cles exiting the light sensor. The circuit senses the light by biasing the LED and current-limiting resistor such that the cathode lead of the LED is at logic one. The anode connects to a relaxation oscillator that starts with anode at logic zero. The LED pulls up the anode in proportion to the amount of light hitting the LED. The reverse-biased LED acts as a solar cell with output current proportional to light. Once the slow-rising anode signal reaches the threshold of the input buffer, the Pin 1 signal becomes a zero, and the D flip-flop, DFF, toggles to zero and drives the anode signal to zero, making Pin 1 a logic one and tristating the input buffer on the next clock cycle, allowing the anode signal to rise again.

The frequency of Oscillator 1 is proportional to light intensity, with typical frequency for bright light of approximately 2000 Hz. The Oscillator 1 signal drives the clock of Count 8. Count 8 resets in State 0 and then is enabled in State 1 for 125 msec. In bright light, Count 8 might count to 250 at the end of the measurement, and, in low light, it might count to only 16. The counter's C_{OUT} signal feeds back to the enable so that the count will saturate at a count of 255 and prevent high-intensity light from wrapping the counter back to zero and taking a false measurement.

State 2 is the LED's blinking state. This state blinks the LED for 125 msec at an intensity that a PWM controls. In State 2, the cathode and anode pins are bias to the emitter mode. The emitter mode forces the anode signal to V_{CC}. The cathode node connects to the PWM output. A logic zero on the cathode node lights the LED, and a logic one turns it off. The cathode signal is the inverted form of the PWM output.

In this example, the PWM is a 4-bit-resolution PWM, but you can use more or fewer bits. The PWM comprises binary counter Count 4 and a binary, 4-bit adder. The Count 4 counter is enabled in State 2, and the cycling output connects to the A input of the 4-bit adder. The B input of the adder connects to the four MSBs (most significant bits) of the light-sensor-frequency counter. The carryout of the adder is the PWM output. The carry-in of the adder is a constant logic one.

The following examples show how the PWM works:

- A logic zero from the intensity measurement results in a logic zero at carryout when Count 4 is zero through 14 and a logic one when Count 4 is 15. This 6.25% duty cycle is a very low-intensity level.
- A value of seven from the intensity measurement results in a logic zero at carryout when Count 4 is zero to seven and a logic one when Count 4 is eight to 15. This 50% duty cycle is a medium-intensity level.
- A 15 from the intensity measurement results in no logic zero at carryout for any Count 4 value and a logic one when Count 4 is zero through 15. This 100% duty cycle is a full-intensity level.

The only function of states 3 to 7 is to wait for the next LED-flash cycle. You can add or remove states to change the flash rate. **EDN**

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Two instrumentation amps make accurate voltage-to-current source

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Many designs require precise voltage-controlled current sources, especially in the presence of variable loads. Common approaches, which use a few op amps and a handful of passive components, have inherent errors due to nonideal component characteristics, such as finite open-loop gain, common-mode rejection, bias current, and offset voltage. Designs using operational amplifiers may require precision resistors to set gain and additional capacitors for stability. In addition, some circuit designs provide currents that are not directly proportional to the input voltage. The voltage-to-current converter in **Figure 1**, for example, relies on the fact that the collector current is approximately equal to the emitter current and provides current in only one direction.

With two instrumentation amplifiers and two transistors, you can build a 0.01%-accurate voltage-controlled current source (**Figure 2**). This current source features a ±10V input-voltage swing that is directly proportional to the output current. It maintains high accuracy, even while delivering as much as 90 mA of output current. The AD620 low-power, low-drift instrumentation amplifiers from Analog Devices (www.analog.com) provide circuit control and error correction but are not part of the output circuit. Thus, you can substitute higher-power transistors for Q_1 and Q_2 to achieve higher output currents. You can configure the instrumentation amplifiers for any gain of one to 10,000 to accommodate input signals lower than 1 mV. Simply connect a resistor across the inputs of both IC_1 and IC_2 to achieve the desired gain.

The first instrumentation amplifier, IC_1, controls the base voltage of the push-pull output stage. The resistors and diodes provide bias to Q_1 and Q_2 to eliminate crossover distortion. IC_2 provides error correction and accounts for deltas in the base-to-emitter voltage. The error voltage, which you measure differentially from the D_1/D_2 junction to the output voltage, feeds into the reference pin of IC_1, summing it with the input voltage. The result is an output current that is directly proportional to the input voltage. This circuit achieves a 0.01% typical dc accuracy across a ±10V input span and 1.5% typical ac accuracy at 1 kHz with an output voltage of ±5V p-p.

