ETP CubeSat Simulator (Part 2, the Classroom Activity Part)

by Mark Spencer, WA8SME, mspencer@arrl.org
ARRL Education and Technology Program Coordinator

In Part One of this article, I described the technical side of a CubeSat Simulator that can serve as a classroom resource for teachers who want to include and introduce the fundamentals of satellite operations into a portfolio of space related classroom activities. The CubeSat Simulator includes an operating satellite model, UHF data link module, ground station receiver with display software for the transmitted telemetry, and a rotator mounting harness to hold the satellite (Figure 15). It was suggested that the CubeSat Simulator might be a valuable addition to your satellite demonstrations at hamfests or club meetings to give your audience a visual of satellite operations as well as give you a prop that can stimulate conversations about ham radio satellites.

In this second part of the article, I will briefly describe an expanded list of classroom activities that come to mind for the CubeSat Simulator.

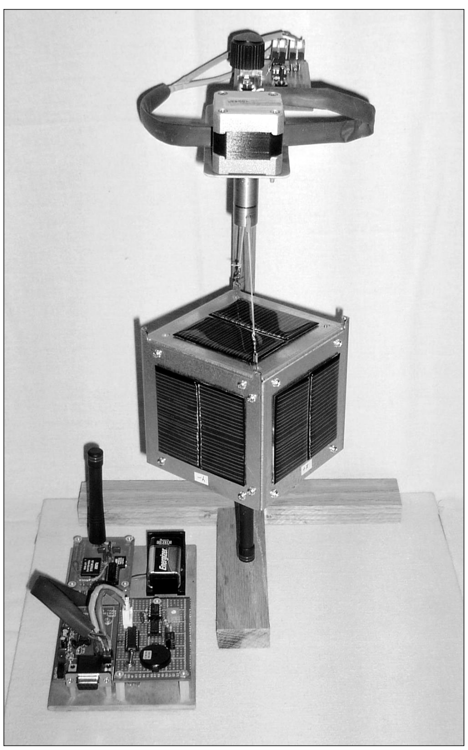


Figure 15: CubeSat Simulator system.

Elementary Level

Build a model of a satellite. Using the satellite shell as a template, students construct satellite models out of construction paper or other material and draw component features to populate their satellite surfaces as their imaginations dictate. Part of this activity would include listening to audio files of the original Sputnik satellite transmissions and comparing those transmissions to the telemetry transmissions of today's technology. The students further study the history of space travel to date by developing a timeline depiction of major milestones in the quest to explore space. During the class period, have satellite tracking software operating in the background and monitor satellite transmissions as the birds come over the horizon.

Figure 16: Voltage measurement setup.

Basic Electronics, System Calibration and Parameters

How much current does the CubeSat Simulator draw during operation? (Answer: transmitting CW: 26 mA, transmitting data: 21 mA, at rest: 19 mA)

What is the minimum panel/battery voltage required for the CubeSat Simulator to operate? (Answer: approximately 3.8 volts)

What is the relationship between analog to digital converter (ADC) value and the voltage that value represents? In this activity the students would use a VOM to measure the voltage on a solar panel and collect a data set of ADC values that the simulator transmits at that voltage. The students would have to figure out a way to control the voltage output of the panel (by restricting the amount of light hitting the panel is probably the easiest way, Figures 16 and 17). Once the data set is collected, it is graphed to illustrate the relationship between ADC and voltage (Figure 18).

How does the angle between the solar panel and the Sun affect the current produced by the solar panel? In this activity the students would have to come up with some sort of jig to allow them to vary and measure the angle between the panel surface and the illuminating source (Sun) and then using a VOM and a 100 ohm load, measure the current. The current is plotted as a function of angle away from nadir (Figure 21).

The pictures (Figures 19 and 20) illustrate one way of accomplishing this activity. A protractor is taped to a side of the satellite. A straw, or in this case a skewer, is taped between the panels to create a shadow across the protractor to give a measurement of the angle relative to nadir.

