ALTA DEVICES

WHITEPAPER

Solar Power Energy Harvesting Electrical Integration

Contents

Executive Summary

When designing small devices powered by Alta Devices solar cells, designers have several energy harvesting chips to choose from so they can optimize getting power from the solar to the system. This article will explain electrical integration design considerations and show examples of energy harvesting methods.

Introduction

Internet-of-Things (IoT), wearables, wireless sensor networks (WSN), and other small devices are poised to revolutionize the connected world of sensors, communication and data collection. Today, most of these devices are powered by disposable batteries. Solar power is a game changer in that it allows devices to be powered much longer or indefinitely without ever changing the batteries.

There are many considerations when designing a solar-powered device such as indoor and/or outdoor solar power characteristics; and maximum power point tracking to optimize solar energy harvesting. The electronic power interface from the solar cell to the device can be designed with different objectives in mind — from extending the life of a primary battery, to creating a system that never needs battery replacement.

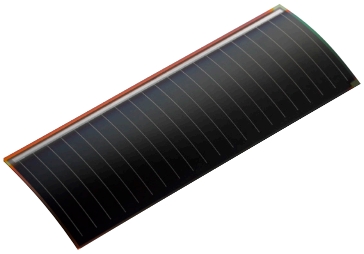

Fig. 1. Alta Devices Cell

Solar Cell Electrical Characteristics

Solar power acts like a current source and is characterized by the current versus voltage or IV curve. The current is proportional to the illumination; and the voltage changes with the load. Solar cells are self-limiting power sources, with more load causing the solar voltage level to drop; and a lighter load allowing the solar voltage to rise toward its open-circuit voltage. Solar cells do not store energy and cannot deliver step-function load demand.

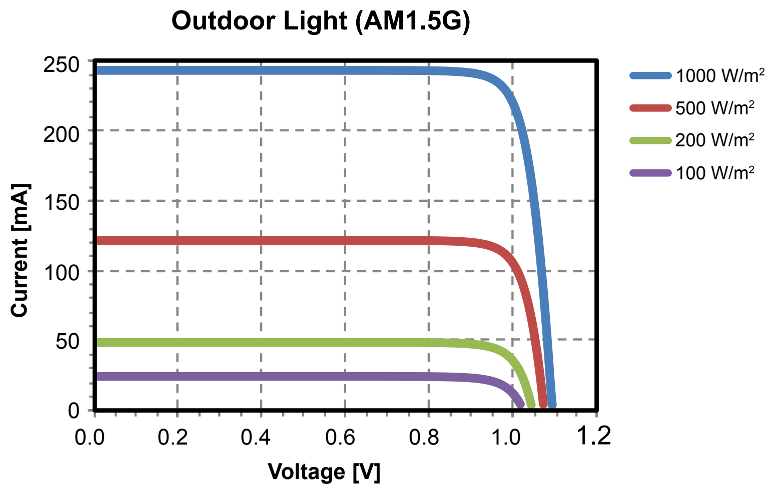

Fig. 2. The Current versus Voltage (IV) curve

Alta Devices' Gallium Arsenide (GaAs) solar cell has the above mentioned characteristics even in very low artificial light conditions. The standard Alta Devices solar cell specifications are listed below, for more detailed specifications see www.altadevices.com.

- Alta Devices solar cell measures 5 cm X 1.71 cm
- Operates indoors down to 200 Lux
- Open circuit voltage is 1.1 V
- Short circuit current is 0.24 A
- Outdoor power: 220 mW in 1000W/m² sunlight
- Indoor power: 390 μW in 500 Lux artificial light
- Multiple cells can be configured in series or in parallel

Maximum Power Point Tracking

Solar cells have a characteristic maximum power point as illustrated in the graph below. Energy harvesting semiconductors with Maximum Power Point Tracking (MPPT) can regulate the solar input impedance to maximize the power drawn from the solar cell.

