design ideas

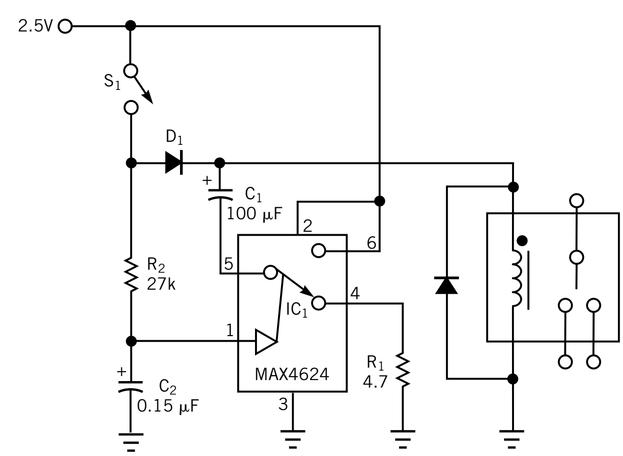
Edited by Bill Travis

Analog switch lowers relay power consumption

Steve Caldwell, Maxim Integrated Products, Chandler, AZ

Designers often use relays as electrically controlled switches. Unlike transistors, their switch contacts are electrically isolated from the control input. However, the power dissipation in a relay coil may render the device unattractive in battery-powered applications. You can lower this dissipation by adding an analog switch that allows the relay to operate at a lower voltage (**Figure 1**). The power that a relay consumes equals V^2/R_{COIL}. The circuit lowers this dissipation after actuation by applying less than the normal 5V operating voltage. Note that the voltage required to turn a relay on the pickup voltage is greater than the pickup voltage required to keep in on the dropout voltage. The relay in **Figure 1** has a 3.5V pickup voltage and a 1.5V dropout voltage. The circuit allows the relay to operate from an intermediate supply voltage of 2.5V. **Table 1** compares the relay's power dissipation with the fixed operating voltages applied and with the circuit in **Figure 1** in place.

Figure 1



By using an analog switch, you can reduce a relay's power consumption.

TABLE 1–RELAY POWER DISSIPATION

Voltage (V)	Current (mA)	Total power dissipation (mW)
5 (normal operating voltage)	90	450
3.5 (pickup voltage)	63	221
2.5 (circuit of Figure 1)	45	112

When you close S_1, current flows in the relay coil, and C_1 and C_2 begin to charge. The relay remains inactive because the supply voltage is lower than the pickup voltage. The RC time constants are such that C_1 charges almost completely before the voltage across C_2 reaches the logic threshold of the analog switch. When C_2 reaches that threshold, the analog switch connects C_1 in series with the 2.5V supply and the relay coil. This action turns the relay on by boosting the voltage across its coil to 5V, which is twice the supply voltage. As C_1 discharges through the coil, the coil voltage drops back to 2.5V minus the drop across D_1, but the relay remains on because its coil voltage is above the relay's 1.5V dropout voltage. Component values for this circuit depend on the relay characteristics and the supply voltage. The value of R_1, which protects the analog switch from the initial current surge through C_1, should be low enough to allow C_1 to charge rapidly but high enough to prevent the surge current from exceeding the peak current specified for the analog switch.

IC_1's peak current is 400 mA, and the peak surge current is $I_{PEAK}=(V_{IN}-V_{D1})/(R_1+R_{ON})$, where R_{ON} is the on-resistance of the analog switch (typically 1.2Ω). The value of C_1 depends on the relay characteristics and on the difference between V_{IN} and the relay's pickup voltage. Relays that need more turn-on energy need larger values of C_1. You select the values for R_2 and C_2 to allow C_1 to charge almost completely before C_2's voltage reaches the threshold of the analog switch. In this example, the time constant R_2C_2 is approximately seven times $(R_1+R_{ON})C_1$. Larger R_2C_2 values increase the delay between switch closure and relay activation.