The **equations** for calculating the output current are:

$$V_{OUT_{IC1}}=\left[\left(V_{IC1}^{+}-V_{IC1}^{-}\right)A_{IC1}+V_{REF_{IC1}}\right].$$

$$V_{REF_{IC1}}=V_{OUT_{IC2}}=\left(V_{IC2}^{+}-V_{IC2}^{-}\right)A_{IC2}+V_{REF_{IC2}}.$$

$$V_{OUT}=V_{OUT_{IC1}}=\left(V_{IC1}^{+}-V_{IC1}^{-}\right)A_{IC1}+\left(V_{IC2}^{+}-V_{IC2}^{-}\right)A_{IC2}+V_{REF_{IC2}},$$

where

$$V_{IC1}^{+}=V_{IN},\ V_{IC1}^{-}=0;\ A_{IC1}=A_{IC2}=1;\ V_{REF_{IC2}}=0.$$

Therefore,

$$V_{OUT}=V_{IC1}^{+}+\left(V_{IC2}^{+}-V_{IC2}^{-}\right),$$

or

$$I_{OUT}=\frac{V_{IN}}{R_L}.$$

This circuit provides a wide output range, as well as output current that is directly proportional to the input voltage and high linearity and precision (**Figure 3**).EDN

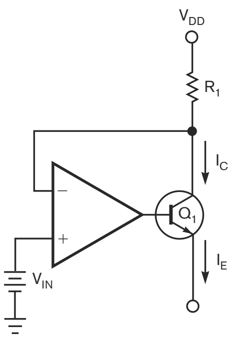

Figure 1 The voltage-to-current converter relies on the fact that the collector current is approximately equal to the emitter current and provides current in only one direction.

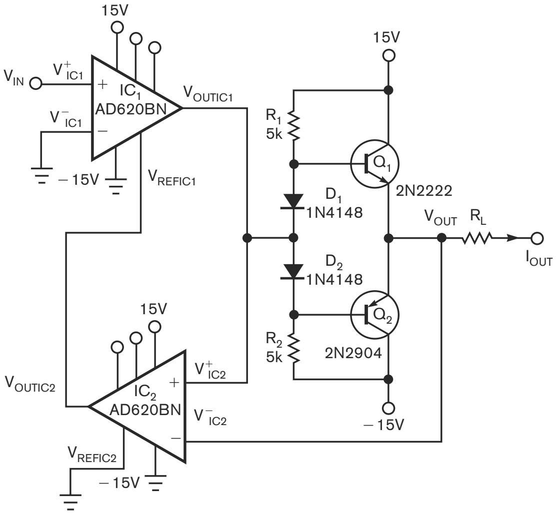

Figure 2 This handy voltage-to-current converter delivers high accuracy over a range of conditions.

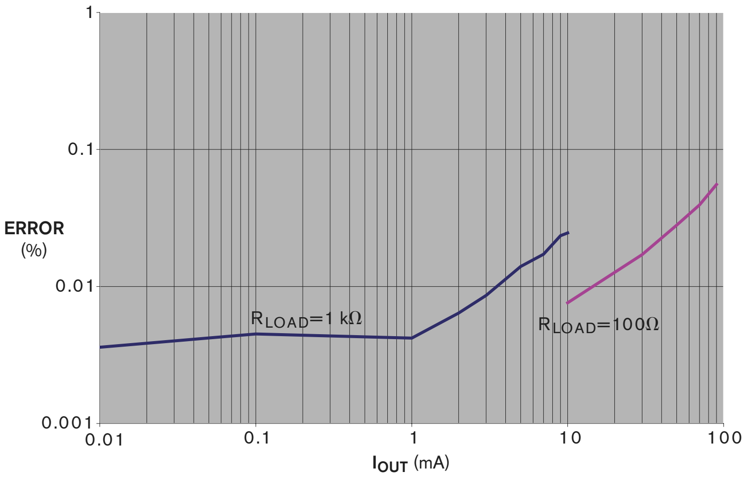

Figure 3 The circuit in Figure 2 provides a wide output range, output current that is directly proportional to the input voltage, and high linearity and precision.

Simple circuit indicates health of lithium-ion batteries

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Lithium-ion batteries are sensitive to bad treatment. Fire, explosions, and other hazardous condition may occur when you charge the cell below the margin that the manufacturer defines. Modern battery chargers can manage the hazardous conditions and deny operation when illegal situations occur. This fact doesn't mean, however, that all cells are bad. In most cases, you can replace the discharged battery and increase your device's lifetime. **Figure 1** shows the circuit for testing battery packs.

When the supply voltage is lower than 2.6V, no current drives the base of the transistor. LED_1 lights up, and