Satellite Operation Activities

How long will the satellite operate in eclipse? (Answer: approximately 7 minutes) For this activity the students start with a fully charged satellite and then operate it without illumination (covered) and determine the time before the satellite transmission stops. They will probably note that toward the end of the usable transmission time that the reported ADC voltages become erratic.

How can you use the telemetry data to determine the rotation rate of the satellite? This activity involves interpreting the ADC plots of the panel voltages and determining the period of the displayed sine waves. The simulator rotator is set to various rotation rates and the students use the collected data to determine the rate of rotation.

How can you use the telemetry data to determine the tilt off-axis of the satellite? This activity involves comparing the

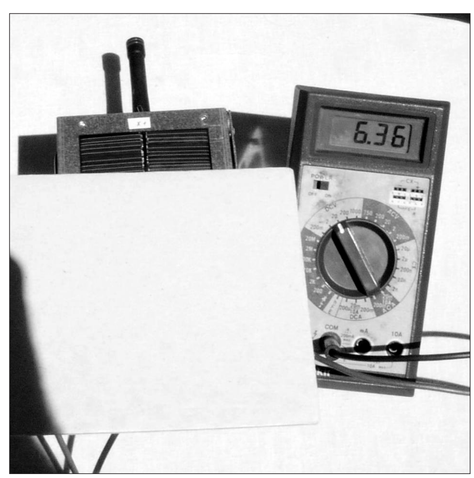


Figure 17: Panel voltage varied by covering up the panel to limit illumination in steps.

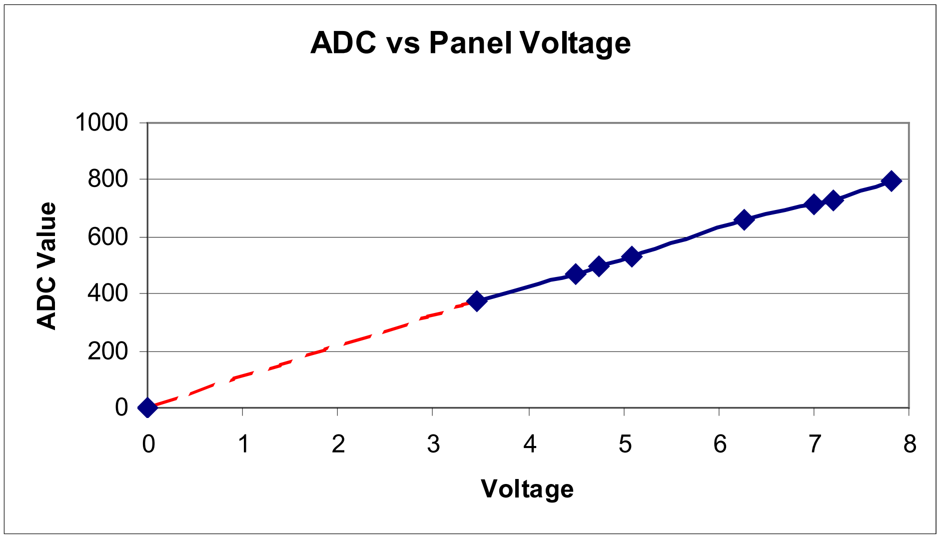


Figure 18: Excel generated graph of voltage vs. ADC value.

collected Z axis data when the satellite is vertical versus when tilted in the harness. When vertical, the Z axis data is virtually flat indicating a constant angle between the Z axis panels and the illumination source. When tilted off nadir, the angle between the Z axis panels and the illumination source varies with the characteristic sine curve. A more advanced exploration would be to use the data to quantify the angle of tilt.

How can you use the telemetry data to troubleshoot a problem with the satellite, for instance, a degraded solar panel? In this activity one of the solar panels is degraded to simulate a problem, in the example here, the panel is simply covered up temporarily. Using the collected data, the students determine what the problem might be and can speculate possible solutions.

