Photovoltaic energy harvesting with the AEM10941

The number of electronic devices increases every day. We are surrounded by connected, tracking or sensing devices. Unfortunately, most of them are powered by disposal batteries. Firstly, they reduce the energy available for the device and they can decrease the number of features. Moreover, they require regular maintenance and incur replacement costs.

Deploying millions of batteries will lead to the replacement of the same number of batteries within the next 5 years. The optimization of each device consumption and the power management cause headaches to end users and industries.

How can you estimate the real lifetime (including temperature influence) and how is it possible to extend it? Which features will you implement with your battery size and how can you optimize its lifetime to avoid changing it too fast?

Energy harvesting offers you a solution to these problems: it provides energy every day in order to supply your device and it removes the maintenance issues.

Three main elements are essential in order to build an energy harvesting system:

- The harvester transforming energy into electrical energy;
- The AEM10941 managing the power from the harvester to a storage element;
- The storage element storing the energy for a later use.

In the particular case of photovoltaic energy harvesting, the harvester is a photovoltaic cell. Other types of harvesters could be electromagnetic, micro turbine or thermoelectric generators. The choice of the energy source is related to the device environment.

The e-peas product AEM10941 is an *ambient energy manager* designed to extract and manage power from a harvester towards a low-power device. The AEM includes one internal boost, one buck and two linear converters. A cold-start circuit and a maximum power point tracking - MPPT - enable, respectively, to start as soon as possible to harvest energy and to extract the maximum power out of the harvester. Furthermore, this AEM stores the harvested energy in an external storage element while protecting it from overcharge and overdischarge. Eventually it provides 2 independent regulated voltages to supply an application circuit.

Figure 1 shows a photovoltaic energy harvesting system using the AEM10941 and any light source (LED light, indoor light or sunlight). Please note that technologies are evolving daily and new solutions dedicated to a specific light spectrum are available.

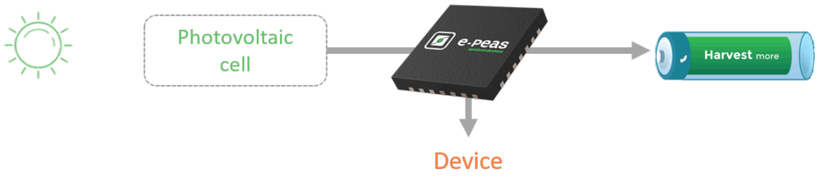

Figure 1: Photovoltaic Energy Harvesting Global System

What is required with the AEM10941?

Harvester

First you will need a photovoltaic cell to transform the light energy into electrical power.

These photovoltaic harvesters are not designed for the same light spectrum. Indeed, some may be more suitable for indoor light or the spectrum of the sun.
The different solutions of photovoltaic harvesters can be classified in several categories according to their composition and / or the manufacturing technique: silicon (amorphous, monocrystalline or polycrystalline), perovskites, tandem, organic, etc.

We listed below the biggest technologies but keep in mind that new technologies emerge every day.

Silicon-based solar cells are the most efficient but also the most polluting and expensive to produce.
Depending on their composition, these solar cells offer different characteristics in terms of efficiency, strength and environment. This first technology, often referred to as the first generation, is being replaced by new technologies mostly because of their cost.

A second generation called thin-film was introduced at lower cost and with lower efficiency.
This technology is based on either amorphous silicon, CIGS - Copper Indium Gallium Selenium - or telluride CdTe - Cadmium.

Finally, more recently, a third generation has emerged and is trying to replace the toxic materials used to manufacture photovoltaic cells. This category is constantly evolving. It includes DSC cells - Dry-sensitized cell or cells called OPV - Organic photovoltaic.

The organic photovoltaic cell is composed of different polymers that absorb light and conduct electrons. The spectrum absorbed as well as the performances depend on the materials used. This makes these harvesters flexible; and most importantly, it reduces manufacturing costs. Please note that organic materials are heterogeneous materials in opposition to silicon which is an organized material. The angle of light does not matter for these organic materials. The amount of light is the determining factor.

