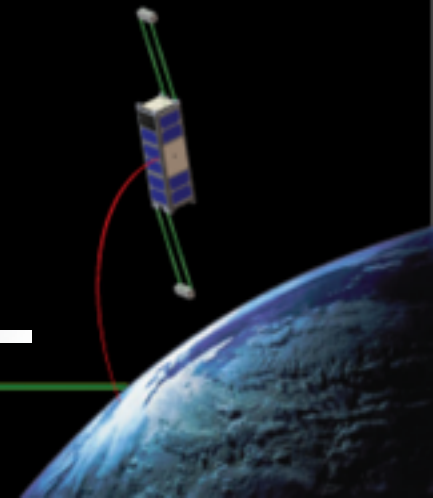


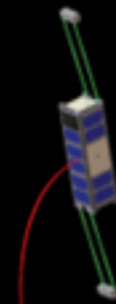
# A Failure Analysis of the ExoCube CubSat

13<sup>th</sup> Annual Cubesat Workshop  
San Luis Obispo, CA  
Wednesday, April 20<sup>th</sup>, 2016



# Background

- To characterize Hydrogen, Helium, Nitrogen and Oxygen, ions and neutrals in the Exosphere.
- Also measure total ion density above ground stations, and Incoherent Scatter Radar (ISR) stations.
- Collaboration between Scientific Solutions, University of Wisconsin in Madison, the University of Illinois, Cal Poly and Funded by the NSF.
- Mass Spectrometer built by NASA Goddard
- Launched aboard a Delta II on the NASA SMAP mission on January 31, 2015.



## Anomaly Investigation Panel

John Noto (Scientific Solutions)

Rick Doe (SRI)

John Bellardo (Cal Poly)

James Cutler (uMich)

Scott Higginbotham (NASA)

Robert Kerr (Scientific Solutions)

Jordi Puig-Suari (Cal Poly, Tyvak)

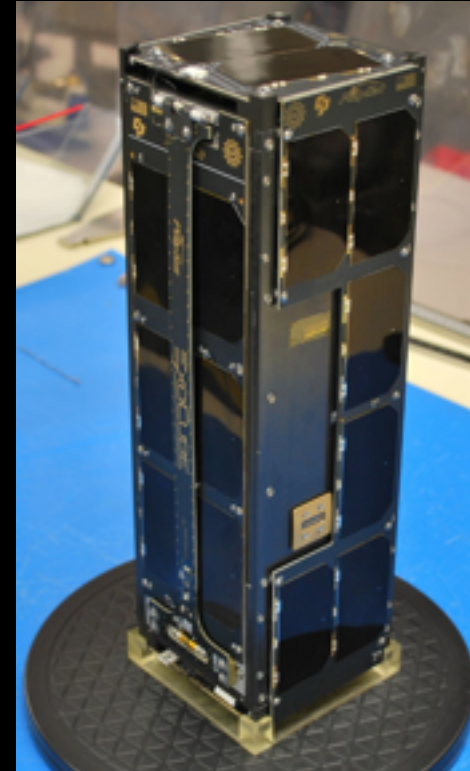
David Hinkley (Aerospace)\*

## Support

Jerry Fuller (Aerospace)

Alex Saunders (Cal Poly)

\* chairman



# Failure Review Process Steps



Establish a set of failure modes

Develop a fishbone and investigation plan

Coordinate a plan among personnel to implement root cause analysis

Establish a battle rhythm and communications protocol (e.g.: tag-ups, telecons)



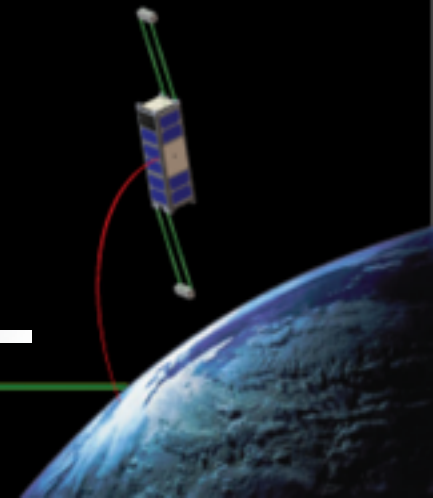
# Failure Modes



Antenna did not deploy

One of gravity gradient booms did not deploy

Radio stopped working 6 months after start of mission



# Anomaly #1: RF Antenna Deploy

## Anomaly Description



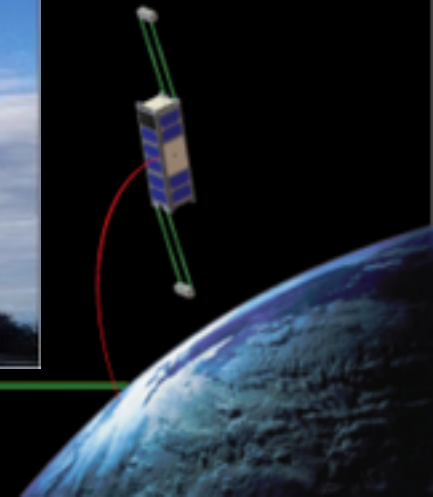
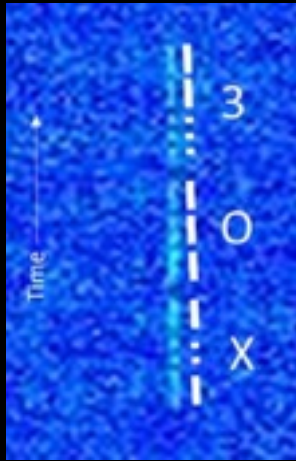
Description: RF antenna did not deploy

Evidence:

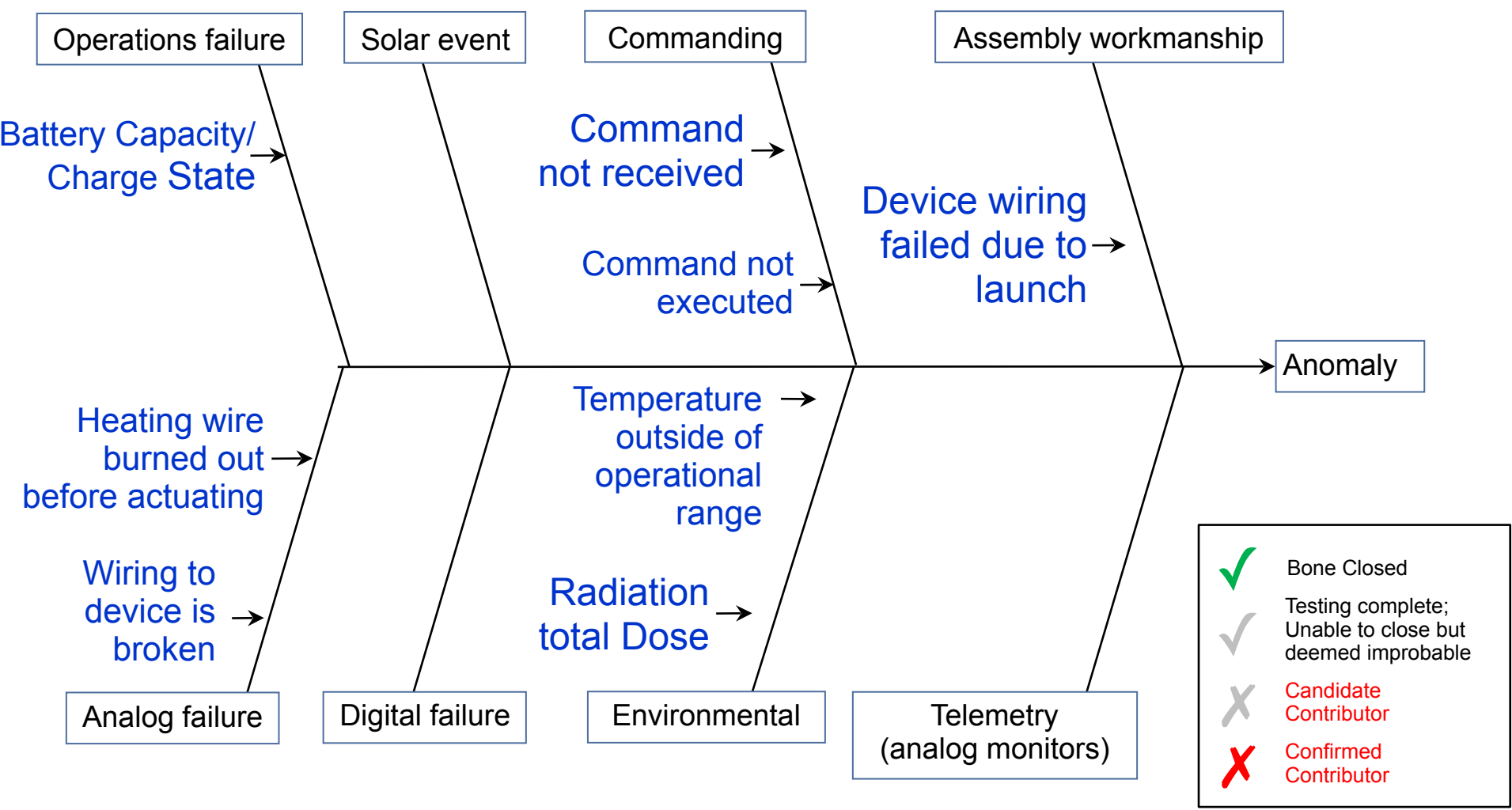
*Gain insufficient without 150' diameter SRI dish or NASA Wallops facilities to talk to satellite - using larger dish, satellite behaved nominally.*

List and timeline of relevant on-orbit events :