What is the minimum number of data points needed to get an accurate picture of the parameter being measured? This activity is actually exploring some concepts borrowed from digital signal processing techniques; the Nyquist frequency or rate and aliasing.

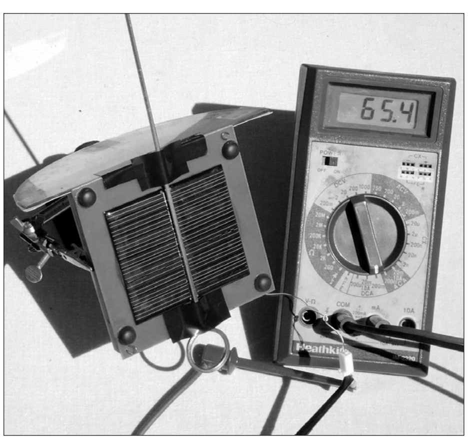


Figure 19: Current measurement setup.

There is significant power consumed by the satellite to transmit the telemetry data, and it is prudent to limit the amount of data transmitted to the minimum rate required to send accurate information to conserving power for other purposes. To obtain accurate information about a waveform (in this case the voltage produced by solar panels on a rotating satellite), the waveform must be sampled at a rate of at least twice the frequency of the wave (the Nyquist frequency). The waveform produced by the panels in the simulator is a nice smooth sine wave therefore we should be able to sample the panels at a minimum rate of twice the rotation rate of the satellite and still be able to recover the information about the waveform without degradation. Sampling the waveform at a high rate will produced more detailed information, but in many cases the added information would be redundant and power wasteful.

In this activity, the satellite is rotated at 4 rpm and data collected over a number of minutes to produce a data set of sufficient size. The CubeSat Simulator is programmed to send data points every second. To simulate reducing the collection rate, data points are simply thrown out and the remaining data is graphed to see if there remains an accurate representation of the full data set. The Nyquist rate for a satellite rotating at 4 rpm would dictate that 8 samples per minute be collected (twice the rotation rate of the satellite) or data points every 60/8 = 7.5 seconds. In Figure 27, the data rate is reduced in steps by throwing out data points to simulate collection rates of every 1 second (the default raw data rate), 4 seconds, 7.5 seconds, 12 seconds, and 16 seconds. In comparing the resulting graphs, the reduced rate down to 4 seconds still produces a fair representation of the sine wave, but at the slower rate of 7.5 seconds (just below the Nyquist rate) the graph begins to show signs of distortion, and at the rates of 12 and 16 seconds, the graphs show a sine wave that is totally different than what is actually happening. This illustrates the concept of aliasing that results from an insufficient sampling rate (a common problem that must be dealt with in DSP).

This activity illustrates that care must be taken when interpreting telemetry data. So for the CubeSat Simulator rotating at 4 rpm, the data rate can be reduced to around 6 seconds between points to conserve power without reducing the information that can be gleaned from the data, however rates lower than that, while further more conserving power, will corrupt the data. This situation would be evident if the students collect the data using the Morse code telemetry mode which is sending data at a rate far below the minimum Nyquist rate.

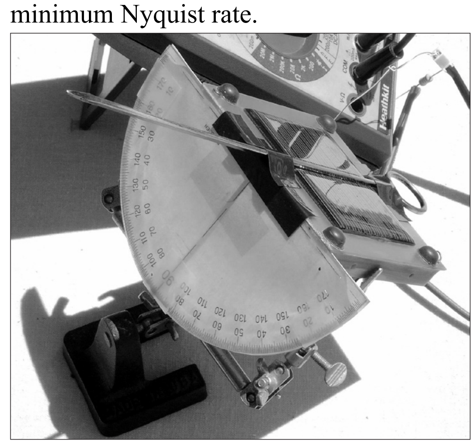


Figure 20: Current measurement angle adjustment setup.

