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## Linear-brightness controller for LEDs has 64 taps

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Applications that include LEDs but no microcontroller or other form of control intelligence can benefit from a simple circuit that provides manual control of the LEDs' light intensity. Among the devices suitable for this purpose are mechanical (analog) and electronic (digital) potentiometers. The digital potentiometer with up and down pushbuttons, an alternative to the mechanical potentiometer, is smaller, more reliable, and usually less expensive (**Figure 1**).

IC<sub>1</sub>, a current regulator, drives a chain of LEDs with current as high as 200 mA. In a standard application circuit, IC<sub>2</sub>'s internal regulator senses the drop across current-sense resistor R<sub>SENSE</sub> in series with the LED chain. Thus, IC<sub>2</sub> controls current through the chain by regulating voltage at the differential inputs, CS<sup>-</sup> and CS<sup>+</sup>, to the set value of 204 mV. Resistors R<sub>A</sub> and R<sub>B</sub> allow the output voltage IC<sub>1</sub>'s Pin 6 to adjust the current level. IC<sub>1</sub> is a 64-tap linear digital potentiometer whose resistance connects between ground and V<sub>5</sub>, a well-regulated voltage that IC<sub>2</sub> internally generates. You manually adjust the RW control voltage (Pin 6), a fraction of V<sub>5</sub>, using the up and down pushbuttons. A few assumptions allow a quick and simplified calculation of the neces-

sary resistor values. Initially, you fix R<sub>A</sub> and then calculate R<sub>B</sub> and R<sub>SENSE</sub>. The assumptions are that you can neglect the maximum 6.93-μA error induced by the bias current at CS<sup>+</sup>; that the value you choose for R<sub>A</sub> is much higher than IC<sub>1</sub>'s equivalent resistance, for which the worst-case value at position 32 (top and bottom resistances plus the wiper series resistance) is 2.9 kΩ; and that R<sub>SENSE</sub> is much less than R<sub>B</sub>.

After setting R<sub>A</sub> at 25.5 kΩ,  $V_{WIPER} = (5V/63) \times N$ , where N is the wiper setting (0 to 63). Then, you solve the equation  $(V_{WIPER} - 0.204V) / R_A = (0.204V - I_{LED} \times R_{SENSE}) / R_B$ . Solve the above equation for R<sub>B</sub> under the conditions for which I<sub>LED</sub> = 0, which are N = 63 and V<sub>WIPER</sub> = 5V (top position): R<sub>B</sub> = 25.5 kΩ × 0.204V / (5V × 0.204V) = 1.085 kΩ. You can choose R<sub>B</sub> from the standard values of 1.07 kΩ (1% series)

