BIAS SUPPLY CIRCUITS PORTABLE POWER
POWER-SUPPLY CIRCUITS

Application Note 1804: Dec 06, 2002

Driving LEDs in Battery-Operated Applications: Controlling Brightness Power Efficiently

White light-emitting diode (LED) drivers provide high efficiency and brightness matching for LCD backlighting in displays. To control brightness, these drivers regulate current going into LEDs that are arranged in either serial or parallel configuration. Charge pumps drives parallel LEDs whose currents are regulated with individual regulators or simple ballast resistors. Inductor based converters deliver current to a string of LEDs, inherently equal. Both configurations aim to drive LEDs efficiently for cell phones, PDAs and digital still cameras.

This application note describes how LEDs (including white LEDs) work and how to drive them in battery-powered LED applications, including lithium-ion (Li+, or Li-ion), nickel-cadmium (NiCd), and nickel-metal-hydride (NiMH) rechargeable hand-held devices, where power consumption is important. It discusses LED brightness-matching, the value of series vs. parallel LEDs, and gives application information for several LED drivers that can drive and control LEDs in an efficient manner.

About LEDs

Light-emitting diodes (LEDs) are the solid-state, highly reliable, efficient counterparts of the evacuated tungsten-filament light bulb.

Epitaxial material based on gallium arsenide phosphide (GaAsP) produces red, green or yellow outputs (Figure 1). Material based on indium gallium nitrate (InGaN) produces blue or white outputs (Figure 2). Different chemistries also produce different electrical characteristics.

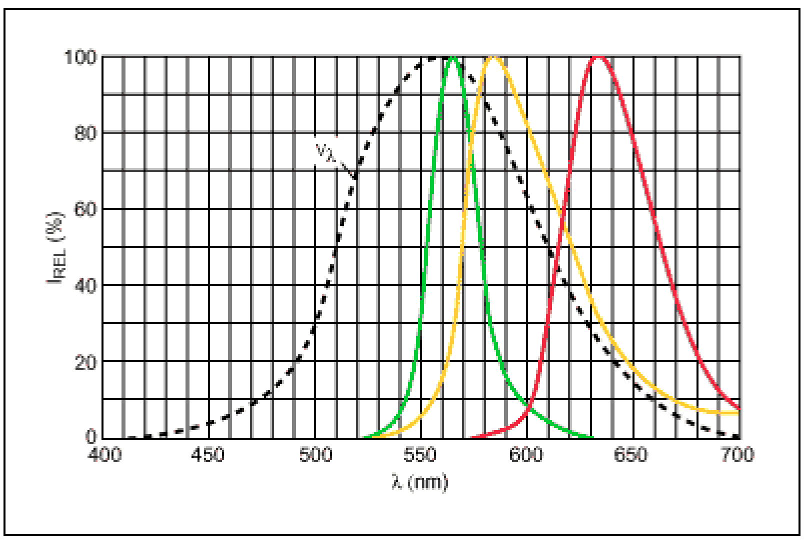

Figure 1. Relative spectral response of red, green and yellow diodes (I_F = 2mA, T_A = 25°C).

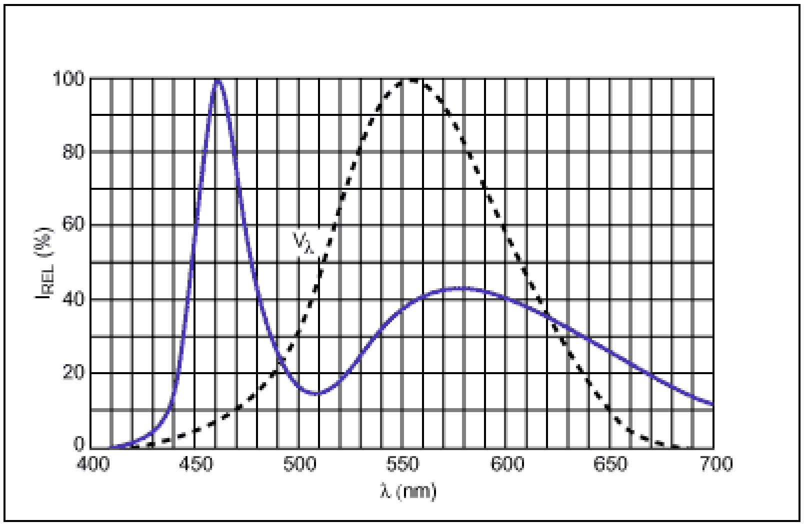

Figure 2. Relative spectral response of white diodes (I_F = 20mA, T_A = 25°C).

