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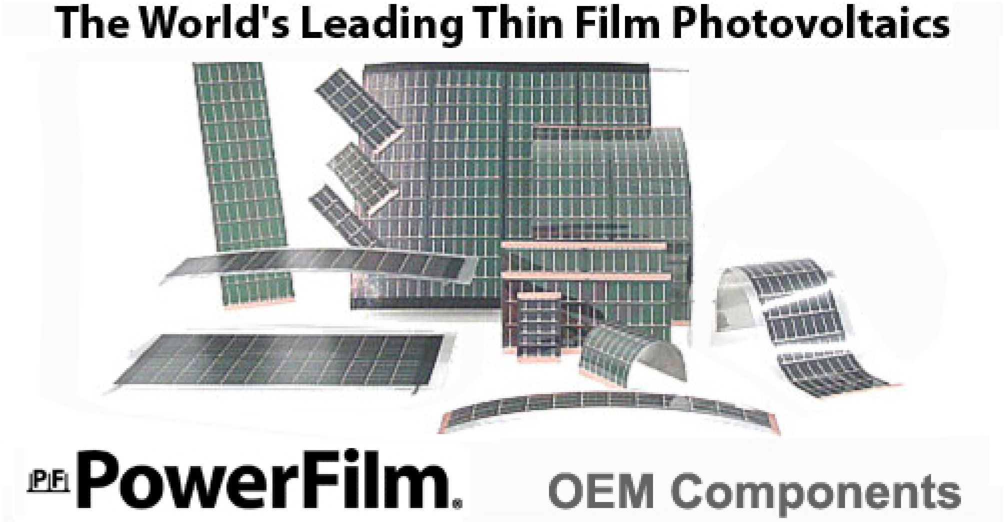

Technical Information: Choosing your Module

The following are considerations and suggestions for choosing the size of solar module needed for your application. The discussion is divided into 2 main parts:

1) Direct use of power from the module
2) Applications including battery storage

Key Concepts

- Module current increases nearly linearly with light intensity.
- Module operating voltage is relatively insensitive to the light intensity, dropping about 5% in 10% of full sun.

Usefull Definitions

- Power point - The operating voltage and current which produce the maximum power from the module. (Forcing the module to operate at a higher or lower voltage results in a less efficient operation).
- Duty Cycle - Percentage of time that an application is expected to operate.
- AM1, AM1.5 - For all intents and purposes - Full sun illumination intensity on a clear day at noon.

Calculations for Systems Without Batteries

Voltage Considerations
The voltage of the module should be selected so that the power point voltage is near the required operating voltage of the application. As a rough estimate, you can figure that the power point voltage is about 75% of the open circuit voltage.

Current Calculations

1. Find the minimum current needed for the application: $\mathbf{I_{min}}$

2. Determine the minimum light intensity (threshold intensity) under which the application will run: $\mathbf{L_{min}}$ (The table below gives a rough idea of light intensity under various conditions. Intensity is rated as a percentage of full sun intensity (also called AM1.5)

Energy Available at Various Light Conditions Relative to Full Sun	
Condition	**Intensity** (% of full sun)
Full sun - Panel square to sun	100%
Full sun - Panel at 45° angle to sun	71%
Light overcast	60-80%
Heavy overcast	20-30%
Inside window, single pane, double strength glass, window & module square to sun	91%
Inside window, double pane, double strength glass, window & module square to sun	84%
Inside window, single pane, double strength glass, window & module 45° angle to sun	64%
Indoor office light - at desk top	0.4%
Indoor light - store lighting	1.3%
Indoor light - home	0.2%

3. Calculate the required full sun current specification for your module: $\mathbf{I_{mod}}$

$\mathbf{I_{mod}} = \mathbf{I_{min}} \times 100\% / \mathbf{L_{min}}$

4. Chose a module that matches the voltage required and the current, $\mathbf{I_{mod}}$ calculated.

Note: Module performance is usually specified in terms of current @ a specific voltage (i.e. 50mA@3V) which gives performance at a specific operating point. This operating point is usually close to the power point. Some modules are specified at full sun and others at lower intensities such as 1/4 Sun. This is done to simplify selection. 1/4 sun is a more typical intensity used by portable electronics and is often chosen as the threshold intensity.

Example Calculations for Applications using Direct Power

Example 1: A radio to be powered by the module requires 9 mA at 3 Volts to operate. You want the radio to operate with any illumination above 20% of full sun.

$\mathbf{I_{mod}} = \mathbf{I_{min}} \times 100\% / \mathbf{L_{min}}$
$\mathbf{I_{mod}} = 9\text{mA} \times 100\% / 20\%$
$\mathbf{I_{mod}} = 45\text{mA}$

You need a module which will produce 45mA @ 3V under full sun illumination.

Example 2: Same as Example 1, but the given operating light is office light. $\mathbf{L_{min}} = 0.4\%$.

$\mathbf{I_{mod}} = \mathbf{I_{min}} \times 100\% / \mathbf{L_{min}}$
$\mathbf{I_{mod}} = 9\text{mA} \times 100\% / 0.4\%$
$\mathbf{I_{mod}} = 2250\text{mA}$

You need a module which will produce 2250mA @ 3V under full sun illumination. This is a very large module for a radio. A better solution may be to use a smaller module coupled with a battery which recharges from the module when left in a window.

