

The **AMSAT**[®] Journal

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The New AMSAT® CubeSat Simulator: Part 2, Classroom Activities

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Abstract—The AMSAT CubeSat Simulator is a Raspberry Pi-based, 3D printed functional model of a CubeSat satellite that transmits current, voltage, and temperature telemetry on the UHF ham radio band. This article describes educational activities that can be performed with the Simulator.

Keywords—cubesat, simulator, telemetry, AMSAT, ham radio, raspberry pi

I. INTRODUCTION

In the previous issue of the AMSAT Journal (November/December 2018), we introduced the AMSAT CubeSat Simulator as a tool for education and demonstrations. We described the proof-of-concept prototype that we built and demonstrated at the 2018 AMSAT Space Symposium in Huntsville, AL.

In this paper, we will describe some educational activities that can be done with the CubeSat Simulator. We will begin by looking at the activities for the original ARRL ETP CubeSat Simulator, as described by Mark Spencer, WA8SME, in the AMSAT Journal November/December 2009 issue [1].

In a future article, we will describe some new activities that we have developed with the new CubeSat Simulator.

II. BACKGROUND

III. The AMSAT CubeSat Simulator, shown in Figures 1 and 2, is a Raspberry Pi-based, 3D printed functional model of a CubeSat that is designed to act, as reasonably as possible, as one flying in Low Earth Orbit (LEO) in order to demystify how satellites work. Like many LEO satellites, this simulator runs on rechargeable battery power and solar panels. It transmits UHF telemetry in the 70 cm ham radio band using the AMSAT OSCAR 7 (AO-7) format using AFSK modulation. For details on the design and construction of the simulator, see our article in the 2018 AMSAT 36th Annual Symposium Proceedings or in the Nov/Dec 2018 issue of the AMSAT Journal [2].

The remainder of this paper will describe the set of activities for the original CubeSat Simulator and discuss how they can be applied to the new CubeSat Simulator. The italicized questions below come directly from Mark Spencer's article.

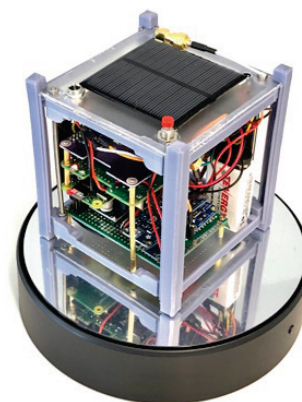


Fig. 1. The AMSAT CubeSat Simulator Proof of Concept Prototype shown on a Rotating Turntable. (**Authors' Note:** The current CubeSat Simulator frame is all 3D printed and has 5 or 6 solar panels.)

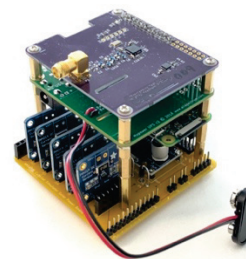


Fig. 2. The CubeSat Simulator board stack showing (from the top) the Digital Transceiver Board, MoPower UPS V2 Board, Raspberry Pi Zero W Board, and the Custom Solar Power Board.

IV. BASIC ELECTRONICS, SYSTEM CALIBRATION AND PARAMETERS

A. How much current does the CubeSat Simulator draw during operation?

The Raspberry Pi is powered by a 5 V bus through the GPIO (General Purpose Input Output) connector. The complete CubeSat Simulator draws about 200 mA during operation, for a total power of about 1 W. A Raspberry Pi W alone draws about 120 mA, the MoPower UPS board draws about 40 mA, and the Digital Transceiver Board draws about 40 mA.

This is significantly higher than the 26 mA of the original ARRL ETP CubeSat Simulator, but that simulator did not include a general-purpose processor. A much more power-efficient processor than the Pi Zero W could be used. For example, the Pi Zero (without the Wi-Fi) draws only 100 mA.

The current from the 9 V battery is about 145 mA at 8 V, since the efficiency of the MoPower UPS Board is about 85 - 90% in supplying 5 V to the Raspberry Pi.

B. What is the minimum panel/battery voltage required for the CubeSat Simulator to operate?

The MoPower UPS V2 board [3] requires 7.1 V in order to charge the 9 V battery and supply 5 V, so that is the minimum voltage. The solar panels in the current prototype are rated at 5.5 V and 110 mA, and that voltage is increased on the Solar Power Board to about 12 V using a Boost Converter circuit module. The solar panel voltage drops to around 3 V under load, resulting in around 8 V output from the Boost Converter.

C. What is the relationship between Analog to Digital Converter (ADC) value and the measured voltage that value represents?

