AMSAT CubeSatSim – Interpreting Telemetry Data – Instructor's Guide

Version 1.0 – Aug 2025 - Fredric Raab KK6NOW - FredricRaab@yahoo.com

Overview:

In these activities, students will assess the operational status and health of the CubeSatSim (CSS) by interpreting the "housekeeping" data sent by the satellite to the ground station. Since all satellites send such status data in addition to their mission-specific data, these activities are applicable to all satellites, small and large.

Students will learn:

- The major subsystems common to all satellites
- The status update messages indicating the health of these systems
- How telemetry values correlate to the orientation and environment of the cubesat.
- How to troubleshoot problems from observing telemetry data

This online Glossary can help with any terms or acronyms you may not know.

Materials:

- Instructor's Guide (this document)
- FoxTelem installation and operation instructions (attached)
- Student Activity Worksheet (PDF)
- Instructor Worksheet with answers (attached)
- Instructor script for advanced exercise scenarios

- AMSAT CubeSat Simulator
- Turntable and LED lamp
- AMSAT FoxTelem software v1.13i or later
- RTL-SDR v3 (not v4) USB radio and antennas
- Computer (Mac, Windows, or Linux)
- Large monitor or projector to show FoxTelem display to class

Preparation:

- Familiarize yourself with the materials listed above.
- Download and install RTL-SDR drivers, software and FoxTelem program.
- Fully charge CubeSatSim batteries (typically 8 hrs)
- Follow the initial procedures (listed under FoxTelem Operations) to determine that the CSS is transmitting and FoxTelem is receiving data
- Upon successfully testing, exit FoxTelem and power down CSS.

Procedure:

1. Organize students into teams of 2 or 3.
2. Have enough worksheets for student teams
3. Connect the FoxTelem system to a projector (or large screen monitor) so all students can view the screen.
4. Follow the instructions on the Instructor's worksheet. Have students follow along and answer the questions on their worksheets.
5. Take questions from the students. Refer to the Instructor's worksheet of explanations.
6. Should time allow, conduct the advanced exercise:
   1. Relocate CSS, turntable and lamp out of the student's view, ideally in direct sun.
   2. Have another student follow the instructions in the scenario script.
   3. Announce the start of each scenario.
   4. Allocated approximately 15 minutes for students to resolve the issue presented.
   5. Upon completion, move onto the next scenario and repeat.

AMSAT CubeSatSim – FoxTelem Installation and Operation
Version 1.0 – Aug 2025

The FoxTelem program was built by AMSAT to decode and display data from their five 1U cubesats in the "Fox" series, launched between 2015 and 2017. It uses a SDR (Software Defined Radio) to receive and demodulate the encoded radio signal from the simulator.

The program is organized by tabs. The Input Tab displays the raw and demodulated signals. Two different modulation techniques can be used: FSK (Frequency Shifted Keying) and BPSK (Binary Phase-Shift Keying). In FSK modulation, data bits (as 0's and 1's) are encoded as changes between two different radio frequencies. In BPSK, data is encoded as changes in the signal's phase. For the CSS, both techniques return the same data. In this example, we will use BPSK. The CubeSatSim-BPSK tab displays the data as it is received.

FoxTelem Installation:

This exercise assumes the FoxTelem v1.13i or later program has been downloaded and installed from https://www.g0kla.com/foxtelem/ and that the RTL-SDR driver has been installed and the RTL-SDR v3 is plugged into the USB port.

FoxTelem Operation:

To start FoxTelem:

1) Open the program by double clicking on the FoxTelem icon.
2) Once opened, the Input tab should be displayed. Verify the following:
   - Telem Format: BPSK 1200bps (Fox1E)
   - RTL SDR shows in pull-down menu
   - IQ is selected
   - Center Frequency set to 434900.0
3) Under the File Menu, select Settings and verify that PSK: Use Costas and Find Signal is checked.
4) Click the Start button
5) Click the Monitor Audio button to listen to the received signal through your computer's speakers.
6) Unplug the Remove Before Flight plug to power on the cubesat.
7) Hold the pushbutton until the Green Power LED flashes three times, then release. The CubeSat should now be transmitting in BPSK mode.
8) Place cubesat flat on the turntable with the antennas on top. Place either in the sun or next to the LED lamp.

