Test Readiness Review

SPECTROM

Scientific Platform for the Exact Control of Thermally Regulated Optical Mechanisms

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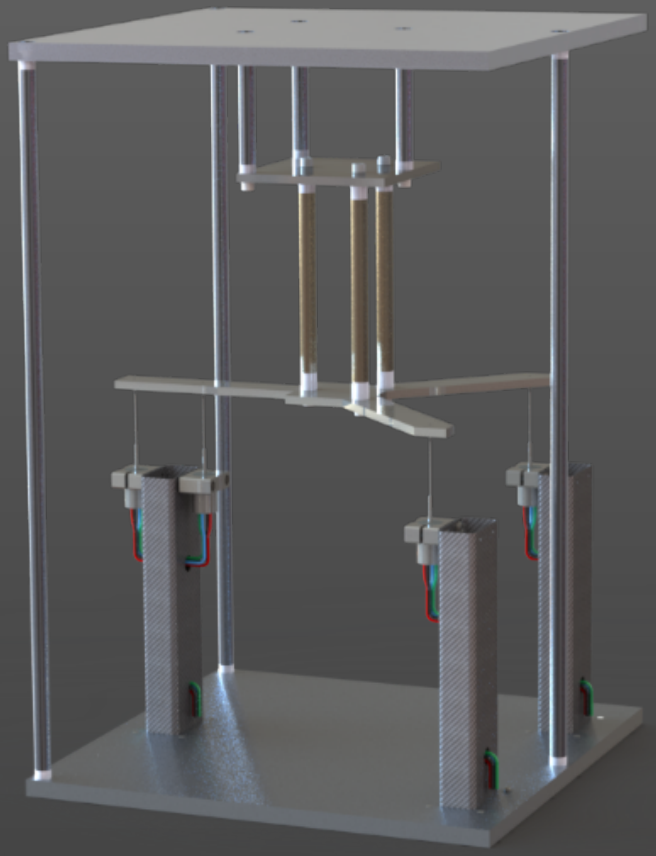
Joe Lopez

Advisor: Bob Marshall

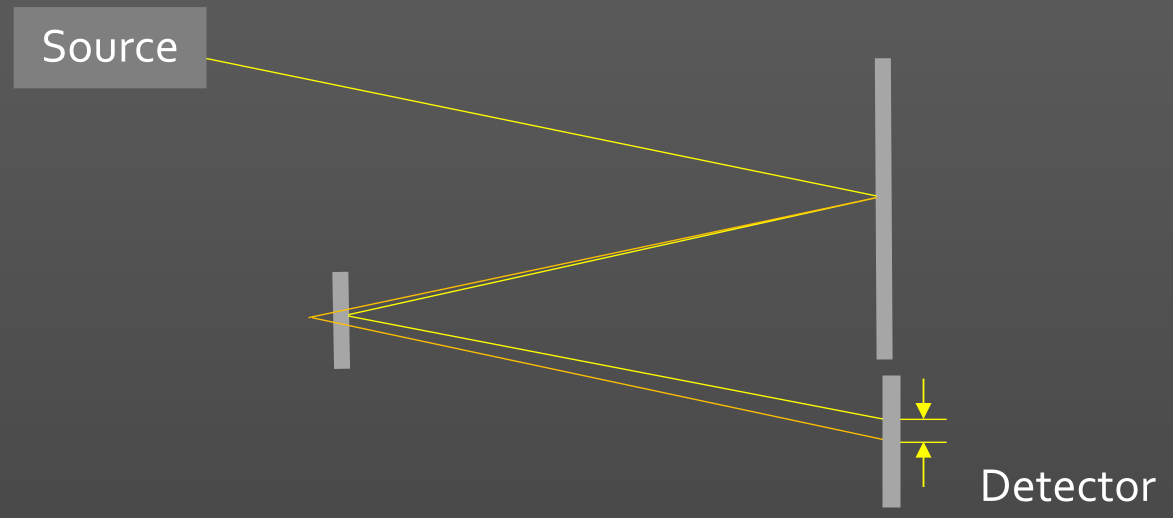
Agenda

- Project Overview
- Schedule
- Test Readiness
  - Electronics Subsystem Tests
  - Software Subsystem Tests
  - Integrated System Tests
- Budget



Project Purpose

- Maintaining precise alignment of optical instrumentation

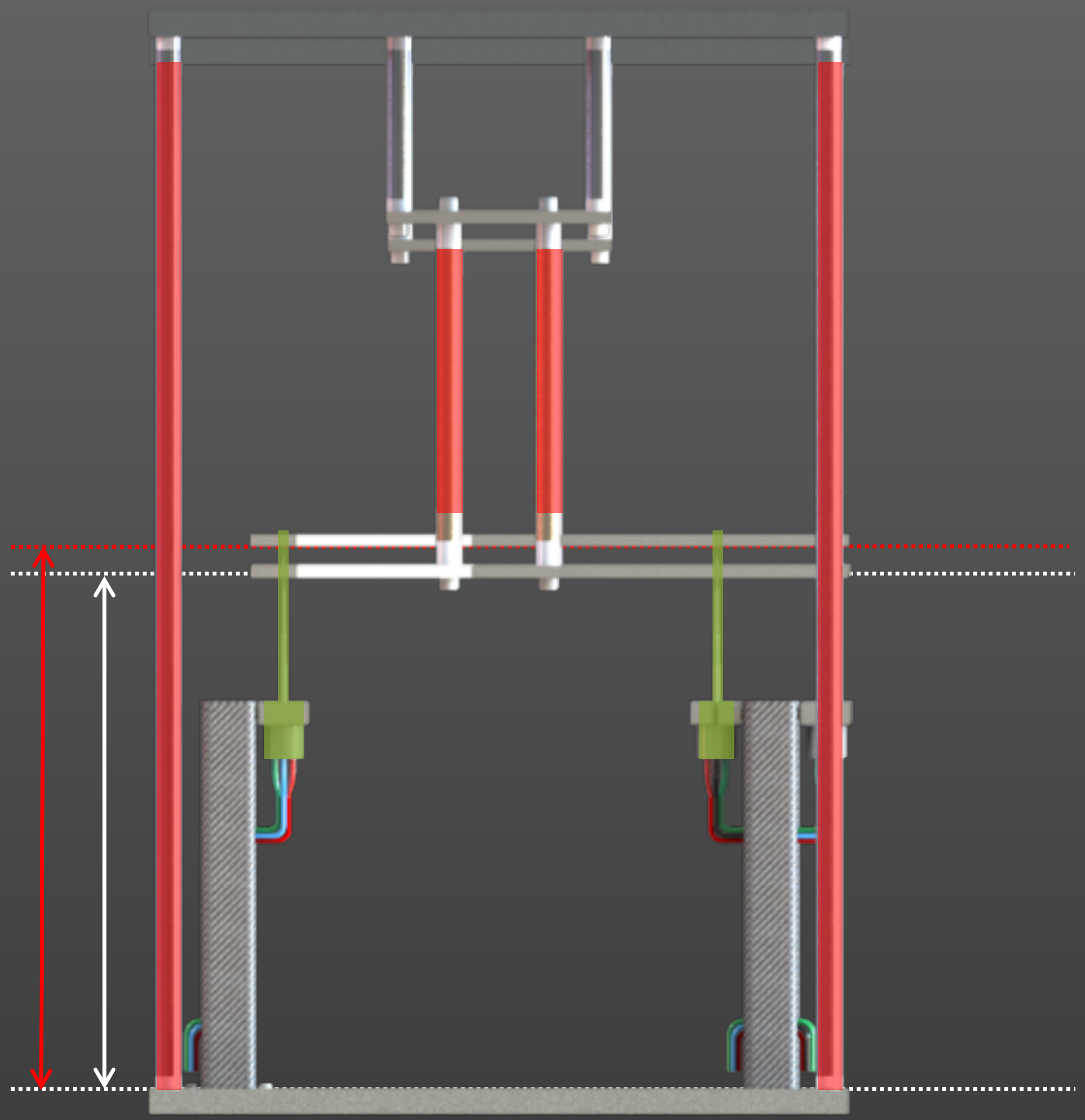


- Optical bench costly carbon fiber composites
- Reduce cost by using aluminum frame
- Thermal expansion for active control mechanism

Project Statement

Design, integrate, and verify precision, of an **active control system** that utilizes **thermal expansion** to adjust the **alignment** of spacecraft optical instrumentation. This system will correct for misalignment introduced by thermal expansion of an **aluminum optical bench**.

Concept of Operations



1. The test bed is heated to induce alignment error between two planes.

2. Alignment error is measured by the Alignment Measurement System (AMS).

3. Heating is applied to the Alignment Correction System (ACS) to maintain alignment of the two planes.

4. Displacement and temperature data are recorded and stored by the electronics package.

Critical Project Elements

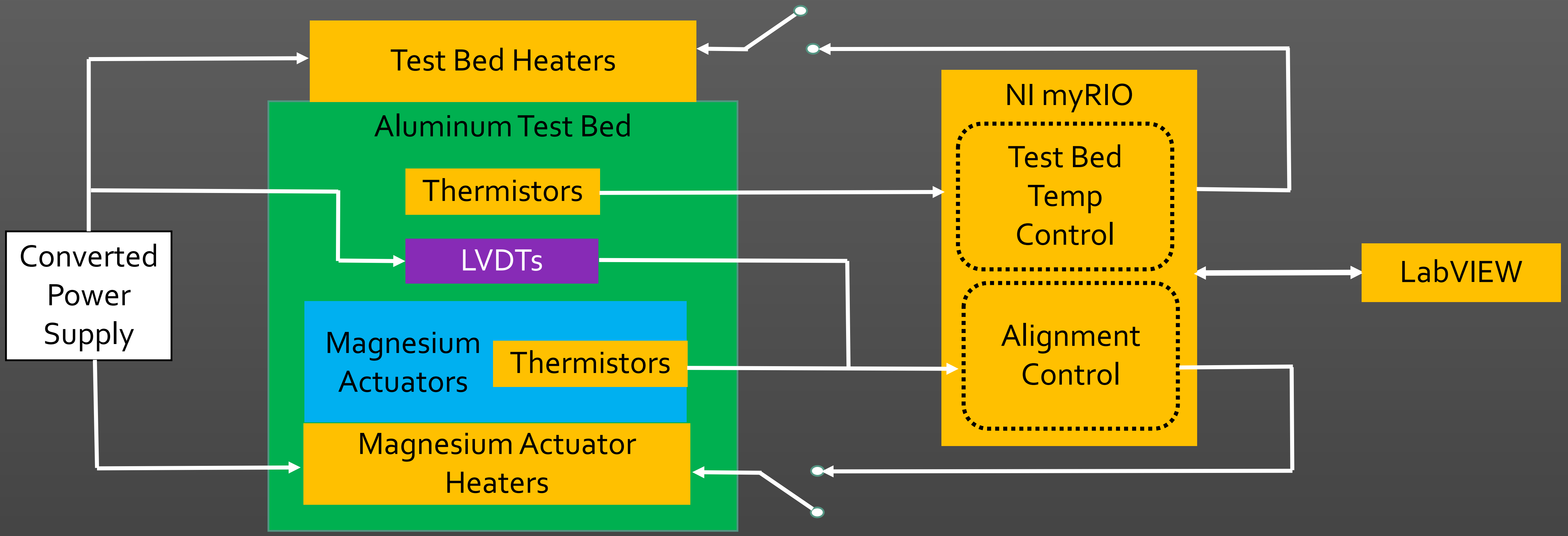
Critical Project Elements	System Solution
Active control of plane alignment using expansion of a high CTE material	Alignment Correction System (ACS)
Accurate measurement of plane alignment in three-axes	Alignment Measurement System (AMS)
Introduction of controlled thermally induced alignment error	Test Bed
Thermal control and measurement of heated elements	Electronics Package

Levels of Success

	Test Demonstration Unit (TDU)	Alignment Correction System (ACS)	Alignment Measurement System (AMS)	Electronics Package
Level 1	• Induce > 100μm of plane alignment translation error over ΔT=10K	• Correct plane alignment to within ±2 μm of original position within 120 seconds	• Measure translation displacement of two planes with 1.75 μm accuracy	• Heater control to enable translation correction within ±2 μm
Level 2	• Induce customer-provided temperature profile to within 0.5 K at all times • Know temperature of actuators to within ±0.2 K at all times	• Maintain plane alignment within ±2μm for 95% of the test bed heating profile		• Active temperature control using thermistor feedback • Record time, position and temperature data for duration of testing
Level 3	• Induce > 50 μm rotational displacement over ΔT of 10 K starting from 296.15 K	• Maintain plane alignment within ±2 μm and ±20 μrad for 95% of the test bed heating profile	• Measure translation and rotation displacements to ±1.75 μm and ±15.3 μrad accuracy	• Record, and display real-time position and temperature data at a rate of at least 1 measurement per second

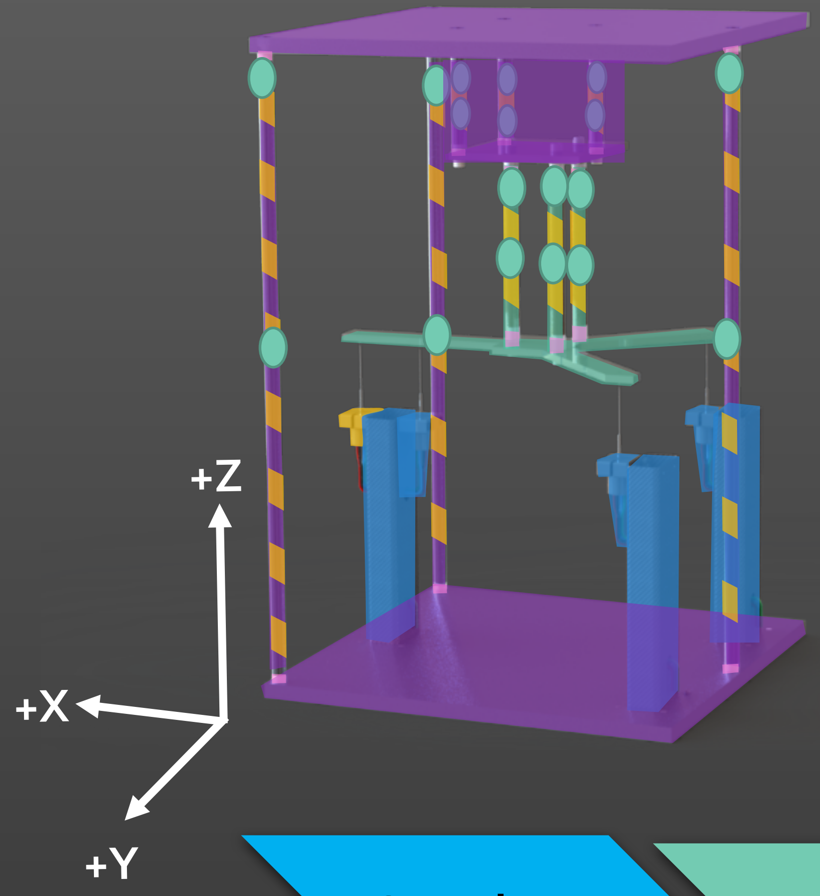
Functional Block Diagram

AMS | ACS | Test Bed | Electronics



Design Overview

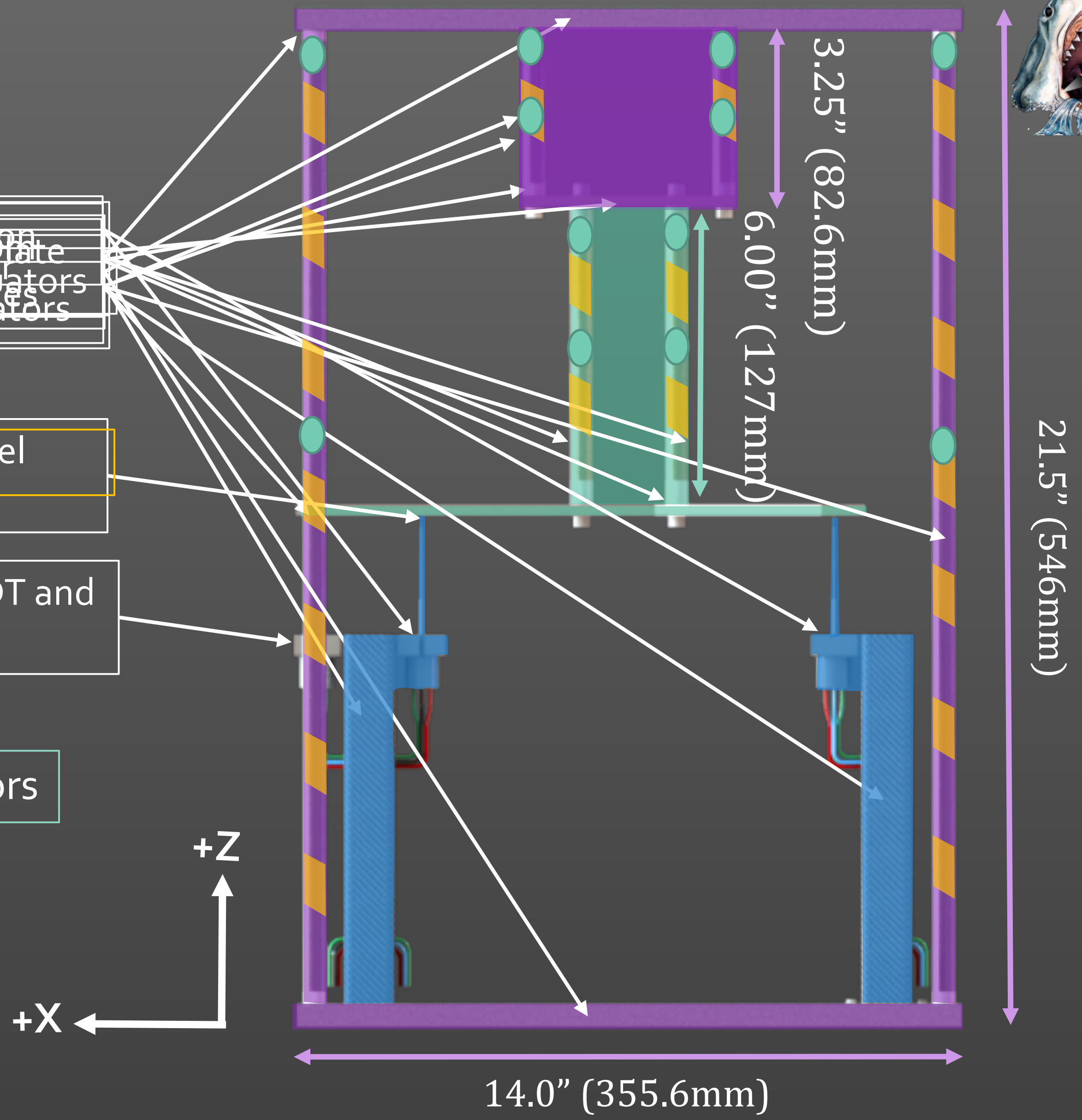
Alignment
Test Bed
Measurement System
Correction System



Stainless Steel
Heaters
"Exocore"

