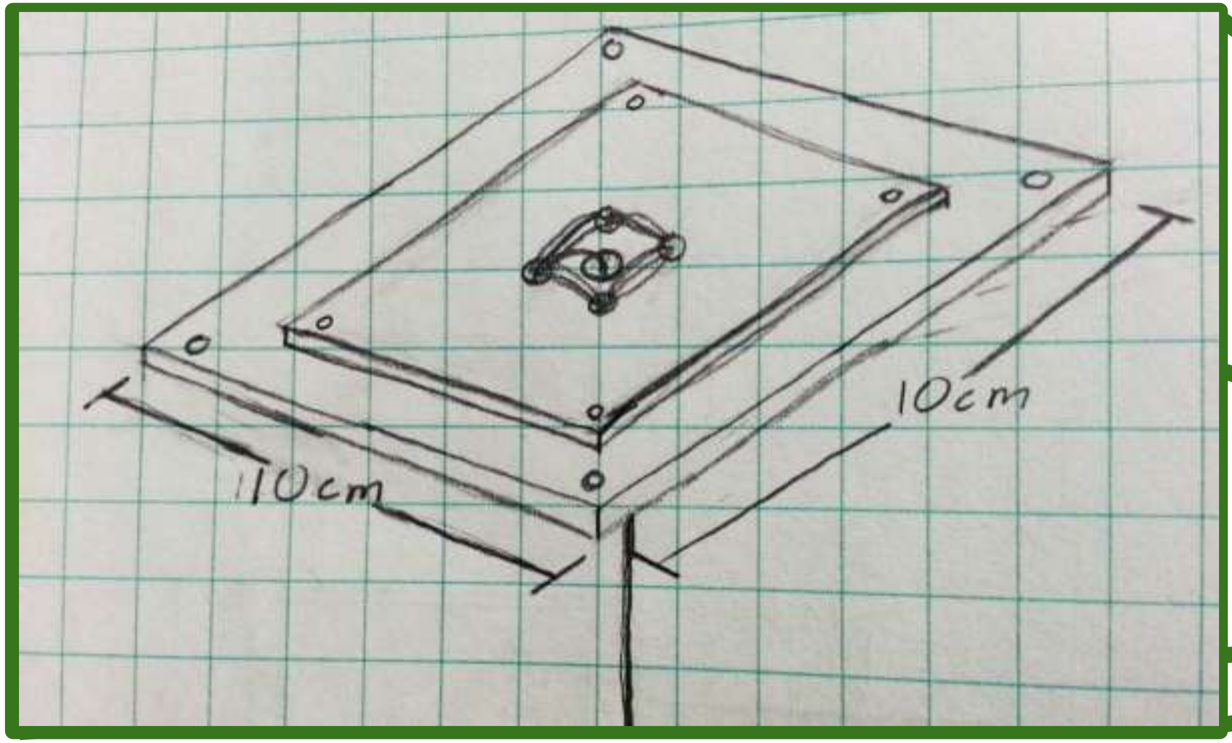
[Backup Slides]