Conclusion Part 2

I envision that the CubeSat Simulator will prove to be a valuable resource that teachers (and hams) can use to help their students to better understand the fundamentals of satellite operations so the students can better appreciate satellite technology that our society is becoming ever-increasingly dependent upon, and want to learn more about space borne assets at an advanced level. Perhaps the CubeSat Simulator will stimulate your fellow ham radio operators to want to "see you on the birds." For additional information about the CubeSat Simulator, or any of the other ETP projects and resources, contact Mark Spencer, WA8SME, at mspencer@arrl.org or 530-495-9150 (Pacific Time Zone).

Figures continue on the next 3 pages ...

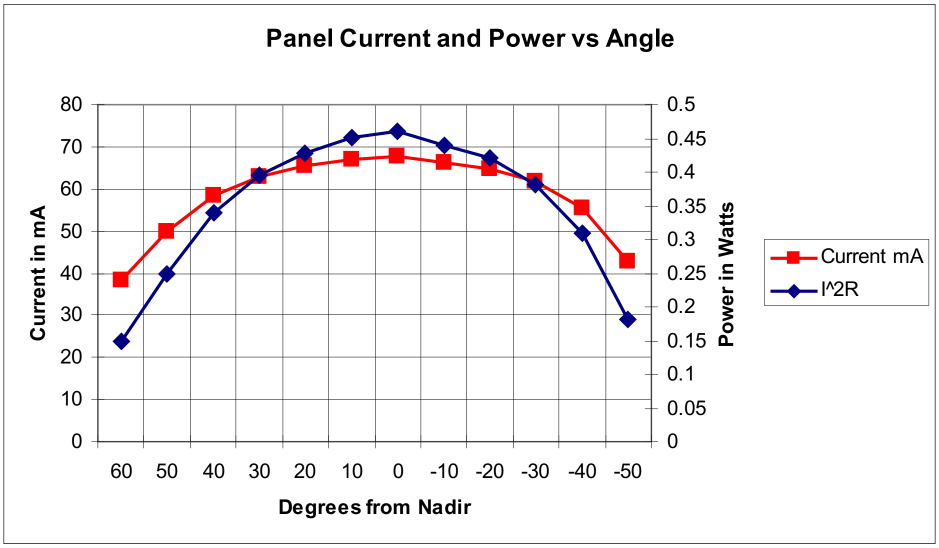
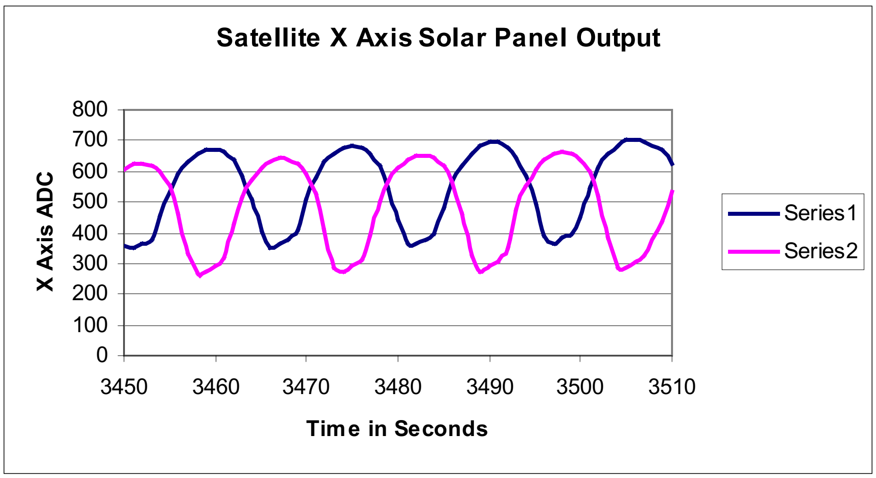
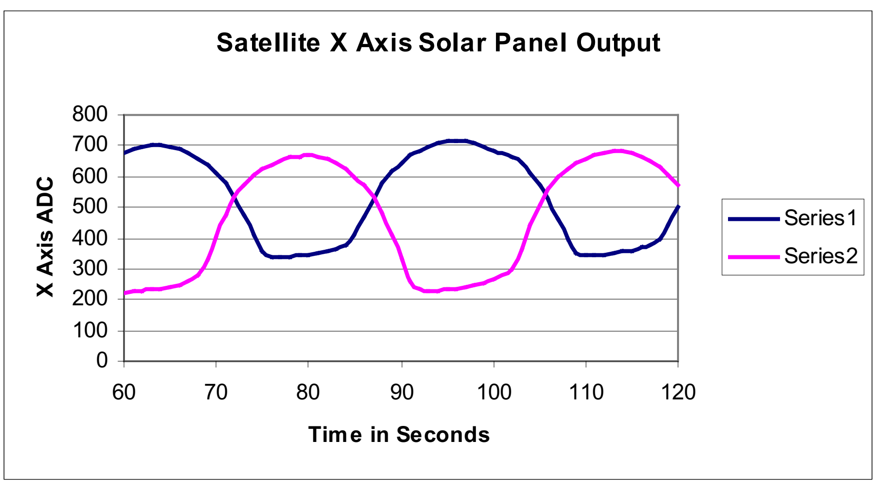