*Date: 2/1/2014      Observation: Weak signal from ExoCube*



# Fishbone Diagram

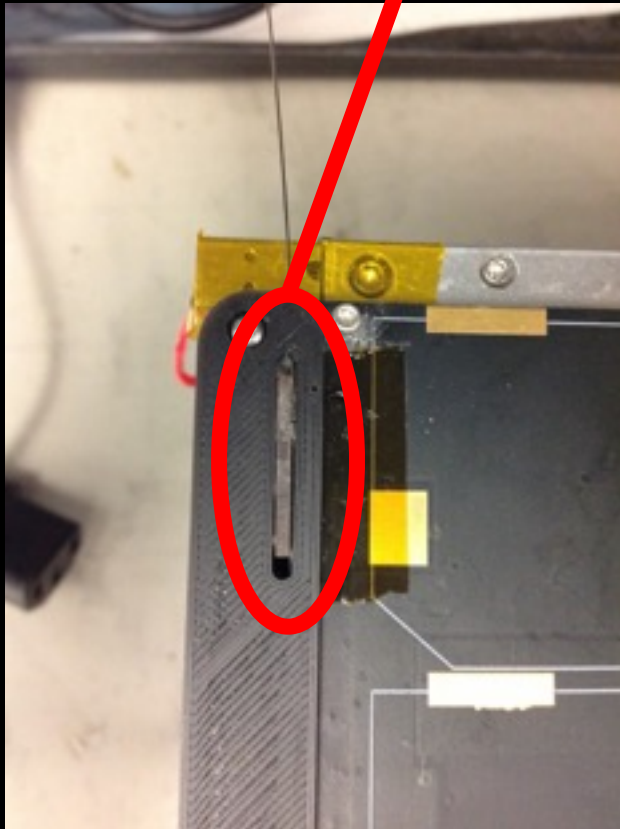


# Anomaly #1: RF Antenna Deploy

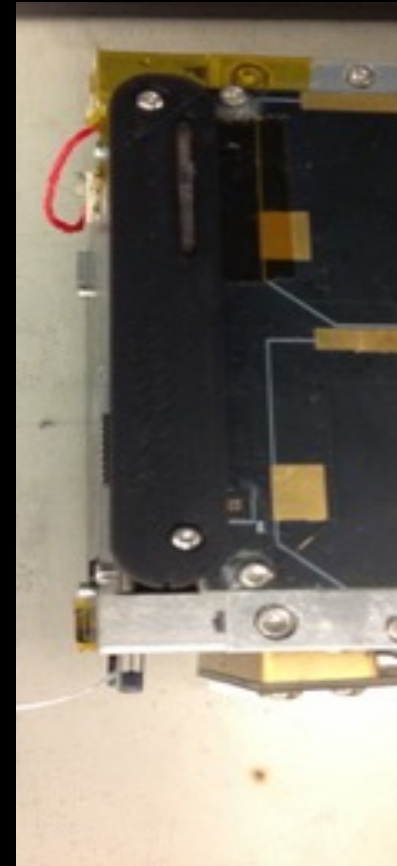
## *Pictures of Hardware*



Matching Board  
And Burn Wire



Antenna Route





# Anomaly #1: RF Antenna Deploy



## *Fault Response of the Burn-circuit IC*

Fault line - Active Low

Fault Occurs When:

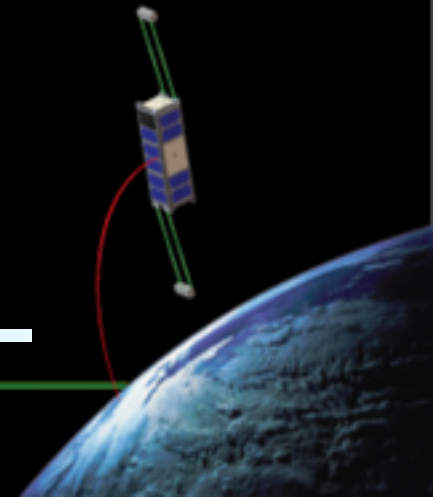
Overcurrent - Over 928.4mA

Over temperature - Over 135°C

Reverse Voltage – Over 190mV

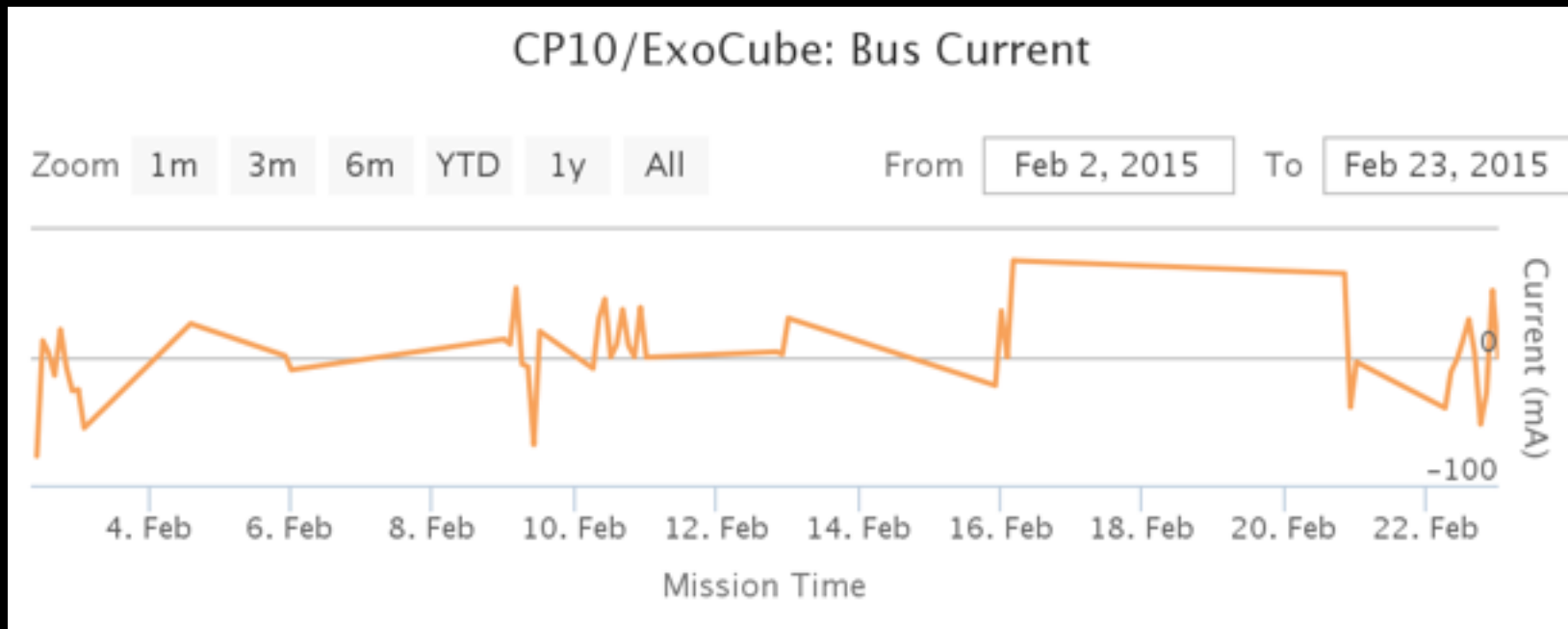
Prevents false reports with an internal delay deglitch circuit

Telemetry Output - First number is the number of times a burn was stopped, and the second is number of times a burn was initiated.