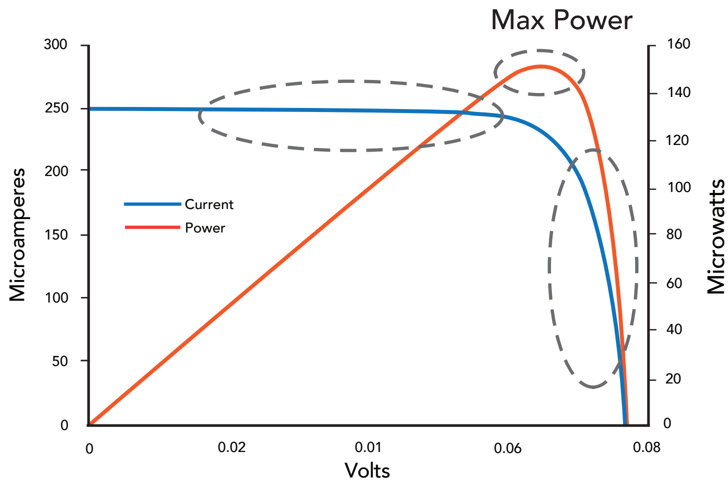

Fig. 3. Low Light IV curve and Maximum Power Point

Equipping energy harvesting electronics with MPPT and input impedance regulation is generally desirable to maximize power output, but may not be needed in certain cases. For example, a linear regulator acting as a current source may want to only maximize the current. There are different MPPT methods used by power electronics devices. Most devices use a simple voltage divider to preset the Voltage maximum power (Vmp) level. This Vmp is known from the solar cell manufacturer's specification. For Alta Devices cells, the Vmp is 88% of Voltage open circuit (Voc) in sunlight and slightly lower, 83 - 85% for indoor light. If the preset cannot precisely set the Vmp due to available resistor values, the Vmp should be set to the lower bias. (For example, given a choice between settings of 82.6% and 83.3%, designers should pick 82.6%.) This is because the power curve (Figure 3) is less steep on the low side of the maximum point. Another and more advanced MPPT method is the Observe and Perturb algorithm which periodically tests for the maximum power point. This algorithm could be an advantage when there is partial shading on the solar cell causing a more complex multi-peak power curve shape.

Solar cells are self-limiting power sources, with more load causing the solar voltage level to drop; and a lighter load allowing the solar voltage to rise toward its open-circuit voltage.

Indoor and Outdoor Light

Because Alta Devices solar cells can operate indoors and outdoors, the electrical system designer must be careful to match the power ratings of the solar cell with the energy harvesting semiconductor device. This is particularly challenging in very low power designs using a single standard solar cell or a small custom cell intended to be used in both indoor and outdoor light thus having a very wide power range while still requiring energy harvesting features. Several options will be discussed later in this document.

Energy Harvesting System Topologies

The electrical interface to the solar panel can use different topologies depending on the system objective. The objective could be to extend battery life or to completely remove the need for batteries. Some energy harvesting devices are integrated with a regulator on the output to the system load when a regulated power source is required. Below some of the common topologies used are described.

Energy Harvesting in Variable Light Conditions

Solar energy can be used for energy harvesting wherever there is light. Alta Devices solar cells demonstrate consistent performance in bright sunlight down to very low indoor light. So the end-use location, indoor or outdoor, must be considered.

Typically an energy harvesting system will use the energy to charge an energy storage device. This usually is a rechargeable battery or a super-capacitor.

Indoor energy could be in the low hundreds of micro-Watts which requires an energy harvesting device that starts-up with very low power and can do MPPT to efficiently draw the low amounts of power from the solar cell.

Outdoor energy harvesting is typically a thousand times higher in the milli-Watt range, so different energy harvesting devices are used in this power range. Low quiescent current is a requirement in any device selected for an energy harvesting design. High efficiency is also important, and is particularly challenging for low power micro-Watt range designs.