Figure 21: Excel generated graph of angle vs. current.





Figures 22-1 and 22-2: Excel generated graphs of rotation rates of 4 and 2 rpm. Measuring periods gives insight into rotation rate.

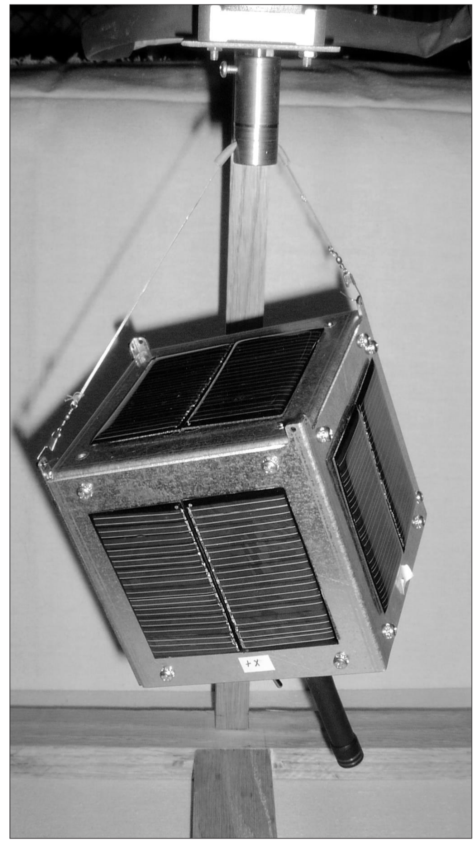


Figure 23: Tilt the satellite at various angles from nadir.

