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Nonvolatile digital potentiometer gates logic signal

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This Design Idea describes a simple alternative to a nonvolatile gating function you typically implement using PAL (programmable-array logic), GAL (gate-array logic), or a CPLD (complex-programmable-logic device). To gate a logic signal to block or transmit it, you usually employ a logic gate, such as an AND gate, and use the gate's second input to define whether the gate blocks or transmits the applied signal. Because logic gates perform immediate Boolean operations, their operations are combinational and without memory.

However, if you must program a gate that should always either block or transmit the signal after system start-up, you must store the "transmit/block" logic state in some form of nonvolatile memory. Two basic methods are available for storing such logic states. The first involves using a microcontroller in combination with nonvolatile memory, such as EEPROM. This method is suitable if the system can wait until the microcontroller reads the logic state from memory and applies it to a hardware pin—typically, through a general-purpose I/O pin. Some systems, however, require that the transmit/block signal be present at start-up. For those systems, the read delay from memory is unacceptable.

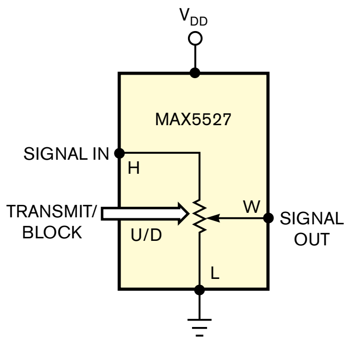

Figure 1 A programmable, nonvolatile digital potentiometer functions as a simple AND gate. Setting the wiper to the device's highest value allows the input signal to propagate to the output; setting the wiper to the lowest value blocks the input signal.

A second method, which is useful for systems without a microcontroller or that cannot wait for the microcontroller to read from memory at boot time, stores the logic state in a device that makes it immediately available at power-up. For this purpose, PAL devices, GAL devices, and CPLDs implement the gating function in combination with programmable nonvolatile memory. These devices offer more than gating with memory, however, and may be overspecified for systems that need only a few such gates. Also, their packages are relatively large to accommodate the many logic-I/O pins they offer.

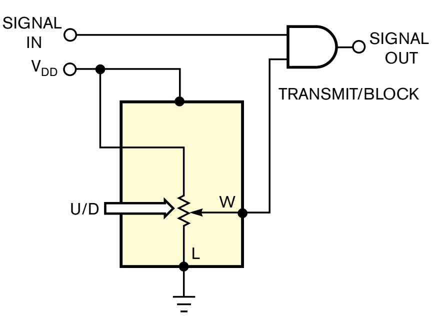

Figure 2 If the bandwidth of the digital potentiometer is too low, you can use the device to drive an AND gate.

If you need only a few nonvolatile gates, consider using a component common in analog- and mixed-signal systems: the digital potentiometer (**Figure 1**). Ground the L end of the resistor string and route the signal into the H end of the string. Then, the wiper output either shorts to ground for blocking or connects to the input signal for transmission.

You can program the digital potentiometer through its serial interface during board or system test. The up/down interface on some digital potentiometers is suitable for that purpose. When selecting a nonvolatile digital potentiometer, you should consider the following criteria:

- Digital potentiometers typically have 32 or more taps; you need at least two. A digital-potentiometer wiper has a resistance associated with the internal switches and should be as small as possible to avoid distorting the switching signal. A typical wiper resistance is 100Ω to 1 kΩ. For the MAX5527 from Maxim (www.maxim-ic.com), wiper resistance measures 90Ω.

- Because the resistance of a digital-potentiometer wiper decreases with increasing supply voltage, you should select a high supply voltage.
- To minimize loading on the signal source and not limit the potentiometer's signal bandwidth, you should select a device with a high end-to-end resistance; 100 kΩ is acceptable for many applications.
- Select a nonvolatile digital potentiometer if you must program the gate's state in nonvolatile memory. Some digital potentiometers are OTP (one-time-programmable); this feature allows you to save the wiper's setting. Using the OTP feature is suitable when you don't expect to make changes in the gating function. The number of gates for which the state must be stored determines the number of potentiometers you need. They are available in arrays of one to six or more per package.

