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Solar-array controller needs no multiplier to maximize power

W Stephen Woodward, Chapel Hill, NC

Solar-photovoltaic arrays are among the most efficient, cost-effective, and scalable "green" alternatives to fossil fuels, and researchers are almost daily announcing new advances in photovoltaic technology. But successful application of photovoltaics still depends on strict attention to power-conversion efficiency. **Figure 1** shows one reason for this attention.

A photovoltaic array's delivery of useful power to the load is a sensitive function of load-line voltage, which in turn depends on insolation—that is, sunlight intensity—and array temperature. Operation anywhere on the current/voltage curve except at the optimal maximum-power-point voltage results in lowered efficiency and a waste of valuable energy. Consequently, methods for maximum-power-point tracking are common features in advanced solar-power-management systems because they can boost practical power-usage efficiency—often by 30% or more.

Because of its generality, a popular maximum-power-point-tracking-control algorithm is perturb and observe, which periodically modulates, or perturbs, the load voltage; calculates, or observes, the instantaneous transferred power response; and uses the phase relationship between load modulation and calculated power as feedback to "climb the hill" of the current/voltage curve to the maximum-power-point optimum. The perturb-and-observe algorithm is the basis of the maximum-power-point-tracking-control circuit (**Figure 2**, in yellow) but with a twist (in blue), which achieves a feedback function equivalent to a current-times-voltage power calculation but without the complexity of a conventional multiplier. The idea relies on the well-known logarithmic behavior of transistor junctions, $V_{BE}=(kT/q)\log(I_C/I_S)=(kT/q)[\log(I_C)-\log(I_S)]$, where V_{BE} is the base-to-emitter voltage. It also relies on the fact that adding logarithms is mathematically equivalent to multiplication. Here's how.

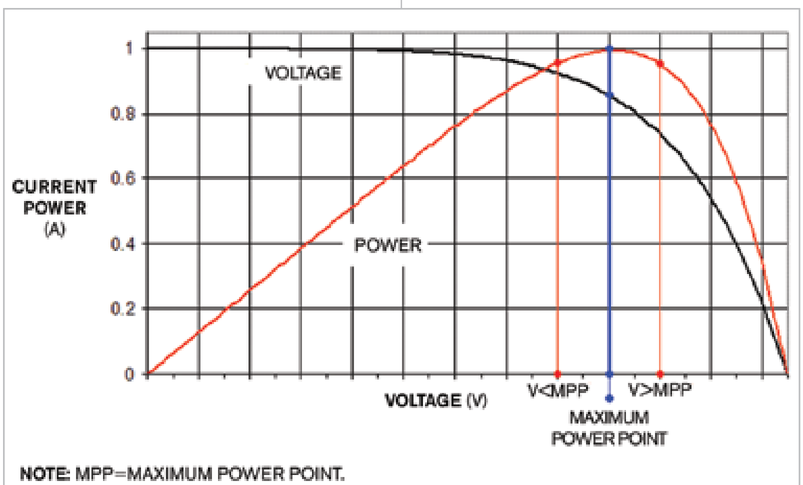

Figure 1 It is important to operate solar-photovoltaic arrays at their maximum power point.

Capacitor C_2 couples a 100-Hz, approximately 1V-p-p-modulation or 1V-p-p-perturbation square wave from the S_2/S_3 CMOS oscillator onto the photovoltaic-input voltage, V. The current/voltage curve of the array causes the input current, I, to reflect the V modulation with a corresponding voltage-times-current input-power modulation. IC_{1A} forces I_{Q1} to equal $I\times x_1$, where I is the solar-array current and x_1 is a gain constant. IC_{1B} forces I_{Q2} to equal V/499 kΩ, where V is the solar-array voltage. Thus, $V_{Q1}=(kT_1/q)1[\log(I)-\log(I_{S1})+\log(x_1)]$, and $V_{Q2}=(kT_2/q)[\log(V)-\log(I_{S2})-\log(499\ k\Omega)]$. V_{Q1} is the base-to-emitter voltage of Q_1; k is the Boltzman constant; T_1 is the temperature of Q_1; q is the elementary charge of the electron; I is the current input