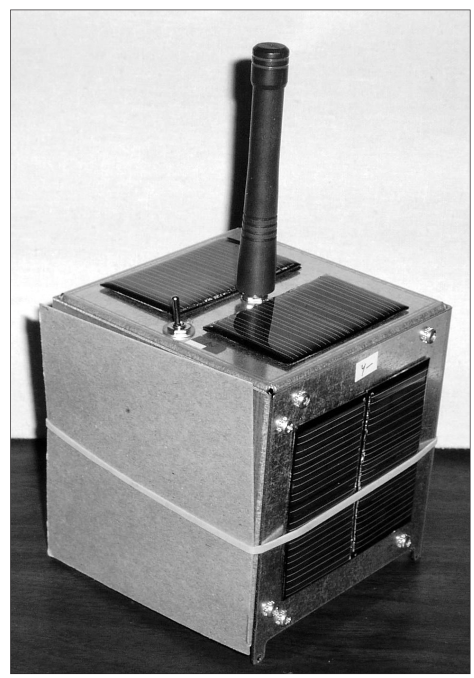
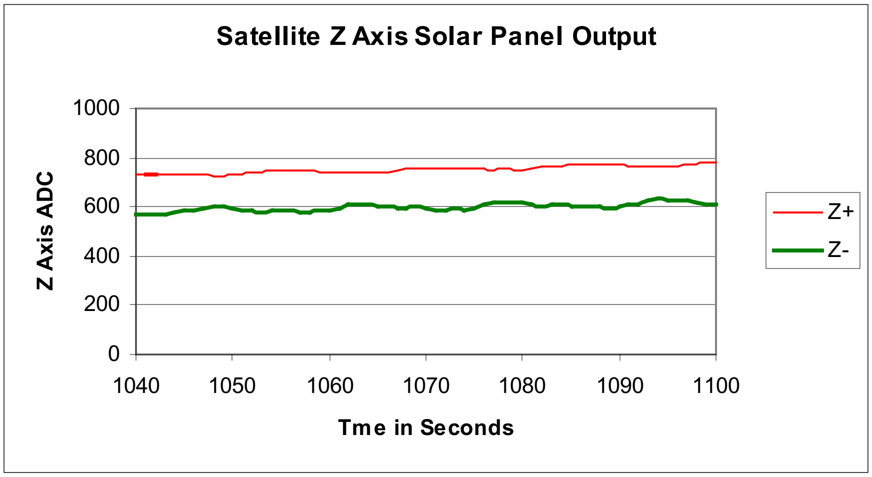
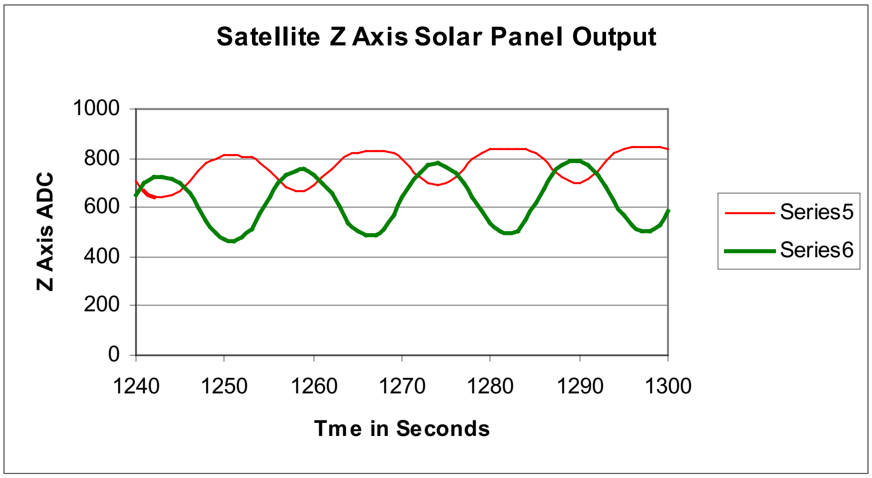
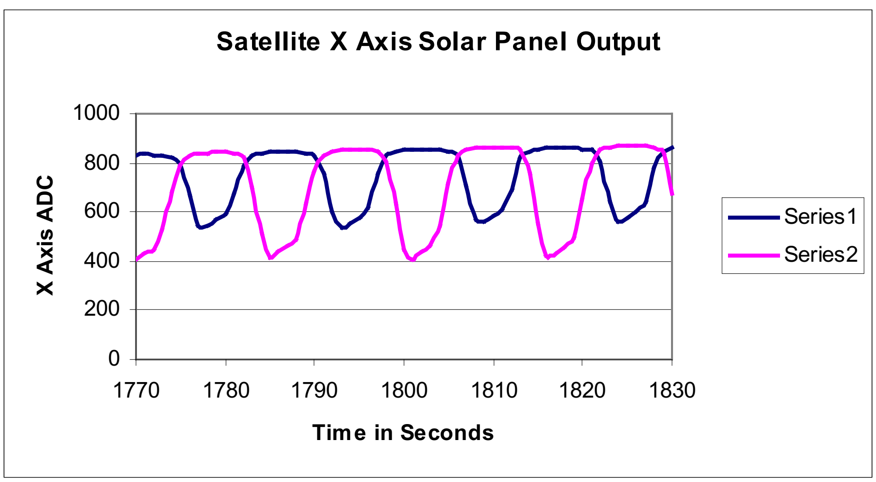


Figure 25: Degrade panel by covering it with an opaque paper.