In Figures 1 and 2, the curve V(**λ**) represents the standard response of a human eye. To obtain white light, you cover a blue emitter with material that emits yellow light when stimulated by blue light. By interpreting this combination as white, the eye creates the spectral response of Figure 2.

Biasing the Diodes

LEDs are current-driven devices in which the light output (luminous intensity in millicandelas) depends directly on the forward current passing through them. A simple biasing circuit that maintains the current (and consequently the light output) at a reasonably constant value, matches the intended power supply with a single current-limiting resistor connected in series with the LED (Figure 3):

$$I_{DIODE} = \frac{V_{SOURCE} - V_F}{R_{LIM} + R_{DS(ON)}}$$

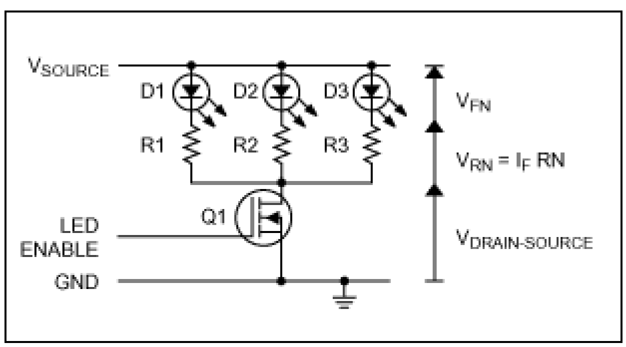

Figure 3. LED biasing with a single resistor per LED.

This method offers low cost, but allows current variations due to the spread of V_F values associated with different diodes. Figures 4 and 5, which illustrate typical forward voltage characteristics vs. forward current, show the variation at 25°C. At the currents specified, the maximum values of V_F rise to 2.7V (+40%) for the GaAsP diode and to 4.2V (+20%) for the InGaN diode. For systems that require multiple diodes, such as a cellphone display backlight (eight diodes), the extra resistors occupy a considerable amount of printed circuit board area.

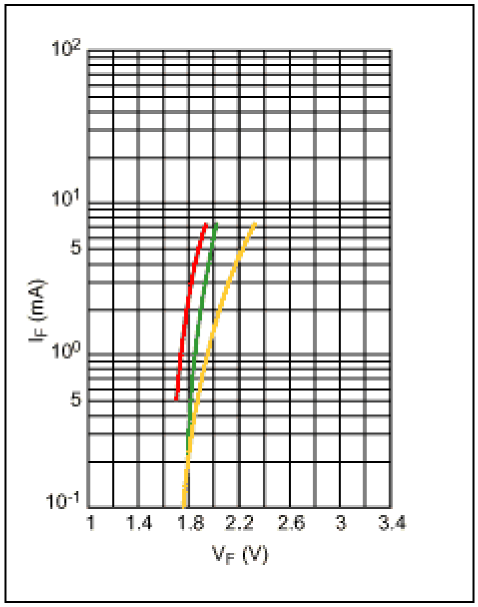

Figure 4. Typical GaAsP forward voltage vs. forward current, at 25°C.

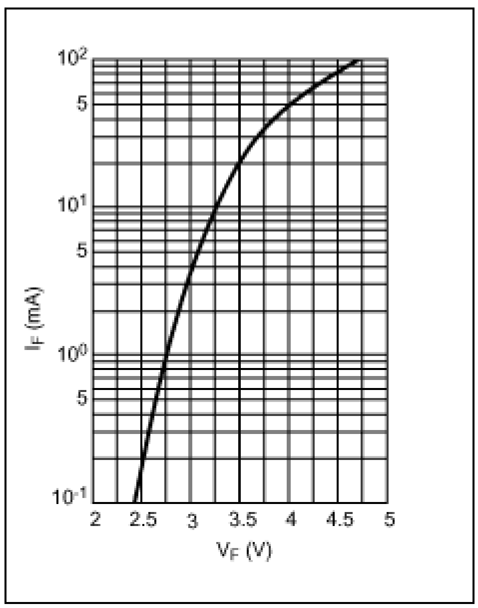

Figure 5. Typical InGaN forward voltage vs. forward current, at 25°C.

You can reduce the effect of V_F variation by increasing the value of V_{SOURCE} beyond $10V_F$. That approach wastes power, however, and is incompatible with a low-voltage battery supply such as a single Li+ cell. The Li+ terminal voltage varies from 3.4V when fully charged to 3V when discharged, so an LED powered by this supply with simple resistor biasing will exhibit a noticeable variation in light output. A better approach (for improving dropout and stabilizing the variation of light intensity with supply voltage) is to employ current biasing.