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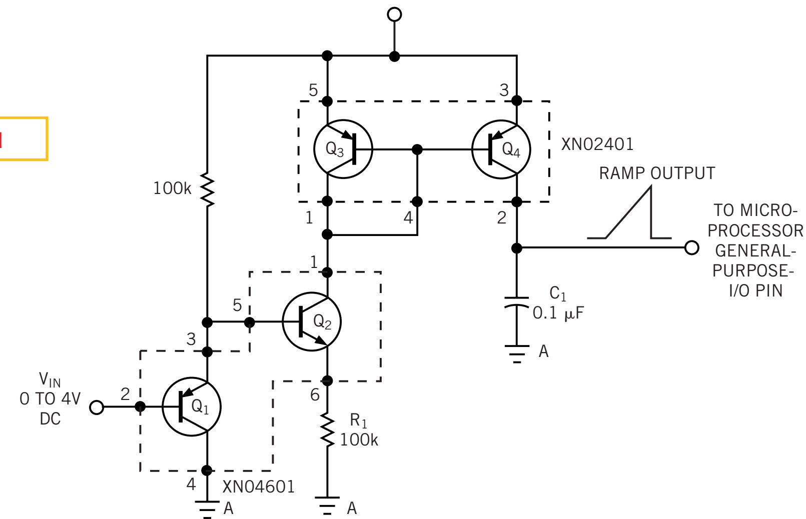
Analog-input circuit serves any microcontroller

Steven Hageman, Agilent Technologies, Santa Rosa, CA

THE SIMPLE ADC in **Figure 1** is perfect for getting analog signals into a purely digital microcontroller. Using just five surface-mount parts, you can assemble it for less than 50 cents (1000), which is approximately half the cost of a single-chip-ADC approach in the same volume. Moreover, this design takes only one pin from the microcontroller to operate. Although you can purchase many microcontrollers with built-in ADCs, in some circumstances, this solution is impractical. For example, you might have an all-digital microcontroller already designed in. In this design, a USB-compatible, digital-only microcontroller needed analog input at low cost for a consumer application. The basic analog portion of the circuit in **Figure 1** uses clever transistor arrays from Panasonic (www.panasonic.com). Q_1/Q_2 and Q_3/Q_4 are single-package, multiple-transistor arrays. The Q_1/Q_2 array forms a voltage-to-current converter. The voltage on Q_1's emitter is a diode drop higher than the voltage on Q_1's base. The V_{BE} drop in Q_2 returns the original input voltage to the top of R_1; R_1 then converts that voltage to a current.

The Q_3/Q_4 array forms a standard current-mirror circuit. The current flowing in Q_3's collector matches the current forced in Q_4's collector. Q_4's collector has high impedance, so Q_4 provides a suitable current source. The current from Q_4 charges C_1 at a rate that is proportional to the input voltage. The values in **Figure 1** allow for a range of conversion times of 3 msec for an input of 4V to 56 msec for an input of 0.1V. The design exploits the fact that most general-purpose microcontrollers have a bidirectional I/O-port structure. That is, you can program a port pin as either an input or an output. When you set a pin as an input, it has very high input impedance, so it can follow the ramp as C_1 charges up. When you program a pin as an output, you can set it low, and it discharges C_1 for the next conversion cycle. This action gives you the basic operation of a single-slope analog-to-digital-conversion cycle.

Figure 1



With two transistor arrays and three discrete components, you can configure an analog front end for a microcontroller.

The basic operations are as follows:

1. Set the ADC pin as a low output to discharge C_1.
2. Reset a suitable timer-counter in the microcontroller.
3. Set the ADC pin as an input.
4. Allow the timer to count until it reads as logic 1 in the microcontroller, or let the timer count to some suitably long value, which suggests that the input is essentially zero.
5. Stop the timer counter.
6. Convert to the timer count by some suitable scaling factor to an ADC reading.
7. Start over for the next conversion.

The conversion from the ramp time to a logic 1 on the microcontroller pin depends on the following factors:

- the logic-1 switching level of your microcontroller;
- the input voltage and, hence, the ramp rate of C_1;
- the value of C_1, which sets the ramp rate;
- the value of R_2, which sets the ramp rate; and
- the microcontroller's timer resolution.

You can boil down these variables to the following equation:

$$\frac{C_1 V_L}{dT} K = V_{IN},$$

where V_L is the voltage level of the microcontroller's zero-to-one conversion, K is the scaling factor that relates to the voltage-to-current conversion of the input stage and timer resolution, and dT is the time count of the conversion cycle. Because C_1V_L is also a constant for a given circuit, you can combine it with K to form a single conversion constant of K_1. Hence, you can reduce the equation to $K_1/dT = V_{IN}$.

