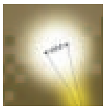
design ideas



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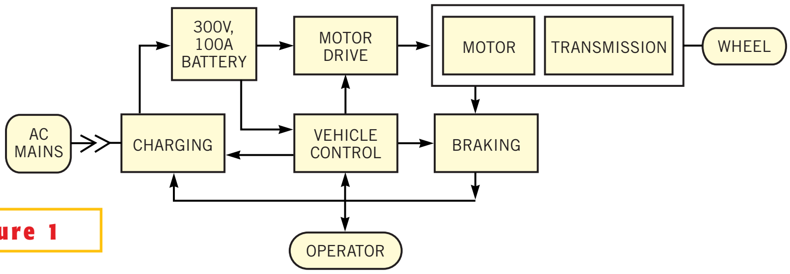
Edited by Bill Travis

Solid-state relays simplify monitoring electric-car battery voltage

Robert Krause, Fairchild Semiconductor, San Jose, CA

FIGURE 1 SHOWS the propulsion system of an electric vehicle. It includes an electric motor, drive electronics, a mechanical transmission, vehicle control/power management, a charging system, and a battery. The long-term performance of the electric vehicle depends on ensuring the electrical health of the battery and its charging system. The battery system in an electric or a hybrid-electric car comprises a series connection of 75 to150 individual 2V cells. This series connection generates a potential voltage of 150 to 300V. The measurement of an individual cell's terminal voltage creates a testing dilemma. The high electrical potential precludes the use of standard differential op amps connected across each cell. The measurement of each cell's voltage entails using a switching network that interconnects an isolated or floating A/D converter between the two terminals of each cell in the string. A measurement method also needs a switching system to sequence this "voltmeter" across each of the 150 cells.

Figure 1



The components of a typical electric vehicle include an electric motor, drive electronics, a mechanical transmission, vehicle control/power management, a charging system, and a battery.

The functional block diagram is an example of an electric car's battery system (**Figure 2**). The battery comprises a series connection of 150 2V cells. This configuration provides a combined potential of 300V. This high dc potential requires the use of an isolated voltage-measurement system. A microcontroller-based isolated voltmeter and isolated switch controller do not provide this function. The cell-measurement system comprises a switching array of 151 of Fairchild Semiconductor's (www.fairchildsemi.com) HSR-412 SSRs (solid-state relays), which provide an off-state blocking voltage of 400V. Each relay is an SPST (single-pole, single-throw), NO (normally open), optically activated switch. As little as 3 mA, or 5 mW, of LED-drive current energize these relays. This low turn-on power consumption eliminates the need for relay-driver ICs.

The first step in measuring the cell's potential is to connect the isolated voltmeter across each cell. A closer look at **Figure 2** reveals how to effect this connection. The input to the isolated voltmeter connects to a two-wire measurement bus. The terminals of this bus are designated A and B. The test points across the various battery cells are designated SSR(N) and SSR(N+1), where (N) is the cell number you are currently measuring. You make Cell 1's voltage measurement by closing SSR$_1$ and SSR$_2$ and leaving all the remaining 149 relays off, or open. Closure of the two SSRs connects Cell 1's positive potential to Node A of the absolute converter through the output of SSR$_1$, and the cell's negative potential to Node B through SSR$_2$. You measure the second cell in the stack by opening SSR$_1$ and closing SSR$_3$ while SSR$_2$ remains on (closed). This sequence connects Cell 2's positive potential to Node B through the output of SSR$_2$ and the cell's negative potential to Node A through the output of SSR$_3$. The process then repeats until all cells have been measured. At this time, the

TABLE 1—THE ALTERNATING POLARITY OF THE A AND B NODES AS THE INDIVIDUAL CELLS ARE MEASURED

Cell number	SSR on (positive cell terminal	SSR on (negative cell terminal)	Voltage at Point A	Voltage at Point B
1	1	2	1	2
2	2	3	2	1
3	3	4	1	2
4	4	5	2	1
5	5	6	1	2
*	*	*	*	*
*	*	*	*	*
148	148	149	1	2
149	149	150	2	1
150	150	151	1	2

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voltmeter returns to Cell 1 and restarts the process.