Current Biasing

As the name of this technique suggests, the LEDs are connected to a current source. Assuming the current source has an adequate dynamic range, this biasing method eliminates the effect of V_F variations. Thus, the individual resistors shown in Figure 5 are replaced with individual current sources (Figure 6). Light output is therefore independent of supply and forward voltages, assuming a sufficient supply voltage to bias the current sources and LEDs. As before, Q1 provides an enable switch.

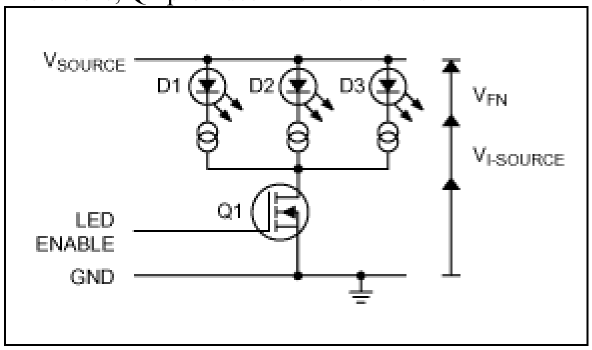

Figure 6. LED biasing with current sources.

An IC (MAX1916) offers the modern approach to LED current biasing. Integrating three current sources in a small SOT23-6 surface-mount package (Figure 7), it implements the current-source approach of Figure 6. Current in the SET resistor is mirrored at the three OUT terminals. These current mirrors embody the principle that if the gate-source potentials for N identical MOS transistors are equal, their channel currents should also be equal. As a further advantage, if the mirrored MOS devices (Q2, Q3, Q4) are M times bigger than the mirror MOS device (Q1), then the output current is M times greater than the mirror current (I_{SET}). Finally, an integrated circuit achieves more accurate current ratios than does a discrete circuit.

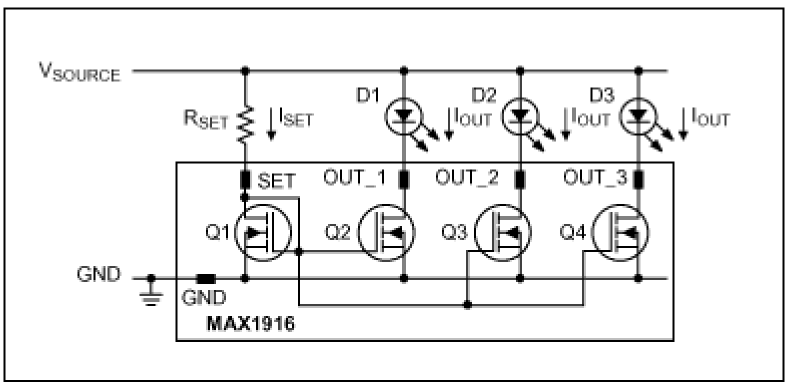

Figure 7. Simplified diagram of MAX1916 LED current mirrors.

The maximum OUT-current mismatch in the MAX1916 is ±5%, and the "mirror constant" is typically 200A/A. In other words, 50µA at the SET terminal produces 10mA ±5% (maximum) at each of the OUT terminals. The SET terminal is internally biased to 1.25V, producing a SET current of:

$$I_{SET} = \frac{V_{SOURCE} - 1.25V}{R_{SET}}.$$

Tolerance on the 1.25V reference is ±5%.

$$I_{OUT} = 200 I_{SET}.$$

Tolerance between the outputs is ±5%.

The OUT-terminal saturation voltage is simply

$$V_{OUT(SAT)} = R_{DRAIN\text{-}SOURCE} \cdot I_{OUT}.$$

Drain-to-source resistance in the MAX1916 is 50Ω maximum over temperature. Thus, a low-current GaAsP diode operating at 2mA requires a minimum voltage of V_F + 100mV to operate correctly, and LED operation can be maintained down to 2.71V. The low dropout value (100mV at 2mA, 1V at 20mA) illustrates the MAX1916 ability to remain in regulation down to very low drain-source voltages.

To achieve a lower dropout voltage and higher output current, the MAX1916 outputs can be connected in parallel with a mirror constant of 600 (Figure 8). Drain-to-source resistance of the parallel outputs is 50/3 = 16.67Ω maximum over temperature. That connection allows a single white LED to operate from 3V at high current (>20mA). (Such LEDs are found in portable cellular-radio backlight applications using optical light-pipe technology.)

