Powering Microcontrollers from Ambient Energy Sources

The green power movement has spawned intense interest in the need for clean and renewable energy sources. This attention is usually focused on large scale power generation to supply homes and industry. However, the need for clean and renewable energy also finds a place with low power applications such as remote microprocessors or industrial sensors. Ambient light, heat and vibration sources can generate power for microcontroller or microprocessor circuits as described in the following. **Scot Lester, Applications Engineer, Texas Instruments, USA**

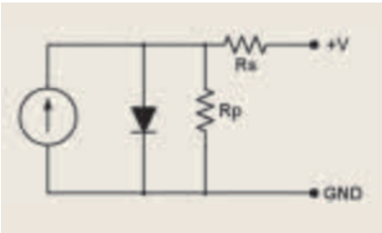


Figure 1: Solar cell model

Remote sensors or processors are normally powered with a battery that requires occasional replacement and pose an environmental hazard when not disposed properly. For some applications, it may be physically difficult or impossible to reach the remote device to change the battery. For other applications, environmental conditions such as high ambient temperatures or mechanical movement make the use of a battery unreliable. For these types of applications, using localised ambient energy sources, otherwise known as energy harvesting, to power the remote device makes sense.

Harvesting power by solar energy

Solar power is the most widely known and used energy harvesting power source today. The solar cell is comprised of a P-N junction with metal electrodes. Photons strike the P-N junction which causes electrons to be ejected from the N-Type material. The number of ejected electrons and, thus, the amount of current that can be generated, is proportional to the number of light photons striking the P-N junction. This P-N junction forms a P-N junction diode, therefore many characteristics of the solar cell parallel those of a diode.

Figure 1 shows the electrical model of a solar cell. It is comprised of a current source shunted by a parasitic diode. The amount of current generated by the current source will be proportional to the surface area of the solar cell and the amount of light incident on it. Since this current source is shunted with a diode, the cell's output voltage is clamped to a value equal to the forward voltage of the diode minus some voltage drop due to current flowing through the series parasitic resistance (R_s), which is due to the electrodes and semiconductor material. From a system standpoint, the solar cell appears to be a current source with a current capability proportional to the amount of light.

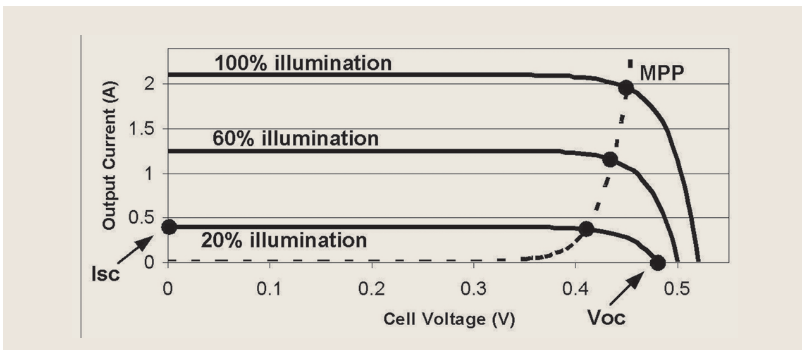
Figure 2 shows the typical characteristics of a 100cm² silicon solar cell with three different solar illumination levels. The cell is capable of generating a maximum of 0.4A with 20% illumination.

The maximum current at this illumination occurs when the cell is shorted and therefore the output voltage is zero. The 0.4A is therefore the short circuit current (I_{sc}). Conversely, the maximum output voltage of 0.45V occurs when there is no load on the output and the output current is zero (open circuit voltage V_{oc}. The values of I_{sc} and V_{oc} will vary depending on the illumination level, the material composition of the cell and the temperature of the cell.

The output power is zero when operating at the V_{oc} or I_{sc} points. Between these two points there is a point where the maximum amount of power can be extracted from the cell, called the Maximum Power Point (MPP). Figure 2 shows three MPPs for the three different illuminations, they move higher in voltage (from 0.41 to 0.44V) as the illumination increases.

