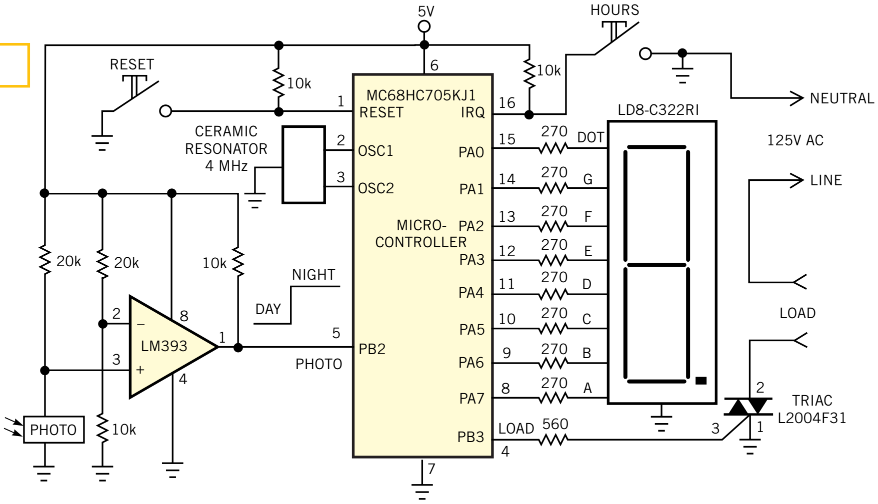
Edited by Bill Travis

Simple phototimer controls load

Abel Raynus, Armatron International, Melrose, MA

Figure 1



When it becomes dark, this circuit turns the load on for a predetermined interval.

In industrial and home applications, the need sometimes exists for a device that, after activation by some physical effect, such as light, temperature, or sound, switches a load on for a predetermined time. The load, such as a lamp, motor, solenoid, or heater, usually derives its power from the ac line. The phototimer in **Figure 1,** based on an inexpensive MC68HC705KJ1 microcontroller, is a simple and inexpensive way to satisfy this need. A load switches on when it becomes dark and stays on for an interval that an operator sets with the Hours pushbutton switch. A seven-segment LED display shows the interval. The time value is a function of the design objectives, the microcontroller software, and the display-interface complexity. The design in **Figure 1** is simple, because it needs only one pushbutton switch and a single-digit display.

The heart of the design is the microcontroller software (**Listing 1**). The routine serves manual and automatic operating modes. The initialization process sets the manual, or continual, mode. This

LISTING 1–ROUTINE FOR PHOTOTIMER-LOAD CONTROLLER

```
0000                $list
0000                $PAGEWIDTH 160
07F1                          org MOR;     resistor osc and input pulldown
07F1      20                  fcb %00100000;
                    ******    I/O PORT BITS *******************************
07F2                LED       equ pA0
07F2                g         equ pA1
07F2                f         equ pA2
07F2                e         equ pA3
07F2                d         equ pA4
07F2                c         equ pA5
07F2                b         equ pA6
07F2                a         equ pA7
07F2                Photo     equ pB2
07F2                Load      equ pB3
                    ********** VARIABLES ******************************
00C0                          org RAM
00C0                Treg      rmb 1 ;Time register
00C1                Tcnt      rmb 1 ;Time counter
00C2                cnt1h     rmb 1 ;counter for 1 hour
00C3                cnt30s    rmb 1 ;counter for 30 sec
00C4                cnt1s     rmb 1 ;counter for 1 sec
                    ******    7-segment CODE TABLE address *************
00C5                adr7s     equ  ROMend+1-$0b ;for 11 constants
                    ******      INITIALIZATION  ************************
0300                          org ROM
0300 [02] A6FF      init      lda     #$ff    ;set prtA as output
0302 [04] B704                sta     ddrA
0304 [05] 3F00                clr     prtA    ;
0306 [05] 1605                bset    3,ddrB ;set pB3 as output
0308 [05] 1701                bclr    Load,prtB ;set Load  off
030A [05] 3FC0                clr     Treg    ;clear
030C [05] 3FC1                clr     Tcnt    ;    all
030E [05] 3FC2                clr     cnt1h   ;       registers
0310 [05] 3FC3                clr     cnt30s  ;                 used
0312 [05] 3FC4                clr     cnt1s
0314 [02] 9A                  cli             ;Interrupt enable
```

(continued on pg 94)

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setting means, that after a 30-sec delay, the load switches on and stays on until you press the Reset pushbutton. The 30-sec delay allows you to change your mind and choose an automatic mode. During the manual mode, the display exhibits "C" for continual. The dot on the display lights every time the load is on, a useful feature when the timer and the load are far away from each other. By pressing the Hours pushbutton, you change the manual mode to an automatic one. In the automatic mode, the display exhibits a time delay in hours. When you press and hold the pushbutton, the digits increment automatically from 1 to 9 every second. This feature comes about by using counter modulo 9 in the external interrupt-service routine (lines 85 to 92 in **Listing 1**). You can download the software associated with this circuit from the Web version of this Design Idea at www.ednmag.com.

