design ideas

Edited by Bill Travis and Anne Watson Swager

Two buttons provide safe start

Vincent Himpe, Alcatel Microelectronics, Desselgem, Belgium

THE CIRCUIT IN **Figure 1** provides a safety interlock that checks the actuation of two pushbuttons before enabling a relay. When you push both buttons, the circuit actuates the relay. At that point, you can release one of the switches without the relay's switching off. The circuit was intended to lock out the engine of an underwater propulsion unit. When handling such units on the surface, a person might accidentally press the actuator switch, which is mounted inside the handles of the propulsion unit. ANDing two switches makes the unit safer but requires two hands, a situation that is sometimes unsuitable. Using the circuit in **Figure 1**, you need two hands to start the engine; once the engine is running, one hand is sufficient to keep it running. When you press no switch, the engine shuts off. The circuit uses a simple 555 timer, IC_1 in a unique way. In this circuit, the 555 serves as a window comparator, followed by a memory element.

Actuating one pushbutton puts the input voltage between the two levels of the comparator and thus has no effect on the state of the 555's internal flip-flop. Only when you press two buttons does the voltage go above the high trigger level and set the flip-flop in the 555. Releasing one button brings the voltage back to a level inside the window and has no effect on the state of the flip-flop. Releasing both buttons brings the input level to ground, thus below the low trigger level, and resets the output. Because the 555 derives its internal levels from a resistive divider, the supply voltage has no influence on the behavior of the circuit. The reset input of the 555 connects to an RC circuit, so the IC resets the output upon power-on. By playing with the resistor values, you can obtain many operating conditions. The high output drive of the 555 can actuate almost any type of relay. The diode at the output protects the 555 from the back-EMF of the relay coil when the relay shuts off.

The detection levels of the 555 are one-third and two-thirds of the supply voltage. R_1 and R_2 are of equal value. When you push no button, the input connects to ground via R_3. When you push one button, the input voltage rises to $V_{CC}R_3/(R_1+R_3)$. When you push both buttons, the input voltage rises to $V_{CC}R_3/(0.5R_1+R_3)$. If $R_3=1.5\ k\Omega$, and $R_1=R_2=1\ k\Omega$, you have the following conditions:

- No buttons: $V_{IN}=0V$; thus, the output is off.
- One button: $V_{IN}=0.6V_{CC}$—below the $0.66V_{CC}$ high level; thus, no change is in state.
- Two buttons: $V_{IN}=0.75V_{CC}$—above the $0.66V_{CC}$ high level; the relay switches on.

The circuit lends itself to modifications. You could add an emergency cutoff by connecting a switch across C_1, providing a permanent reset of the output. Or, for delayed action, you could connect capacitors across R_1 and R_2. You can also manipulate the detection levels by connecting a resistor between Pin 5 and V_{CC} or ground. (DI #2555)

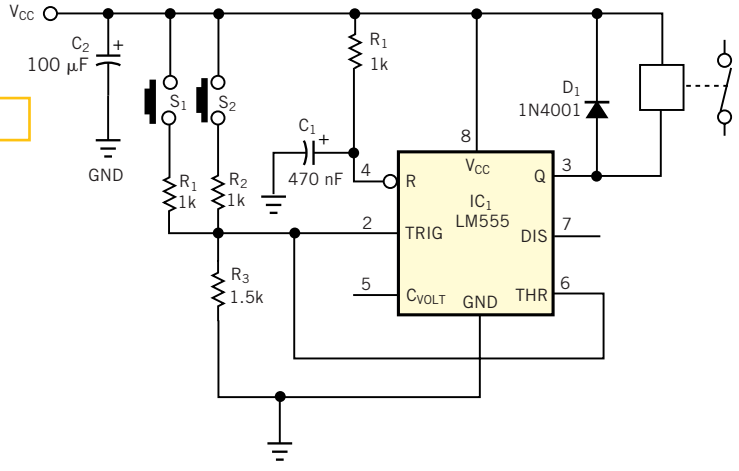

Figure 1 Two buttons turn on the relay; one buttons keeps it going.