Verification LVDT and Support

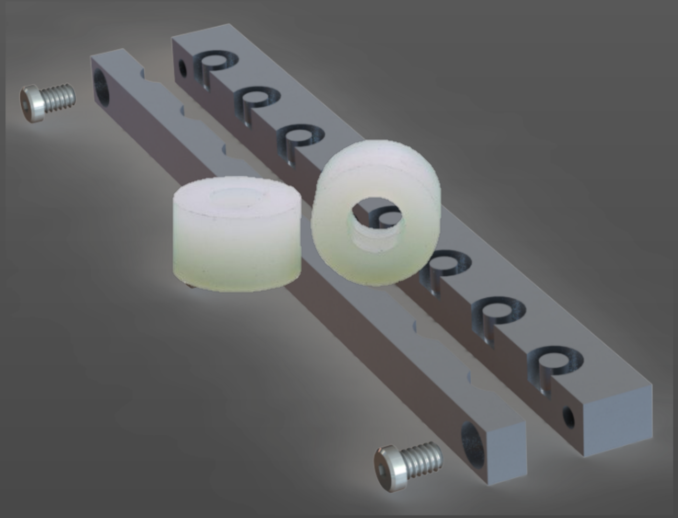
Temp Sensors



Overview | Schedule | Test Readiness | Budget

Critical Issues and Updates Since MSR

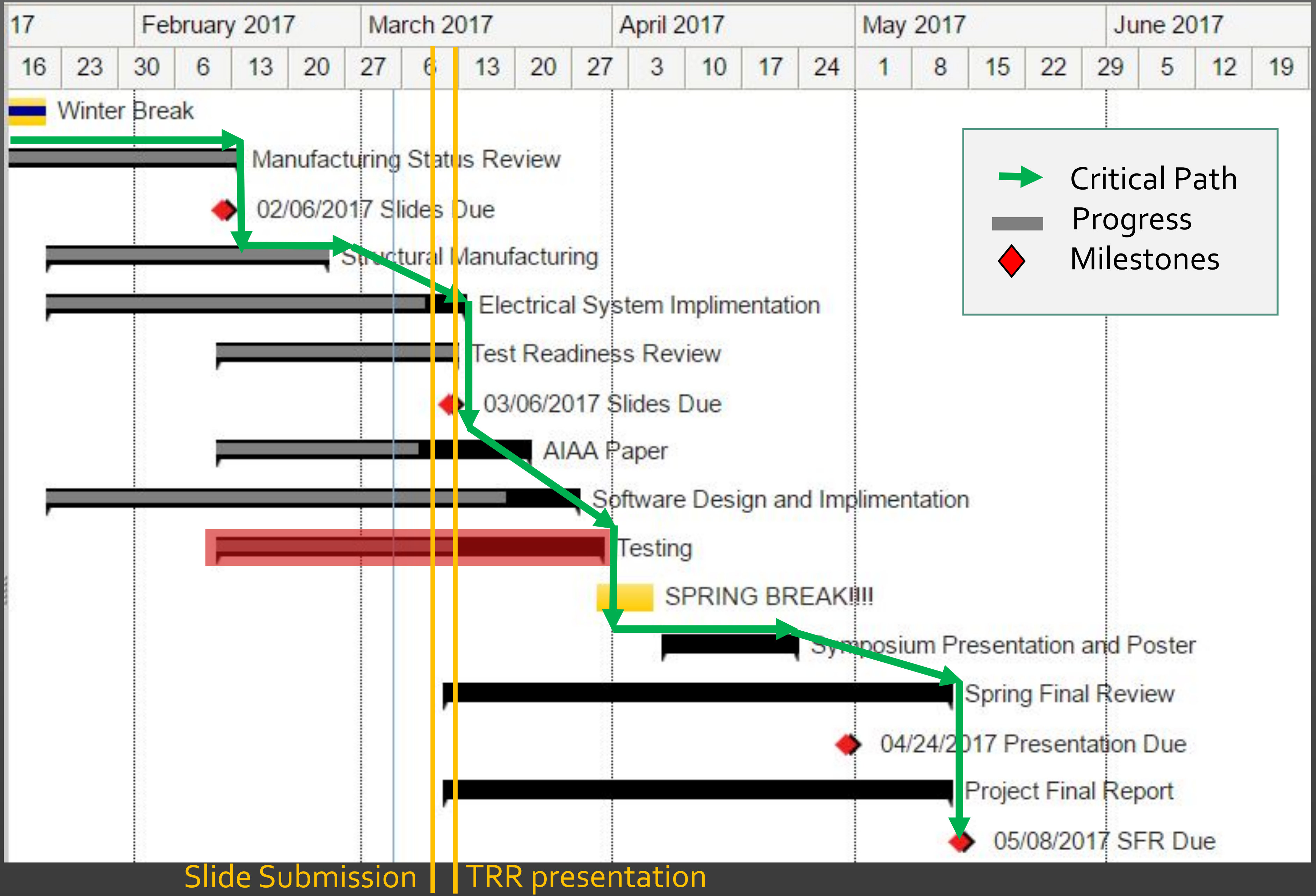
- Updates:
  - Nylon spacers vs manufacture epoxy washers
  - Structure entirely manufactured
  - LVDT signal conditioning circuit design changes
  - Schedule changes



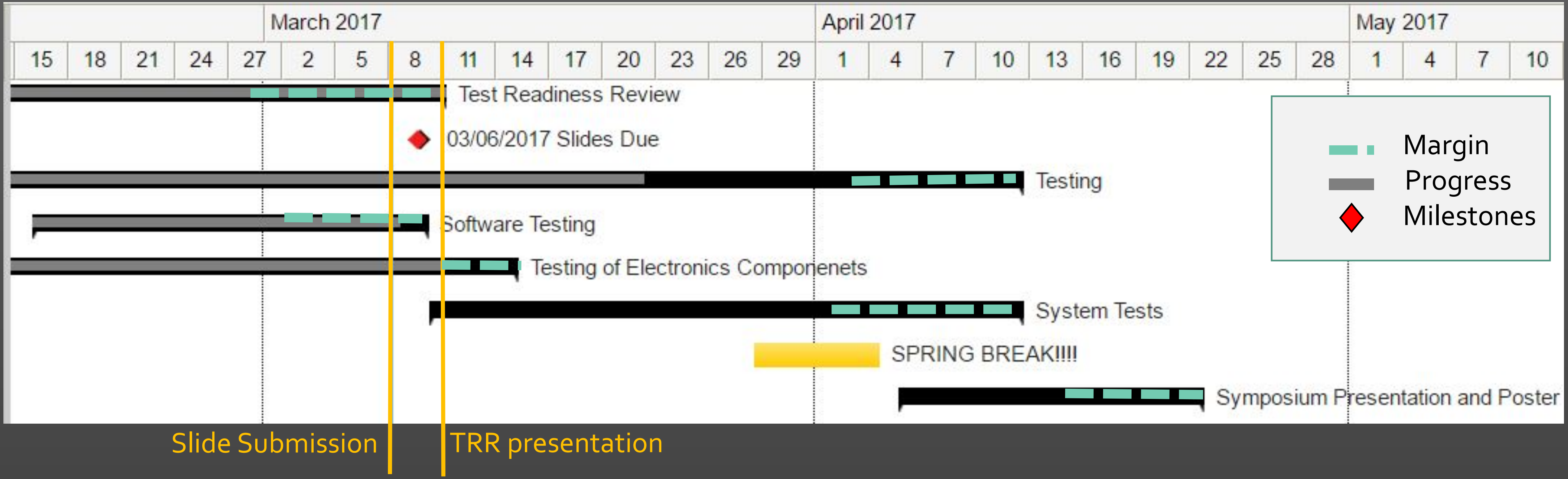
- Critical Issues
  - LVDT calibration testing is behind schedule
  - Software behind schedule

Schedule

Overview


17
February 2017
March 2017
April 2017
May 2017
June 2017
16 23 30 6 13 20 27 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19
Winter Break
Manufacturing Status Review
02/06/2017 Slides Due
Structural Manufacturing
Electrical System Implimentation
Test Readiness Review
03/06/2017 Slides Due
AIAA Paper
Software Design and Implimentation
Testing
SPRING BREAK!!!!
Symposium Presentation and Poster
Spring Final Review
04/24/2017 Presentation Due
Project Final Report
05/08/2017 SFR Due
Critical Path
Progress
Milestones
Slide Submission
TRR presentation

Testing Schedule



Test Readiness

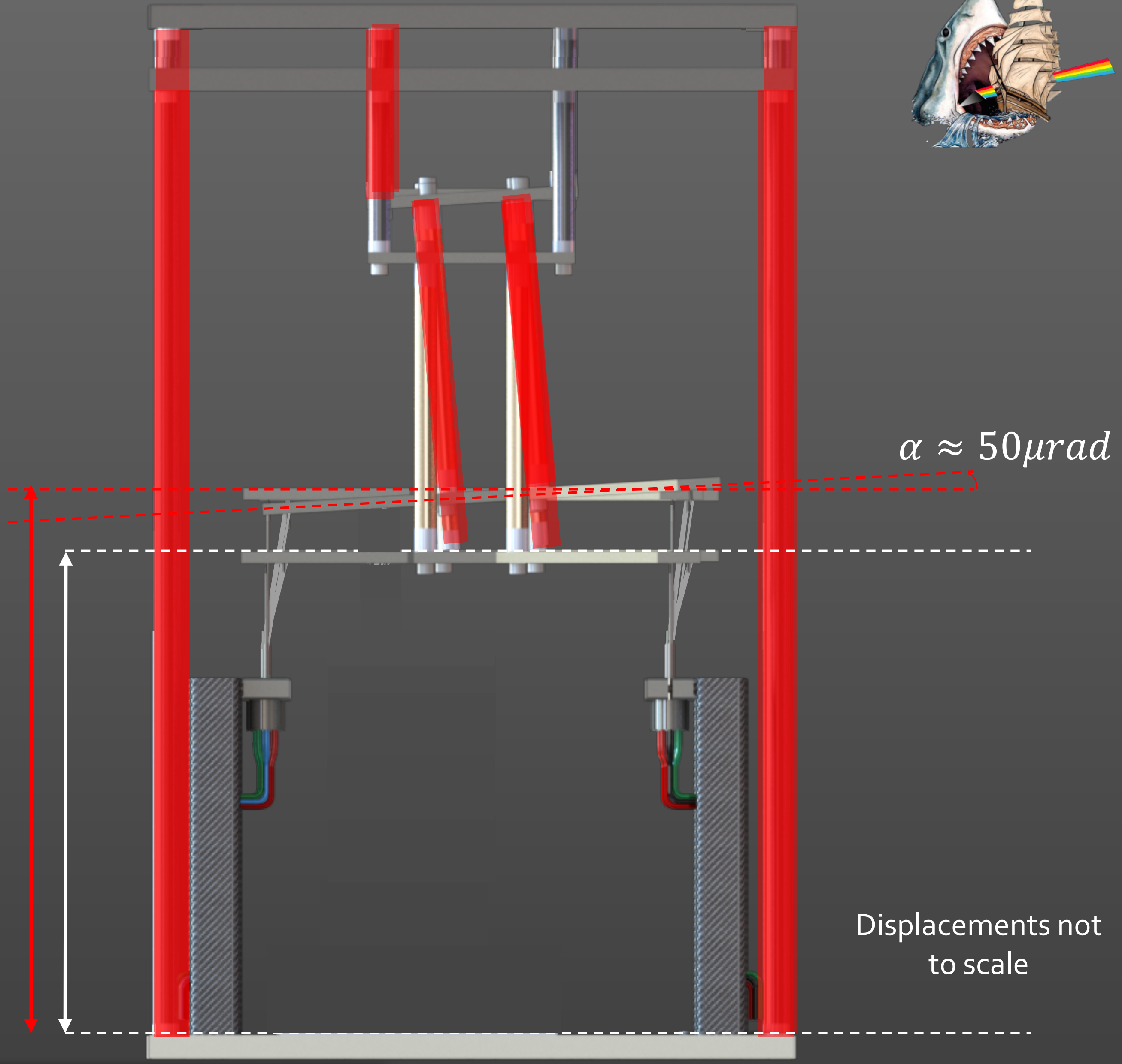
Static Zeroing Test

Conops:

1. Heating is applied to the test bed to induce translation and rotation alignment error

2. ACS heaters apply ΔT to correct rotational misalignment

3. ACS heaters apply ΔT to correct for translation errors

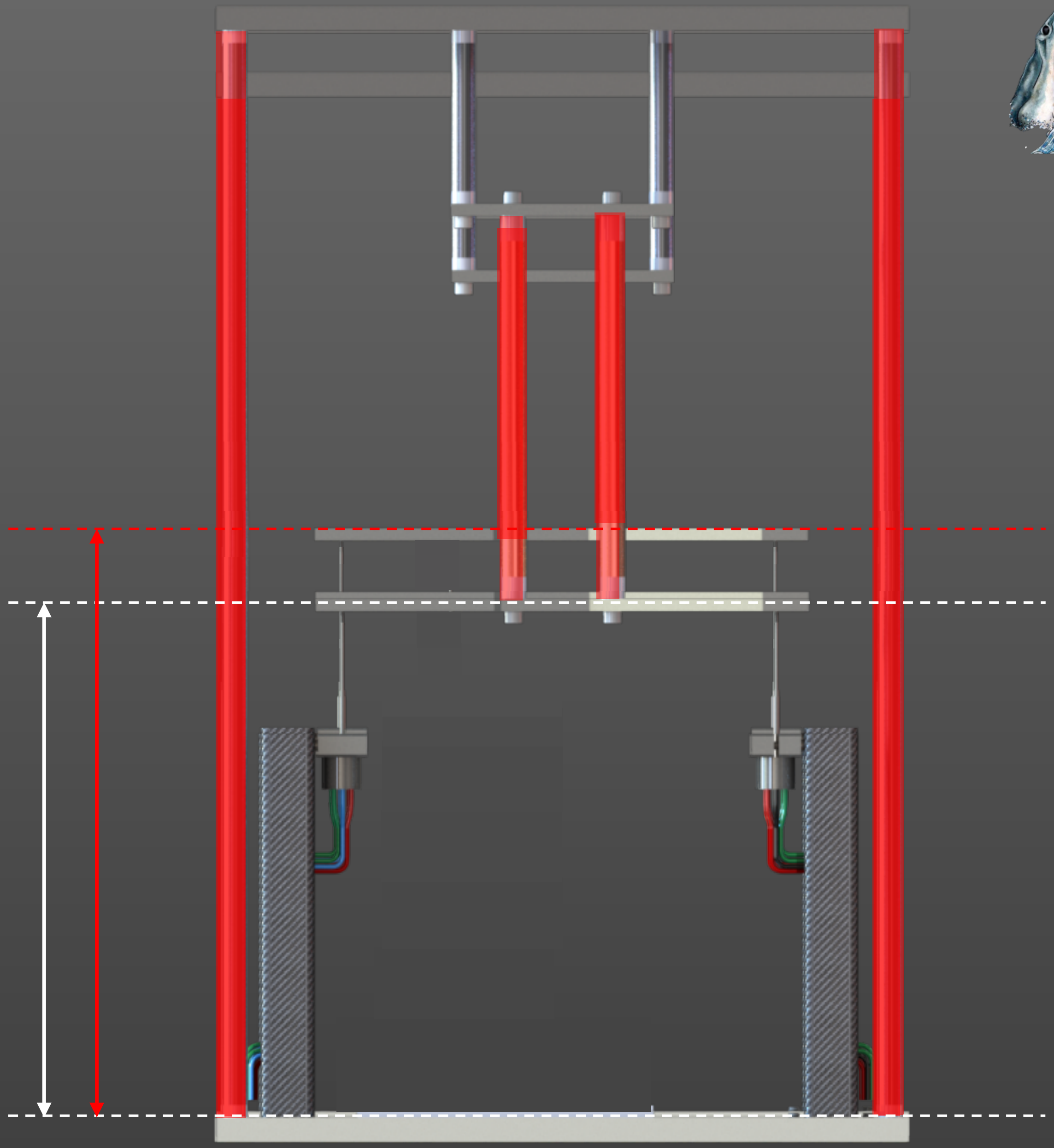


Dynamic Test

Conops:

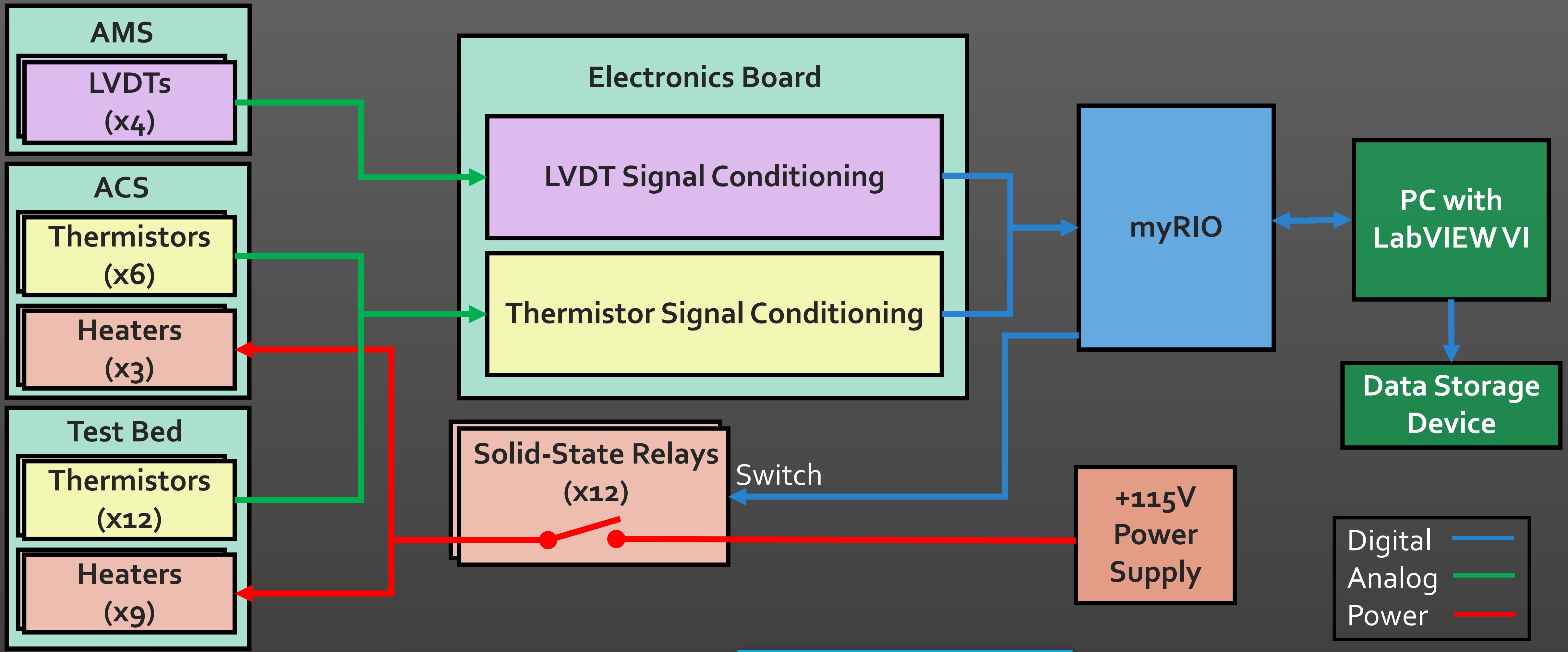
1. Test bed heaters apply ΔT to induce specified temperature profile