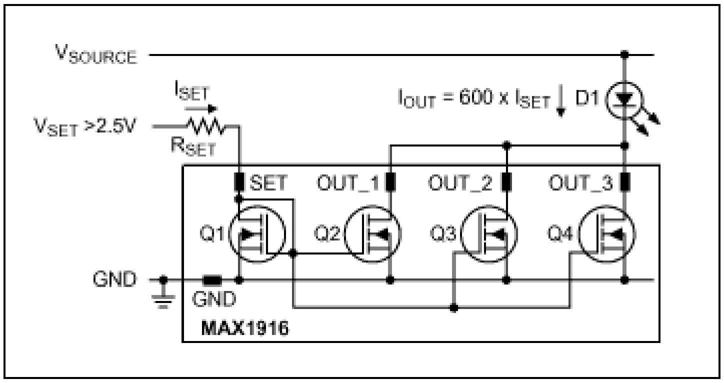

Figure 8. Parallel outputs provide lower saturation and higher current gain.

The voltage supply for the set current terminal may be derived separately from the main high-current supply. For a MAX1916 operating in a cellular radio, for example, V_{SET} may be obtained from the RF circuit's low-noise +2.8V power supply. When powered directly from a single Li+ battery, the MAX1916 is suitable for operation with GaAsP low-forward-drop LEDs. A different approach is required for InGaN white LEDs powered from a lithium battery, because the input voltage may be insufficient to bias those LEDs.

Inductor-Free Boosted Supply for White LEDs

A boosted supply is required for white LED applications, because the forward voltage (3.5V to 4.2V at 20mA) is higher than that of other LED types. You can implement such a supply by combining the MAX1916 with a regulating charge pump from the MAX682-MAX684 family. Output currents are 250mA, 100mA, or 50mA respectively, and the output voltage is 5.05V from a minimum 2.7V input voltage (Figure 9). Shutdown can be commanded via the MAX684 shutdown terminal or via the MAX1916's EN control. High-frequency operation reduces the capacitor values considerably: for a MAX684 operating with I_{SHDN}/ = 22µA at 1MHz, C_{IN} = 220nF, C_{PUMP} = 100nF, and C_{OUT} = 470nF. With R_{SET} = 43k as shown, the LED current is 22mA.

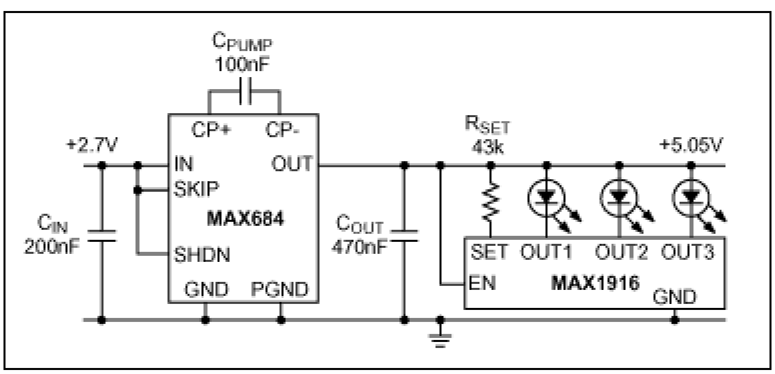

Figure 9. Charge pump helps control three LEDs.

As an alternative, a new high-frequency charge pump (MAX1910, MAX1912) provides a fixed output of 5V at 60mA maximum from inputs in the range 2.7V to 5.3V. The capacitor values are small, thanks to fixed-frequency operation at 750kHz. A unique control scheme limits the input current ripple.

A charge-pump boost circuit for current control of the LED (Figure 10) produces a typical regulating feedback voltage of 1.235V. Thus, $I_{PK} = 1.235/R_{SENSE}$. A 24Ω current-sense resistor produces a 50mA current through the diode.

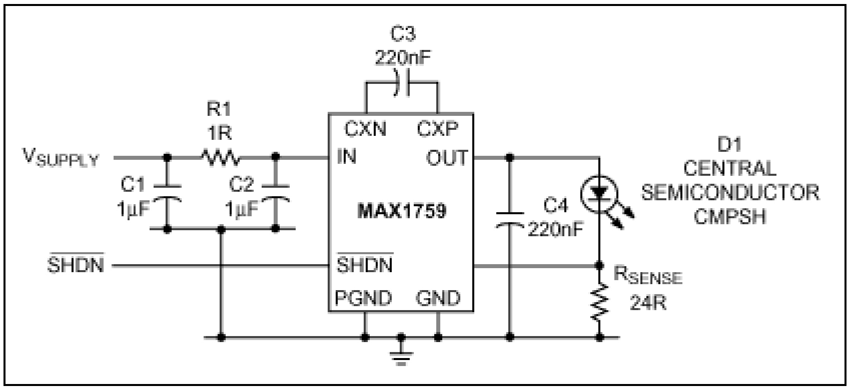

Figure 10. Peak current-bias regulation with boost charge pump drives single white LED.

In operation, the boosted output voltage rises until the LED begins to conduct. At the regulation point, boost action stops until the next cycle. Typical white LEDs require a forward bias (V_F) of 3.5V ±10%. Added to the feedback regulating voltage, that bias produces 4.735V at the MAX1759 output pin. Output ripple is acceptable in this circuit because the level present (40mV) does not produce LED-output variations visible to the eye—especially given the small value of the output capacitor. The Figure 10 circuit also eliminates an input-output path otherwise present during shutdown.

Inductor-Based White-LED Controller

Combining a boost converter and current control in a 6-pin SOT23 IC, the MAX1848 uses current sensing to drive as many as three strings of three white LEDs from an input supply in the range 2.6V to 5.5V (Figure 11). The MAX1848 boost converter employs voltage feedback to regulate current into the LEDs. A sense resistor of low value (5Ω) saves power and maintains efficiency. Analog control sets the overall LED brightness.

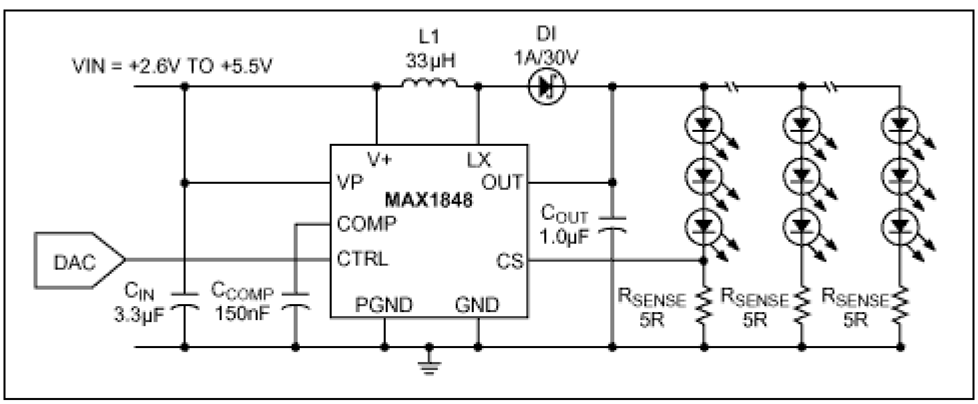

Figure 11. Inductor-based current regulation with boost PWM DC-DC converter drives multiple LEDs.

In a typical application L1 = 33µH, D1 is a 30V, 1A Schottky diode, C_{IN} = 3.3µF, C_{COMP} = 150nF, C_{OUT} = 1.0µF, and R_{SENSE} = 5Ω. LED current is related to the control voltage:

$$I_{OUT} = V_{CTRL} / 13.33R_{SENSE}.$$

Brightness is controlled by a DAC or a fixed potential divider on the CTRL pin. The voltage control range is +250mV to +5.5V, and shutdown is accomplished by grounding the control pin. Circuit efficiency while delivering 800mW to the load is as high as 88%.

Inductor-Based White-LED Controller

An IC suitable for controlling a variety of LED configurations (MAX1916) is a triple n-channel, variable current source. It controls red, green and yellow GaAsP LEDs directly from a single Li-ion battery, and when combined with a suitable charge-pump boost converter it controls white InGaN LEDs. For higher-power applications in which as many as nine white LEDs are controlled from a Li-ion battery, the inductor-based MAX1848 enables a minimum-component-count circuit that delivers 800mW output power with 88% efficiency.

A similar version of this article appeared in the November 2002 issue of *El Norden* magazine.

A288, December 2002

MORE INFORMATION

MAX1759:	QuickView	-- Full (PDF) Data Sheet (248k)	-- Free Sample
MAX1848:	QuickView	-- Full (PDF) Data Sheet (336k)	-- Free Sample
MAX1910:	QuickView	-- Full (PDF) Data Sheet (328k)	-- Free Sample
MAX1912:	QuickView	-- Full (PDF) Data Sheet (328k)	-- Free Sample
MAX1916:	QuickView	-- Full (PDF) Data Sheet (224k)	-- Free Sample
MAX682:	QuickView	-- Full (PDF) Data Sheet (168k)	-- Free Sample
MAX683:	QuickView	-- Full (PDF) Data Sheet (168k)	-- Free Sample
MAX684:	QuickView	-- Full (PDF) Data Sheet (168k)	-- Free Sample