The digital potentiometer's bandwidth determines the maximum data rate for signals transmitted through the potentiometer. If the switching rate of these applied logic signals is too high for the available potentiometers, you can use a conventional, high-speed logic gate with a digital potentiometer controlling the transmit/block input (**Figure 2**).EDN

Soft-limiter circuit forms basis of simple AM modulator

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One of the most popular circuits for amplitude control in oscillators is the soft-limiter circuit (**Figure 1a**). When the output voltage, $V_{OUT}(t)$, is small, diodes D_1 and D_2 are off. Thus, all of the input current, $V_{IN}(t)/R_1$, flows through the feedback resistor, R_2, and the output voltage is:

$$V_{OUT}(t) = -\frac{R_2}{R_1} V_{IN}(t).$$

This portion is the linear part of the limiter-transfer characteristic in **Figure 1b** with slope of $-(R_2/R_1)$.

On the other hand, when $V_{OUT}(t)$ goes positive, V_A becomes more positive, thus keeping D_1 off; however, V_B becomes less negative. Then, if you continue to decrease $V_{IN}(t)$, you will reach a positive value of the output voltage, at which V_B becomes approximately 0.7V, and diode D_2 conducts. Thus, the positive-limiting value at the output, V_{L+}, is:

$$V_{L+} = \frac{R_6}{R_5} V_{REF} + \left(1 + \frac{R_6}{R_5}\right) V_\gamma,$$

where V_γ is the forward voltage of the diodes—approximately 0.7V. If $V_{IN}(t)$ decreases beyond this value, $V_{OUT}(t)$ will increase, more current is injected into diode D_2, and V_B remains at approximately $-V_\gamma$. Thus, the current through R_5 remains constant, and the additional diode current flows through R_6. Therefore, R_6 appears, in effect, in parallel with feedback resistor R_2, and the incremental gain, A_V, ignoring the diode's resistance, in the positive-limiting region is:

$$A_V = -\frac{R_2 \| R_6}{R_1}.$$

Note that, to make the slope of the transfer characteristic small in the limiting region, you should select a low value for R_6. You can derive the transfer characteristic for positive $V_{IN}(t)$ or negative $V_{OUT}(t)$ in a manner identical to that of the above description. You can easily see that, for a positive $V_{IN}(t)$, diode D_1 plays an identical role to the one that diode D_2 plays for negative $V_{IN}(t)$. So, the negative-limiting level, V_{L-}, is:

$$V_{L-} = -\left[\frac{R_4}{R_3} V_{REF} + \left(1 + \frac{R_4}{R_3}\right) V_\gamma\right],$$

and the slope of the transfer characteristic in the negative-limiting region is:

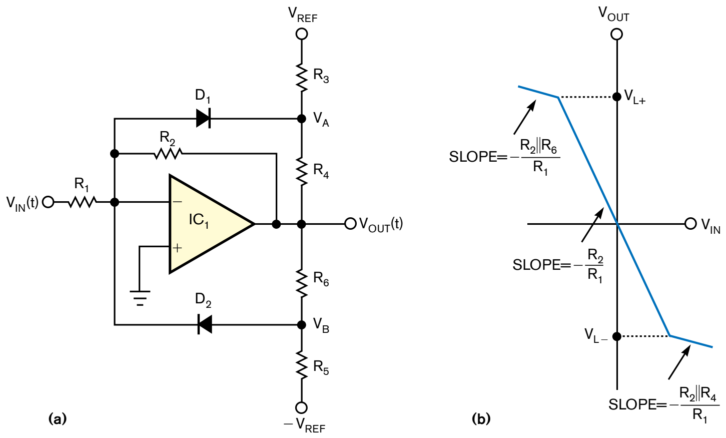

Figure 1 Diodes in the feedback circuit form the basis of this soft limiter (a). The transfer characteristic of the limiter circuit shows inflection points when the diodes begin to conduct (b).