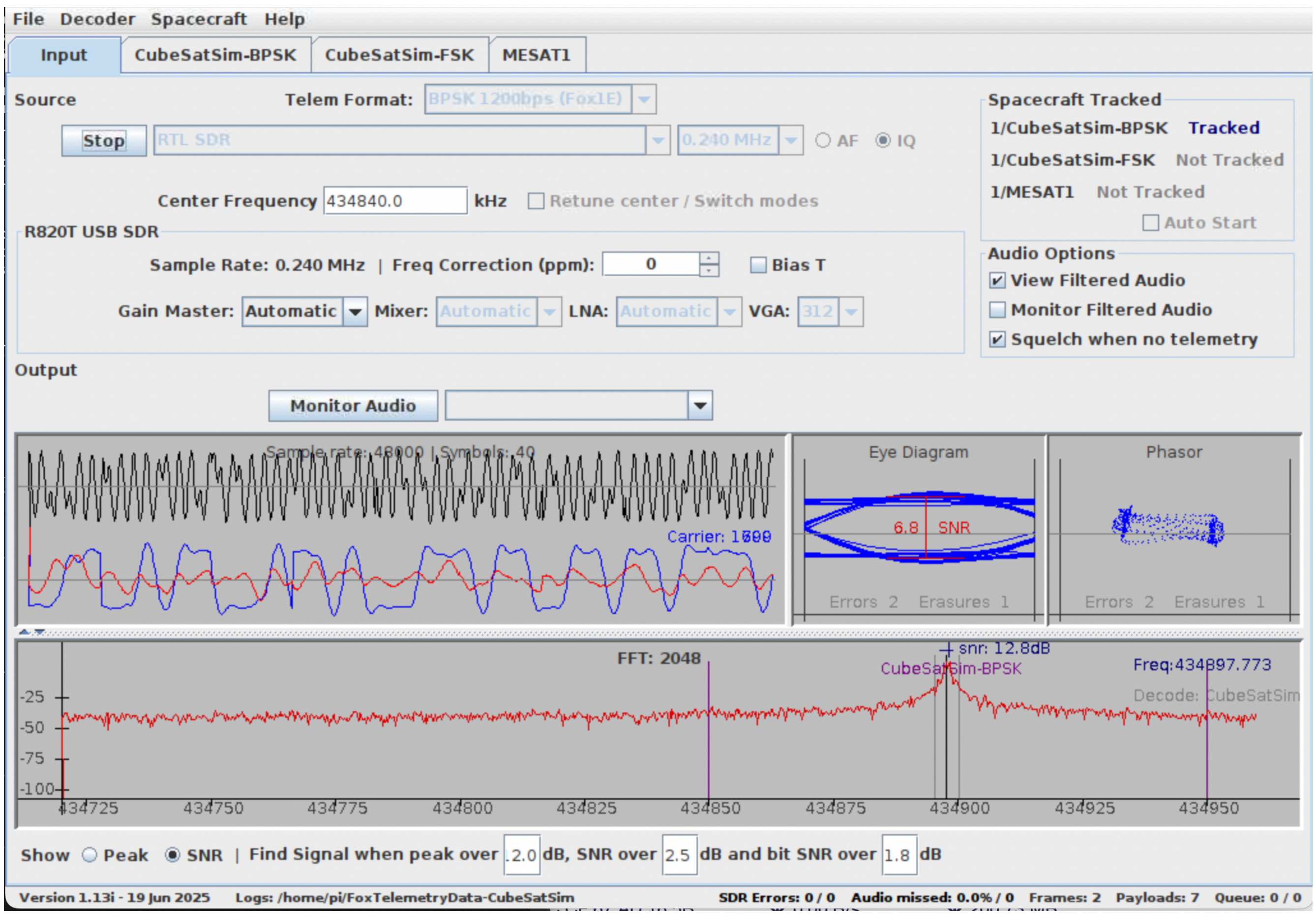
   NOTE: The current produced by the solar panels when exposed to LED lamps is very low compared to that produced in direct sunlight. If possible, conduct the following observations when the CubeSat is in sunlight near a window, or better, outside.

9) Start the turntable spinning at L (Low) speed.

10)Listen for call-sign transmitted in Morse code
11)Listen for the data sounding like static with occasional short buzzes.
12)Click the "Silence Speaker" button to turn off audio monitoring.

13)Wait for FoxTelem to lock on to the signal. The Eye Diagram should appear eye-shaped; the Sample Rate will appear like square waves; the Frequency Spectrum should show a peak at approximately 434900 as shown below

NOTE: Pay special attention to the sound of the signal and the waveform shown in the Sample Rate window. These can change depending on the satellite's transmission mode. Most satellites transmit in multiple modes.