After the time-delay setting elapses, the microcontroller waits for night—in other words, for a high level on the Photo input—to switch on the load. During that wait, the dot in the display blinks in 1-sec intervals. When it becomes dark, the LM393 voltage comparator's output switches high and triggers the program to continue. The load switches on, and the dot in the display stops blinking and stays on. The display digit shows the elapsed working time. When this time expires, the load and the dot in the display switch off, and the display exhibits "E." You can stop the process at any time by pressing the Reset pushbutton. Otherwise, the microcontroller automatically repeats the entire sequence every night. The circuit in **Figure 1** is extremely flexible. The circuit can switch on the load using any physical effect just by changing the sensor on the comparator input. You can also modify the software for different time delays. As an example, you might want to display two-digit hours and two-digit minutes. In this case, you should use decoder/drivers, such as the CD4511 or MM74HC138, to configure an interface with the display.

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LISTING 1—ROUTINE FOR PHOTOTIMER-LOAD CONTROLLER (CONTINUED)

```
0315 [03] BEC0          39  main     ldx     Treg       ;Treg --> X
0317 [06] CD0363        40           jsr     display    ;Time --> display
031A [06] CD03A8        41           jsr     dly30s     ;delay 30 sec
031D [04] 3DC0          42  mode     tst     Treg       ; Treg = 0?
031F [03] 274D          43           beq     manual
0321 [05] 1100          44           bclr    LED,prtA      ;LED off
0323 [05] 1701          45           bclr    Load,prtB     ;Load off
0325 [05] 050130        46  Auto     brclr   photo,prtB,blink;is it a day?
0328 [05] 1100          47           bclr    LED,prtA      ;LED off
032A [06] CD03A8        48           jsr     dly30s        ;delay for 30 sec
032D [05] 050128        49           brclr   photo,prtB,blink;is it a day?
0330 [05] 1601          50           bset    Load,prtB     ;Load on
0332 [05] 1000          51           bset    LED,prtA      ;LED on
0334 [03] B6C0          52           lda     Treg          ;Treg --> Tcnt
0336 [04] B7C1          53           sta     Tcnt
0338 [06] CD03B4        54  work     jsr     dly1h         ;delay for 1 hour
033B [05] 3AC1          55           dec     Tcnt          ;decrement Tcnt
033D [03] 2707          56           beq     TimeEnd       ;time is expired
033F [03] BEC1          57           ldx     Tcnt          ;Tcnt --> X
0341 [06] CD0363        58           jsr     display       ;new Time --> display
0344 [03] 20F2          59           bra     work
0346 [05] 1701          60  timeEnd bclr     Load,prtB     ;Load off
0348 [02] AE0A          61           ldx     #$a           ;"E" --> display
034A [06] CD0363        62           jsr     display
034D [05] 0401FD        63  night    brset   photo,prtB,night;wait for a dawn
0350 [06] CD03B4        64           jsr     dly1h         ;delay for 1 hour
0353 [05] 0401F7        65           brset   photo,prtB,night;wait for a dawn
0356 [03] 20BD          66           bra     main
                        67  ****************************************************
0358 [06] CD039C        68  blink    jsr     dly1s      ;delay 1 sec
035B [03] B600          69           lda     prtA
035D [02] A801          70           eor     #%00000001
035F [04] B700          71           sta     prtA
0361 [03] 20C2          72           bra     Auto
                        73  ****************************************************
0363 [05] D607C5        74  display lda     adr7S,x ;code,x --> Acc
0366 [04] B700          75           sta    prtA     ;Acc --> prtA
0368 [05] 070102        76           brclr  Load,prtB,disEnd ;is Load off?
036B [05] 1000          77           bset   LED,prtA ;LED on
036D [06] 81            78  disEnd   rts             ;return from display
                        79  ****************************************************
036E [05] 1000          80  manual   bset    LED,prtA      ;LED on
0370 [05] 1601          81           bset    Load,prtB     ;Load on
0372 [03] 20A9          82           bra     mode
0374 [06] CD0392        83  ExtInt   jsr    dly01s   ;debouncing delay 100 ms
0377 [03] 2F12          84           bih    m3       ;if IRQ=1,end of Interrupt
0379 [03] BEC0          85  m0       ldx    Treg     ;Treg -->X
037B [02] A309          86           cpx    #9       ;Treg > 9?
037D [03] 240F          87           bhs    m1
037F [05] 3CC0          88           inc    Treg     ;Treg + 1
0381 [03] BEC0          89  m2       ldx    Treg     ;Treg --> X
0383 [06] CD0363        90           jsr    display ;Treg --> display
0386 [06] CD039C        91           jsr    dly1s    ;delay 1 sec
0389 [03] 2EEE          92           bil    m0       ;is IRQ-pin still low ?
038B [05] 120A          93  m3       bset   IRQR,ISCR ;IRQ reset
038D [09] 80            94           rti               ;return from ExtInt
038E [05] 3FC0          95  m1       clr    Treg     ;0 --> Treg
0390 [03] 20EF          96           bra    m2
0392 [02] A680          97  dly01s lda #128T       ;100 ms delay
0394 [03] 5F            98  lp1    clrx
0395 [03] 5A            99  lp2    decx
0396 [03] 26FD         100         bne lp2
0398 [03] 4A           101         deca
0399 [03] 26F9         102         bne lp1
039B [06] 81           103         rts
                       104  ****************************************
039C [02] A60A         105  dly1s  lda #10T   ;0,1s x10=1sec delay
039E [04] B7C4         106         sta cnt1s
03A0 [06] CD0392       107  d1s    jsr dly01s
03A3 [05] 3AC4         108         dec cnt1s
03A5 [03] 26F9         109         bne d1s
03A7 [06] 81           110         rts
                       111  ****************************************
03A8 [02] A61E         112  dly30s lda #30T ;1s x10=30sec delay
03AA [04] B7C3         113         sta cnt30s
03AC [06] CD039C       114  d30s   jsr dly1s
03AF [05] 3AC3         115         dec cnt30s
03B1 [03] 26F9         116         bne d30s
03B3 [06] 81           117         rts
                       118  ****************************************
03B4 [02] A678         119  dly1h  lda #120T ;30s x120=1 hour
03B6 [04] B7C2         120         sta cnt1h
03B8 [06] CD03A8       121  d1h    jsr dly30s
03BB [05] 3AC2         122         dec cnt1h
03BD [03] 26F9         123         bne d1h
03BF [06] 81           124         rts
                       125  *****************************************
07C5                   126           org    adr7s
07C5      9C60DAF2     127           fcb    $9c,$60,$da,$f2,$66
          66
07CA      B63EE0FE     128           fcb    $b6,$3e,$e0,$fe,$e6,$9e
          E69E
                       129  *****************************************
07FA                   130           org    VECTORS+2
07FA      0374         131           fdb    ExtInt
07FE                   132           org    VECTORS+6
07FE      0300         133           fdb    init
```