# Anomaly #1: RF Antenna Deploy

## Telemetry Evidence



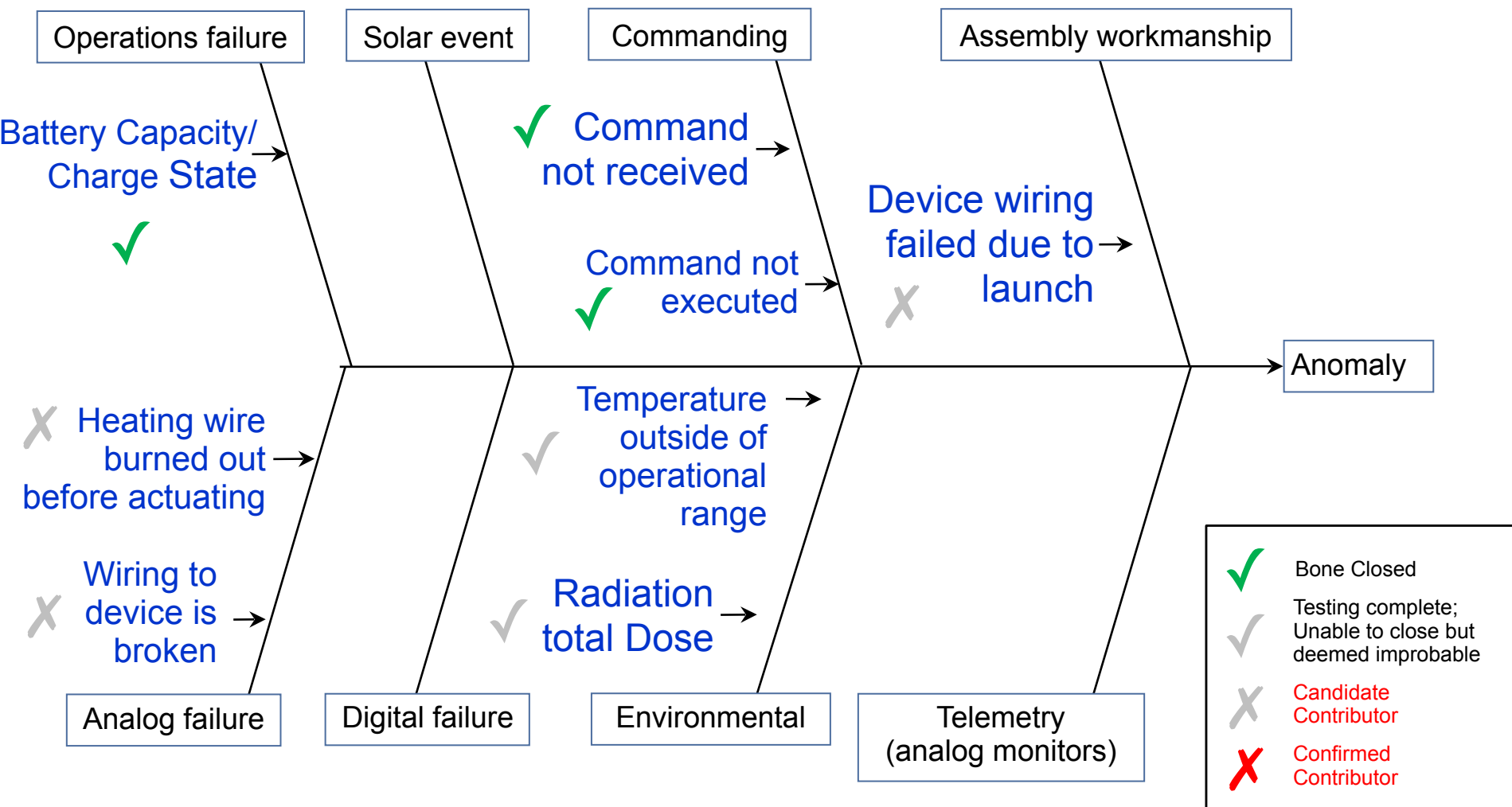
- Antenna deployment draws approximately 1 A of current
- However, no large current draw events seen in the first month

Current did not flow when commanded



# Anomaly #1: RF Antenna Deploy

## Fishbone Diagram



Likely that burn wire electrical path broke (burn wire itself or wires leading to it)

# Anomaly #1: RF Antenna Deploy



## *Evidence for Bone Closure*

### **Operations Failure**

#### *Battery Charge State*

Closed by showing that battery voltage was in the nominal range during deployment times.

### **Analog Failure**

#### *Heating Wire Burned Out*

Possible contender since no current was flowing through the burn wire.

#### *Wiring to Device is Broken*

Possible contender vibrations could have disconnected the wire leading to the burn element.



# Anomaly #1: RF Antenna Deploy



## *Evidence for Bone Closure*

### **Commanding**

#### *Command not Received, or not Executed*

Closed by viewing telemetry showing total number of completed burn commands.

### **Environmental**

#### *Temperature Outside of Operational Ranges*

Deemed not probable since command executed and satellites temperature was not out of nominal range

#### *Radiation Dose*

Closed considering EXOCUBE was only in orbit a few days before deployment was commanded, hard to test.

### **Assembly Workmanship**

#### *Device wiring failed due to launch.*

Possible that wire to heating element solder joints could have broken.



