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Inspect solar cells without a microscope

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Solar cells convert light energy into electricity, making them a renewable energy source. Solar-cell manufacturers often use SEMs (scanning electron microscopes) to detect defects in solar cells while they're still in wafer form. Although SEMs can see down to a solar cell's grain structure, they can be slow because their scan area is small. A SEM must scan a wafer many times to cover it.

Instead of using a SEM, you can use an SWIR (shortwave-infrared) camera system to detect defective cells. You can take advantage of a solar cell's electroluminescence signature to find defects on a solar cell. A cell's light has a wavelength of about 1.1 micron, which results when you apply a forward bias voltage and forward operating current of at least 7A to the cell. An SWIR sensor can provide an image of an entire wafer, eliminating the need to scan the wafer. The sensor identifies defects by detecting a wafer's electroluminescence.

Figure 1 shows the system, which uses an SWIR sensor that converts an image into an analog voltage. A preamplifier boosts the signal to a level sufficient for an ADC in a digital-processing module to digitize the analog signal at 10M samples/sec.

The ADC's digital output travels through an LVDS (low-voltage-differential-signaling) data interface to a Dalsa (www.dalsa.com) frame-grabber card in a computer. Custom image-processing software, written in C++, processes the data, producing an image of the entire wafer on the computer's screen.

The board containing the sensor, preamplifier, and ADC also has a microcontroller, which generates a clock signal for the timing of the sensor and the ADC. An RS-232 communica-

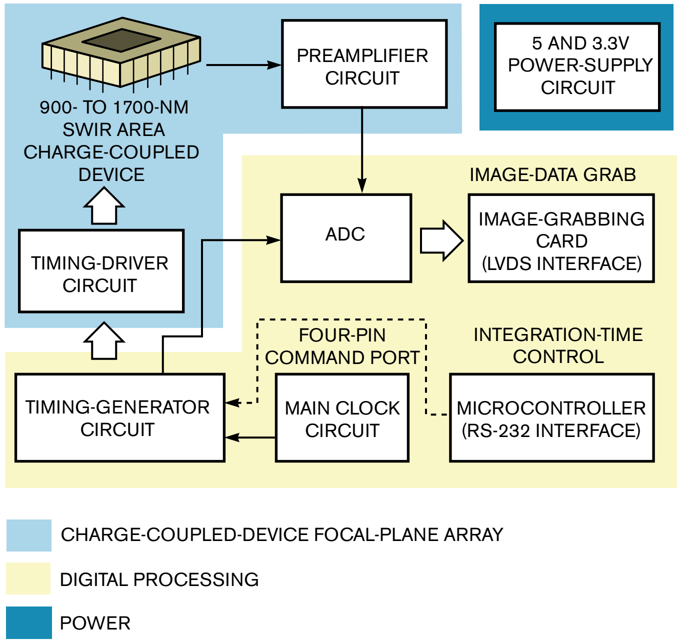

Figure 1 An ADC digitizes an analog signal from an SWIR sensor and sends the signal to a frame grabber for processing.

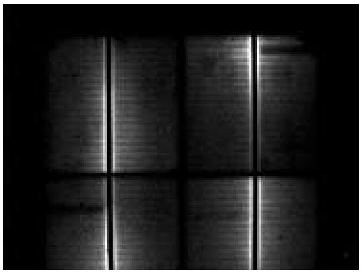

Figure 2 An electroluminescence image of solar cells shows dark areas that indicate failed cells.

tions port on the Atmel (www.atmel.com) microcontroller allows it to communicate with a PC to get commands from the user who set parameters such as the SWIR sensor's operating mode. A timing-driver circuit sends the clock signal to the SWIR sensor.

Figure 2 shows the image from the SWIR camera circuit. This image shows the intensity distribution of the cell's light output. A homogenous intensity-distribution image is essential for a high-quality solar cell, but solar cells always show some inconsistencies. All defects resulting in a local reduction of the carrier concentration are visible on the electroluminescence image as dark bars.**EDN**

Solar-powered sensor controls traffic

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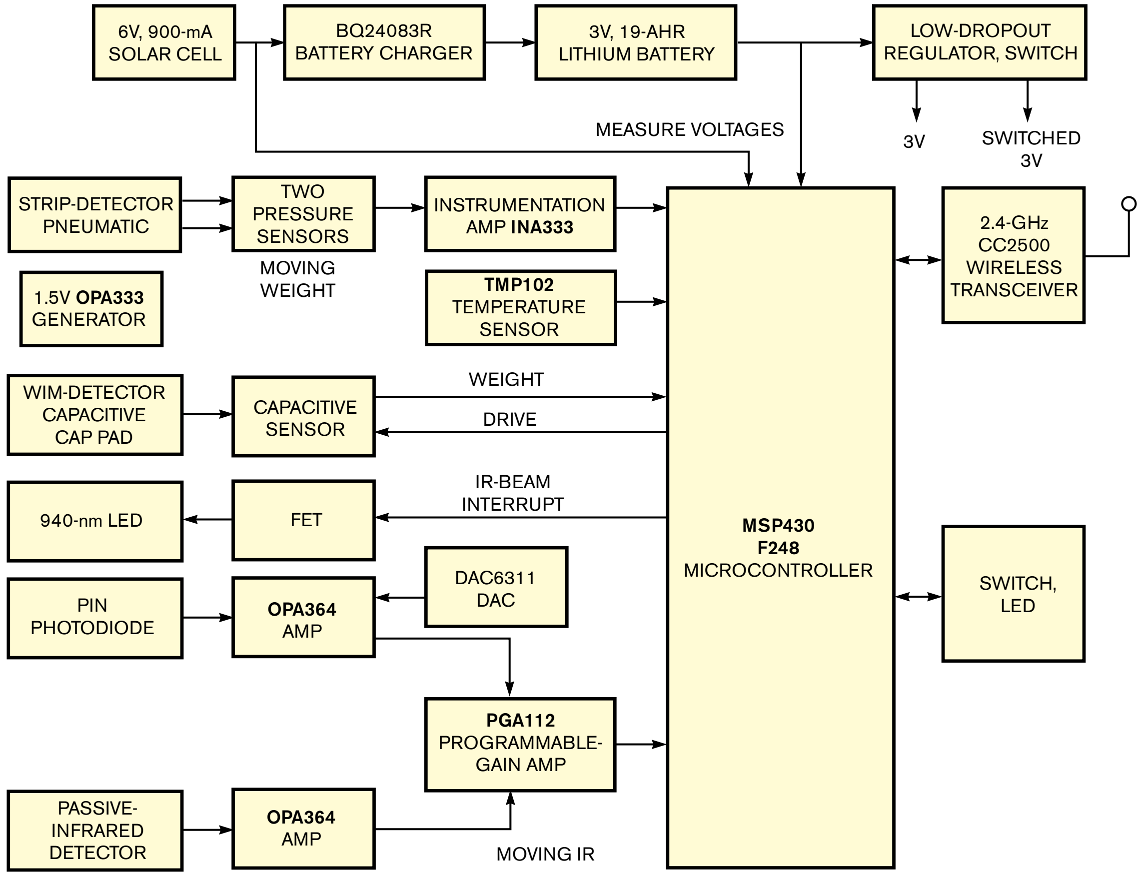
Have you ever sat in your car waiting for the light to turn green when nobody's using the cross street? This wait is due to the fact that the sensors controlling these traffic signals—in one large-suitcase-sized box per intersection—are classically dumb, with relays, cams, and switches, although they now may include software that accepts data from local sensors, automobile-sized inductive loops buried in the asphalt. Modern controllers have gained some intelligence. For example, they may share

WINNING ENTRY IN EDN's RECENT ONLINE IRON CIRCUIT DESIGNER CONTEST; see the complete design at www.edn.com/091126dia



NOTE: ITEMS IN BOLDFACE ARE ON THE IRON CIRCUIT DESIGNER CONTEST APPROVED-PARTS LIST.

Figure 1 Most of the circuit amplifies outputs from four sensors, digitizes them with the MSP430's 12-bit ADC, does some preprocessing, and messages the controller.

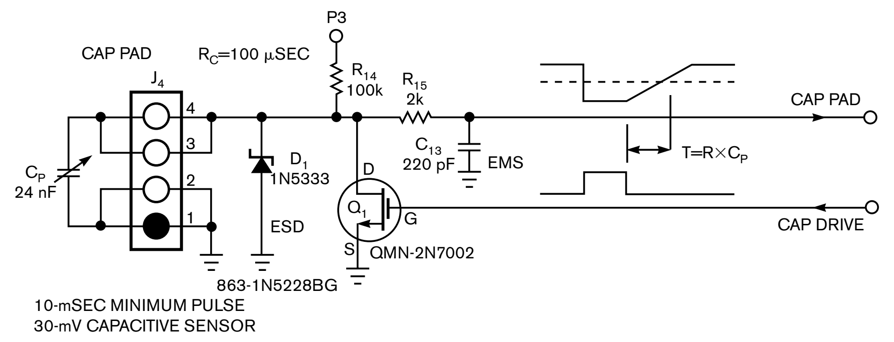


Figure 2 The Cap Pad sensor has a nominal capacitance of about 24 nF at rest, with a change of about 7% full-scale when a truck passes.

data with nearby intersections, respond to radio requests from emergency vehicles, and sometimes take commands from a traffic-control center. This Design Idea describes the TSP (traffic-sensor post), a more accurate, effective, inexpensive, and easy-to-install approach to monitoring traffic flow. These sensors measure vehicle location and speed in four or more streets at an intersection or at a distance from the intersection for early warning. A second application of this technology, the WIM (weight-in-motion) sensor, weighs moving trucks.

The circuit comprises a wireless, solar-powered sensor array that handles all the data collection at an intersection (**Figure 1**). Cities can install these sensors at each of the four corners of an intersection for full coverage. The sensors send data to the single controller box over IEEE 802.15.4 in a star network. The approach combines four sensors in an inexpensive, low-maintenance, 6-in.-diameter, 6-foot-tall post. You can build the circuit into the post that holds the traffic lights, or you can use it stand-alone. Not all TSPs require all four sensors; you can select those that your application needs based on usage. The TSP is the first wireless approach to this problem, and one of the sensors, the Cap Pad, provides a huge advantage over current expensive and inaccurate WIM sensors (**Figure 2**).

The TSP uses a PIR (passive-infrared) sensor that looks 10 microns into the deep-IR band for moving IR sources. This technology finds use in inexpensive motion-detecting lamp controls and senses vehicles from 30 feet away. The detection range is good, the parts are cheap, and the beam can see through a layer of dirt. It can't measure speed, distance, or direction.

The TSP also uses conventional pneumatic tubes. Rubber tubes are stapled to the asphalt and feed two pressure sensors. This approach accurately measures speed, but permanent installations cannot use it because it gets damaged easily. Municipalities often deploy pneumatic tubes to measure traffic volume in road construction.

The Cap Pad comprises a 10-in.×12-foot sandwich of three 0.05-in.-thick stainless-steel sheets separated by two 0.05-in.-diameter closed-cell urethane-foam layers (**Figure 3**). You capacitively measure the 0.025-in. deflection of the pad under a truck's tire to weigh the axle. One Cap Pad can handle the WIM requirements, and using two can add speed and direction information. You use multiple pads to handle multilane roads. The Cap Pad can be fastened to the asphalt with adhesive or pavement tape or buried under as much as an inch of asphalt for protection. Its materials cost is only a couple hundred dollars, a huge saving over the piezoelectric WIM sensors currently in use.

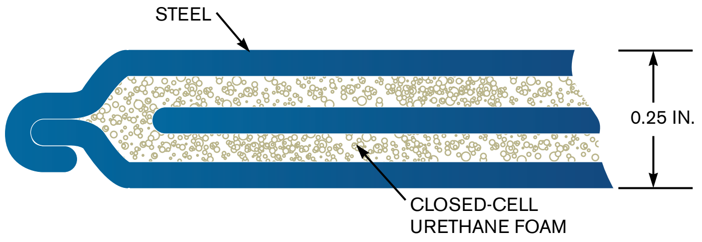


Figure 3 The Cap Pad sensor is a 10-in.×12-foot sandwich of three 0.05-in.-thick stainless-steel sheets separated by two 0.05-in.-diameter closed-cell urethane-foam layers.

The TSP also uses a near-IR transmitter/receiver using a pulsed LED for transmission and a PIN (positive-intrinsic-negative) photodiode for reception. Both need cylindrical lenses to focus the beam to a 2°-wide, 5°-high ellipse that covers a remote retroreflective screen, as in highway signs, or to the IR sensors on another TSP. A multilayer optical bandpass filter that removes visible light further improves the range.

Precision capacitive sensors can measure an air gap between adjacent metal plates to subnanometer accuracy. Unfortunately, accuracy in the WIM application requires flat and parallel surfaces, and the Cap Pad has neither. Capacitive sensors can also accurately measure a force on adjacent flat plates with a restoring spring, but flatness and parallelism are still requirements. Maintaining parallelism over a 10-in. pad would be difficult, and roads are seldom flat.

If compression of the air pockets in closed-cell foam provides the restoring force, however, the resulting spring constant changes from the conventional $F=K\times x$ of springs or cantilevered beams to $F=P0\times H/(H-x)$, where F is force, P0 is atmospheric pressure, H is the starting gap, and x is the displacement. The result of this **equation** is that the capacitance of the pad varies linearly with applied force, and the surfaces of the Cap Pad no longer need to be parallel or flat. It accurately measures a force regardless of its size.

Most of the circuit amplifies outputs from the four sensors, digitizes them with the MSP430's 12 bit-ADC, does some preprocessing, and messages the controller. The 6V solar panel, 40 IXYS (www.ixys.com) solar cells in series, charges a 19-Ahr, 3V, lithium-polymer battery through IC_1. Low-dropout regulator/switch IC_2 regulates battery output at 3V. The battery generates more than 4V at full charge and 3.2V at the end of charge, and the low-dropout regulator at 42 mA generates only 50 mV. IC_2 also switches active-mode 3V power.

The road-strip sensor senses the 0.1- to 1-psi pulse when a car drives over the pneumatic tubes. A 400Ω silicon bridge sensor differentially outputs approximately 50 mV. Instrumentation amplifiers IC_3 and IC_4 boost the output to a few volts. The pressure sensor, as well as the Cap Pad and the PIN sensor, has a quiescent level with no traffic. A timer detects the no-traffic state and stores this level in RAM, updating every second to follow slow offset drifts from environmental factors, so sensor offset accuracy is not critical. The pressure sensor's scale accuracy—at approximately 30%—is relatively uncritical, but the Cap Pad's scale accuracy should be a few percentage points or less. All sensors must have good resolution.

IC_5 handles accurate temperature measurements, which are necessary for the Cap Pad, whose temperature dependence results from the elastic modulus change of polyurethane. The Cap Pad has a nominal capacitance of about 24 nF at rest, with a change of approximately 7% full-scale when a truck passes. The Cap Drive pulse discharges this capacitance at a 700-Hz rate, and a 100-kΩ resistor charges it to 3V with a 240-μsec time constant. A timer times the number of pulses it takes to cross the internal $V_{DD}/2$ reference using the internal comparator, and, because you can clock the timer at 12 MHz, the resolution is 1%. You can get increased resolution by timing out the nominal quiescent pulse width and capturing the pulse's level at that point with the 12-bit ADC.

The Cap Pad's sandwich construction shields the active element from electromagnetic interference, but a 3W zener diode cleans up any remnant lightning strokes. The IR LED drive is a 20-to-1 current mirror to handle LED voltage variation. A DAC handles the PIN photodetector's offset because the extreme night-to-day dynamic range would overrange the 12-bit DAC. The PIR sensor turns moving deep-IR targets into bipolar millivolt voltage pulses with its special segmented lens and dual-element pyroelectric detector. A PGA (programmable-gain amplifier) selects and variably amplifies the PIR sensor's signal and the PIN signal. The timer uses standard connections.

For a power budget, more schematics, and more details of this circuit, see the Web version of this article at www.edn.com/091126dia.**EDN**

Self-oscillating H bridge lights white LED from one cell

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You can build a self-oscillating H bridge by replacing the pull-up collector resistors of a classical BJT (bipolar-junction-transistor) astable multivibrator with PNP BJTs (**Figure 1**). Because this circuit oscillates at supply voltages as low as 0.6V, you can use it in general low-voltage, low-power push-pull applications. You can, for example, drive a diode-capacitor charge pump to generate negative supply voltage in battery-powered systems. This Design Idea shows how to use it to light a white LED from one cell without an inductor.

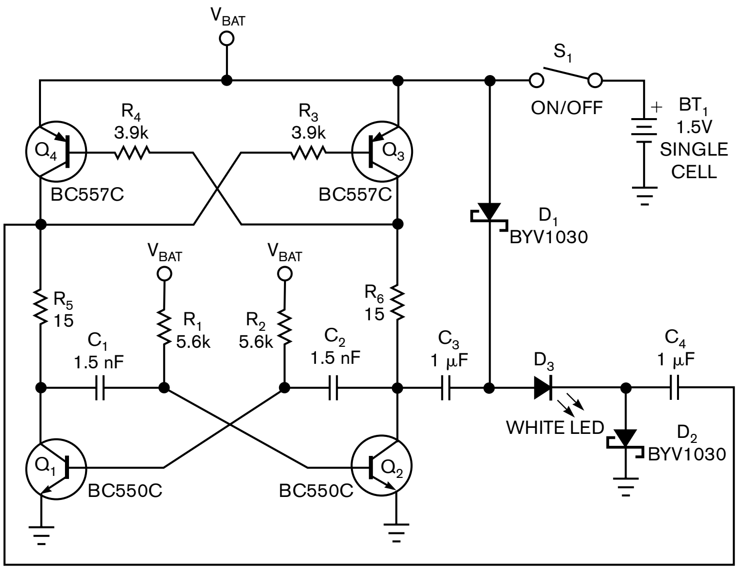

Figure 1 Resistors R_1 and R_2 and capacitors C_1 and C_2 set the oscillation frequency.

Transistors Q_1, Q_2, Q_3, and Q_4 form the H bridge, which acts as a simple charge-pump converter and requires only two small, inexpensive ceramic capacitors, C_3 and C_4, to perform its function. When Q_2 and Q_4 are on, capacitors C_3 and C_4 charge to the battery voltage through forward-biased Schottky diodes D_1 and D_2. When Q_1 and Q_3 are on, they discharge the capacitors through resistors R_5 and R_6 and the LED. Because this process repeats at a high rate of speed, the LED appears always on.

The circuit oscillates with a frequency based on time constants R_1C_1 and R_2C_2. During discharge, the voltage that develops across resistors R_5 and R_6 and the LED remains approximately constant because of the high switching frequency. The measured value, for a nominal 1.5V battery voltage, is 3.8V—enough to drive a white LED with a forward voltage of 3 to 3.5V. Resistors R_5 and R_6 set the LED's peak current and limit the possible current spikes that a push-pull output stage can produce.

Choosing the astable oscillator's frequency involves a trade-off between the time necessary to charge capacitors C_3 and C_4 and the need to reduce their discharge. For a given capacitance value of C_3 and C_4, you must experiment to find the optimum frequency. With the component values in **Figure 1**, the frequency and the duty cycle are about 66 kHz and 50%, respectively, and the LED's drive current is a square-wave signal with 20-mA peak value and 10-mA average value. The LED dims gradually as the battery voltage decreases, and the LED is off when the battery voltage falls below 0.9V. For high efficiency, use small-signal transistors with high dc current gain and low collector-to-emitter saturation voltage. Note that the circuit can drive any type of LED; in this case, you should increase current-limiting resistors R_6 and R_5 to achieve the LED-drive current your application requires.**EDN**

Low-cost LCD-bias generator uses main microcontroller as control IC

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LCD circuits often require a −10V voltage at 2 to 15 mA to bias a graphics-LCD-driver IC. You can usually accomplish this task with an external charge-pump IC, such as Maxim's (www.maxim-ic.com) ICL7660, but that approach adds cost to the design. Instead, you can control a buck-boost switch-mode regulator using the same microcontroller that sends data to the LCD. In addition, you can sequence the power rails under software control, as some types of LCD controllers require.