In this case, the test code was written for Microchip Technology's (www.microchip.com) PIC16F84 microcontroller. This device has a measured V_L of 1.28V; the counter has a resolution of 1 µsec. It's probably best to empirically determine the factor K_1. Set up the counter resolution as desired, allow the microcontroller to make and display that conversion time or send it through a debugger, and, given that you have an exact V_{IN}, K_1 is then easy to determine. In this case, K_1 turned out to be 2V×5700 µsec=11,400.

The constant K_1 serves to convert the raw timer count to a voltage. To obtain high resolution, you normally use floating-point math. If you need to display the value, floating-point math might be appropriate, but most applications entail reading a potentiometer or some other system level. In such applications, the output is a bar-chart display or some control value. Thus, you waste microcontroller resources by using floating-point math throughout the conversion process. With careful selection of circuit components, fixed-point math can usually provide, for example, an 8-bit representation (0 to 255) for an input range of 0 to 4V. If you scale the timer/counter by 64, instead of a count of 5700 μsec for an input of 2V, you obtain 89. Then, if you want this 89 to correspond to a half-scale value of 128, the value of K_1 becomes 11,392. A 16-bit unsigned word easily accommodates this value, and you need no floating-point math in the conversion. The accuracy of this ADC is approximately 5% with no adjustments. The resolution is a function of the timer resolution and how tight the code makes the conversion loop. The resolution can be many times the absolute accuracy. Moreover, the converter is monotonic.

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Transistor tester fits into your pocket

Jean-Bernard Guiot, DCS AG, Allschwil, Switzerland

It can be helpful to rapidly and easily determine the polarity (npn or pnp) and function of a transistor. The pocket-transistor tester in **Figure 1** is ideal for quickly testing without regard to such parameters as gain and frequency response. You connect the transistor, or device under test, between the collectors, T, of an astable multivibrator. Thus, the V_{CE} voltage of the device under test is alternately positive and negative. Two LEDs connected in an antiparallel configuration to the device alternately light as long as the device is not conducting. The frequency of the multivibrator is a function of the values of C and R_B. If the device under test conducts in only one direction, then only one LED turns off. If the device conducts in both directions, then both LEDs turn off. You can leave the base of the device unconnected to check for excessive leakage current or short circuits between base and collector or base and emitter. Using the switch, S_1, you can connect the base to the collector to inject current into the base of the device under test. **Table 1** sums up the behavior of the tester.

TABLE 1—TESTING RESULTS

Test	D_1	D_2	S_1	Comments
1	On	Off	Off	Wrong connection? Invert C and B.
2	Off	On	Off	Wrong connection? Invert C and B.
3	Off	Off	Off	Device under test shorted (bad).
4	On	On	Off	Device under test is OK if test 5 or 6 is OK.
5	On	Off	On	Device under test is pnp.
6	Off	On	On	Device under test is npn.

You can also test diodes connected between C and E, FETs, small thyristors, and triacs. You can mount the entire circuit inside a small housing, such as one measuring 20×30×60 mm. You can effect the external connections to the device under test with wires terminated in alligator clips or by using a connector. It is practical and economical to use a five-pole DIN plug with the pinout shown in **Figure 2a**. This pinout allows you to easily connect any transistor, regardless of the arrangement of the CBE connections. **Figure 2b** shows the S_1 switch connections. S_1 is a DPDT switch with three positions:

- Position 1 is On, with no base current (S_1 open).
- Position 2 is Off (middle position).
- Position 3 is On, with base current (S_1 closed).

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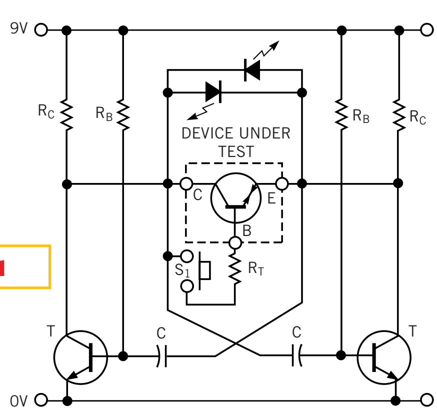
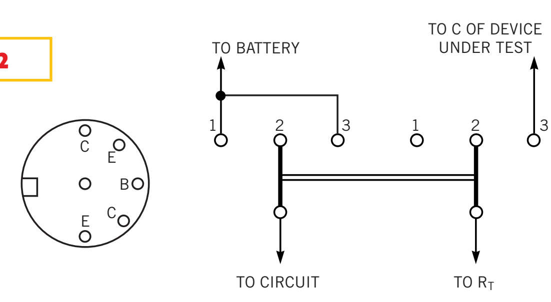
Figure 1