Solar cells can be stacked in series to increase the output voltage. They may also be stacked in parallel to increase the output current capability. For low power applications, it is beneficial to use a single cell. However, the output voltage of the cell, a nominal 0.5V, is typically too low to power a microprocessor or other circuits. This voltage must be stepped-up to a usable voltage such as 3.3V via a boost converter.

Figure 2: Typical solar cell I-V curve



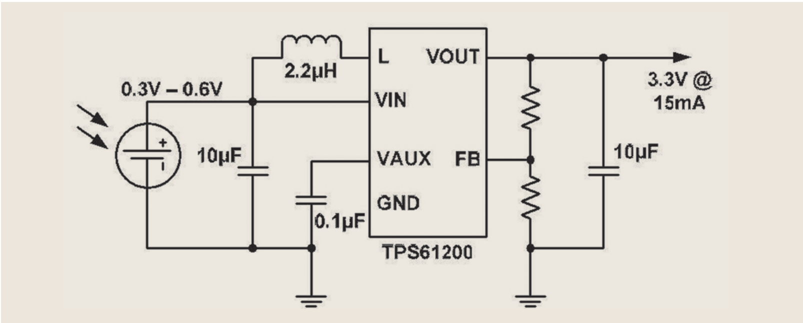


Figure 3: **Solar cell boost converter with TPS61200**

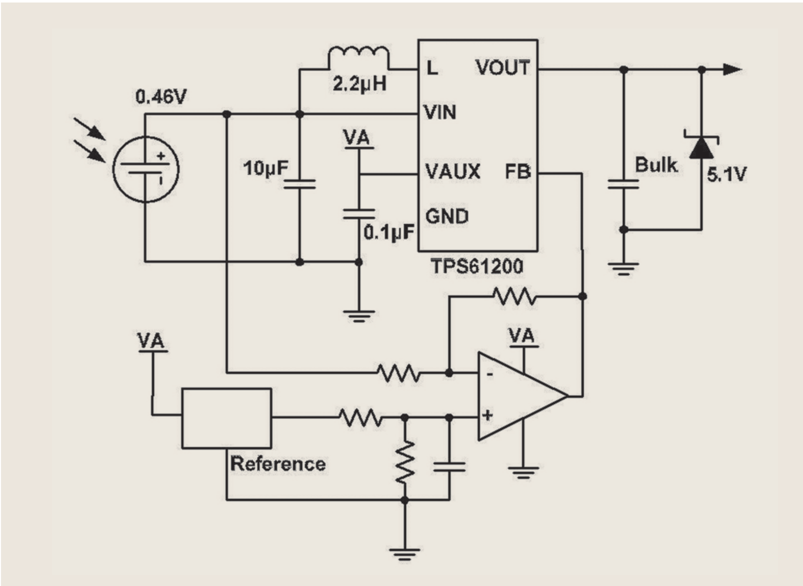


Figure 4: **Constant power boost converter**

The most critical specification for the boost converter is that it can start up from the cell's open circuit voltage at typically 0.5V. Once the boost converter starts and draws current from the solar cell, the cell's output voltage will start to decrease toward the MPP. The boost converter must be able to continue to operate with input voltages as low as 0.35V for the cell shown in Figure 2, in order to provide power over a wide range of illumination levels. Figure 3 shows a boost converter specifically made to operate from a single solar cell. The converter will start switching when the input voltage is 0.5V or higher. The converter can continue switching with input voltages as low as 0.3V and is configured to provide a regulated 3.3V with up to 15mA of output current.

The converter regulates the output to a fixed voltage by drawing what power is available at its input. If the cell is fully illuminated, the converter may not necessarily be operating at the MPP point. The converter could actually draw more power from the cell if needed. Some applications do not require a regulated output voltage, but rather require that the maximum power is harnessed from the cell. An example of such an application would be a battery or super capacitor charger. In these applications, the converter needs to harness the maximum power available from the cell, by operating at the MPP point of the cell, and store it in a bulk charge storage device. The super capacitor's voltage is allowed to increase up to the maximum voltage allowed by the system. The feedback loop of the converter can be modified to operate the cell at its MPP point.