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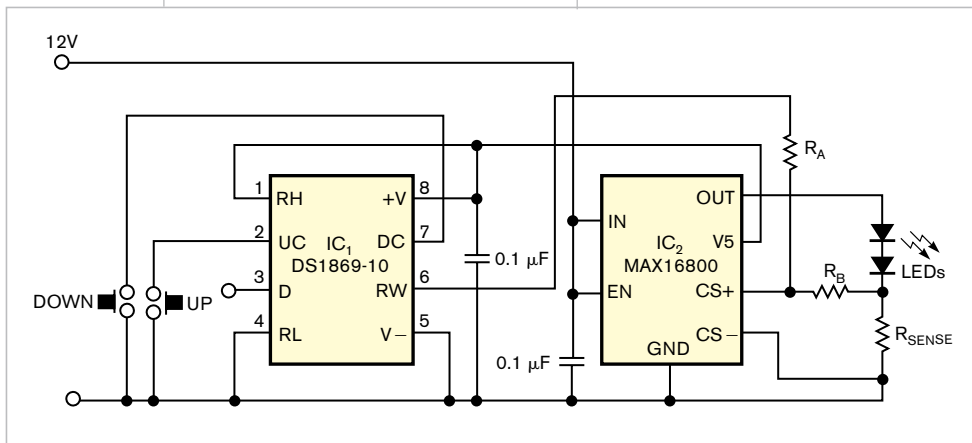
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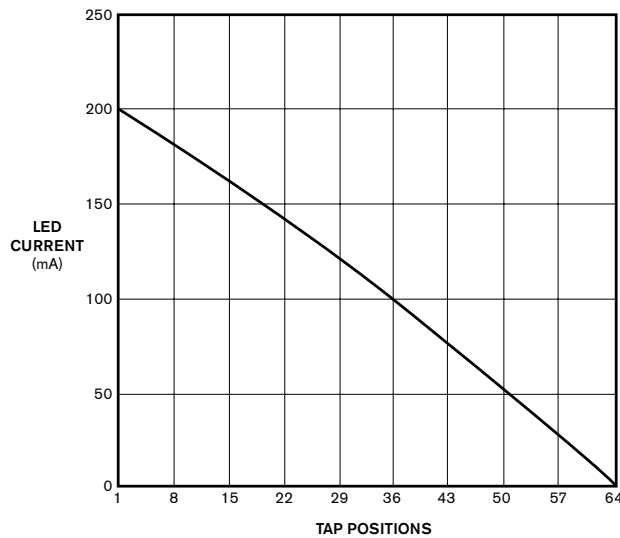
or 1.1 kΩ (5% series). At the bottom position, where V<sub>WIPER</sub> = 0 and LED current is the maximum of 200 mA, brightness should be the maximum available. Solving for R<sub>SENSE</sub>,  $R_{SENSE} = [0.204V + (0.204V \times (1.085 / 25.5))] / 0.2A = 1.063\Omega$ ; 1.07Ω is a standard value in the 1% series.

A graph of LED current versus tap position shows a slight nonlinearity



**Figure 1** This brightness-control circuit lets you manually adjust the LED brightness using the up and down buttons.

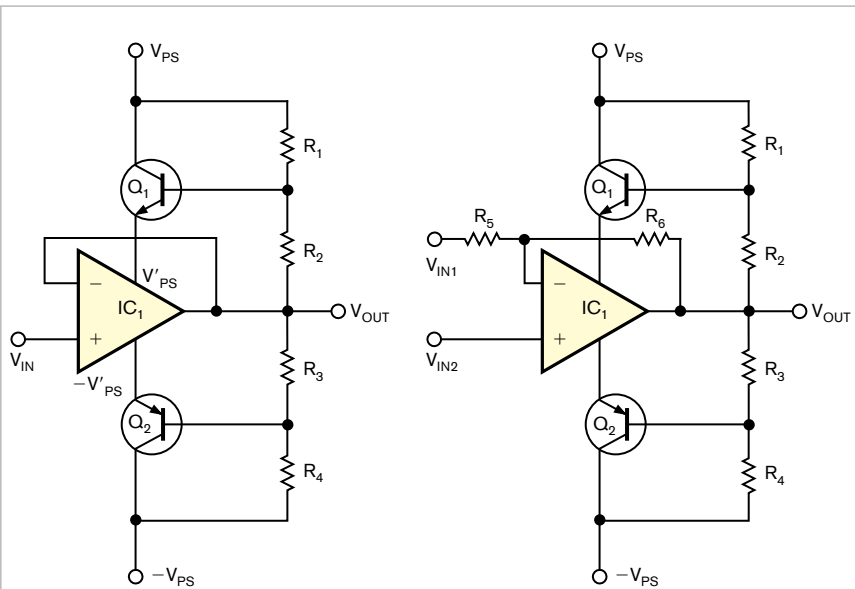
because of the variation in resistance you see looking into the wiper at different tap positions (**Figure 2**). At the extreme ends of the potentiometer, you see only the  $400\Omega$  wiper resistance. As the wiper moves toward midpoint, the resistance increases toward a maximum of one-quarter of the end-to-end resistance value. Because  $IC_1$  is a  $10\text{-k}\Omega$  potentiometer, the resistance the wiper sees at midpoint is about  $2.5\text{ k}\Omega$  in series with  $R_{WIPER}$ . This variation introduces a maximum linearity error of 8%, which is negligible in most LED applications.  $IC_2$  offers thermal protection against excessive heat and overload conditions. For effective power dissipation and to avoid thermal cycling, you must connect the exposed pad of the package to a large-area ground plane. **EDN**



**Figure 2** A plot of LED current versus tap position in Figure 1 exhibits only a slight nonlinearity.

## Controlled power supply increases op amps' output-voltage range

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**Figure 1** These simple circuits present the general methods of connecting the amplifier as an inverter or a follower to effect increased output voltage.