Helmholtz Cage Testing Structure: Backup Calculations - Allowable Shear Modulus

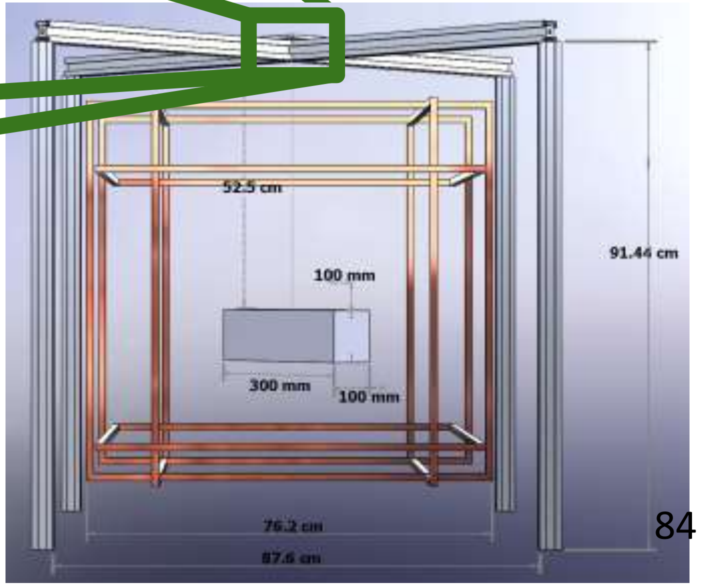


Backup Slides

Helmholtz Cage Testing Structure: Backup - Attachment



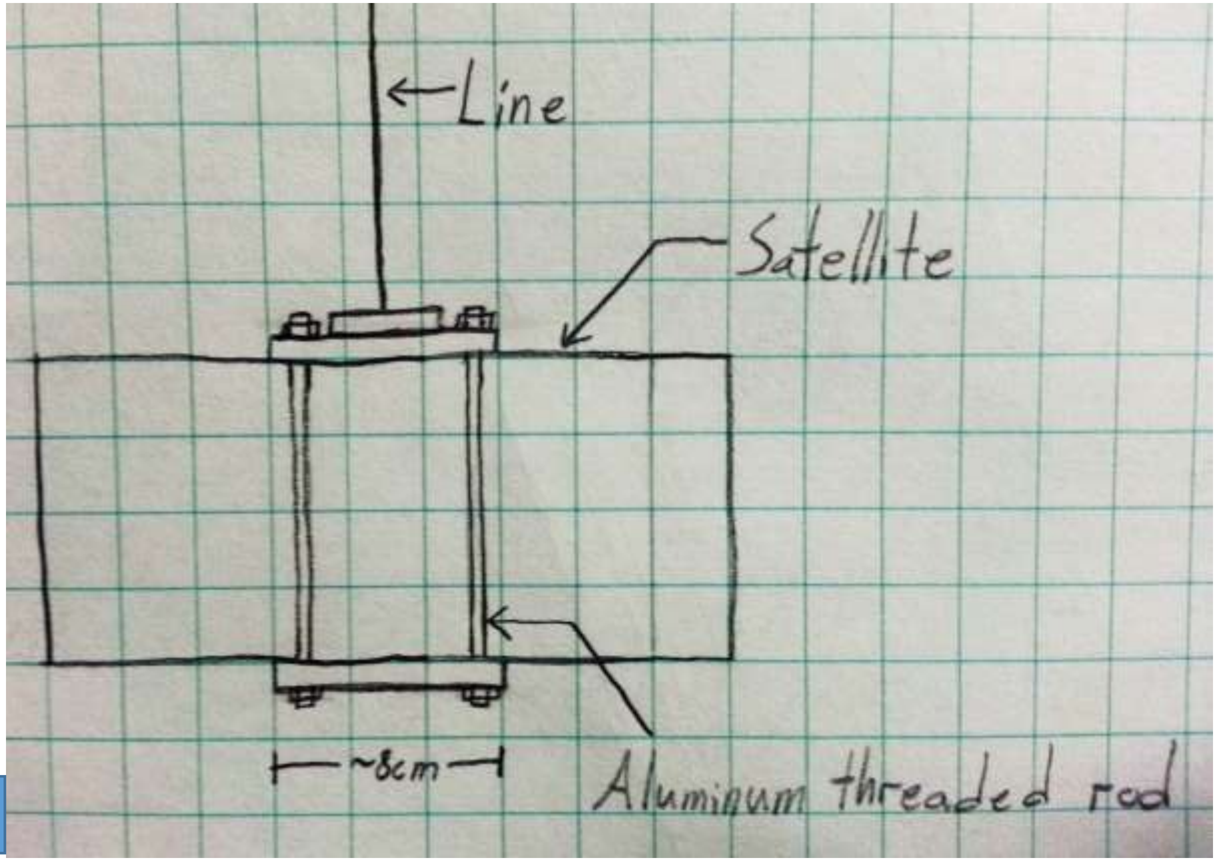
Top Attachment Mechanism

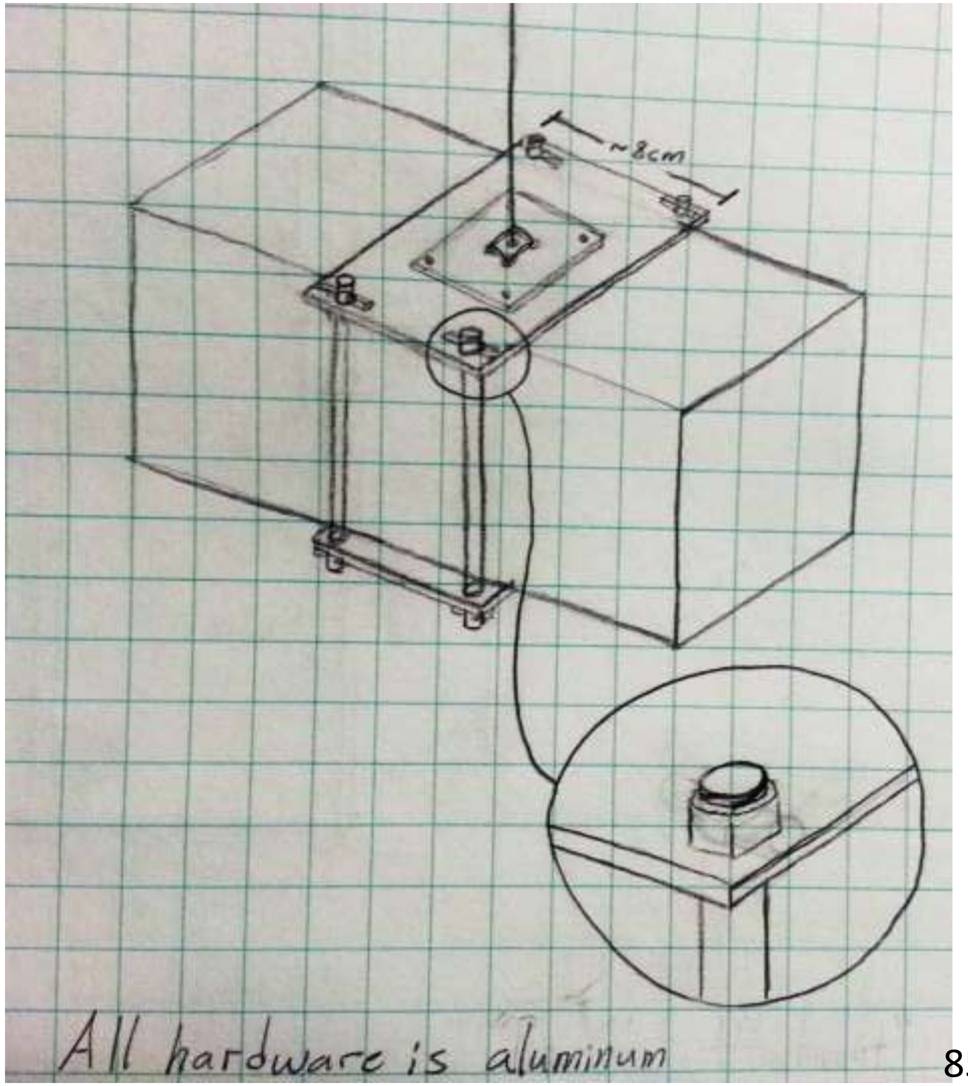


Backup Slides

Helmholtz Cage Testing Structure: Backup - Attachment

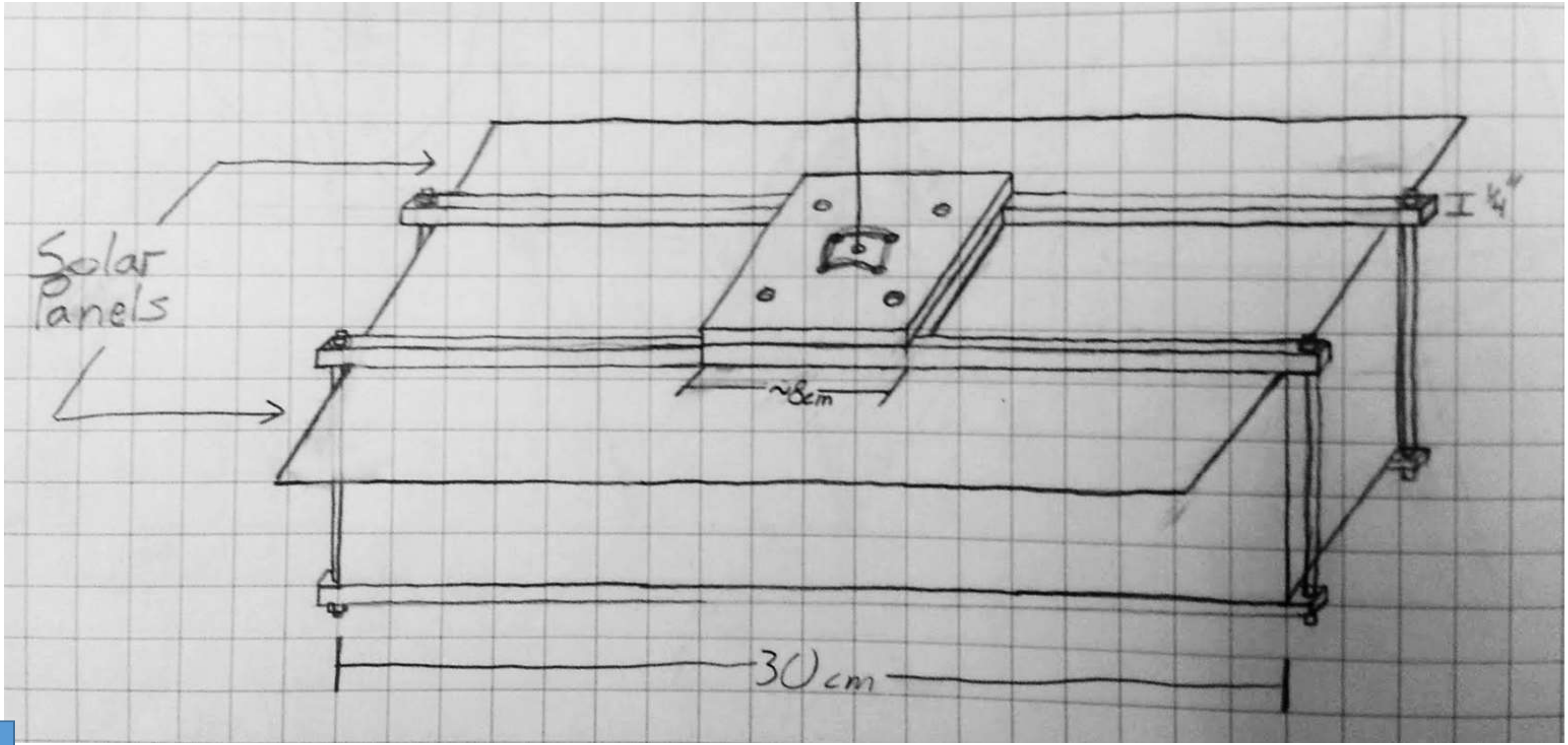
Satellite Attachment Mechanism 1





Backup Slides

Helmholtz Cage Testing Structure: Backup - Attachment



Satellite Attachment Mechanism 2

Backup Slides

Trade Study Weights and Results

Criteria	Sub-Criteria	Percentages		Ratios	
Resistance	-	30%	-	0.30	-
Time to Design	-	10%	-	0.10	-
Time to Make	-	20%	-	0.20	-