NOTES:
TRANSISTORS (T) ARE BC108, BC547, 2N3904, 2N2222...
CAPACITORS (C) ARE 100 nF.
R_C=470Ω, R_B=39 kΩ AND R_T=3.9 kΩ.
LEDs ARE PREFERABLY RED.

This simple tester allows you to test the polarity and function of a transistor.

Figure 2



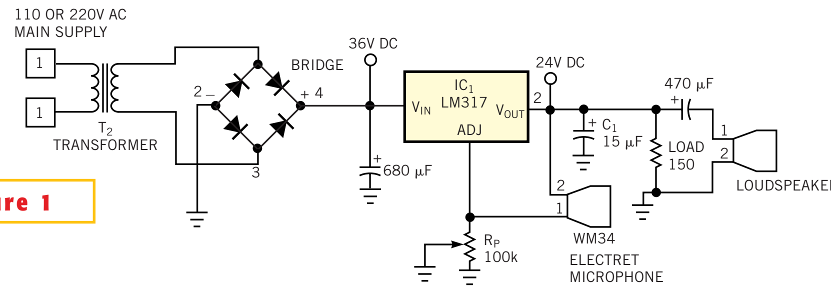
A DIN connector (a) allows you to easily connect transistors; a DPDT switch provides various testing options (b).

Circuit combines power supply and audio amplifier

Susanne Nell, Breitenfurt, Austria

THE CIRCUIT IN **Figure 1** can help if you must transfer dc power and audio over a pair of copper wires. One application for such a circuit is a low-cost door-opening system with speech input. The circuit uses only one IC, the well-known LM317, a low-cost power-supply regulator. Using this chip, you can modulate the adjustment-pin input with the audio signal from an electret condenser microphone, connected between the output and the adjustment terminals of the IC. The LM317 regulates the output in such a way that the voltage on the microphone is always 1.25V dc. This application uses a WM34 electret microphone, which comes in a standard 10-mm capsule from Panasonic and is common in low-cost equipment. You can use nearly any electret capsule, because the well-regulated voltage on the microphone never exceeds 1.25V. Every electret capsule contains an integrated JFET-based impedance converter that translates speech into a current flowing from the source to the drain terminal. This current through the microphone modulates the voltage on the variable resistor, R_P. Because the output of the LM317 must follow the voltage on R_P, you obtain a low-impedance audio signal riding on the output dc voltage.

Figure 1



A novel circuit uses the adjustment pin of a regulator IC to provide audio amplification.

The microphone directly modulates the adjustment pin, so a smoothing capacitor, such as C_1, for noise and hum does not influence the level of the audio signal. C_1 shunts some of the audio signal to ground, but the LM317 compensates for the loss with internal gain. To avoid excessive losses in the LM317, use a capacitor with as low a value as possible. The circuit works well without a capacitor, but values as high as 47 µF do not present a problem. Using R_P, you can adjust the dc output voltage and the gain for the microphone signal. For proper operation, the LM317 needs to deliver a minimum current of 4 mA from its output terminal. If your design uses no loudspeaker, you can connect a load resistor to sink this 4 mA. Designs using low-impedance loudspeakers must also have load resistors. You must add the ac current in the audio signal to the minimum current requirement of 4 mA. For an 8Ω loudspeaker, you need a minimum resistive load of 470Ω to avoid distortion.

