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READERS SOLVE DESIGN PROBLEMS

LED senses and displays ambient-light intensity

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In addition to their customary roles as indicators and illuminators, modern LEDs can also serve as photovoltaic detectors (**references 1** and **2**). Simply connecting a red LED to a multimeter and illuminating the LED with a source of bright light, such as a similar red LED, produce a reading of more than 1.4V (**Figure 1**). One model for a reverse-biased LED comprises a charged capacitor that connects in parallel with a light-dependent current source (**Reference 1**). Increasing the incident light increases the current source and more rapidly discharges the equivalent capacitor to the supply voltage.

Figure 2 shows a method of using an LED as a photovoltaic detector. Connecting one of the microcontroller's outputs, Pin 2, to the LED's cathode applies reverse bias that charges the LED's internal capacitance to the supply voltage. Connecting the LED's cathode to Input Pin 3 attaches a high-impedance load to the LED. Illuminating the LED generates photocurrent. Originally charged to the supply voltage, the LED's internal capacitance discharges through the photocurrent source, and, when the voltage on the capacitor falls below the microcontroller's lower logic threshold voltage, Pin 3 senses a logic zero. Increasing the incident-light intensity more quickly discharges the capacitor, and lower light levels decrease the discharge rate. The microcontroller, an Atmel AVR ATtiny15 (www.atmel.com/dyn/products/product_card.asp?part_id=2033), measures the time for Pin 3's voltage to reach logic zero and computes the amount of ambient light incident on the LED. In addition, the microcontroller flashes the same LED at a frequency proportional to the incident light's intensity.

Figure 3 shows a 3-mm, super-bright-red LED, D_1, from Everlight Electronics Co Ltd (www.everlight.com), which comes in a water-clear encapsulant as an ambient-light sensor. Having only four components, the circuit operates from any dc-power source from 3 to 5.5V. The circuit uses only three of six of the AVR ATtiny15's I/O pins, and the remaining pins are available to control or communicate with external devices. The sensor LED connects to the AVR microcontroller's port pins PB0 and PB1; another port pin, PB3, produces a square wave with a frequency proportional to the incident-light intensity. The circuit operates by

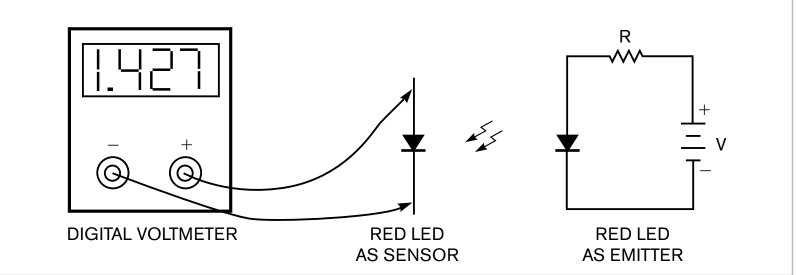

Figure 1 Two identical LEDs, closely spaced in a light-shielded housing, form a photovoltaic-characterization fixture. Choose resistor R and voltage source V to apply nominal forward current to the illuminating LED.

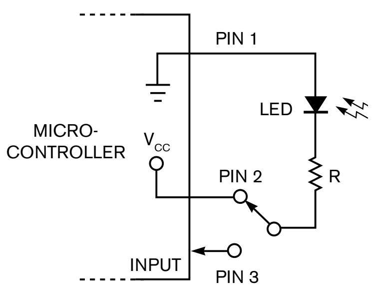

Figure 2 Connecting one of the microcontroller's outputs, Pin 2, to the LED's cathode applies reverse bias that charges the LED's internal capacitance to the supply voltage. Connecting the LED's cathode to Input Pin 3 attaches a high-impedance load to the LED. (Note that pin numbers are representative only and not actual pin numbers.)

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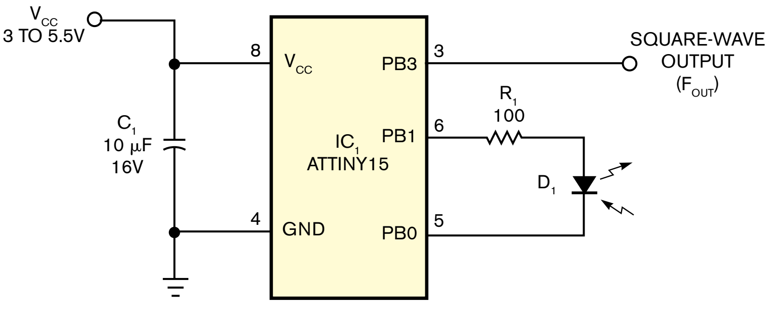

Figure 3 An LED doubles as a light-level sensor. Output PB3 delivers a square wave whose frequency increases as light intensity increases.

