

Citizen Explorer 1 Solar Panel Efficiency Testing



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Abstract. The solar panels for the Citizen Explorer 1 spacecraft consist of Gallium Arsenide cells originally rated at 24 percent efficiency. The panels were constructed in 1997 in anticipation of a 1999 launch. Due to various delays the Citizen Explorer spacecraft has not yet been launched. With the solar panels being seven years old they have experienced degradation in energy conversion efficiency. Testing was conducted on 20 February 2004 to determine the current efficiency of each panel. It was found that the average efficiencies of the panels were 13.81 percent for the panel on the spacecraft's positive x-axis, 14.27 percent for the negative x-axis panel, 13.43 percent for the y-axis panel, and 13.22 for the z-axis panel. The reduced efficiencies for the solar panels will impact the on orbit power margin, and may impact the ability of the spacecraft to carry out its primary mission as originally designed.

1. Solar Panel Description

The Citizen Explorer 1 (CX) spacecraft has four solar panels to provide electrical power during the mission. These panels were custom made for CX. The solar cells are Gallium Arsenide, providing an energy conversion efficiency of 24% when new.

The placement of the four panels allows for constant illumination of at least three panels when in view of the sun. Figure 1 shows the placement of the solar panels on the spacecraft. The positive x axis (+X) panel is shown on the left side of the spacecraft, the negative x axis (-X) panel is on the right side of the space craft. The y axis panel (Y) is the lower of the two center panels. Finally the z axis (Z) panel is the upper of the two panels.

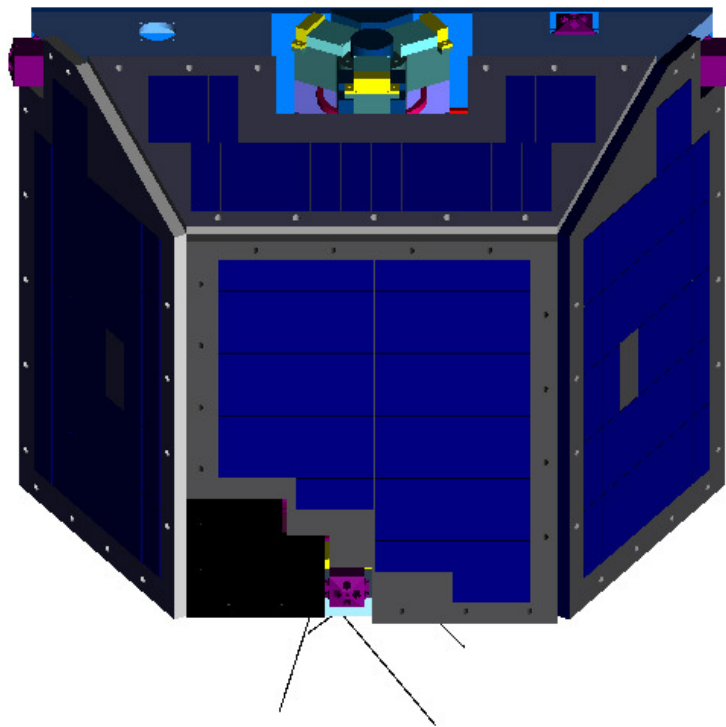


Figure 1 - Citizen Explorer 1 External Configuration¹

Each solar cell used on CX measures 3.94056 square inches, or 2.5423×10^{-3} square meters. (Metric units will be used for the remainder of this paper.) The two X panels and the Y panel have 36 cells each for an area of 9.1523×10^{-2} square meters per panel, while the Z panel has only 18 cells for an area of 4.5761×10^{-2} square meters.

¹ Image Credit: http://citizen-explorer.colorado.edu/systems/structures/images/cx_w_panels.jpg. Note: Image has been rotated 180°.

2. Efficiency Testing

It was necessary to conduct efficiency testing of the solar panels to determine their current efficiency. The solar panels were manufactured in 1997 in anticipation of a 1999 launch. Due to delays and other issues, CX has yet to launch.