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PWM circuit uses one op amp

Ferran Bayes, Electronica Digital, Barcelona, Spain

A previous design idea is reminiscent of a similar but somewhat simpler circuit (see "Low-power PWM circuit is simple, inexpensive," *EDN*, Jan 6, 2000, pg 119). This circuit delivers a rectangular signal with duty cycle varying between 0 and 100% in response to an input signal varying from 0 to 5V dc (**Figure 1**). As with the above-mentioned circuit, the frequency is not constant (**Figure 2**), but the circuit is so simple that it can be useful in certain applications. In response to the hysteresis R_2 provides and the time constant R_3C_1, the comparator delivers the rectangular wave (**Figure 3**). The voltage V− at the inverting input swings between the two threshold levels, V_{TH} and V_{TL}. If you assume that $R_2 >> R_1$, then V+ is always very close to V_{IN}. R_3C_1 averages the signal at V_{OUT}, and the dc voltage at V− is proportional to the duty cycle of V_{OUT}. The closed feedback loop tries to make V− equal to V+; therefore, the duty cycle at V_{OUT} is proportional to V_{IN}.

The voltage at V_{OH} determines both the output signal's high level and the full-scale range of V_{IN}. It can have any value, insofar as it does not surpass the common-mode input range of the comparator. The mathematical analysis of the circuit is easy if we assume that, because $V_{TH}-V_{TL}$ is small, we can approximate the exponential charge and discharge of C_1 to assume the characteristic stemming from a constant-current source/sink. During the charging phase, the current is approximately $(V_{OH}-V_{IN})/R_3$, so:

$$V_{TH}-V_{TL}=\frac{(V_{OH}-V_{IN})T_1}{R_3C_1}.$$

Similarly, during the discharge phase, we can assume the current is $V_{IN}/3$, and

$$V_{TH}-V_{TL}=\frac{V_{IN}T_2}{R_3C_1}.$$

Matching the two equations yields

$$\frac{T_2}{T_1}=\frac{V_{OH}-V_{IN}}{V_{IN}},$$

and the duty cycle is

$$\text{DUTY CYCLE}=100\frac{T_1}{T_1+T_2}=$$

$$100\frac{1}{1+\frac{T_2}{T_1}}=100\frac{V_{IN}}{V_{OH}}.$$

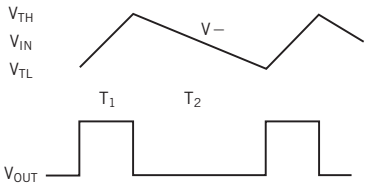
You can see that the duty cycle is directly proportional to V_{IN}: 0% for $V_{IN}=0V$ and 100% for $V_{IN}=V_{OH}$. Moreover, the duty cycle is essentially independent of the component values, with the constraint that $R_2 >> R_1$ to keep hysteresis small. An inverse relationship between duty cycle and V_{OH} can be useful in some applications, so consider V_{OH} as an additional input. The output frequency follows the relationship

$$f=\frac{(R_1+R_2)(V_{OH}V_{IN}-V_{IN}^2)}{R_3C_1V_{OH}^2R_1},$$

reaching its maximum at $V_{IN}=V_{OH}/2$.

Tests with a TLC393 CMOS comparator and a bipolar LM393 reveal that the TLC393 performs better at low values of V_{IN}, because of its lower V_{OL}. Avoid loading the comparator's output; buffer it if necessary, because the loading can degrade the switching levels. (DI #2552)

Figure 3



The voltage at the inverting input follows a linear ramp.

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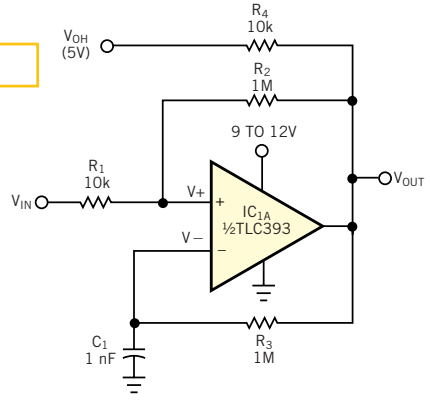
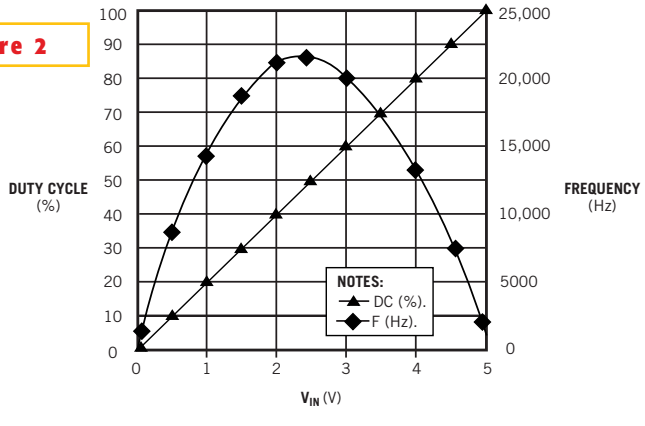
Figure 1