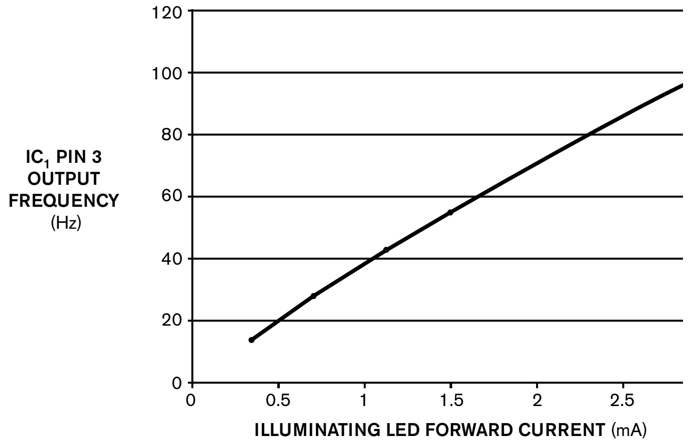

Figure 4 The frequency of the circuit's square-wave output exhibits good linearity versus light level for identical sensor and source LEDs.

first applying forward bias to the LED for a fixed interval and then applying reverse bias to the LED by changing the bit sequences you apply to PB0 and PB1. Next, the microcontroller reconfigures PB0 as an input pin. An internal timing loop measures the interval, T, for the voltage you apply to PB0 to decrease from logic one to logic zero.

Reconfiguring pins PB0 and PB1 to apply forward bias to the LED completes the cycle. Time interval T varies inversely with the amount of ambient light incident on the LED. For lower light, the LED flashes at a lower frequency, and, as the incident-light intensity increases, the LED flashes more frequently to provide a visual indication of the incident-light intensity.

For low values of forward current, an LED's light-output intensity is fairly linear (**Reference 2**). To test the circuit, couple the light output of a second and identical LED to the sensor LED, D_1, in **Figure 3**. Ensure that external light doesn't strike the sensor LED by enclosing the LEDs in a sealed tube covered with opaque black tape. Varying the illuminating LED's forward current from 0.33 to 2.8 mA produces a relatively linear sensor-flash-frequency plot (**Figure 4**).

The efficiency of an LED as a sensor depends upon its reverse-biased internal-current source and capacitance. To estimate the reverse photocurrent, connect a 1-MΩ resistor in parallel with a sensor LED and measure the voltage across the resistor while applying a constant level of illumination from an external source. Replace the 1-MΩ resistor with 500- and 100-kΩ resistors and repeat the measurements. For a representative LED under constant illumination and shielded from stray ambient light, we measured a photocurrent of approximately 25 nA for all three resistor values. For the same level of illumination applied to the sensor LED, measure the frequency generated at Pin PB3.

To calculate the LED's reverse-biased capacitance, substitute the delay-loop time, the LED's photovoltaic current, and the microcontroller's logic-one and -zero threshold voltages into the equation and solve for C, the LED's effective reverse-biased junction capacitance: $(dV/dt)=(I/C)$, where dV is the measured logic-one voltage minus the logic-zero voltage, dt is the measured time to discharge the LED's internal capacitor, and I is the calculated value of LED's photocurrent source. The calculated values for the selected LED range from 25 to 60 pF. This range compares with the data in **references 3** and **4**, although **Reference 3** reports only the current source's values. You can download the AVR microcontroller's assembly-language firmware, **Listing 1**, from this Design Idea's online version at www.edn.com/061109di1.**EDN**

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4 "Optocoupler Input Drive Circuits," Application Note AN-3001, Fairchild Semiconductor, 2002, www.fairchildsemi.com/an/AN/AN-3001.pdf.

