EDITED BY BRAD THOMPSON
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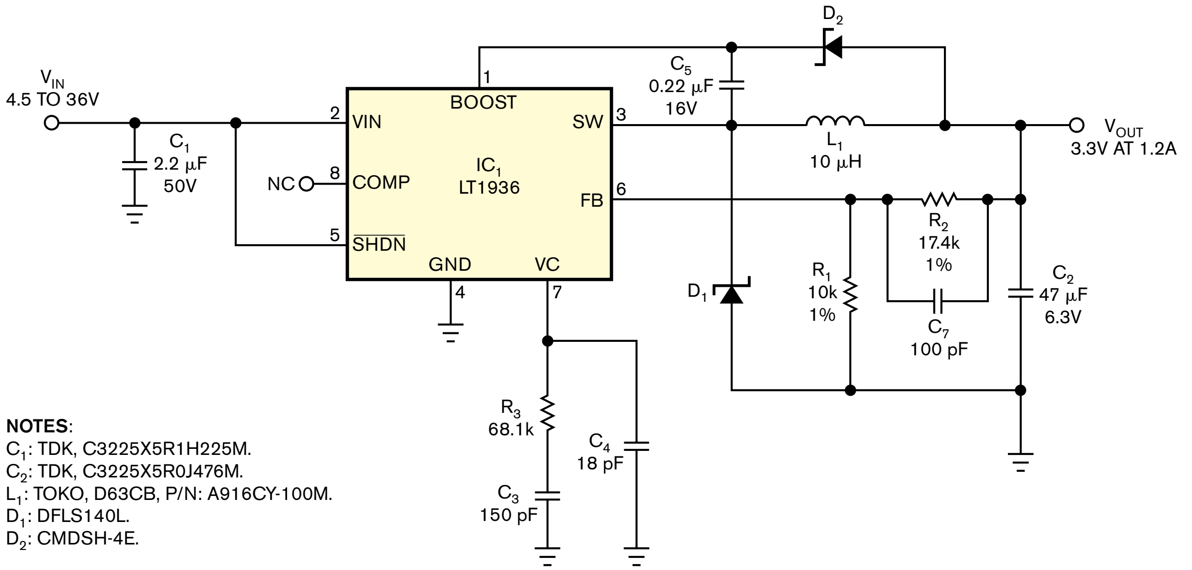
Extend low-output-voltage switching regulator's input range

Hua (Walker) Bai, Linear Technology, Milpitas, CA

Internal operating voltages in electronic devices continue to decrease, but input-source voltages don't change. As the difference between input and output voltages increases, so does the improvement in efficiency that a switching regulator offers. Unfortunately, as a switched-mode step-down converter's output voltage decreases, the decrease imposes limitations on the circuit's input-voltage range. This Design Idea shows how to extend a low-output-voltage step-down converter's input-voltage range.

