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Powering LED arrays in backlight applications

Driving the series string requires a suitable supply circuit.

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LEDs are becoming an increasingly popular backlighting option for all types of liquid-crystal displays, large and small, as more efficient and more cost-effective white LEDs become available on the market. The advantages of LED backlighting include low cost, high reliability, low voltage, low EMI, high immunity to vibration, wide operating-temperature range and wide dimming range. These features make LED backlighting particularly suitable for handheld applications, such as cellular phones, portable media players, digital still and video cameras, and GPS receivers, among others.

An LED backlight has two basic configurations: edge lit or array lit. Edge-lit displays use one or many side-emitting LEDs along the sides of the display. Array-lit displays employ multiple LEDs arranged in a grid pattern directly behind the display. In both configurations, the LED light source is coupled with light guides and diffusers that distribute the light evenly behind the display.

The design challenge lies in driving the series string of LEDs, since the total voltage drop across the string may exceed the supply rail. One solution is to use an IC such as Intersil's EL7801, a high-power LED backlight driver with integrated 36-V FET, capable of driving one to eight high-power LEDs in series from a wide range of input voltages.

The 1-MHz pulse-width modulation (PWM) converter can be configured in boost or buck topologies, supporting a wide variety of LED backlight applications.

LED light level can be controlled by adjusting the dc bias via the Level pin, or by applying an external PWM signal to the EN/PWM pin. Since LED color temperature varies with bias current, PWM dimming offers better control of color temperature because current through the LEDs is kept constant. The EL7801 provides a 5-V gate driver synchronized to the EN/PWM pin. It can be used to control an external FET, which disconnects the LED stack during the PWM dimming signal-off period. A voltage applied to the Level pin then sets the output current of the converter during the PWM "on" period.

A minimal bill-of-materials LED-backlight application using an EL7801 in boost configuration to drive a string of eight series-connected LEDs is shown in **Figure 1**.

In this application, eight series-connected LEDs are driven from a 12-V supply. A logic-level PWM dimming signal is applied to the EN/PWM input to control average LED current. Current in the LED load during the PWM ON time is determined by the value of the feedback sense resistor R_3 , and the target feedback-regulation voltage (V_{FB}). With Mode tied to V_{DC} , voltage across the feedback resistor is set by V_{Level} , with

$$I_{LED} = V_{FB} / R_{Sense}$$

$$V_{FB} = V_{Level} / 5$$

The value of V_{FB} should be kept in the 50-mV to 450-mV range for linear operation. With Mode pin tied to ground, V_{FB} is set to 400 mV via an internal reference, and resistors R_1 and R_2 can be omitted.

For applications that require more than eight series-connected LEDs, multiple strings of series-connected LEDs can be controlled using a single EL7801 device. A backlight application using the EL7801 to drive four strings of eight series-connected LEDs is shown in **Figure 2**.

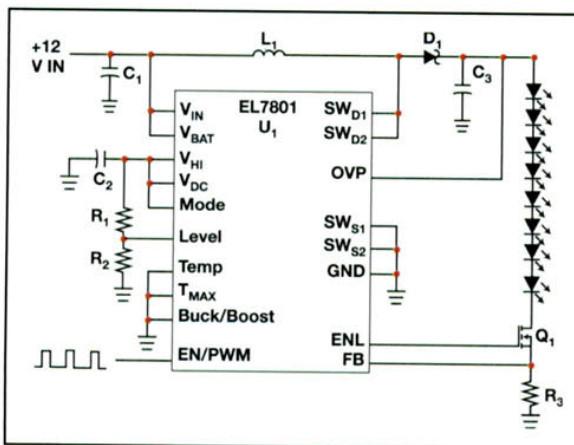


Fig 1: Basic boost converter drives a string of LEDs.