Figure 4 shows how the feedback loop of a standard converter can be modified to draw the maximum power. In this circuit, the duty cycle of the converter is adjusted to keep the input voltage at 0.46V which is the MPP point for the cell at full illumination. This, in effect, makes the converter a regulated or constant power converter rather than a constant voltage converter. A 5.1V Zener diode is used to clamp the output voltage so that the capacitor does not charge up to a voltage that is beyond the rating of the capacitor or the converter.

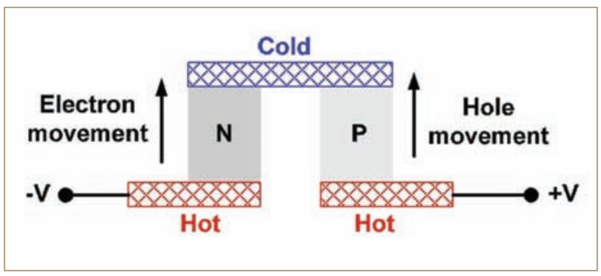


Figure 5: **Basic components of a thermoelectric generator cell**

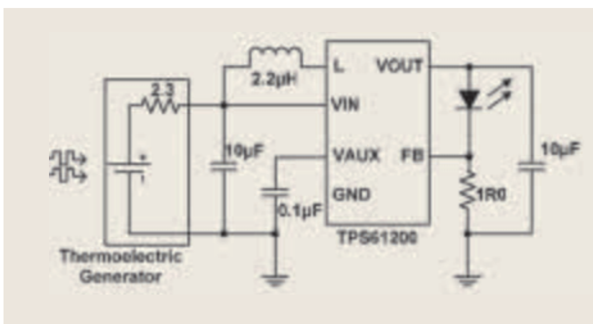
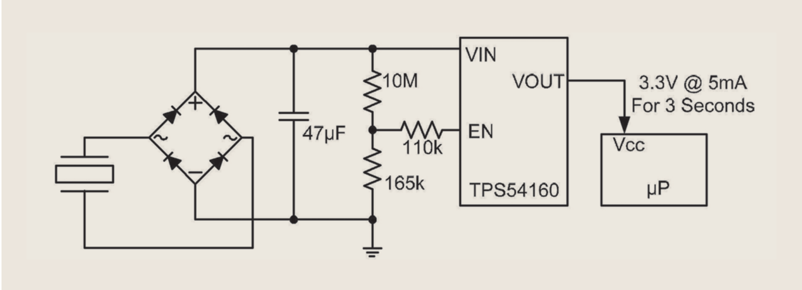


Figure 6: **Boost converter TPS61200 to power a 500mA LED**

Figure 7: Regulator for a piezoelectric generator powering a microprocessor for 3s



Harnessing thermal energy

There are many instances where excess or waste heat is available to power circuits. This heat flow can be used to produce electricity to power circuits.

A thermoelectric generator is comprised of two surfaces, one hot and one cold, separated by N- and P-type semiconductor materials. The electrons in the N-type material that are closest to the hot surface are more energised than the electrons near the cold surface. The hot energised electrons move toward the cold less energised electrons. The P-type material has a similar effect, but with holes rather than electrons. The hole and electron movements produce a current that can be used to power circuits. Figure 5 shows the basic components of a thermoelectric generator cell. These cells can be stacked in series to increase the output voltage, or in parallel to increase the output current capability. A typical thermoelectric generator will have hundreds of these cells in series and parallel, in order to produce a useable amount of power.