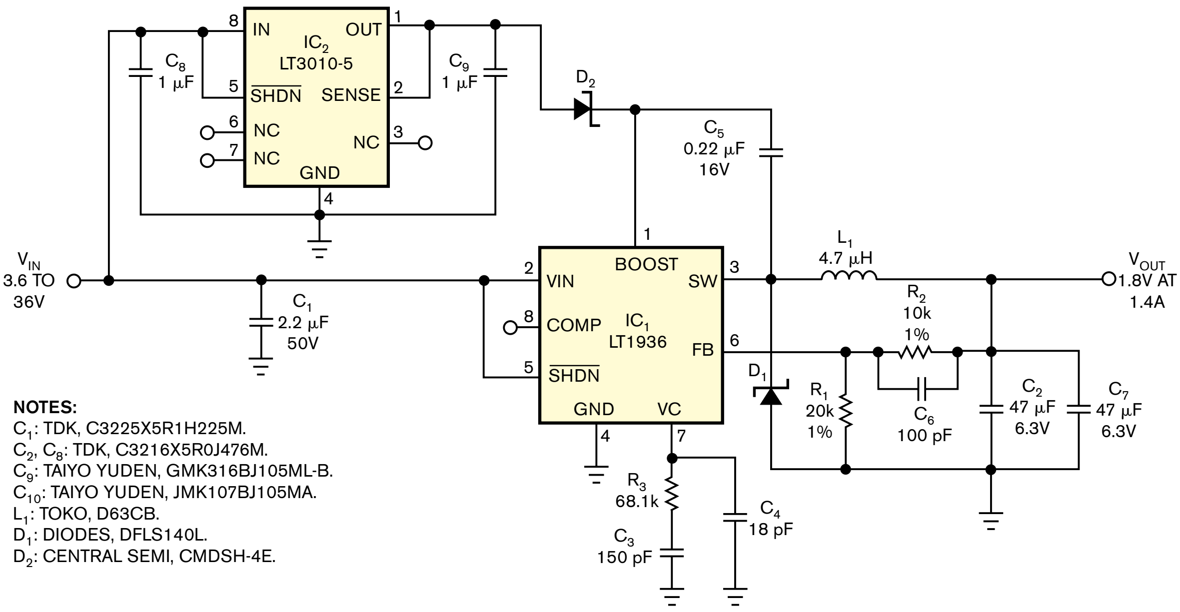
A switching-mode step-down regulator, such as Linear Technology's (www.linear.com) LT1936 (IC_1), includes an internal high-side NPN power transistor between its input, V_{IN}, and switched-output (SW) pin. For highest efficiency, the high-side NPN transistor requires a base voltage that's higher than the input voltage. The circuit of **Figure 1** works best for output voltages greater than 3V. A charge pump comprising diode D_2 and capacitor C_5 maintains the voltage at the Boost pin 3V above V_{IN}. When IC_1's internal power transistor switches off, the voltage at SW goes to ground through D_1. Boost capacitor C_5 charges to 3V supplied from V_{OUT} through D_2. When the power transistor turns on, the voltage at SW jumps to V_{IN}, and the voltage at the Boost pin jumps to V_{IN}+3V, which provides sufficient head room to drive the power transistor into saturation for greatest efficiency.

However, output voltages below 2.8V no longer provide sufficient drive volt-



NOTES:
C_1: TDK, C3225X5R1H225M.
C_2: TDK, C3225X5R0J476M.
L_1: TOKO, D63CB, P/N: A916CY-100M.
D_1: DFLS140L.
D_2: CMDSH-4E.

Figure 1 For efficient operation at output voltages of 3.3V or higher, a charge pump comprising D_2 and C_5 provides a voltage boost that provides sufficient drive for IC_1's internal switching transistor.



NOTES:
C_1: TDK, C3225X5R1H225M.
C_2, C_8: TDK, C3216X5R0J476M.
C_9: TAIYO YUDEN, GMK316BJ105ML-B.
C_{10}: TAIYO YUDEN, JMK107BJ105MA.
L_1: TOKO, D63CB.
D_1: DIODES, DFLS140L.
D_2: CENTRAL SEMI, CMDSH-4E.

Figure 2 At outputs as low as 1.8V, efficient operation at low input voltages benefits from an added low-dropout regulator, IC_2, for the Boost pin, which extends the circuit's input-voltage range.

age to fully saturate IC_1's switching transistor, and the circuit's efficiency suffers due to increased voltage drop across the transistor. In this situation, connecting D_2's anode to V_{IN} instead of V_{OUT} doubles the Boost pin's voltage to twice the value of V_{IN} but limits V_{IN} to 20V to avoid exceeding the Boost pin's allowable maximum voltage. For outputs lower than 2.8V, the circuit in **Figure 2** extends V_{IN}'s maximum voltage to 36V. When the input exceeds 5.3V, a Linear Technology LT3010-5 low-dropout voltage regulator maintains the voltage across C_9 at 5V. As a result, for input voltages at V_{IN} of 5.3 to 36V, the voltage at the Boost pin always remains at 5V above V_{IN}. **Figure 3** shows a 36V input applied to V_{IN} and the resultant voltages at the SW and Boost pins. In **Figure 3**, the maximum Boost-pin voltage reaches 41V, safely below the pin's 43V maximum rating. For values of V_{IN} of 3.6 to 5.3V, IC_2 operates in dropout mode and introduces only a 300-mV drop from its input to its output. **Figure 4** shows that, even at the circuit's minimum 3.6V input, the Boost pin remains 3.3V above V_{IN}, and IC_1's internal NPN transistor receives sufficient drive voltage for saturated operation.EDN