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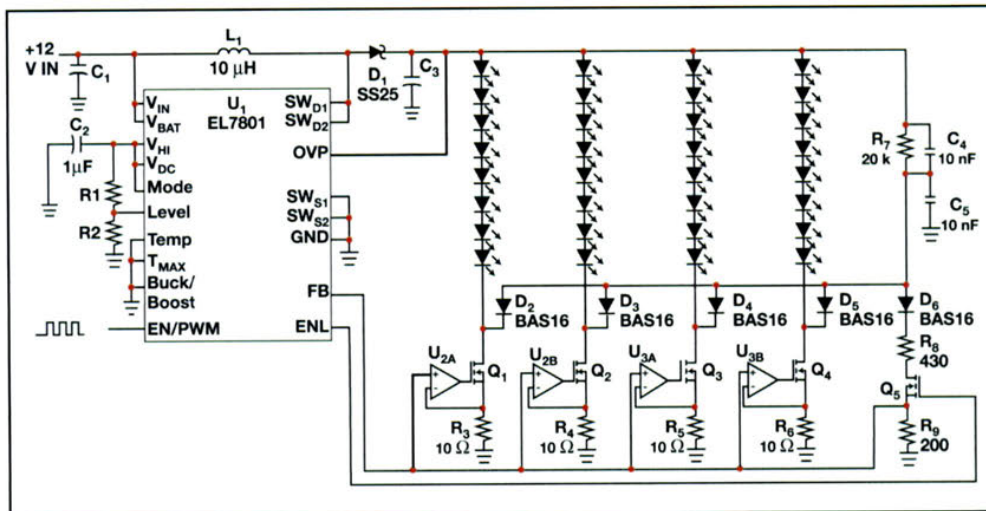


Fig 2: Enhanced design drives four series strings in parallel.

In this application, a total of 32 LEDs are driven from a 12-V supply. In much the same way as the application depicted in Figure 1, LED brightness is controlled by applying a logic-level PWM signal on the EN/PWM input. The LED current during the PWM on-time is controlled by the voltage at Level.

U_2 and U_3 are dual single-supply op amps, configured as voltage-controlled current sinks. Looking at the leftmost leg, we see that current flowing through the LED string also flows through Q_1 and R_3 . The op amp will adjust the gate drive of Q_1 to force the voltage across R_3 to be equal to V_{FB} . LED current during the PWM ON time is determined by the voltage on the Level pin.

$$I_{LED} = V_{Level} / (5 \cdot R_3)$$

With the 10- Ω current sense resistors shown in Figure 2, a voltage of 1 V applied to Level will result in 20-mA current per LED leg. LED current can be increased by reducing the value of the current sense resistors, or by increasing V_{Level} .

The op amps selected for this application must be able to function with input voltages near ground. The op amps will typically be single-supply type, powered from the EL7801 V_{DC} output. Therefore a rail-to-rail op amp is suggested (for instance, Intersil EL5220CY). With this circuit, leg-to-leg current matching is primarily a function of the op amp's input offset error, so an op amp with a low V_{OS} specification is preferred.

The op amp output slew rate is

also an important consideration to maximize system efficiency and dimming linearity, and becomes increasingly important as the frequency of the PWM dimming signal increases.

Diodes D_2 through D_5 identify the LED string that exhibits the greatest combined forward-voltage drop. The voltage at the bottom of this LED string also appears at the cathode of D_6 . During the PWM dimming-signal's on-time, ENL is driven to 5 V, turning Q_5 on. The control loop of the EL7801 will then increase the switching duty cycle until V_{FB} reaches the desired voltage level. At this time, the voltage across R_8 becomes equal to the minimum drain-source voltage of the four current-sink MOSFETs (Q_1 through Q_4). Therefore, the value of resistor R_8 determines the minimum voltage that will appear across any of the current-sink MOSFETs.