The amount of power produced by the thermoelectric generator is determined by the geometry and materials of the cell, and by the temperature difference between the hot and the cold surface. The reliable generation of power requires that the temperature difference remain high between the two surfaces. The temperature of the hot surface will usually be determined by the heat generating portion of the system. The designer must provide a method to remove thermal energy from the cold surface to keep the surface cool. This will usually be a large heat dissipative surface with some amount of air flow. If there is no heat removal from the cold surface, then the cold surface will eventually heat up to the same temperature as the hot surface and no power will be generated.

The output power and internal resistance both vary with temperature. Additionally, the output voltage varies with temperature and output current due to the internal resistance. For these reasons, there is almost always some form of DC/DC converter used to regulate the voltage from the generator. Figure 6 shows a thermoelectric generator used to drive a high power white light LED with 500mA of current. The thermoelectric generators output is rated at 2.8V but varies anywhere between 2 and 2.8V, depending on the amount of heat applied and the load. The DC/DC converter used (also TPS61200) has 0.3 to 5.5V input voltage range, so it can fully illuminate the LED once the output of the generator is above 2V. Below 2V the converter will be power limited. It will still continue to illuminate the LED, but at a lower current.

Generating electricity from vibration

Generating electricity from vibration or other repetitive movement is accomplished using a piezoelectric (PE) material, a crystalline material that is electrically neutral in its normal state. The crystal contains both positive and negative charged material, however, the non-symmetrical physical arrangement of the crystal makes the net potential difference across the crystal zero. As a force is applied in one direction to the crystal, the crystal lattice shifts slightly which moves the charged partials relative to each other so they no longer make a net zero potential difference along one axis. A very large potential difference is created between one face of the crystal and its opposite side. Electrodes are mounted to these two sides, one plus the other negative, so that energy can be extracted from the PE material.

Since there is not a large number of excess electrons available in the crystal, the generator has a low current capability, but with a very high output voltage. The magnitude of the output voltage will relate directly to the amount of deflection or stress in the crystal. Once the force is removed from the crystal, the crystal will relax back to its normal state, typically with some amount of mechanical oscillation. The output voltage of the PE material will therefore look like an AC generator.

Depending on the physical and electrical characteristics of the generator, each spike may contain between 1 and 5mJ of energy. Each output spike is typically not sufficient to power a circuit. To be useful in powering circuits, the high voltage pulse train needs to be rectified and used to charge a bulk energy storage element such as a battery or a capacitor. Since the energy must be collected and stored in order to obtain usable amount of power, the piezoelectric generator is best used in system requiring intermittent operation. The system must wait until there is enough energy stored in the bulk capacitance, so that the system can complete its task before the storage device is discharged.

Figure 7 shows a simplified schematic of a power converter that is suitable for piezoelectric energy harvesting. The 47µF capacitor provides the bulk energy storage for the rectified high voltage pulse train from the piezoelectric generator. The three resistors on the enable pin of the TPS54160 set the enable and UVLO voltage thresholds. In this example, the power converter will remain disabled and in a low quiescent current state until the voltage on the bulk capacitor reaches 55V. Once the voltage on the capacitor is 55V, the TPS54160 will enable itself and provide a regulated 3.3V output to the microprocessor. The voltage across the bulk capacitor will decrease rapidly as the converter provides power to the microprocessor. The device will continue to provide current to the load until the voltage across the bulk capacitor decreases to 4V. The TPS54160 will then disable itself and re-enter a low quiescent current state. With this example, the bulk capacitor and TPS54160 can provide a regulated 3.3V output at 5mA of current for 3s for the microprocessor to complete its task

Conclusion

There are several ambient sources of power available in the environment such as vibration, solar and thermal energies that can be used to power microprocessors or microcontrollers. Each source has a variable output that is dependent on many electrical, mechanical or physical properties, so the output power must be conditioned or regulated in some manner in order to be usable. Low and/or wide input voltage range converters help to ease the implementation of an energy harvesting system.

Literature

PCIM 2008 Proceddings (ISBN 978-3-89838-605-0), pages 489 - 494.