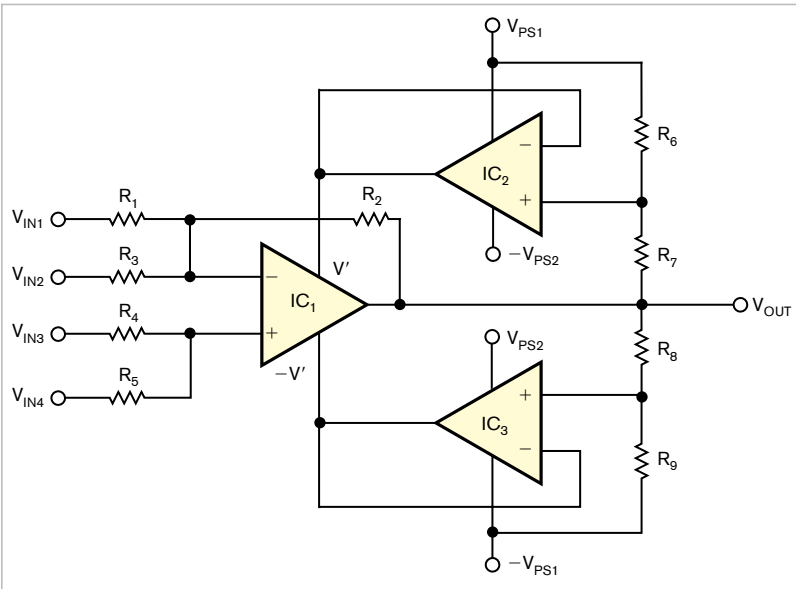
Increasing the output voltage of IC operational amplifiers usually involves adding high-voltage external transistors. The resulting circuit then requires correction to retain its operating characteristics. This correction is difficult, especially for precise amplifiers. This Design Idea presents an alternative: the use of a controlled power supply for the operational amplifier itself, which can increase the output voltage for many precise operational amplifiers without altering their operational characteristics. You can accomplish this task by connecting controlled transistors to the power supply of the amplifier. Resistor dividers that connect to the amplifier's output and bipolar high voltages control these transistors (**Reference 1**). The simple circuits in **Figure 1** present general methods of connecting the amplifier as an inverter or a follower to effect increased output voltage.

Dividers with resistors  $R_1$ ,  $R_2$ ,  $R_3$ , and  $R_4$  determine the scale of power supply  $V'_{PS}$  and  $-V'_{PS}$  for the amplifiers. If the output voltage ranges from  $\pm 22\text{V}$ ,