DSC solar cells - Dry-sensitized cells - are a non-toxic alternative for indoor lighting. Indeed, these cells can operate in a spectrum around 775 nm which corresponds to the spectrum of LEDs and neon lights. Please note that for applications that are often in the shade, this technology offers very good returns at lower cost.

Perovsky cells are based on organic and inorganic components (lead or tin halide). These cells announce a low production cost for performances equal to or greater than the first generation.

Tandem cells are a combination of two materials, including for the moment a layer of silicon to improve efficiency.

In general, the behavior of these harvesters is characterized by the power available under a given light and by the light spectrum. This light is expressed in several units which makes the comparison difficult only based on datasheets.

- The LUX unit is a photometric unit that includes the interaction with the human eye. In reality, it measures the amount of light perceived by the eye.
- The unit of irradiance expressed in W per m2 is a radiometric unit, i.e. a physical measurement of the power of light.

We strongly recommend you to always test your photovoltaic cell below your light condition since the light spectrum and the position could impact its efficiency.

Storage element

Regarding the choice of the storage element, there are two main categories. Either one or the other may seem more suitable depending on the environment, the load consumption profile and the required autonomy.

Supercapacitors offer a longer lifetime but a smaller energy density. They present a larger temperature range and are able to work below 0 °C. However, they are more expensive and possess a higher self-discharge rate. Their low ESR - Equivalent Serie Resistor - allows high current peaks without voltage drops, and they can be used with a battery as an energy buffer.
The actual geometries can be made of cylindrical or flat products such as prismatic packages. One of the main features of supercapacitors is their internal leakage as they discharge internally over time.
Products available on the market show a capacity from a few mF to tens of Farad.

Single-cell products show a nominal voltage below 3 V; however, they can be stacked to create dual or triple cells. When doing so, a balancing circuit is required to avoid using only one of the cells. Such feature is integrated in the AEM10941.

A large amount of rechargeable battery technologies exists and present different characteristics. Their more significant advantages are their cost and their high energy density; even if both vary with the technology. The regulations related to the transportation of some technology (using chemicals) could be a limitation. Furthermore, most of the technologies cannot work at low or high temperature. The geometry can go from a coin, cylindrical or laminated cell to a pin type. The nominal voltage depends on the chemistry and varies with the technology. Technologies using lithium chemistry show, most of the time, a nominal voltage above 3 V. The famous Li-ion battery has a nominal voltage of 3.6 V.
The lifetime of these batteries is highly related to the way they are charged and discharged. Charging them to their maximum voltage could damage or reduce their lifetime. A voltage protection (maximum and minimum voltages) is important, especially with autonomous devices with a long lifetime.

The main technologies available on the market are listed below:

Lithium-ion batteries show the highest energy density but they require some protection because of their chemistry.
Lithium Polymer batteries are safer with a fast rate of charge and discharge. They only work with positive temperatures and are more expensive.
A large number of associations exist to build up a battery with lithium-ion technology. Some of them are made of nickel (NCA - NMC) to improve energy density. Others are combined with manganese (LMO) in order to enable a higher current at a lower ESR or with cobalt for the purpose of improving energy density. Phosphate and titanate are also used to provide a higher life cycle.
NiMH batteries require less protection and are cheaper. However, they have a lower energy density than Li-ion batteries and have some memory effect.
Solid State batteries are not a technology in themselves, but they include the entire structure of batteries with solid electrolytes. Although they can be more expensive, they are safer and have a higher energy density. Lithium-ceramic batteries contain very small components with a high charge/discharge rate but for small capacity and at high cost.
Silver-Zinc technology is eco-friendlier and safer; however, it has a low life cycle at high cost.

Both options are described below for high-level characteristics. One is not better than the other and the choice will depend on the device requirements.