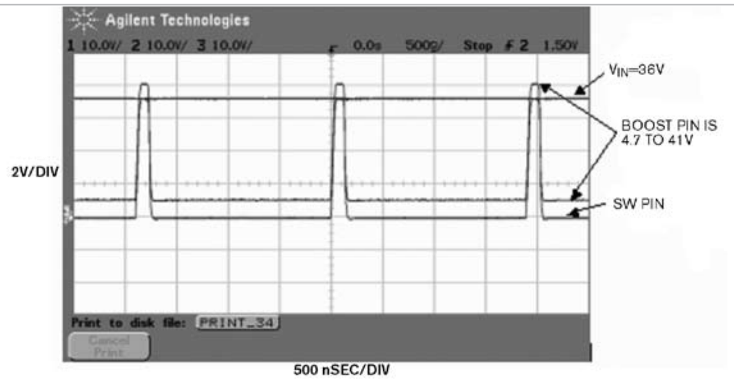


Figure 3 At a maximum input voltage of 36V (V_{IN}), waveforms at the SW and Boost pins show a 5V boost-voltage margin for the circuit of Figure 2.

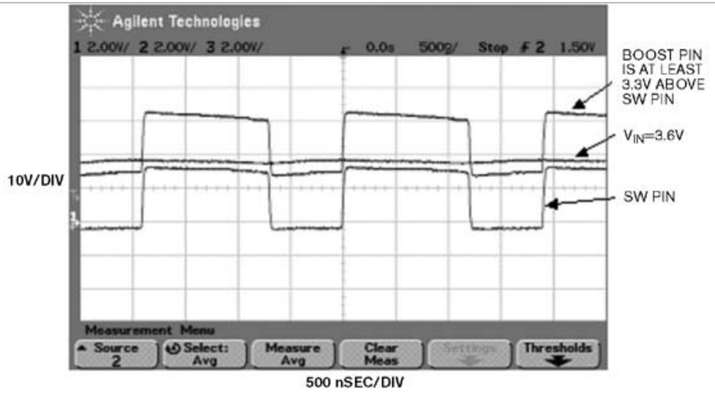


Figure 4 At 3.6V input (V_{IN}) and 1.8V output, a voltage of 3.3V at IC_1's boost pin ensures that IC_1's internal switch still operates in saturated mode.

Automatic latch-off circuit saves batteries

Kieran O'Malley, On Semiconductor, West Kingston, RI

Although rechargeable batteries offer many advantages, they can suffer damage and shortened service lives if they're fully drained of their charge. The circuit in **Figure 1** shuts off a battery-powered appliance—in this instance, an LED flashlight receiving power from NiMH (nickel-metal-hydride) cells—when the battery voltage falls below a preset limit. Although intended for an LED flashlight, this circuit can apply to any battery-powered application. Without ensuring that the user will remove the batteries for recharging, this circuit latches the flashlight off when the battery voltage falls below the usable limit and thus provides a strong hint that it may be time to recharge.

Although a simple nonlatching voltage comparator can switch off power, removing the battery's load causes a voltage rebound, and the comparator restores power, forcing the light into a flashing mode. This circuit turns off the flashlight, and it remains off until the user manually turns on the light using switch S$_1$.

A 600-mA NCP1421 PFM step-up synchronous-rectifier dc/dc-converter, IC$_1$, from On Semiconductor (www.onsemi.com) forms the heart of the circuit, but the basic design applies to many other converters offering similar features (**Reference 1**). The NCP1421's key features include an integrated LBI/EN (low-battery input/enable) and an open-drain LBO (low-battery output). Operating from two AA-size NiMH batteries, the circuit comprises the components of a normal boost regulator: an inductor, input and output capacitors, and a current-sense circuit to the right of IC$_1$. A combination of the LED's forward voltage, which R$_3$ and R$_2$ divide down, and voltage across current-sense resistor R$_1$ produces a feedback voltage for comparison with the NCP1421's 1.2V nominal reference voltage.

On the input side, IC$_1$'s LBI/EN pin connects to the battery through a voltage-divider network formed by resistors R$_4$, R$_5$, and R$_{10}$. The NCP1421 remains enabled while the voltage on LBI/EN exceeds 1.2V. When the voltage on LBI/EN falls below 1.2V, the LBO-detector pin goes low, switching on Q$_3$ and supplying current to Q$_1$'s base. When Q$_1$ switches on, Q$_2$'s base goes low and latches the virtual SCR (silicon-controlled rectifier) formed by Q$_1$ and Q$_2$, an MBT3946DW1 integrated dual transistor, IC$_2$.