Example 3: You want a flashing LED for a point of purchase display which works under store illumination. The flasher circuit uses an average of 0.1mA at 2.4 Volts to power 5 LEDs. From the chart above we see that store lighting gives $\mathbf{L_{min}} = 1.3\%$

$\mathbf{I_{mod}} = \mathbf{I_{min}} \times 100\% / \mathbf{L_{min}}$
$\mathbf{I_{mod}} = 0.1\text{mA} \times 100\% / 1.3\%$
$\mathbf{I_{mod}} = 7.7\text{mA}$

You need a module which will produce 7.7mA @ 2.4V under full sun illumination.Alternatively, you might look at the low-light specifications where performance is given at 0.4% of full sun (about 400 Lux). This can be normalized to the 1.3% level.

Calculations for Systems with Batteries

Voltage considerations

For battery charging applications, the operating voltage of the module should be at least as high as the charging voltage of the battery. This is higher than the battery's output voltage. A single NiCd battery has a typical output voltage of 1.2 volts, but requires 1.4 Volts for charging purposes. A 12 Volt lead acid battery needs a charging voltage from 14 to 15 Volts. In cases where a blocking diode is required to prevent the battery from discharging through the solar module when the module is in the dark, an additional 0.6 V is required. As an example, a battery pack with 3 NiCd batteries, which operates at 3.6 Volts, needs a module with either 4.2 or 4.8 V depending on whether a blocking diode is used.

Is a blocking diode required?

When the solar module is in the dark and still connected to the battery, it is simply a forward biased diode and can drain current from the battery. This is less of a problem for amorphous silicon modules than single crystalline modules, but can still be a problem if the module is in the dark a large percentage of the time. The leakage rate also drops dramatically if the open circuit voltage of the module is significantly larger than the output voltage of the battery. For applications that get sun daily, diodes can probably be ignored if the module is sized correctly. If the application is going to spend extended time in a case or drawer, however, a blocking diode would be advisable. Each application should be evaluated individually for this choice.

Current calculations

1. Calculate average current draw: $\mathbf{I_{avg}}$. This is equal to the current draw of the application times the duty cycle.
2. Estimate the average illumination on the module, $\mathbf{L_{avg}}$ (i.e. 4 hours of full sun per day averages to $\mathbf{L_{avg}}$ = 4/24 = 16.6% of full sun average illumination over the day). See table above for help on this.
3. Calculate the module current requirement. $\mathbf{I_{mod}} = \mathbf{I_{avg}} \times 100\% / \mathbf{L_{avg}}$.
4. Select the module that matches the voltage required and current $\mathbf{I_{mod}}$ calculated.

Example Calculations for Applications with Batteries

Example 1: A yard light draws 20mA and you want it to work for 8 hours per night. You estimate that you get the equivalent of 4 hours of full sun per day.

$\mathbf{I_{avg}} = \mathbf{I_{app}}$ x duty cycle
$\mathbf{I_{avg}}$ = 20ma x 8hr / 24hr
$\mathbf{I_{avg}}$ = 6.67ma

$\mathbf{L_{avg}}$ = 100% x 4hr/24hr
$\mathbf{L_{avg}}$ = 16.67%

$\mathbf{I_{mod}} = \mathbf{I_{avg}}$ x 100% / $\mathbf{L_{avg}}$
$\mathbf{I_{mod}}$ = 6.67ma x 100% / 16.67%
$\mathbf{I_{mod}}$ = 40ma

Example 2: A mobile phone draws 3mA in standby mode and 300mA in talk mode. It is assumed that the phone is used in the talk mode for an average of 10 minutes per day, while in the standby mode for 23hrs and 50 minutes. The phone can get an equivalent of 2 hours of direct sunlight per day. Find the module size needed to keep the phone charged.

$\mathbf{I_{avg}} = \mathbf{I_{app}}$ x duty cycle
$\mathbf{I_{avg}}$ = {3mA x [(23hr 50 min)/24hr]} + [300mA x (10min/24hr)]
$\mathbf{I_{avg}}$ = {3mA x [(23hr x 60min) + 50 min]/(24hr x 60min)] + {300mA x [10min / (24hr x 60min)]}
$\mathbf{I_{avg}}$ = [3mA x .993] + [300mA x .0069]
$\mathbf{I_{avg}}$ = 5.05mA

$\mathbf{L_{avg}}$ = 100% x 2hr/24hr
$\mathbf{L_{avg}}$ = 8.33%

$\mathbf{I_{mod}} = \mathbf{I_{avg}}$ x 100% / $\mathbf{L_{avg}}$

I_{mod} = 5.05mA x 100% / 8.33%
I_{mod} = 60mA

If the charging voltage of the phone is 6V, you will need a 6V, 60mA module at the very least to supply all needed power from the module.

Example 3: A fishing boat has a 12 volt battery system which powers a trolling motor and depth finding equipment. The boat is in use 4 days out of every month and requires an average of 2A for 6hrs of use per day. The boat will get an average of 4.5hrs of sunlight per day. Calculate the module size needed considering a monthly cycle.

I_{avg} = I_{app} x duty cycle
I_{avg} = 2A x [(4 x 6hr)/30 days]
I_{avg} = (2A x 1000mA/1A) x (24hr / 720hr)
I_{avg} = 2,000mA x 0.0315
I_{avg} = 63mA

L_{avg} = 100% x 4.5hr/24hr
L_{avg} = 18.75%

I_{mod} = I_{avg} x 100% / L_{avg}
I_{mod} = 63mA x 100% / 18.75%
I_{mod} = 336mA

If the boat is used 4 days per month with the days separated by equal time intervals, a 14V 400mA module should be sufficient to store enough energy to run the boat. However, if the boat were used 2 consecutive days, there would not be enough time to fully recharge the battery before the next day's use. If the capacity of the battery is sufficient, this will not be a problem, but if the capacity of the battery is such that only one day's energy can be stored in it, more charging capacity will be needed and the calculations will have to be redone on a daily cycle.

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