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Supply derives 5 and 3.3V from USB port

Chad Olson, Maxim Integrated Products, Sunnyvale, CA

THE CIRCUIT IN **Figure 1** derives its power from a USB port and produces 5 and 3.3V supply rails for portable devices, such as digital cameras, MP3 players, and PDAs. The circuit allows the port to maintain communications while, for example, charging a lithium-ion battery. IC_2 boosts the battery voltage, V_{BATT}, to 5V, and IC_3 buck-regulates that 5V output down to 3.3V. IC_1, a lithium-ion battery charger, draws power from the USB port to charge the battery. Pulling its SELI terminal low sets the charging current to 100 mA for low-power USB ports, and pulling SELI high sets 500 mA for high-power ports. Similarly, pulling SELV high or low configures the chip for charging a 4.2 or 4.1V battery, respectively. To protect the battery, IC_1's final charging voltage has 0.5% accuracy. The $\overline{CHG}$ terminal allows the chip to illuminate an LED during charging.

IC_2 is a step-up dc/dc converter that boosts V_{BATT} to 5V and delivers currents as high as 450 mA. Its low-battery detection circuitry and true shutdown capability protect the lithium-ion battery. By disconnecting the battery from the output, "true shutdown" limits battery current to less than 2 µA. An external resistive divider between V_{BATT} and ground sets the low-battery trip point. Connecting the low-battery output, LBO, to shutdown, SHDN, causes IC_2 to disconnect its load in response to a low battery voltage. The internal source impedance of a lithium-ion battery makes IC_2 susceptible to oscillation when its low-battery-detection circuitry disconnects a low-voltage battery from its load. As the voltage drop across the battery's internal resistance disappears, the battery voltage increases and turns IC_2 back on. For example, a lithium-ion battery with 500-mΩ internal resistance, sourcing 500 mA, has a 250-mV drop across its internal resistance. When IC_2's circuitry disconnects the load, forcing the battery current to zero, the battery voltage immediately increases by 250 mV.

The n-channel FET at LBO eliminates this oscillation by adding hysteresis to the low-battery-detection circuitry. The circuit in **Figure 1** has a low-battery trip voltage of 2.9V. When V_{BATT} drops below 2.9V, LBO opens and allows SHDN to switch high, turning on the FET. With the FET turned on, the parallel combination of 1.3 MΩ and 249 kΩ eliminates oscillation by setting the battery turn-on voltage to 3.3V. The turn-off and turn-on points are according to the following equations:

$$V_{BATT}(TURN-OFF) = V_{LBI} \times \frac{R_1 + R_2}{R_2},$$

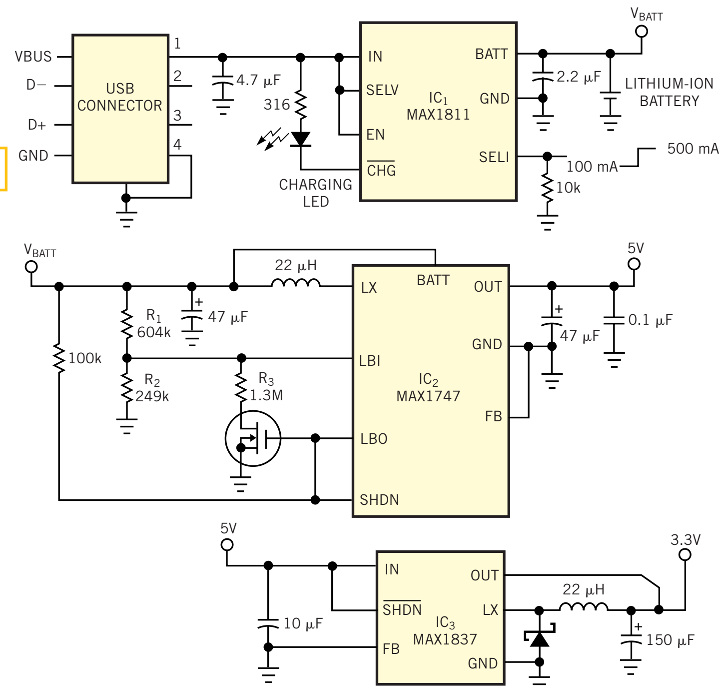
where V_{LBI}=0.85V, and

$$V_{BATT}(TURN-ON) = V_{LBI} \times \frac{R_1 + R_2'}{R_2'},$$

where

$$R_2' = \frac{R_2 R_3}{R_2 + R_3}.$$

Figure 1



Drawing power from a USB port, this circuit generates 5 and 3.3V supply voltages for portable applications.

Finally, a step-down converter, IC_3, provides buck regulation to convert 5V to 3.3V and delivers currents as high as 250 mA with efficiency exceeding 90%.

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