Additional Components	-	15%	-	0.15	-
Ease of Use	-	15%	-	0.15	-
Cost	-	10%	-	0.10	-
		100%		1.00	

Summary Matrix		Magnetic Levitation		Mechanical Bearing		Hanging		Air Bearing	
Criteria	Weight	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Resistance	30%	5	1.50	3	0.90	4	1.20	3	0.90
Time to Design	10%	2	0.20	4	0.40	3	0.30	2	0.20
Time to Make	20%	3	0.60	4	0.80	4	0.80	2	0.40
Additional Components	15%	3	0.45	5	0.75	4	0.60	2	0.30
Ease of Use	15%	4	0.60	5	0.75	2	0.30	3	0.45
Cost	10%	3	0.30	3	0.30	5	0.50	2	0.20
TOTAL		-	3.65	-	3.90	-	3.70	-	2.45

Logistics

Detailed Preliminary Budget

System	Item	Quantity	Item Cost	Total
Interface Board	Master Microcontroller	1x5	$3.94	$19.70
	Slave Microcontroller	22x5	$1.18	$129.80
	USB to UART	1x5	$4.50	$22.50
	Current Sensor	2x5	$4.82	$48.20
	Linear Voltage Regulator	2x5	$0.51	$5.10
	PCB (2-layer)	2x5	$33.00	$330.00
			TOTAL:	**$555.30**
Helmholtz Cage Hang	Extruded Aluminum	22ft.	$12.00/ft.	$264.00
	¼" Aluminum Plate	4sq.ft.	$37.80/sq.ft.	$151.20
	Line	20in.	$0.0023/ft.	$20.00
	Fasteners			$100.00
			TOTAL:	**$535.20**

System	Item	Quantity	Item Cost	Total
Sun Sensor Calibration	Aluminum	1	$100.00	$100.00
	Ball Bearing	1	$30.00	$30.00
	Rotary Magnetic Encoder	1	$80.00	$80.00
	DC Motor	1	$70.00	$70.00
	Analog to Digital Converter	1	$30.00	$30.00
	LCD Display	1	$30.00	$30.00
	Anodized Coating	1	$300.00	$300.00
			TOTAL:	**$640.00**
Extra Elements	Project Poster	2	$43.00	$86.00
	Miscellaneous		$200.00	$200.00
			TOTAL:	**$286.00**

Backup Slides