Astro 331X Lab 1: Electrical Power

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Overview

FlatSAT's solar array, shown in Figure 1, consists of four silicon photovoltaic cells. The cells can be connected in series or in parallel. Before completing the lab you will predict array performance for each configuration using the provided specifications to determine if the solar array will satisfy mission requirements in FlatSAT's 500 km orbit. During the lab you will gather the data necessary to generate an I-V plot for your array (series and parallel). After the lab you will use the I-V plot and the measured illuminance to calculate your array's efficiency.

Lab execution

You will illuminate FlatSat's solar array to validate your prelab predictions and create an empirical I-V plot. By adjusting a potentiometer in the circuit, the array will generate different voltages. At each point, you will measure both voltage and current with Adafruit's INA219 current sensor breakout board. Use these data to create your plot.

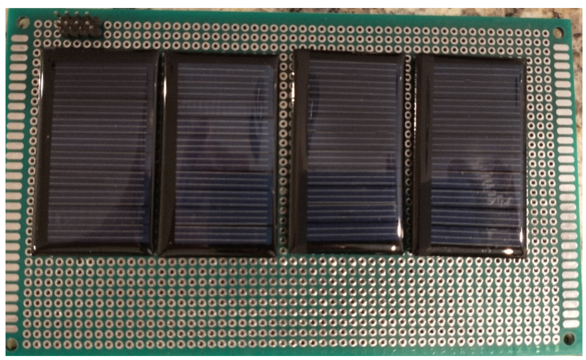

Fig. 1 FlatSAT's solar array

Prelab predictions

You have already measured the solar array's short-circuit current and open-circuit voltage. Complete Table 1.

Table 1 Predicted array output

	V_{oc} (V)	I_{sc} (mA)	P (mW)
series			
parallel			

In your lab notebook, draw predicted I-V curves for the series- and parallel-connected arrays. Assume beginning-of-life conditions.

Calculate array performance if FlatSat were launched into a circular orbit with a 500 km altitude. Use the performance parameters in Tables 3 and 4 (in Appendix A).

Solve for the number of solar cells that FlatSat would need to meet its power requirements.

Math

Here are the equations you will need.

Earth's angular radius:

$$\sin\rho = \frac{R_e}{R_e + h} \tag{1}$$

$$Per = 2\pi\sqrt{\frac{a^3}{\mu}} \tag{2}$$

$$T_e = Per\frac{2\rho}{360°} \tag{3}$$

$$T_d = Per - T_e \tag{4}$$

Earth's radius: $R_e = 6378.137\,\mathrm{km}$ Earth's gravitational constant: $\mu = 398\,600.5\,\mathrm{km^3/s^2}$

Power required from solar arrays to generate adequate power to spacecraft:

$$P_{req} = \frac{P_{ecl}T_{ecl} + P_{sun}T_{sun}}{T_{sun}} \tag{5}$$

Power generated by solar array at BOL:

$$P_{BOL} = S\eta I_d \cos\theta A \tag{6}$$

Solar input: $S = 1358\,\mathrm{W/m^2}$

Power generated by solar array at EOL:

$$P = P_{BOL}\left(1 - annual\ degradation\right)^{elapsed\ years} \tag{7}$$

Solar array efficiency:

$$\eta = \frac{P_{\text{panel}}}{A_{\text{panel}}E_e} \tag{8}$$

A luxmeter measures illuminance, E_v, in lux. 1 lx = 1 lm/m^2. The lumen is the SI unit of brightness, which weights light by wavelength according to the standard luminosity function of human visual perception. Illuminance can be converted to irradiance, E_e, with Equation 9.

$$E_e = \frac{E_v}{K} \tag{9}$$

For unfiltered sunlight, luminous efficacy, K, is 122 lm/W [1]. For incandescent halogen worklight bulbs, it is 19.3 lm/W [2].

Postlab Data Analysis

Produce an IV plot using the data you collected during the lab. It should look like Figure 2 (but it should contain both series and parallel data).

Using your measured peak power (remember, $P = IV$) and the measured solar illuminance collected with the luxmeter, calculate the efficiency of your solar array.

Summarize your results as in Table 2.

Compare your results to the predicted results. Discuss and explain any differences. Discuss the difference between serial and parallel array performance. Do the observed results match your predictions? How does the measured efficiency compare to the manufacturer's stated efficiency?

Update your recommendation. You may find that you need a different number of cells.

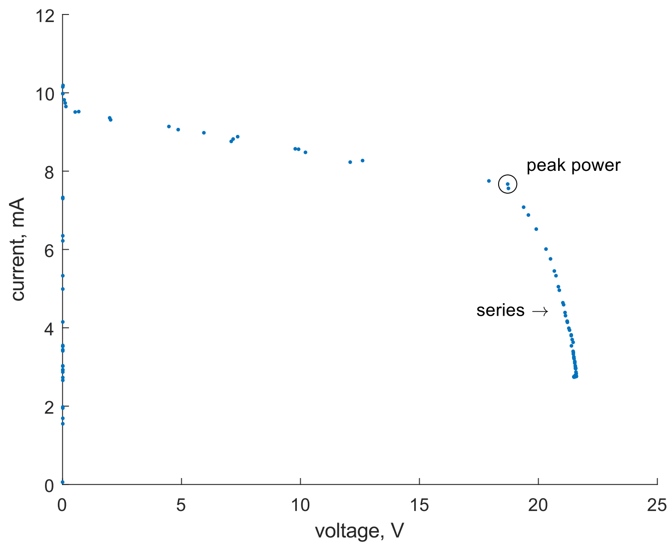

Fig. 2 Sample I-V curve

Table 2 Predicted array output

	V_{oc} (V)	I_{sc} (mA)	P (mW)	efficiency (%)
series				
parallel				

References

[1] Michael, P. R., Johnston, D. E., and Moreno, W., "A conversion guide: Solar irradiance and lux illuminance," *Journal of Measurements in Engineering*, Vol. 8, No. 4, 2020, pp. 153–166.

[2] Philips Lighting, *Plusline Small*, 9 2022, `https://www.lighting.philips.com/api/assets/v1/file/PhilipsLighting/content/fp924735544280-pss-global/924735544280_EU.en_AA.PROF.FP.pdf` retrieved 2022-02-11.

Appendix A: Key parameters

Table 3 Mission, orbit, and spacecraft parameters

Mission life	3 years
Power in eclipse	2 W
Power in sunlight	4 W
Power regulation	direct energy transfer*
Worst sun incidence angle	25°
Worst beta angle	0°

*See paragraph after Eqn 11-5 in SMAD

Table 4 Cell & panel parameters (*single cell)

Dimensions*	53 mm × 33 mm
Short-circuit current*	30 mA
Open-circuit voltage*	5 V
Efficiency	14.8%
Inherent degradation	46.78%
Cells	4
connection	series & parallel