2. ACS heaters apply ΔT in order to actively correct for displacement error



Electrical Subsystem Tests

Electronics Package CONOPS

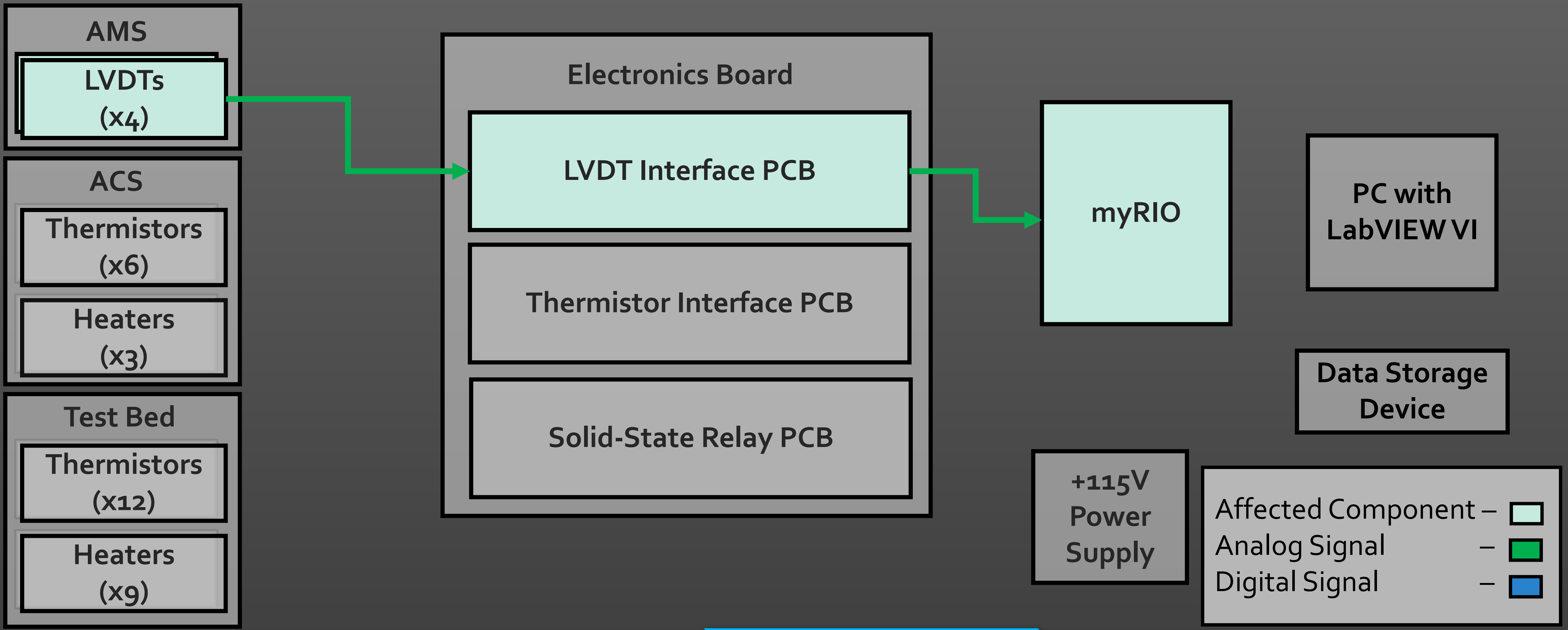


Electrical Test Scope

3 Critical Components Interfaces to Test: Thermistors, LVDTs, Heaters

Test Performed	Components Effected	Purpose	Status
LVDT-PCB Interface	LVDT PCB	Correct gain output	Complete
Thermistor Calibration	Thermistors	Calibrate thermistors to characterize resistance	Complete
Thermistor-PCB Interface	Thermistors, Therm PCB	Multiplexing verification	Complete
Heater-myRIO Interface	Heaters, Heater PCB, myRIO	myRIO switching capabilities	Complete
LVDT Sensitivity	LVDT	Verify manufacturer datasheet sensitivity	Incomplete (21 hrs scheduled)

LVDT Interface Testing



LVDT Sensitivity

Purpose:

- Verify linearity of LVDT signal in full range and working range
- Verify manufacturer stated sensitivity

Motivation:

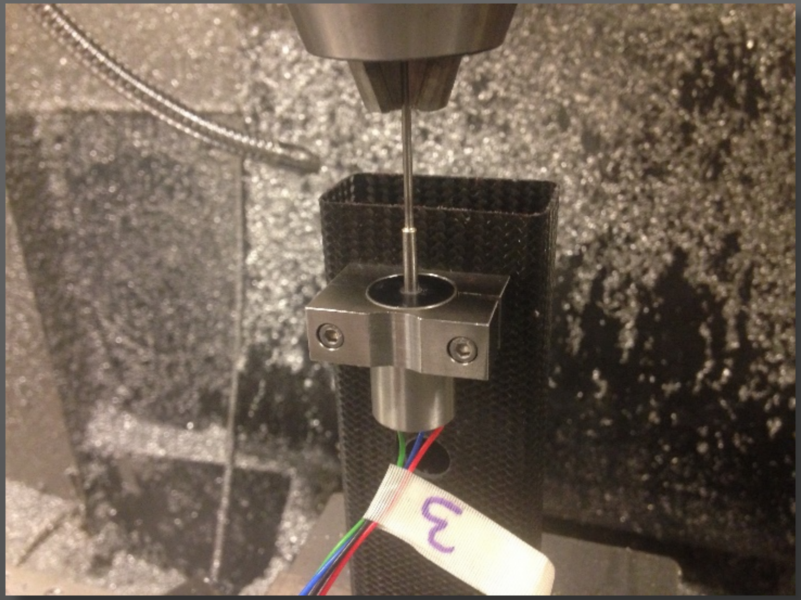
Original testing showed LVDT sensitivity varying test to test

Preliminary Results:

- Mill has uncertainty with 0.0001" increment adjustment
- Full LVDT Range shows constant, linear sensitivity

Remaining Work:

Establish confidence in working range sensitivity



Risk Mitigation:

Inaccurate displacement measurements

Requirement Trace Back:

- Displacement/Rotation measurement accuracy (±1.75 μm, ±15.3 μrad)
- Control Precision (±2 μm, ±20μrad)

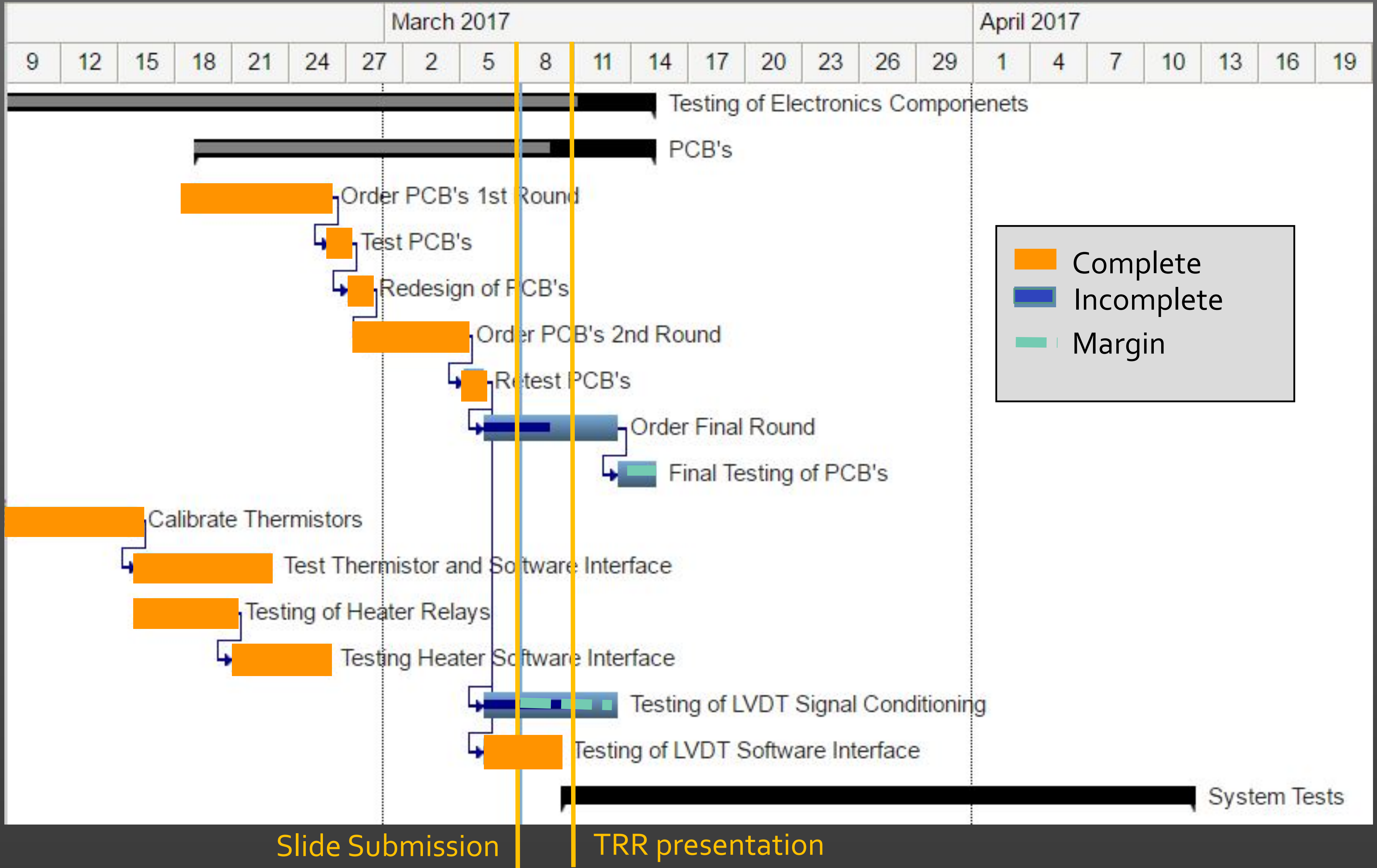
Equipment	Test Procedure	Facilities
• LVDT (x4) • LVDT PCB Rev 3 • Mill • Voltmeter • Power Supply	1. Secure LVDT in mill 2. Lower core known distance 3. Compare output voltage to expected voltage	ASEN Machine Shop

Electrical System - Next Steps

- PCB Boards
  - Third and final round ordered, will be populated upon arrival

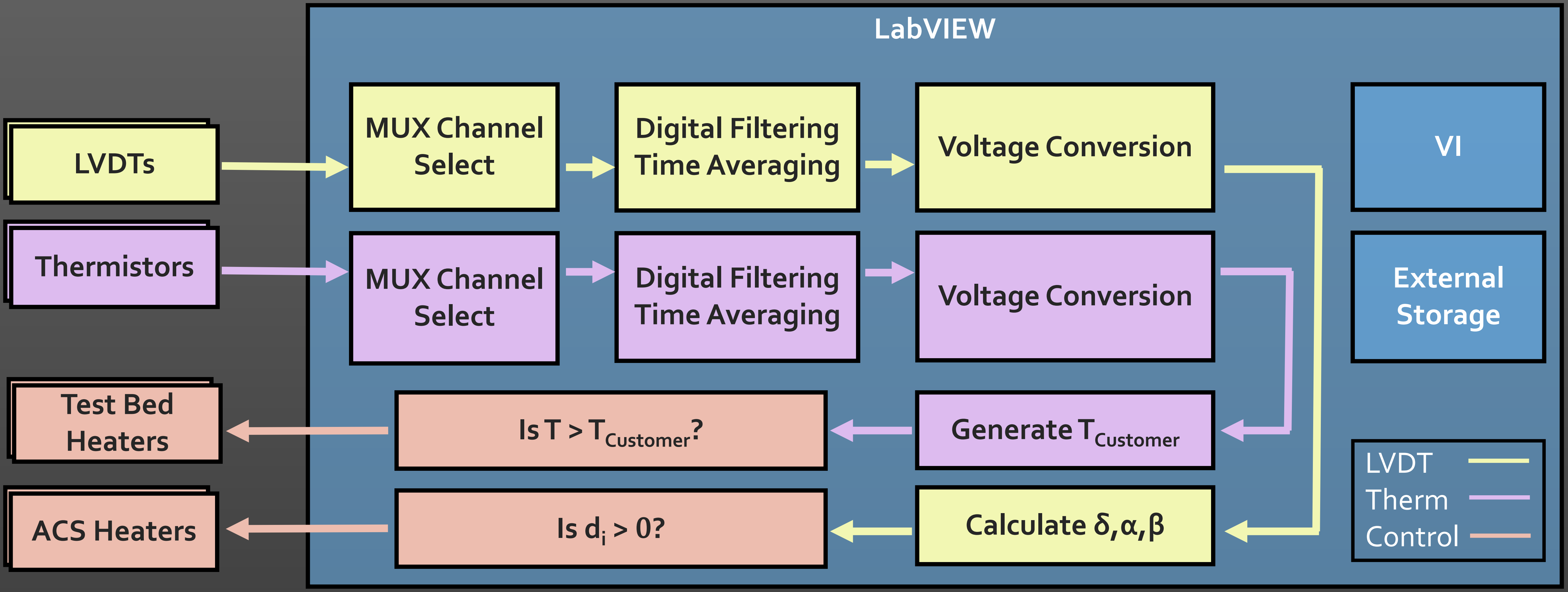
- LVDT sensitivity testing
  - Test LVDT output over 300 µm working range to establish confidence bounds on sensitivity
  - Verify gains are adjusted on PCB to account for each individual LVDT

Electronics Schedule



Software Subsystem Tests

Software CONOPS

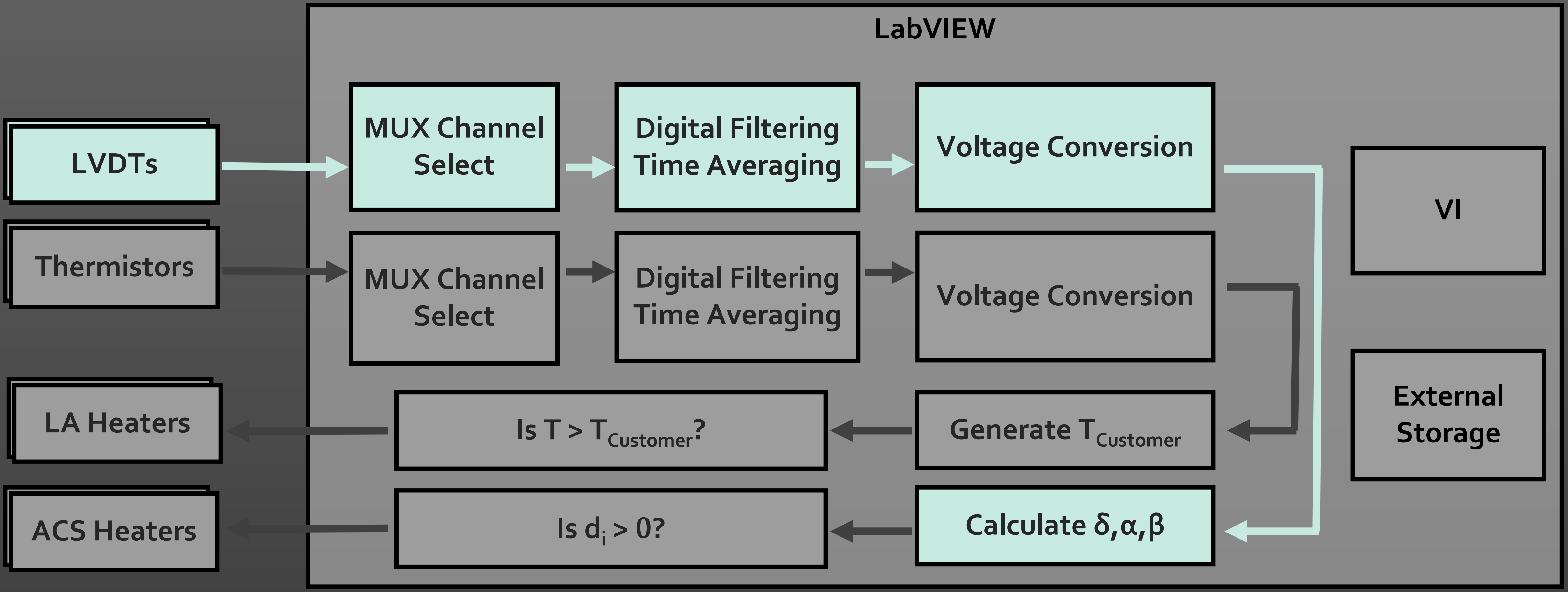


Software Test Scope

3 Critical Software Interfaces to Test: Thermistors, LVDTs, Heaters

Test Performed	Components Effected	Purpose	Status
LVDT Voltage Conversion	LVDTs	Verify conversion from input voltages to displacements	Complete
Thermistor Voltage Conversion	Thermistors	Verify conversion from input voltages to temperatures	Complete
Heater Control – Dynamic Test	Heaters	Verify heaters turn on at correct times in control sequence	Complete
Heater Control – Static Test	Heaters	Verify heaters turn on at correct times in control sequence	In Progress (12 hrs scheduled)
Data Display/Storage	N/A	Post-processing	In Progress (6 hrs scheduled)

LVDT Voltage Conversion

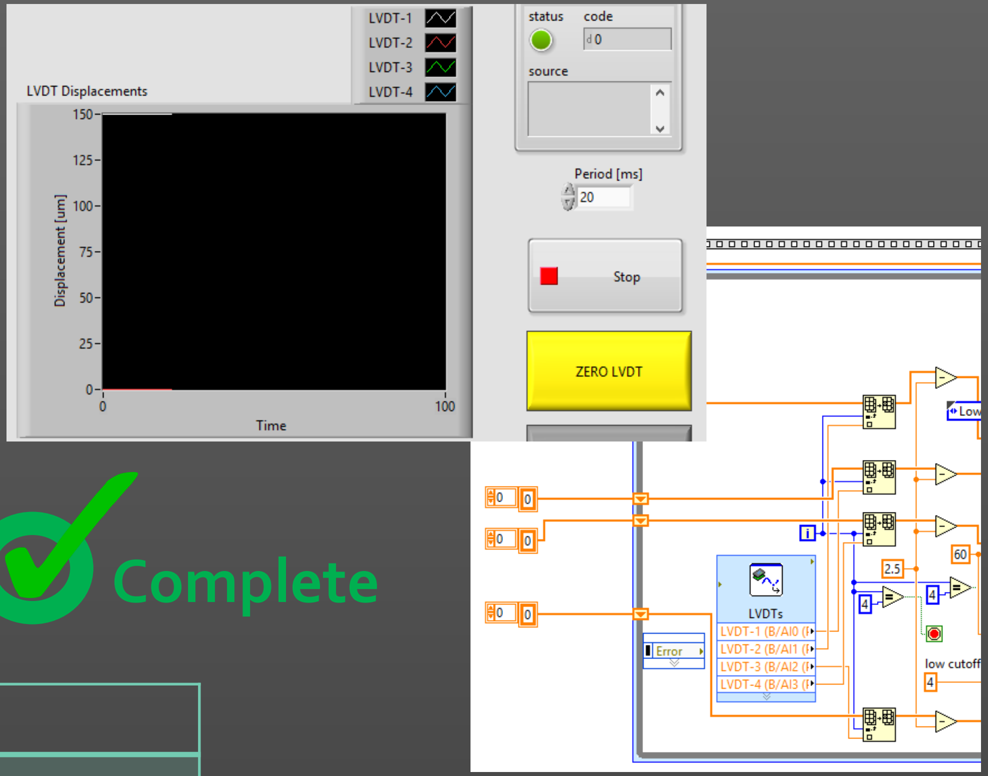


LVDT Voltage Conversion Testing

Purpose:
- Simulate LVDT measurement voltage signal
- Verify correct conversion from voltages to displacements

Results:
- 0-5V myRIO input range mapped to 300μm working range
- Validated all lines and subVI's between input and output
- System of equations implemented correctly

Requirement Trace Back:
- Alignment measurement (±1.75 μm, ±15.3 μrad)
- Electronics Package sensor interfacing



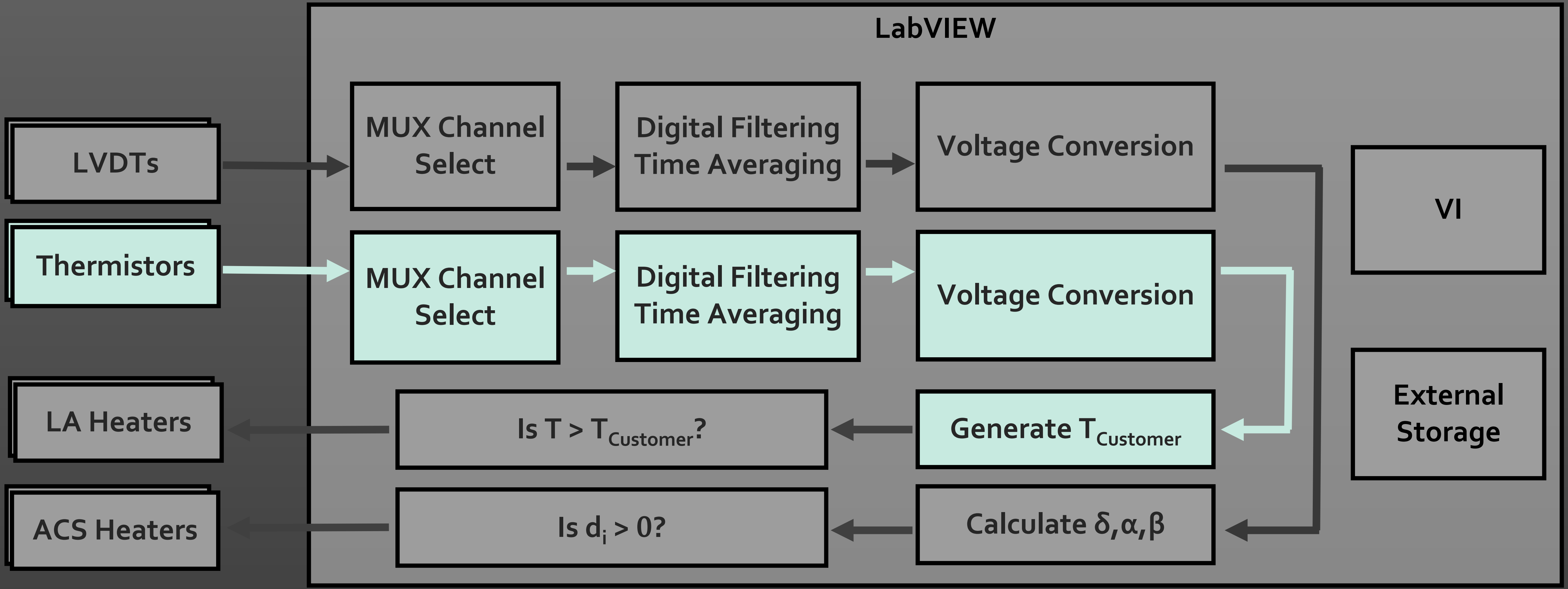
Complete

Equipment	Test Procedure	Facilities
• LabVIEW	1. Replace analog input block with known constant 2. Run VI 3. Verify resulting displacement from LVDT inputs	Bobby's Lab