Energy Storage: Battery and Super-Capacitor

Typically an energy harvesting system will use the energy to charge an energy storage device. This usually is a rechargeable battery or a super-capacitor. Different battery chemistries have different charging methods, sometimes called charge algorithms. These could be a simple constant voltage (CV) applied to the battery; or a more complex multistage charge profile. For example, a low power pre-charge, followed by a constant current (CC) stage to bulk charge, and then a CV stage to top off. A super-capacitor has a less complex charging method that uses an applied voltage to charge the super-cap voltage asymptotically, basically the same as any common capacitor except the time-to-charge is much longer because of the huge capacitance.

Battery Replacement

Solar energy can be used to make a self-powered system which never needs battery replacement. This calculation must be made using energy-time units (Watt-Hours). First calculate the load requirements in Watt-Hours in one day. Most lighting cycles are completed in one 24 hour day. The total one day power requirement must be met by the solar energy harvested in Watt-Hours. The battery capacity in Watt-Hours will need to power the load during the hours of darkness. (Note that the electronics and battery power conversion efficiencies need to be accounted for in these calculations.)

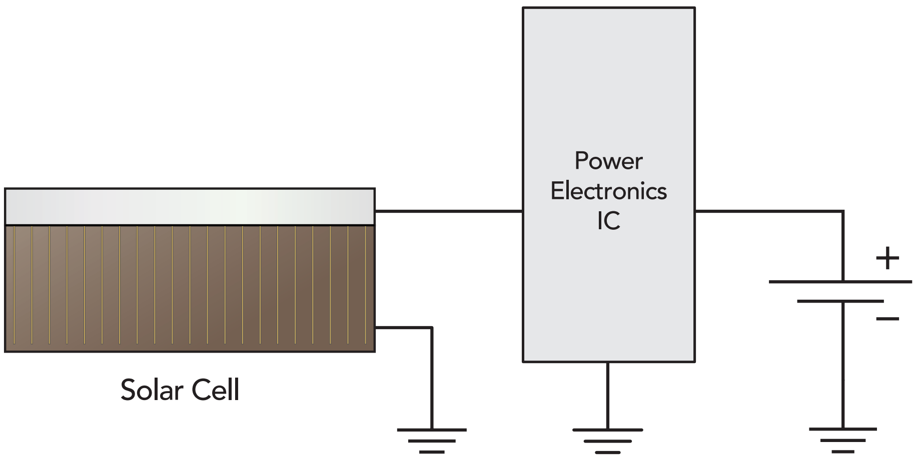

Fig. 4. Battery Replacement Block Diagram

Battery Extension

A battery extension design will usually have two energy storage devices. There is a primary battery which is typically a replaceable non-rechargeable battery. The objective of a battery extension design is to increase the time between replacements of the primary battery. Solar energy is harvested and stored in a secondary battery (or super-capacitor). If the energy in the secondary battery is sufficient, the system will switch the power source from the primary to the secondary battery. When the secondary battery is drained below a certain threshold due to lack of re-charging from the solar cells, the system switches back to use the primary battery.

Solar energy can be used to make a self-powered system which never needs battery replacement.

