An improved offline driver lights an LED string

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A constant current is better than a constant voltage for driving LEDs. In this proposed circuit, a common constant-voltage regulator is changed into a constant-current source for LEDs. In addition, a startup current limiter is used to suppress large current surges, and a voltage chopper is employed for a wide ac input of 96 to 260 V\textsubscript{RMS}.

![Circuit Diagram](image)

**Figure 1** This circuit drives a string of LEDs with a constant current over the entire worldwide range of ac-mains voltages. The resistor in series with the LED string provides a convenient point to measure LED current via its voltage drop.

The concept presented here originates from two Design Ideas published in 2011 ([references 1 and 2](#)) and was developed to improve power efficiency at a low cost. The circuits shown in figures 1 and 2 both have the same brilliance of an inductorless chopper and the same controversial issue of power efficiency. To improve the power efficiency, you should observe two principles: The resistors of the chopper should dissipate as little power as possible, and the chopper should switch at the appropriate threshold voltage, $V_{TH}$. In addition, $V_{TH}$ should be as close as possible to the operating voltage across the LED string. This approach minimizes the power dissipation of the constant-current regulator (CCR) while maintaining a constant LED current.
The chopper operation is similar to the circuit of Figure 1; the larger LED series resistor, instead of a constant-current source, provides the current-limit function.

The circuit shown in Figure 3 is an example that follows the principles described above, with a power efficiency of about 85%. Voltage regulator IC₁ and R₅ form a 20-mA CCR. The LED string has a sufficient number of LEDs to require 120V at 20 mA. The voltage across R₆ provides a means for indirect measurement of the LED current.

Vₚₘₘₜ is the diode bridge full-wave rectified output voltage above which, when divided by R₆ to R₃, the 68V bias of D₅ is overcome, turning on Q₁ and turning off Q₂. C₁ charges quickly to Vₚₘₜ while Q₂ is on, then discharges slowly into the LED string until the next half-cycle of the incoming ac.

Vₚₘₜ must be no less than required to maintain the LED operation voltage of 120V at the end of C₁’s discharge and no more than 1.414 times the Vₚₘₚ of the lowest ac level. With 120V required for the LEDs, plus the 3V input-to-output differential required by IC₁, plus 1.25V developed across R₅, the minimum C₁ voltage will be 124.25V. For simplicity, this figure can be rounded up to 125V.

As shown in Figure 4, the C₁ discharge time is much longer than the charge time during a 50-Hz half-cycle of 10 msec. During this period, the peak-to-peak voltage across C1 is almost 20 mA×10 m/sec=9.09V. Thus, U₁ₐₘₜ=125V+9.09V=134.09V. For simplicity, this result can be rounded up to 135V. This is Vₚₘₜ; any voltage above this turns Q₁ on and gets chopped off by Q₂.
Figure 4 The yellow and blue traces, respectively, present the voltage across $C_1$ and $R_6$ in the circuit at 220V$_{\text{RMS}}$ (at 50 Hz ac). The two traces remain at the same position when the ac input changes from 96V$_{\text{RMS}}$ to 260V$_{\text{RMS}}$.

When $Q_1$ switches on, the power consumption of $R_4$ in Figure 3 is less than 20 mW at 260V$_{\text{RMS}}$ input, and the $R_1$-$R_2$-$R_3$-$D_5$ divider dissipates less than 100 mW. This result is almost negligible compared with the 2.4W consumed by the LEDs. These resistors are large value so as to consume as little power as possible. $R_3$ allows fine adjustment of $V_{\text{TH}}$ to match the actual drop across the LED string.

A startup current limiter has been included to limit the large inrush current surge through $C_1$ and $Q_2$ that would occur if the ac were switched on at a time in its cycle just before $V_{\text{TH}}$ was reached. A current-limiting resistor would reduce efficiency on every cycle, but $R_9$ limits only the surge to 1.35A at power-up until $C_2$ charges sufficiently to turn on $Q_3$.

As the ac input increases, the power consumption of the chopper rises a little and power efficiency decreases somewhat, as shown in Table 1.

<table>
<thead>
<tr>
<th>$V_{\text{RMS}}$ ac at 50 Hz</th>
<th>96</th>
<th>140</th>
<th>180</th>
<th>220</th>
<th>260</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power efficiency (%)</td>
<td>90</td>
<td>87</td>
<td>86</td>
<td>85</td>
<td>82</td>
</tr>
</tbody>
</table>

This improved circuit can run at 96V to 260V ac (at 50 Hz). For a larger LED current, increasing the capacity of $C_1$ and decreasing the resistance of $R_5$ are suggested. For a different LED operation voltage, some parameters should be recomputed in the same way as in the foregoing analysis. The lower the LED operation voltage is, the lower the ac input voltage can be. This Design Idea can also apply to ac at 60 Hz.

Author’s notes:

1. Use high-voltage through-hole resistors or series surface-mount resistors to achieve at least 400V withstand. A fuse is suggested for safety against shorts.
2. Safety warning for novice experimenters: Lethal voltages are present in this circuit; use caution when testing and operating it. If scoping, use an isolation transformer to float the circuit’s ac
input from earth ground; do not float the oscilloscope chassis. The scope ground cannot be
connected to the circuit without isolation.
3. Do not push the button with ac voltage applied. For safe maintenance, keep pressing the button
to discharge C₁ through R₁₀ until D₈ goes out.

References