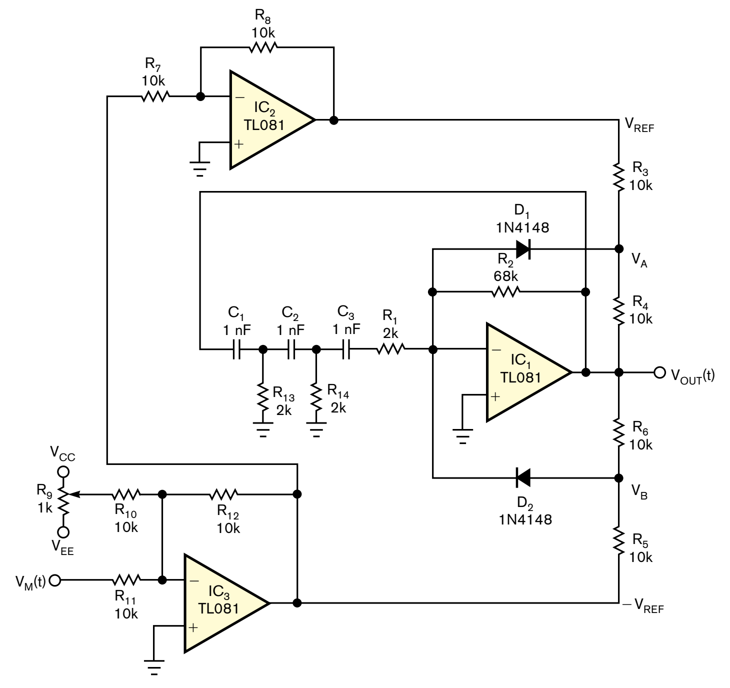

Figure 2 Inserting the soft limiter into the feedback loop of a phase-shift oscillator enables a simple AM modulator.

$$A_V=-\frac{R_2\|R_4}{R_1}.$$

Note that increasing R_2 results in a higher gain in the linear region and keeps V_{L+} and V_{L-} unchanged. When you remove R_2, the soft limiter turns into a comparator.

Thus, the circuit of **Figure 1a** functions as a soft limiter, and you can independently adjust the limiting levels V_{L+} and V_{L-} by selecting the appropriate resistor values and reference voltages, $\pm V_{REF}$. Therefore, you can use a control voltage to change these limiting levels. You can base a simple AM modulator on this configuration. The RC (resistance/capacitance) phase-shift oscillator in **Figure 2** includes a soft limiter in its voltage amplifier. You can alternatively use any similar RC or LC (inductance/capacitance) oscillator. You can modify the reference voltages, V_{REF} and $-V_{REF}$, with the input modulating voltage, $V_M(t)$. This voltage dynamically adjusts the saturation levels of the oscillator's output. The ratio of the limiter resistors determines the output amplitude and the modulation index.

Figure 3 shows the waveforms of the modulating input, $V_M(t)$, and the oscillator's modulated output, $V_{OUT}(t)$, with the component values of **Figure 2**. In this case, $V_M(t)$ is a sinusoidal waveform with an amplitude equal to 3V, and trimmer R_9 adds a 5V offset voltage. The circuit works in a similar way to a four-quadrant analog multiplier.**EDN**

REFERENCE

[1] Sedra, Adel S, and Kenneth C Smith, *Microelectronic Circuits: Fourth Edition*, ISBN 0-19-511663-1, 1998, Oxford University Press, New York.

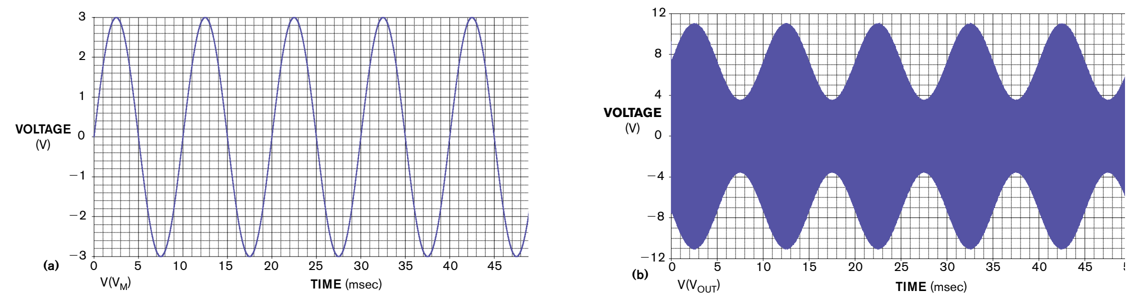

Figure 3 The modulating input, $V_M(t)$ to the circuit in Figure 2 (a) obtains the modulated output voltage, $V_{OUT}(t)$ (b).

