# Astro 331 Prelab 1: Electrical Power

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Documentation:

- DFAS writing guide (I used to write these instructions—you should read it but don't need to list it in your documentation statement)
- Cite references as necessary, but don't include course notes, course text (SMAD), or these instructions as documentation
- Don't forget to update your own documentation statement when you write your prelab report!

## I. Objective

`\section{Objective}` will produce a numbered section.

## Objective

`\section*{Objective}` will produce an unnumbered section.

FlatSAT will operate for 3 years in a 500 km orbit. Its solar panel must provide enough power to operate the spacecraft during that time. The purpose of this lab is to quantify the performance of FlatSAT's solar array and validate that it will meet mission requirements.

## Nomenclature

| | | | | | |
|---|---|---|---|---|---|
| $P$ | = | power (W) | **Subscripts** | | |
| $S$ | = | solar irradiance (W/m$^2$) | $EOL$ | = | end of life |
| $\beta$ | = | beta angle (°) | | | |
| $\Phi$ | = | eclipse fraction (°) | $req$ | = | required |

## Approach

FlatSAT's solar array, shown in Figure 1, consists of four silicon photovoltaic cells. The cells can be connected in series (4S) or parallel (4P).

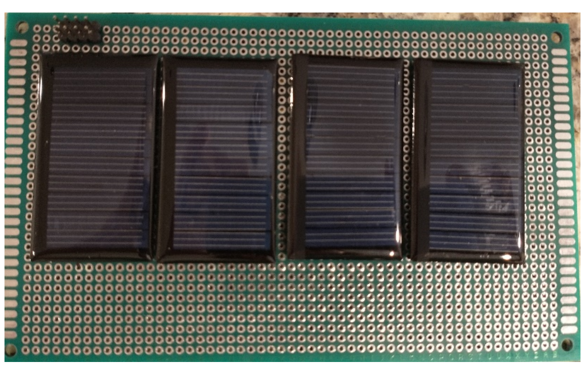

**Fig. 1 FlatSAT's solar array**

During this lab, the team will use take current and voltage measurements from FlatSAT's solar array, connected both in series and in parallel. Initial measurements were taken with a digital multimeter to establish the expected limits. Further measurements will be taken with a current sensor connected to an Arduino microcontroller.

The solar array will be wired in series with the current sensor and a 10 kΩ potentiometer. The potentiometer's resistance will be varied to measure multiple current and voltage at multiple points on the I-V curve.

FlatSAT spends a portion of each orbit in the Earth's shadow. This fraction, $\Phi$, depends on the angular size of Earth, $\rho$ from the spacecraft's orbital altitude. Eclipse time also varies with the beta angle, $\beta$, which is the angle between the sun vector and its projection onto the orbital plane. Beta angle changes over time for all orbits except equatorial and sun-synchronous orbits. A spacecraft experiences the longest eclipses when $\beta = 0$, which will be used to determine the worst case eclipse length. FlatSAT will operate in a circular orbit at an altitude of 500 km, which is a semi-major axis of 6878.137 km.

Period, Eclipse time, and Daylight time are found using Equations 1–3.

$$Per = 2\pi\sqrt{\frac{a^3}{\mu}} \tag{1}$$

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

$$T_d = Per - T_e \tag{3}$$

**Solar array output**
The solar array's beginning of life power output is given by Equation 4.

$$P_{BOL} = S\eta I_d \cos\theta A \tag{4}$$

where $\theta$ is the panel's incidence angle, or angle between the sun vector and the panel's normal vector.

**Efficiency**
Solar array efficiency is a ratio of the array's areic power to the irradiance of the incident radiation.

$$\eta = \frac{P_{\text{panel}}}{A_{\text{panel}}E_e} \tag{5}$$

A luxmeter measures illuminance 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 with Equation 6.

$$E_e = \frac{E_v}{K} \tag{6}$$

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

## Experimental Results

**!This section should not appear in your prelab report, but should be in your final lab report!**

**!Your results section should be more comprehensive than this example!**

Figure 2 shows the solar array's output when wired in series. Summary results are shown in Table 1. The voltage is slightly higher than expected, but the current is much less than expected.