Supercapacitors	**Batteries**
- Charge starting from 0 V	- Pre-charged by manufacturer
- Lower energy density	- High energy density
- Lower ESR	- High ESR
- Longer lifetime	- Lifetime limited in life cycle
- Stable technology - no security regulations	- Transport regulations
- Standard temperature range	- Temperature limitation
- Can be discharged until 0 V	- No overdischarge allowed
- Leakage current	- No leakage allowed before deploying the system
- No current peak limit	- Limited current peak

Energy balance

To build an energy harvesting system correctly, the most important consideration is to ensure that enough energy will be harvested once it is available; and to guarantee that enough energy will be stored to supply the load when no power is available at the source. For a sunlight supplied device, it means harvesting energy during the day and storing it for the night. The autonomy with no light could be bigger based on the device use case. In the end, the idea is to understand these requirements in order to wisely estimate when power will be available and what energy should be stored.

As described below, the energy consumed by the device - called LOAD - must be lower than the energy available from the light source at the device location. Moreover, the energy consumed when no power is available must be lower than the energy stored in the storage element. Therefore, the size of the storage element must be wisely chosen.

$$\mathrm{E_{LOAD}} < \mathrm{E_{HARVESTED}} \qquad \text{and} \qquad \mathrm{E_{LOAD\,noPower}} < \mathrm{E_{STORED}}$$

These conditions represent guidelines for the harvester and the storage element size.
The size of the harvester will be based on the environment and the expected power from the source in order to supply the load.
One way to reduce the photovoltaic area is to decrease the load consumption (by using a duty cycle or low-power components).

The storage element is sized based on the device consumption and the required autonomy.
The autonomy refers to the time during which the device must be working without any power coming from the source. This period could be a weekend if the device is working with office lights.

Example of a photovoltaic supplied device powered by indoor light

Let's use an example of an application with an advertizing BLE beacon sent each 9.5 s and some sensors measuring the temperature, the humidity and the luminosity. We could assume that the sensors are supplied by office indoor lighting of about 500 lux (a common value for indoor environments).

The global average consumption is about 50 µW which leads to 4.32 J over a whole day - including a leakage current of 1 µA in the storage element.
If we include AEM internal losses, a converter efficiency of 89% from the storage element, an internal boost converter efficiency of 70% (for a 0.4 V input voltage) and 8 hours during which power is available from the ambient source, we can estimate that the expected power from the photovoltaic cell is about 240 µW.

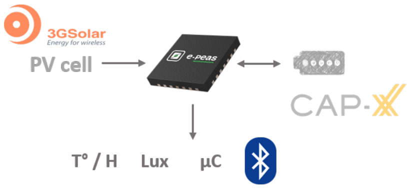

Figure 2: High-level Schematic of the Demo Kit

Please note that the internal boost efficiency refers to the worst case (small input voltage). For a higher input voltage (up to 5 V), the efficiency will be up to 95%.

The DSC photovoltaic cell (35 mm by 50 mm) from 3GSOLAR can be used as the harvester. It provides around 490 µW below 500 lux, meaning that 8 hours below this low light luminosity each day generates more than enough energy.

Regarding the storage, assuming that the light is back each morning, we can estimate that we must only store a part of the energy: the one required to supply the load for 16 hours. This energy is about 3.6 J.
By using a supercapacitor for the storage, this energy will be stored between the maximum allowed voltage and the minimum one. Indeed, if the AEM10941 linear converter is used, the LDO outputs are cut off when the voltage on the storage element reaches its minimum voltage (*defined by the AEM configuraton as described in Table 7 in the datasheet*).

With an HVOUT voltage configured at 3.3 V, the minimum allowed voltage by the AEM structure is 3.6 V. The minimum size required to store energy between 4.5 V and 3.6 V is about 0.98 F. The GS230F dual-cell supercapacitor from CAP-XX offers a 1.2 F capacity with a maximum voltage of 5 V. Their internal leakage current is about 1 µA per F.

Figure 3: Photovoltaic Supplied Demo Kit

The complete demo kit (65 mm x 65 mm x 10 mm) only needs 8 hours below 500 lux to harvest and store enough energy to make the device autonomous and easy to deploy.

For orders, please contact our distributors or our sales team: sales@e-peas.com.

Feel free to contact our support department for more technical details: support@e-peas.com.