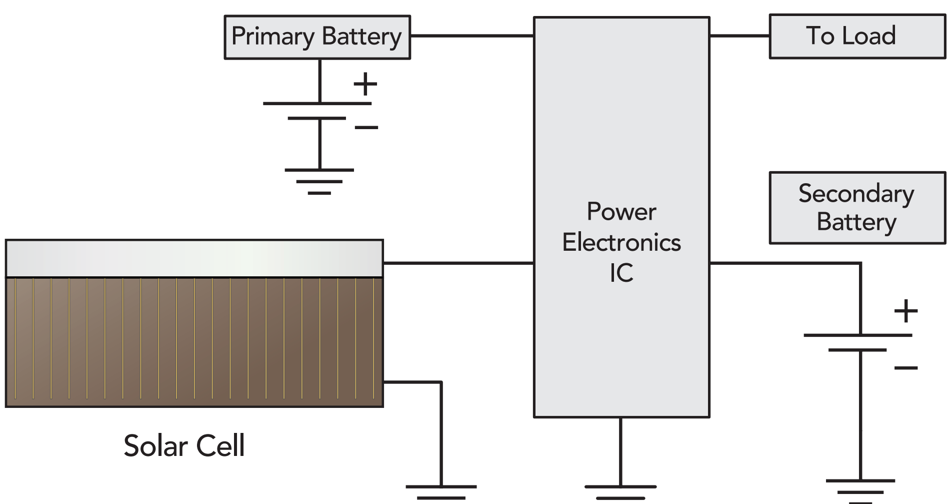

Fig. 5. Battery Extension Block Diagram

Multiple Power Sources and Reverse Biasing

When multiple power sources (solar, battery, etc.) are used together, the designer must not allow reverse biasing of the solar cell. This will cause long term damage to the solar cell. Designers should check if their chosen energy harvesting chip has reverse bias protection built-in. If it is not built in they will need to place a diode in series with the solar cell. Caution should be taken if the energy harvesting chip is in the Buck regulator topology, as the intrinsic diode in the Field Effect Transistor (FET) will pass reverse current.

Integrated Regulated Outputs

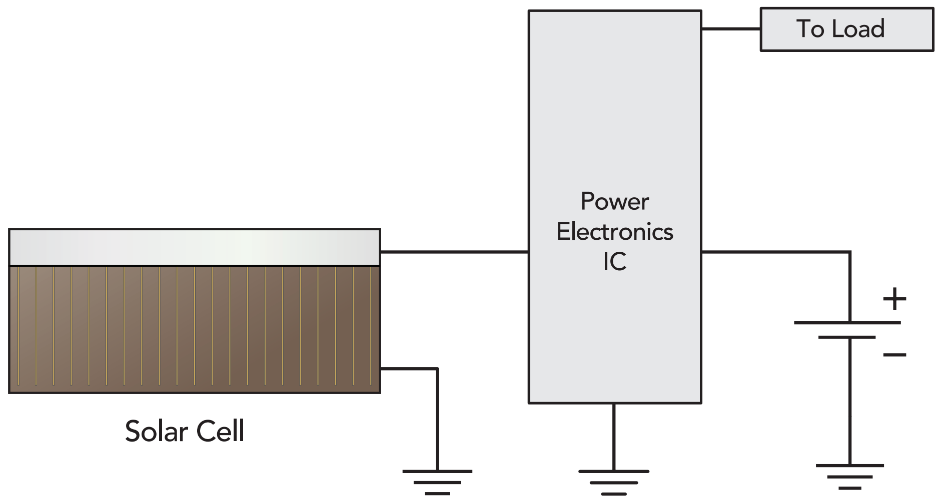

Fig. 6. Integrated Regulated Output Block Diagram

Some systems, including some microcontrollers, do not need a tightly regulated voltage supply, so they can use a wider range output than some energy harvesting electronics output. In other types of systems, a regulated voltage is required. In these cases a voltage regulator is needed for each voltage level required. A high efficiency switching regulator can be used when power inefficiencies must be minimized.

Design Guide

In the design guide below, semiconductor energy harvesting devices are highlighted. This is not an exclusive list and is intended to show examples of the types of devices available. Every designer should do their own due diligence before choosing any integrated circuit IC.

Examples are shown for small single solar cell indoor and outdoor designs; as well as slightly larger 5 or 6 solar cell designs.

Indoor Single Cell Designs (75μW – 1mW)

Using a single solar cell presents challenges of ultra-low power management. Even test and measurement are challenging because the quiescent current in the instrument skews the reading from the actual. An Alta Device solar cell operates in very low light conditions where energy can still be harvested.