Circuits monitor and balance large lithium-ion batteries

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When using rechargeable lithium-ion cells in large batteries, such as those in an electric vehicle, you encounter unique problems. Bus voltages greater than 100V preclude the use of a standard IC for overcharge and overdischarge protection. In addition, because many cells connect in series, small differences in cells' self-discharge rates eventually lead to unequal levels of charge. Therefore, you must correct the cell balance. This Design Idea provides one strategy for protecting and balancing large, high-voltage batteries. The circuit in **Figure 1** monitors

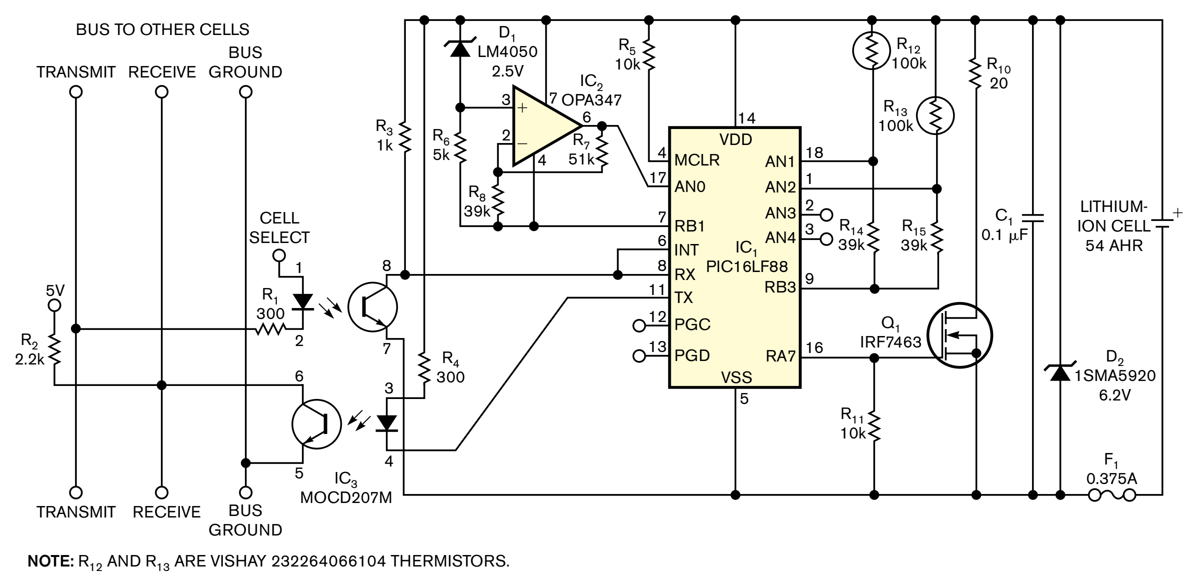

Figure 1 A microcontroller connects directly to a lithium-ion cell and a battery string to monitor the cell's voltage and temperature. This process shunts current through R_{10} under program control to equalize the cell's self-discharge. Each cell in the battery gets its own monitor. The monitors communicate with a controller through optoisolators.

the voltage of a single lithium-ion cell that connects in series in a battery. The circuit communicates with a supervisor processor. The supervisor monitors all cells in the battery, opens a protection switch in case of a problem, and determines where and when balancing is necessary. This approach easily scales to an arbitrarily high bus voltage.

A PIC16LF88 microcontroller gets power directly from the cell voltage, which ranges from 3 to 4.2V. With no need for voltage regulation, the quiescent current of the entire circuit is less than 1 µA, minimizing self-discharge of the battery. Fuse F_1 and zener D_2 protect the monitor from high voltage in the unlikely event that the cell becomes disconnected from the battery. An optocoupler connects between the cell monitor and an asynchronous serial bus, running at 9600 baud. A cell-select line, driven by the supervisor, selects one cell at a time. The MOCD207M optocoupler has a tightly toleranced current-transfer ratio, so it operates predictably over the possible range of supply voltages. Although the quiescent current of this isolator is near zero, the supervisor can wake up the monitor from sleep at any time by sending a pulse over the serial line.