Gallium arsenide solar cells degrade over time. With the CX solar panels sitting in a clean room for seven years, they have degraded.

2.1 Test Equipment

To conduct the solar panel efficiency test it was necessary to use both off the shelf hardware as well as hardware specifically built to support the testing of the CX spacecraft.

To allow for the attachment of an external variable resistor and measurement devices it is necessary to use one of the breakout boxes built for CX. The break out boxes provides ports for measuring voltage and current loads on the various lines. Connection to the ports is via a cable with a bayonet connector. The ports also allow for the connection of external devices.

For the solar panel efficiency test it was necessary to measure the voltage output and current being drawn from the solar panel using two handheld multimeter. To measure the exact resistance of the variable resistor at each setting a third multimeter was used.

As the power output from the solar panel is a percentage of the solar power input or flux it is necessary to determine the solar flux during the test. To accomplish this a MicroDataLogger Model 202 built by the Architectural Energy Corporation was used in conjunction with two pyranometers built by Li-Cor. The pyranometers measure solar flux and output this value as a voltage. It is then possible to convert this voltage to solar flux using provided information.

To configure, run, and off load data from the MicroDataLogger it was necessary to use a laptop computer with a serial port.

2.2 Test Implementation

Prior to conducting the solar panel efficiency tests it is necessary to protect the solar panels from contaminants when removed from the clean room. The solar panels already have a clear acrylic panel to protect them from impacts, but to prevent contamination the panels were wrapped in a clear three mil-inch plastic sheeting and seams were sealed using kapton tape. The only part of the panel that was allowed to be outside the protective wrapping was the power connector, which is a DB-9 connector.

One of the two pyranometers was wrapped in the same three mil-inch plastic sheeting that covered the solar panels so that the reduction in solar flux could be determined. Once the pyranometer was prepared; it was connected along with the uncovered pyranometer to the MicroDataLogger. The logger was configured to record the pyranometer output once every three seconds for the duration of the test.

Each solar panel was tested for a range of electrical loads induced by varying the resistance. The electrical load was increased until the voltage output began to decrease dramatically, signaling that the voltage vs. load curve had passed the knee. A knee curve is a curve that cannot be defined by a standard trend line due to the drastic change in slope at the “knee”.

After the test and returning the solar panels to the clean room, the acrylic protective cover was removed from the positive X panel. The cover was then placed over a pyranometer to determine the solar flux loss from the acrylic.

3. Results & Analysis

The raw results of the solar panel tests provided resistance, current, and voltage measurements for the solar panels as well as solar flux values for both the covered and uncovered pyranometers. It was found that there was an average solar flux loss of 1.44 percent caused by the 3-mil plastic sheeting and an average loss of 1.33 percent solar flux loss due to the acrylic. Therefore only 97.33 percent of the solar flux was reaching the solar panels at any time.

The knee curves referred to in the previous section are shown in Figure 2. Figure 2 shows the relationship between the solar panel output voltage and the current being drawn.