# Anomaly #2: Magnetometer Boom Deploy

## *Anomaly Description*



Description: One out of two booms did not deploy

Evidence:

*Boom magnetometer readings did not align with spacecraft navigation magnetometer readings*

List and timeline of relevant on-orbit events :

*Date: July 20th 2015*

*Observation: Extra Current draw indicating burn*

*Date: July 27th 2015*

*Observation: Mag boom data indicates one deployed*

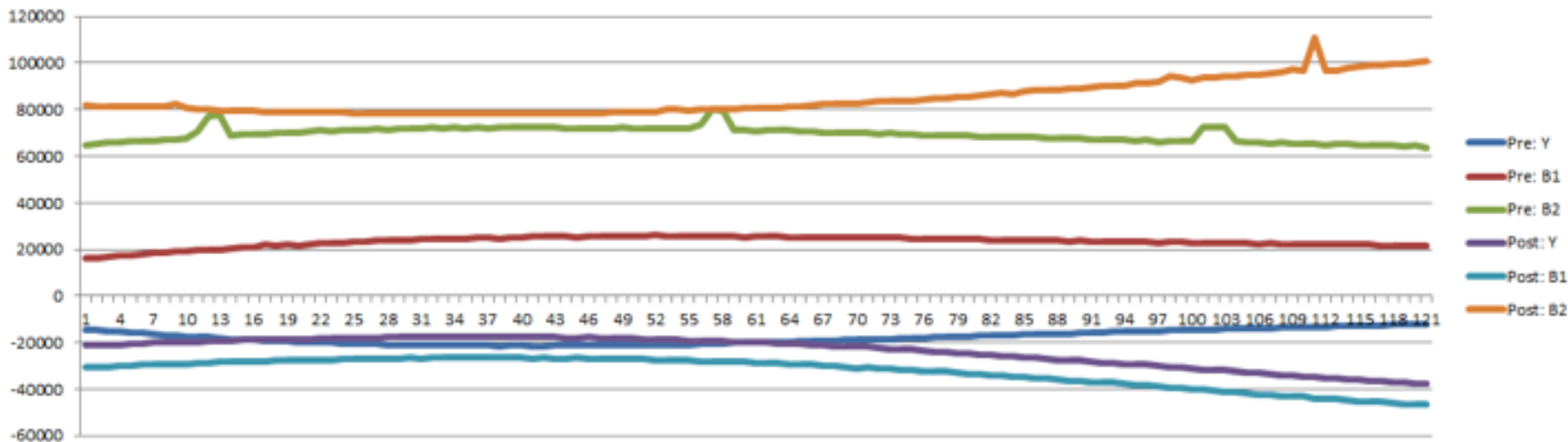


# Anomaly #2: Magnetometer Boom Deploy

*Magnetometer readings*



### Mag X Axis



Pre: Y, B1, B2 (Dark Blue, Red, Green respectively) Values do not line up.

Post: Y, B1, B2 (Violet, Light Blue, Orange respectively) Values of Post Y and B1 line up.

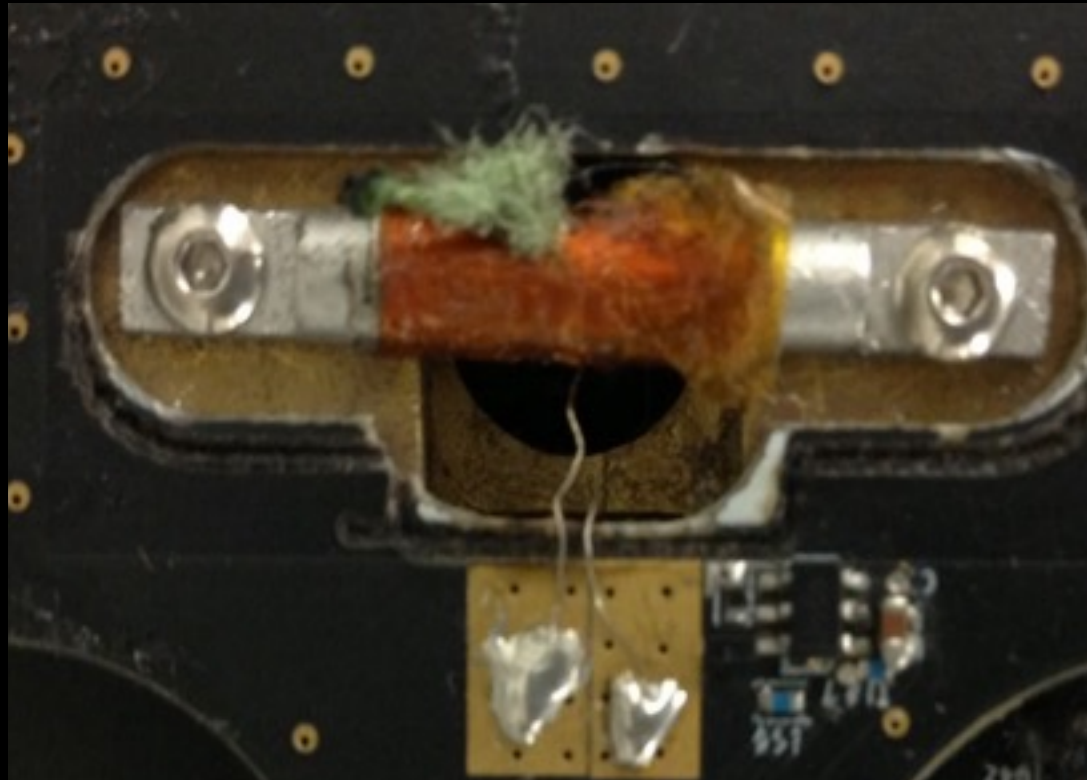
Post Y and B2 do not line up. B1 deployed and B2 did not.