The monitor measures cell voltage by measuring the fixed voltage of the LM4050 with respect to the unknown supply. Op amp IC_2 scales the signal to achieve 3-mV resolution using the microcontroller's built-in 10-bit ADC. The reference, op amp, and gain error introduce voltage offsets, which you can calibrate in software. The remaining error arises from temperature variation of these parameters. R_7 and R_8 use a temperature coefficient of 25 ppm/°C. The resulting accuracy of the voltmeter is ±7.5 mV over 0 to 50°C. By biasing the reference from a digital output, the voltmeter draws current only when necessary. The same trick biases several thermistors, which measure the temperature of the monitored cell.

This cell monitor can balance an overcharged cell by shunting 200 mA through R_2. Although the shunt current is smaller than the battery's maximum discharge current of 12A, it is more than enough current to balance the differential self-discharge of series-connected cells.EDN

White-LED driver operates down to 1.2V supply voltage

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Many LED drivers, using both charge pumps and inductors, are available to boost the 1.2 to 2.4V available from single- and dual-cell NiMH (nickel-metal-hydride) batteries to the 3.6V that white LEDs require. However, most of these circuits, such as the Maxim (www.maxim-ic.com) MAX1595, require a minimum input voltage of approximately 2.5V to operate properly. The MAX1595 works with an input voltage of 2.4V but does not ensure an adequate output until the input voltage reaches approximately 3V. Furthermore, as the battery voltage decreases to the threshold level, the output becomes erratic. The circuit in **Figure 1** uses a flip-flop to generate flux in an inductor, which then charges a capacitor in the common boost configuration. US Patent 4,068,149 describes the flip-flop's operation in an application for operating an incandescent safety lamp's flasher (**Reference 1**).

In **Figure 1**, R_1 provides a path for starting current through the base-emitter junctions of Q_1 and Q_2. Q_2 thus turns on and, in so doing, turns on Q_1, rapidly forcing both transistors into saturation. However, C_1 charges through R_2 to the battery voltage minus the base-emitter drop of Q_1 and the saturated collector-emitter voltage of Q_2, eventually causing Q_1 to turn off and thereby also turning off Q_2. C_1 then discharges through R_1 and R_2 and the forward-biased base-collector junction of Q_2. The R_2C_1 time constant determines the turn-on time, and $(R_1+R_2)(C_2)$ determines the turn-off time. C_2 acts as the capacitive input filter for the current flowing from L_1 when Q_2 is off and provides a substantially constant voltage to power D_2, a standard white LED.

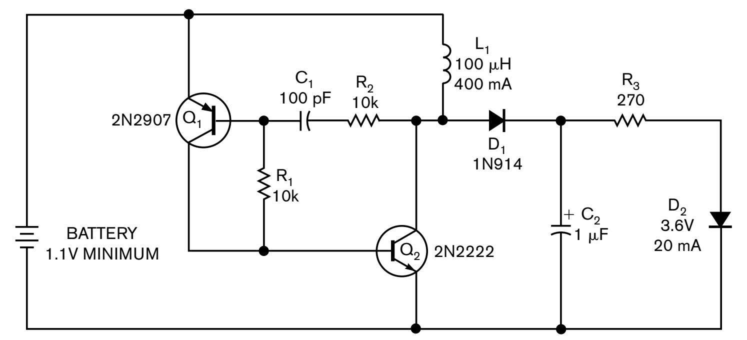

Figure 1 In this circuit, transistors Q_1 and Q_2 form a flip-flop that toggles at 60 kHz, providing a drive current for the output LED down to the 1V battery voltage.

The output voltage is proportional to the battery voltage.

With the component values in **Figure 1** and with L_1, a Coilcraft (www.coilcraft.com) MSS7341-104MLB, the operating frequency is approximately 60 kHz. With a battery voltage of 2.36V from two NiMH cells, approximately 20 mA of current flows through the LED. In tests simultaneously driving two LEDs, each with its own current-limiting resistor, R_3, the energy-conversion efficiency of the circuit at this battery voltage is approximately 80%. Operation continues with battery voltages of slightly more than 1V, and the delivered current diminishes but still provides usable illumination.**EDN**

REFERENCE

1 Wuchinich, David G, "Flasher circuit with low power drain," US Patent 4,068,149, Oct 28, 1975, http://patft.uspto.gov.