14)Verify the Frame count at the bottom right of the screen is incrementing approximately every 4 seconds

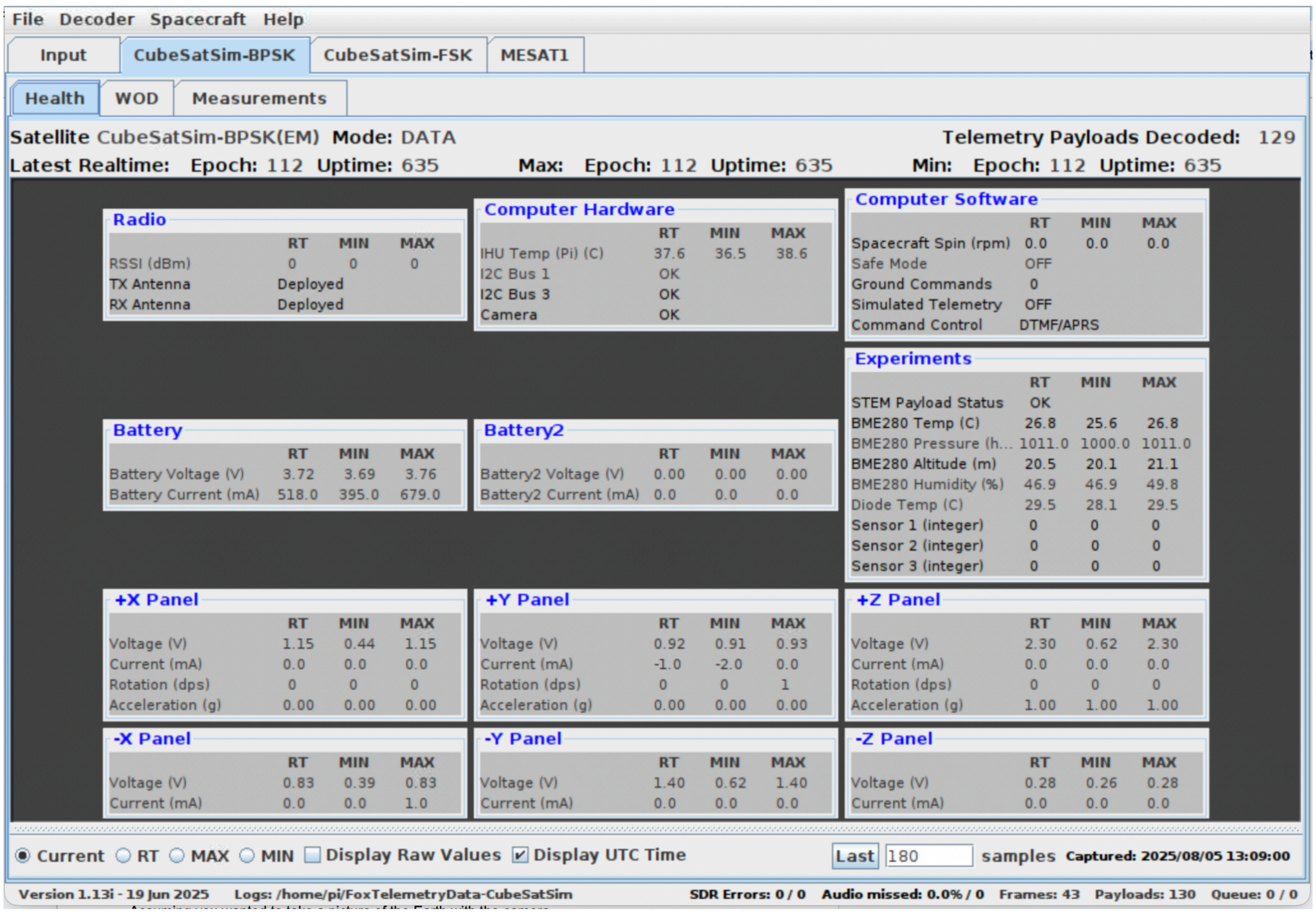
15)Click on the CubeSatSim-BPSK tab. The information required for the activities can be found on this tab.