In addition, Q$_1$ latches the LBI/EN pin low to prevent IC$_1$ from turning on again upon load removal. To restart the circuit, switch S$_1$ must interrupt the circuit's power. Resistors R$_4$, R$_5$, and R$_{10}$ set the battery-voltage trip point for the LBO detector. R$_5$ also sets the current drawn from the battery when the SCR activates. The circuit switches off when the battery voltage drops to approximately 1.3V, a point at which the LBI/EN pin reaches 1.2V. EDN

REFERENCE

1 NCP1421 data sheet, www.onsemi.com/pub/Collateral/NCP1421-D.PDF.

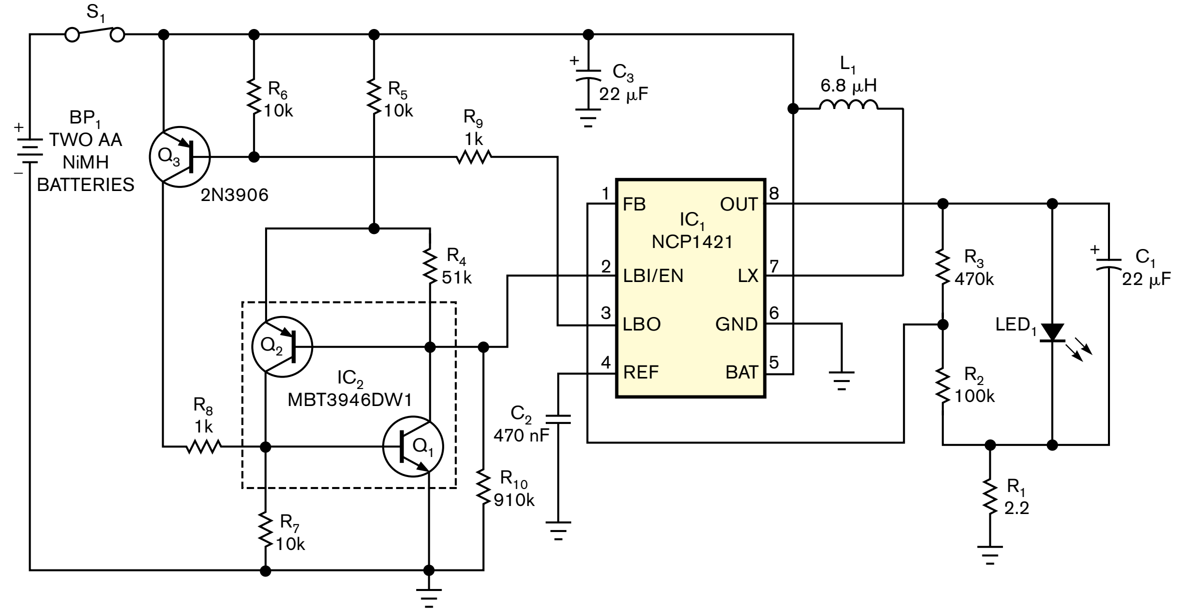


Figure 1 This circuit extends the lives of rechargeable batteries by removing power at a preset voltage and preventing over-discharge.

Switching regulator reduces motor brake's power consumption

Alain Minoz, Elekta Instrument AB, Stockholm, Sweden

For safety reasons, a motor that drives a safety-critical electromechanical assembly often includes an electromagnetic brake on its drive shaft. The brake typically comprises a solenoid coil that actuates a mechanical clutch, and, when you power it, the brake allows the drive shaft to rotate. Although simple and robust, the brake requires a lot of energy to release the clutch and then much less energy to remain actuated.

Measurements show that a brake rated for 24V dc requires a minimum of 18V to release and as little as 8V holding voltage. Substituting those numbers into the equation $P_{COIL}=V^2/R_{COIL}$ shows that, while actuated, the brake consumes less than a quarter of the power required for its initial release. Conversion of excess release power into heat normally doesn't pose problems. However, a precision positioner that uses a brake mounted on a long drive screw can suffer from unacceptable errors if the heat expands the drive screw and alters the assembly's position.