This voltage-controlled PWM circuit is simplicity personified.

Figure 2



Output frequency is a nonlinear function of the input voltage.

Use 8051's power-down mode to the fullest

Jerzy Chrzaszcz, Warsaw University of Technology, Poland

The 8051 series µCs offer idle and power-down modes, both of which you invoke by setting appropriate control bits from the code. For instance, a 5V, 12-MHz Atmel AT89C2051 consumes approximately 9 mA in active mode, 1.8 mA in idle mode, and only 12 µA in power-down mode. Although power-down savings outperform those of the idle mode by two orders of magnitude, the only way to restore the AT89C2051's operation from a power-down state is to reset, which constitutes a serious drawback for system designers. This disadvantage holds true for most 8051-compatible processors; only high-end models wake from power-down state by interrupt. However, a simple method exists for using an ordinary 8051 in power-down mode with interrupt recovery. You can easily adapt the proposed solution for various requirements; the only assumption is that an external device, such as a keyboard or sensor, asserts an interrupt request, which is negated when the processor takes a specific action, such as reading the status register. When the µC has nothing to do, the program switches the external pin on the µC low, and the µC enters power-down mode.

The incoming interrupt request passes through the NOR gate (**Figure 1a**), causing a processor reset (**Figure 1b**). When the port pin is automatically high, the gate closes, negating the reset signal. Such a scenario requires an initialization program to distinguish between cold restart (power-up) and warm restart (wake-up). You can easily accomplish this function by checking whether locations in data memory match a predefined pattern (signature), which is set just before entering power-down mode. For details on the warm-restart concept, refer to application note AN424, "8051 family warm boot determinations" from Philips. Another problem is restoring special-function registers' contents—unlike internal data RAM, which remains unchanged, Special-function registers are automatically initialized upon reset. Depending on the application, some registers may always be set to predefined values, and some must be stored in data memory before entering power-down mode and reloaded during warm restart. You can download the necessary software listings from *EDN*'s Web site, www.ednmag.com. Click on "Search Databases" and then enter the Software Center to download the file for Design Idea #2557. (DI #2557)

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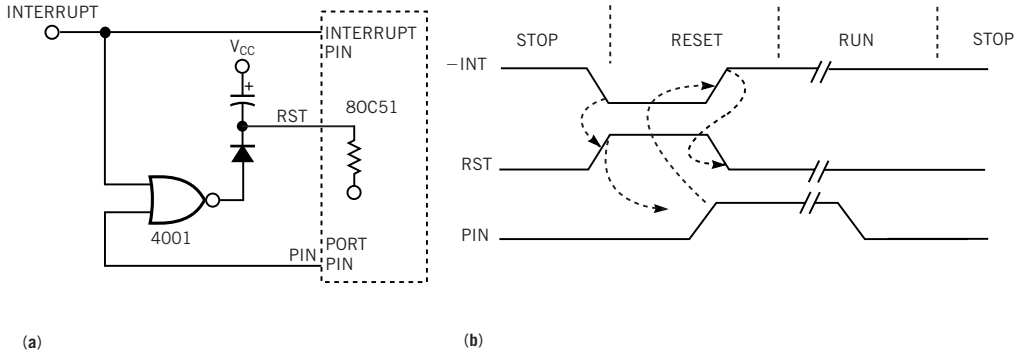
Figure 1



A simple NOR gate (a) allows interrupt-driven wake-up from power-down mode (b).