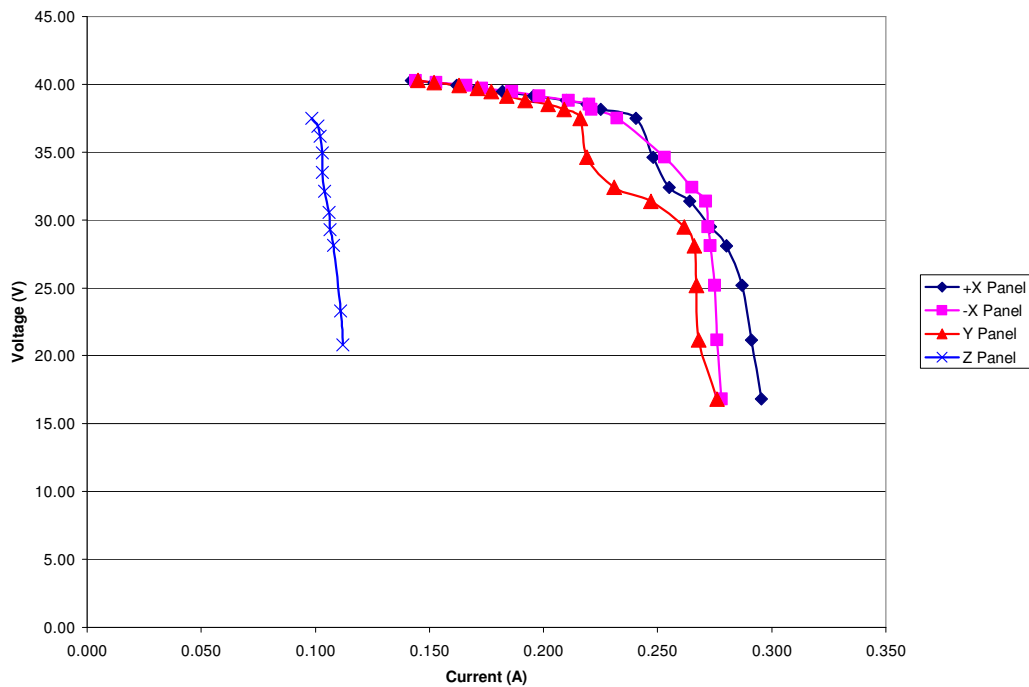


Figure 2 - Solar panel voltage vs. current draw.

It can be seen that the Z panel reach its knee at the first measurement and the voltage output dropped rapidly with the larger current loads. The +X, -X, and Y panels all have a good knee curve with half the values above the knee and half the values below the knee.

Knowing the current and the voltage values for all the measurements it is possible to determine the power output for each panel using the relation:

$$P = IV$$

Figure 3 shows the relation of panel power output to the current draw.

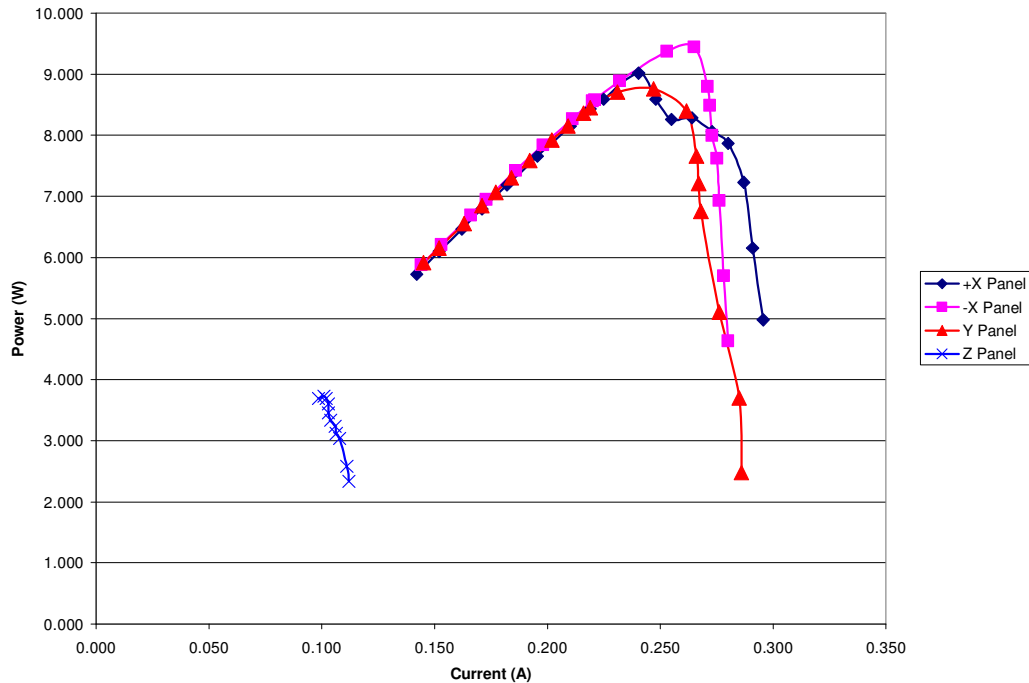


Figure 3 - Solar panel power vs. current draw

As is expected from looking at the voltage plot the power output from the Z panel is much less than the other three panels. The shape of the knee curve has changed the knee is now the maximum current. This is caused by the increase in current being greater than the decrease in voltage before the knee and less than the decrease after the knee.