Delay line upgrades vintage scope

Robert Houtman, Blaine, WA

Vintage triggered-sweep oscilloscopes find use in many applications. However, they have no internal delay line, so they can't display the pulse that triggers the sweep. Moreover, early laboratory scopes contain delay lines having insufficient delay to display such pulses during a uniform portion of the sweep. With such oscilloscopes, the true pulse shape remains a mystery. You can circumvent these limitations if you add an external delay line and equalizer. The scope can then display the exact trigger-point trace. The instrument then becomes easier to use, and the measurements become more trustworthy. For every additional microsecond of equalized cable, the scope can display a microsecond of pretrigger information. **Figure 1** shows the components you need to implement these improvements on a Philips PM3230 10-MHz oscilloscope. The components are a wideband amplifier to restore the signal to its original level and provide a trigger; a 750-nsec delay cable; and a passive, two-stage equalizer.

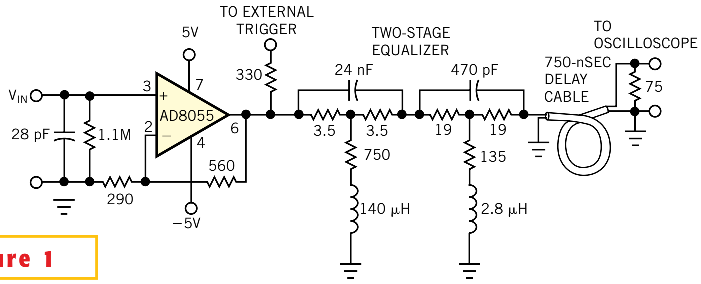

Figure 1

This circuit modifies vintage oscilloscopes having no internal delay line.