Mitigated Risk:
Software completion and debugging

Overview | Schedule | Test Readiness | Budget

Thermistor Conversion



Therm Voltage Conversion Testing

Purpose:

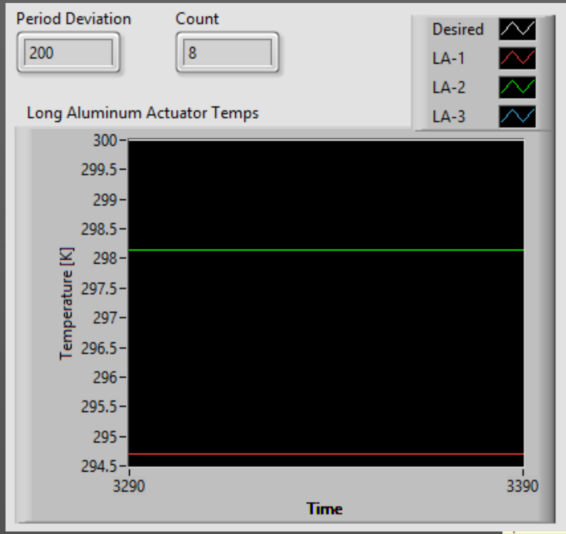
- Simulate thermistor measurement signals
- Verify correct conversion from voltage to temperature

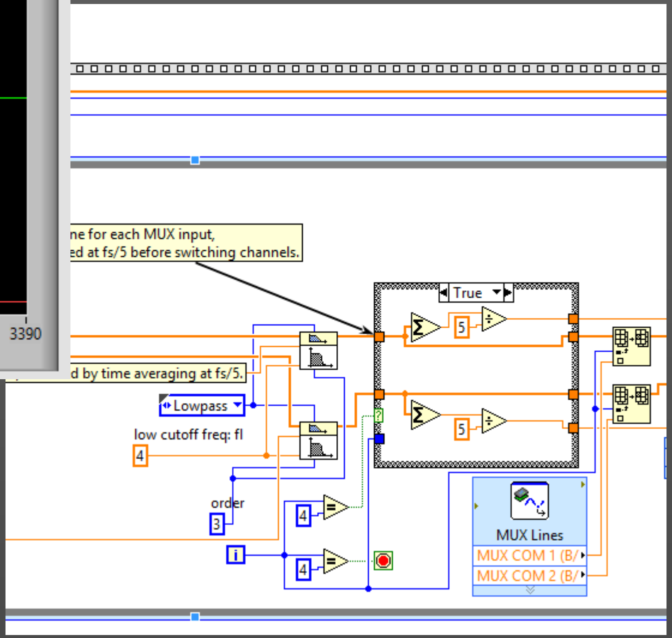
Results:

- For known R_{sense} and R_{ref}, output voltage is correct
- Validated all lines and sub VI's between input and output
- Customer temperature profile generated correctly

Requirement Trace Back:

- Temperature measurement (+/- 0.2K)
- Temperature control (+/- 0.3K)





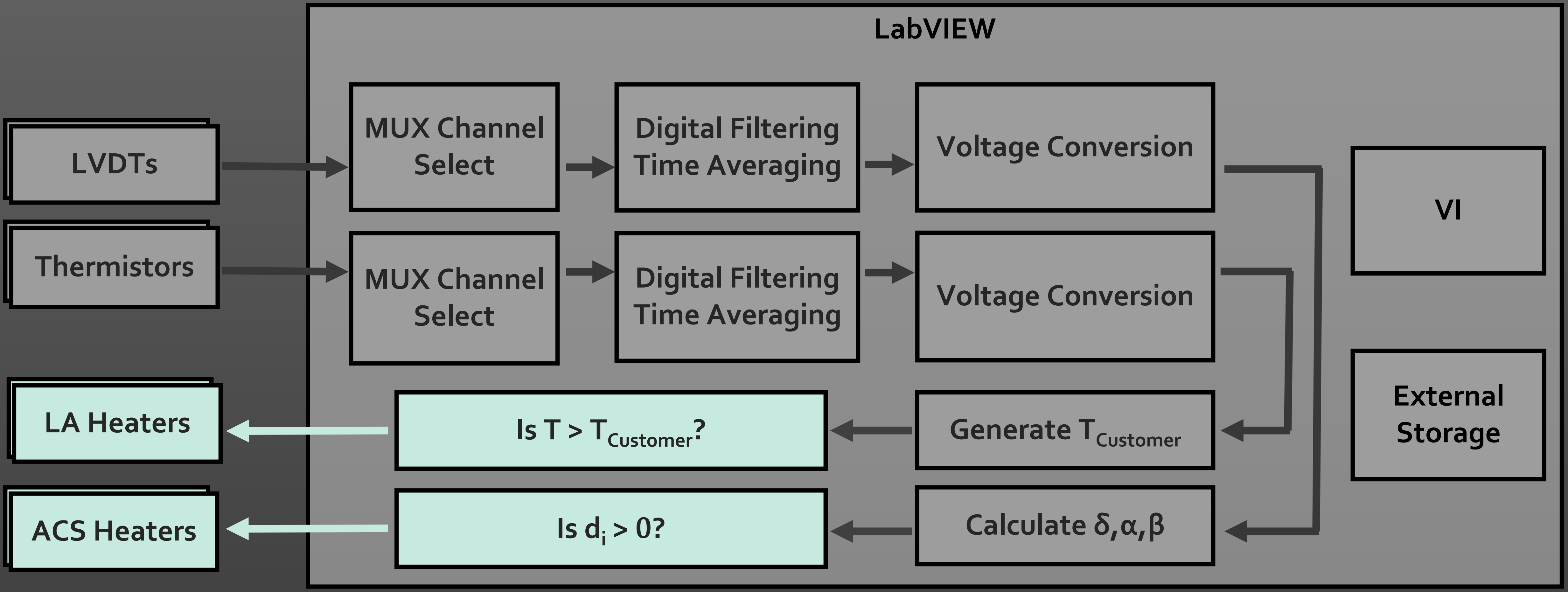
Complete

Equipment	Test Procedure	Facilities
• LabVIEW	1. Replace analog input block with known constant 2. Run VI 3. Verify temperature of replaced thermistor inputs	Bobby's Lab

Risk Mitigation:

Software completion and debugging

Heater Control – Dynamic Test



Heater Control – Dynamic Testing

Purpose:

- Simulate measured bar temperature LVDT displacement to simulate heater control response
- Verify heaters turn ON/OFF at correct times

Results:

- Dynamic test control logic is bug-free and correct
- Verified LED indicator status for all applicable heaters

Requirement Trace Back:

- Temperature control
- Active feedback loop

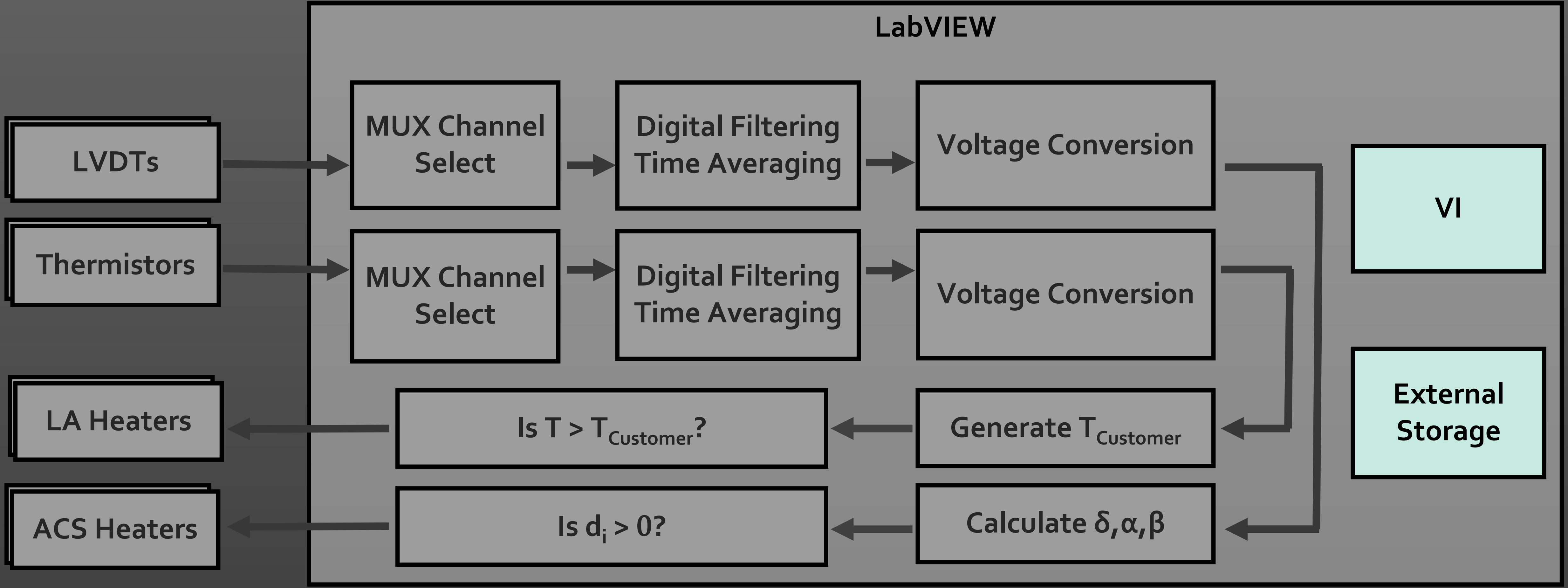
Complete

Equipment	Test Procedure	Facilities
• LabVIEW	1. Set bar temp to value greater than $T_{Customer}$ 2. Run VI, verify LED ON 3. Set LVDT reading to value greater than zero 4. Run VI, verify LED ON	Bobby's Lab

Risk Mitigation:

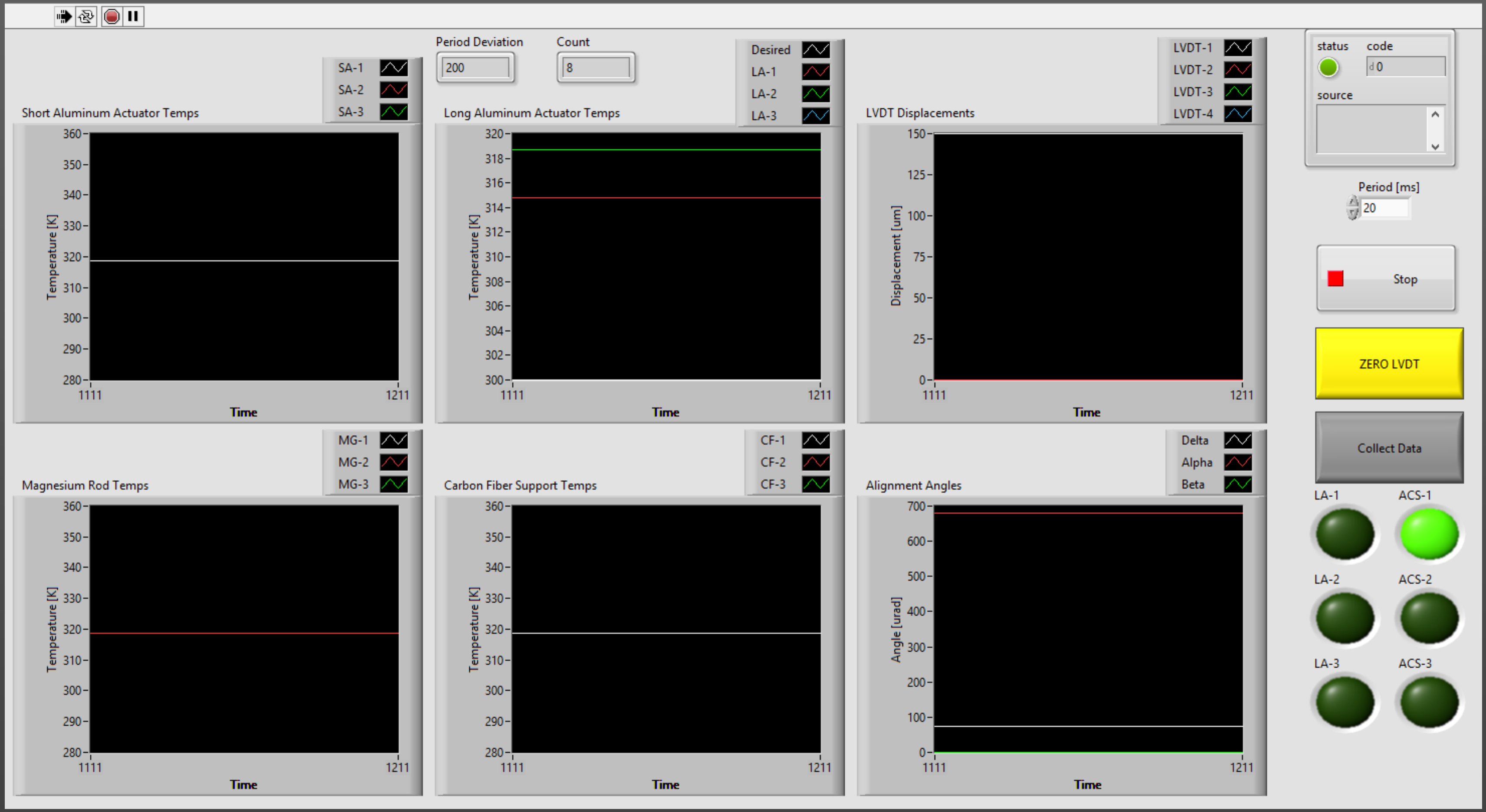
Software completion and debugging

Data Display/Storage



Overview | Schedule | Test Readiness | Budget

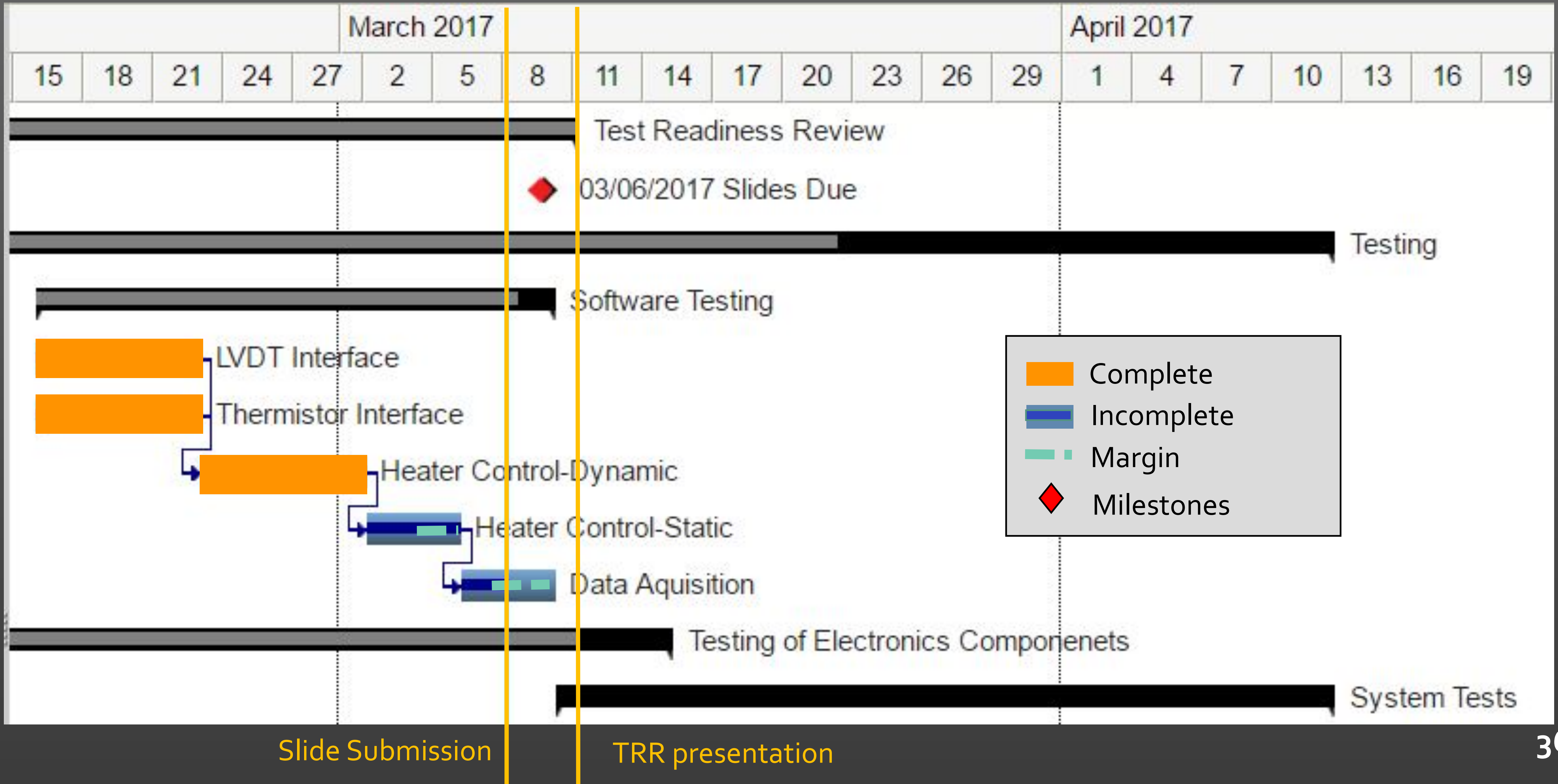
Data Display/Storage



Software Status– Next Steps

- Static Test - heater control (12 hrs scheduled)
  - Development initially delayed until Dynamic Test debugging complete
    - Code functionality largely copy and paste, desire to eliminate unnecessary work
  - Currently under development
- Data storage (6 hrs scheduled)
  - Underway, working on implementing VI (courtesy of Bobby/Trudy)

Software Schedule



Integrated System Testing

Requirement Verification Mapping

	Component Test: PCBs	Component Test: Rod Groups	Component Test: Translation and Rotation	Static Zeroing Test	Dynamic Test
			TB1, TB3		TB2, TB3
				ACS1	ACS2, ACS3
			AMS1, AMS3	AMS1, AMS3	AMS1, AMS3
		EP2		EP1-EP3	EP1-EP3
Test Bed			DR 1.3	DR 1.3.1, DR 1.5	DR 1.6,
Correction		DR 2.2, DR 2.2.2.1,	DR 2.5,	DR 2.2.1, DR 2.3,	DR 2.2.2, DR 2.3,
Measurement				DR 3.1, DR 3.2	DR 3.1, DR 3.2
Electronics	DR 4.1.1.1, DR 4.2.1.1			DR 4.1.1, DR 4.2, DR 4.2.1	DR 4.1, DR 4.1.1, DR 4.2, DR 4.2.1
				Control Model	Control Model
				Thermal Model	Thermal Model

KEY
Levels of Success
Derived Requirements
Models

Verification matrix constructed, all requirements mapped

Static Zeroing Test

Purpose:

- Simulate initial zeroing of the system alignment upon arrival in orbit
- Verify precision of Alignment Correction System (ACS)

Objectives:

- Validate control system design
- Validate thermal and control models

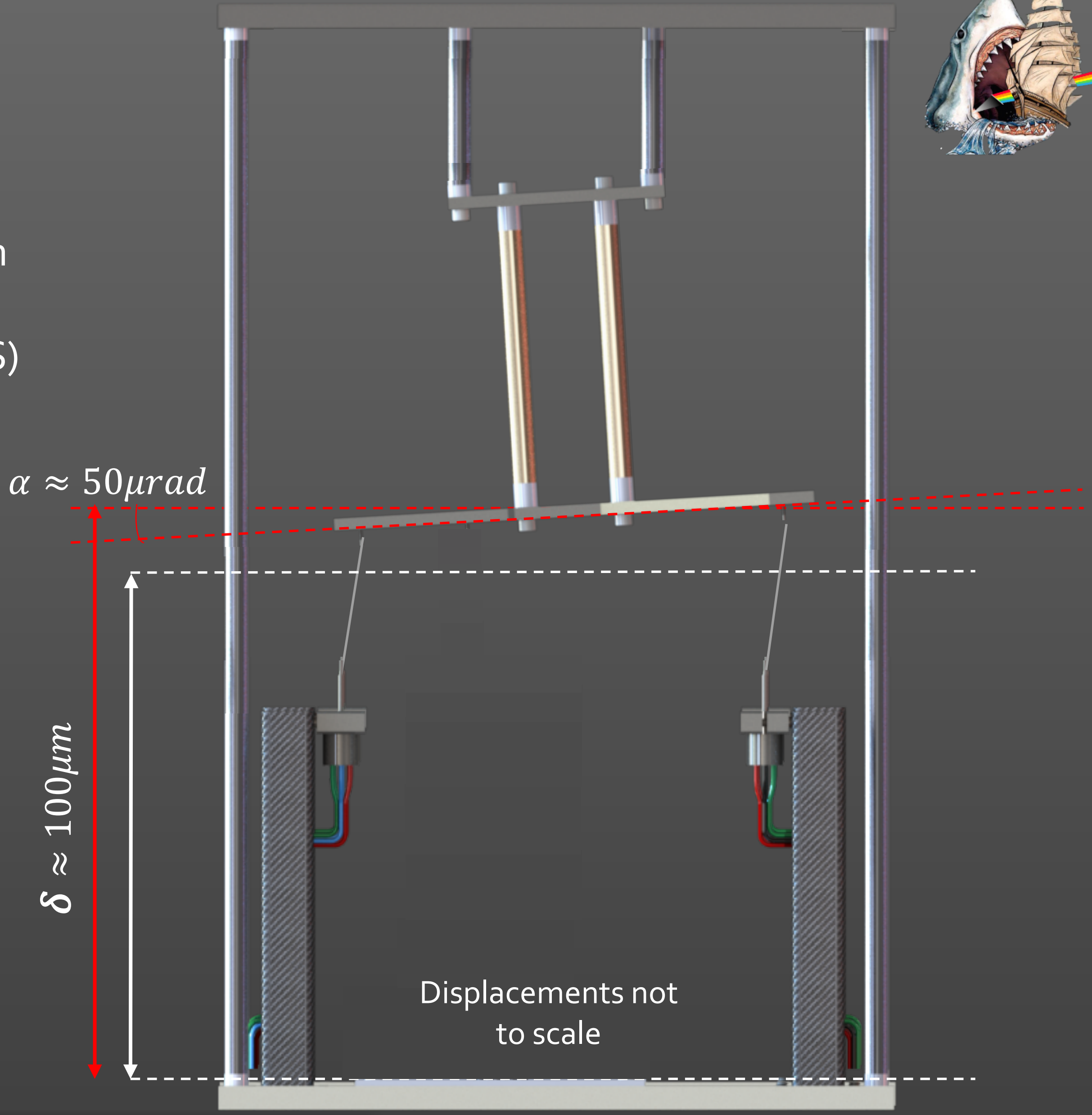
Requirement Verification:

Direct verification of 9 requirements (slide 39)

- Temperature Control
- Alignment measurement accuracy
- Active control implementation

Model Validation:

Thermal and Control Models



Static Test Logistics

Summary:

Zero alignment within ±20 µrad and ±2 µm within 600 sec, maintain zeroed position

Duration:

~ 600 seconds

Data Collection:

Temperature state of actuators , Translational Displacement, Rotational Displacement

Test Equipment	Test Procedure	Test Facilities
• Anti-vibration table • Fully-integrated TDU • Power supplies • DAQ system • Control laptop with software installed	1. Set-up TDU on anti-vibe table 2. Verify system integration with power, heaters and software 3. Verify ambient readings from all sensors are expected 4. Turn on anti-vibration table 5. Wait 30 seconds before opening “StaticTest.vi” 6. Run “StaticTest.vi” 7. Repeat Test TBDx	JILA X1B12 Lab

Integrated Dynamic Test

Purpose:

- Validate control system design under simulated on-orbit thermal loading

Objectives:

- Prove feasibility of thermal expansion driven control system
- Induce customer-provided temperature profile in Test Bed
- Verify system alignment-corrective capabilities by following a known temperature profile

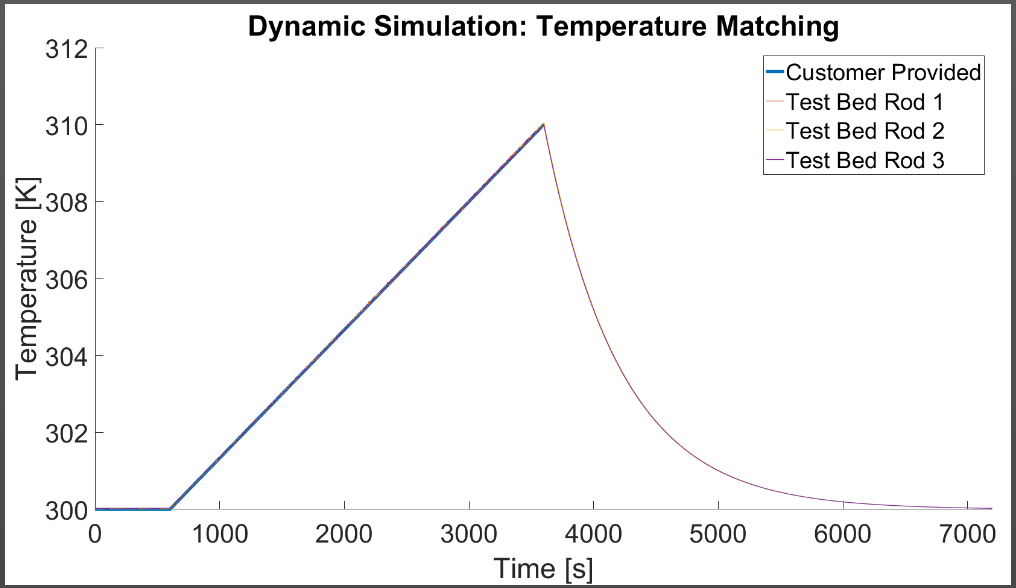
Validated Models:

- Thermal and Control Models

Requirement Verification:

Direct verification of 9 requirements (slide 39)

- Execution of temperature profile
- Maintain plane alignment for 95% of temp profile
- Alignment measurement accuracy
- Active control implementation



Dynamic Test Logistics

Purpose:

Induce customer-provided temperature profile, and verify alignment-corrective capabilities of system when following a known temperature profile

Duration:

~ 120 min

Data Collection:

Temperature state of actuators , Translational Displacement, Rotational Displacement

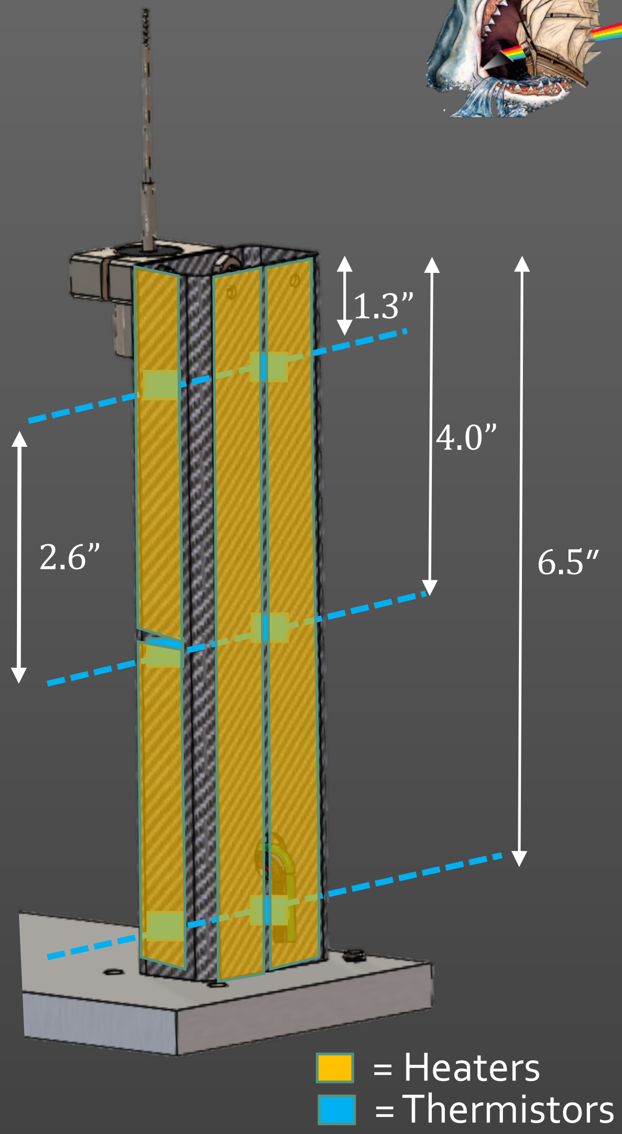
Test Equipment	Test Procedure	Test Facilities
• Anti-vibration table	1. Set-up TDU on anti-vibe table	JILA X1B12 Lab
• Fully-integrated TDU	2. Verify system integration with power, heaters and software	
• Power supplies	3. Verify ambient readings from all sensors are expected	
• DAQ system	4. Turn on anti-vibration table	
• Control laptop with software installed	5. Wait 30 seconds before opening “StaticTest.vi”	
	6. Run “DynamicTest.vi”	

LVDT Support Characterization Test

Purpose: Characterize expansion of carbon fiber supports under 10° ΔT thermal load

Motivation: Customer required, added in replacement of test bed design update

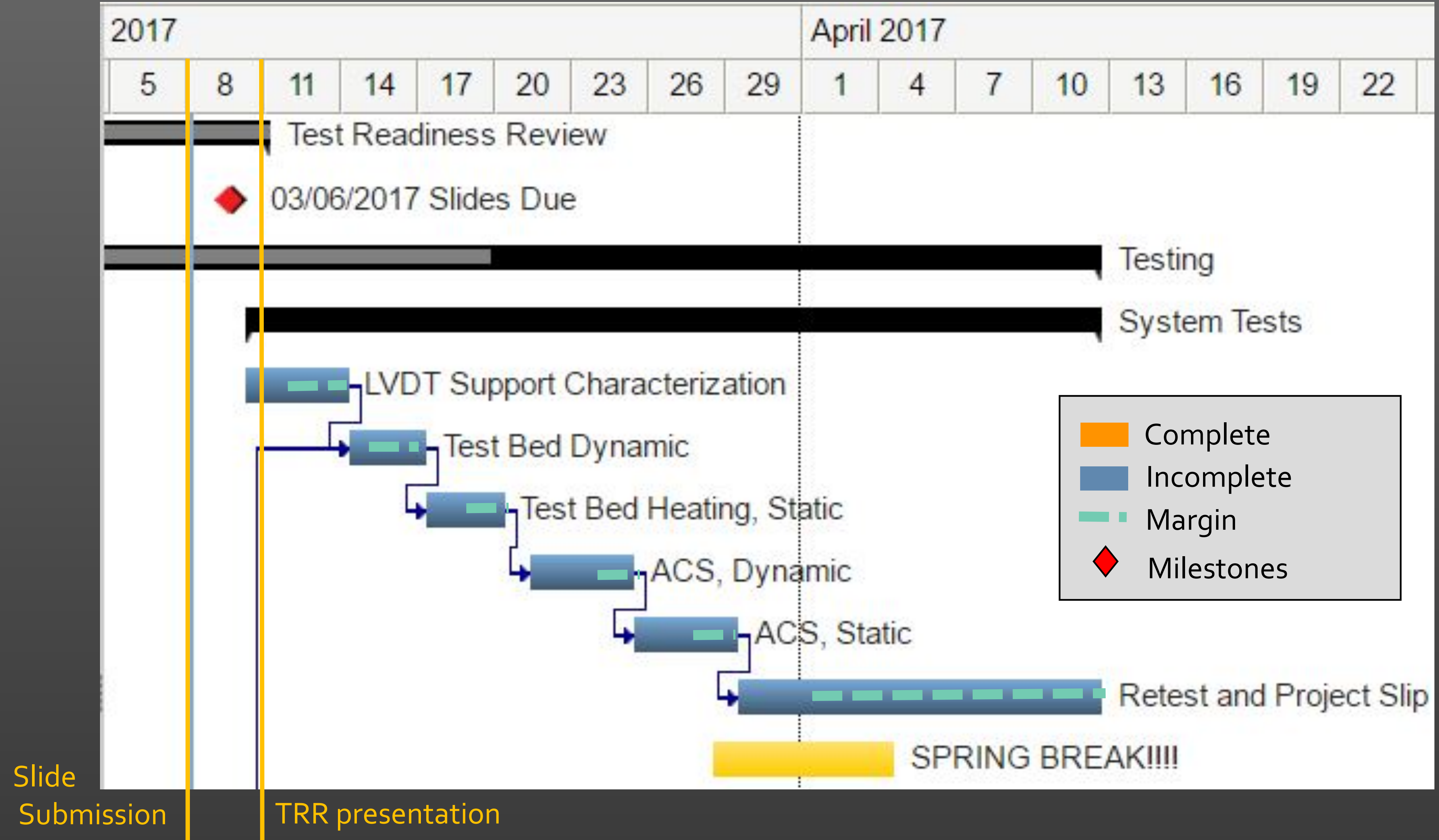
Equipment	Test Procedure	Facilities
• Assembled Test Unit • Heaters (x8) • Thermistors (x18) • Glass plate (x4) • Aluminum Tape • Power Supply • DAQ System	1. Attach thermistors to specified locations on LVDT Support 2. Secure heaters as specified in test plan to LVDT Support using aluminum tape 3. Start DAQ system, verifying all sensor inputs 4. Turn on heaters until 10° ΔT is achieved. Repeat 10x. 5. Record measured expansion of LVDT support	JILA X1B12 Lab



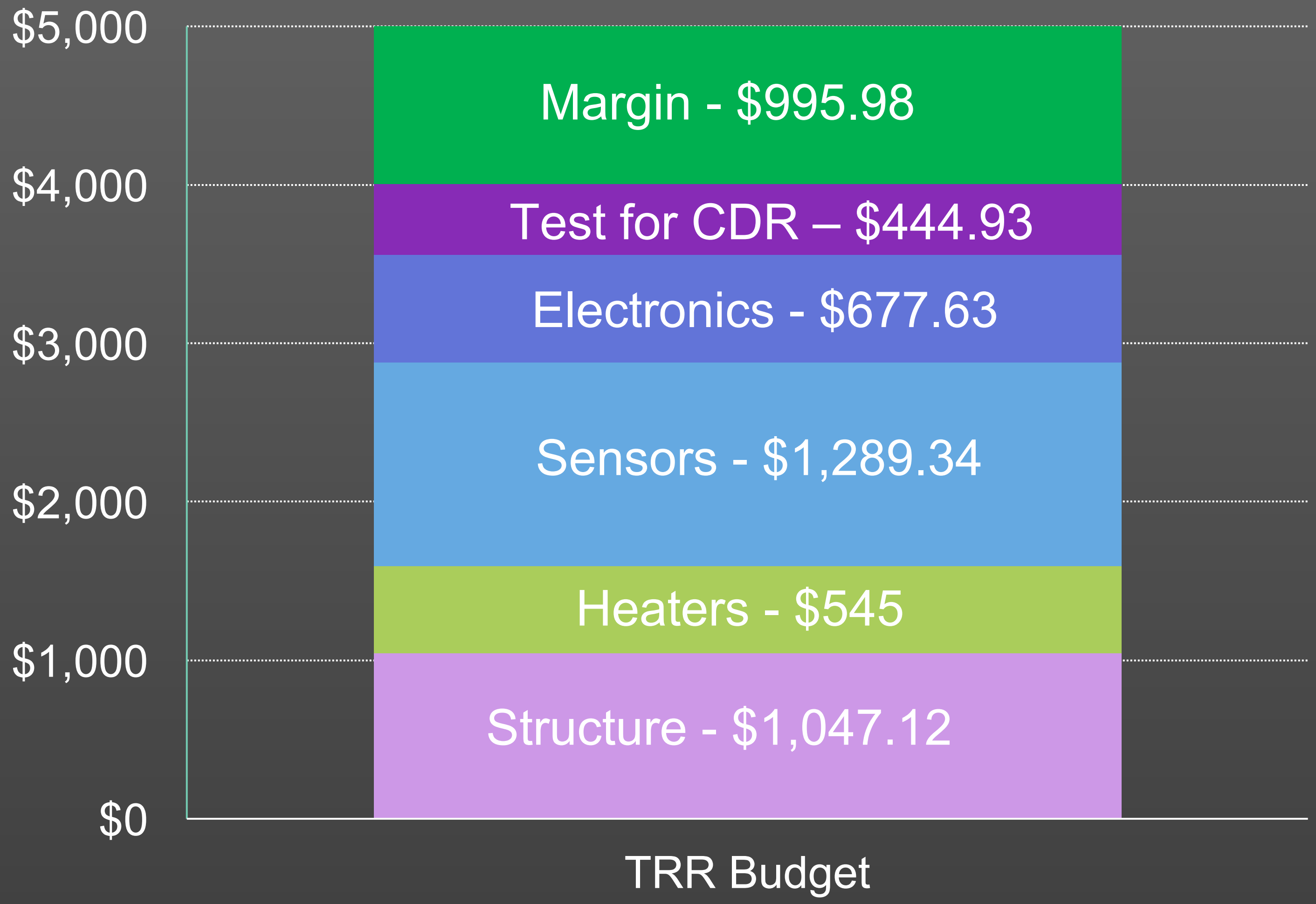
Mitigation: Characterizes error introduced by expansion of the LVDT supports

Test does not contribute towards requirement satisfaction

Systems Testing Schedule



Budget



Total Margin: $995.68

When it breaks we can replace:

- LVDT: $320
- PCB: $40
- Heater: $50 x2 = $100
- Al and Mg Rods: $80

Total = $540 ✓

Questions?