One method of solving the problem involves actuating the brake by applying 24V dc for a brief interval and then reducing the holding voltage to 12V. Under these conditions, the brake dissipates only a quarter of the initial power and thus operates at a reasonable temperature. **Figure 1** shows the influence of actuation voltage on the brake's temperature. As expected, lowering the voltage after actuation drastically lowers the brake's temperature and therefore its effects on the positioning screw.

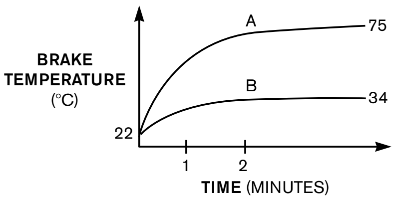


Figure 1 Under continuous operation with 24V applied, the brake's temperature stabilizes at 75°C, or 53°C above ambient temperature (Curve A). Applying a 24V actuation pulse for a few seconds and then applying a 12V holding voltage stabilizes the brake at 34°C, or only 12°C above ambient temperature (Curve B).

Figure 2 shows one obvious voltage-reduction approach, which uses relays and a power resistor to halve the voltage applied to the brake. Setting the current-limiting resistance, R_{POWER}, equal to the brake's solenoid resistance, R_{BRAKE}, reveals a few problems. First, the power resistor must dissipate as much power as the brake solenoid's coil. Second, the relays and power resistor occupy considerable space on a pc board. Third, proportioning the values of the R_1C_1 delay circuit's components to achieve a few seconds' delay can prove difficult.

Figure 3 shows another approach, which uses the actuator coil's inductance and replaces relays with an IC. The voltage you apply to the brake need not be continuous, and applying a PWM (pulse-width-modulated) voltage works as well as applying a dc holding voltage because the coil's inductance integrates the current pulses.

A switched-mode voltage regulator can provide an inexpensive and effective PWM-drive voltage. For example, National Semiconductor's (www.national.com) LM2575 adjustable regulator, IC_1, operates over a 7 to 40V range and includes an on/off-control input and a high-impedance feedback input, but any other switching-regulator IC with these two characteristics would also serve. Resistors R_1 and R_2 determine the holding voltage (**Figure 4**). Capacitor C_3 filters the PWM signal to a dc voltage at the feedback input and also maintains the feedback input for a few seconds during start-up at ground, forcing the regulator to deliver the full input voltage to actuate the brake. Diode D_1 quickly discharges the capacitor when the regulator switches off, diode D_2 clamps the switch-off transient voltage that the brake's actuating coil produces, and diode D_3 protects IC_1 against reverse voltage. Photocoupler IC_2 isolates the brake controller from the control circuit.

During start-up, the duration of the regulator's 24V actuation-pulse output fluctuates from 1 to 4 seconds (**Figure 4**). Fortunately, the variation has no impact on the circuit's function but could

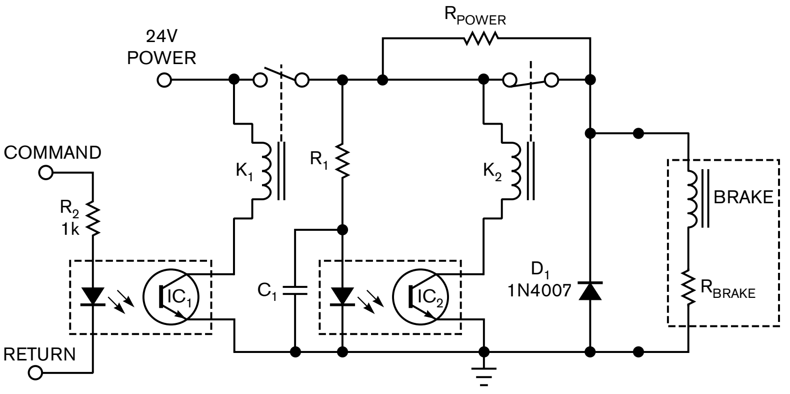


Figure 2 Actuating the brake release trips relay K_1 and applies 24V to the brake. An RC network delays K_2's actuation. When normally closed relay K_2 opens, resistor R_{POWER} reduces the voltage applied to the brake to the holding level.