CATV cables, such as RG6U, RG59U, and others, are commonly available at garage sales and second-hand stores. You connect the 75Ω cables with solid or foam dielectrics using standard CATV connectors to make the 750-nsec delay line. A low-impedance driver displays the bipolar step response of the delay line, as the eye pattern in **Figure 2a** shows. The delay line transmits approximately 65% of the signal at audio frequencies, because of resistive losses. The losses increase at higher radio frequencies, because of the skin effect in the conductor. The theoretical form for the step response that the skin-effect loss causes is a complementary error function, $\mathrm{cerf}(kl/\sqrt{t}$ (**Reference 1**). The time, t, refers to the start of the step after traversing the cable of 160m length. Computer evaluation of this function shows the constant to be $k=2.6\times 10^{-7}(\mathrm{sec})^{0.5}/\mathrm{m}$ for best agreement with the step response in **Figure 2a**. You cannot adequately correct this functional form by using the usual single-bridged-T filter. You therefore apply time-domain methods to obtain the two-stage, pole-zero-cancellation equalizer in **Figure 1** (**Reference 2**). This double-bridged-T filter corrects the cable's phase and amplitude distortion over a 10-MHz band.

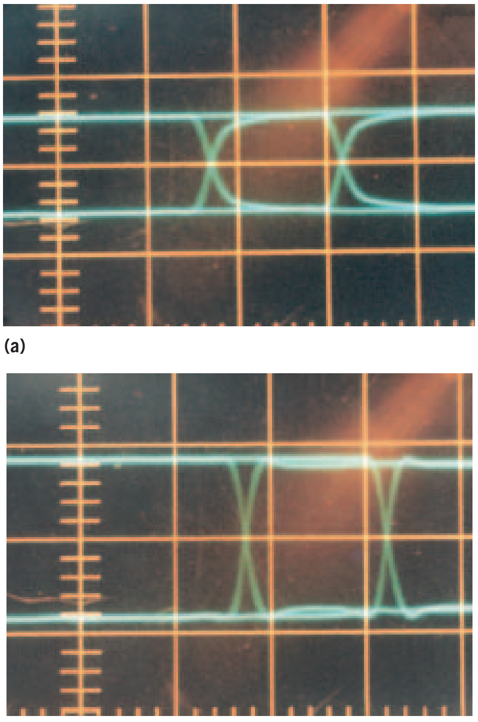

Figure 2

The step response through the 750-nsec cable (a) and the complete network, including the cable (b), differ.

Each of these two filters is basically a resistive attenuator, but fast steps can bypass the attenuation during a time constant, τ. For short times, the equalizer's input port sees a load of only the 75Ω cable via the capacitor, which presents a short circuit at high frequencies. The inductor presents an open circuit at high frequencies, so the resistors have no effect for short times. Eventually, as t surpasses τ in the step response, the capacitor and inductor yield to the resistive attenuator while presenting the 75Ω load to the equalizer's input. With only the first, τ=180-nsec filter, the step response becomes a more finely rounded waveform. With the second, τ=25-nsec filter, the step response is a sharp step, limited only by the oscilloscope's bandwidth. Each filter resides in a reclaimed CATV signal-splitter box. You can connect these 75Ω constant-resistance filters at various locations along the delay line without incurring reflections. You can therefore use this arrangement to fine-tune the passive components to eliminate residual reflections, using time-domain reflectometry.

The AD8055-based amplifier has greater-than-100-MHz bandwidth, fully adequate for the 10-MHz oscilloscope. Its input impedance is 1 MΩ in parallel with 30 pF to match the oscilloscope's input and its low-capacitance probes. **Figure 2b** shows the final eye pattern, using the amplifier, the two-stage equalizer, and the 750-nsec delay cable. This pattern is essentially identical to the eye pattern that ensues using the oscilloscope without the circuit in **Figure 1**, except for the 750-nsec temporal shift. You can see the benefit of the circuit in **Figure 3**. Trace A shows the original impulse response of the oscilloscope without the circuit. Trace A is merely an uninteresting, featureless trace. For Trace B, the input impulse passes through the amplifier to the external-trigger input and then through the equalizer and delay cable to the oscilloscope's input. Because its delay is longer than the intrinsic delay of the oscilloscope in starting its sweep, a clean pulse of approximately 20 nsec appears on the display. You can now use the complete unit as a 10-MHz laboratory oscilloscope.

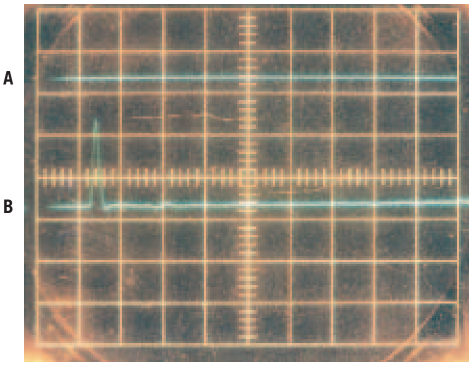

Figure 3 Traces A and B show the impulse response, respectively, without and with the delay network.

You can define an input impulse as an even function composed purely of cosine waves of zero phase. However, the cable's impulse response is simply the derivative of the waveform in **Figure 2a** and acquires a long, slow tail. This impulse response is thus no longer an even function, so its composite cosine waves have evidently acquired various phase shifts accruing to the cable. **Figure 3** illustrates that the circuit in **Figure 1** corrects these phase shifts and amplitude variations. Trace B shows a short, symmetrical pulse with no tail, an even function as similar as possible to the input impulse using this oscilloscope.

References

1. Nahman, NS, "The measurement of baseband pulse risetimes of less than 10^{-9} second," *Proceedings of the IEEE*, Volume 55, No. 6, June 1967, pg 855.

2. Houtman, Hubert, "1-GHz sampling oscilloscope front-end is easily modified," *Electronic Design*, Sept 18, 2000, pg 175.

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Circuit reduces negative-voltage stresses on control IC

Michael Day, Texas Instruments Inc, Dallas, TX

In a synchronous, buck switching power supply, the two FETS and the output inductor meet at the phase node (**Figure 1**). The phase node often connects directly to the control IC. The voltage on this node swings from the input voltage to some voltage lower than ground. If the voltage goes too far below ground, the ESD structures or other circuitry within the control IC can become forward-biased, causing currents to flow through the chip's substrate. These unwanted currents can cause erratic behavior and damage to the IC under certain circumstances. Although it is impossible to keep the phase node from going below ground, it is necessary to keep the voltage at the control IC from going so far negative that it adversely affects or damages the IC.

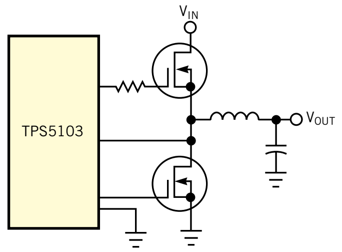

Figure 1 This classic buck regulator suffers from excessive negative phase-node voltage.

Trace A in **Figure 2a** shows the phase-node voltage waveform with $V_{IN}=12$V, and $V_{OUT}=3.5$V at 8A. When the top FET is on, the output current flows through that FET and the inductor to the output. During this time, the phase-node voltage is equal to V_{IN}. The bottom FET must remain off until after the top FET fully turns off. When the top FET turns off, the current then flows from ground, through the bottom FET, and through the output inductor. Dead time is the time lag between turning off the top FET and turning on the bottom FET. During the dead time, the current flows through the body diode of the bottom FET, and the phase-node voltage is approximately −1V, depending on the current levels and the FET parameters. When the bottom FET turns on, the current flows through the FET structure rather than through the body diode. During this time, the voltage is a function of the output current and the resistance of the FET.

During the dead time, the negative voltage coupled with parasitic ringing can apply a negative voltage that exceeds the maximum voltage ratings of the control IC. Trace B in **Figure 2b** shows the phase node when the top FET turns off. The output current flows through the body diode of the bottom FET, and the voltage drop across the FET is −0.76V. With the ringing in the circuit, the phase-node voltage can exceed −1V, a voltage applied directly to the control IC. When the bottom FET turns on, the voltage drops to approximately −0.1V (8A×0.013Ω). Adding a Schottky diode in parallel with the bottom FET helps, but a Schottky diode is large and expensive and has little effect on the voltage. Trace C in **Figure 2b** shows the voltage that occurs with the addition of a large D-Pak MBRD835L Schottky diode. The diode reduces the voltage to −0.6V. With ringing, the control IC sees −0.7V.

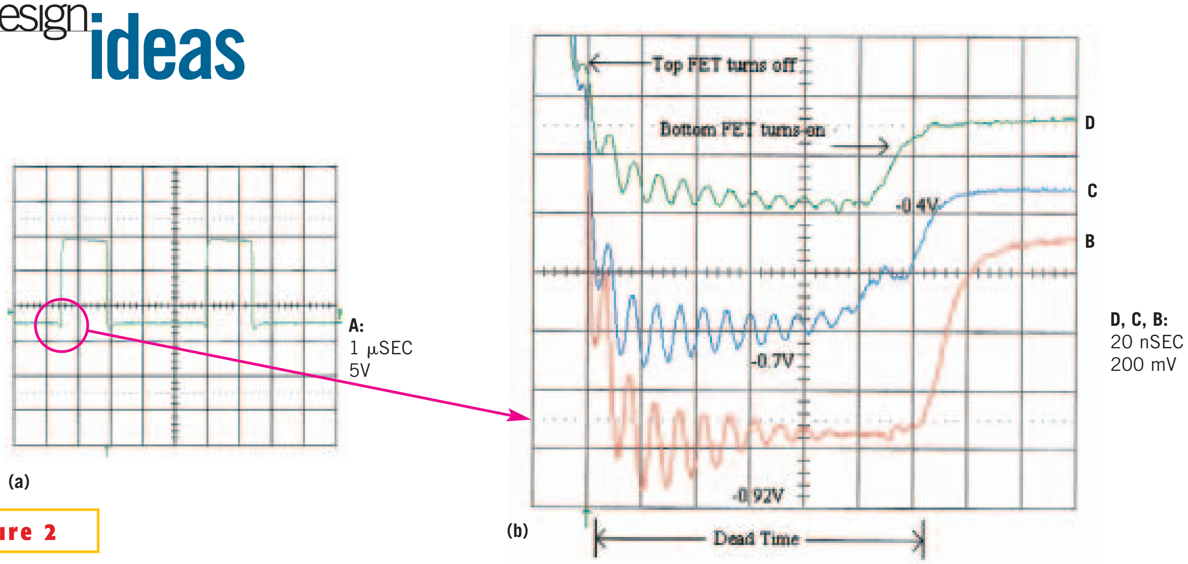

Figure 2

Expanding the dead-time waveforms (a) leads to three scenarios (b): the unadorned buck regulator (Trace B), adding a Schottky diode (Trace C), and the simple solution in Figure 3 (Trace D).

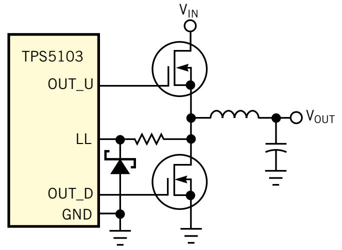

Figure 3

Moving one resistor and adding a small Schottky diode minimizes the phase-node voltage.

The circuit in **Figure 3** is small and inexpensive and significantly reduces the phase-node voltage at the control IC. The gate-drive resistor moves from the gate to the source of the top FET. Following the current from the IC as it charges and discharges the gate capacitance of the top FET shows that moving the resistor has no effect on the circuit operation. An SOT-23 or an SOD-123 Schottky diode with a current rating of 0.5A connects to the control IC. As you can see in Trace D of **Figure 2b**, when the voltage across the FET's body diode goes to −1V, the Schottky diode clamps the voltage on the IC to approximately −0.3V. The full output current flows through the FET, and the gate-drive resistor limits the current through the Schottky diode. This solution is small and inexpensive and prevents erratic operation or damage to the power-supply control IC.

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Track multisite temperatures on your PC

Clayton Grantham, National Semiconductor, Tucson, AZ

The low-cost circuit in **Figure 1** allows you to track four remote temperatures with thermistor sensors through the parallel port on your PC. This four-zone thermometer instrument has a temperature range of −40 to +90°C and a resolution of better than ±1°C. You can calibrate its accuracy to within 1°C over a 0 to 50°C span and within 3°C over a −40 to +90°C span. Thermistors are low-cost, passive, rugged components, making them a good choice for temperature sensing. The signal-conditioning hardware in **Figure 1** performs a simple voltage division to partially linearize the thermistors. Temperature data in the form of thermistor voltages goes into Excel macros, and software performs a fifth-order-equation fit using calibration coefficients to convert the data into Celsius temperatures. This Design Idea focuses on the electronics in Zone 1; the other zones behave similarly. You can implement one, two, three, or all four zones without software modification.

All components have low power (quiescent current) consumption to minimize LPT1 sourcing requirements. Four LPT1 outputs at D0 (Zone 1), D2 (Zone 2), D4 (Zone 3), and D6 (Zone 4) power this application. The hardware typically requires less than 162 μA of current per zone. Parallel-port drivers within your PC generally source at least 400 μA. Supervisory circuit IC_1 monitors the voltage from the LPT1 port. The reset output signal of IC_1 goes back to the parallel port at S7 for software error-checking at initialization. The software ascertains that the hardware is present and that the minimum voltage from D0 of the LPT1 port is greater than approximately 4.65V. Most PCs have a 5V parallel-port interface, but a few have only 3.3V available. For 3.3V PCs, you need to scale the voltage options of the components you use.

IC_2 is a voltage reference for both the RT_1-R_7 voltage divider and the ADC, IC_3. Inasmuch as IC_2 is common to the divider and the ADC, you obtain accurate ratiometric analog-to-digital conversion, and gain, offset, and thermistor-interchangeability errors are at a minimum. The low temperature coefficient of IC_2

(grades are available with lower than 10 ppm/°C) ensures that the circuit exhibits high accuracy in the environments that a portable PC encounters. You should also select R_4 and R_7 with thermal performance in mind. A 0.1% tolerance, 25-ppm/°C metal-film resistor is a good choice. If you intend to use the circuit in a temperature-controlled lab, then you can use less expensive components. RT_1 operates in a zero-power resistance mode, in which self-heating errors are negligible. RT_1 and R_7 form a voltage divider that only slightly linearizes the exponential equation of the NTC thermistor's negative-resistance-versus-temperature relationship: $R_T=R_{T0}\exp[(T_0-T)/(T\times T_0)]$. The software performs further curve fitting.

IC_3 and IC_4 (the ADC block) perform the voltage-measurement function. IC_4, a rail-to-rail op amp, buffers the R_6-C_3 lowpass filter. The serial output of IC_3 (D0) connects to the parallel port at S3. The converted (8 bits) voltage representing the temperature data, sampled from the divider voltage, goes to the parallel port. C0 of the parallel port controls the timing of IC_3's clock input. C1 of the parallel port controls IC_3's CS input; a negative-going front starts the conversion. Resistors R_1, R_2, and R_3 help provide the logic interface between IC_3 and the parallel port. Pulling the thermistor connections either above the PC's 5V supply level or below ground could result in damage to the circuit, the PC, or both. R_4 and R_6 provide some protection. However, to be completely safe, you should isolate the thermistors from any external voltage potential. With no thermistor connected, the temperature reading assumes the zero-voltage temperature, which is −40°C.

IC_1 also has a manual reset that provides direct user control for external triggering. If you depress the momentary switch, S_1, and select the "Trig" button on the user form, then the circuit performs a temperature measurement. The hardware turns off when the user form clos-

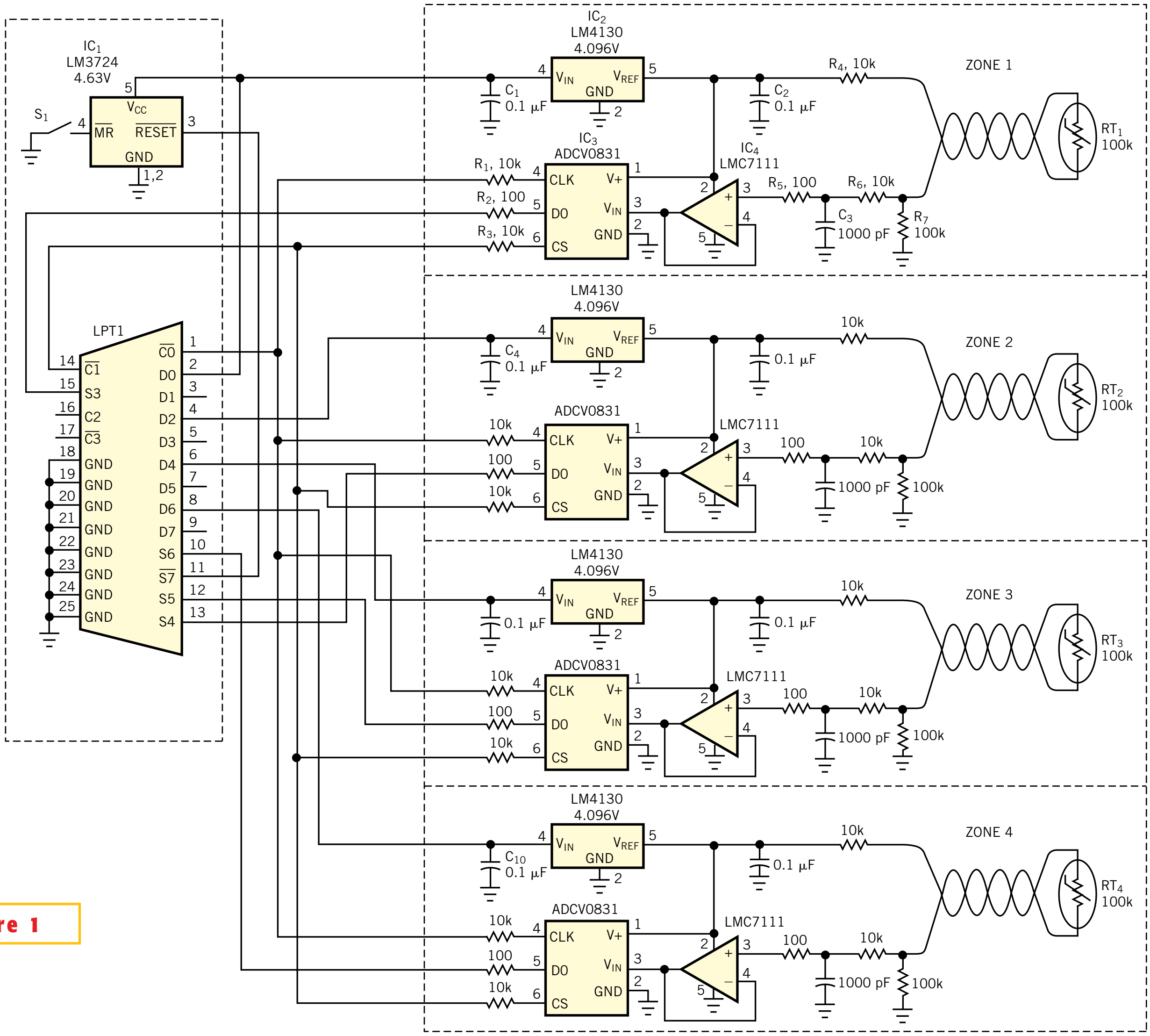

Figure 1

This PC-based thermometer derives its power from the parallel port and uses thermistors to sense four temperature zones.

es. The program control resides in Excel (running under Office 2000) macros that perform I/O through the LPT1 port of the PC. The program uses a free file "Input32.dll" to bit-wise-control the parallel port's digital I/O. The author of the .dll file is Jonathan Titus, editorial director of *Test and Measurement World*. You load QuadZone.xls with its macros, connect the circuit of **Figure 1** to the parallel port, and then run the *ControlPanel* macro. A user form (**Figure 2**) pops up, overlaying the spreadsheet, and connects temperature-measurement actions with the electronics. Your possible options using the user form are single-temperature measurement, multiple-temperature measurements separated by user-defined time intervals, linked measurements that append the data to an Excel spreadsheet, and externally triggered single-temperature measurements. You can download the spreadsheet and the .dll file from the Web version of this Design Idea at www.ednmag.com.

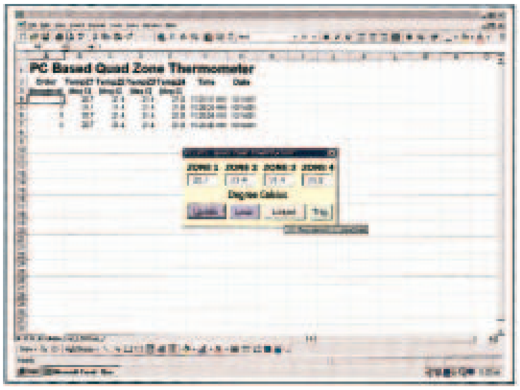

Figure 2 The user form, which floats in front of an Excel spreadsheet, measures the temperature of four thermistors connected to LPT1.

The user form displays a single quad-zone temperature measurement when you press the Update button on the user form. Measurement data links to the cells from columns A to G (named "data") in the spreadsheet when you press the Linked button. When you press the Loop button, the circuit samples measurement data in user-defined intervals. S_1 externally triggers measurement data if you press the Trig button. By using macros within Excel, all the graphing, analysis, and data-storage utilities common to Excel are available for familiar usage. The macros in the .xls listing contain the basic interface features for capturing the signal-conditioned thermistor-sensor signals. Within Module 1, the declaration of Input32.dll needs to include its directory path. The code for input/output of temperature data is within the user-form module.

The macros also include a software-calibration routine that steps users through a temperature-calibration sequence. With the thermistor inside a calibrated oven, you right-click on the user form to initiate calibration. The "cal" spreadsheet of **Figure 2** stores the raw calibration data. The "FitChart" chart plots this raw data and displays a fifth-order-polynomial trend-line equation. The user-form code uses the equation's coefficients to scale and display the temperatures in the user form.

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