Backup Slides

Electrical Risks & Results Summary

Test Performed	Requirements Fulfilled	Expected Results	Risks Mitigated
LVDT-PCB Interface	• Displacement measurement • Control Precision	LVDT signal outputs filtered and conditioned as expected	• Inaccurate displacement measurements • Signal noise
Thermistor Calibration	• Temperature knowledge	Calibrated thermistors will behave in a more predictable manner, with higher accuracy	• Inaccurate and imprecise temperature readings • Loss of heater control
Thermistor-PCB Interface	• Temperature knowledge • Control Precision	MUX can be switched via software from the myRIO to control thermistor channel selection	• Signal noise • Loss of heater control
Heater-myRIO Interface	• ACS Control	myRIO can be used to control switching of heaters via software	• Loss of heater control
LVDT Sensitivity	• Displacement measurement	LVDTs respond as expected, based on given manufacturer sensitivity	• Inaccurate displacement measurements

LVDT-PCB Interface Testing

Purpose:

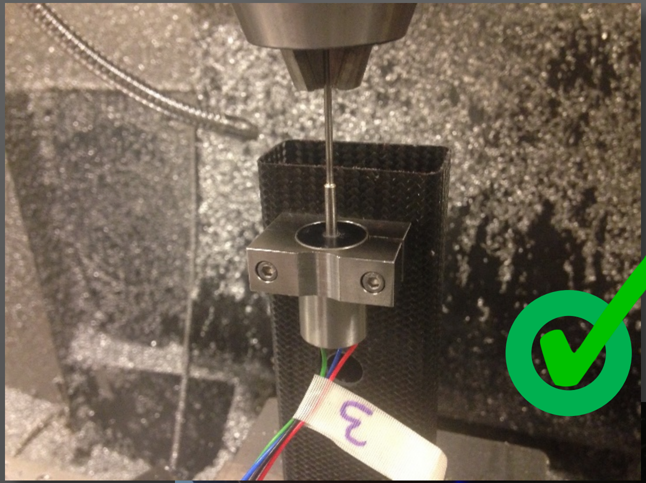
- Verify measurement accuracy of LVDTs over working range of 300μm
- Validate circuit design:
  LVDT output gains expand 25,00 μm/ 12.8V working range to 300 μm / 5V range
- Establish confidence in manufacturer spec'd sensitivity

Risk Mitigation:

- Inaccurate LVDT measurement
- Signal Noise

Requirement Trace back:

- Displacement/Rotation measurement accuracy (±2 μm, ±20 μrad)



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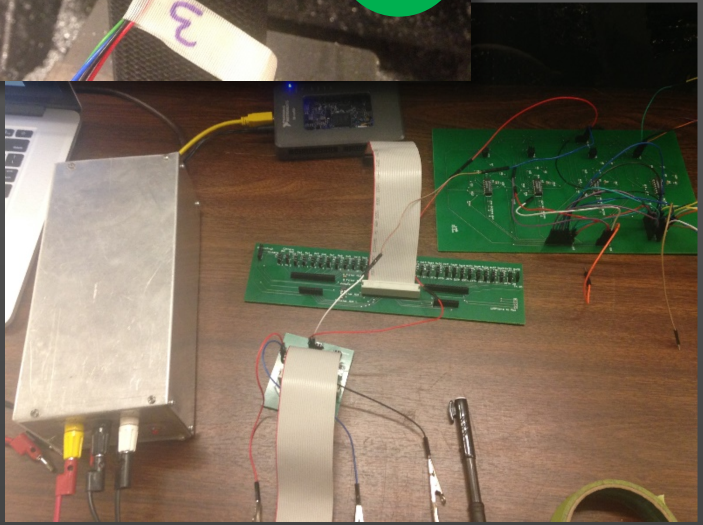
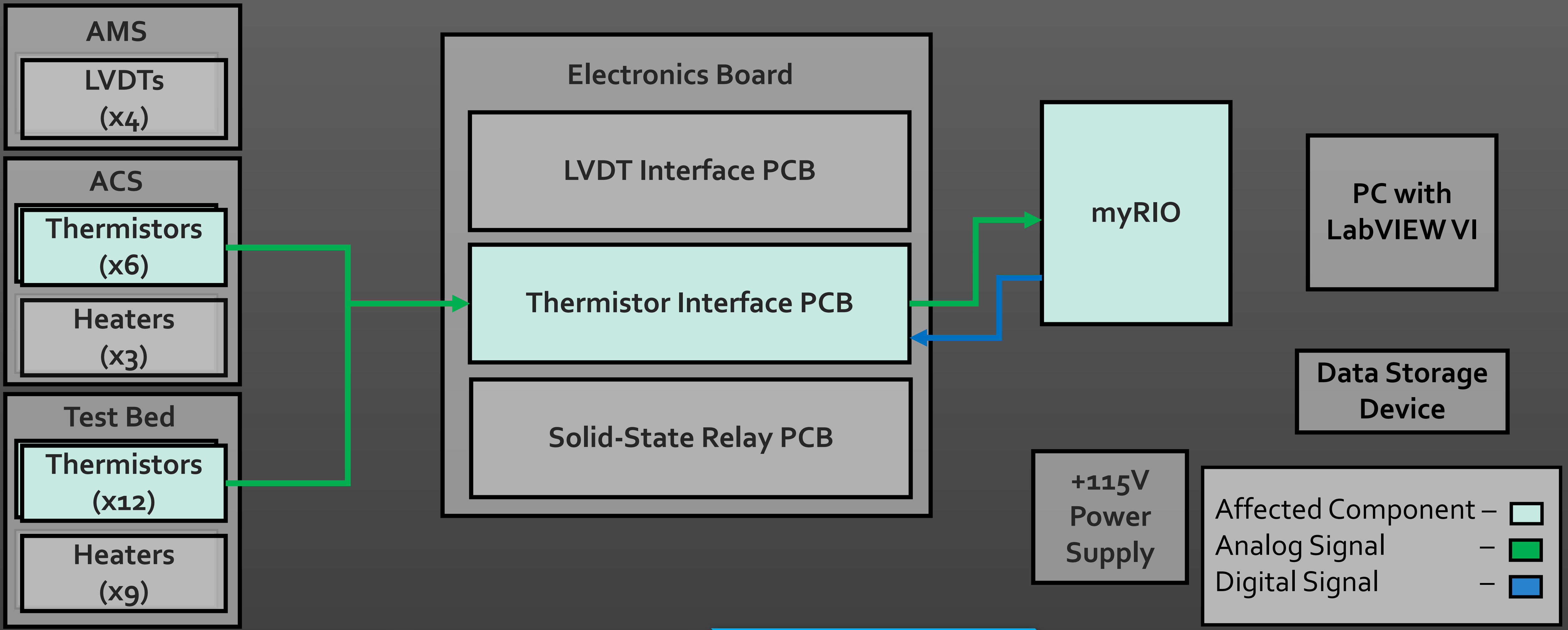


Equipment	Test Procedure	Facilities
• LVDT (x4) • Mill • Power Supply • myRIO • LabVIEW • Voltmeter • LVDT PCB	1. Mount LVDT housing to support, secure in mill vice 2. Secure core in mill chuck 3. Align LVDT core and housing 4. Record mill +Z displacement at 0V 5. Lower LVDT core by 0.001" increments, recording voltage output pre and post conditioning	ASEN Machine Shop

Thermistor Interface Testing



Thermistor PCB-Interface Testing

Purpose:

Verify myRIO/MUX compatibility and Rev1 PCB design

Results:

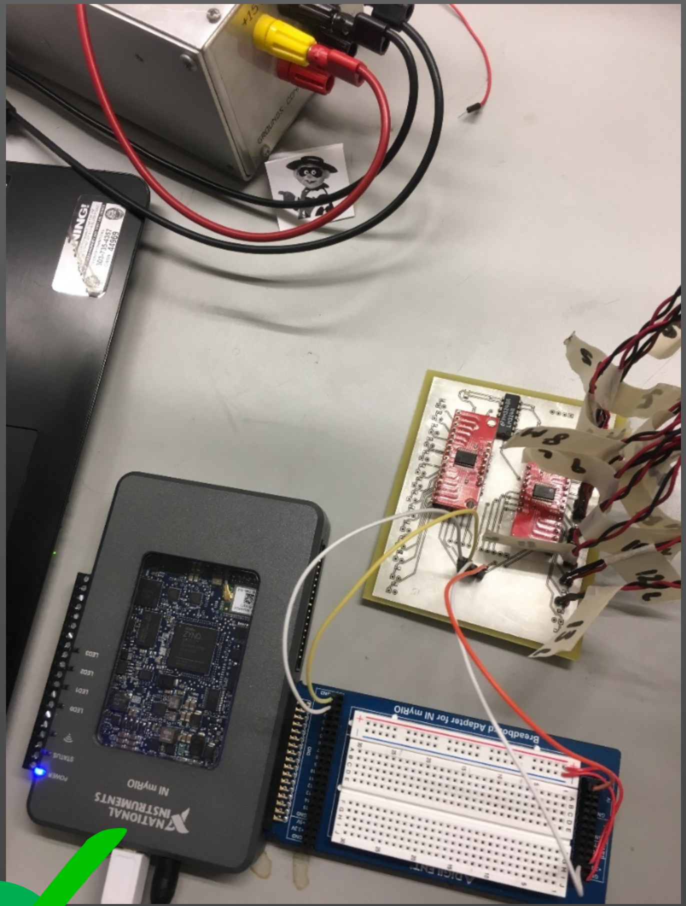
- Updated signal filtering
- Discovered important software bugs to fix
- Verified PCB

Risk Mitigation:

- Signal noise
- Loss of heater control

Requirement Trace Back:

- Temperature Knowledge
- Control Precision



Equipment	Test Procedure
• Thermistors • Therm PCB Rev1 • Voltmeter • myRIO • LabVIEW	1. Manually select each channel using myRIO I/O manager 2. Measure thermistor voltage drop before and after MUX 3. Confirm rapid voltage change before and after MUX upon applying heat to specific thermistor

Complete

Thermistor Calibration Test

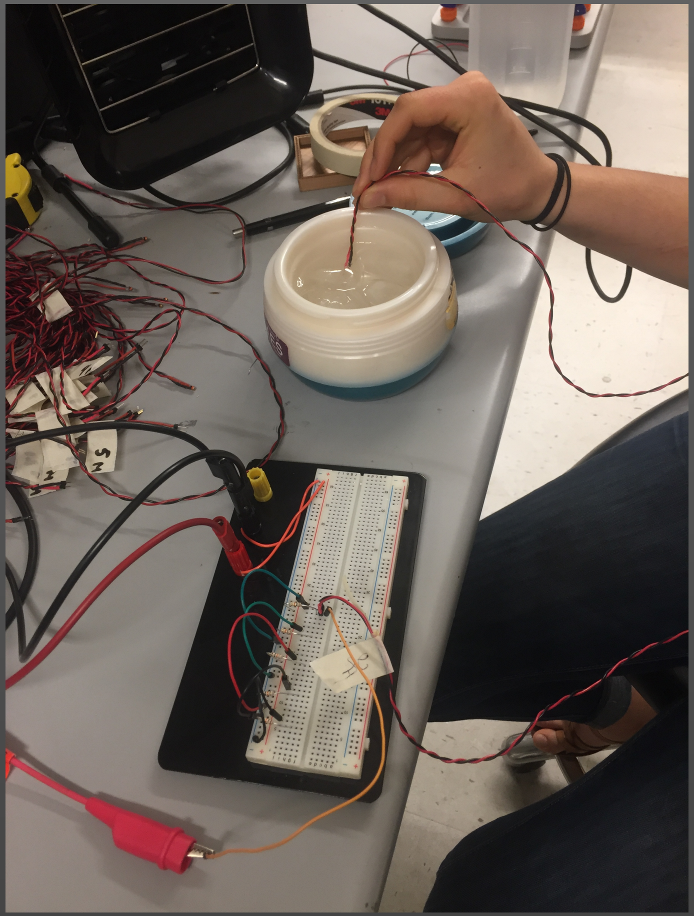
Purpose: Determine Sense Resistance for thermistor accuracy calibration

Results:
- 28 thermistor values recorded
- All values within expected range

Equipment	Test Procedure	Facilities
• Thermistors (x28) • DI Water • Ohm meter	1. Place thermistor in ice bath 2. Record Resistance	• Bobby's Lab

Risk Mitigation:
Inaccurate temperature measurement

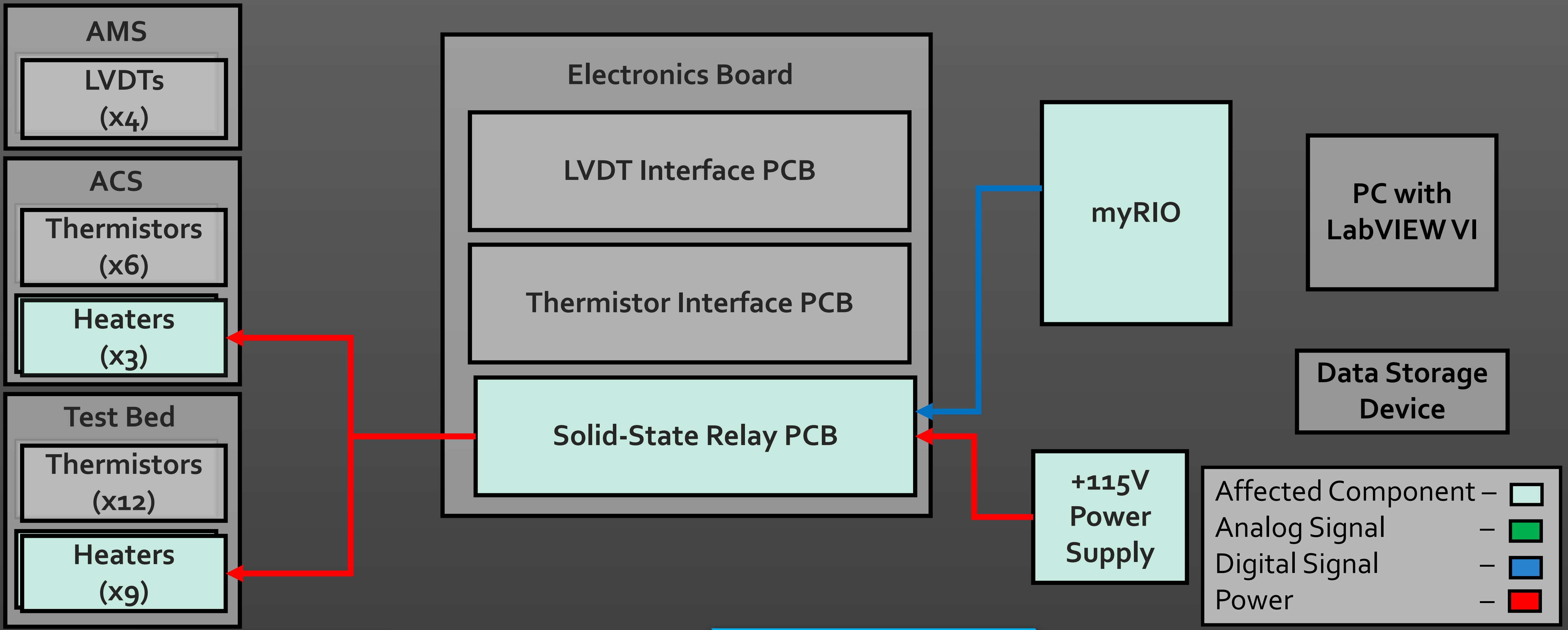
Requirement Trace Back:
- Temperature accuracy requirement



Complete

Overview | Schedule | Test Readiness | Budget

Heater Interface Testing



Heater myRIO-Interface Testing

Purpose:

Verify heater control using SS Relays

Results:

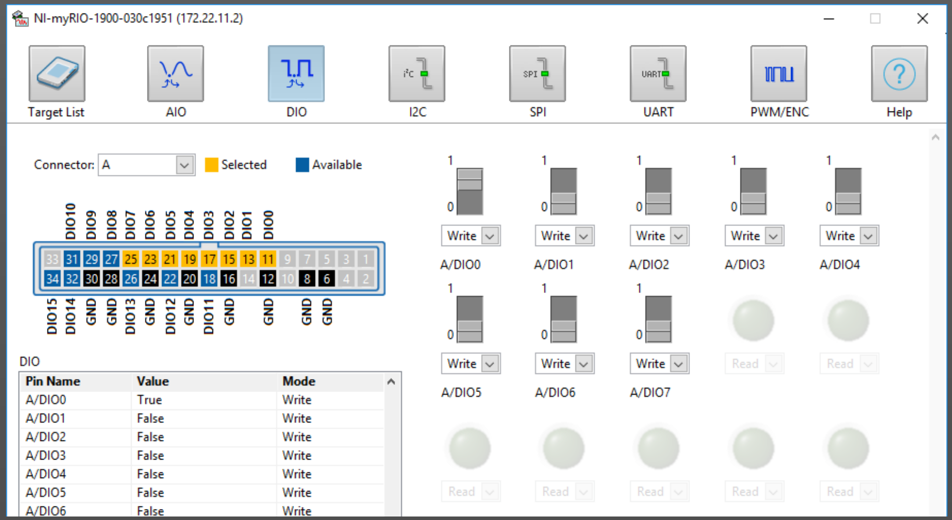
- Circuit design of PCB validated
- Control of 12 heaters achieved

Risk Mitigated:

Loss of heater control

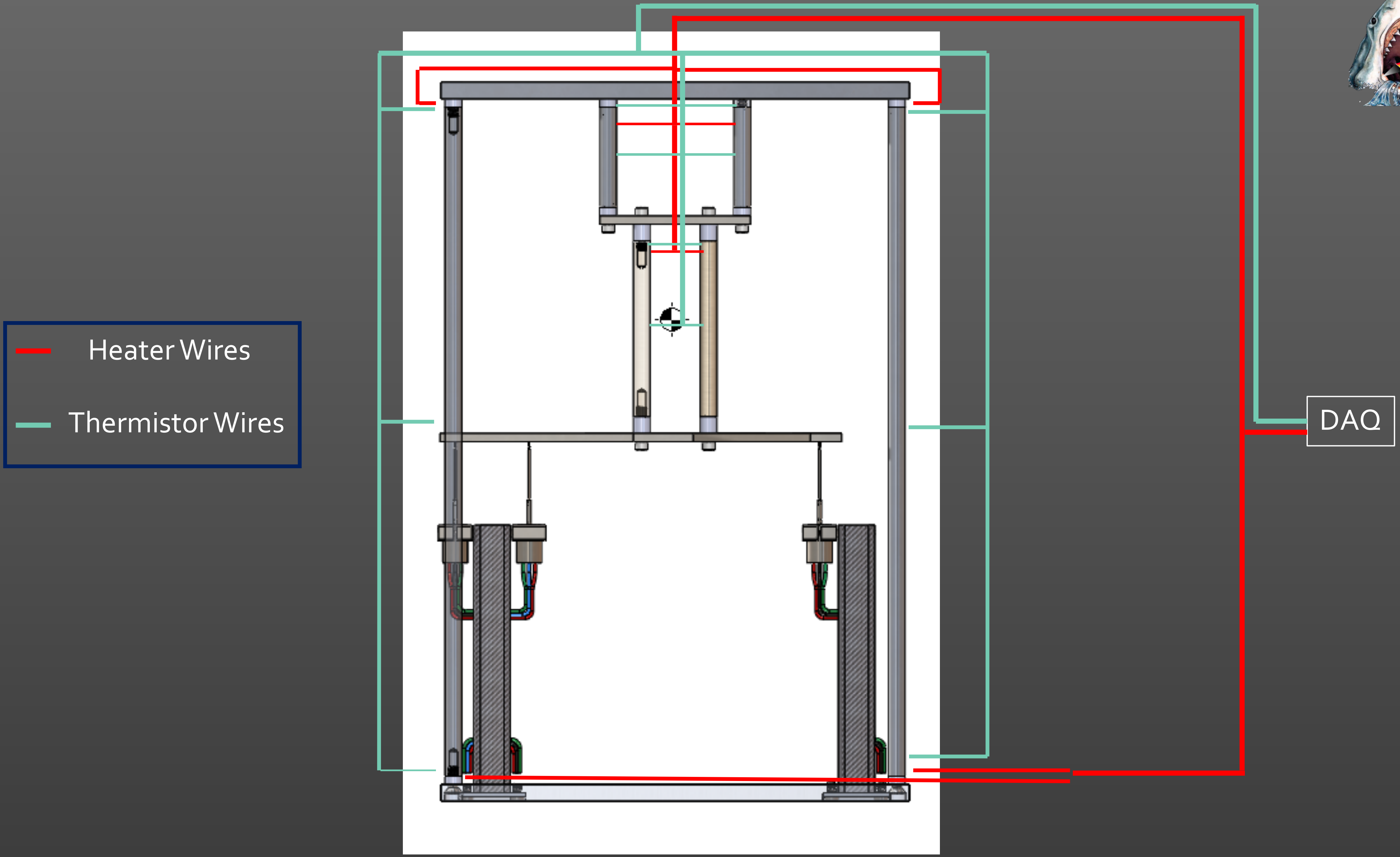
Requirement Trace Back:

ACS control



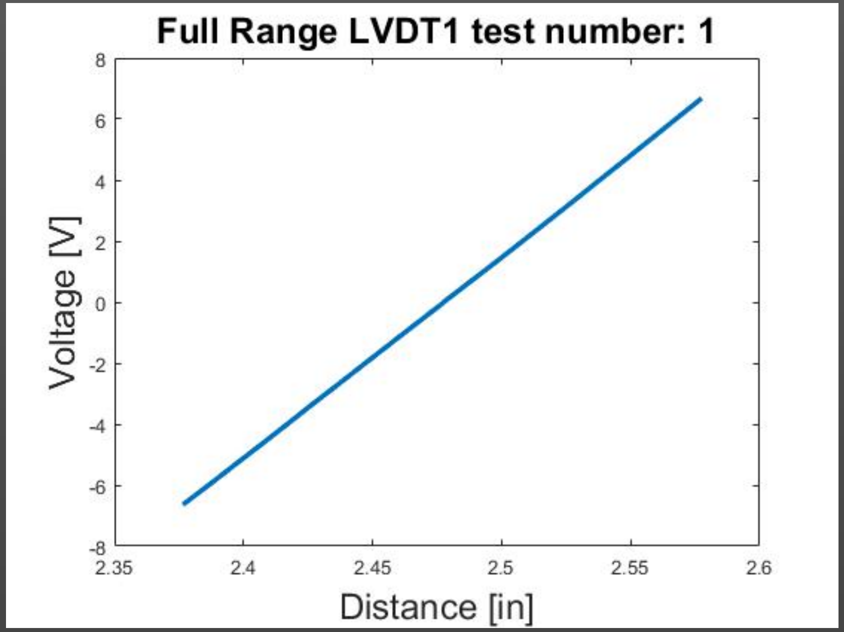
Equipment	Test Procedure	Facilities
• Heaters (x12) • Heater PCB • myRIO • LabVIEW	• Used myRIO DIO to manually turn on heaters • Verified heater control	• Senior Design Room

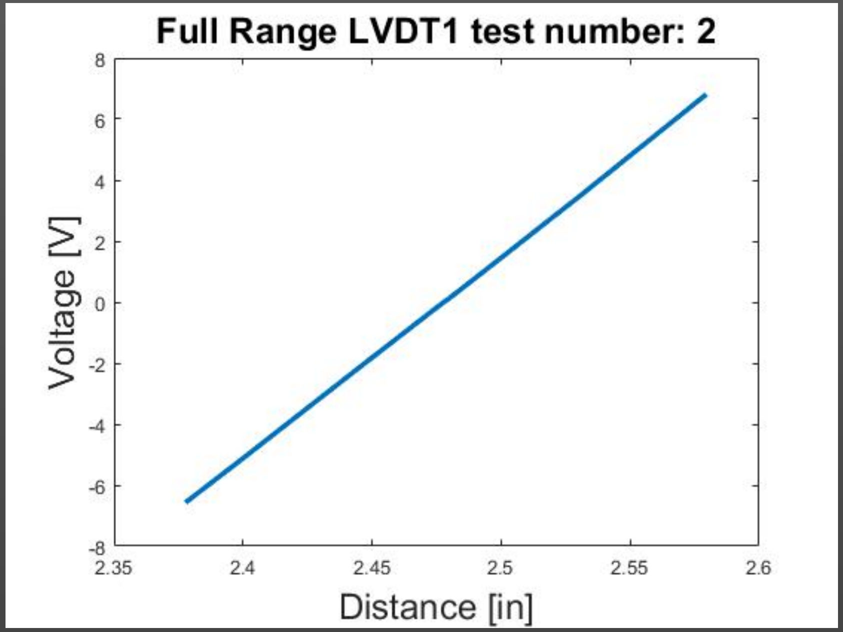
Complete

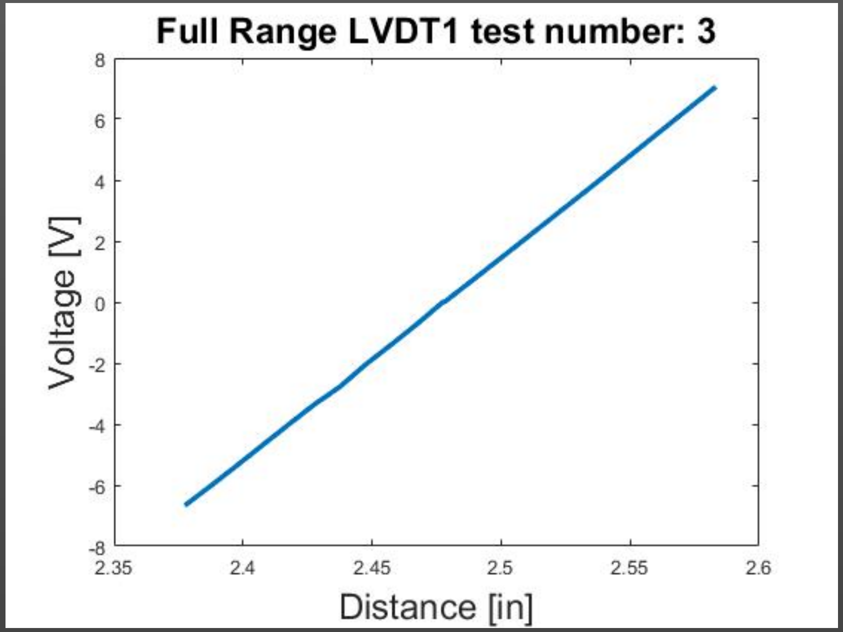

Heater Wires
Thermistor Wires
DAQ

LVDT 1 Sensitivity Plots

- Tested LVDT 1 three times







Software Scope

Sensors
Raw, unfiltered voltages

→

PCBs
Signal conditioning

→

myRIO
Peripherals

→ V_{IN} →

LabVIEW
V_{IN} → Meaningful Data

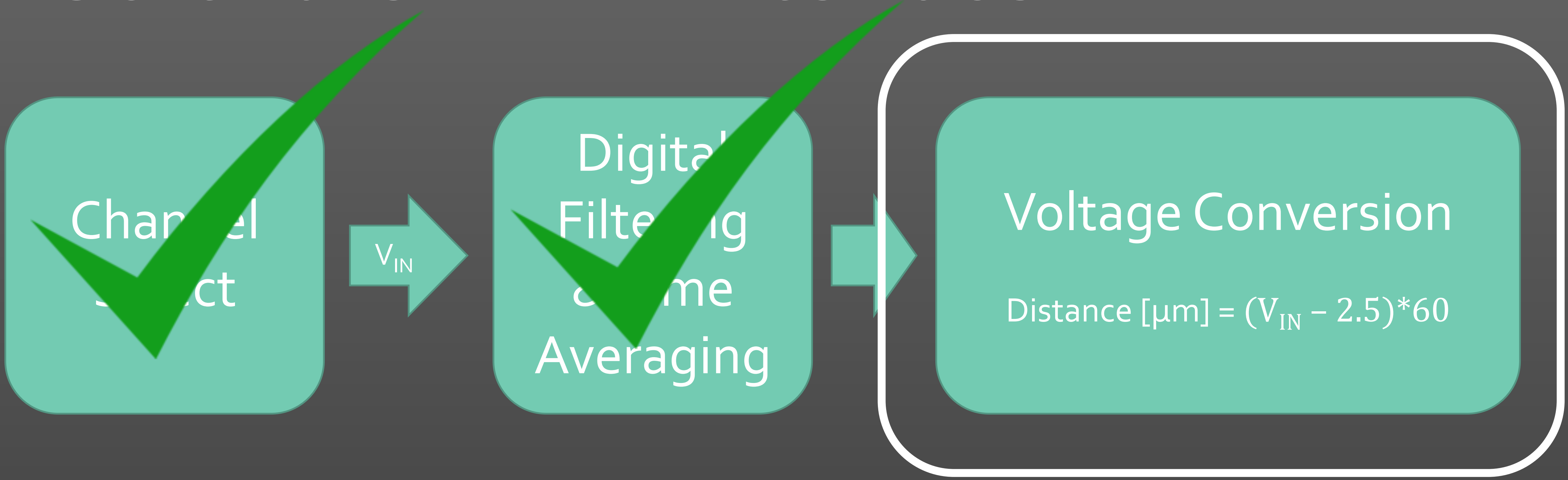
Focus of software development and testing

Software: V_{IN} → Meaningful Data

Four distinct aspects to software testing:

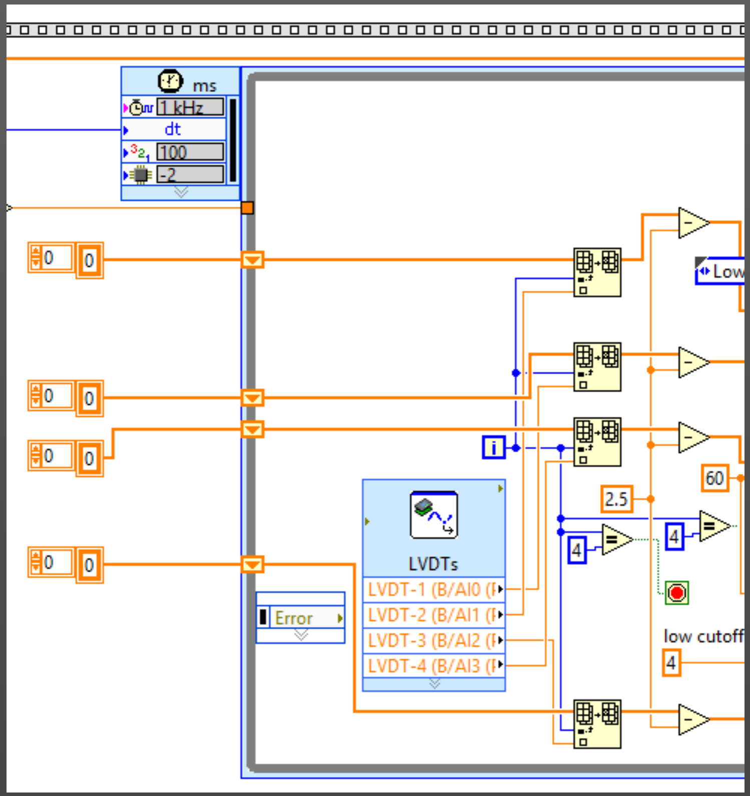
- LVDT Interface
- Thermistor Interface
- Heater Control
- Data Display & Storage

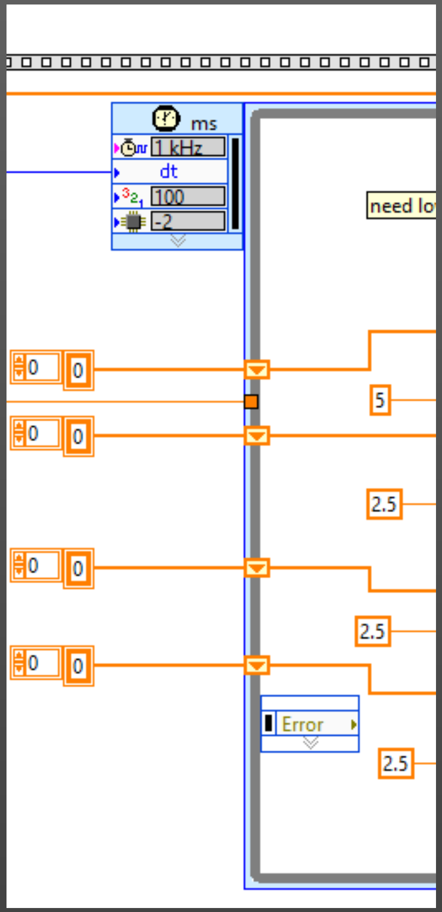
Software: LVDT Interface



Testing rationale: Replace V_{IN} with known value, verify output

Software: LVDT Interface

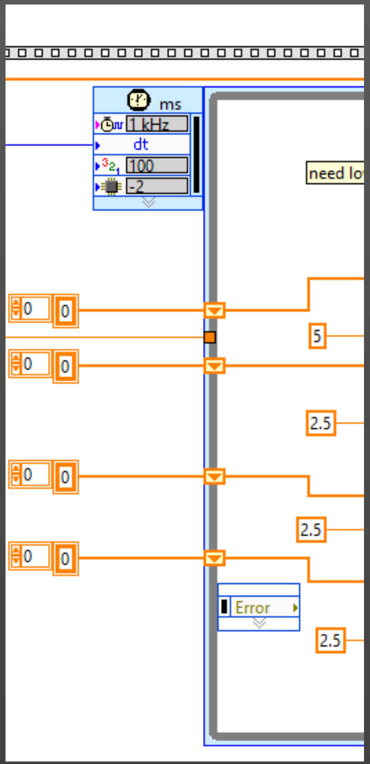


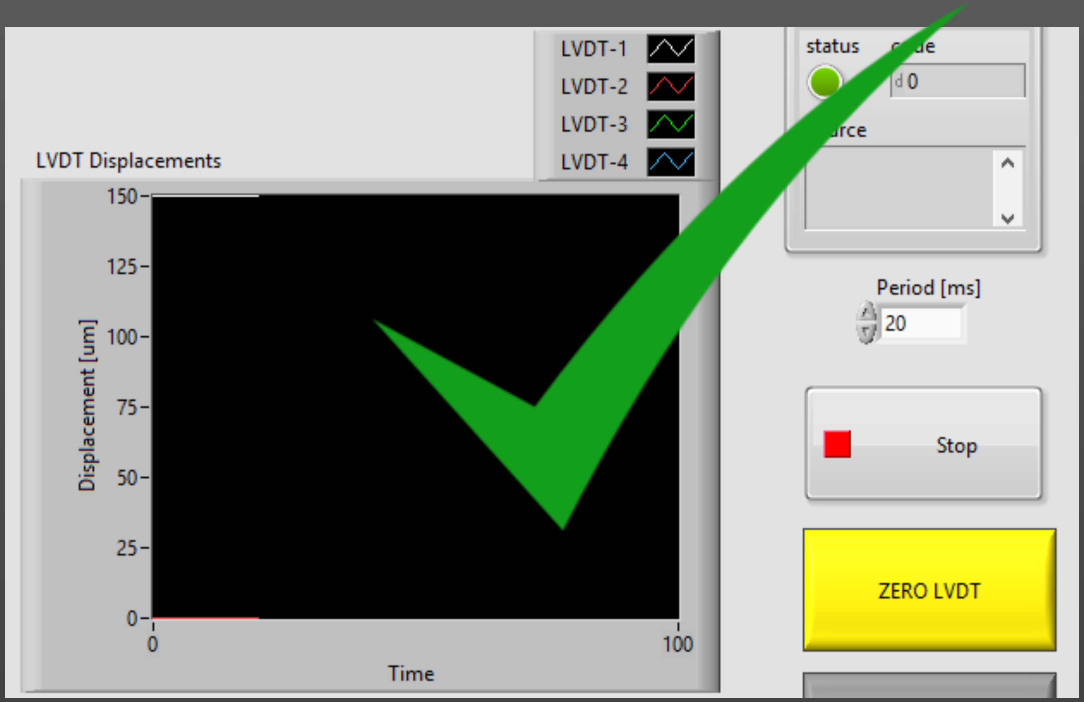


Overview | Schedule | **Test Readiness** | Budget

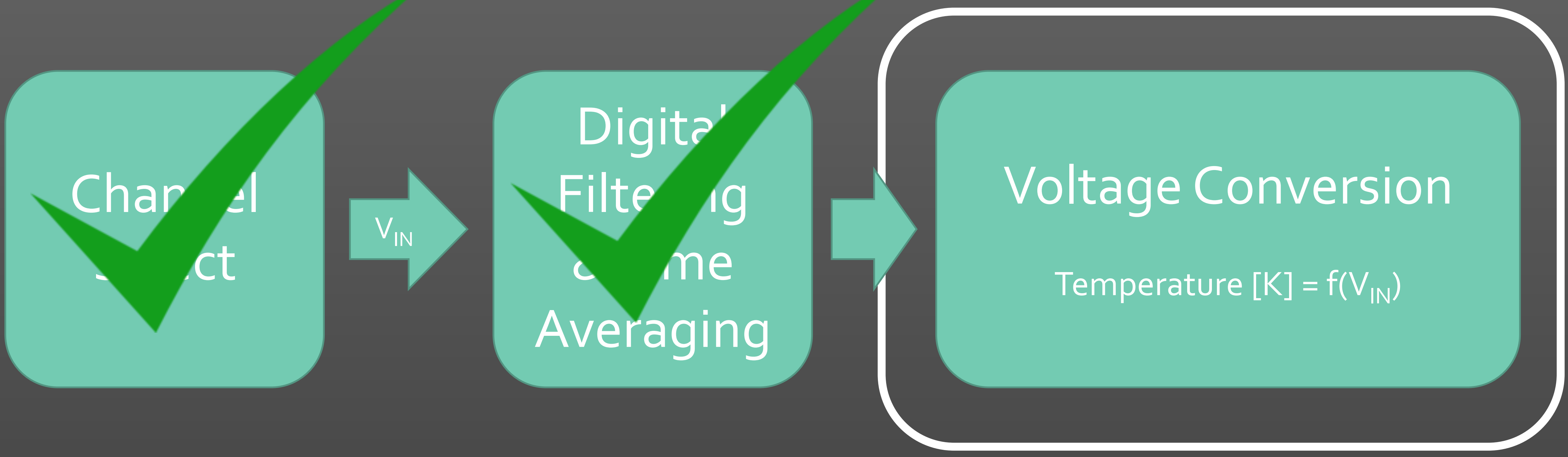
Software: LVDT Interface

For a 5V (2.5V) input, expecting to see a 150µm (0µm) displacement.