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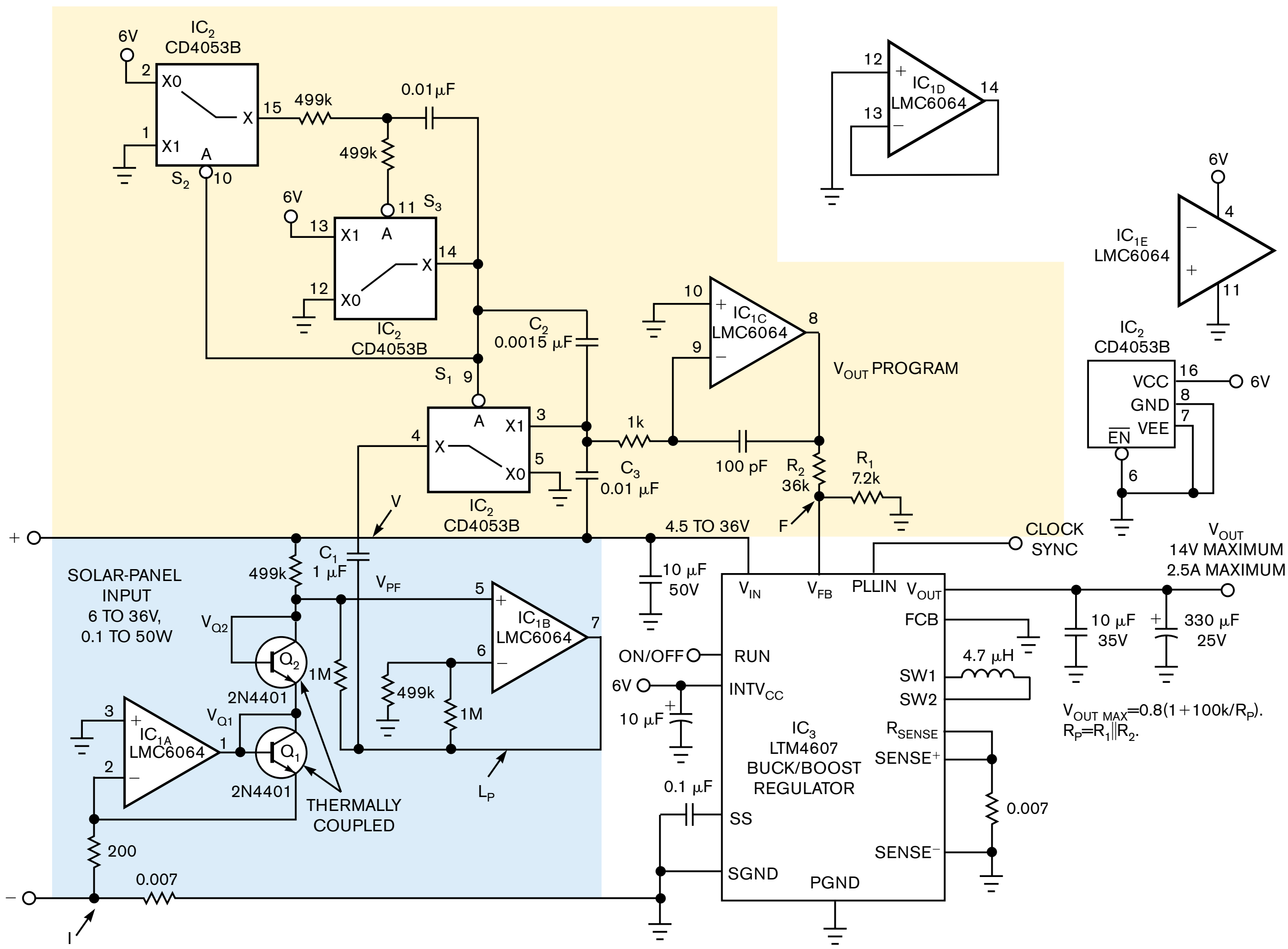

Figure 2 This maximum-power-point-tracking controller relies on the well-known logarithmic behavior of transistor junctions.

from the solar panel's negative terminal; I_{S1} is the saturation current of Q_1; x_1 is the arbitrary gain constant, which IC_3 determines; V is the voltage input from the solar panel's positive terminal; I_{S2} is the saturation current of Q_2; K is degrees Kelvin; V_{PF} is the power-feedback signal; and V_{IP} is the calculated power-input signal. Because k, q, I_{S1}, I_{S2}, x_1, and 499 kΩ are all constants and $T_1=T_2=T$, however, for the purposes of the perturb-and-observe algorithm, which is interested only in observing the variation of current and voltage with perturbation, effectively, $V_{Q1}=(kT/q)\log(I)$, and $V_{Q2}=(kT/q)\log(V)$.