AC line powers microcontroller-based fan-speed regulator

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A microcontroller requires dc operating power in the 2 to 5.5V range, an amount that a battery or a secondary power source can easily supply. However, in certain situations, a microcontroller-based product must operate directly from a 120 or 220V-ac power outlet without a step-down transformer or a heat-producing, voltage-decreasing resistor. As an alternative, a polyester/polypropylene film capacitor rated for ac-line service can serve as a nondissipative reactance (**Figure 1**). Capacitor C_1, a 2-μF AVX (www.avxcorp.com) FFB16C0205K rated for 150V rms, provides a significant ac-voltage drop that reduces the voltage you apply to a diode-bridge rectifier, D_1. A flameproof metal-film resistor, R_1, limits current spikes and transient voltages induced in the ac-power line by lightning strikes and abrupt load changes. In this application, the ac current does not exceed 100 mA rms, and a 51Ω, 1W resistor provides adequate current limiting. R_2, a 5W, 160Ω Yageo (www.yageo.com) type-J resistor, and D_2, a 1N4733A zener diode, provide 5V regulated power for the microcontroller, a Freescale (www.freescale.com) C68HC908QT2.

The schematic shows a representative circuit for a microcontroller-based fan-speed regulator in which a thermistor senses air temperature and the microcontroller drives a

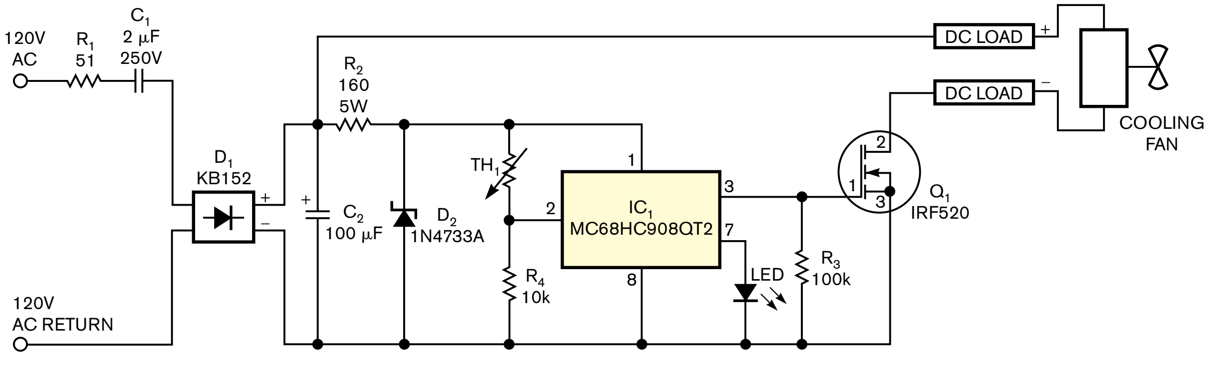

Figure 1 C_1 provides capacitive reactance, which limits ac-input current without dissipating excessive heat in this dc fan-speed controller.

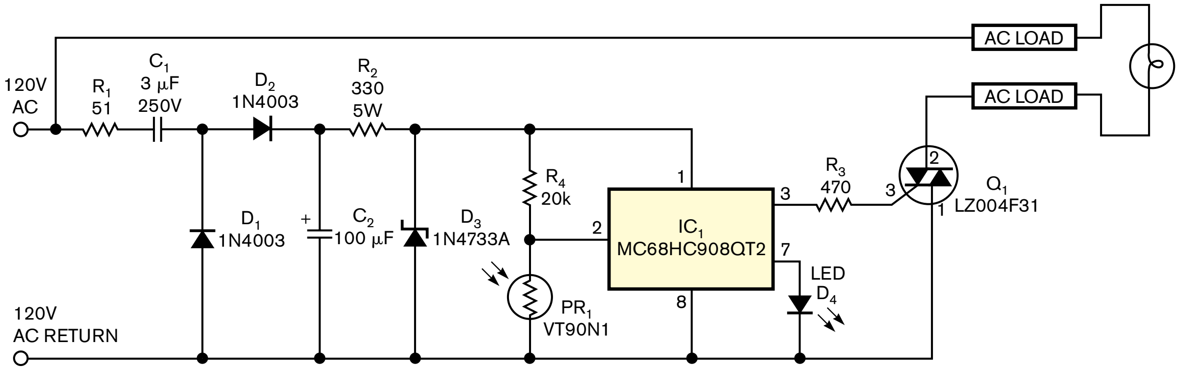

Figure 2 A two-diode rectifier and lamp-control bidirectional thyristor share a common return path to the ac line.