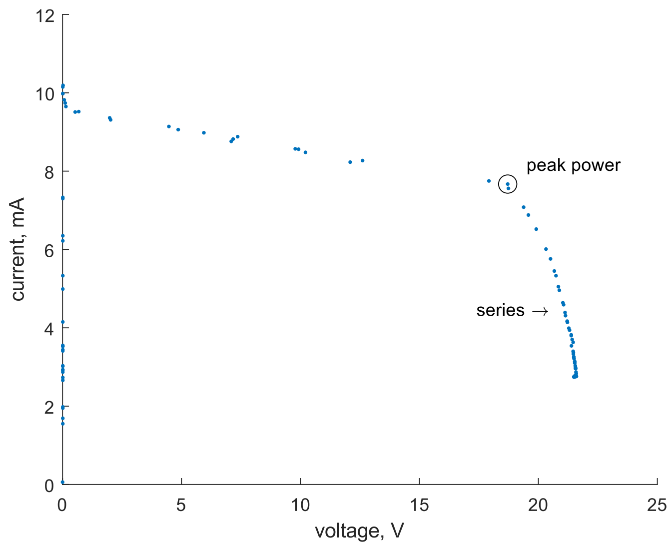


**Fig. 2 Series I-V curve**

**Table 1 Electrical measurements**

| | $V_{oc}$ (V) | $I_{sc}$ (mA) | peak power (mW) | efficiency (%) |
|---|---|---|---|---|
| series | 21.5 | 10.19 | 143.5 | |
| 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 2 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° |

**Table 3 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 |

**Appendix B: theoretical calculations**

```
clearvars; clc;
format compact
```

# calculate power required from solar array

```
% constants
Re = 6378.137; % (km)       Earth's radius
mu = 398600.5; % (km^3/s^2) Earth's gravitational constant

% given
h = 5e2; %  (km)    orbital altitude
beta = 0; % (deg)   orbital plane angle
Pe = 2; % (W) power required in eclipse
Pd = 4; % (W) power required in daylight

% from SMAD--just after Eqn 11-5
etaE = 0.65; % (unitless) elec efficiency during eclipse
etaD = 0.85; % (unitless) elec efficiency during daylight

% calculations
a = Re + h; % (km) semi-major axis

rho = asind(Re/(Re+h)) % (deg) Earth's angular radius


Phi = 2* acosd(cosd(rho)/cosd(beta)) % (unitless) eclipse fraction

Per = 2*pi* sqrt(a^3/mu) %  (sec)   orbital period
Te = Per * Phi/360 %        (sec)   time in eclipse
Td = Per - Te %        (sec)   time in daylight

P_req = (Pe*Te/etaE + Pd*Td/etaD) / Td % (W) power required from array
```

```
rho =
   68.0187
Phi =
  136.0373
Per =
   5.6770e+03
Te =
   2.1452e+03
Td =
   3.5318e+03
P_req =
    6.5748
```

# calculate power provided by arrays

```
% constants
S = 1367; % (W/m^2) solar irradiance
```

```
% given
eta = 0.148; % (unitless) solar cell efficiency
A = 4 * 0.053 * 0.033; % (m^2) solar array area
Id = 0.4677 ; % (unitless) cell inherent degradation
theta = 25 ; % (deg) worst-case incidence angle
life = 3; % (yr) mission life

% from SMAD
degrade = 0.0375; % (/yr) annual degradation

Pbol = S* eta * Id * cosd(theta) * A
Peol = Pbol *(1-degrade)^life
```

```
Pbol =
    0.6000
Peol =
    0.5350
```

*Published with MATLAB® R2022b*

## Appendix C: Matlab code for experimental data

```
clearvars; clc;
load('iv_data');

figure(1); clf; hold on

iv2.power = iv2.currentmA .* iv2.voltageV;
[~,pp] = max(iv2.power);

series_peak = iv2.power(pp)

plot(iv2.voltageV, iv2.currentmA, '.')
plot(iv2.voltageV(pp), iv2.currentmA(pp), 'ko', ...
    'MarkerSize', 10)

xlabel('voltage, V')
ylabel('current, mA')

text(20.5 ,4.5, 'series \rightarrow', ...
    'HorizontalAlignment','right')
text(19.5, 8.2, 'peak power')

saveas(gcf, 'iv_curve.svg')
```