The series connection of Q_1 and Q_2 yields $V_{PF}=V_{Q1}+V_{Q2}=(kT/q)[\log(I)+\log(V)]=(kT/q)\log(VI)$, and, because of IC_{1B}'s noninverting gain of three, $V_{IP}=3(kT/q)\log(V\ I)\simeq 765$ µV/% of change in watts. The V_{IP} log (power) signal couples through C_1 to synchronous demodulator S_1, and error integrator and control op amp IC_{1C} integrates the rectified S_1 output on C_3. The IC_{1C} integrated error signal closes the feedback loop around the IC_3 regulator and results in the desired maximum-power-point-tracking behavior.

Using micropower parts and design techniques holds the total power consumption of the maximum-power-point-tracking circuit to approximately 1 mW, which avoids significantly eroding the efficiency advantage—the point of the circuit in the first place. Meanwhile, simplifying the interface between the maximum-power-point-tracking circuit and the regulator to only three connection nodes—I, V, and F—means that you can easily adapt the universal maximum-power-point-tracking circuit to most switching regulators and controllers. Therefore, this Design Idea offers the efficiency advantages of a maximum-power-point-tracking circuit to small solar-powered systems in which more complex, costly, and power-hungry implementations would be difficult to justify. EDN

Simple microcontroller-temperature measurement uses only a diode and a capacitor

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Using a PN-junction diode for temperature measurement usually depends on its 2-mV/K temperature coefficient. Conventionally, you must amplify and digitize this voltage with an ADC before you can use the value in a microcontroller. Less well-known is the fact that the *reverse* current of a PN-junction diode shows a good exponential dependency over temperature; increasing the temperature by approximately 12K doubles the leakage (**Figure 1**). An easy way to measure current over such a large range of two to three decades is to charge and discharge a capacitor and measure the time or frequency.

A general-purpose I/O pin of a microcontroller charges a capacitor either by using it temporally as an output or by enabling a pull-up resistor, which is available in some controllers (**Figure 2a**). After charging the pin, you configure it as a high-impedance input, and a capacitor discharges through the leakage current of the diode (**Figure 2b**). The discharge time then is proportional to the temperature of the diode; thus, the diode exhibits exponential behavior. Depending on the type of diode, the exponential behavior can be nearly ideal. Calibration of a base point is necessary because the absolute value of the current varies greatly at a given temperature.

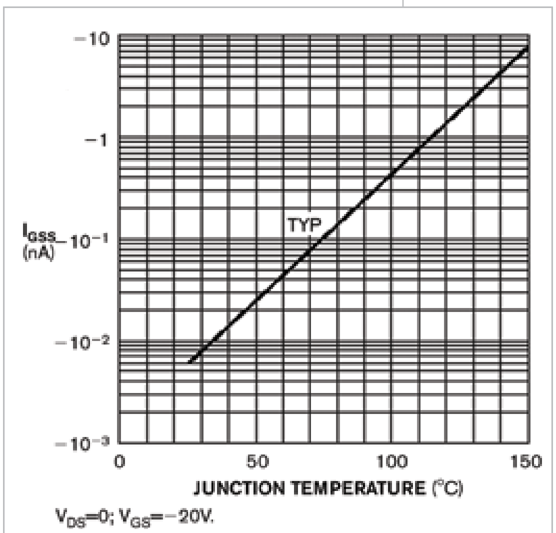

Figure 1 The reverse current of a PN-junction diode shows an exponential dependency over temperature; increasing the temperature by approximately 12K doubles the leakage.

Selecting the diode and the value of the capacitor requires some care. The smaller the PN junction, the smaller the reverse current and the longer the discharging time. Periods longer than a few seconds are usually unsuitable. Making the capacitor's value too low leads to errors because the capacitance of any cable and the capacitance of the PN-junction diode come into effect.