fan's motor. **Figure 2** illustrates a light-intensity regulator based on an inexpensive two-diode rectifier and a bidirectional-thyristor-lamp controller that share a common ground. IC_2, a Fairchild (www.fairchildsemi.com) MOC3021-M bidirectional-thyristor-driver optoisolator, separates the lamp-return path from the microcontroller's ground return (**Figure 3**). In each of the three circuits, the Kingbright (www.kingbright.com) W934GD5V0 LED indicator includes a built-in current-limiting resistor (not shown). **EDN**

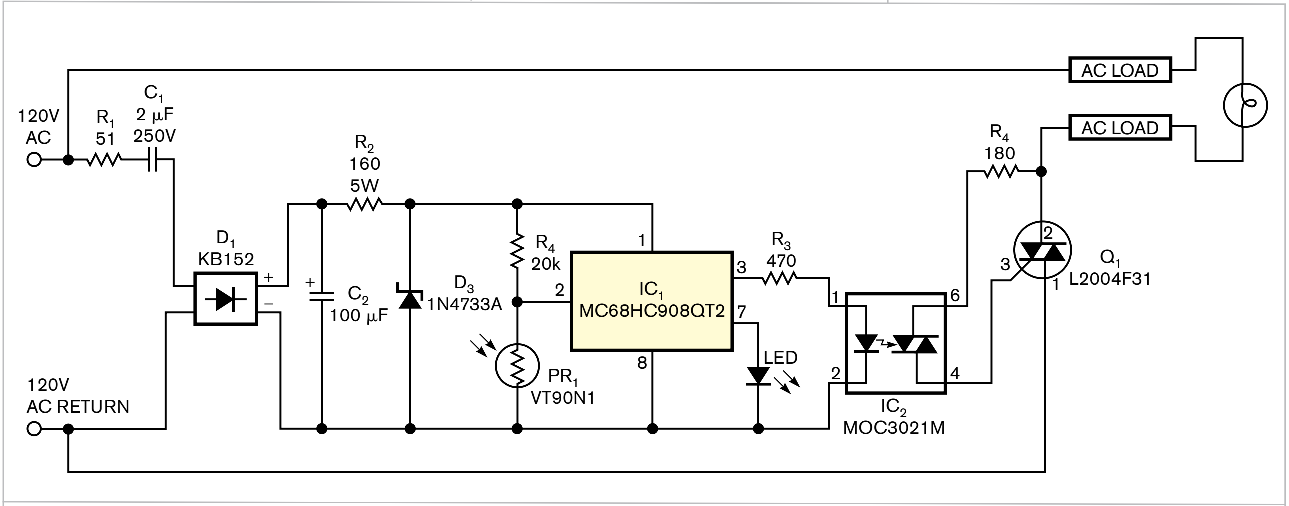

Figure 3 An optoisolator separates the bidirectional thyristor's high-current ac-line return path from the microcontroller's power supply.

Simple circuits sort out the highest voltage

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In a water-cooled power converter, analog-output sensors measure the cooling water temperature at three locations. If any of the three temperatures rises above a preset threshold, an alarm sounds and attracts the attention of the system's operator. When the alarm activates, knowing which measurement site has reached the highest temperature saves troubleshooting time and prevents system damage. The circuit in **Figure 1** delivers an analog-output voltage equal to the highest of three input voltages that drives a display for continuous temperature monitoring. LED indicators identify which of three sensors shows the highest temperature. An external adjustable-threshold comparator (not shown) monitors the analog-voltage output and activates an audible alarm.

Each of three analog input signals spans a range of 0 to 10V. Driven by the highest-voltage input, which you apply at IN_1 in this example, operational amplifier IC_{1A} functions as a voltage follower with diode D_1 in its feedback path. The op amp's open-loop gain divides the diode's forward-voltage drop to a fraction of its nominal value, producing an "ideal diode" with a voltage drop of millivolts.