BPSK Tab Layout:

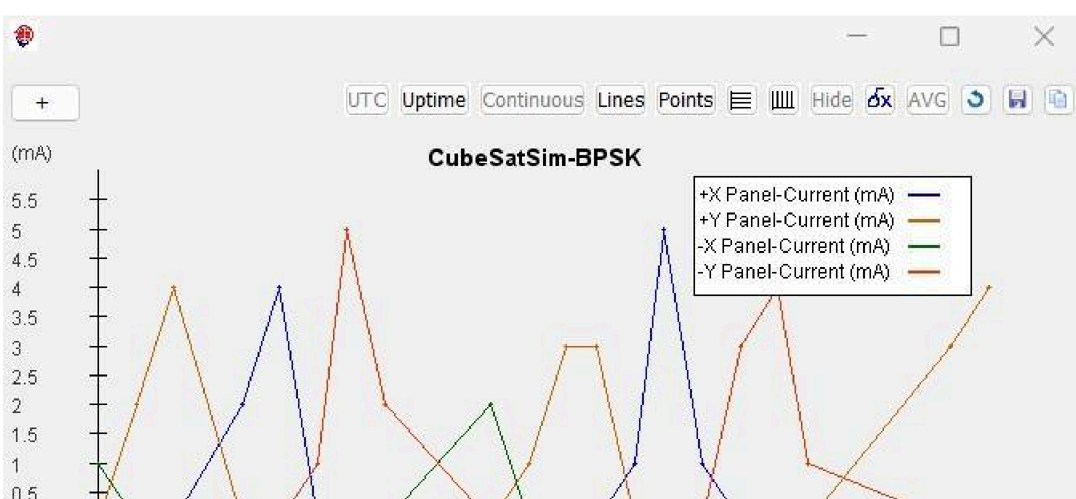
Each box represents a subsystem of the CubeSatSim and each contains the following columns:

- RT (real-time) is the most recent measurement value received.
- MIN (minimum) is the lowest measurement value received.
- MAX (maximum) is the highest measurement value received.

The measurements most relevant to these activities are those of the battery and solar panels. Note that the Inertial Measurement Unit's (IMU) X, Y, Z values are contained within the +X, +Y and +Z panel boxes.



Plotting Data:



Clicking on any measurement value opens a window containing the plot of that measurement over time. The number of data points displayed can be set in the samples box. The Uptime is the number of seconds since the CSS has been powered on or rebooted.

Additional measurements can be added to the plot by clicking the **+** button. Select the desired measurement from the pull down menu. To remove a measurement from the plot, select it again from the pull down menu.

The vertical axis of the plot automatically scales to accommodate the values.

The above plot shows the current produced by each of the solar cells as the CSS (placed on on a turntable) spins past a LED lamp. Note the results are much more significant when the CSS is placed in direct sunlight.

Experiments Box:

This box contains measurements from the BME280 sensor. It measures the following:

Temperature (in Celsius) – typically room temperature
Pressure (in hPa) – atmospheric pressure (1 inch of mercury = 33.863 hPa)
Altitude (in meters) – computed from pressure (sea level = approximately 1000 hPa)
Humidity (in percentage)

Diode Temperature is another way of computing temperature. However it needs to be calibrated and for our purposes it can be ignored.

Sensors 1, 2, and 3 are zero unless additional sensors have been added and are not used here.

Experiments

	RT	MIN	MAX
STEM Payload Status	OK		
BME280 Temp (C)	26.8	25.6	26.8
BME280 Pressure (h...	1011.0	1000.0	1011.0
BME280 Altitude (m)	20.5	20.1	21.1
BME280 Humidity (%)	46.9	46.9	49.8
Diode Temp (C)	29.5	28.1	29.5
Sensor 1 (integer)	0	0	0
Sensor 2 (integer)	0	0	0
Sensor 3 (integer)	0	0	0

AMSAT CubeSatSim – Interpreting Telemetry Data – Activity Guide
Version 4 – Aug 2025

Group: ___________________________________Date: ________________

Introduction:

In this activity, you will learn how to assess the operational status and health of a CubeSat by interpreting the “housekeeping” data included in the telemetry data sent by the satellite to ground stations. Since all satellites send such data in addition to their mission-specific data, the skills you acquire are applicable to all satellites, small and large. Large satellites typically have more systems to monitor, thus more housekeeping data to send.

These activities take you through the FoxTelem sections, each representing a CubeSat subsystem. Use this worksheet to record your observations. In some cases, you will be asked to hypothesize the reason for your observation.