Figures 24-1 and 24-2: Excel generated graphs of data from nadir to some off-axis tilt. The Z-axis panels pick up sinusoidal characteristics.



Figures 26-1 (above) and 26-2 (next page): The problem with one of the panels is evident by comparing data plots.

Apogee View - continued from page 3 ...

on spacecraft experience for engineering students.

Moving forward …. AMSAT continues to deal with ITAR. Our four commodity jurisdiction requests that were submitted to the State Department last July to transfer export control of those subsystems that AMSAT was developing for Phase 3-E (and eventual placement into Eagle) to the Commerce Department were denied. Again, AMSAT is left with no clear guidance on what constitutes appropriate behavior regarding development of spacecraft systems in an open source public domain environment that AMSAT has always followed. Consequently, we submitted an Advisory Opinion request to the Directorate of Defense Trade Controls (DDTC) on December 4th asking specific questions regarding AMSAT's activities and whether the steps we are taking in public domain will allow us to openly exchange technical information with AMSAT-DL and AMSAT-UK. Without such guidance, AMSAT is left with very restrictive options for working on international satellite projects with other AMSAT organizations.

AMSAT has spent a significant amount of money on legal fees on both ITAR and the clean room litigation. While it has been very disappointing that we're spending money on attorneys and the regulatory process rather than building hardware, this is money that has been well spent given the environment in which we've found ourselves. We at least have resolved the legal issues regarding past ITAR activities with P3-E and freed ourselves from a disappointing relationship with UMES/HISS. Again, we're now in position to move forward rather than continue to deal with past concerns.

Moving forward … NASA has informed AMSAT that the schedule of work for EVAs at the International Space Station is being revised. The planned deployment of ARISSat-1 from the ISS is now being scheduled for either Fall 2010 or early 2011 rather than Spring 2010. This schedule adjustment also impacts when ARISSat-1 will be flown to the Space Station with upload likely to take place sometime in summer 2010 rather than in January. These revisions were made in response to new higher priority ISS work that must be done during the EVA that ARISSat-1 was originally scheduled to deploy in April 2010.

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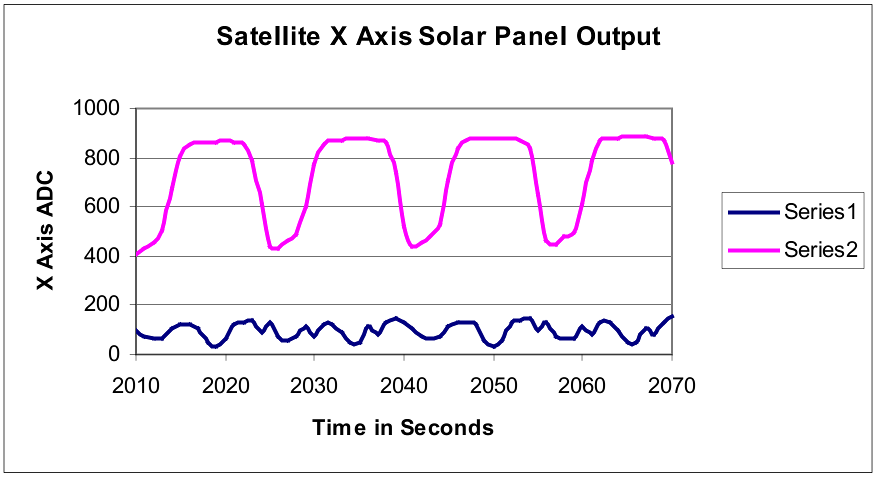

Figure 26-2 (above): The problem with one of the panels is evident by comparing data plots.