On boom did not deploy

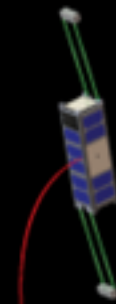


# Anomaly #2: Magnetometer Boom Deploy

*Pictures of hardware*



Process for installing burn wire has challenges





# Anomaly #2: Magnetometer Boom Deploy

*Fault Response of the Burn-circuit IC)*



Fault line - Active Low

Fault Occurs When:

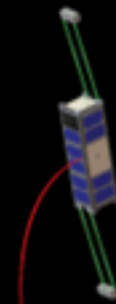
Overcurrent – Set by an external resistor - Over 450mA

Over temperature - Over 135°C

Reverse Voltage - Over 190mV

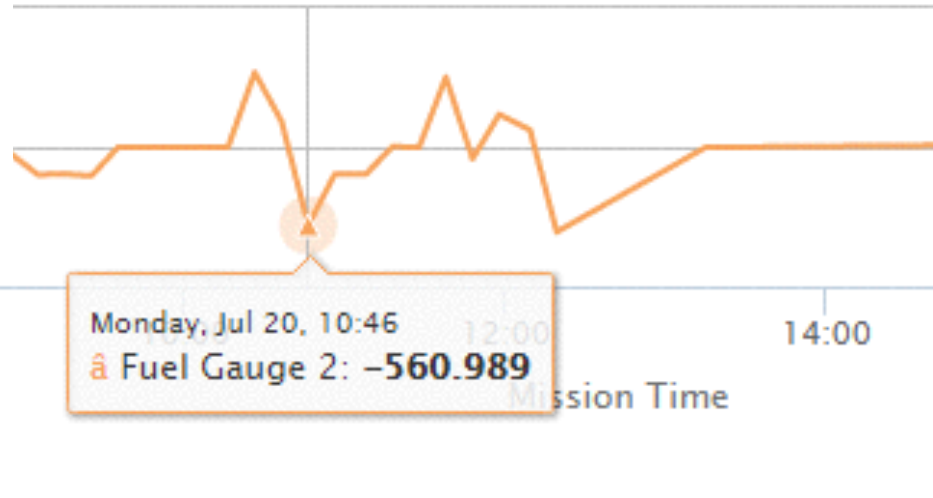
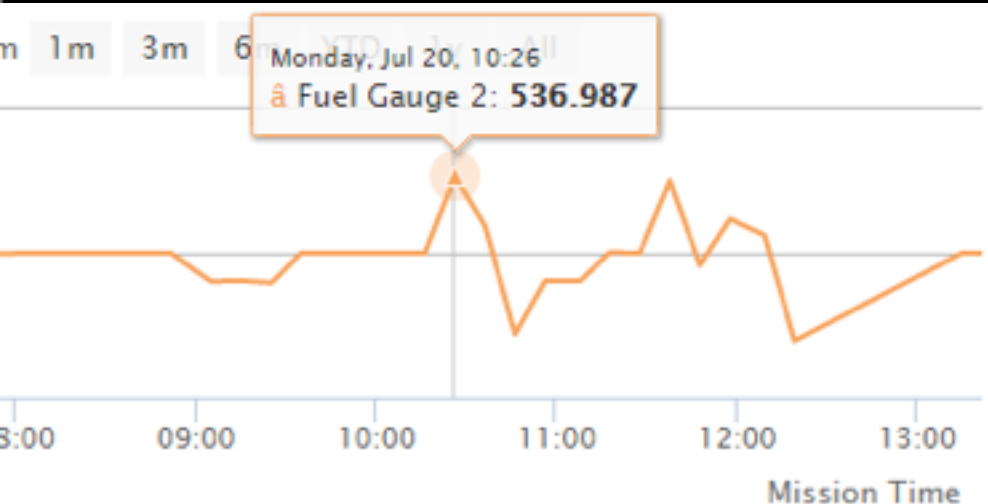
Prevents false reports with an internal delay deglitch circuit.

No Faults Were detected



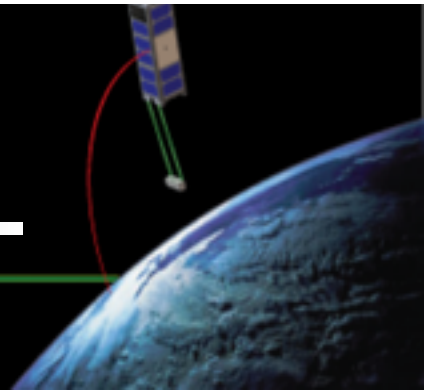
# Anomaly #2: Magnetometer Boom Deploy

Telemetry evidence



- Approximately 1100 mA indicates both burn wires active.
- Data from day of boom deployment July 20th.

Commanded current was realized



# Anomaly #2: Magnetometer Boom Deploy

## Telemetry evidence



fuelGaugeOne	volt:	4.040588 V
fuelGaugeOne	current:	-0.297989 A
fuelGaugeOne	currentAccum:	2.026993 A
fuelGaugeOne	volt:	4.040588 V
fuelGaugeOne	current:	-0.528000 A
fuelGaugeOne	currentAccum:	2.026993 A
fuelGaugeOne	volt:	4.035690 V
fuelGaugeOne	current:	-0.528000 A
fuelGaugeOne	currentAccum:	2.026993 A
fuelGaugeOne	volt:	4.035690 V
fuelGaugeOne	current:	-0.528000 A
fuelGaugeOne	currentAccum:	2.026993 A
fuelGaugeOne	volt:	4.035690 V
fuelGaugeOne	current:	-0.728989 A
fuelGaugeOne	currentAccum:	2.025986 A
fuelGaugeOne	volt:	4.035690 V
fuelGaugeOne	current:	-0.728989 A

- About 430 mA current per boom.
- Differences can be explained with the error associated with the switch error of approximately +/- 40mA.

