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AND FRAN GRANVILLE

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READERS SOLVE DESIGN PROBLEMS

Precision full-wave signal rectifier needs no diodes

José M Blanes and José A Carrasco,
University Miguel Hernández, Elche, Spain

DIs Inside

Rectifier circuits based on semiconductor diodes typically handle voltage levels that greatly exceed the diodes' forward-voltage drops, which generally don't affect the accuracy of the rectification process. However, the rectified signal's accuracy suffers when the diode's voltage drop exceeds the applied voltage. Precision rectifier circuits combine diodes and operational amplifiers to eliminate the effects of diode voltage drops and enable high-accuracy, small-signal rectification. By taking advantage of modern operational amplifiers that can handle rail-to-rail inputs and outputs, the circuit in Figure 1 dispenses with diodes altogether, provides full-wave rectification, and operates from a single power supply.

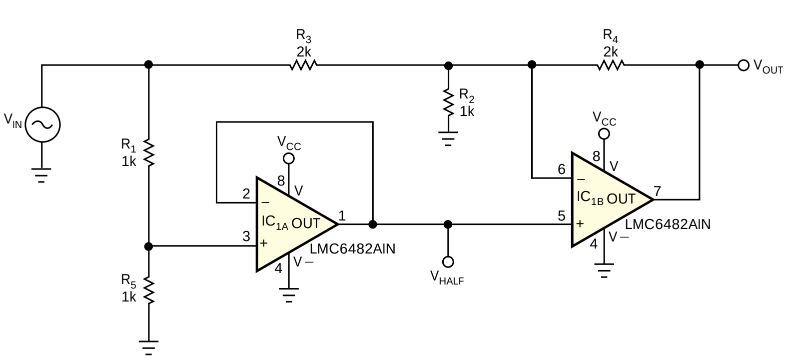


Figure 1 This precision full-wave-rectifier circuit uses two op amps and no diodes. When altering the basic design, note that resistors R_3 and R_4 are both twice the value of R_2 and that R_1 and R_5 are equal.

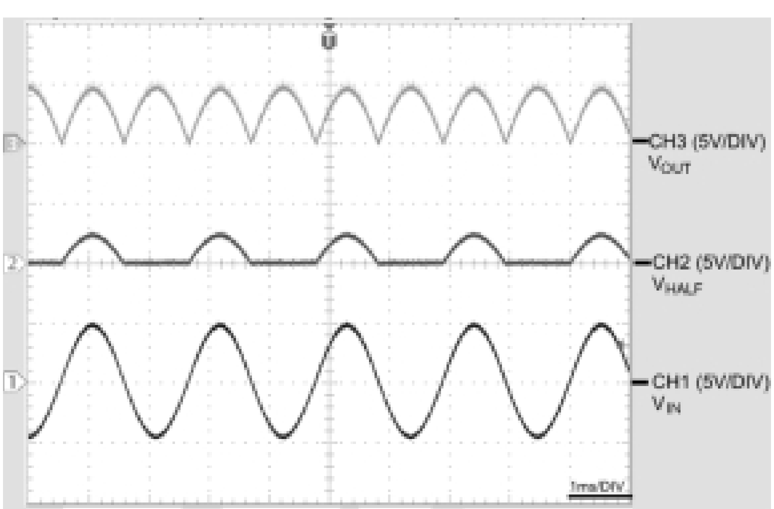


Figure 2 From bottom to top, the waveforms show V_{IN} (CH1), V_{HALF} (CH2), and V_{OUT} (CH3).

The circuit operates as follows: If $V_{IN}>0V$, then IC_{1A}'s output, V_{HALF}, equals $V_{IN}/2$, and IC_{1B} operates as a subtracter, delivering an output voltage, V_{OUT}, equals V_{IN}. In effect, the circuit operates as a unity-gain follower. If $V_{IN}<0V$, then $V_{HALF}=0V$, and the circuit behaves as a unity-gain inverter and delivers an output of $V_{OUT}=-V_{IN}$. Figure 2 shows the circuit's input signal at V_{IN}; its intermediate voltage, V_{HALF}; and its output voltage, V_{OUT}.

The circuit uses a single National Semiconductor LMC6482 chip and operates in the linear regions of both operational amplifiers. Suggested applications include low-cost rectification for automatic gain control, signal demodulation, and process instrumentation. The circuit relies on only one device-dependent property: The amplifiers must not introduce phase inversion when the input voltage exceeds the negative power supply; the LMC-6482 meets this requirement. EDN

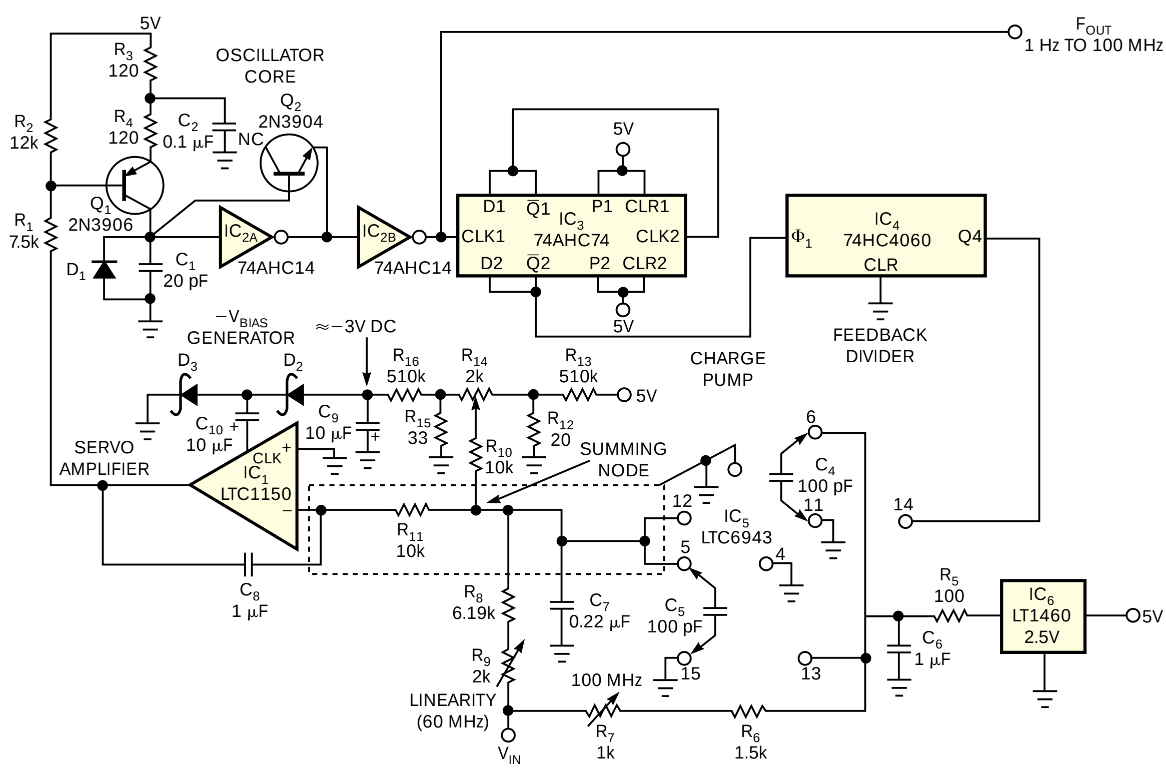
1-Hz to 100-MHz VFC features 160-dB dynamic range

Jim Williams, Linear Technology Corp

The VFC (voltage-to-frequency-converter) circuit in **Figure 1** achieves a wider dynamic range and a higher full-scale output frequency—100 MHz with 10% overrange to 110 MHz—by a factor of 10 over any commercially available converter. The circuit's 160-dB dynamic range spans eight decades for a 0 to 5V input range and allows continuous operation down to 1 Hz. Additional specifications include 0.1% linearity, a 250-ppm/°C gain/temperature coefficient, a 1-Hz/°C zero-point shift, and a 0.1% frequency shift for a 10% power-supply-voltage variation. A single 5V supply powers the circuit.

Chopper-stabilized amplifier IC_1, an LTC-1150, controls a crude but wide-range oscillator core comprising bipolar transistors Q_1 and Q_2 and inverters IC_{2A} and IC_{2B}. In addition to delivering a logic-level output, the oscillator core clocks divide-by-four counter IC_3, which in turn drives IC_4, a 74HC4060 configured as a divide-by-16 counter.

After undergoing a total division by 64 in IC_3 and IC_4, the oscillator core's output drives a charge pump comprising IC_5, an LTC6943, and its associated components. The averaged difference between the charge pump's output and the applied input voltage appears at the summing node and biases IC_1, thereby closing the control loop around the wide-range oscillator core.



NOTES:
1. D_1: JPAD-500, D_2, D_3: BAT-85, R_5, R_6, R_8: TRW-IRC TYPE MAR-6, 1% METAL-FILM, C_4, C_5: WIMA TYPE FKP-2 CAPACITORS, AND C_7, C_8: WIMA TYPE MKS-2 CAPACITORS.
2. CONNECT ALL COMPONENTS AT Q_1'S COLLECTOR WITH A MINIMUM-AREA AIR-INSULATED "FLOATING" JUNCTION OVER A RELIEVED AREA OF GROUND TO MINIMIZE STRAY CAPACITANCE.
3. ENCLOSE R_{11} AND ITS CONNECTIONS TO R_9, R_{10}, IC_1'S INVERTING INPUT, C_7, AND PINS 5 AND 12 OF IC_5 WITHIN SOLDER- AND COMPONENT-SIDE GUARD TRACES TO INTERCEPT ANY BOARD-SURFACE LEAKAGE CURRENTS. (NOTE THAT THE DASHED LINE DEFINES THE GUARD TRACE.)
4. CONNECT IC_2'S UNUSED INPUTS TO GROUND. THE SCHEMATIC OMITS POWER-SUPPLY CONNECTIONS TO MOST ICS FOR CLARITY

Figure 1 Featuring a 160-dB dynamic range corresponding to a 1-Hz- to 100-MHz-frequency span, this voltage-to-frequency converter operates from a single 5V power supply.

The circuit's extraordinary dynamic range and high speed derive from the oscillator core's characteristics, the divider/charge-pump-based feedback loop, and IC_1's low dc input errors. Both IC_1 and IC_5 help stabilize the circuit's operating point by contributing to overall linearity and stability. In addition, IC_1's low offset drift ensures the circuit's 50-nV/Hz gain-versus-frequency characteristic slope and permits operation as low as 1 Hz at 25°C.

Applying a positive input voltage causes IC_1's output to go negative and alter Q_1's bias. In turn, Q_1's collector current produces a voltage ramp on C_1 (upper trace in **Figure 2**). The ramp's amplitude increases until Schmitt trigger inverter IC_{2A}'s output (lower trace in **Figure 2**) goes low, discharging C_1 through Q_2 (connected as a low-leakage diode). Discharging C_1 resets IC_{1A}'s output to its high state, and the ramp-and-reset action continues.

The leakage current of diode D_1, a Linear Systems JPAD-500, dominates all other parasitic currents in the oscillator core, but its 500-pA maximum leakage ensures operation as low as 1 Hz. The two sections of charge pump IC_5 operate out of phase and transfer charge at each clock transition. Components critical to the charge pump's stability include a 2.5V LT-1460 voltage reference, IC_6; two Wima FKP-2 polypropylene film/foils; 100-pF capacitors, C_4 and C_5; and the low charge-injection characteristics of IC_5's internal switches.

The 0.22-μF capacitor, C_7, averages the difference signal between the input-derived current and the charge pump's output and applies the smoothed dc signal to amplifier IC_1, which in turn controls the bias applied to Q_1 and thus the circuit's operating point. As noted, the circuit's closed-loop-servo action reduces the oscillator's drift and enhances its high linearity. A 1-μF Wima MKS-2 metallized-film-construction capacitor, C_8, compensates the servo loop's frequency response and ensures stability. **Figure 3** illustrates the loop's well-behaved response (lower trace) to an input-voltage step (upper trace).

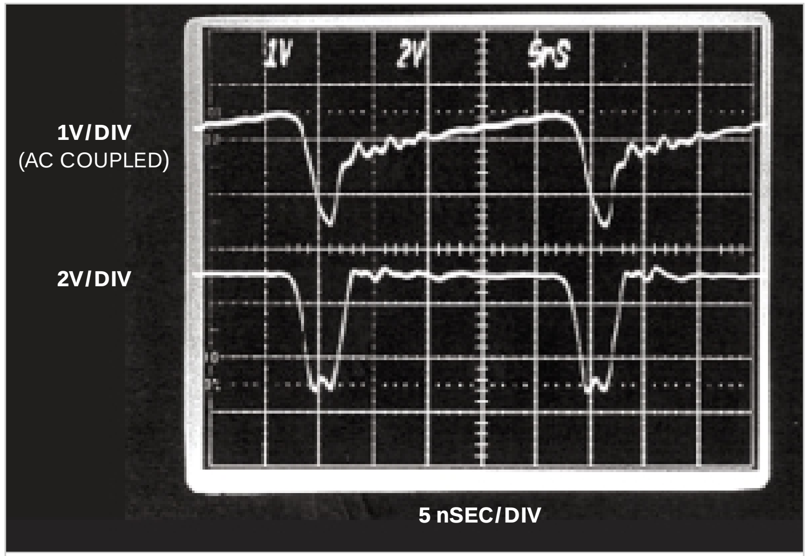


Figure 2 On a 700-MHz real-time oscilloscope, the oscillator-core waveforms at a 40-MHz operating frequency show the ramp-and-reset waveform at Q_1's collector (upper trace) and Q_2's emitter (lower trace).

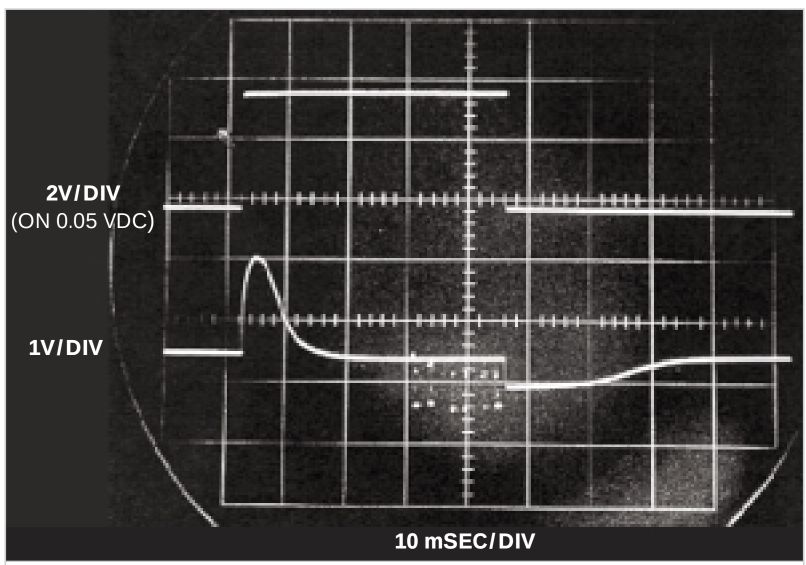


Figure 3 In response to an input-voltage step (upper trace), the voltage at the circuit's summing junction shows a 30-msec settling time.

For the circuit to achieve its design goals, certain special techniques and considerations apply. Diode D_1's leakage current dominates all other parasitic leakage currents at IC_{2A}'s input, and thus Q_1 must always supply sufficient source current to sustain oscillation and ensure operation as low as 1 Hz.

The circuit's 100-MHz full-scale upper frequency limit forces stringent restrictions on the oscillator core's cycle time, and only 10 nsec is available for a complete ramp-and-reset sequence. The reset interval imposes an ultimate speed limit on the circuit, but the upper trace in **Figure 2** shows a 6-nsec reset interval that falls comfortably within the 10-nsec limit. A path from the circuit's input to the charge pump's output allows for correction of small nonlinearities due to residual charge injection. This input-derived correction is effective because the charge injection's effects vary directly with the oscillation frequency, which the input voltage determines.

Although you can use the component values given in Figure 1 to assemble prototypes and small production quantities of the circuit, you need to consider component selection for optimum manufacturability and high-volume production. Table 1 lists certain components' target values and estimated selection yields. The notes in Figure 1 list the key components that the design uses.

To calibrate the circuit, apply 5V to the input and adjust the 100-MHz trimmer, R_7 for a 100-MHz output. Next, connect the input to ground and adjust trimmer R_{13} for a 1-Hz output. Allow for an extended settling interval because, at this frequency, the charge-pump update occurs once every 32 sec. Note that R_{13}'s adjustment range accommodates either a positive or a negative offset voltage because IC_1's clock output generates a negative bias voltage for R_{13}. Next, apply 3V to the input and adjust R_9 for a 60-MHz output. A certain amount of interaction occurs among the adjustments, so repeat the process until you arrive at optimum values for the three calibration frequencies. EDN

TABLE 1 SELECTION CRITERIA FOR COMPONENTS

Component	Selection parameter at 25°C	Typical yield (%)
Q_1	I_{CER}<20 pA at 3V	90
Q_2	I_{EBO}<20 pA at 3V	90
D_1	75 pA at 3V; I_{REV}<500 pA	80
IC_{2A}	I_{IN}<25 pA	80
IC_1	I_B<5 pA at V_{CC}=5V	90
IC_{2A}, IC_{2B}	Must toggle with 3.6-nsec-wide (at-50%-level) input pulse	80

Cascode MOSFET increases boost regulator's input- and output-voltage ranges

Scot Lester, Texas Instruments, Dallas, TX

Targeting use in portable-system applications that require raising a battery's voltage to a higher level, IC boost regulators often include output transistors that can drive storage inductors. However, most boost regulators' absolute-maximum input-voltage rating typically doesn't exceed 6V, an adequate level for battery operation. In addition, breakdown voltage of the regulator's output transistor limits the regulator's absolute-maximum output voltage to 25 to 30V, which may be too low for some applications.

You can extend a boost regulator's output-voltage range by adding an external transistor that has a higher breakdown voltage than the regulator. However, the internal design of a typical boost regulator's control circuitry often prevents direct drive of an external transistor's base or gate. As an alternative, you can add an external higher voltage transistor by connecting it in a cascode configuration.

Most boost regulators feature a peak-current-control method that reduces the number of external components and thus shrinks the overall pc-board area of the converter circuit. Figure 1 shows a boost regulator based on a TPS61040 boost controller, IC_1, which uses peak-current control.

Applying input voltage V_{IN} to IC_1's V_{CC} pin and to one leg of inductor L_1 turns on IC_1's internal MOSFET switch, Q_1, allowing a gradually increasing amount of current to flow from V_{IN} through L_1, Q_1, and internal current-sense resistor R_1. The circuit's internal controller monitors the volt-

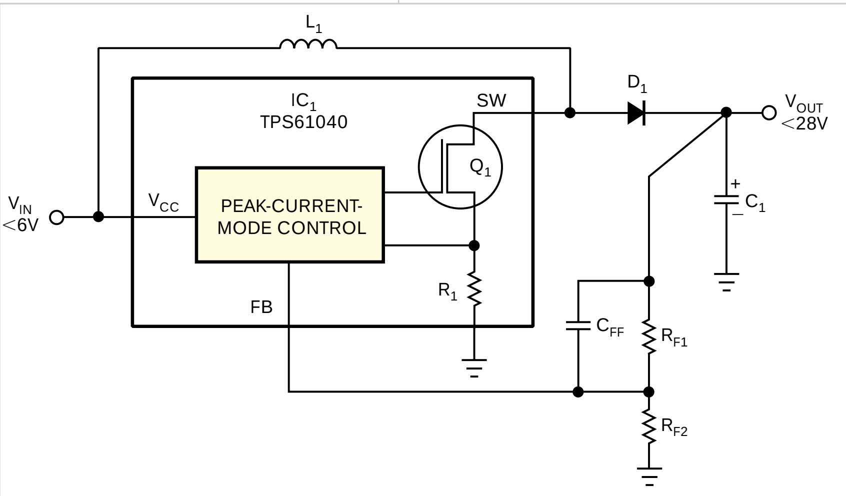


Figure 1 Based on the "barefoot" TPS61040, this dc/dc boost converter delivers output voltages only within IC_1's ratings.

age across sense resistor R_1 and, upon reaching a predetermined current limit, turns off Q_1.

Interrupting the current through L_1 raises the voltage across the inductor and applies forward bias to diode D_1, which conducts and charges output capacitor C_1 to a higher voltage than would be available from the input voltage alone. The input voltage, L_1's inductance, and the preset peak current through R_1 all affect Q_1's on-time, and the output voltage sensed by IC_1's FB (feedback) pin and its external components determines Q_1's off-time. To maintain operation and set Q_1's off-time, IC_1's internal controller must monitor current through L_1 using Q_1 and R_1.

You can add a higher voltage MOSFET transistor, Q_2 (**Figure 2**), for applications that require an output voltage higher than the internal transistor's breakdown voltage. To maintain the circuit's current-flow path through L_1 and IC_1's SW pin, you connect the external transistor in a cascode, or common-gate, configuration.

Q_2 comprises a low-on-resistance, low-gate-voltage-threshold MOSFET with the addition of diode D_2 between Q_2's gate and source. To ensure the circuit's proper operation, V_{CC}—5V in this example—must exceed Q_2's gate-threshold turn-on voltage. In operation, IC_1's internal control circuit turns on Q_1, which pulls Q_2's source close to ground level and turns on Q_2 with almost 5V of gate-to-source potential.

Current flows through inductor L_1, external transistor Q_2, internal transistor Q_1, and sense resistor R_1, and IC_1's control circuit "sees" no difference with the installation of Q_2. Once the inductor current reaches its preset limit, Q_1 turns off, leaving Q_2 with no path for current to flow from its source. The voltage on Q_2's drain rises rapidly to the desired output voltage plus the voltage drop across D_1. As the drain voltage rises, Q_2's drain-to-source capacitance attempts to pull the MOSFET's floating source above 5V, which forward-biases D_2, connects IC_1's SW pin voltage to 5V plus one diode drop, and clamps Q_2's source to the same voltage.

A boost converter delivers a 180V output at 4 mA (V_{OUT}) to bias a laser circuit from a 9V power supply (V+). In this application, the 5V input supply need provide only enough current—typically, a few milliamperes—to drive IC_1's internal logic and the gate of cascode MOSFET Q_2. You can use a dropping resistor and zener-diode voltage regulator (not shown) to supply the 5V requirement from the 9V supply. You can drive the inductor and IC_1 from a common power supply or from a separate source that's within Q_2's breakdown-voltage rating. The cascode circuit also can produce any output voltage that's within Q_2's drain-to-source breakdown-voltage rating. Specify other components with an appropriate voltage rating—for example, breakdown-voltage ratings of inductor L_1 and capacitor C_1 should safely exceed the desired output voltage. EDN

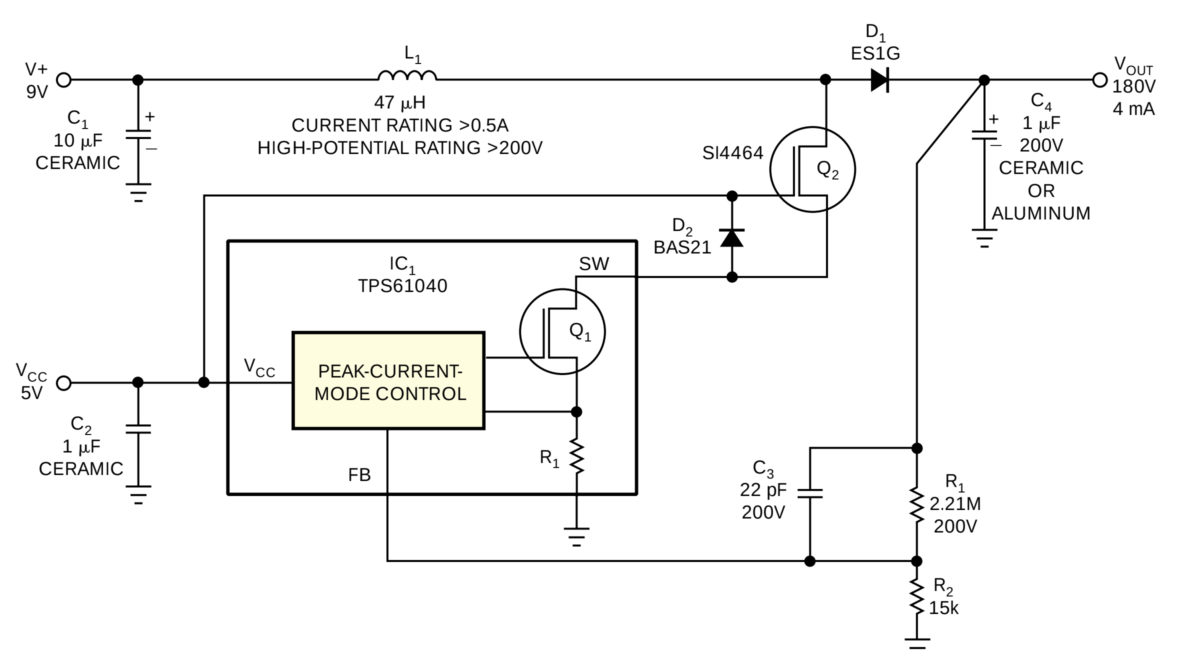


Figure 2 Adding an external cascode-connected MOSFET transistor, Q_2, with higher breakdown-voltage ratings, enables the circuit to produce higher output voltages.