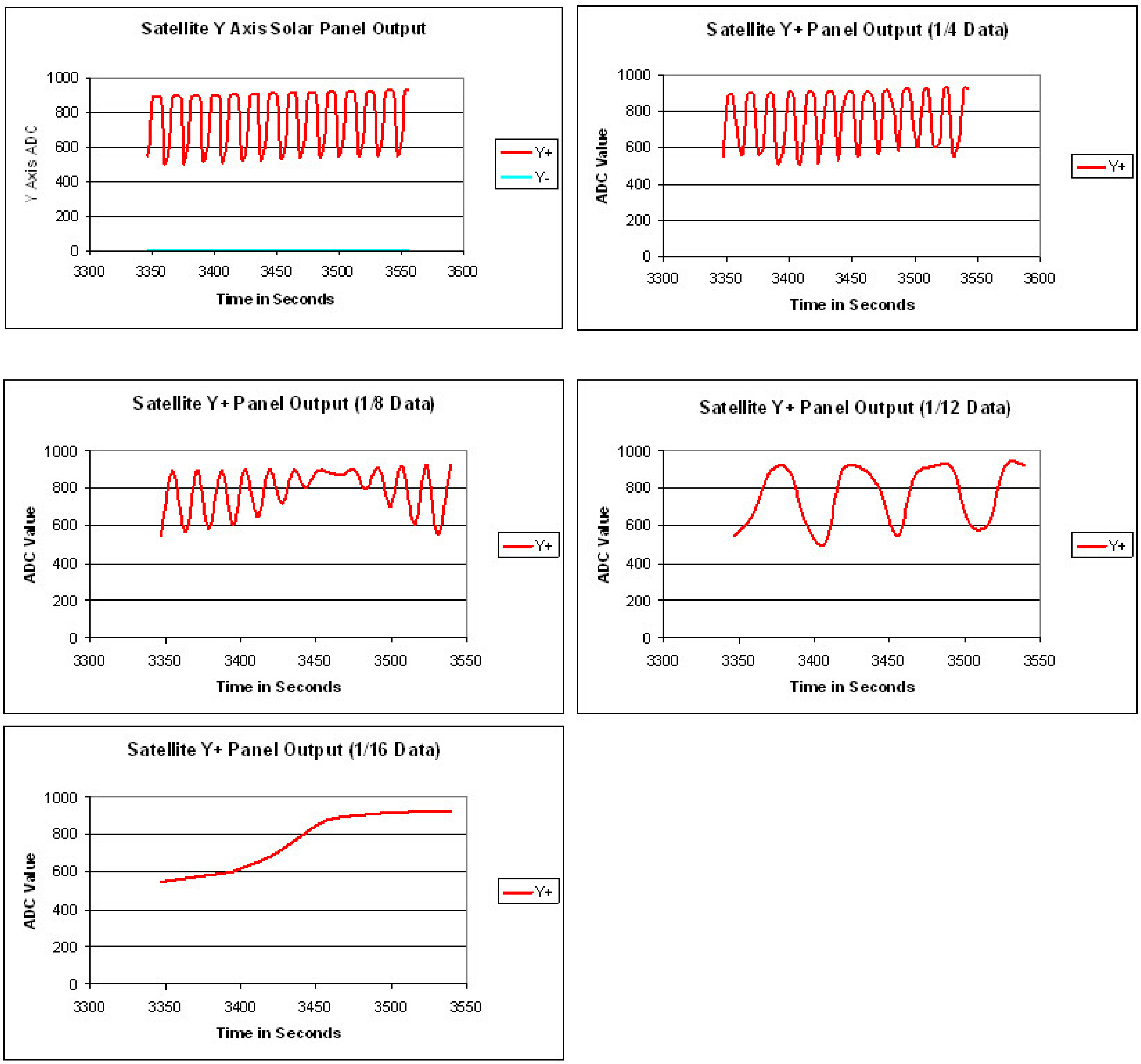

Figure 27: Simulate data collection rate reductions by "throwing out" data points. At rates just above the Nyquist rate, the data looks right; at or ferent. Reducing t