Current source allows measuring three-wire RTD

John Wynne, Analog Devices, Limerick, Ireland

In applications in which you need remote measurement of temperature with a three-wire RTD (resistance-temperature detector), it is important to eliminate the ohmic errors caused by the excitation current flowing through the wiring resistance. You can locate the RTD more than 1000 ft from the ADC with wiring resistance in the tens of ohms. Normally, you would remove the ohmic errors by using two identical current sources that convert the wiring drops to a common-mode signal that the differential input of the ADC rejects. This technique is based on the not-unreasonable

assumption that the wiring resistances of the three-wire RTD are equal. **Figure 1** shows a typical circuit based on this assumption. The two current sources are assumed to be identical and to track each other closely over temperature and supply-voltage changes. However, a finite level of mismatch exists. In applications in which accuracy is paramount, it may be wise to use only one excitation-current source for the RTD and thus avoid any potential mismatch between two sources. However, the single-current-source approach for exciting a three-wire RTD complicates the effort to reject the ohmic drops, because you can no longer eliminate the wiring drops as a common-mode signal.

Nevertheless, you can still eliminate the wiring drops by using a two-channel ADC and a little extra software computation. You take two conversions, and software subtracts the error term stemming from the wiring resistance. In **Figure 2** the wiring resistances are represented by lumped elements R_{L1}, R_{L2}, and R_{L3}. Assume that the wiring resistance of all three leads is equal ($R_{L1}=R_{L2}=R_{L3}=R_L$). In fact, it is necessary only that R_{L2} and R_{L3} be equal, because R_{L1} appears in both equations. The circuit uses the RTD in an "upside-down" fashion. Two FET switches, SW_A and SW_B, direct the excitation current through the appropriate legs of the RTD. To avoid interruptions in the current flow, make-before-break switching is advisable. Starting with both switches closed, SW_A opens, and the AD7711A takes a measurement. The measured voltage is $2I_1R_L$, which represents the out-and-back wiring drop. Next, SW_A closes, and SW_B opens. The ADC takes a measurement on Channel 2. The measured voltage is $2I_1R_L+V_{RTD}$. This signal represents the out-and-back wiring drop plus the desired signal. The V_{RTD} term is the first result subtracted from the second. The onboard, 400-µA current source of the AD7711A serves as the excitation current in **Figure 2**. (DI #2556)