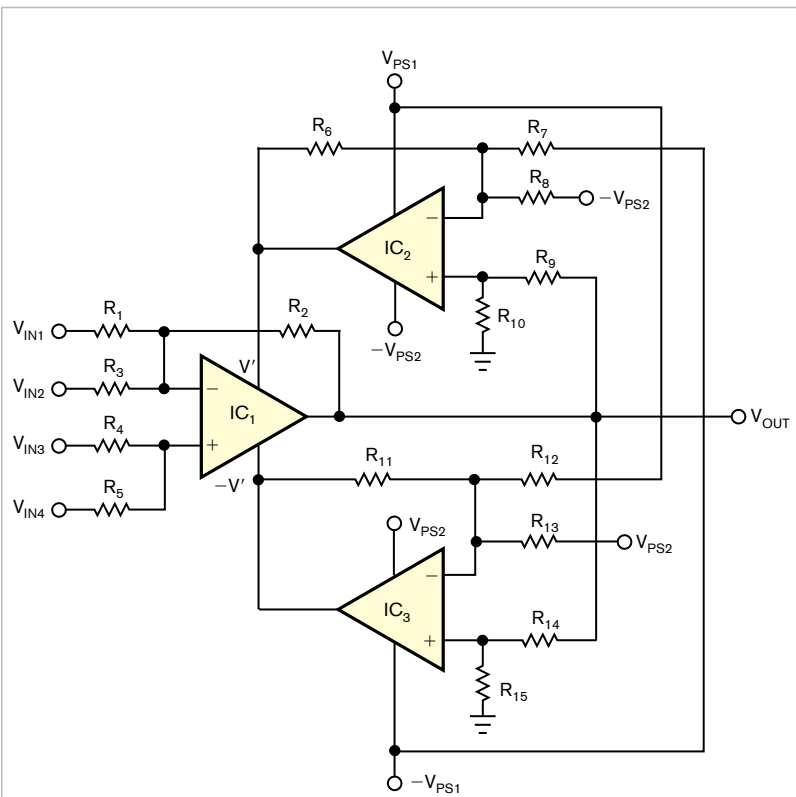
resistor  $R_1=R_2=R_3=R_4=R$ , and  $V_{PS}$  and  $-V_{PS}$  are 28V, then voltages  $V'_{PS}$  and  $-V'_{PS}$  fall in the following range, allowing for any additional loss:  $V'_{PS} = V_{PS}R_7/(R_1+R_2) + V_{OUT}(-V_{OUT})R_7/(R_1+R_2)$ , and  $-V'_{PS} = -V_{PS}R_3/(R_3+R_4) + V_{OUT}(-V_{OUT})R_4/(R_3+R_4)$  or  $3V < V'_{PS} < 25V$  and  $-3V > -V'_{PS} > -25V$ . However, power-supply circuits include transistors, which create junction resistance, affecting the amplifier's operation.

You can use supporting amplifiers to reduce losses and increase the quality of the output voltage of the primary amplifier. The requirements for supporting amplifiers are simple. They should have power supplies with opposite polarity from and lower applied voltage than that of the main power supply. They should provide the necessary power to the primary amplifier, and their frequency range should be slightly higher than that of the primary amplifier. You can use supporting amplifiers to eliminate the transitional resistances of transistors in power-supply connections. Thus, these circuits offer flexibility across a range of amplifier configurations (references 2 and 3).

**Figure 2** shows an example of how to connect supporting amplifiers as follows. You derive output voltages  $V'_{PS}$  and  $-V'_{PS}$  from resistor connections with the following equations:  $V' = V_{PS1}R_7/(R_6+R_7) + V_{OUT}(-V_{OUT})R_7/(R_6+R_7)$ , and  $-V' = -V_{PS1}R_8/(R_8+R_9) + V_{OUT}(-V_{OUT})R_9/(R_8+R_9)$ . If the supporting amplifiers have a power supply of 28V for  $V_{PS1}$  and  $-2V$  for  $-V_{PS2}$  for amplifier  $IC_2$ , then  $-V_{PS1} = -28V$ ,  $V_{PS2} = 2V$  for amplifier  $IC_3$ , and the output voltage of amplifier  $IC_1$ ,  $V_{OUT}$ , is 24V or  $-24V$ . Also,  $R_6=R_7=R_8=R_9=R$ , such that  $V' = 28V \times 0.5 + 24V \times 0.5 = 26V$ . Further,  $-V' = -28V \times 0.5 + 24V \times 0.5 = -2V$  for  $V_{OUTMAX} = 24V$ .  $V = 28V \times 0.5 - 24V \times 0.5 = 2V$ , and  $-V' = -28V \times 0.5 - 24V \times 0.5 = -26V$  for  $V_{OUTMIN} = -24V$ . You can achieve the greatest voltage range by using separate power supplies—one for the normal voltages of the amplifier and one for the regulated part of the output voltage (**Figure 3**).



**Figure 2** Replacing the transistors with op amps reduces losses and increases the quality of the output voltage of the primary amplifier.



**Figure 3** You can achieve the greatest voltage range by using separate power supplies—one for the normal voltages of the amplifier and one for the regulated part of the output voltage.