Alta Devices also offers a “sensor” cell. This cell is half the physical size of a standard cell making it compelling for a very small device application. The current capacity is half a standard single cell (2.5cm x 2cm) and can go down to low power levels of 75µW in extremely low light, which can still be harvested by a few energy harvesting ICs including the three examples in this section.

Three Examples of Indoor Energy Harvesting ICs

1. Analog Devices ADP5090 and ADP5091

Analog Devices ADP5090 and ADP5091 are ultra-low power, synchronous, boost dc-to-dc converters. The MPPT Vmp level is preset by a resistor input divider. This device will start up with very low current making it compatible with the indoor light Alta Devices solar cell.

The output is adjustable for charge termination maximum voltage and minimum low voltage which allows setting an output range to the energy storage device. Additionally a "power good" indicator can be set by resistors.

Both devices also can be optionally used in a primary battery life extension system. The ADP5091 is a newer device with faster startup and an integrated low dropout linear regulator to provide voltage regulation to the load.

2. ST Microelectronics SPV1050

The SPV1050 is an ultra-low power and high-efficiency energy harvester and battery charger, which implements the MPPT function. In its boost configuration, it can be used with a single solar cell. It can start up very quickly with extremely low start up power requirements making it compatible with the indoor light Alta Devices Solar cell.

The SPV1050 device charges most batteries, and the end-of-charge and the minimum battery voltage can be set by resistors.

The MPPT Vmp level is pre-set by a resistor input divider. An unregulated voltage output is available as well as two fully independent LDOs (1.8 V and 3.3 V) can be independently enabled through two dedicated pins.

3. Texas Instruments BQ25504, BQ25505, and BQ25570

Texas Instruments (TI) makes a family of ultra-low power energy harvesters: the BQ25504 DC-DC boost converter and charger. The BQ25505 adds primary battery extension, and the BQ25570 adds an integrated buck regulator. These devices can start up very quickly making it compatible with the indoor light Alta Devices solar cell. Additionally, these devices have a wide power range making them versatile enough for limited outdoor solar energy harvesting.

The MPPT Vmp level is preset by a resistor input divider. These devices can store energy in most battery types and super-capacitors. The undervoltage and overvoltage charge levels are programmed by resistors. A battery power good signal is available to warn or enable loads.

The BQ25505 is for battery extension designs. A primary battery connection to the load is managed for when the solar energy charged secondary battery (or super-cap) is too low. The BQ25570 has an integrated buck regulator for use with loads that require a regulated voltage.

Outdoor Single Cell Designs (1mW – 210mW)

Single solar cell outdoor light applications can harvest a thousand times more energy than indoors. Energy harvesters must be compatible with the higher power range, the good news is that there are many more devices to choose from. Low voltage input compatible with the solar cell, a low quiescent current, a soft-start current feature, MPPT, and high efficiency are some of the features to look for.

Three Examples of Outdoor Energy Harvesting ICs

1. ST Microelectronics SPV1040

The SPV1040 device is a low power, low voltage, monolithic step-up converter with an input voltage range from 0.3 V to 5.5 V so it is compatible with up to six solar cells in series.

The SPV1040 has an embedded Perturb and Observe MPPT algorithm, which is a more sophisticated method than the preset Vmp method. The device employs an input voltage regulation loop, and sets the charging battery voltage using a resistor divider. The maximum output current is set with a current sense resistor according to charging current requirements.

A maximum current threshold (up to 1.8 A) can be preset and the battery temperature can be monitored and managed. An input source reverse polarity protection prevents damage in case of reverse connection of the solar panel at the input.

2. Linear Technology LTC3105

The LTC3105 is a high efficiency step-up DC/DC converter that can operate from input voltages as low as 225mV and can handle up to 400mA so it is compatible to use with a single solar cell in outdoor applications. The MPPT Vmp level is preset by resistors.

The LTC3105 also has a separate LDO to provide a regulated rail while the main output is charging. In shutdown, the quiescent current is very low and integrated thermal shutdown offers protection from an over temperature condition.