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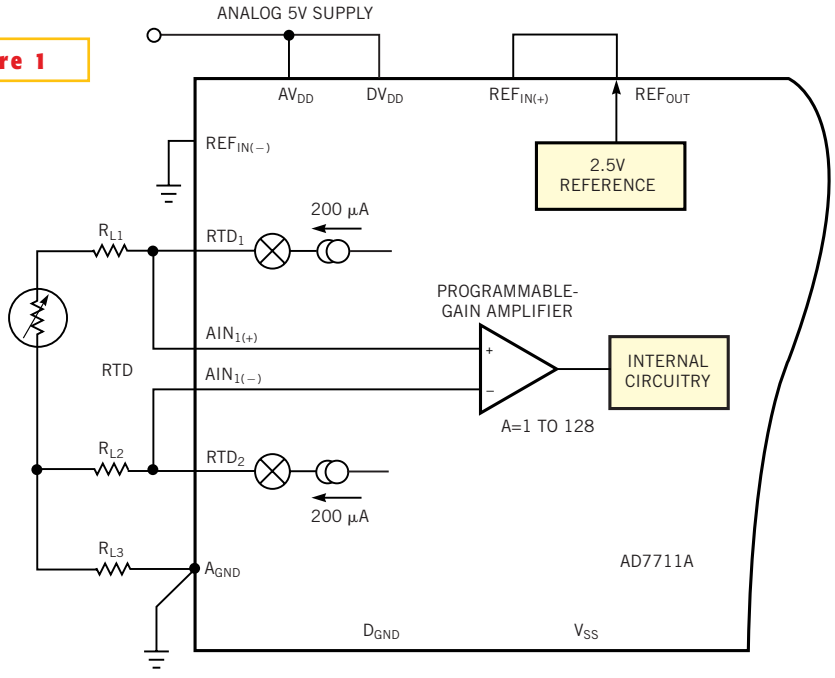
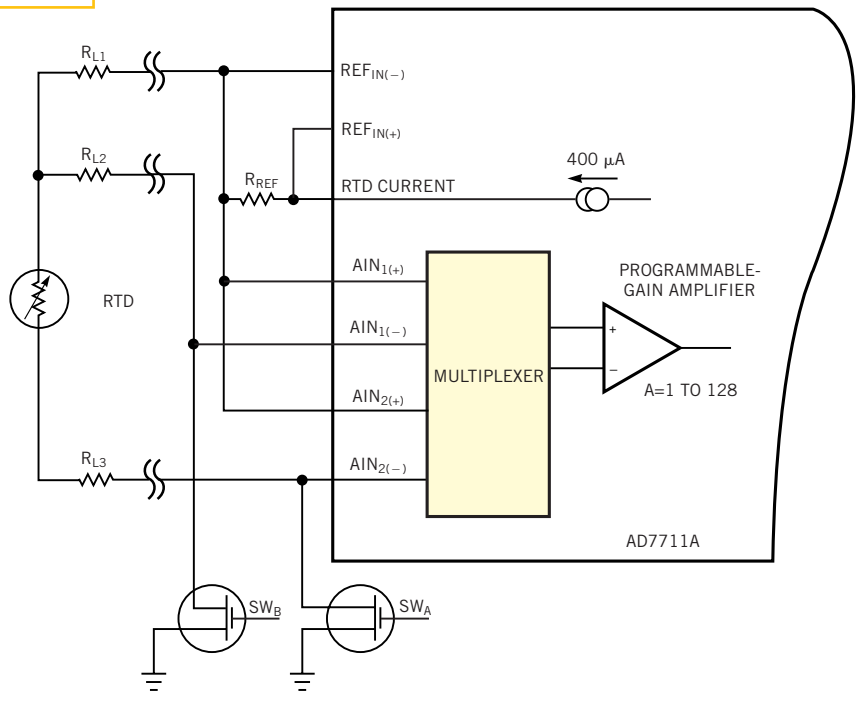
Figure 1



Two current sources turn wiring drops into a common-mode signal.

Figure 2



One current source and a software subtraction eliminate wiring-drop errors.

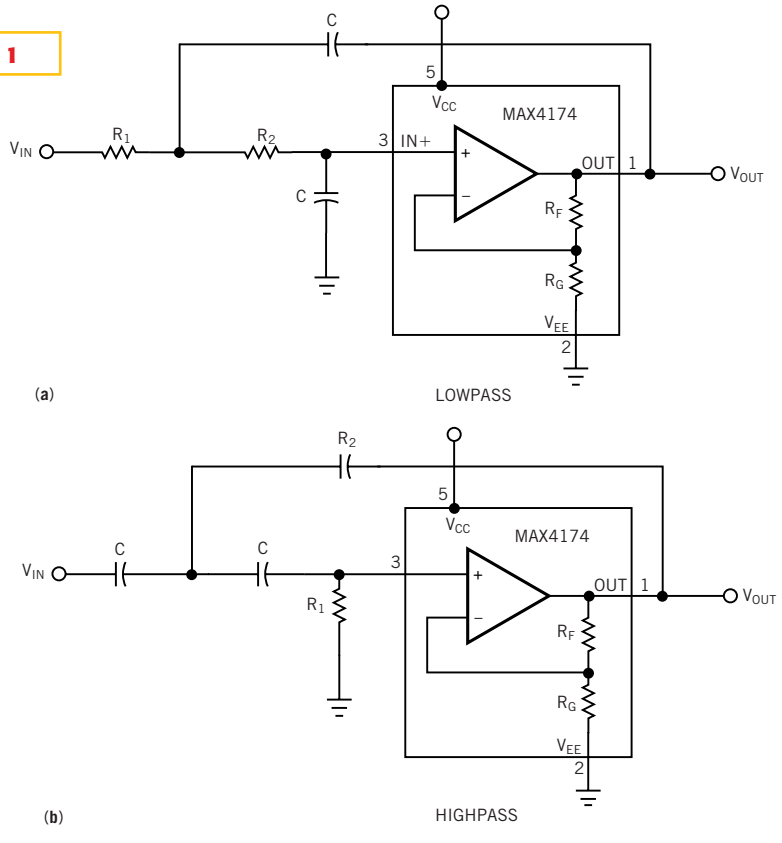
Fixed-gain op amps simplify filter design