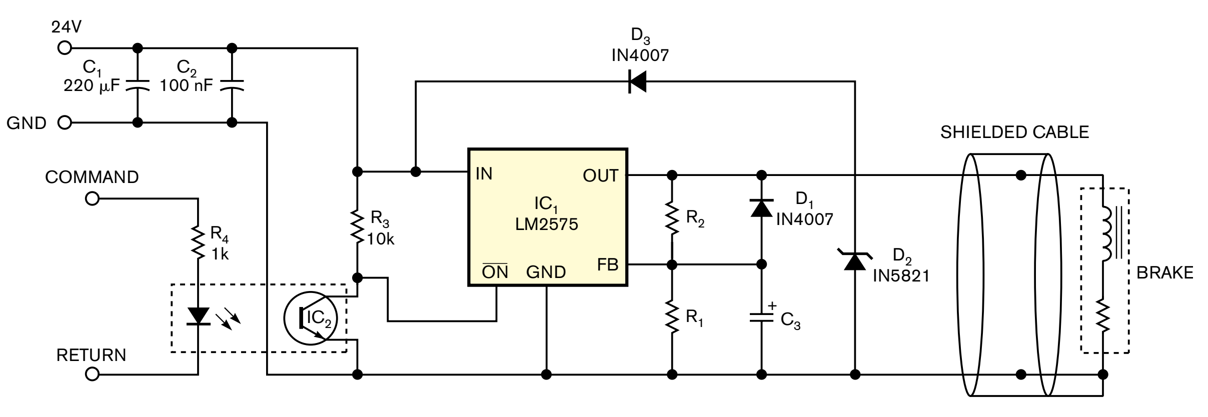


Figure 3 Applying the command input switches on PWM regulator IC$_1$, and capacitor C$_1$ holds IC$_1$'s feedback input low, applying a maximum output voltage of 24V to the brake until C$_1$ fully charges. As the feedback voltage slowly rises to 1.23V, the regulator's output voltage decreases to approximately 12V, the brake's nominal holding voltage.

present a problem if another application requires a precisely timed actuation pulse. After start-up, the regulator delivers a 12V holding voltage, reducing the power demand to one-quarter of the start-up value. As a bonus, the circuit uses inexpensive components, occupies only a few square centimeters of pc-board area, and eliminates the need for two electromechanical relays. Wiring for the PWM-drive voltage can radiate electrical noise unless the circuit is adjacent to the brake. For remote installation, use a shielded twisted-pair cable to minimize noise radiation. EDN

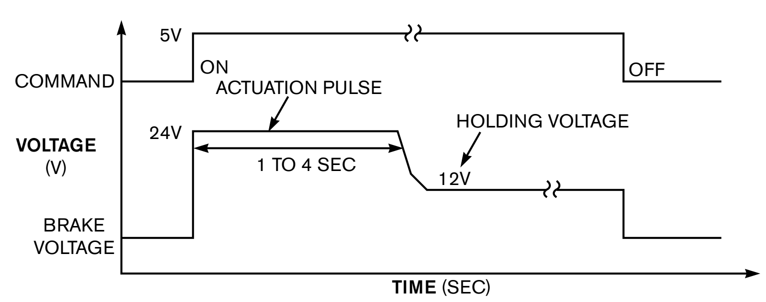


Figure 4 After the actuation pulse applies full voltage to the brake, the regulator's output gradually decreases to the nominal holding voltage.

Analog divider uses few components

David Cripe, Chatham, IL

Although microprocessors may offer more-precise calculations, there's still room for analog-computation techniques in a designer's circuit collection. As a case in point, the analog-divider circuit in **Figure 1** offers reasonably good accuracy for the price of a few inexpensive components. Given two voltages, V$_A$ and V$_B$, as its inputs, the circuit delivers an output of 5V multiplied by the ratio of V$_A$ divided by V$_B$. In operation, a TLC555, the CMOS version of the ubiquitous 555 timer, serves as a free-running Schmitt-trigger RC oscillator, IC$_2$. Its output signal at Pin 3 drives resistor R$_1$ and capacitor C$_1$. The voltage at C$_1$ drives IC$_2$'s trigger (Pin 2) and threshold (Pin 6) inputs, closing the timing loop and establishing oscillation. A low-impedance open-drain MOSFET at IC$_2$'s discharge pin switches low whenever IC$_2$'s output goes low.