To increase efficiency of the system, the value of R_8 can be reduced. However, the

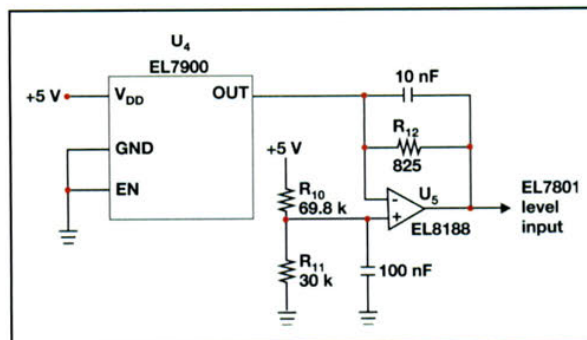


Fig 3: A light sensor can be used to control LED current.



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ratio of R_8 to R_9 must be greater than the ratio of the current-sink MOSFET $R_{DS(ON)}$ to the current-sense resistors ($10\ \Omega$ in this example), in order for the circuit to generate equal current in each LED string.

Since the voltage across each of the $10\text{-}\Omega$ resistors at R_3 through R_6 is equal to the feedback voltage, the legs that exhibit a lower combined LED forward-voltage drop will see an increased drain-source voltage at the current-sink MOSFETs. The designer should consider the LED forward-voltage tolerance across the operating temperature and desired LED current ranges, and select current-sink MOSFETs capable of handling the worst-case power-dissipation condition.

During the PWM OFF time, the ENL signal is driven low, turning off Q_5 . The voltage across R_9 then becomes zero. The voltage-controlled current-sink circuits respond, in turn, by driving the gate of the connected MOSFETs low, disabling the current flow through the LEDs.

Capacitors C_4 and C_5 allow some of the output voltage ripple to appear at the feedback circuit node, and this helps stabilize the EL7801 control loop. The EL7801 employs a direct-summing control loop with current feedback. No error amplifier is used in the system. This arrangement provides fast transient response and makes use of the output capacitor to close the loop. A combination of ceramic and low-ESR electrolytic capacitors can be used to minimize implementation costs. Generally, the higher numbers of LEDs, lower V_{FB} voltages and smaller values of current sense resistors will require smaller-value output capacitors to achieve loop stability. In the circuit depicted above, with 20 mA of LED current per leg, a total of $40\ \mu\text{F}$ of capacitance at C_3 is recommended.

It may be desirable to sense the actual light output of the LEDs, and adjust the LED current to maintain a precise level of luminous intensity. A method of controlling LED current with a light sensor IC is shown in **Figure 3**.

The circuit shown in Figure 3 can replace the fixed-voltage divider at the Level input depicted in Figures 1 and 2, to provide a method of maintaining a constant light out-

put. The EL7900 is a light-to-current optical sensor combining a photodiode and current amplifier on a single monolithic IC. Output current is directly proportional to the light intensity on the photodiode.

$$I_{OUT} = E_V \cdot (60\ \mu\text{A} / 100\text{ lux})$$

Where E_V is illuminance in lux

The op amp at U_5 is configured as a

current-to-voltage converter. The voltage divider formed by resistors R_{10} and R_{11} sets the output voltage when no light is present at the EL7900 sensor. With the values of R_{10} and R_{11} shown, the output of U_5 is 1.5 V when there is no light present. Resis-

tor R_{12} is selected to provide the desired gain of the system.

$$V_{OUT} = V_{REF} - (E_V \cdot R_{12} \cdot (60\ \mu\text{A} / 100\text{ lux}))$$

where V_{REF} is the voltage at the non-inverting input of U_5 .

The component values shown in Figure 3 were selected to provide a 1-V output at $1,000\text{-lux}$ light input. When light intensity increases, the output voltage of this light-sensing circuit decreases, and the attached EL7801 circuit will respond by decreasing the switching-duty cycle, thus reducing LED current, (see **Table**).

Conclusion

In conclusion, devices such as Intersil's EL7801 LED backlight driver are highly versatile and can be used in a variety of applications, including those that require power for more than eight LEDs. When used in conjunction with an EL7900 light-to-current sensor, these devices can easily implement applications that require a constant light output. ■

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Table: Luminance vs. output voltage

E_V (illuminance, in lux)	V_{OUT}
0	1.500
100	1.451
200	1.401
500	1.253
1,000	1.005
2,000	0.510
3,000	0.015