Dan Christman, Maxim Integrated Products, Sunnyvale, CA

Simple second-order filters meet many filtering requirements. A low-order lowpass filter, for example, is often adequate for antialiasing in ADC applications or for eliminating high-frequency noise in audio applications. Similarly, a low-order highpass filter can easily remove power-supply noise. When you design such filters with built-in gain, fixed-gain op amps can save space, cost, and time. **Figure 1** illustrates the use of fixed-gain op amps in building second-order lowpass and highpass Sallen-Key filters. Filter "cookbooks" are useful in designing these filters, but the cookbook procedures usually break down for a given response, such as Butterworth, if the gain set by R_F and R_G is greater than unity. What's more, the cookbook component-value formulas can yield unrealistic values for the capacitors and resistors.

Butterworth filters, for example, offer the flattest passband. They also provide a fast initial falloff and reasonable overshoot. You can easily design such filters using **Table 1** with the following equations: $R_2=1/(2\pi f_C C\sqrt{X})$ and $R_1=XR_2$. For a gained filter response, the use of a fixed-gain op amp reduces cost and component count. It also reduces sensitivity, because the internal, factory-trimmed, precision gain-setting resistors provide 0.1% gain accuracy. To design a second-order Butterworth lowpass or highpass filter using a fixed-gain op amp, follow these steps:

Figure 1



Sallen-Key filters use fixed-gain op amps to realize a second-order Butterworth response.

TABLE 1—BUTTERWORTH-FILTER-DESIGN CRITERIA

Gain	Lowpass X	Highpass X
1.25	*	1.372
1.5	2	1.072
2	0.5	0.764
2.25	0.404	0.672
2.5	0.343	0.602
3	0.268	0.5
3.5	0.222	0.429
4	0.191	0.377
5	0.15	0.305
6	0.125	0.257
7	0.107	0.222
9	0.084	0.176
10	0.076	0.159
11	0.07	0.146
13.5	0.057	0.121
16	0.049	0.103
21	0.038	0.08
25	0.032	0.068
26	0.031	0.066
31	0.026	0.056
41	0.02	0.043
50	0.017	0.035
51	0.017	0.035
61	0.014	0.029
81	0.011	0.022
100	0.009	0.018
101	0.009	0.018

*** A gain of 1.25 is impossible to obtain with matched capacitors for the lowpass case.**

1. Determine the corner frequency f_C.
2. Select a value for C.
3. For the desired gain value, locate X under the proper column heading in **Table 1**.
4. Calculate R_1 and R_2 using the equations.

Choosing C and then solving for R_1 and R_2 lets you optimize the filter response by selecting component values as close to the calculated values as possible. C can be lower than 1000 pF for most corner frequencies and gains. Fixed-gain op amps come optimally compensated for each gain version and provide excep-

tional gain-bandwidth products for systems operating at high frequencies and high gain. Suppose, for example, you must design a lowpass filter with a 24-kHz corner frequency and a gain of 10. Step 1 is complete (f_C=24 kHz). Next, complete Step 2 by selecting a value for C, say 470 pF. In **Table 1**, note that X=0.076 for a lowpass filter with a gain of 10. Substitute these values in the equations:

$R_2 = 1/(2\pi f_C C\sqrt{X} = 1/(2\pi \times 24\ \text{kHz} \times 470\ \text{pF} \times \sqrt{0.076} = 51\ \text{k}\Omega$, and $R_1 = XR_2 = 0.076 \times 51\ \text{k}\Omega = 3.9\ \text{k}\Omega$. With these component values, the circuit in **Figure 1** yields the second-order Butterworth lowpass response in **Figure 2**. (DI #2551)