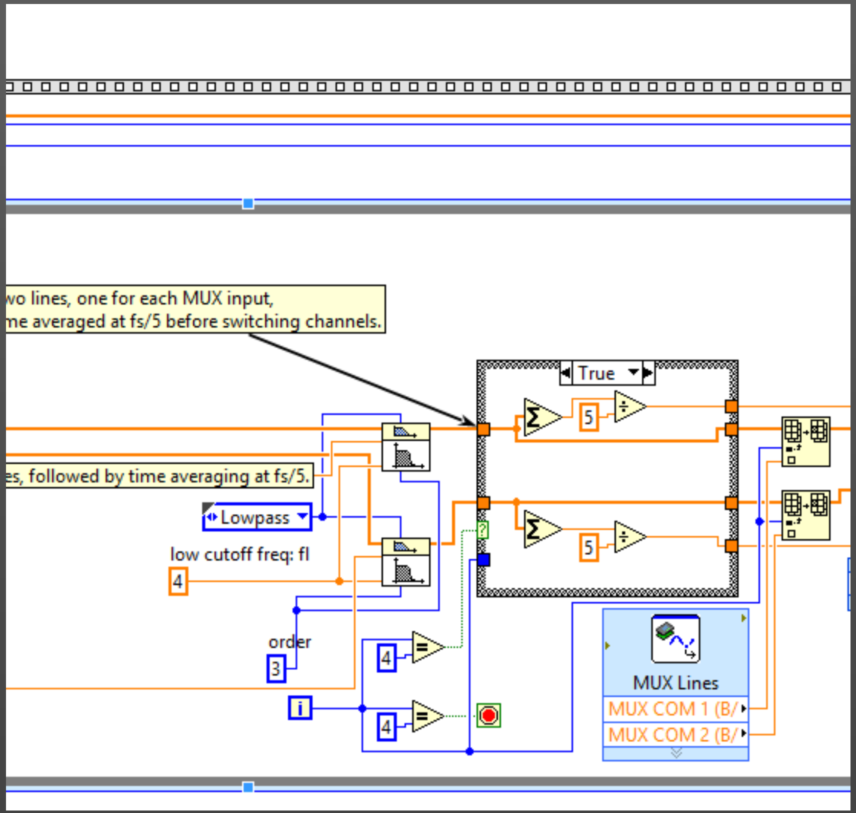


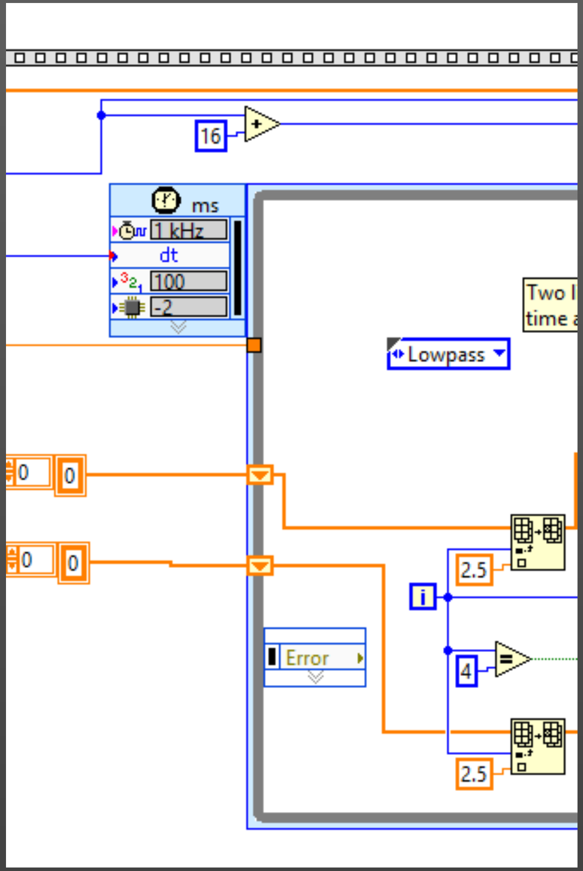
Software: Thermistor Interface



Testing rationale: Replace V_{IN} with known value, verify output

Software: Thermistor Interface

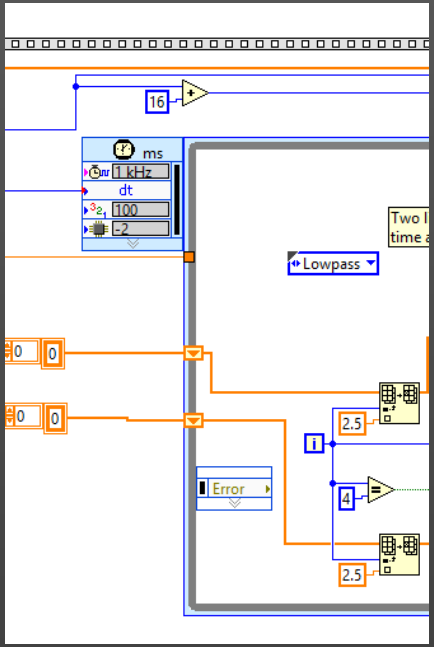


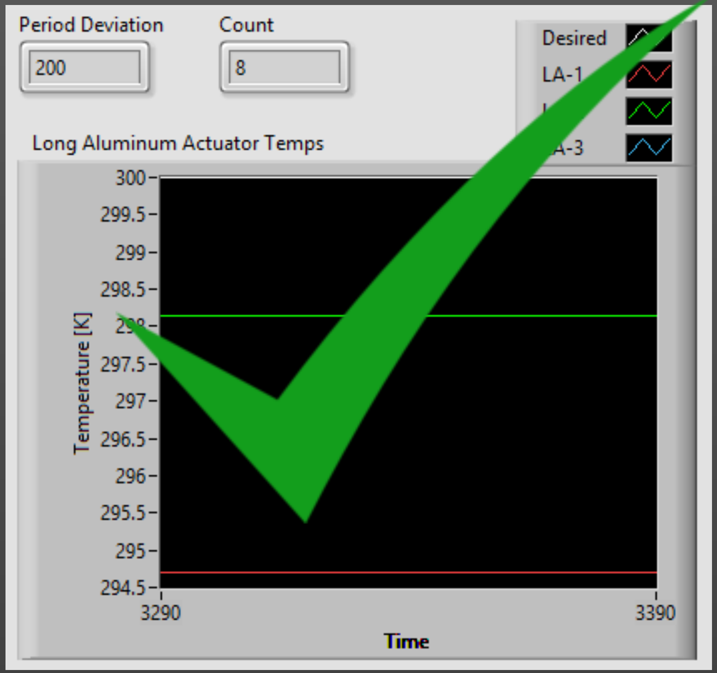


Overview | Schedule | Test Readiness | Budget

Software: Thermistor Interface

For a 2.5V input, expecting to see an average bar temperature of 294.67 K .
(Calculated for LA-1, as variable Rref and Rs will affect temp for each rod)





Overview | Schedule | Test Readiness | Budget

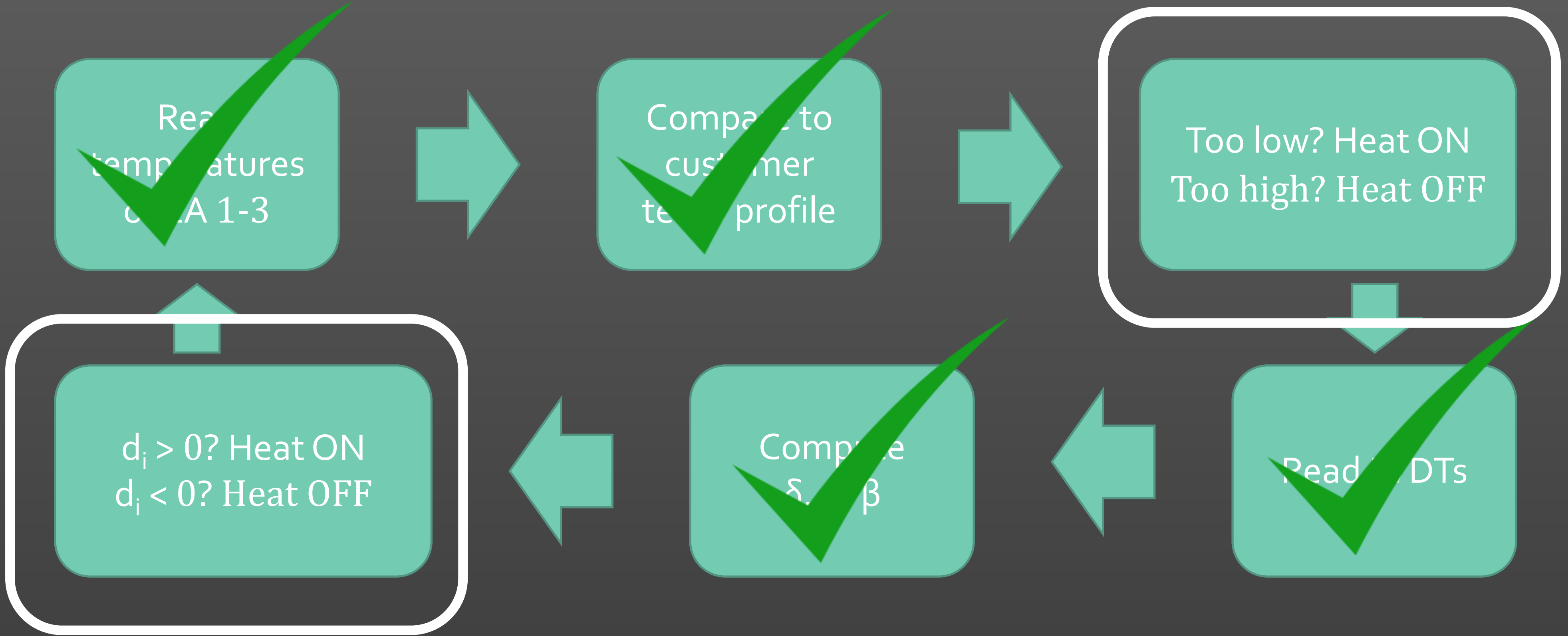
Software: Heater Control

Two system-level tests, each with distinct control sequences.

- Dynamic:
  - Track customer temp profile while maintaining alignment.
- Static:
  - Induce translational and rotational error, correct in given time.

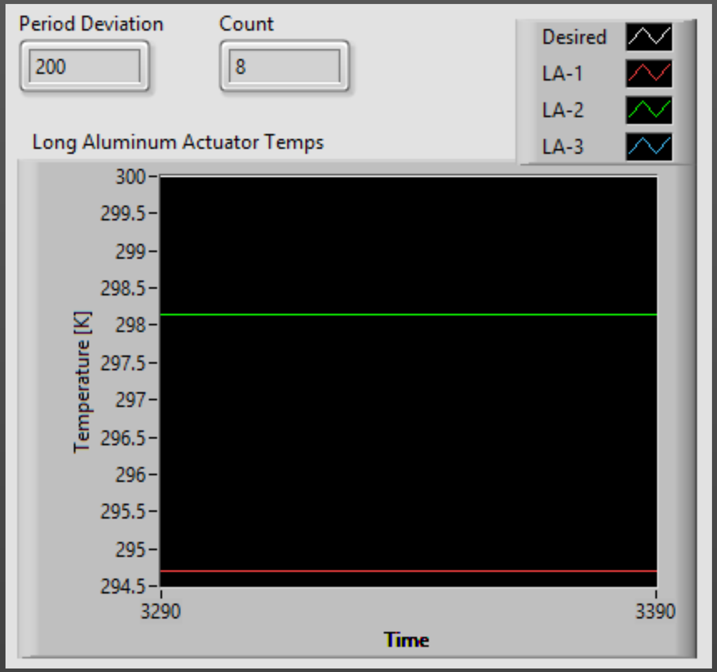
Software: Heater Control - Dynamic

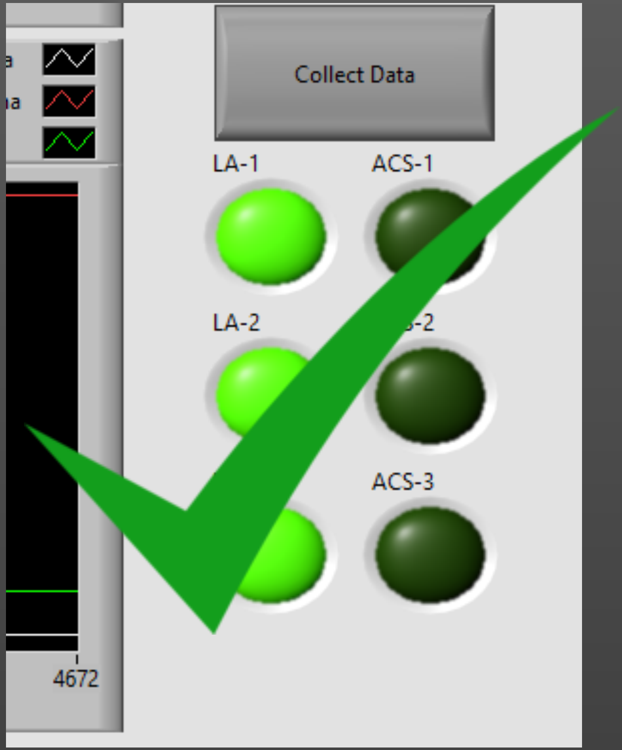
Track customer temp profile while maintaining alignment.



Software: Heater Control - Dynamic

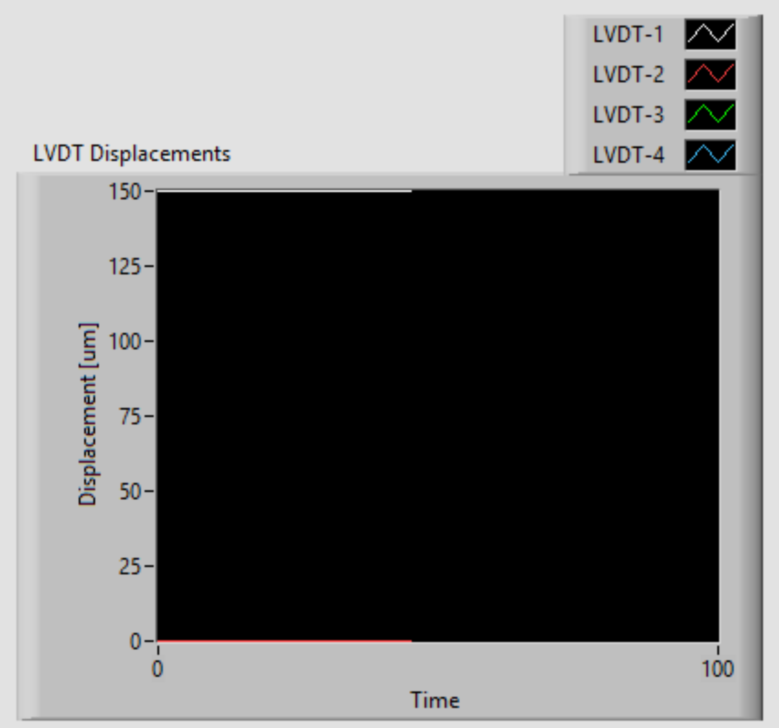
What if the bar temperature < customer profile? Does the respective test bed heater turn on?

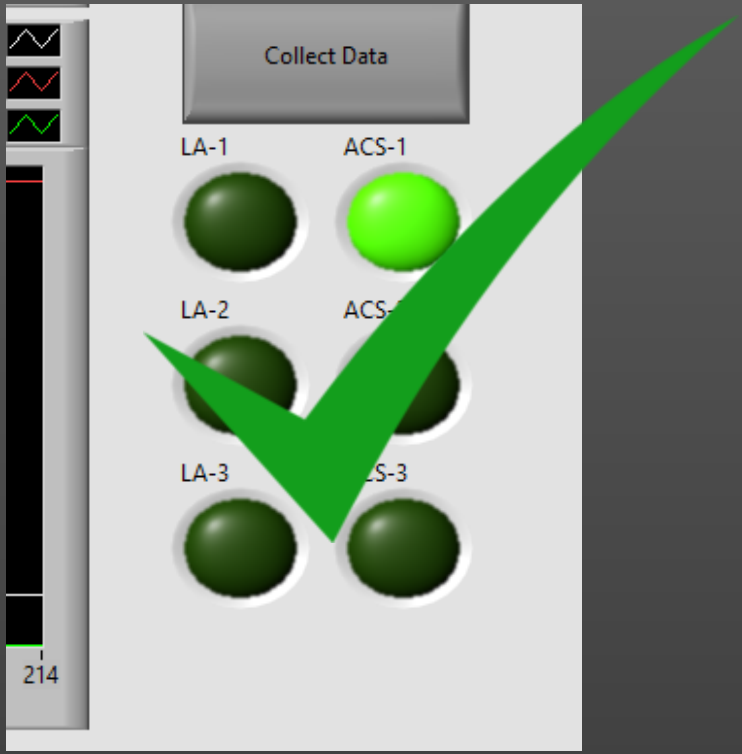




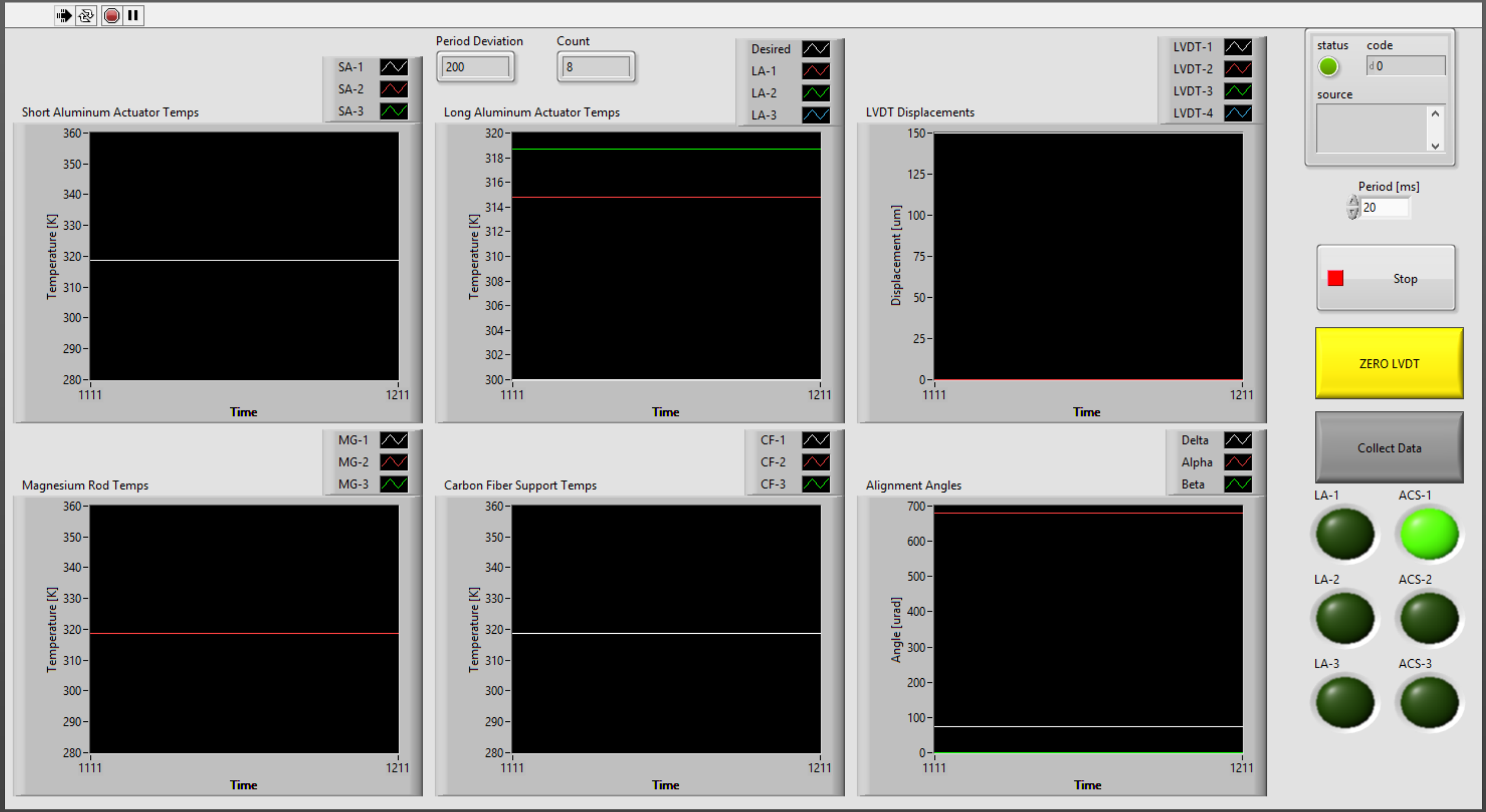
Software: Heater Control - Dynamic

What if $d_i > 0$? Does the respective ACS heater turn on?





Software: Data Display & Storage



Item/order

A	B	C	D	E	F	G	H	I
Item/order	**Cost**	**Status**				**Predicted**		
Al rods	43.98	Acquired		Still need: PCBs		Al rods	43.98	
Mg rods	38.44	Acquired				Mg rods	38.44	
Test Heater	55	Acquired				Test Heater	55	
Demo Board	155.49	Acquired				Demo Board	155.49	
16bit ADC	14.95	Acquired				16bit ADC	14.95	
Bread Board	54.75	Acquired				Bread Board	54.75	
LTC Chip	32.02	Acquired				LTC Chip	32.02	Acquired
Breakout Boards	46.31	Acquired				Breakout Boards	46.31	Acquired
Printing FFR	3.99	Acquired				Aluminum Plates	300	
Plates and Shims	527.67	Acquired				Stainless Steel Plates	119	
LVDTs and Mounts	1261.67	Acquired				Carbon Fiber Rods	210	
Relays	86.57	Acquired				Surface Mounts	50	
MUX/ therms	27.67	Acquired				PCBs	99	
Carbon Fiber Rods	144.45	Acquired				Heaters	725	
Heaters	544.36	Acquired				LVDTs	1360	
Screws	155.32	Shipped				LVDT Mounts	120	
Epoxy	63.45	Acquired				Therms	13.5	
Extender cable MyRio	24.74	Acquired				Shipping	180	
Plugs and end mills	114.28	Shipped				Margin	400	
New Relays	224.44	Acquired				**Total**	**4017.44**	
End Mill and Nylon Screws	41.95	Acquired						
PCB1	61.09	Acquired						
PCB 2	61.09	Acquired	Test	444.93				
Surface Mount Resistors	46.61	Acquired	Materials:	1047.12				
Surface Mount Resistors2	31.1	Acquired	Electronics:	677.63				
PCB round 2	115.4	Ready for Pickup	Sensors:	1289.34				
Shipping for last LVDT Mount	11.59	Shipped						
Female Headers	15	Acquired						
Total Cost:	**4003.38**							