With the solar flux value being known within a second of the readings it is possible to determine the efficiency of the solar panels by dividing the power output by the solar flux.

Figure 4 on the next page shows the relationship between solar panel efficiency and current draw.

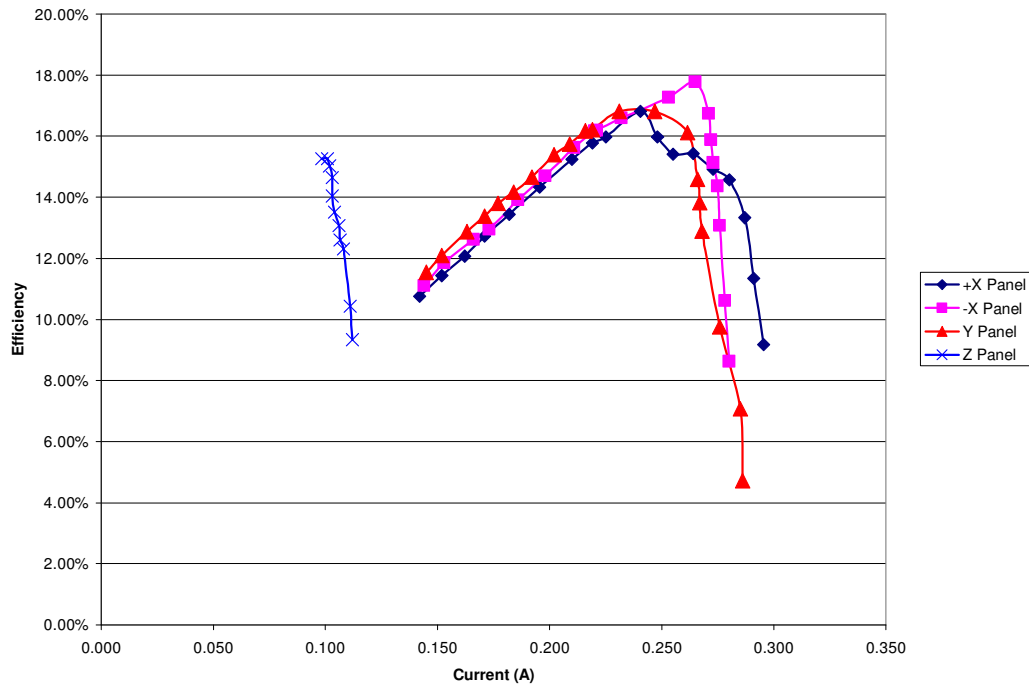


Figure 4 - Solar panel efficiency vs. current draw

The shape of the knee curves for the efficiency plot is the same as the power plot. The low power output of the Z panel is off set by the lower solar flux values when it was tested.

Table 1 shows the maximum and average efficiency values for all four panels.

Table 1 - Panel efficiencies

Panel	Efficiency	
	Maximum	Average
+X	16.80%	13.81%
-X	17.78%	14.27%
Y	16.82%	13.43%
Z	15.26%	13.22%

4. Conclusions

Due to delays the solar panels built for Citizen Explorer 1 have degraded over time. To determine the extent of the degradation of the panels it was necessary to conduct a solar panel efficiency test. This test determined the efficiency of each panel. As shown all four panels have average efficiencies below 15 percent, which impacts the power margin available on orbit.

The impact on the available power margin may prevent the spacecraft from powering up various subsystems without first shutting down other subsystems. This effects the mission goals as it may not be possible to power the space to ground communications hardware while

taking readings from the science instruments. The exact impact of the reduced solar panel efficiencies needs to be evaluated by the Citizen Explorer 1 mission operations team as well as by project management.

5. License

This section added 2008

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