Be sure to note how the telemetry values change based on the orientation and environment of the CubeSat. In these exercises, you can see and manipulate the physical CubeSat. When in space, (and in an advanced exercise), you only have the telemetry data available. Using only that data, you can assess the position and health of the satellite.

Subsystem Status

Look across the top row of data to determine the status of subsystems. In order, left to right, top to bottom.

Computer Hardware

What is the temperature of the IHU (Internal Housekeeping Unit – in this case, the processor chip)? *Typically 42C*

Is the camera operational? *OK = Yes*

Are the I2C buses operational? *OK = Yes*

Computer Software

Spacecraft Spin (in revolutions per minute) is zero because the cubesat simulator software doesn’t calculate the spin rate.

CubeSat is placed in safe mode to save power when battery voltage drops below 3.6 volts

Ground Commands displays the number of commands received by the CubeSat when you are using the Command and Control function - link to Wiki page for instructions.

Simulated Telemetry: If on, the cubesat is transmitting simulated data. Is it set to on? *No*

Battery (raw values measured at battery)
What is the total battery voltage? ________________________
What are the current (milliamp) values? ________________________
Why sometimes negative and sometimes positive? *Current is negative when battery is charged via USB or solar panels*

Battery2 - readings of a second Battery board - will be zero unless a 2U CubeSatSim
What is the Battery2 voltage value? Is it as expected? ________________________
What is the Battery2 current value? Is it as expected? ________________________

Payload Experiments
Is the payload operational? *OK = Yes*
Are the values shown reasonable and why? ________________________
Is there a difference between the BME280 Temp and the Diode Temp? If so, why? ________________________

Solar Panels

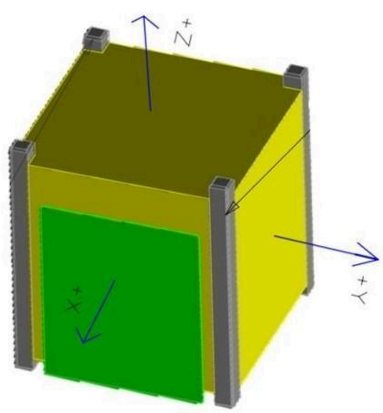
These sections display the voltage and current generated by each solar panel. In addition, the Plus (+) panels have measurements for:

- Acceleration (in g's where 1 g = 1 gravity) can be used to determine the cubesat's orientation in relationship to Earth
- Rotation (in degrees per second – range = 0 – 360) that can be used to determine how and how fast the cubesat is spinning

The CubeSat Design Specification (CDS) standard defines the X, Y, and Z sides of a 1U CubeSat https://www.cubesat.org/cds-announcement. Below is a figure from that document:

Consider the CubeSat's orientation for the following questions:

- +Z is the top of the CubeSat with the antenna connections. -Z is the bottom, or opposite size.
- +X is the side with the pushbutton and LEDs. -X is the opposite side with the optional camera.
- +Y is the side 90 degrees counter-clockwise to the +X. -Y is the opposite side of +Y.



Acceleration (Orientation)

Many cubesats contain an Inertial Measurement Unit (IMU) that contains an accelerometer and gyroscope. Typically, the accelerometer is measuring the change in the object's velocity. A positive value indicates the velocity is increasing – the object is speeding up or accelerating. A negative value indicates the velocity is decreasing – the object is slowing down or decelerating.

When the object is at a constant speed or is at rest, the acceleration is zero. However, the accelerometer is still responding to the Earth's gravity and thus can be used to detect the CubeSat's orientation in 3 dimensions: +1 indicates that the side is pointing upwards.

With the antennas on top, which axis has the highest acceleration value and what's the value?	*+Z value = approximately +1*
Place the cubesat's +X panel face down on the turntable. *How have the acceleration values changed? And why?*	*+Z value now zero* *+X value = approximately -1* *since accelerometer is inverted*
Find an object that you can place under the +X side (with pushbutton) such that the top +Z side is tilted at an approximately 45 degree angle.	
What are the three acceleration values? Can you explain each?	___________________________
Assuming you wanted to take a picture of the Earth with the camera pointing straight down, what would the accelerometer values be for each axis?	____________________________

Exercise: Have a person hold the cubesat in different orientations (positions) and record how the acceleration values change with each orientation.

Then, without looking, determine the orientation of the cubesat solely by looking at the acceleration values.