The circuit includes IC_1, an Atmel (www.atmel.com) Attiny15 microcontroller (**Figure 1**), which provides regulation with 200-mV-p-p ripple at a 30-mA load current when supplying −10V. **Listing 1**, which is available in the online version of this Design Idea at www.edn.com/091126dib, lets you download the source code, which uses only 4.8% of the total CPU time to achieve the stated regulation, even with a relatively low-speed clock frequency of 1.6 MHz.

To minimize CPU time, the software uses the 8-bit on-chip PWM (pulse-width modulator) to drive Q_1. With the on-chip ADC in free-running mode, the microcontroller generates a hardware interrupt with a period of 7.69 kHz. The interrupts have one drawback: If they stop, the circuit can go out of regulation. Thus, you must take care when using interrupts with long processing times. The Attiny15 uses an on-chip, 16× PLL (phase-locked loop) to drive the PWM timer. You can achieve a PWM carrier frequency of 100 kHz, which allows the use of a relatively low-capacitance filter capacitor, C_1.

Two constants in the source code let you alter the bias voltage of the circuit's output voltage. These constants employ basic buck-boost-converter theory (**Reference 1**). The following **equation** defines the maximum 8-bit constant, or threshold, that the ADC reads on the chip: $51.2\times\{V_{CC}-[(V_{CC}-V_{MAX})/(R_4+R_5)]R_5\}$, where V_{MAX} is the maximum desired output voltage and V_{CC} is the supply voltage. To achieve optimum operation, increase the PWM signal's duty cycle when you need higher voltages. Use the following **equation** to determine the 8-bit PWM's value: $255-V_{OUT}/(V_{OUT}-V_{IN})\times 255$, where V_{OUT} and V_{IN} are the output and input voltages, respectively. In practice, however, if you keep the current at less than 2 mA, this requirement is less important.

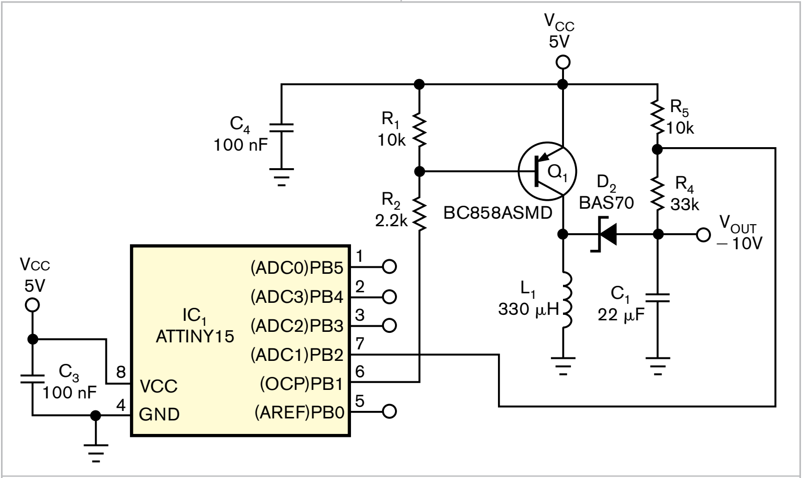

Figure 1 An Attiny15 microcontroller provides regulation with 200-mV-p-p ripple at a 30-mA load current when supplying −10V.

The circuit can deliver currents that Q_1's collector current predominantly delivers. This current is the peak output current that the circuit can safely deliver. The following **equation** calculates the current: $I_{OUTMAX}=(V_{IN}\times 0.08)/V_{OUT}$, where I_{OUTMAX} is the maximum output current. If your design needs higher current, then substitute a BC327 for Q_1. Additionally, the inductor should have a maximum rms (root-mean-square) current value of at least twice the peak output current and preferably be a low-ESR (equivalent-series-resistance) type to maximize circuit efficiency. **EDN**

REFERENCE

1 Hart, Daniel W, *Introduction to Power Electronics*, First Edition, pg 202, Prentice Hall, Oct 25, 1996, ISBN-10: 0023511826, ISBN-13: 978-0023511820.