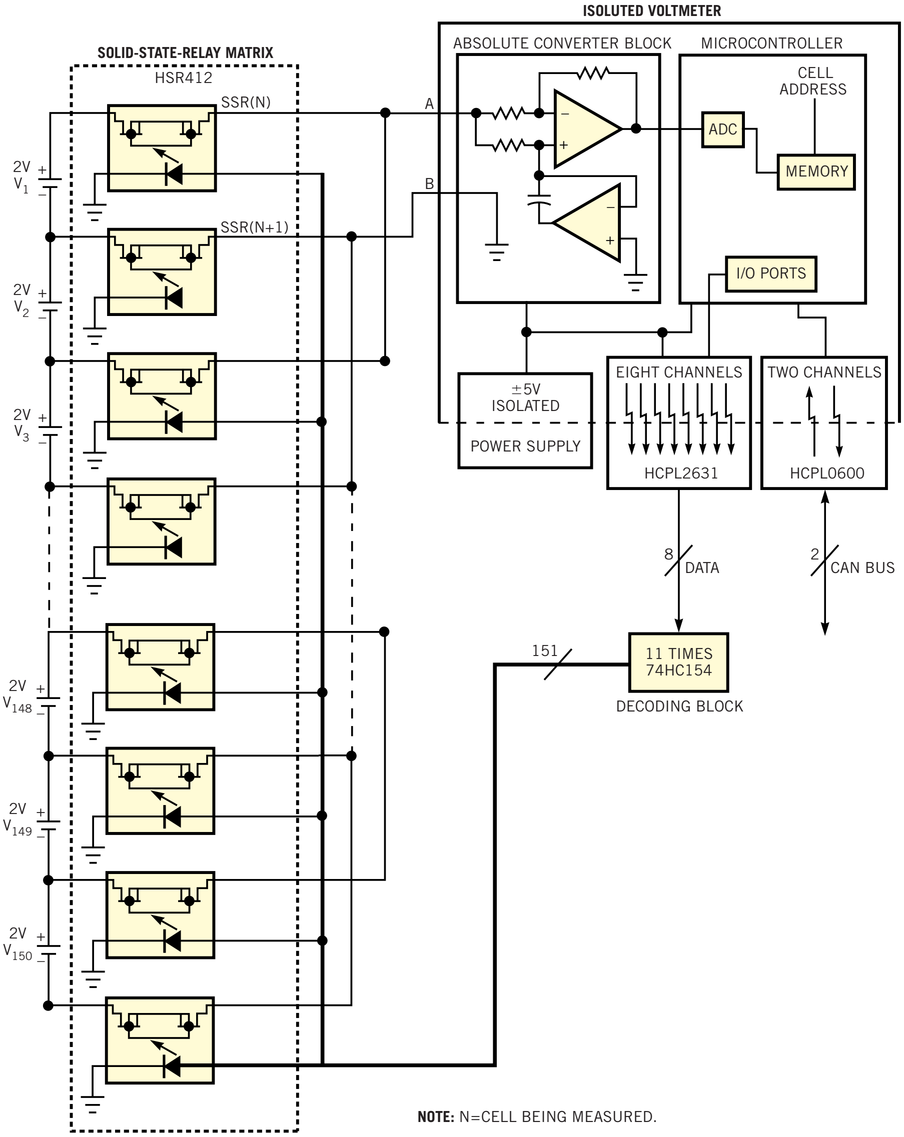


Figure 2 An SSR-based switch matrix allows you to measure individual cells in an electric car's battery.

Table 1 shows the alternating polarity of A and B wires as the cells are measured. To measure the voltage of an individual cell (N), SSR(N) and SSR(N+1) are energized and all other SSRs are off, or open. The alternating polarity of the measurement lines requires the addition of an absolute-value converter between the bus lines and the microcontroller's analog-to-digital input. The microcontroller controls the sequence of measurement events. To measure a cell, the microcontroller sends out a discrete 8-bit digital address corresponding to the cell being measured. This address goes to a decoding block composed of 11 74HC154 multiplexers. The data is transmitted through an array of eight channels of high-speed HCPL2631 optocouplers. The optocouplers provide the common-mode voltage isolation between the 300V battery voltage and the chassis ground. The dual-channel density of the HCPL-2631 optoisolator reduces component count in the block to four. The system addresses the individual cells every 3 msec. This time is how long it takes to turn on and turn off the HSR412 SSR. A cell-voltage measurement takes place 600 μsec after the cell has been addressed. The SSR's turn-on time is less than 500 μsec, thus permitting a 100-μsec acquisition time for the microcontroller's 10-bit A/D converter. The sum of the turn-on and -off times of an SSR times the number of cells measured determines the cycle time. When you use the HSR412, the measurement time for 150 cells is less than 450 msec.