There is no direct access to the ADC value in the new simulator, since the voltage and current sensing is done using the INA219 modules which are read by the Raspberry Pi over the I2C bus [4]. The equivalent activity would be to examine the raw telemetry data (which is roughly in AO-7 format) and figure out the mapping between the solar panel current and the telemetry value, or the battery voltage and the telemetry value. This process is known as *calibration*. Here is a complete packet or frame of telemetry data:

```
hi hi 114 199 199 199 299 200 201 250 329 350 300 300
446 400 400 400 500 500 500 500 600 600 600 650
```

In the raw telemetry from the CubeSat Simulator, the 1B, 1D, and 1C channels (channel 1B represents the last two digits of the second telemetry channel that begins with a 1, i.e. 199, in this example) represent the solar panel current from the +X, +Y, and +Z panels. Under eclipse (no illumination), these three values will be 199 199 199, so 99 represents no current. As illumination increases, the values will be observed to change to 98 then 97 going down as far as about 89 which represents about 100 mA of current from the solar panel. Using this, the relationship between the raw telemetry and the solar panel current could be determined. This formula could be verified by examining the telemetry analysis spreadsheet formula [5].

D. How does the angle between the solar panel and the Sun affect the current produced by the solar panel?

This information could be gathered by drawing angle increment lines on a piece of paper, then positioning the CubeSat Simulator at each angle for two data packets. Figure 3 shows how this can be done with a halogen work lamp illumination source.

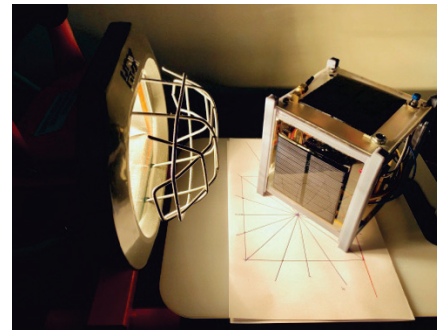


Fig. 3. Determining Solar Panel Current at Different Angles.

Figure 4 shows a resulting Solar Panel Current vs Angle plot.

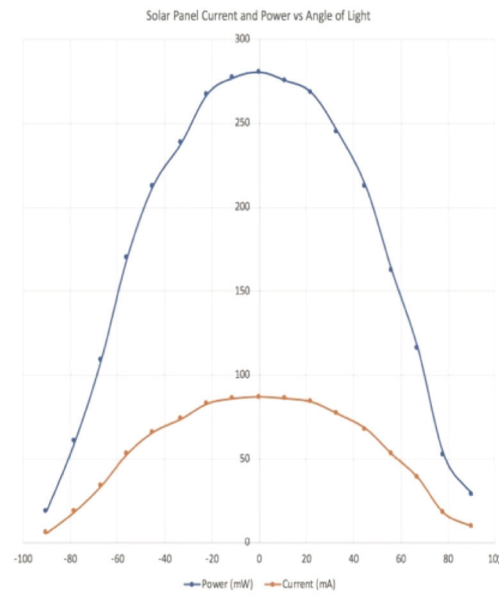


Fig. 4. Solar Panel Current vs Angle using the Method of Figure 3.

V. SATELLITE OPERATION ACTIVITIES

A. How long will the satellite operate in eclipse?

For the 9.6 V NiMH (Nickel Metal Hydride) battery, discharging in eclipse (darkness) from 9.6 V to 7.1 V took about 113 minutes. At this point, the MoPower UPS V2 board automatically shut down the Raspberry Pi processor to protect the SD card file system integrity.

The capacity rating of the 9.6 V battery is 200 mAh (milli-Ampere-hour), meaning it can supply 200 mA (or 0.2 A) for one hour (60 x 60 seconds) before being fully discharged. The battery can supply approximately $9.6 \times 0.2 \times 60 \times 60 = 6900$ Joules (J) of energy, which should run the CubeSat Simulator (which requires about 145 mA at an average voltage of 8.5 V) for at least $6900 / (8.5 \times 0.145 \times 60) = 94$ minutes, which compares well with the observed value.

B. How can you use the telemetry data to determine the rotation rate of the satellite?

We can simulate the effects of rotation using a halogen work lamp and two-speed battery powered turntable as demonstrated in Figure 5. With +X, +Y, and +Z solar panels, the time between successive peaks of either the +X or +Y panels gives the period, and the inverse of the period gives the rotation rate.

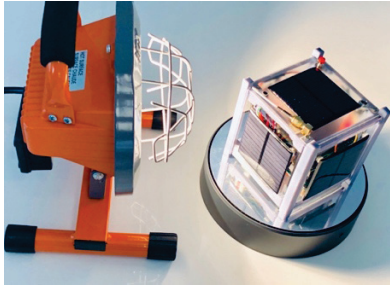


Fig. 5. Using a halogen work lamp and a turntable to simulate satellite rotation in orbit.