IC<sub>1</sub> is the primary amplifier. Supporting amplifiers IC<sub>2</sub> and IC<sub>3</sub> have asymmetrical power supplies. You could use many types of amplifiers in this circuit, but modern operational amplifiers may be preferable because they allow the use of the complete range of the power supply and because they handle rail-to-rail input and output. In this circuit, V<sub>PS1</sub> = 28V, -V<sub>PS1</sub> = -28V, V<sub>PS2</sub> = 2V, and -V<sub>PS2</sub> = -2V. The voltages of the primary amplifier are V' = -(-V<sub>PS1</sub>)R<sub>6</sub>/R<sub>7</sub> - (-V<sub>PS2</sub>)R<sub>6</sub>/R<sub>8</sub> + (-V<sub>OUT</sub>)R<sub>10</sub>/[(R<sub>9</sub> + R<sub>10</sub>)] [R<sub>7</sub>R<sub>8</sub> + R<sub>6</sub>(R<sub>7</sub> + R<sub>8</sub>)]/R<sub>7</sub>R<sub>8</sub>. Further, -V' = -(V<sub>PS1</sub>)R<sub>11</sub>/R<sub>12</sub> - (V<sub>PS2</sub>)R<sub>11</sub>/R<sub>13</sub> + (-V<sub>OUT</sub>)R<sub>15</sub>/

(R<sub>14</sub> + R<sub>15</sub>)[R<sub>12</sub>R<sub>13</sub> + R<sub>11</sub>(R<sub>12</sub> + R<sub>13</sub>)]/R<sub>12</sub>R<sub>13</sub>. Set R<sub>6</sub> = R<sub>10</sub> = R<sub>11</sub> = R<sub>15</sub> = R, R<sub>7</sub> = R<sub>8</sub> = R<sub>12</sub> = R<sub>13</sub> = 2R, and R<sub>9</sub> = R<sub>14</sub> = 3R, such that R<sub>6</sub>/R<sub>7</sub> = R<sub>6</sub>/R<sub>8</sub> = R<sub>11</sub>/R<sub>12</sub> = R<sub>11</sub>/R<sub>13</sub> = 0.5, R<sub>10</sub>/[(R<sub>9</sub> + R<sub>10</sub>)] = R<sub>15</sub>/[(R<sub>14</sub> + R<sub>15</sub>)] = 0.25, and [R<sub>7</sub>R<sub>8</sub> + R<sub>6</sub>(R<sub>7</sub> + R<sub>8</sub>)]/R<sub>7</sub>R<sub>8</sub> = [R<sub>12</sub>R<sub>13</sub> + R<sub>11</sub>(R<sub>12</sub> + R<sub>13</sub>)]/R<sub>12</sub>R<sub>13</sub> = 2. Then, substitute these values into the amplifier voltages yields V' = 14V + 1V + (-V<sub>OUT</sub>)0.5, and -V' = -14V - 1V + (-V<sub>OUT</sub>)0.5. Minimum and maximum values for each power supply are 1.5V ≤ V ≤ 28.5V, and -1.5V ≥ -V ≥ -28.5V. The total voltage of the power supply has a limit of 30V, ranging from 1.5 to 28.5V and from -1.5 to -28.5V. This range

permits an increase of the output voltage of the primary amplifier by ±27V. EDN

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## Single-IC-based electronic circuit replaces mechanical switch

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A simple and inexpensive electronic circuit uses a low-cost pushbutton switch to toggle the electrical power on and off. The circuit replaces a more costly and bulky push-push mechanical switch. The pushbutton switch triggers a monoshot circuit. The monoshot circuit's

output triggers a toggle flip-flop, which inverts its output state and controls power to the load.