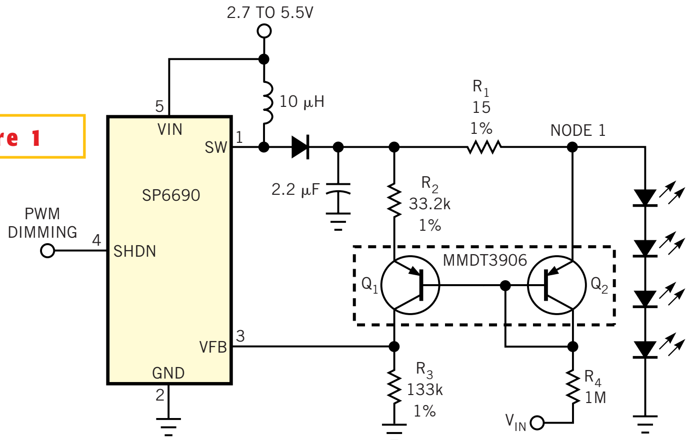
When you measure an individual cell, the V(N)-to-V(N+1) bus potential is approximately 2V. This figure is the differential-mode voltage. The V(N)-to-V(N+1) potential to chassis ground ranges from 2 to 300V, depending on the cell under measurement. This 300V common-mode voltage is well within the 400V off-state blocking voltage of the HSR412. The switch-matrix-control circuits must also be able to accommodate this 300V common-mode voltage. The SSR easily solves this problem. The LED-to-SSR switch isolation voltage is 4 kV rms, which is more than adequate for a 300V system. The 300V common-mode voltage requires that an isolated dc/dc converter powers the microcontroller. The microcontroller records the absolute value of the cell voltage and stores this value and cell number in its onboard memory. At the conclusion of an entire measurement cycle, the microcontroller formats the data to comply with a standard automotive serial-bus format. An example is CAN Bus. Once formatted, the data routes to the vehicle-control computer via a bidirectional, optically isolated link. This link uses two high-speed HCPL-0600 logic-compatible optocouplers. Once that data is received and acknowledged, the measurement cycle can repeat.□

Scheme provides high-side current sensing for white-LED drivers

Dimitry Goder, Sipex Corp, San Jose, CA

White LEDs find wide use in backlighting color-LCD screens in most portable devices, such as cellular phones, PDAs, and MP3 players. Multiple LEDs often connect in series to ensure that the same current flows through every LED. To forward-bias these LEDs, a voltage of 10 to 16V comes from an inductor-based boost regulator, such as an SP6690. However, white LEDs are behind the display, whereas boost regulators are on the main pc board, and it is important to minimize the number of interconnects. You can obtain the best results if you implement high-side and differential-current sensing. In this case, the boost regulator's output looks like a high-voltage true current source. Of course, LEDs need to connect to ground at some point, but it is unimportant where they connect. For example, the display itself can locally pick up ground. This approach allows you to effect a "single"-wire connection. The simple circuit in **Figure 1** shows the implementation of the idea.

Figure 1



This circuit provides high-side current sensing for driving a string of white LEDs.

R_1 acts as a current-sense resistor. The diode-connected Q_2 level-shifts the voltage at Node 1 and applies it to the base of Q_1. These transistors come in one package and provide closely matched V_{BE} voltage when they operate at the same current. Because the V_{BE} values match, the emitter of Q_1 is at the same voltage as Node 1. As a result, the voltage across resistor R_2 matches the drop across R_1 and produces Q_1 emitter current that equals V_{R1}/R_2. This current flows to Q_1's collector and creates a voltage drop across R_3. The boost-regulator SP6690 regulates the voltage across R_3 at 1.22V, the IC's internal reference voltage. R_4 provides current bias for Q_2. The value of R_4 allows the Q_1 and Q_2 collector currents to match. You calculate the value of R_1 as follows: $R_1=R_3\times(V_{OUT}-V_{IN}-V_{BE})/1.22$, where V_{OUT} is the combined LED forward voltage. The output current is $I_{OUT}=0.3A/R_1$. The circuit in **Figure 1** sets I_{OUT} at 20 mA, but you can adjust it by using a different R_1 value. Note that you could return R_4 to ground, but it instead connects to V_{IN}. This connection removes quiescent current through the resistor and Q_1/Q_2 when the SP6690 is in shutdown mode.□