Representing the calculation's denominator, an input voltage, V$_B$, drives IC$_2$'s discharge pin through a resistive-voltage divider comprising R$_3$ and R$_4$. Regardless of IC$_2$'s frequency of oscillation, a pulsed voltage appears at IC$_2$'s Pin 7 with the same duty cycle as IC$_2$'s output signal at Pin 3 and an amplitude of 0V to V$_B$/2. A voltage follower, IC$_{1B}$, buffers IC$_2$'s discharge output and drives a lowpass filter comprising R$_8$ and C$_3$, yielding a voltage that equals V$_B$/2 multiplied by IC$_2$'s duty cycle. A second resistive voltage divider, R$_6$ and R$_7$, halves the numerator-input voltage, V$_A$, and applies the signal to integrator IC$_{1A}$, along with the output from the lowpass filter, R$_8$ and C$_3$. The integrator's output voltage drives current through R$_2$ into C$_1$, creating a bias voltage that in turn controls IC$_2$'s output pulse width and forming a feedback loop.

In operation, the feedback loop forces IC$_2$'s duty cycle to equalize the voltages at IC$_{1A}$'s Pin 2 and Pin 3, such that V$_B$ multiplied by the duty cycle equals V$_A$, or the duty cycle equals the ratio of V$_A$ to V$_B$. IC$_2$'s output at Pin 3 comprises a 0 to 5V pulse waveform. The feedback circuit controls this waveform and in turn drives a lowpass filter, R$_5$ and C$_4$, to generate a dc-output voltage equal to 5V multiplied by the pulse width, or $V_A \times 5V/V_B$.

Aside from the tolerances of the resistors in divider networks R_3 and R_4 and R_6 and R_7, the primary source for inaccuracy in the circuit arises from the nonzero on-resistance of IC_2's discharge switch and the inability of discharge-switch-voltage follower IC_{1A}'s output to reach 0V. Keeping the circuit's resistance values high tends to reduce this effect. A Spice simulation of this circuit indicates that, aside from the effects of resistor tolerances, the circuit achieves a worst-case accuracy of 0.5%. (Editor's note: For greatest accuracy, use a regulated, 5V power supply.) **EDN**

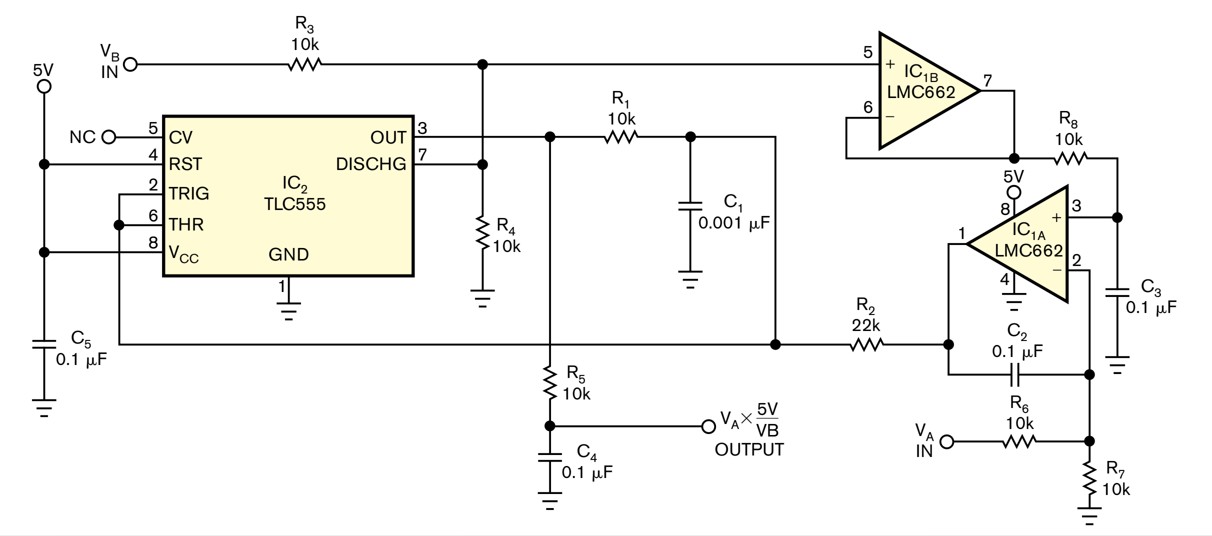


Figure 1 This low-cost pulse-width modulator performs analog division. Inputs V_A and V_B control this low-cost pulse-width modulator, and a lowpass filter follows it.