Several implementations of the scheme are possible. Figure 1 shows a single-IC implementation. The circuit uses two flip-flops, IC<sub>1</sub> and IC<sub>2</sub>, in the same IC, CD4027B. You con-

figure IC<sub>1</sub> as a monoshot circuit by feeding its output back to its reset pin through an RC network. IC<sub>1</sub> outputs a high on the rising edge of the clock by tying its J input high and its K input low. The pushbutton switch connects between the clock input of IC<sub>1</sub> and ground. The switch can also connect between the clock input and the positive supply, V<sub>DD</sub>. By tying IC<sub>2</sub>'s J and K inputs high, IC<sub>2</sub> becomes a toggle flip-flop. The output of IC<sub>1</sub> clocks IC<sub>2</sub> and toggles its output on the rising edge of the IC<sub>1</sub> output.

You can understand the operation of the circuit by observing the waveform at different points of the circuit (Figure 2). When you press the pushbutton switch, due to debouncing, IC<sub>1</sub>'s output goes high on the clock's rising edge. Capacitor C<sub>1</sub> starts charging through R<sub>1</sub> toward high voltage. At the same instant, IC<sub>2</sub> receives a rising-edge transition at its clock and toggles its output. When capacitor C<sub>1</sub>'s voltage exceeds the threshold of the IC<sub>1</sub> reset pin, IC<sub>1</sub> resets, and its output goes low. C<sub>1</sub> now discharges through R<sub>1</sub> to low voltage. The charging and discharging rate of C<sub>1</sub> are equal. The duration of the monoshot circuit's output pulse handles the switch-press time and the debouncing period. Varying

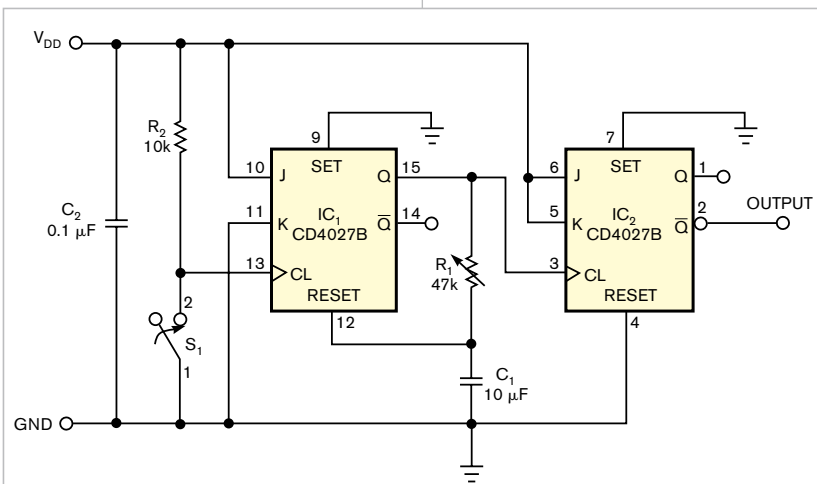
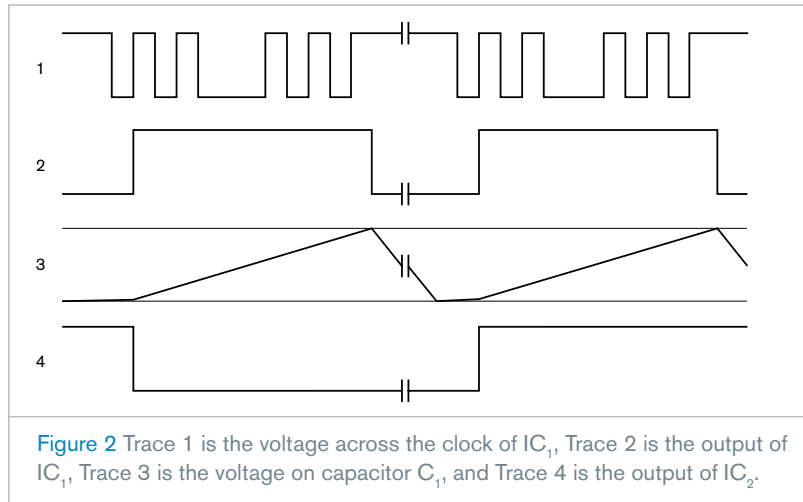


