

±32V Triple-Output Supply for LCDs, CCDs and LEDs Includes Fault Protection in a 3mm × 3mm QFN

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Introduction

The task of designing a battery powered system with multiple high voltage supplies is a daunting one. In such systems board space is at a premium and high efficiency is required to extend battery life. Supplies must be sequenced in start-up and shut-down, and multiple supplies must be able to maintain regulation without interaction across supplies.

The LT3587 is a 1-chip solution that combines three switching regulators and three internal high voltage switches to produce two high voltage boost converters and a single high voltage inverter. The LT3587 is designed to run from inputs ranging from 2.5V to 6V, making it ideal for battery powered systems. Small package size and low

component count produces a small, efficient solution. Typical applications include digital still and video cameras, high performance portable scanners and display systems, PDAs, cellular phones and handheld computers that have high voltage peripherals such as CCD sensors, LED backlights, LCD displays or OLED displays.

Features

To keep the component count low, the LT3587 integrates three high voltage power switches capable of switching 0.5A, 1A and 1.1A at up to 32V in a 3mm × 3mm QFN package. Each of the positive channels includes an output disconnect to prevent a direct DC path from input to output when

the switches are disabled. The LT3587 also includes a bidirectional fault pin (FLT), which can be used for fault indication (output) or for emergency shutdown (input).

The LT3587 offers a wide output range, up to 32V for the positive channels (channels 1 and 3) and -32V for the inverter (channel 2). Channel 3 is configurable as either a voltage or current regulator. When configured as a current regulator, channel 3 uses a 1-wire output that requires no current sense or high current ground return lines, easing board layout. A single resistor programs each of the three channels output voltage levels and/or the channel 3 output current level.

Intelligent soft-start allows for sequential soft-start of channel 1 followed by the inverter negative output using a single capacitor. Internal sequencing circuitry disables the inverter until channel 1 output has reached 87% of its final value.

Triple-Output Supply for CCD Imager and LED Backlight

Figure 1 shows a typical application providing a positive and negative voltage bias for a CCD imager and a 20mA current bias for an LED backlight. All three channels of the LT3587 use a constant frequency, current mode control scheme to provide voltage and/or current regulation at the output.

The positive CCD bias is configured as a simple non-synchronous boost converter. Its output voltage is set to 15V via the feedback resistor R_{FB1} . The 15μH inductor (L1) is sized for a maximum load of 50mA. The negative CCD bias is configured as a non-synchronous Ćuk converter. Its output voltage is set at -8V using the feedback resistor R_{FB2} . The two 15μH

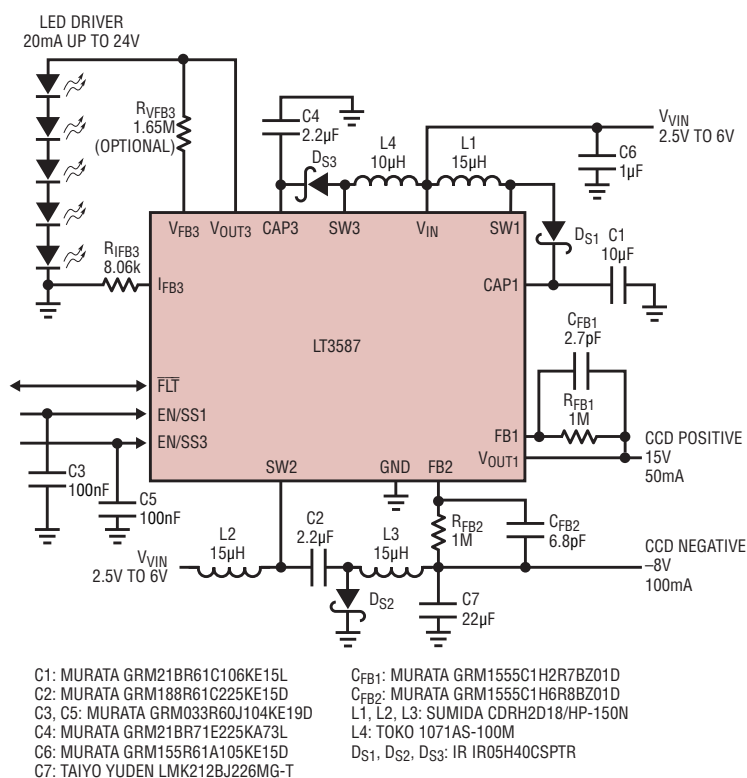


Figure 1. Solution for a Li-Ion powered camera provides positive and negative supplies for biasing a CCD imager and an LED driver for a 5-LED backlight

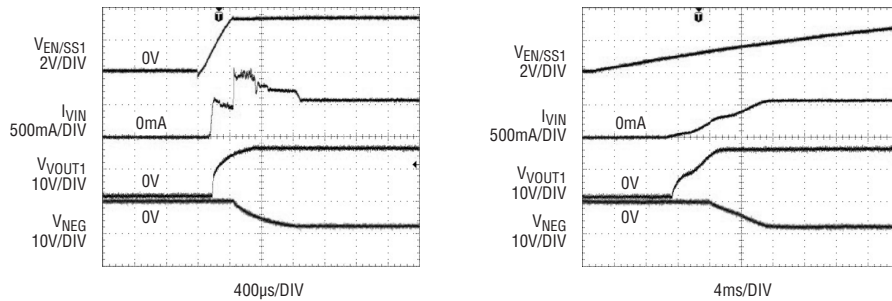


Figure 2. Start-up waveforms with no soft-start capacitor, and with a 10nF soft-start capacitor

(L2 and L3) inductors are sized for a maximum load of 100mA.

The LED backlight driver is configured as an output-current-regulated boost converter. Its output current is set at 20mA using the current programming resistor R_{IFB3} . The 10µH inductor (L4) is sized for a typical load of 20mA at up to 24V. Note the optional voltage feedback resistor, R_{VFB3} , on the LED driver. This resistor acts as a voltage clamp on the LED driver output, so that if one of the LED fails open, the voltage on the LED driver output is clamped to 24V.

Soft-Start

All channels feature soft-start (a slow voltage ramp from zero to regulation) to prevent potentially damaging large inrush currents at start-up. Soft-start is implemented via two separate soft-start control pins: EN/SS1 and EN/SS3. The EN/SS1 pin controls the soft-start for channel 1 and the inverter, while the EN/SS3 pin controls the soft-start for channel 3. Both of these soft-start pins are pulled up with a 1µA internal current source.

A capacitor from the EN/SS1 pin to ground (C3 in Figure 1) programs a soft-start ramp for channel 1 and channel 2 (the inverter). As the 1µA current source charges up the capacitor, the regulation loops for channel 1 and channel 2 are enabled when the EN/SS1 pin voltage rises above 200mV. During start-up, the peak switch current for channel 1 proportionally rises with the soft-start voltage ramp at the EN/SS1 pin. The inverter switch current also follows the voltage ramp at the EN/SS1 pin, but its switch current ramp does not start until the

voltage on the EN/SS1 pin is at least 600mV. This ensures that channel 2 starts up after channel 1. Channel 1 and channel 2 regulation loops are free running with full inductor current when the voltage at the EN/SS1 pin is above 2.5V.

In a similar fashion, a capacitor from the EN/SS3 pin to ground (C5 in Figure 1) sets up a soft-start ramp for channel 3. When the voltage at the EN/SS3 pins goes above 200mV, regulation loop for channel 3 is enabled. When the voltage at the EN/SS3 pin is above 2V, the regulation loop for channel 3 is free running with full inductor current.

Start-Up Sequencing

The LT3587 also includes internal sequencing circuitry that inhibits the channel 2 from operating until the feedback voltage of channel 1 (at the FB1 pin) reaches about 1.1V (about

87% of the final voltage). The size of the soft-start capacitor controls channel 2 start-up behavior.

If there is no soft-start capacitor, or a very small capacitor, then the negative channel starts up immediately with full inductor current when the positive output reaches 87% of its final value. If a large soft-start capacitor is used, then the EN/SS1 voltage controls the inverter channel past the point of regulation of the positive channel. Figure 2 shows the start-up sequencing without soft-start and with a 10nF soft-start capacitor.

Output Disconnect

Both of the positive channels (channels 1 and 3) have an output disconnect between their respective CAP and V_{OUT} pins. This disconnect feature prevents a DC path from forming between V_{IN} and V_{OUT} through the inductors when switching is disabled (Figure 1).

For channel 1, this output disconnect feature is implemented using a PMOS (M1) as shown in the partial block diagram in Figure 3. When turned on, M1 normally provides a low resistance, low power dissipation path for delivering output current between the CAP1 pin and the V_{OUT1} pin. M1 is on as long as the voltage difference between CAP1 and V_{IN} is greater than 2.5V. This allows the positive bias to stay high as long as possible while the negative bias discharges during turn off.

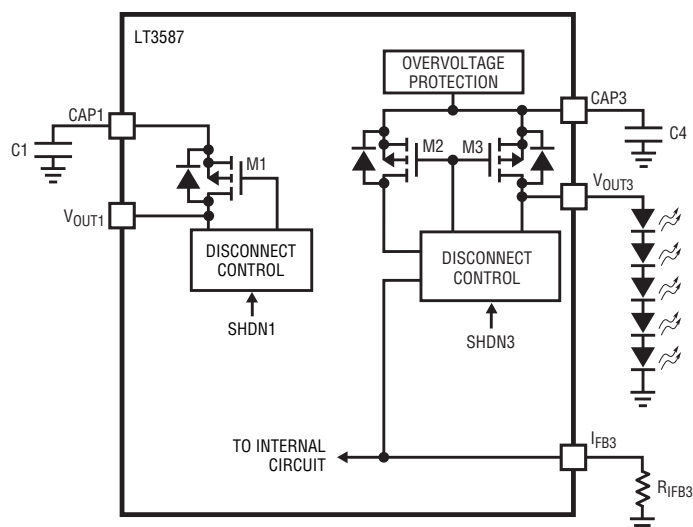


Figure 3. Partial block diagram of the LT3587 showing the disconnect PMOS for channels 1 and 3

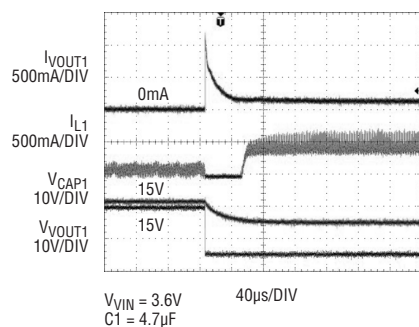


Figure 4. Channel 1 short circuit event

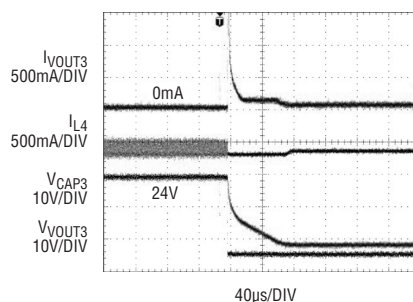


Figure 5. Channel 3 short circuit condition with and without 20mA current limit

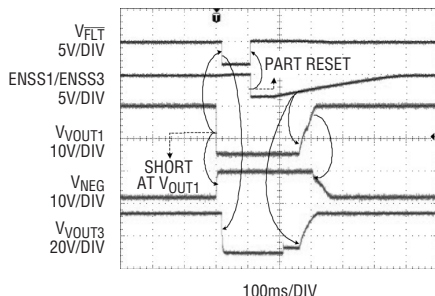


Figure 6. Fault detection of a short circuit event

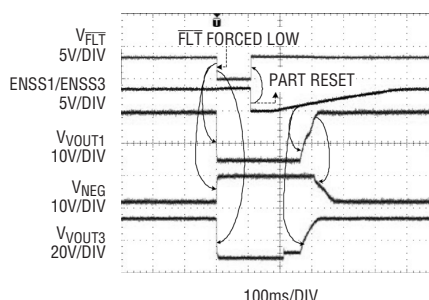


Figure 7. Waveforms for when the $\overline{\text{FLT}}$ pin is externally forced low

The disconnect transistor M1 is current limited to provide a maximum output current of 155mA. There is also a protection circuit for M1 that limits the voltage drop across CAP1 and V_{OUT1} to about 10V. When the voltage at CAP1 is greater than 10V, such as during an output overload or short circuit to ground, then M1 is set fully on, without any current limit, to allow for the voltage on CAP1 to discharge as fast as possible. When the voltage across CAP1 and V_{OUT1} reduces to less than 10V, the output current is then again limited to 155mA. Figure 4 shows the output voltage and current during an overload event with V_{CAP1} initially at 15V.

The output disconnect feature on channel 3 is implemented similarly using M3 (Figure 3). However, in this case M3 is only turned off when the EN/SS3 pin voltage is less than 200mV and the regulation loop for channel 3 is disabled.

The disconnect transistor M3 is also current limited, providing a maximum output current at V_{OUT3} of 100mA. M3 also has a similar protection circuit as M1 that limits the voltage drop across CAP3 and V_{OUT3} to about 10V. Figure 5

The LT3587 is a versatile, highly integrated device that provides a compact solution for devices such as cameras, handheld computers and terminals requiring multiple high voltage supplies. A low part count and a 3mm × 3mm package keep the solution size small. High efficiency conversion makes it suitable for battery powered applications. Adjustable output voltage and wide output range of up to 32V for the positive boosts, and -32V for the inverter, make it a flexible solution for systems that require high voltage supplies.

shows the output voltage and current during an overload event with V_{CAP3}

Fault Detection and Indicator

The LT3587 features fault detection on all outputs and a fault indicator pin, $\overline{\text{FLT}}$. The fault detection circuitry is enabled only when at least one of the channels has completed the soft-start process and is free running with full inductor current. Once fault detection is enabled, if any of the enabled channel feedback voltages (V_{FB1}, V_{FB2} or the greater of V_{FB3} and V_{IFB3}) falls below its regulation value for more than 16ms, the $\overline{\text{FLT}}$ pin pulls low.

One particularly important case is an overload or short circuit condition on any of the outputs. In this case, if the corresponding loop is unable to bring the output back into regulation within 16ms, a fault is detected and the $\overline{\text{FLT}}$ pin pulls low.

Note that the fault condition is latched—once activated all three channels are disabled. Enabling any of the channels requires resetting the part by shutting it down (forcing both the EN/SS1 and EN/SS3 pins low below 200mV) and then on again. Figure 6 shows the waveforms when a short circuit condition occurs at channel 1 for more than 16ms and the subsequent resetting of the part.

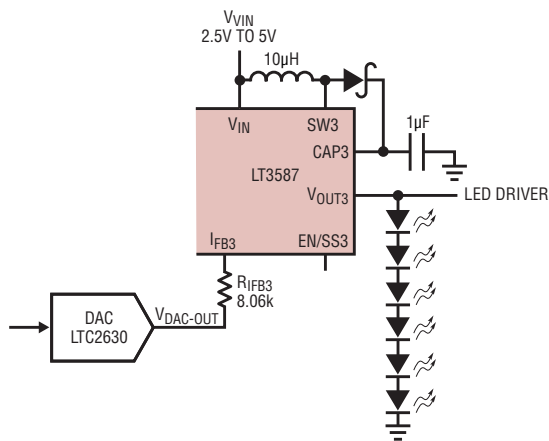


Figure 8. Analog dimming using a DAC and a resistor

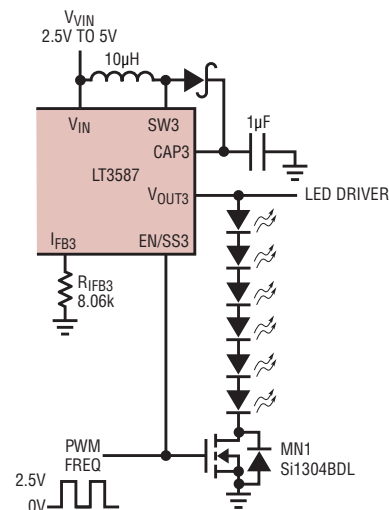


Figure 9. Driver for six LEDs with PWM dimming

Besides acting as a fault output indicator, the $\overline{\text{FLT}}$ pin is also an input pin. If this pin is externally forced below 400mV, the LT3587 behaves as if a fault event has occurred and all the channels turn off. In order to turn the part back on, remove the external voltage that forces the pin low and reset the part. Figure 7 shows the waveforms when the $\overline{\text{FLT}}$ pin is externally forced low and the subsequent resetting of the part.

Dimming Control for Channel 3 as a Current-Regulated LED Driver

As shown in Figure 1, one of the most common applications for the channel 3 is as a current regulator for a backlight LED driver. In many high end display applications requiring an LED backlight, the ability to dim the display brightness is crucial for implementing a power saving mode or to maintain contrast in different ambient lighting conditions.

There are two different ways to implement a dimming control of the LED string. LED current can be adjusted by either using a digital to analog converter (DAC) and a resistor R_{IFB3} or by using a PWM signal.

Analog Dimming Using a DAC and a Resistor

For some applications, the preferred method of brightness control is using a DAC and a resistor. This method

is more commonly known as analog dimming. This method is shown in Figure 8.

Since the programmed V_{OUT3} current is proportional to the current through R_{IFB3} , the LED current can be adjusted by changing the DAC output voltage. A higher DAC output voltage level results in lower LED current and hence lower overall brightness. For accurate dimming control, keep the DAC output impedance low enough to sink approximately 1/200 of the desired maximum LED current. Note the maximum possible output current is limited by the output disconnect current limit to 100mA.

