White LED Voltage Booster Uses 555 Timer IC

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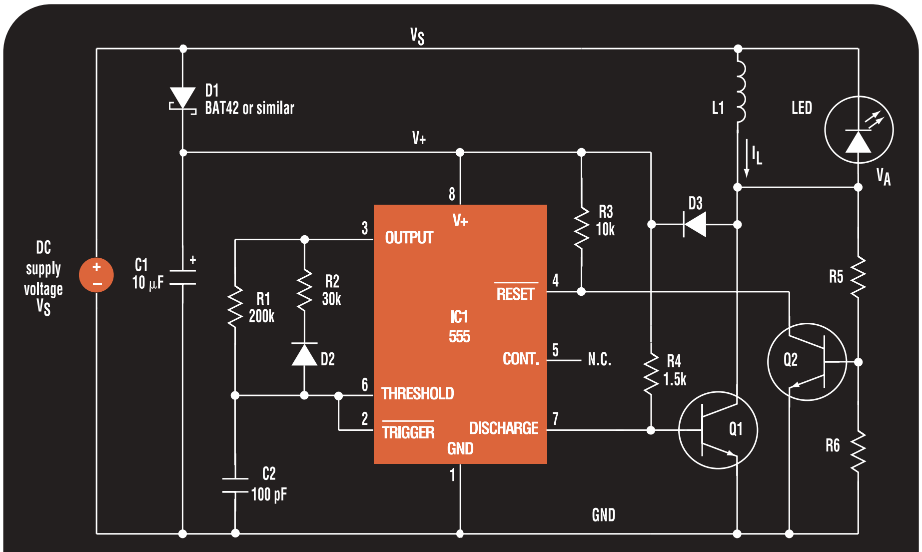
This voltage-booster circuit for driving one or more white LEDs uses a 555 timer as its main element *(see the figure)*. The timer, IC1, functions as a resettable astable multivibrator where R1, R2, and C2 are the timing components.

When the supply voltage, V_S, is first applied, D1 conducts and reservoir capacitor C1 charges to a voltage just less than V_S. Initially, transistor Q2 is off, IC1's $\overline{\text{RESET}}$ input is high, and the OUTPUT pin goes high, allowing C2 to charge up via R1. During this time, the DISCHARGE pin is pulled up by R4, which turns on Q1, and the current (I_L) in inductor L1 starts to ramp up. Because Q1 is saturated, both D3 and the LED are reverse-biased.

When the voltage on C2 crosses the threshold voltage at pin 6 of IC1, both the OUTPUT and DISCHARGE pins go low, and Q1 turns off. The resulting "back EMF" generated across L1 instantaneously raises the LED's anode voltage (V_A) above V_S, thereby illuminating the LED. Diode D3 is now forward-biased and pulls up IC1's supply voltage (V+) to a level some 2 to 4 V higher than V_S.

C2 is now quickly discharged via D2



D2, D3: 1N4148 or similar

L1, Q1, Q2, R5, R6: See text

Ideal for single-cell applications, this 555-based boost circuit produces adequate LED intensity even if the supply voltage falls below 1.0 V.

Don Tuite

JUST FOR YOU

Welcome to the first of many "Analog and Power Ideas for Design." The feature will return next month. If the reader response is positive, the plan is to publish this section 13 times in 2005. A&P IFD is the launch of something new and something old for *Electronic Design*.

The magazine has always tried to run as many reader-submitted design articles as possible, but the industry downturn left us strapped for pages until recently. Still, our issue-by-issue reader polls show that you want more design information, and believe me, whenever the *Electronic Design* editors meet, one of the bones of contention is always, "Where's the real design stuff?" We all realize that the real design stuff has to be reader-generated.

The good news is that page counts are rising and *Electronic Design* can now run more design submissions from readers. So, we're returning to something old with a revamped Ideas for Design department.

The new wrinkle is that we're using targeted demographics to deliver additional specialized content to precisely the readers who are most interested in it. In other words, if you're reading this, it's because you indicated an interest in analog or power design when you submitted your subscription form.

Analog and power-supply design are closely tied (try to run a fast, high-res analog-to-digital converter on a noisy rail) and are arguably one of the more mysterious disciplines in the EE curriculum. We hope this section will help all practitioners share the secrets of the craft.

As always, we welcome your comments and suggestions. Send them to me at **dtuite@penton.com.** **ED Online 8977** and R2, ready for the next cycle. Provided the values of R5 and R6 are chosen correctly, Q2 turns on while the LED is $\overline{\text{RESET}}$ input. When the energy stored in L1 is exhausted, the LED and D3 again become reverse-biased, and V_A falls to a low level. Q2 now turns off, allowing IC1 to commence another cycle, and C2 again begins to charge via R1. The process repeats thousands of times a second, so the LED appears to be continually illuminated.

The circuit uses three “tricks” to optimize performance. First, the bootstrapping provided by D3 boosts the timer’s supply voltage, enabling the circuit to continue working even when V_S drops below 1 V. In addition, it provides enhanced base drive for Q1 via R4. Second, the “feedback” provided via Q2 ensures that a new cycle begins as soon as L1’s energy is depleted, thereby maximizing the average LED current. Third, Q1 is driven from the timer’s open-drain DISCHARGE terminal, rather than from the OUTPUT pin. Therefore, the base drive doesn’t depend on the current-source capabilities of the 555’s output terminal.

Transistor Q1, which should be a low-saturation type, is driven on for a time t_{ON}, given by:

$$t_{ON} = K \times R1 \times C2 \qquad \text{(s)}$$

where K is a constant that depends on the particular type of 555 timer used. The LED’s peak current is roughly equal to the maximum inductor current, $I_{L(max)}$, where:

$$I_{L(max)} = [(V_S - V_{CE(sat)})/L1] \times t_{ON} \qquad \text{(A)}$$

If Q1’s saturation voltage is low, say less than 50 mV, we can ignore $V_{CE(sat)}$ and simplify the expression to:

$$I_{L(max)} = (V_S/L1) \times t_{ON} \qquad \text{(A)}$$

Thus, for a particular value of V_S, the values of R1, C2, and L1 may be selected to obtain the largest value of $I_{L(max)}$ that produces maximum LED brightness without exceeding its peak current rating.

Resistors R5 and R6 should be chosen to ensure that Q2 is off when $V_A = V_S$ (the case when power is first applied), and on when the LED is forward-biased ($V_A > V_S$). Q2 itself should be a small-signal device with good current gain.

For efficient, low-voltage operation, a CMOS timer such as Intersil’s ICM7555 or Texas Instruments’ TLC555 should be used. These types are specified to function with a supply voltage as low as 2.0 V. Plus, their internal discharge transistors are able to pull pin 7 down to around 100 mV or less, ensuring that Q1 can be turned fully off.

A test circuit built using a TLC555 for IC1, and Q1 = ZTX649, Q2 = BC546, L1 = 100 µH, R5 = 56 kΩ, and R6 = 10 kΩ was found to start up with V_S as low as 1.0 V. The circuit produced excellent brightness in a Lumileds *(www.lumileds.com)* LXHL-PW01 white LED. Transistor Q1’s “on” time (t_{ON}) was around 20 µs, resulting in a peak inductor current of around 300 mA at V_S = 1.5 V. However, this could easily be altered by changing the values of C2 and R1, and/or L1. Performance was equally impressive using an ICM7555, although the minimum startup voltage was slightly higher at 1.2 V.

The circuit is ideal for single-cell applications, because it continues to generate adequate LED intensity even when the supply voltage falls below 1.0 V. Also, two or more LEDs may be connected in series, although there will be a corresponding reduction in brightness. ***ED Online 8968***

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Handy Circuit Options Boost Output Of Capacitive Supplies

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Capacitive supplies are very attractive for applications that don’t require isolation from the mains supply. Simple, inexpensive, lightweight, and reliable, they run cool and don’t generate interference. However, they suffer from a significant disadvantage: If you need an output current in excess of tens of milliamperes, the dropping capacitor tends to become bulky. This is especially true when the output must be referenced to one of the mains terminals, as is often the case with triac-driving circuitry. The only option then is to use the half-wave voltage-doubler topology, which unfortunately halves the available output current.

Another solution is to use a current-multiplying rectifier to boost the output current. By adding some components to the standard half-wave doubler circuit *(Fig. 1a)*, you obtain the current-doubling variant *(Fig. 1b)*.

In Figure 1b, another capacitor (C3) is inserted into the path of the positive half-cycle current. Thus, it receives the same charge as C2, the main output capacitor.

During the negative half-cycle, D3 is blocked while Q1 conducts via R2, connecting the positive side of C3 to that of C2. On the negative side, D1 provides a path from C3 to the ground, which effectively parallels both capacitors. This doubles the charge that’s transferred each cycle to the output, also doubling the available output current. D4 resets the charge of C1 during the negative half-cycles. With this improvement, we’re now on an

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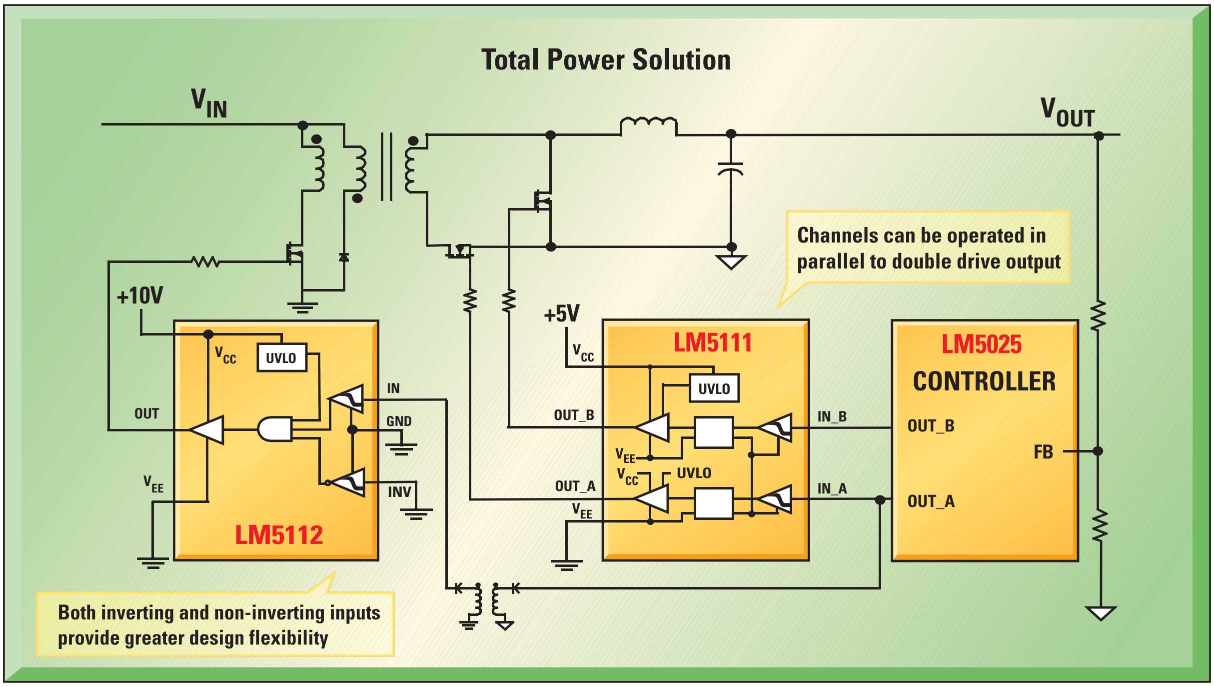

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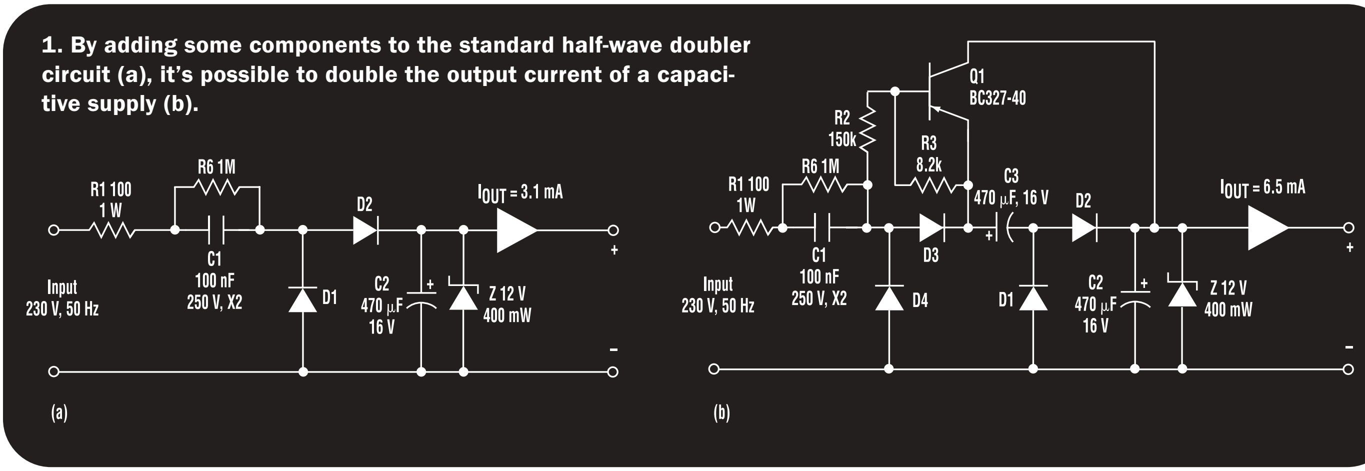
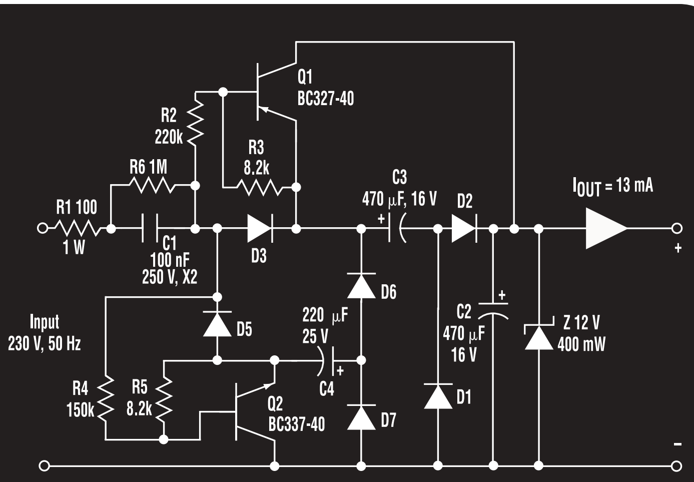
1. By adding some components to the standard half-wave doubler circuit (a), it's possible to double the output current of a capacitive supply (b).



equal footing with a full-wave circuit, but with a common terminal between the input and the output.

Further improvements are also possible. Up to this point, the negative half-cycle hasn't actively contributed to the current output. The circuit of Figure 2 changes that situation. During the negative half-cycle, C4 is charged via D5 and D7, and Q2 is blocked because it's negatively biased. When the input becomes positive, Q2 conducts via R4, as does D6, connecting C4 to the input of the previously examined circuit. This effectively doubles its input current. Because it operates "blindly" on any current, whatever its origin, it also gets doubled. The end result is an output current equal to four times that of the initial circuit of Figure 1a.

It's worth saying a word about component selection, especially for those unfamiliar with capacitive supplies. For safety reasons, it's essential that C1 be an X-rated model (that is, suitable for connection across the mains). A 100-nF value was used in this example. The value of R1 isn't critical. It simply limits the inrush current when the supply is plugged in and the ac waveform is at or near its maximum. But it should be able to withstand the full mains peak voltage, which is 325 V in the example.



2. The negative half cycle doesn't actively contribute to the output of the Figure 1 circuits. The variation shown here uses the negative half cycle to double the input current, producing four times the output current of the circuit in Figure 1a.

But it's better to plan for the worst case. If the circuit is plugged in carelessly, the capacitor may be charged to a maximum, then disconnected briefly and connected again to the mains waveform at the opposite maximum. If this happens, the peak voltage seen by the resistor is twice the mains peak voltage, or 650 V in this example. If a 100-Ω resistor is used, as in the example, the peak current will exceed 6 A. Although this peak is of a short duration, it heavily stresses the resistor.

Therefore, you should either select a component specifically designed for pulse operation or use an oversize standard resistor. A 1-W standard film resistor appears to work well with up to 1-µF capacitors. Then, if the resistor is too small and eventually fails, the good news is that it will fail open-circuit. Carbon-composition resistors have almost completely disappeared nowadays, and they should never be used in this application because of their propensity to fail in unpredictable ways, posing a serious fire hazard.

R6 is optional. It's a discharge resistor preventing the continued presence of a high voltage on the mains plug terminals after the equipment is unplugged. Although the energy stored in C1 isn't high enough to be harmful, it can give an unpleasant shock to the user. C2, the filter capacitor, should be dimensioned according to your ripple requirements (not forgetting that the ripple frequency equals the mains frequency). C3 is identical to C2. The value of C4 is half that of C2, but it sees a double voltage.

WARNING: As with all capacitive supplies, a potentially lethal shock hazard exists because the output is galvanically connected to the mains. Be sure to observe the correct power-line polarity. An isolation transformer is recommended when working on, or testing, the circuit. Make sure that all local electrical codes are followed.

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The peak current ratings for Q2 and Q1, respectively, are the output current and twice that value. Their base resistors must be computed accordingly. The diodes aren't critical, but they should not be underdimensioned, due to the aforementioned turn-on peak current. The 1N4001 diodes are perfectly suitable.

This circuit reduces size at the expense of some complexity. The cost is on average similar to that of the standard solution, being rather lower for high currents and vice versa. Although the circuit is fairly reliable, it can't match a plain capacitor in this respect: Each component added also increases the risk of failure. Therefore, if you're looking for the highest possible reliability, the conventional solution of Figure 1a remains preferable. ***ED Online 8969***

LOUIS VLEMINCQ, transmission specialist at Belgacom, obtained a master's degree in electronics from the InRaCi (Institut de Radio-Cinematographie), Forest, Belgium.

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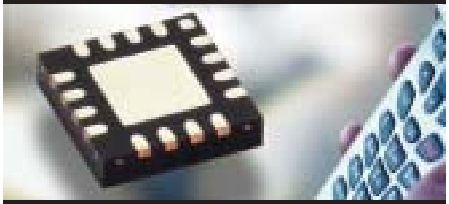

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