Rotation:

Cubesats in space may rotate (spin) on one or more of their axes; sometimes all 3. There are two ways to calculate the spin rate:

- Many cubesats contain an Inertial Measurement Unit (IMU) that contains an accelerometer and gyroscope. The gyroscope returns the change in direction (angular velocity) in degrees per second (dps). The gyroscope values are reported in Foxtelem. Note: there are 360 degrees per revolution, thus 6 degrees per second equals 1 revolution per minute.

- As the cubesat rotates, different sides of the cubesat receive full sunlight while their opposite side receives partial or no sunlight. By measuring the change in the solar panel current output over time, the software can calculate the spin rate for each axis. This method will be demonstrated in the next exercise.

With the turntable speed set to high, what panel axis is displaying the highest rotational value? What is that value in degrees per second (DPS)?	*+Z axis when antennas are pointing upwards*

Calculate the spin rate in revolutions per minute. Also compute the time required to make one revolution (in seconds). Using a stopwatch, find the number of seconds required by the CSS to complete one revolution. Do the numbers agree? ____________________________
Set the turntable speed to low and repeat this activity.

Solar Panel Output Power

The CubeSat Simulator's solar panels typically output 4 volts when exposed to direct sunlight. As the light level decreases, so does the output voltage. Even dim light may produce 1 or 2 volts. Total darkness should produce 0 volts. However, a very small voltage may be reported due to the diode in series with each solar panel..

A more significant value is the amount of current produced, since it is current that does the work of powering the CubeSat and recharging the batteries. Also, current varies more with light intensity than the voltage varies.

NOTE: The current produced by the solar panels when exposed to LED lamps is very low compared to that produced in direct sunlight. If possible, conduct the following observations when the CubeSat is in sunlight near a window, or better, outside.

With the turntable off, position the cubesat such that the +X panel (containing the push button) is directly facing the lamp. What are the voltage and current readings for the +X and +Y panels? ____________________________
Rotate the cubesat 90 degrees clockwise such that the +Y panel is directly facing the lamp. How have the readings of the +X and +Y panels changed? ____________________________

Turn on the turntable with speed set to high and observe how the readings change over four rotations.

The FoxTelem software can display a graph of multiple telemetry parameters over time. To graph a value, click on its name or value in the table. Then click the '+' button and pull-down other values to add to the graph.

First graph the current values of the +X, +Y, -X, -Y panels over four rotations. What relationships do you observe? What parameter changes the most?

See plot in FoxTelem operation section.

Using Output Current and Voltage to Calculate Spin Rate

Measure the time (in seconds) between the peaks of the value that changes most. Use this value to calculate the spin rate in degrees per second and rotations per minute. ____________________________

How does this spin rate compare to that provided by the IMU? ____________________________

Satellite battery power when in eclipse [the Earth's shadow]

A typical cubesat in low earth orbit circles the globe every 90 to 120 minutes. Ideally the cubesat's battery needs enough current to power the cubesat while it is in darkness. And the solar cells must generate enough current to both power the cubesat AND recharge the batteries. Otherwise, the cubesat's CPU will power down once voltage drops lower than a certain level.

NOTE: The following exercises require the passage of time often more than 3 hours. Thus they are best performed when you have other activities to do.

How long will the cubesat operate in eclipse?

Shut down the CubeSatSim using the pushbutton, then plug the "Remove before flight" (RBF) plug into the cubesat and plug the cubesat into a USB adapter. Once the battery is fully charged, remove the USB cable. Turn off the turntable. Place the cubesat in a dark area and remove the RBF plug to start the cubesat.

Start FoxTelem and configure to plot battery voltage and current. Wait until the FoxTelem stops receiving packets, indicating the cubesat has shut down.

How much time has elapsed? Is this enough time to power the cubesat while in eclipse, typically 90 to 120 minutes? ____________________________

Keep FoxTelem running. Turn on the turntable. How much time elapses before the cubesat resumes transmitting? ____________________________
Note: Do this experiment only if the CSS is in direct sunlight.

Advanced Exercise:

By now, you have seen how the telemetry values correlate to the orientation and environment of the cubesat. For this exercise, the cubesat will be located in the back of the room and the instructor will follow a predefined script simulating several different scenarios that can occur in orbit. You will determine the status and health of the satellite from the telemetry data. (No peeking at the cubesat!)

For each scenario, record what you have observed, what values have changed, and what may have caused that condition.

Scenario 1 Observations:

Possible Cause:

Scenario 2 Observations:

Possible Cause:

Scenario 3 Observations:

Possible Cause:

Scenario 4 Observations:

Possible Cause: