electronic design

LED Power-Management Strategies For LCD Backlighting

Most small-size color LCD displays today use white LEDs for backlighting. These systems usually involve handheld devices with an LED drive circuit powered by a battery whose output voltage varies over time. Therefore, an optimum LED driver design requires a system approach covering:

- Battery type
- LCD characteristics
- System power requirements and efficiency
- LED driver IC and its external components
- Printed-circuit-board (pc-board) layout and component placement
- Possible noise generated by the LED driver
- RF immunity in cell-phone applications

Nowadays, lithium-ion (Li-ion) batteries are the most widely used batteries. These batteries start at 4.2 V when they're fully charged, but they drop down to 3.2 V when discharged. Therefore, the driver circuit must operate properly over this input voltage range.

Power requirements affect LED brightness and efficiency. An LED's light output is proportional to its current, so uniform brightness requires dedicated drive circuitry that controls a constant current for every member of the LED array. This must remain true for exposure to cold temperature or when the battery is low.

In most backlight designs, white LEDs are spaced evenly along one side of the LCD. The number of LEDs is proportional to the dimensions of the LCD. Some LCDs have integrated LEDs already connected in series or in parallel. Typically, larger-size LCDs require serial topologies, sometimes with multiple strings in parallel.

A serial configuration has the benefit of ensuring that all LEDs in a string have the same current. Thus, they will exhibit similar brightness throughout the panel. Serial topologies have the advantage of minimizing the number of connections to the LCD. This is usually accomplished with a flex pc board that results in smaller size and lower cost.

This article describes how to best optimize the drive circuit for LED backlighting an LCD panel. That means acquiring a better understanding of drive topologies, as well as battery and LCD characteristics. Among the topics discussed are charge-pump efficiency, inductive boost topologies, and selection of inductors.

LED Configuration and Driver IC

Small, white LEDs for backlighting typically exhibit forward voltages of 3.4 V at 20 mA. These LEDs may require a higher voltage than that available from the battery, so their drive voltage must get a boost. There are two ways to increase LED voltage in LCD designs: use a capacitive charge-pump topology or an inductive boost converter. Series topologies often employ inductive boost LED drivers, while parallel LED topologies typically go with fractional charge-pump ICs. The LCD configuration and overall system requirements usually dictate the choice of charge pump or inductive boost converter approach. A charge pump is usually easier to implement and guarantees lower noise performance, whereas the inductive boost converter generally exhibits higher efficiency.

Figure 1 shows a typical circuit for backlighting a two-inch cell-phone LCD incorporating a fractional charge pump. The charge pump is attractive because it requires a small number of external components and minimal pc-board real estate. Meeting this goal today are 3-mm by 3-mm driver ICs and 0402-size capacitors.

The 1X/1.5X fractional charge pump supports two modes of operation with automatic mode selection, depending on the battery input voltage as well as the LED forward voltage. Typically, when the

HIGHLIGHTS

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Charge-Pump Efficiency

Charge-pump efficiency is the ratio of the output-to-input power:

$$\text{Efficiency} = P_{LED}/P_{IN} = P_{LED}/(V_{IN} \times I_{IN})$$

where P_{LED} = LED power and P_{IN} = input power. Therefore, for a given LED current and V_{IN}, an input current increase reduces circuit efficiency. There are two methods for adjusting LED current to increase efficiency. One uses an external resistor. The other is to control the driver with pulse-width modulation, which controls LED current and brightness.

Inductive Boost Topology

For larger LCDs, or battery-powered devices where efficiency is critical, the preferred solution is the inductive boost-converter IC for series-connected LEDs. With an inductive boost converter, an inductor boosts the input voltage by transferring the energy from the input to the output.

Inductor Selection

Generally, larger-size inductors handle higher currents and generate less loss. Small-dimension inductors are often desirable on the pc-board from a design standpoint, but they aren't always recommended. When excessive current flows through the inductor, its inductance decreases and acts less as an inductor and more like a simple resistor due to the magnetic core saturation.

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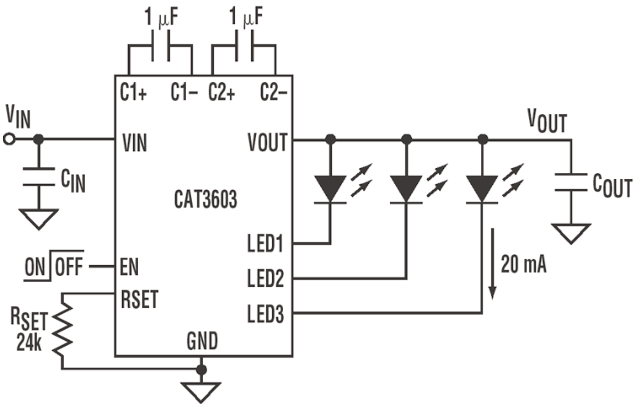

Fig. 1 A fractional charge-pump IC provides three parallel outputs for white LEDs.

battery voltage exceeds 3.6 V, the driver operates in "1X mode" where the supply is directly connected to the output via a pass transistor. This linear mode exhibits the highest efficiency and lowest noise.

When the battery voltage drops below 3.6 V, the driver transitions from 1X mode to 1.5X mode, boosting the output to 1.5 times the battery input voltage. It uses a switching scheme with two flying capacitors (C1 and C2 in Figure 1) that transfer energy to the load. During the transition, the input current steps up 1.5 times, causing the battery to discharge faster. For example, with three LEDs at 20 mA, the supply current is about 60 mA in 1X mode, and goes up to about 90 mA in 1.5X mode.

Charge-Pump Efficiency

Charge-pump efficiency is the ratio of the output-to-input power:

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Under normal conditions, most white LEDs have a forward voltage (V_F) between 3 and 3.6 V. Lower V_F LEDs allow the driver to operate longer in 1X mode, which has better efficiency. Ambient temperature also affects the forward voltage with a coefficient of about -7 mV/°C, causing VF to increase at a lower temperature.

The 1.5X mode guarantees a regulated and accurate current in the LEDs. Any switching noise reflects back onto the supply, but is mostly filtered by the input capacitor. Charge-pump solutions are desirable when low-noise performance is critical, such as in RF communication devices.

There are two methods for adjusting LED current. One uses an external resistor $R_{SET,}$ as shown in Figure 1. The other approach is to control the driver with pulse-width modulation (PWM) that controls LED current and brightness.

Component placement is critical. Therefore, all four capacitors (Fig. 1, again) should be placed close to the LED driver IC. When the driver operates in 1.5X mode, switching current flows through the flying capacitors (C1 and C2). Therefore, the loop areas should be as small as possible to avoid any interference. Because of their low equivalent series resistances (ESRs), use ceramic capacitors (X5R or X7R dielectric material) rather than tantalum types. You can locate these LEDs remotely with no degradation to the LED current, which is dc (making EMI a non-issue).

The driver will amplify noise in the R_{SET} resistor, resulting in LED current noise that flows back into the supply, which leads to potential RF interference in cell-phone applications. The cell phone's RF section should not be placed close to the R_{SET} resistor. The R_{SET} resistor should be tied directly to the ground plane with a minimum loop area and avoid any current path.

Inductive Boost Topology

For larger LCDs, or battery-powered devices where efficiency is critical, the preferred solution is the inductive boost-converter IC for series-connected LEDs. Figure 2 shows an example of an application circuit for a 4-in. LCD that has eight LEDs in series, which is compatible with single Li-ion batteries.

With the inductive boost converter, an inductor boosts the input voltage by transferring the energy from the input to the output. An integrated power-FET switch inside the driver lies between the SW pin and ground. When the switch turns on, the inductor current ramps up. When the switch turns off (open), inductor current discharges through the Schottky diode into the output capacitor. Output capacitor C2 maintains a dc output voltage with small ripple. LED current is mainly dc, allowing the LED to be placed away from the driver without causing EMI.

For best performance, place all other components—inductor, Schottky diode, and input and output capacitors—close to the driver IC. High current flowing though the inductor creates a magnetic field that can be an EMI source. Resistor R1, located between the regulated feedback (FB pin) and ground, sets the LED current as $I_{LED} = V_{FB} / R1$. To prevent coupling noise from amplifying inside the driver, connect R1 directly to the ground pin of the driver.

Inductor Selection

In Figure 2, the recommended inductance value is 33 μH, which is usually indicated in the LED driver data sheet along with its current rating. Generally, larger-size inductors handle higher currents and generate less loss. Small-dimension inductors are often desirable on the PCB from a design standpoint, but aren't always recommended. When excessive current flows through the inductor, its inductance decreases and acts less as an inductor and more like a simple resistor due to the magnetic core saturation.

The increase of current (di/dt) is set by the ratio V/L, where V is the voltage across the inductor L. Steeper current slopes cause higher peak currents with spikes flowing through the internal switch, and may damage the driver or other components in the system. Inductor current rating (also called saturation current) is an indication of the recommended maximum peak current.

To select the smallest inductor size for the application, the peak current should be within the current rating of the inductor. For a given load, the lowest input voltage determines the highest input current or the worst-case condition. For example, using the previous application circuit, Figure 3 shows switching waveforms for the inductor current and the SW pin voltage when powered from a low V_{IN} at 3.1 V.

Figure 3a shows normal operation at 320 mA, peak, with a 33-μH inductor rated at 320 mA and no inductor saturation.

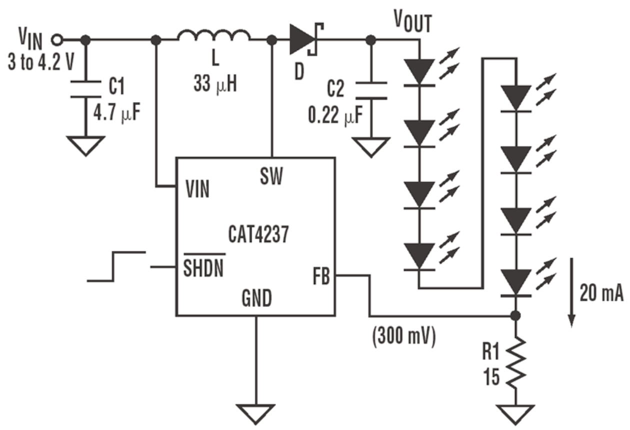

Fig. 2 A boost-converter IC supplies a single output for eight white backlighting LEDs in series.

Figure 3b shows operation with inductor core saturation at a peak current around 450 mA. In practice, you can monitor inductor current with a clamp-on current probe placed on a connecting a wire between the inductor and the power supply. This measurement should be done under the worst-case condition, which is when V_{IN} is at the low end of the range and the load current is maximum. The current waveform is then seen on the oscilloscope connected to the probe, like the waveforms shown in Figure 3.

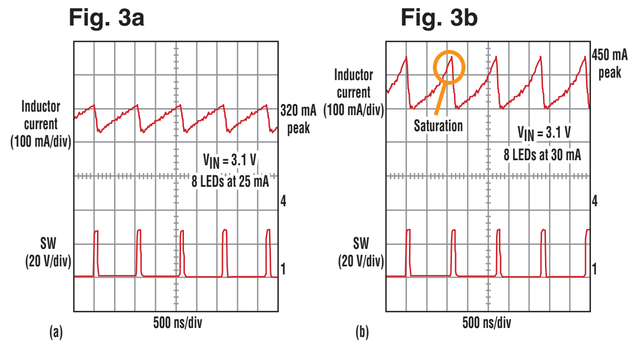

Fig 3. Switching waveforms for inductor current are shown for normal (a) and saturated (b) operation.

Boost Ratio and Efficiency

When driving long strings of LEDs at high current, operation from higher supply voltages is better because it reduces the input current. For example: $I_{IN} = P_{LED} / (H \times V_{IN})$ where I_{IN} = dc average input current; V_{IN} = input voltage; H = driver efficiency; and P_{LED} = output power.

Therefore, going from a 3-V to a 6-V supply cuts I_{IN} by one-half. Inductive boost converters have a switch current limit for internal protection that limits input current. As a result, the only way to increase the output power, or LED current, is to use a higher input voltage (Fig. 4).

Another benefit of driving LEDs from a higher supply voltage is that efficiency is usually higher when the ratio V_{OUT} / V_{IN} is lower. For example, when going from 3-V to 5-V supply, the efficiency increases about 5% due to decreasing power losses. Some power losses occur in the driver IC because its internal switch resistance $R_{DS(ON)}$ causes an IR drop. Also, switching losses arise that are proportional to the switching frequency.

Both losses cause the driver-IC temperature to increase slightly, which usually isn't an issue since the driver itself dissipates only a small fraction (less than 10%) of the overall power. The inductor also dissipates power due to its series resistance, also resulting in the inductor case temperature increase. A minor loss occurs in the Schottky diode because of its turn-on forward voltage drop (less than 0.5V). Overall, efficiency is good for inductive solutions, with typical values between 80 and 90% depending on the test conditions and components used.

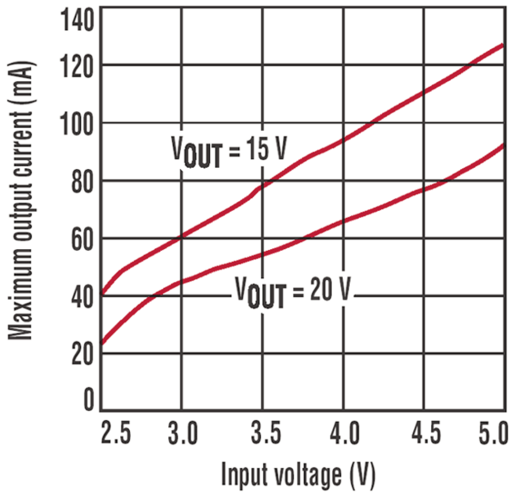

Fig. 4 As indicated by the graph, a higher input voltage is needed to increase power output when using inductive boost converters.

There's a limit as to how much the input voltage can be multiplied to get to a high output voltage, which is set by the boost converter's maximum duty cycle. The duty cycle D is defined as the ratio of the switch on-time TON to the switching period T ($D = T_{ON} / T$), and the input-to-output voltage ratio of the boost converter is:

$$V_{IN} / V_{OUT} = 1 - D$$

where V_{IN} = input voltage and V_{OUT} = output voltage. For example, a maximum duty cycle of 90% is equivalent to a V_{IN} to V_{OUT} boost ratio of 10. In other words, from a 3-V supply, the theoretical maximum output is about 30 V.

For a small-size LCD backlight, we may first consider parallel LEDs, where charge-pump drivers offer the easiest design path with small and low-cost solutions. With serial strings of three to 10 LEDs, an inductive boost converter demands more work. But, the end result is slightly better efficiency. There's not a clear dominance in the market for serial or parallel LED configuration. In the future, we will see LEDs replacing CCFL in backlight applications for larger displays, such as found in car-navigation systems and notebook computers. These larger panels will favor implementation with a serial string of LEDs due to their easier interconnection and the higher efficiency in the driver circuit.