Figure 1 A pair of flip-flops configured as a monoshot and a toggle flip-flop debounce a simple, inexpensive pushbutton switch.

the value of  $R_1$  varies the pulse period, and you can set  $R_1$  for different types of pushbutton switches. Complementary outputs of  $IC_2$  are available, and you can use them to drive power switches, such as transistors, MOSFETs, relays, and shutdown pins of switching regulators. The circuit operates over a supply voltage of 3 to 15V and can control power to analog and digital circuits. **EDN**

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**Figure 2** Trace 1 is the voltage across the clock of  $IC_1$ , Trace 2 is the output of  $IC_1$ , Trace 3 is the voltage on capacitor  $C_1$ , and Trace 4 is the output of  $IC_2$ .

## Microcontroller drives H bridge to power a permanent-magnet dc motor

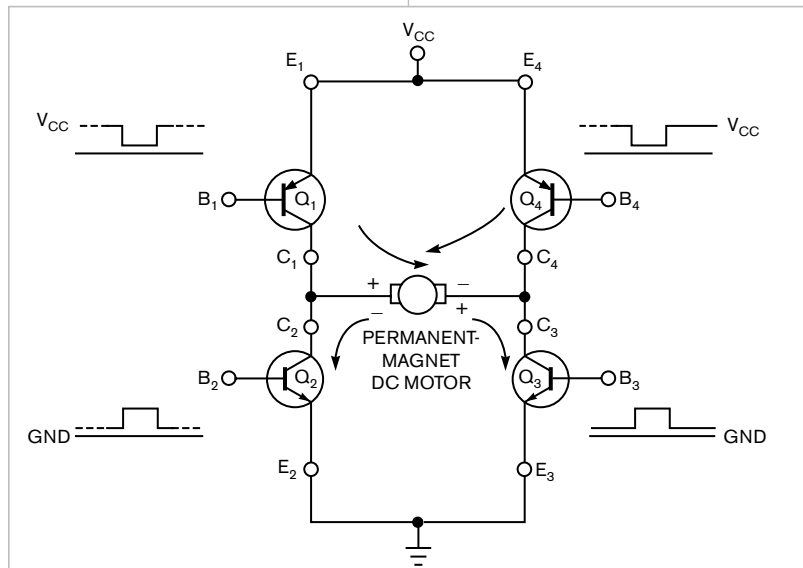
Luca Bruno, ITIS HenseMBERger Monza, Lissone, Italy

 A traditional method of driving a low- to medium-power permanent-magnet dc motor involves using four MOSFET or bipolar transistors in an H-bridge configuration. For example, in **Figure 1**, the motor connects between collector pairs  $C_1$  and  $C_2$  and  $C_3$  and  $C_4$ . Turning on diagonally opposite transistor pairs  $Q_1$  and  $Q_3$  or  $Q_2$  and  $Q_4$  steers current through the motor and allows for reversal of its direction. However, this method requires that each of the four transistors receive its own control input. Depending on the motor's voltage requirements, the upper two drive signals may require electrical isolation or a level-shifter circuit to match the microcontroller's output-voltage limitations.

This Design Idea describes an alternative circuit that drives only the H bridge's two low-side switching transistors. In a standard bipolar-transistor H bridge for bidirectional motor control,  $Q_1$ 's and  $Q_4$ 's bases connect to  $Q_3$ 's and  $Q_2$ 's collectors through resistors  $R_3$  and  $R_4$  (**Figure 2**). Inputs  $V_{INA}$  and  $V_{INB}$  each control a pair of switches. When  $Q_2$  turns on, resistor  $R_4$  and diode  $D_6$  pull  $Q_4$ 's base low, saturating  $Q_4$  and

pulling current through the motor and  $Q_2$ . Similarly, turning on  $Q_3$  pulls  $Q_1$  into saturation and drives the motor in the opposite direction. Diode  $D_5$  ensures that  $Q_1$  remains off when  $Q_4$  conducts, and  $D_6$  performs the same function for  $Q_4$  when  $Q_1$  conducts. Resistors

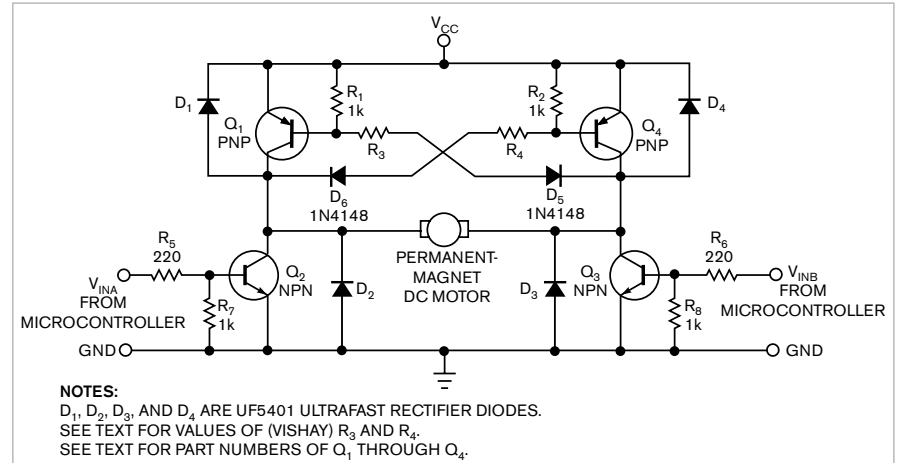
$R_1$ ,  $R_2$ ,  $R_7$ , and  $R_8$  increase the switching speed of their associated transistors, and resistors  $R_5$  and  $R_6$  limit base-current drain from the microcontroller's 5V high-logic-level outputs to approximately 15 to 20 mA. Resistors  $R_3$  and  $R_4$  set  $Q_1$ 's and  $Q_4$ 's saturation base currents. Their value depends on the motor-supply voltage and  $Q_1$ 's and  $Q_4$ 's dc current-gain according to the following equation:  $R_3 = R_4 \leq [(V_{CC} - V_{BE(ON)}(Q_4) - V_F(D_6) - V_{CE(SAT)}(Q_2)) / (I_{MOTOR} / (continued on pg 82))]$



**Figure 1** In an H-bridge output-driver stage, diagonally opposed transistor pairs conduct to energize a dc motor. The circuit requires four control signals.

$h_{FE(MIN)}(Q_4)$ ]. For best performance, select bipolar-junction transistors with low collector-emitter saturation voltages,  $V_{CE(SAT)}$ , and high values of dc-current gain,  $h_{FE}$ . Currently available medium-power transistors compete favorably with MOSFETs by offering these characteristics in combinations that minimize collector-power dissipation and require little base drive.

Discrete devices such as On Semiconductor's ([www.onsemi.com](http://www.onsemi.com)) NS-S40200LT1G PNP and NST489AMT1 NPN bipolar transistors work well in the circuit in **Figure 1**. For a more compact implementation, you can select an integrated H bridge, such as Zetex's ([www.zetex.com](http://www.zetex.com)) ZHB6790, which operates at power-supply voltages as high as 40V, with 2A continuous and 6A peak pulse-current collector ratings. Its minimum current gain of 500 at a collector current,  $I_C$ , of 100 mA can decrease to 150 at  $I_C$  of 2A. At a worst-case collector current of 2A in  $Q_2$  and  $Q_3$ , achieving a saturation voltage of 0.35V or less requires a



**Figure 2** This improved H-bridge-driver circuit uses transistors in complementary pairs and requires only two low-level control signals.

base current of 13 to 20 mA. Fortunately, many microcontrollers' outputs can source or sink as much as 25 mA and thus directly drive the H bridge independently of the motor's power-supply voltage. To further reduce drive current or to use a standard CMOS or TTL IC as a drive source, you can buffer  $Q_2$ 's and

$Q_3$ 's inputs with small-signal transistor inverters. As an option, you can connect fractional-ohm resistors between the emitters of  $Q_2$  and  $Q_3$  and ground. This approach can provide analog voltages proportional to motor current, allowing the microcontroller to detect a stalled or overloaded motor. **EDN**