Figure 6 shows that the peaks of the +X panel are at data packets 5, 18, 31, and 44 which corresponds to a period of 13 packets between peaks. A stopwatch indicates the CubeSat Simulator sends a packet every 4 seconds, so that gives an average period of 52 seconds. Therefore, the frequency is 0.02 rotations per second or about 1.2 RPM (Rotations Per Minute).

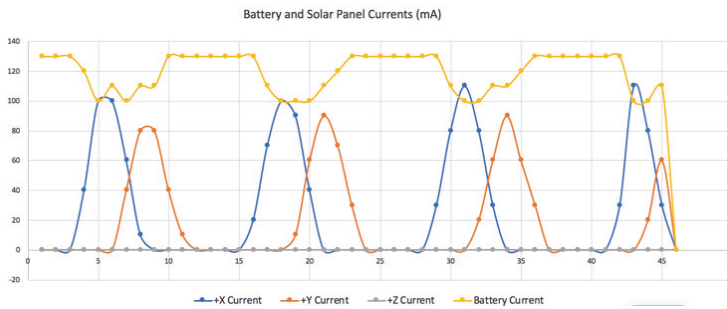


Fig. 6. Spreadsheet Graph of +X, +Y, +Z, and Battery Currents at Low Speed Setting in Turntable. (Authors' Note: This early prototype only had 3 panels. The current model supports up to 6 panels. As a result, all the graphs in this paper are missing the -X, -Y, and -Z panel currents.)

Figure 7, with the turntable speed set to high, the current peaks at packets 2, 11, 20, and 29, or at a period of 9 packets. This gives an average period of 36 seconds. The frequency is 0.03 rotations per second or about 1.7 RPM.

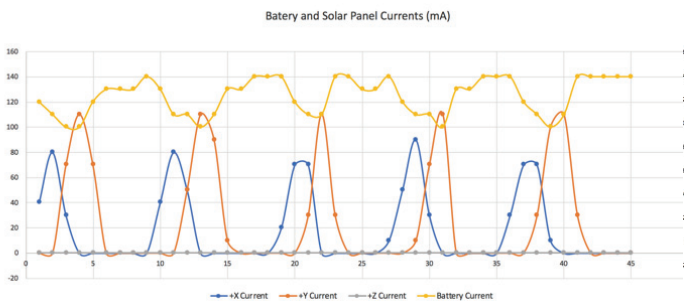


Fig. 7. Spreadsheet Graph of +X, +Y, +Z, and Battery Currents at High Speed Setting in Turntable.

C. How can you use the telemetry data to determine the tilt off-axis of the satellite?

Figures 6 and 7 show a rotation about the Z axis, since the halogen lamp is at right angles to the +X and +Y panels. The +Z panel is at right angles to the lamp so it outputs puts no current. We can simulate an off-axis rotation by angling the CubeSat Simulator on the turntable, as shown in Figure 8. See Figures 9 and 10 for two different off-axis tilts.



Fig. 8. Simulating Off Axis Rotation.

In Figure 9, instead of the +X and +Y peaks being roughly similar, the +Y peak is higher. Also, we see a small +Z peak which is aligned with the smaller +X peak. This indicates that the off-axis tilt is towards the +X axis.

In Figure 10, the +X peak is higher, and smaller +Z peak is aligned with the +Y peak, indicating that the off-axis tilt is towards the +Y axis.

Note that the graph of Figure 4 could be used to determine the angle of tilt in degrees.

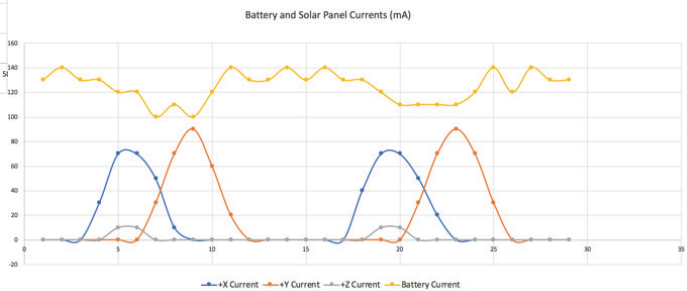


Fig. 9. Spreadsheet Graph of +X, +Y, +Z, and Battery Currents with Off Axis Tilt in X Direction.

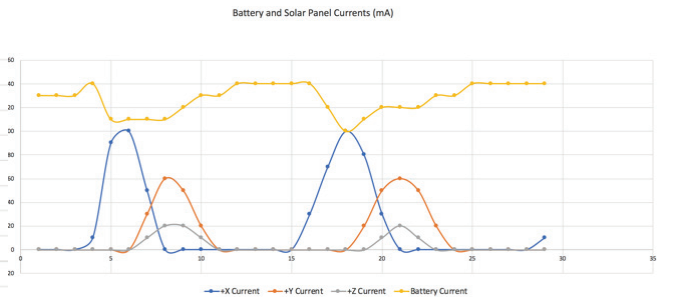


Fig. 10. Spreadsheet Graph of +X, +Y, +Z, and Battery Currents with Off Axis Tilt in Y Direction.