3. Texas Instruments BQ25504, BQ25505, and BQ25570

The TI devices mentioned above in the Indoor design section have a wide power range making them versatile enough for limited outdoor as well as indoor solar energy harvesting.

If the designer's power requirements are within the power range of the TI devices, a small single solar cell system operating both indoors and outdoors can be made.

5 & 6 Cell Battery Chargers (1mW indoor, 1W outdoor)

As we increase the number of solar cells used, the power range to cover indoor and outdoor operation becomes less of an issue. In this example, 5 or 6 solar cells are connected in series to create a higher voltage and thus more power. However, at these higher power levels, battery charging methods are an important consideration. One must insure the battery charging electronics are capable of charging the battery chemistry used. Using a linear charger, the current drawn from the solar cell should be optimized.

Two Examples of ICs for 5&6 Cell Chargers

1. Linear Technology LTC4079

The LTC®4079 is a low quiescent current, high voltage linear charger for most battery chemistry types. The maximum charge current is adjustable from 10mA to 250mA with an external resistor. The battery charge voltage is set using an external resistor divider. Thermal regulation ensures maximum charge current up to the specified limit without the risk of overheating. Charging can be terminated by either C/10 or adjustable timer.

The MPPT Vmp is preset with resistors using the EN pin, the Input voltage regulation reduces charge current when the input voltage falls to the Vmp level or the battery voltage. Other features include temperature qualified charging, bad battery detection, automatic recharge with sampled feedback in standby for negligible battery drain, and a charge status output.

2. Texas Instruments BQ24210

The BQ24210 device is a highly integrated Li-Ion linear charger targeted at space-limited portable applications. The battery is charged in three phases: conditioning, constant current and constant voltage with an IC thermal protection and safety timer. The charge current value is programmable through an external resistor. The MPPT Vmp is preset by resistors, to provide input voltage regulation.

5-cell Super-Capacitor Regulator (1mW Indoor, 1W Outdoor)

Using a super-capacitor is an alternative to a battery. The super-cap has less charging issues and during discharge the low charge level curve is more constant compared to a battery so the power could be useful at much lower levels. A super-cap could be charged directly from a solar panel; however power electronics are usually used to protect the system by turning off the load at low charge thresholds; and to regulate to a useful voltage. Low quiescent current is necessary in the electronics so as not to discharge the super-cap when not being charged by the solar panel. Additionally, a blocking diode must be used in series with the solar panel to prevent reverse current flow when there is no solar energy available.

Example of Super-Capacitor with a Regulator

Texas Instruments TPS62740

This is a step down Buck converter with very low quiescent current; and supports output currents up to 300mA. The device can be operated by 5 or 6 solar cells and a super-capacitor as the input voltage range allows up to 5.5V. The output voltage is pin selectable within a range from 1.8V to 3.3V. The power good pin can be used to enable a load switch, so the load can be disconnected when the solar and super-cap voltage falls below a preset level.

Conclusion

There are several options to electrically integrate Alta Devices solar within small electronic systems. Energy harvesting chips' power range must be matched to the solar power available and load power consumption. Designers should consider their objectives for battery replacement or extension topologies. Other features to consider are regulated output and "power good" enabled load switches. Using Alta Devices solar cells to extend battery life or to completely eliminate batteries under any lighting conditions enables designers to create devices for next generation IoT, wearables and wireless sensors products.

References

Analog Devices http://www.analog.com/

Linear Technology http://www.linear.com/

Texas Instruments http://www.ti.com/

ST Microelectronics: http://www.ST.com/

ABOUT ALTA DEVICES

Alta Devices (*www.altadevices.com*) holds the world record for single-junction solar cell efficiency (28.8%). It manufactures ultra-lightweight gallium-arsenide based solar cells in its Sunnyvale, California factory and provides application engineering support to OEM customers worldwide. Alta Devices can be contacted at info@altadevices.com.