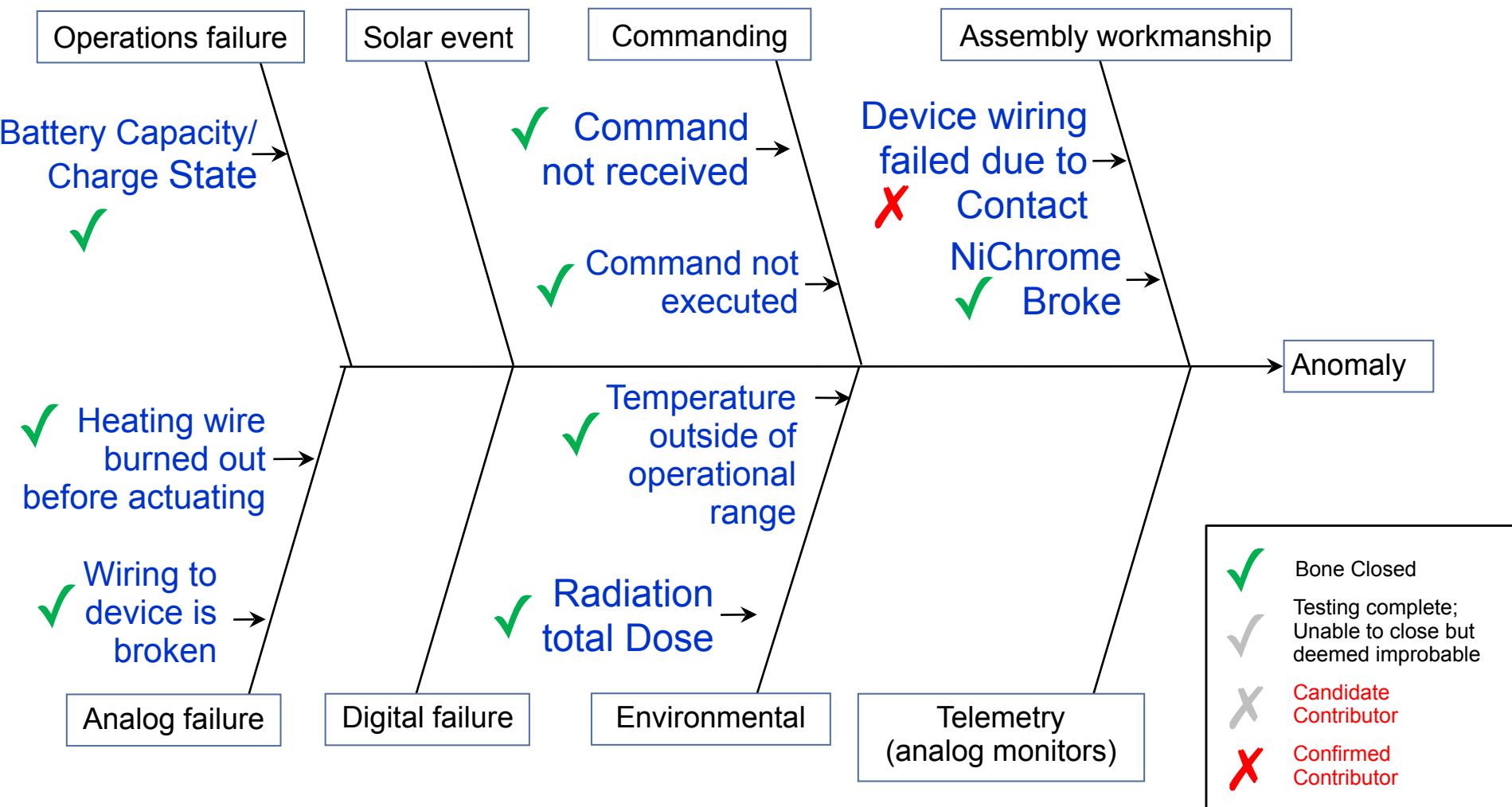
Commanded current was realized

---



# Anomaly #2: Magnetometer Boom Deploy

## Fishbone Diagram



Conclude insufficient contact between burn wire and restraint filament

# Anomaly #2: Magnetometer Boom Deploy



## *Evidence for Bone Closure*

### **Operations Failure**

#### *Battery Charge State*

Closed by showing that battery voltage was in the nominal range during deployment times.

### **Analog Failure**

#### *Heating Wire Burned Out*

Closed by showing current flow through the burn circuit.

#### *Wiring to Device is Broken*

Closed by showing current flow through the burn circuit.



# Anomaly #2: Magnetometer Boom Deploy



## *Evidence for Bone Closure*

### **Commanding**

*Command not Received, or not Executed*

Closed since current telemetry shows commands executed successfully

### **Environmental**

*Temperature Outside of Operational Ranges*

Closed by showing the circuit works and the current flow was nominal.

*Radiation Dose*

Closed by showing the circuit works and the current flow was nominal

### **Assembly Workmanship**

*Device wiring failed due to launch.*

Closed by showing current flow was nominal.

*Burn Wire did not Make Good Contact with Fishing Line*

Deemed the most probable since in lab testing shows that burn wire was hot, but did not cut the fishing line..