Op amps IC_{1B} and IC_{1C} function as high-input-impedance inverting comparators. Each "sees" the highest input voltage on its inverting input and one of two lower input voltages, IN_2 and IN_3, on its noninverting input and delivers an output voltage near that of the negative-supply-voltage rail. Thus, only IC_{1A} delivers a positive-voltage output to MOSFET Q_1's gate, and IC_{1B} and IC_{1C} deliver negative outputs to the gates of Q_2 and Q_3. Q_1 turns on, lighting LED D_4 and drawing approximately 5 mA to develop 11V across R_3, which guarantees that Q_2 and Q_3 and their corresponding LEDs remain off. The voltage that develops across R_1 represents the largest voltage of the three inputs, and resistor R_4 and

THE CIRCUIT DELIVERS AN ANALOG-OUTPUT VOLTAGE EQUAL TO THE HIGHEST OF THREE INPUT VOLTAGES THAT DRIVES A DISPLAY FOR CONTINUOUS TEMPERATURE MONITORING.

capacitor C_1 form a lowpass filter that reduces high-frequency noise that the sensor cables pick up. Voltage follower IC_{1D} buffers the filter's output voltage. **Figure 2** (pg 136) shows the results of an LTSpice simulation featuring three sinusoidal inputs and the resultant analog output summed with a small dc-offset voltage for clarity.

The breadboarded circuit works as designed. Given its electrically noisy location near a 300-kHz, 30-kW switched-mode power converter, it uses slow-switching 1N4004 diodes to avoid malfunctions, which the rectification of stray high-frequency interference introduces. In less noisy environments, use any small-signal diode whose peak-inverse voltage exceeds at least 30V. Most varieties of operational amplifiers work well in the circuit, but for greater high-frequency immunity, use a JFET-input quad op amp, such as Texas Instruments' (www.ti.com) TL084.

Although the circuit's prototype uses red-LED indicators, LEDs of other colors work well. To change the LEDs' current to another value, change the values of R_2 and R_3, keeping approximately the same 3-to-2 ratio. For example, values of 1.8 kΩ for R_2 and 1.2 kΩ for R_3 drive the "on" LED with approximately 10 mA. If you increase the LED current, note that the resistors continuously dissipate power. For greatest reliability, choose resistors rated for twice the calculated power dissipation.**EDN**