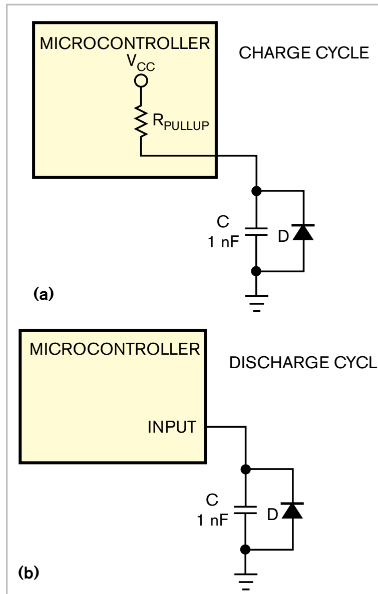

Figure 2 Capacitor C first charges through the pull-up resistance of the microcontroller's I/O pin configured as an output (a). The capacitor then discharges through the reverse leakage of diode D_1 (b).

Typically, a power diode, such as a 1N4001 with a capacitance of 1 nF, gives suitable results. The discharge time is approximately 0.3 to 1 sec at room temperature, falling into the millisecond range at 100°C. The PN-junction diode of a power transistor should also work.EDN

Current mirror drives multiple LEDs from a low supply voltage

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Driving LEDs at a regulated current from low supply voltages can be difficult because minimal overhead voltage is available for control circuits. A current-mirror architecture is suitable but usually works only with ICs with well-matched transistors and in which the silicon substrate holds them at one temperature. However, high currents—approximately 100 mA—are not normally possible. A thermal runaway can occur in circuits using unfavorable combinations of discrete bipolar transistors. In this scenario, one LED-driver transistor becomes slightly hotter than the others, its gain increases, and it takes more current and gets even hotter until it self-destructs. This Design Idea shows how you can avoid this problem for pulsed-current-mirror applications.

The current mirror comprises Q_4 through Q_7 with connected bases and emitters, and the collector current of Q_3 is the control output (**Figure 1**). Resistor R_3 converts Q_3's collector current to a feedback voltage. Transistors Q_1 and Q_2 form a voltage-difference amplifier. The control-transistor current after feedback is $1.2V/R_3$, and the LEDs have a similar current. Because of the pulsed operation—say, 25% duty at 3 Hz—the transistor temperature does not reach a stable value and cools again toward the ambient temperature during the off period. The thermal-runaway effect does not have time to develop.

The capacitor prevents transient oscillations at switch-on or -off. Use the same transistor type for Q_4 through Q_7 and mount all of them on the same part of the PCB (printed-circuit board). The supply voltage can be as low as 2.5V for certain LEDs, especially infrared types, and the collector current can exceed 100 mA per LED.EDN

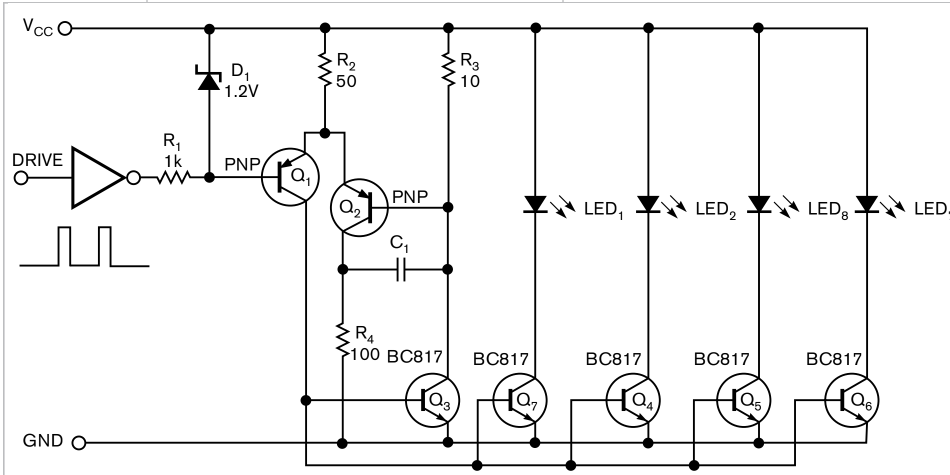

Figure 1 A pulsed-current mirror comprising transistors Q_4 through Q_7 drives multiple LEDs from a low supply voltage.