# Anomaly #3: Radio stopped working

## *Anomaly Description*



Description: Radio transmissions ceased

Evidence:

*Nothing has been heard from satellite since 6 months after mission start  
Noticeable degradation of performance 1 week prior to silence*

List and timeline of relevant on-orbit events:

*Date: 7/30/2014*

*Observation: RF Temperature Sensor Reset*

*Date: 7/30/2014*

*Observation: Poor Radio Performance*



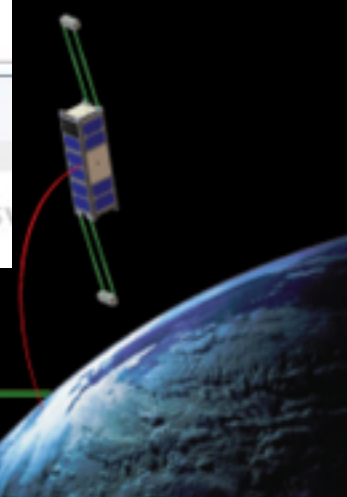
# Anomaly #3: Radio stopped working

## Telemetry evidence



### Overview:

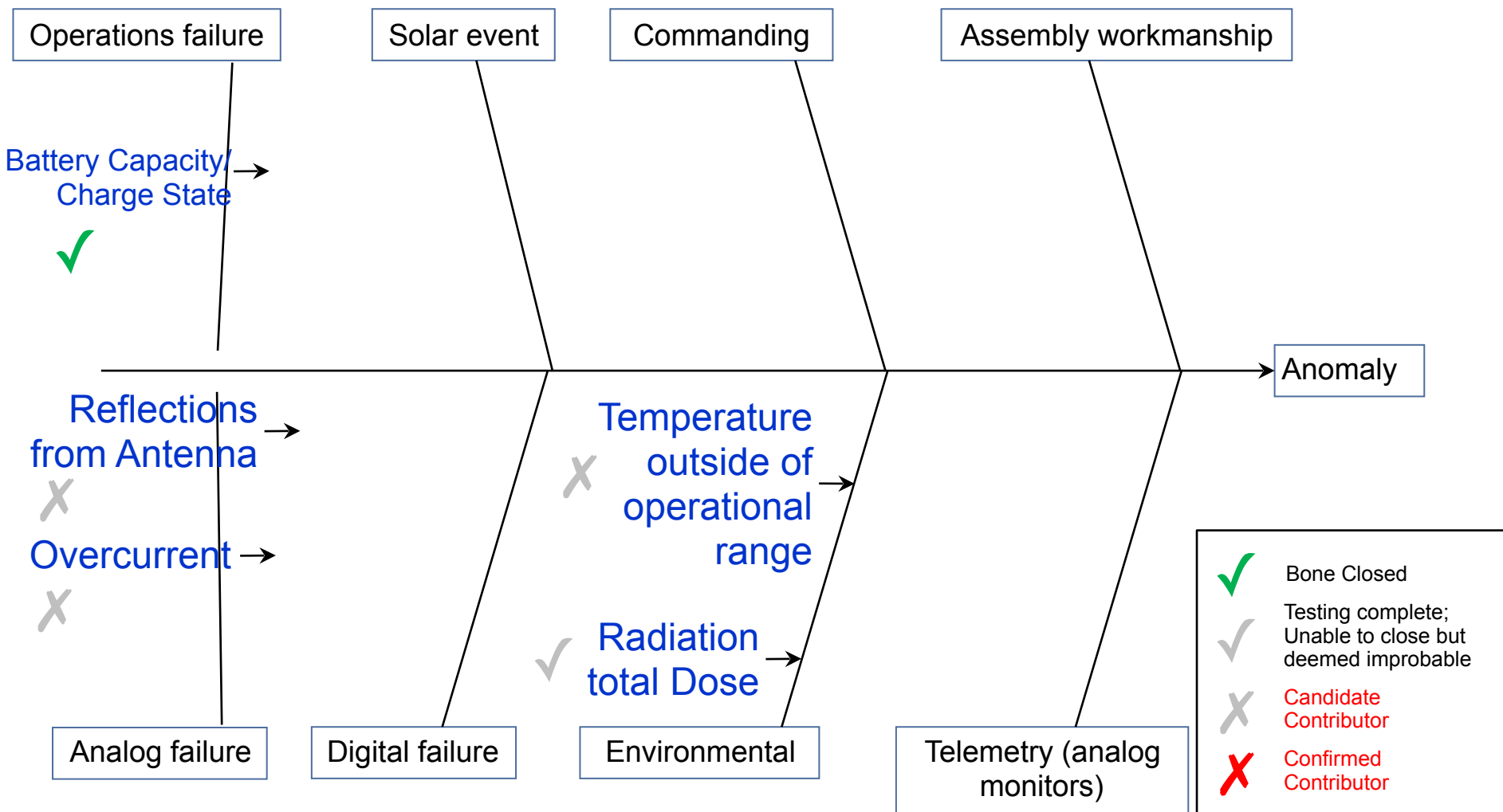
- Radio amplifier saw a large amount of reflections.
- Large amount of power dissipated in amplifier.





# Anomaly #3: Radio stopped working

*Fishbone*



**Suspect RF amplifier failed due to reflected RF energy from undeployed antenna**

# Anomaly #3: Radio stopped working

## *Evidence for Bone Closure*



### **Operations Failure**

#### *Battery Charge State*

Closed by showing that battery voltage was in the nominal range during deployment times.

### **Analog Failure**

#### *Reflections From Radio*

Possible contender because the antenna did not deploy which causes RF reflections.

#### *Overcurrent*

Possible, subset of RF reflections. Reflections could increase the voltage reflected which would drive current back through the amplifier.

### **Environmental**

#### *Temperature Outside of Operational Ranges*

Possible contender since a mismatch of the antenna causes more current to be used.

#### *Radiation Dose*

Closed because it can not be easily tested.



# Lesson's Learned

- Design for testability and repeatability
  - NiChrome needed to be reset after every test
- Design more reliable systems
  - Technically
  - Procedurally

“Failure is only the opportunity to begin again,  
only this time more wisely.” - Henry Ford



# Questions?