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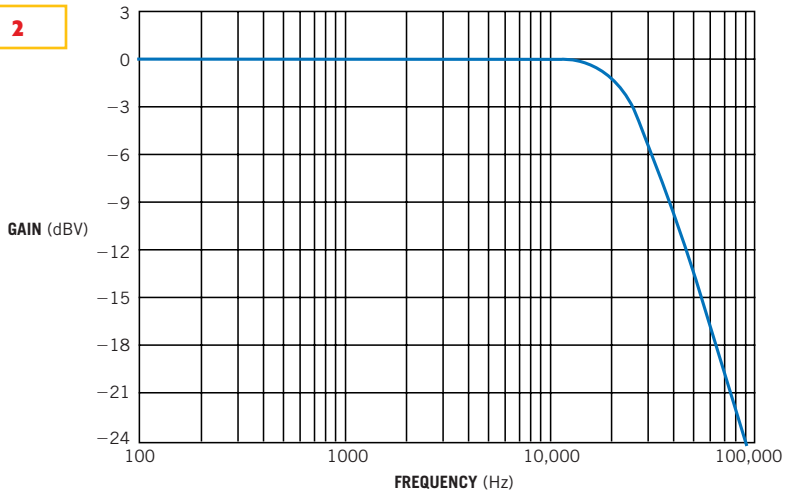
Figure 2



Using the circuit values in the text, the circuit in Figure 1a produces this Butterworth response.

Use your printer port as a high-current ammeter

K Suresh, Indira Gandhi Centre for Atomic Research, Kalpakkam, India

With a few inexpensive components and INT1Ch, you can turn the printer port of your PC into a high-current ammeter. This design's goal is to make remote high-current measurements, but you can use this technique to remotely measure any other similar analog electrical quantity, such as voltage and charge, at moderate speeds without going for expensive, PC-based general-purpose or tailor-made data-logging add-on cards.

In **Figure 1a**, a low temperature-coefficient manganin element senses the high current of the remote module. The manganin element gives an output of 0 to 500 mV, which is V_{IN} to the circuit, for an output-current range of 0 to 100A. Instrumentation amplifier IC_1 amplifies this output voltage by 2. Voltage-to-frequency converter IC_2 digitizes this amplified voltage to a resolution of 13 bits. The values of R_1, R_2, and C_1 give a serial output-pulse train at a rate of 10 kHz/V according to $F_{OUT}=V_{IN}/10(R_1+R_2)C$.

The converter's output linearity of less than 0.01% ensures a linear conversion of the sensed voltage/current to frequency throughout the current range.

Figure 1b shows the other part of the circuit that attaches to the PC's LPT printer port. This circuit couples the converter's output pulses through an optocoupler. It also conditions and counts the pulses using a 16-bit counter, IC_4 and IC_5, whose output bits IC_7 and IC_8 buffer. The circuit hooks the buffer outputs to the input port, STATUS port at 0x379h, of the printer adapter. The circuit inhibits or allows the pulses to the counter by controlling the output bit D_2 (DATA port at 0x378h) of the printer port to enable or disable AND gate IC_4. The PC reads the counter output a nibble at a time by controlling the address inputs of a two-to-four decoder (IC_9) using D_0 and D_1 bits of the DATA port. The decoder outputs in turn control the buffer outputs.

A simple Turbo C program controls the remote current measurement. (You can download the program from *EDN*'s Web site, www.ednmag.com. Click on "Search Databases" and then enter the Software Center to download the file for Design Idea #2550). The timer-tick interrupt, 0x1Ch, which occurs 18.2 times/sec and whose only task is to keep track of the time of day, generates the timebase. The timer-tick interrupt executes the TIMEBASE() routine to update the TIMER variable. To make a measurement, the printer port first disables the pulses to the counter by setting D_2 of the data port to logic 0 and clearing the counter contents by setting D_3 to logic 1 and resetting it to logic 0. To enable the

pulses to the counter, D_2 bit of data port is a logic 1. For each 0x1C interrupt, the TIMER increments. When the TIMER reaches 18 (in approximately 0.989 sec), disabling the D2 bit to logic 0 inhibits the pulses. Also at this time, the program corrects the timebase to 1 sec by applying correction factor CF=18.2/18. The ISENSE() routine sequentially reads the counter-output nibbles starting from LSNIBBLE through the status port by applying addresses 0x00 to 0x03 to the decoder. The program applies the correction factor to the values and displays the value of the sensed current CURRENT. The program sets the TIMER variable to zero and clears the counters. The unit is now ready for another measurement cycle. (DI #2550)