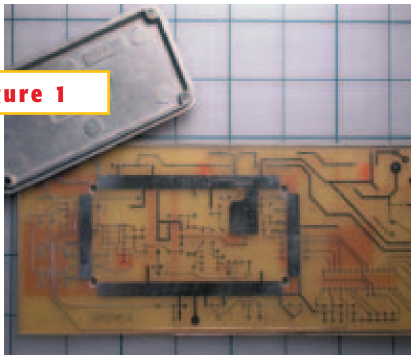
Simple technique makes low-cost pc-board shields

Steve Hageman, Windsor, CA

Many pc-board assemblies require shields to reduce susceptibility to interference from electromagnetic fields. A classic example is a radio receiver, in which the front end usually needs high isolation from the tuning synthesizer. Historically, shields for low-volume or low-cost applications involve trade-offs. You can't justify the cost of a custom-cast shield, and shields machined from aluminum burn through money as fast as the end mills go dull. You can make a simple shield for just a few dollars by using commonly available die-cast aluminum "project boxes," such as those from Hammond Manufacturing (www.hammondmfg.com). These boxes come in sizes from 2×2 in. to more than 7×4 in. You turn the project box into a shield by sandwiching the pc board between the top and the bottom of the box, thus completely enclosing the sensitive circuitry.

The basic idea is to choose a box that is big enough to fit the sensitive circuitry that you want to shield. Then, lay out the circuit in such a way that you can sandwich the board between the cover and the body of the project box. To have a continuous ground around the lip of

Figure 1

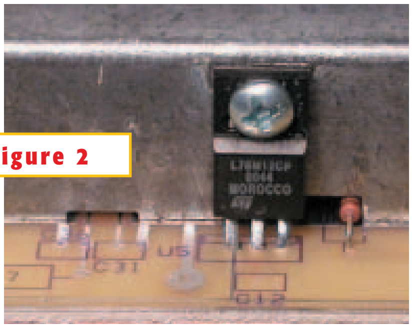


You should place a ground track on the top and the bottom of the pc board where the project-box shield sits.

the box, place a 1/8- to 1/4-in.-wide ground track all the way around the area where the box will sit on the top and the bottom sides of the board. Then, add mounting holes in the corner so that you can assemble the box around the pc board and screw it together (**Figure 1**). To get signals into and out of the shield on a multilayer board is easy: Just use the inner layers and go under the ground track. On a double-sided board, you can break the track for traces, or—better yet—you can use a 0.25W resistor to bridge the track. The 0.25W-resistor method serves two purposes. First, it allows a signal to get over the ground track without cutting it. Second, it is a perfect place to add impedance to the signal line and hence obtain high-frequency filtering. This method can help to prevent stray signals from getting into the sensitive circuitry you are trying to protect.

For both the methods mentioned, you need to notch the box's body with a mill or file (**Figure 2**) to provide clearance to the resistor or traces. Note, however, that this notch acts as a waveguide for RF signals, so keep the following in mind: The longest dimension of any gap should be much less than one-quarter of a wavelength at the highest frequency of interest. In high-performance shielding work, strive to keep the gaps below one-twentieth of a wavelength. If you want to "fill up" the gap, you can buy conductive foam or metal gaskets from 3M and WL Gore (www.3m.com and www.gore.com); you can use these gaskets to fill in any gap to make it electrically smaller. Likewise, any gaps in the box-to-pc-board contact as it sits on the ground track also act as waveguides. Depending on the required frequency of operation, these gaps may or may not cause a loss of shielding effectiveness (**Reference 1**). As a side benefit, you can also use the shield as a heat sink. By placing TO-220 regulators outside the box, you can attach the regulators' heat sink to the enclosure. Thus, you have not only a shield, but also a heat sink (**Figure 2**).□

Figure 2



You can mill small notches in the shield to provide signal access. As a side benefit, you can use the shield as a heat sink for TO-220 regulators.

Reference

1. Ott, Henry, *Noise-reduction techniques in electronic systems*, Wiley-Interscience, 1988, ISBN 0-471-85068-3.

Lowpass filter has improved step response

John Guy and Robert Nicoletti, Maxim Integrated Products, Sunnyvale, CA

A common problem that arises when you design lowpass filters for signal conditioning is the filters' effect on the system's time-domain response. Because pushing the cutoff frequency lower slows the step response, the system may fail to recognize significant changes within a reasonable amount of time. The circuit in **Figure 1** accommodates lower cutoff frequencies without sacrificing the step-response time. A window comparator monitors the delta (difference) between the filter's input and output. When the delta exceeds ±50 mV, the filter increases its slew rate by increasing the cutoff frequency by an order of magnitude. The switched-capacitor filter, IC$_1$, normally operates as a self-clocked device. Capacitors C$_1$ and C$_2$ set the cutoff frequency at 0.1 Hz, and other circuitry forms a dynamic window comparator. Transistor pairs Q$_1$-Q$_2$ and Q$_3$-Q$_4$ form a complementary current mirror whose output flows through R$_2$ and R$_3$, creating a delta of ±50 mV. Connecting the output voltage to the center tap of the two resistors centers the delta on the output voltage. You therefore set the window comparator's upper threshold at V_{OUT}+50 mV and the lower threshold at V_{OUT}−50 mV.

R$_4$ and C$_3$ provide lowpass-filtering to the original input signal, producing a 312-Hz cutoff frequency that reduces sensitivity to momentary glitches. The filtered input drives the window comparator's input. If that input is outside the

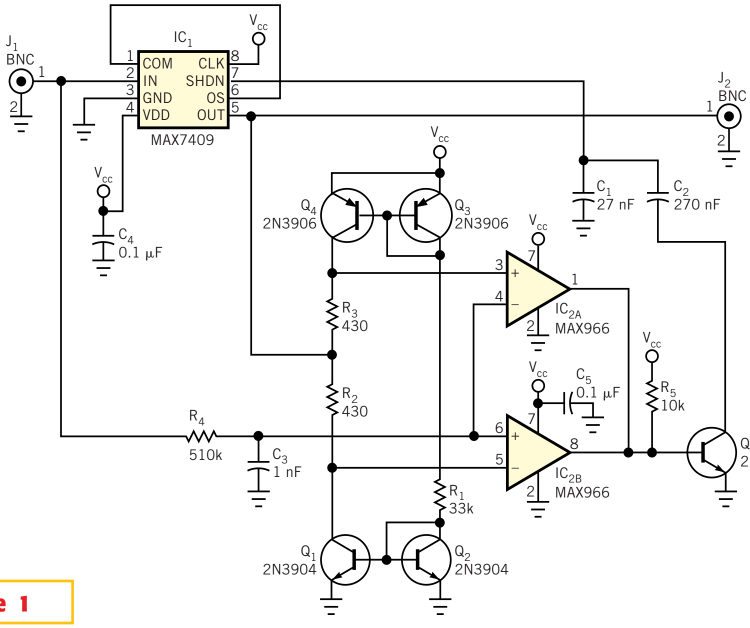


Figure 1

This lowpass filter maintains a fast step response by dynamically adjusting its cutoff frequency.

±50-mV window, comparator IC_{2A} or IC_{2B} asserts its output low. The low output drives Q_5 into cutoff, causing its collector to assume a high impedance. Because Q_5's collector no longer grounds capacitor C_2, the filter's cutoff frequency increases by a factor of 10. When the system's output changes to within 50 mV of the input, the cutoff frequency throttles back to its quiescent state. **Figure 2**'s oscilloscope photo shows the effect. The top trace is a step from 1.5 to 2.5V, the middle trace is the output with optimization circuitry enabled, and the bottom trace shows the filter's unmodified response. The optimized response includes a slight perturbation during the cutoff-frequency transition, but is five times faster than that of the unmodified circuit. The circuit in **Figure 1** is configured for low cutoff frequencies, but you can rescale it for higher frequencies by changing C_1 and C_2. You can also modify R_2 and R_3 for different window values, for which the delta equals the resistance multiplied by 115 μA. The comparator must be an open-drain type.□

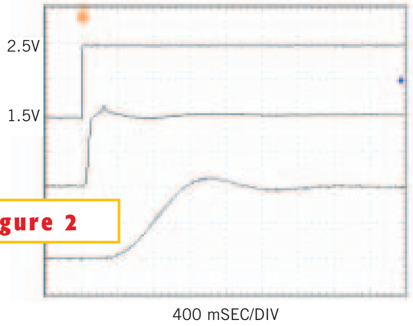


Figure 2

These traces show the time-domain response for the circuit in Figure 1 with optimization circuitry (middle trace) and without it (bottom trace).

Fault-latch circuit protects switchers

Craig Varga, National Semiconductor, Phoenix, AZ

Many power-supply designers like to have a regulator latch off in the event of an overcurrent situation or other fault condition. Yet, many PWM controllers do not internally support this latch-off function. Most do, however, have a power-good output and an enable function. The circuit in **Figure 1** adds that latch-off capability at low cost in little additional space. The design is based on the LMS33460, which is a power-supply monitor in a tiny, five-lead SC-70 package. You just need to combine it with a few small passive parts, and the circuit is complete. When the Enable Input signal goes high, the voltage at the top of C_1 rises quickly to 5V. Because the output voltage is not yet alive, P_{GOOD} stays low, charging C_1 through R_1. Because the voltage on C_1 is zero at the instant of turn-on, Pin 5 of IC_1 pulls up to 5V and begins to drop at a time constant that C_1, R_1, and R_2 determine. If the output does not reach its normal operating voltage before the Pin 5 voltage drops to less than 3V, IC_1 pulls its output low and latches the regulator off.

If, however, the output comes into regulation before the latch times out, P_{GOOD} goes high and C_1 begins to discharge, raising the voltage on Pin 5 and keeping the supply enabled. R_2 provides a couple of volts to IC_1 to keep the IC alive in the event of a latch condition, and D_1 pulls down on the PWM's Enable when the system-enable command switches low. C_1 can be a small tantalum or ceramic capacitor. If you use a ceramic unit, choose a good dielectric, such as X5R. Also, the 5V supply's rising in less than 1 msec or so may eliminate the Enable, and the whole circuit simply runs from the 5V supply. **Figure 2** shows a normal start, and **Figure 3** shows start-up with the second output of a two-output regulator shorted. In both cases, the top trace is the system-enable signal, the second trace is IC_1's Pin 5, the third trace is the PWM Enable at IC_1's Pin 4, and the bottom trace is the regulator's output voltage. You can see in **Figure 3** that IC_1's Pin 5 decays to 3V, at which point it pulls the PWM Enable low, latching off the regulator.□

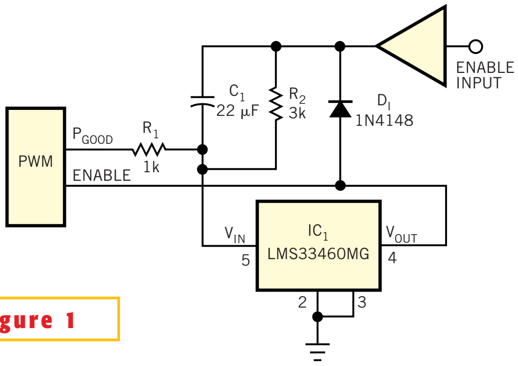


Figure 1

This circuit adds a latch-off function to PWM controllers lacking this feature.

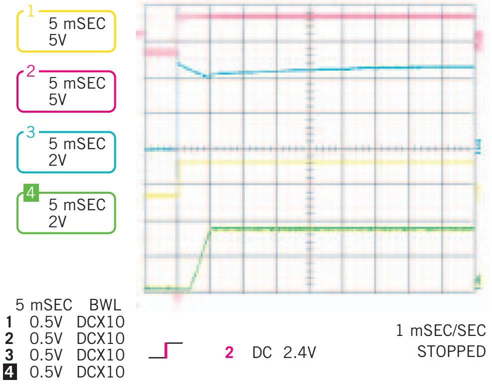


Figure 2

This circuit shows a normal start-up sequence for the circuit in Figure 1.

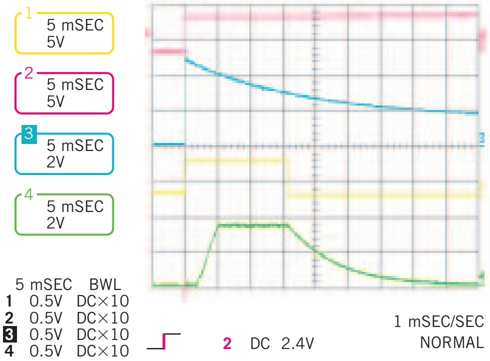


Figure 3

These traces represent start-up with the second output of a two-output regulator shorted.