Buffer amplifier and LED improve PWM power controller's low-load operation

Gregory Mirsky, LaMarche Manufacturing Co, Des Plaines, IL

Texas Instruments' UCC3895 offers a good base for building a high-efficiency, pulse-width-modulated, switched-mode power supply that suits either current- or voltage-mode control. Designed for driving a full-bridge power inverter using two sets of complementary outputs, Out A through D, the circuit controls power by phase-shifting outputs C and D with respect to A and B. The manufacturer's data sheet provides a detailed description (**Reference 1**). However, when lightly loaded and configured for current-mode control, the controller can produce asymmetric-width pulses on its lagging outputs, C and D, under start-up conditions. **Reference 2** provides a complete description of the problem and a workaround.

Unfortunately, the workaround evokes other problems when you use the IC in other circuit implementations. **Figure 1**, from **Reference 2**, shows a partial schematic featuring the UCC3895 in a peak-current-mode-control circuit in which R_1 serves as a pullup resistor, providing a dc offset for the voltage ramp. However, for a significant portion of the ramp waveform, diode D_1 doesn't conduct and therefore narrows the power supply's dynamic range by cutting off a portion of the ramp voltage at IC_1's Pin 3.

Figure 2 shows another approach that requires additional components but delivers the full magnitude of the voltage ramp to Pin 3 of IC_1 and provides the approximately 1V-dc offset that **Reference 1** requires. Transistors Q_1 and Q_2, resistors R_1 and R_2, and LED D_3 form an emitter-follower amplifier for the ramp voltage available at IC_1, Pin 7 across timing capacitor C_1. This arrangement provides reliable current-mode operation over the full range from no-load to full-load output current by delivering a

DIs Inside

90 Temperature controller has "take-back-half" convergence algorithm

94 MOSFET enhances low-current measurements using moving-coil meter

96 Shunt regulator serves as inexpensive op amp in power supplies

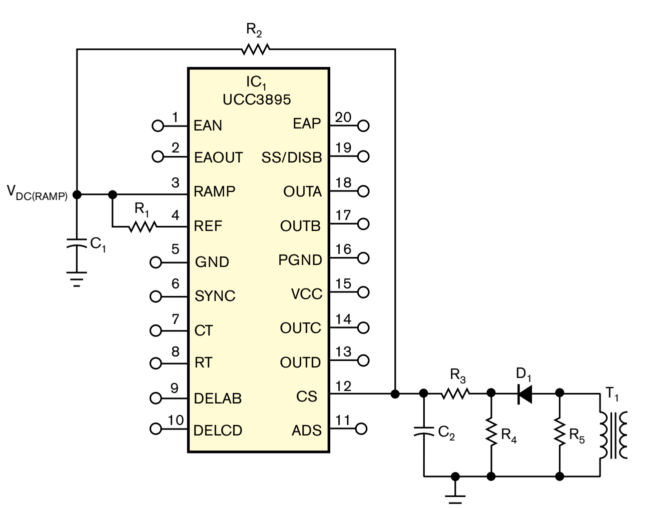

Figure 1 An added resistor, R_1, helps improve light-load operation of a popular switched-mode power-supply controller by eliminating output asymmetry.

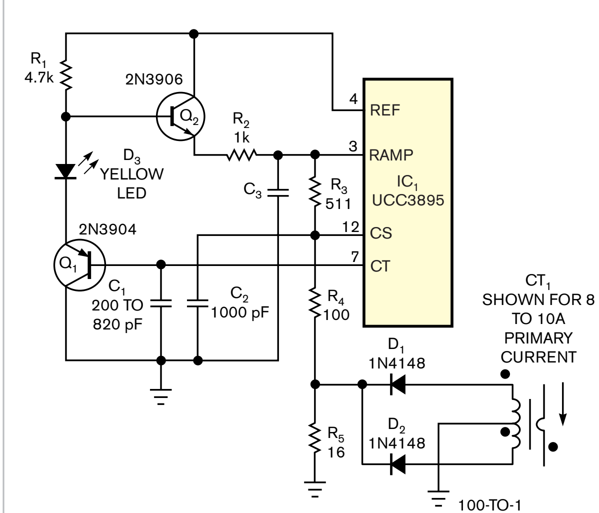

Figure 2 For even better performance, add a level-shifting amplifier to the ramp-voltage path.

sawtooth drive with a dc offset to IC_1's ramp input. Diode D_3, a yellow LED, performs a 1.7V level translation without introducing any substantial signal loss. The component values not shown depend on the application. EDN

REFERENCES

1 "UCC3895 BICMOS Advanced Phase Shift PWM Controller," Texas Instruments data sheet, http://focus.ti.com/docs/prod/folders/print/ucc3895.html.

2 Mappus, S, "UCC3895 OUTC/OUTD Asymmetric Duty Cycle Operation," Texas Instruments Application Report, SLUA275, September 2002.

Temperature controller has "take-back-half" convergence algorithm

W Stephen Woodward, University of North Carolina, Chapel Hill, NC

"The unfortunate relationship between servo systems and oscillators is very apparent in thermal-control systems," says Linear Technology's Jim Williams (**Reference 1**). Although high-performance temperature control looks simple in theory, it proves to be anything but simple in practice. Over the years, designers have devised a long laundry list of feedback techniques and control strategies to tame the dynamic-stability gremlins that inhabit temperature-control servo loops. Many of these designs integrate the temperature-control error term T_S-T in an attempt to force the control-loop error to converge toward zero (**Reference 2**).

One tempting and "simple" alternative approach makes the heater power proportional to the integrated temperature error alone. This "straight-integration" algorithm samples the temperature, T, and subtracts it from the setpoint, T_S. Then, on each cycle through the loop, the loop gain, F, multiplies the difference, T_S-T, and adds it as a cumulative adjustment to the heater-power setting, H. Consequently, $H=H+F\times(T_S-T)$.

The resulting servo loop offers many desirable properties that include simplicity and zero steady-state error. Unfortunately, as **Figure 1** shows, it also exhibits an undesirable property: an oscillation that never allows final convergence to T_S. Persistent oscillation is all but inevitable because, by the time that the system's temperature corrects from a deviation and struggles back to $T=T_S$, the heater power inevitably gets grossly overcorrected. In fact, the resulting overshoot of H is likely to grow as large as the original perturbation. Later in the cycle, H's opposite undershoot grows as large as the initial overshoot, and so on.

Acting on intuition, you might attempt to fix the problem by adopting a better estimate of H whenever the system's temperature crosses the setpoint, $T=T_S$). This Design Idea outlines a TBH (take-back-half) method that takes deliberate advantage of the approximate equality of straight-integration's undamped overshoots and undershoots. To do so, you introduce variable H_O and run the modified servo loop, except for the instant when the sampled temperature, T, passes through the setpoint, $T=T_S$. Whenever a setpoint crossing occurs, the bisecting value $(H+H_O)/2$ replaces both H and H_O. As a result, at each setpoint crossing, H and H_O are midway between the values corresponding to

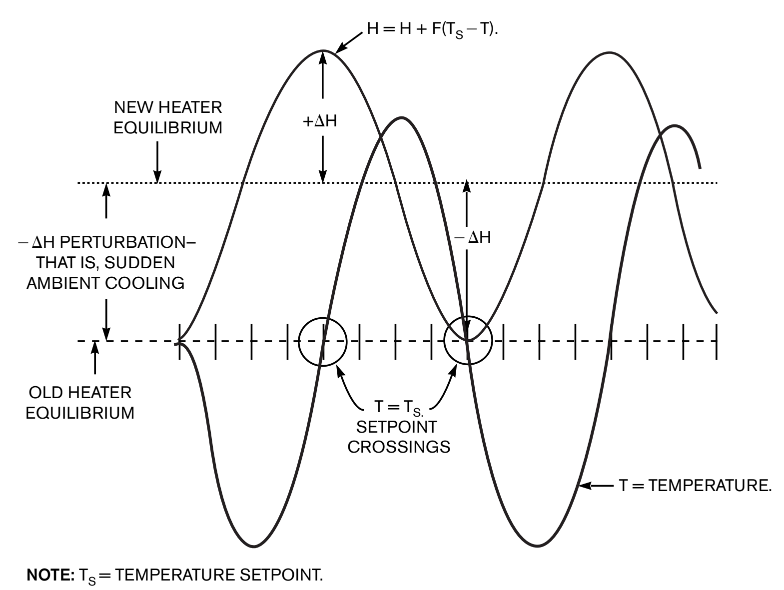

Figure 1 A simple integrating control algorithm virtually guarantees that the system's temperature oscillates and never converges to the setpoint temperature, T_S.

the current (H) and previous (H_O) crossings. This action takes back half of the adjustment applied to the heater setting between crossings. **Figure 2** shows how a simulated TBH algorithm forces rapid half-cycle convergence.

Successful applications of the TBH algorithm range from precision temperature control of miniaturized scientific instrumentation to managing HVAC (heating/ventilation/air-conditioning) settings for crew rest areas in Boeing's 777 airliner. Experience with TBH applications shows that, with a reasonable choice for loop gain, F, the algorithm exhibits robust stability.

In general, a TBH system's natural cycle time is proportional to the square root of the ratio of the thermal time constant to F. Based on both simulations and experiments, a cycle time that's at least eight times longer than

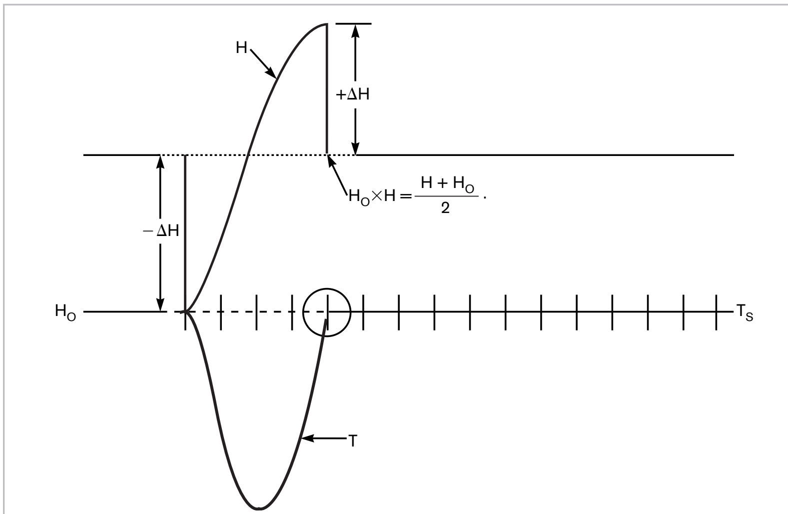

Figure 2 In this simulation, applying the "take-back-half" algorithm forces convergence to the setpoint value in a single half-cycle.

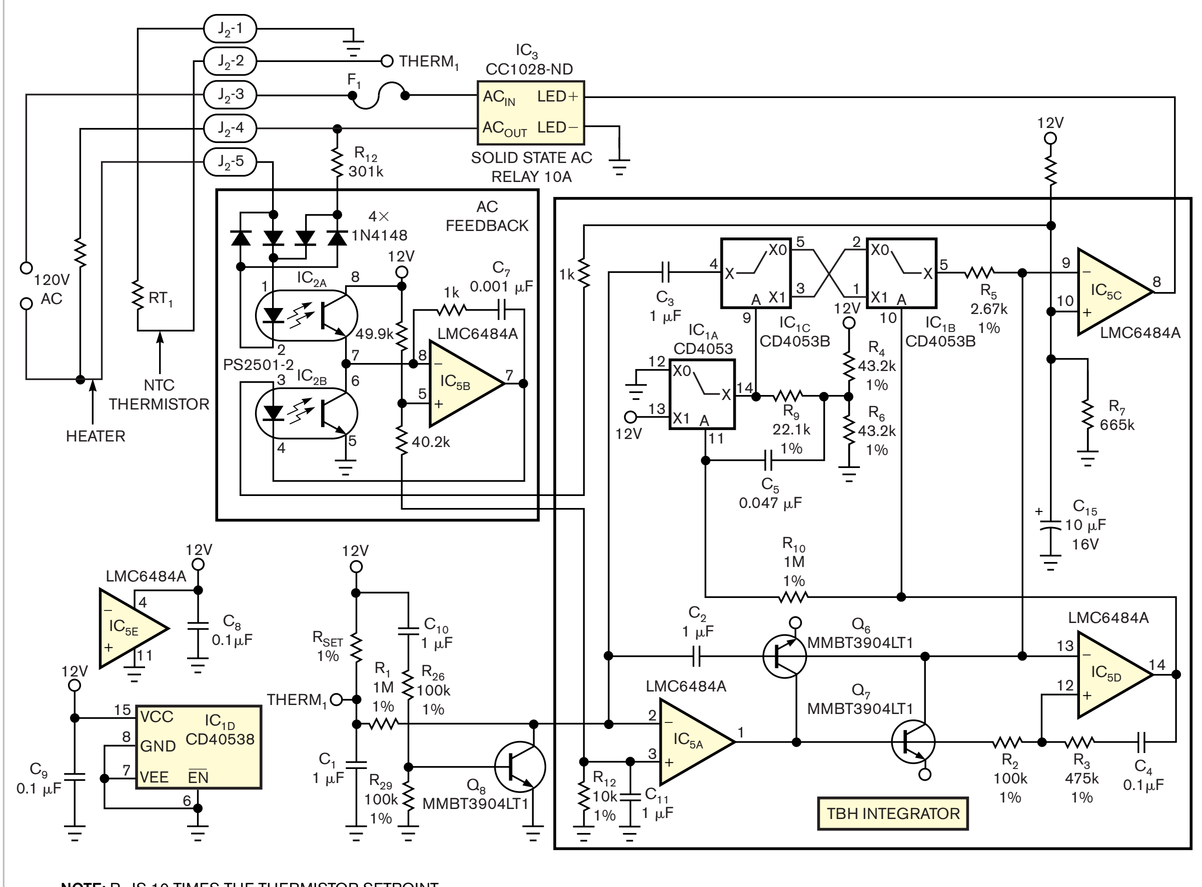

Figure 3 For safety, this version of a TBH heater controller features full isolation of the ac-line and control circuits.

the heater-sensor time delay ensures convergence. Therefore, setting loop gain F low always achieves convergence, and the steady-state error, T_S-T, remains equal to zero.

Figure 3 shows a practical example of a TBH controller that's suitable for managing large thermal loads. Thermistor RT_1 senses heater temperature. The output of error-signal integrator IC_{5A} ramps negative when $T<T_S$ and ramps positive when $T_S>T$, producing a control signal that's applied to comparator IC_{5C}, which in turn drives a solid-state relay, IC_3, which is rated for 10A loads.

Comparator IC_{5D} and the reverse-parallel diodes formed by the collector-base junctions of Q_6 and Q_7, and the CMOS switches of IC_1 perform the TBH zero-crossing convergence function.

In most temperature-control circuits, it's advantageous to apply a reasonably linear feedforward term that represents the actual ac voltage applied to the heater; the need for complete galvanic isolation between the control and the power-handling circuits complicates this requirement. In this example, a linear isolation circuit comprising a PS2501-2 dual-LED/phototransistor optoisolator (IC_{2A} and IC_{2B}) and op-amp IC_{5B} delivers feedback current to C_{15} and IC_{5C} that's proportional to the averaged ac heater current. As a bonus, the feedback circuit provides partial instantaneous compensation for ac-line voltage fluctuations. EDN

REFERENCES

1. Williams, Jim, *Linear Applications Handbook*, Linear Technology, 1990.
2. "Hybrid Digital-Analog Proportional-Integral Temperature Controller," www.discovercircuits.com/C/control3.htm.

MOSFET enhances low-current measurements using moving-coil meter

Stefan Strózecki, Institute of Telecommunications ATR, Kaliskiego, Poland

A previous Design Idea describes an interesting and useful method for using a moving-coil analog meter to measure currents in the less-than-1A range (**Reference 1**). The design offers considerable flexibility in the choice of meter-movement sensitivity and measurement range and simplifies selection of shunt resistors. Although the design uses a bipolar meter-driver transistor, under some circumstances, a MOSFET transistor represents a better choice. The original circuit comprises a voltage-controller current sink that measures the bipolar transistor's emitter current, but the transistor's collector current drives the analog meter. A bipolar transistor's emitter and collector currents, I_E and I_C, respectively, are not identical because base current, I_B, adds to the emitter current.

You can express these current components as $I_E=I_C+I_B$ and then as $I_C=I_E-I_B$. Whether base current adversely affects the measurement accuracy depends on the magnitude of I_B and the magnitude of the common-emitter current gain, β, because base current $I_B=I_C/\beta$. When β is greater than 100, the base current's contribution to emitter current is generally negligible. However, β is sometimes smaller. For example, the general-purpose BC182, an NPN silicon transistor, has a low-current β of only 40 at room temperature. If you were to use a 15-mA-full-scale meter in the transistor's collector, full-scale base current I_B at minimum β would amount to 0.375 mA. Subtracting base current from collector current introduces a 2.5% error.

But if you use a moving-coil meter that requires 150 μA for full-scale deflection, the measurement error increases considerably because β decreases as collector current decreases. For the BC182, reducing collector current from a few milliamps to 200 μA, current gain decreases β by a factor of 0.6 and adversely affects the meter reading's accuracy.

To solve the problem and improve the circuit's accuracy, you can replace the

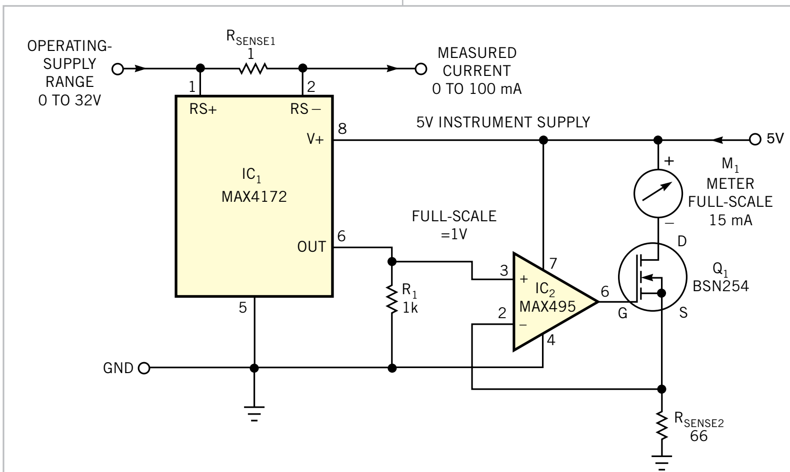

Figure 1 This updated version of an earlier Design Idea uses a MOSFET to drive an analog meter display, offering great flexibility in power-supply-current measurement.

BC182 with an N-channel MOSFET, such as the BSN254 (**Figure 1**). Because a MOSFET draws no gate current, its drain current, I_D, equals its source current, I_S. When you select a MOSFET for the circuit, note that the device's gate-source threshold voltage should be as low as possible. For example, the BSN254 has a room-temperature gate-source threshold-voltage range of 0.8 to 2V. The remainder of the circuit design proceeds as in the original Design Idea; that is, for a maximum voltage drop of 1V across R_1, you calculate R_{SENSE2} as follows: $R_{SENSE2}=(1V/I_{METER})$, where R_{SENSE} is in ohms, 1V represents the voltage drop across R_1, and I_{METER} is the full-scale meter reading in amps. Note that a 1-kΩ resistor at R_1 develops 10V/1A output across sense resistor R_{SENSE1}. In this application, 100 mA produces 0.1V across R_{SENSE1}, and the voltage across R_1 thus corresponds to 1V for full-scale deflection of the meter.EDN

REFERENCE

1. Bilke, Kevin, "Moving-coil meter measures low-level currents," *EDN*, March 3, 2005, pg 72, www.edn.com/article/CA505070.

Shunt regulator serves as inexpensive op amp in power supplies

Michael O'Loughlin, Texas Instruments, Nashua, NH

Developed as a three-terminal shunt regulator, the popular and multiple-sourced TL431 IC offers designers many intriguing possibilities beyond its intended application. Internally, the TL431 comprises a precision voltage reference, an operational amplifier, and a shunt transistor (**Figure 1a**). In a typical voltage-regulator application, adding two external resistors, R_A and R_B, sets the shunt-regulated output voltage at the lower end of load resistor R_S (**Figure 1b**).

In today's power-supply market, cost reduction drives most designs, as evidenced by Asian manufacturers that have resorted to shaving pennies off their power-supply products by using single-sided pc boards. This Design Idea shows how a three-terminal shunt regulator can replace a more expensive conventional operational amplifier in a power-converter design.

A switched-mode power supply uses a galvanically isolated feedback portion of a PWM circuit (**Figure 2**). In designs that omit a voltage amplifier, a shunt regulator can serve as an inexpensive op amp. Resistors R_1 and R set the power supply's dc output voltage, and optocoupler IC_2 provides galvanic isolation. Resistor R_1 provides bias for the optocoupler and the TL431, IC_1. Resistor R_3 and zener diode D_1 establish a fixed bias voltage to ensure that bias resistor R_1 does not form a feedback path. Resistors R_1 and R_2 control the gain across the optocoupler. In most designs, the ratio of R_2 to R_1 is roughly 10-to-1.

Components C_P, C_Z, and R_Z provide frequency compensation for the control loop. The optocoupler includes a high-frequency pole, f_P, in its frequency response, an item that most optocouplers' data sheets omit. You can use a network analyzer to determine the location of the high-frequency pole or estimate that the pole occurs at approximately 10 kHz. The following **equation** describes the compensation network's small-signal transfer function:

$$G_C(s)=\frac{\Delta V_{ERR}}{\Delta V_{OUT}}=\frac{(s\times R_Z\times C_Z+1)}{s\times R_1(C_Z+C_P)\left(\frac{s\times R_Z\times C_P\times C_Z}{C_P+C_Z}+1\right)}\times\frac{R_2}{R_1}\times\left(\frac{1}{\left(\frac{s}{2\times\pi\times f_P}+1\right)}\right).$$

Note that, under some circumstances, adding a bypass capacitor across diode D_1 may be necessary for output-noise reduction.EDN

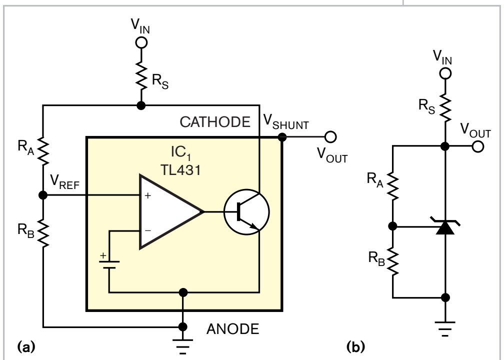

Figure 1 Despite the block diagram, the TL431 is internally complex (a), but you need only three external resistors to use the TL431 in a basic shunt-regulator circuit (b).

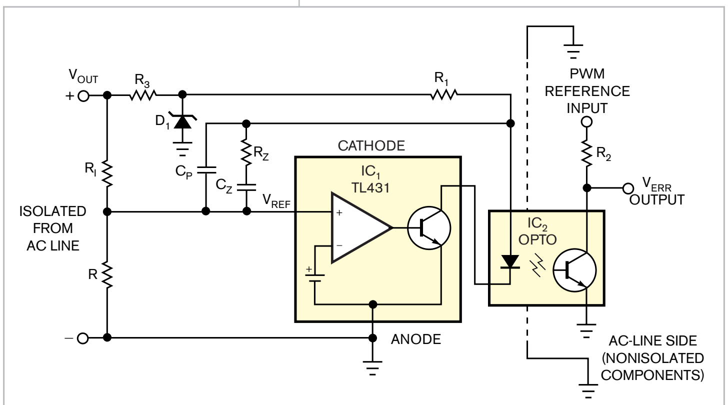

Figure 2 A TL431 replaces a more expensive operational amplifier in this power supply's PWM feedback-regulator circuit.