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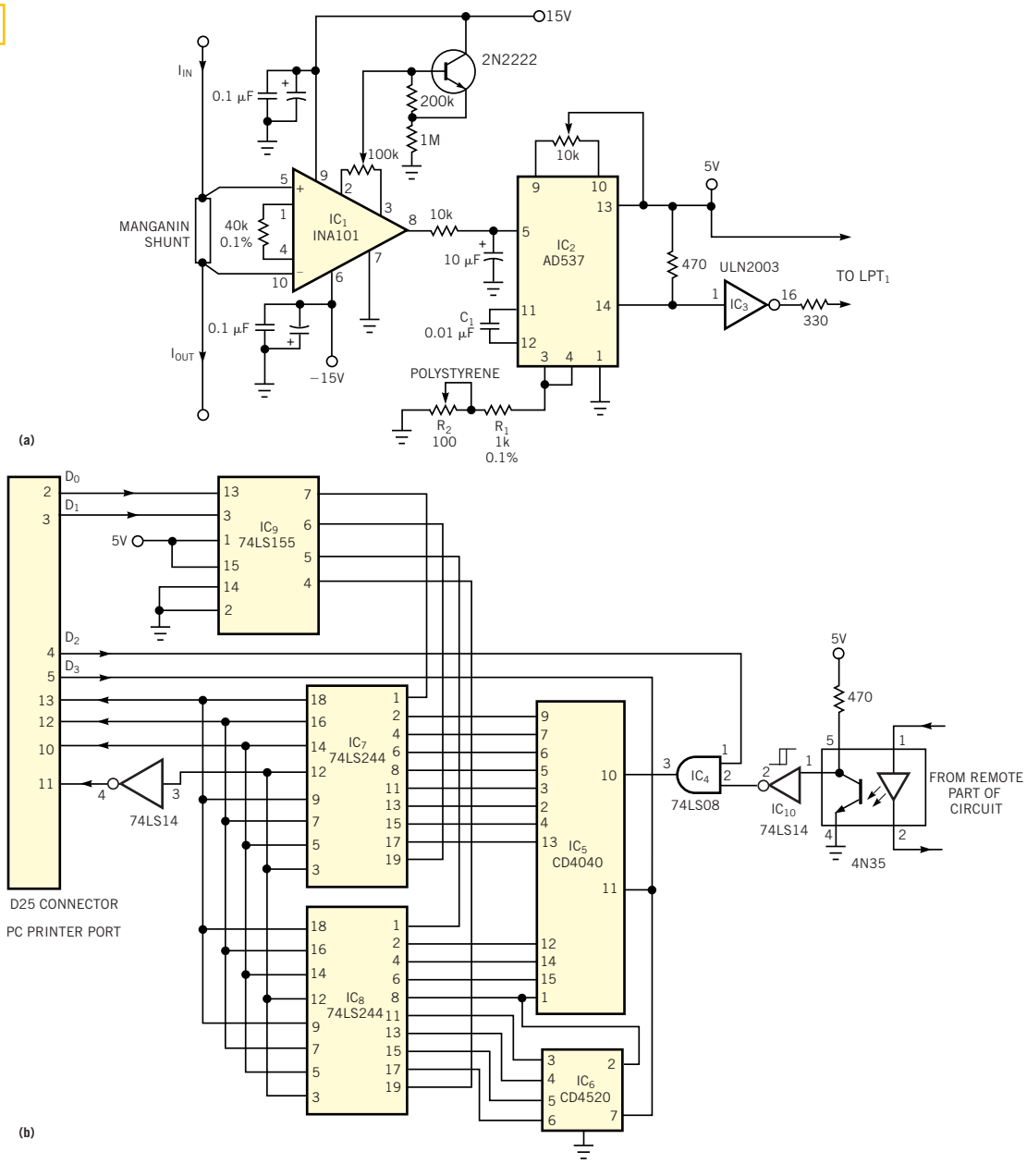
Figure 1



A low-temperature-coefficient manganin element senses the high current of the remote module, and IC_2's voltage-to-frequency converter digitizes the resulting amplified voltage (a). This result, in turn, attaches to the PC's LPT printer port through an optocoupler, counters, and buffers (b).