D. How can you use the telemetry data to troubleshoot a problem with the satellite, for instance, a degraded solar panel?

By unplugging or partially covering a solar panel, you will be able to see a deviation from normal in telemetry plots.

E. What is the minimum number of data points needed to get an accurate picture of the parameter being measured?

By successively reducing the number of data points (samples) in half, we can determine the minimum sampling rate for the telemetry data. Figure 11 shows three graphs which represent the same telemetry as Figure 6 but with fewer data points. The top graph of Figure 11 uses about $\frac{1}{2}$ of the data points of Figure 6, but the shape of the graph is still clearly the same. Some information is lost compared to Figure 6, but basic information such as peak values and the frequency of rotation can still be determined. The middle graph of Figure 11 reduces the data points in half again, to be $\frac{1}{4}$ the data points of Figure 6. Now some of the peak amplitude information is lost, but the frequency of rotation can still be roughly estimated. The lower graph of Figure 11 reduces the data points in half again, resulting in $\frac{1}{8}$ of the data points of Figure 6. This graph clearly loses peak information and frequency information.

Based on this, the sample rate of the middle graph represents the lowest sample rate without losing too much information. This corresponds to about one sample every 16 seconds for the rotation rate of 1.2 RPM. For faster rotation rates, the sample rate would need to be increased.

VI. CONCLUSION

We have successfully applied the original activities proposed by Mark Spencer for his ARRL ETP CubeSat Simulator to the new AMSAT CubeSat Simulator. These activities can be used in the classroom to teach a number of principles of satellite behavior. In our next article, we will describe some new activities that can be performed with the CubeSat Simulator.

The authors are always looking for feedback on these activities or new activities. Please share any feedback with us at ku2y@amsat.org and n8pk@amsat.org.

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- [2] <https://countingfromzero.net/amsat/CubeSatSimPaper.pdf>
- [3] <http://www.allspectrum.com/mopower/>
- [4] <https://learn.adafruit.com/adafruit-ina219-current-sensor-breakout/downloads>
- [5] <https://github.com/alanjohnston/CubeSatSim/tree/master/spreadsheet>

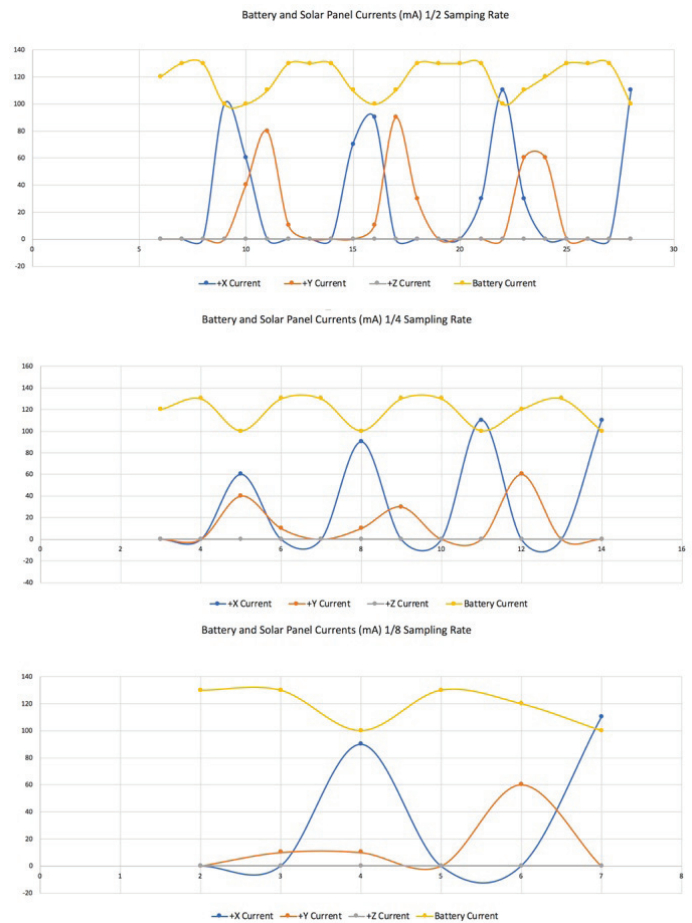


Fig. 11. Comparison of Different Sampling Rates on Current Telemetry.



Fig. 12. The authors, Pat Kilroy, N8PK, and Alan Johnston, KU2Y, at College Park Airport (CGS) at the ARISS Education Summit, November 2018.

Authors' Note:

This article is Part 2 in a series. The other parts are available in the AMSAT Journal or online at <http://cubsatsim.org/papers>