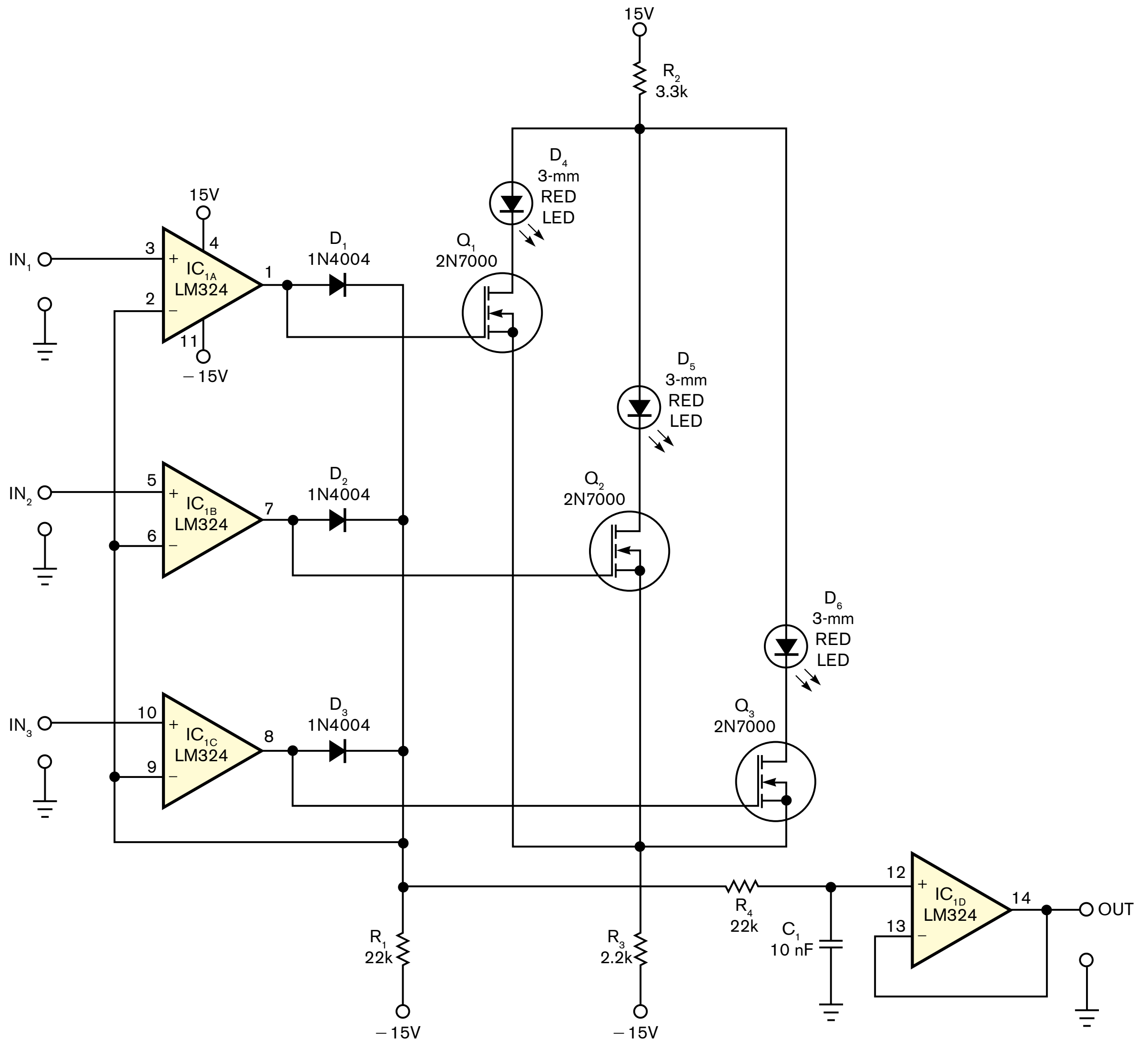

Figure 1 This circuit's output voltage tracks and indicates the highest of three input voltages and can drive an external strip-chart recorder or alarm comparator.

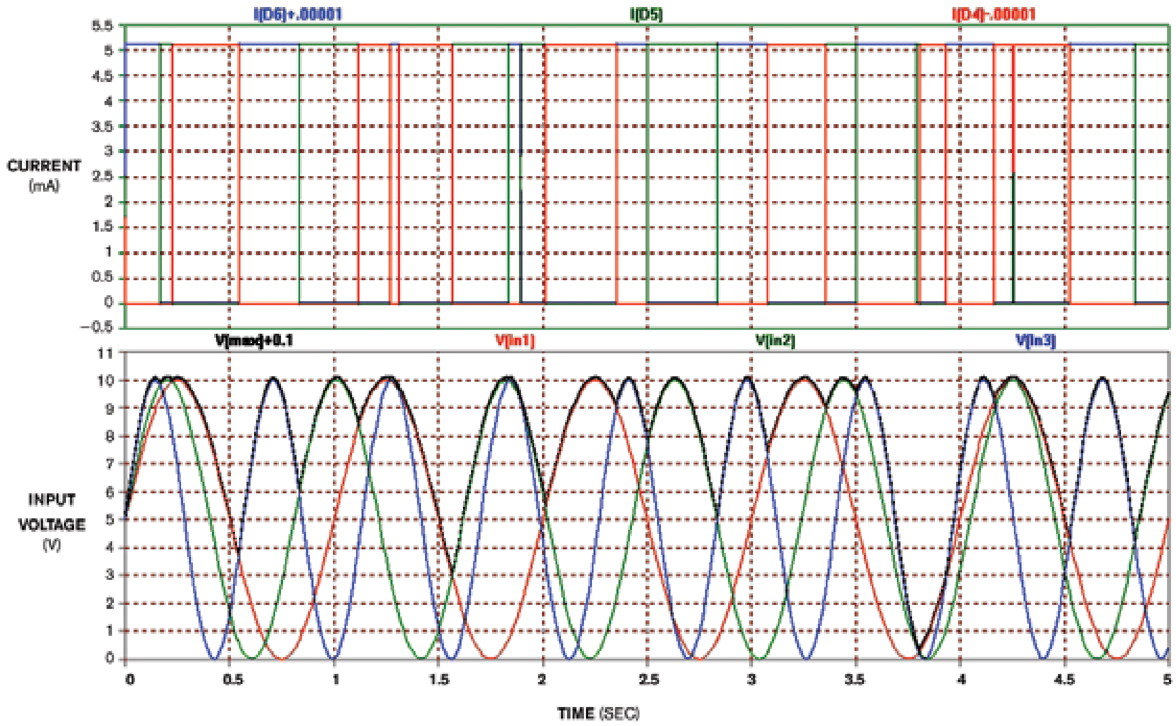

Figure 2 Three sine waves of different frequencies provide input voltages (lower traces) that evoke the greatest-of-three response in the current through R_2 (top trace, in which colored horizontal segments match the largest inputs).