PWM Dimming

One problem with analog dimming as described above is that changing the forward current flowing in the LEDs not only changes the brightness intensity of the LEDs, it also changes the color. This is a problem for applications

that cannot tolerate any shift in the LED chromaticity.

Controlling the LED intensity with a direct PWM signal allows dimming of the LEDs without changing the color. A PWM frequency of ~80Hz or higher guarantees that there is no visible flicker. The amount of on-time in the PWM signal is proportional to the intensity of the LEDs. The color of the LEDs remains unchanged in this scheme since the LED current value is either zero or a constant value ($I_{\text{VOUT3}} = 160\text{V}/R_{\text{IFB3}}$).

Figure 9 shows an LED driver for six white LEDs. If the voltage at the CAP3 pin is higher than 10V when the LED is on, direct PWM dimming method requires an external NMOS. This external NMOS is tied between the cathode of the lowest LED in the string and ground.

The output disconnect feature and the external NMOS ensure that the LEDs quickly turn off without discharging the output capacitor. This allows the LEDs to turn on faster. Figure 10 shows the PWM dimming waveforms for the circuit in Figure 9.

The time it takes for the LED current to reach its programmed value sets the achievable dimming range for a given PWM frequency. At extreme lower end of the duty cycle, the linear relation between the average LED current and the PWM duty cycle is no longer preserved. The minimum on time is

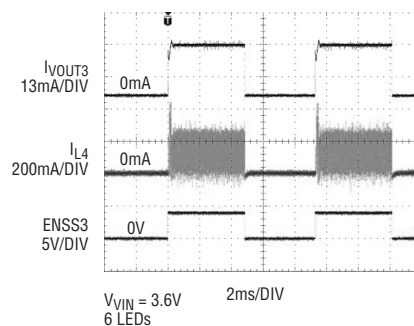


Figure 10. PWM dimming waveforms

chosen based on how much linearity is required for the average LED current. For example for the circuit in Figure 9, to produce approximately 10% deviation from linearity at the lower duty cycle, the minimum on time of the LED current is approximately 320 μ s (3.2% duty cycle) for a 3.6V input voltage and a 100Hz PWM frequency. The achievable dimming range for this application is then 30 to 1 (approximately the reciprocal of the minimum duty cycle).

The dimming range can be significantly extended by combining PWM dimming with analog dimming. The color of the LEDs no longer remains constant because the forward current of the LED changes with the output voltage of the DAC. For the six LED application described above, the LEDs can be dimmed first by modulating the duty cycle of the PWM signal with the DAC output at 0V. Once the minimum duty cycle is reached, the value of the DAC output voltage can be increased to further dim the LEDs. The use of both techniques together allows the average LED current for the six LED application to be varied from 20mA down to less than 1 μ A (a 20000:1 dimming ratio).

Channel 3 Overvoltage and Overcurrent Protection

Channel 3 can be configured either as a voltage regulated boost converter or as a current regulated boost converter. The regulation loop of channel 3 uses the greater of the two voltages at V_{FB3} and I_{FB3} as feedback to set the peak current of its power switch. This architecture allows for a programmable current limit on voltage regulation or voltage limit on current regulation.

When configured as a boost voltage regulator, a feedback resistor from the output pin V_{OUT3} to the V_{FB3} pin sets the voltage level at V_{OUT3} at a fixed level. In this case, the I_{FB3} pin can either be grounded if no current limiting is desired or be connected to ground with a resistor to set an output current limit value (I_{LIMIT}). As briefly noted before, the pull up current on the I_{FB3} pin is controlled to be typically 1/200 of the output load current at

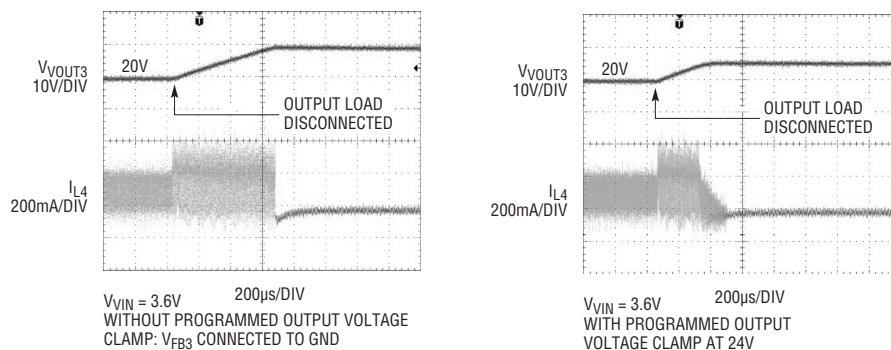
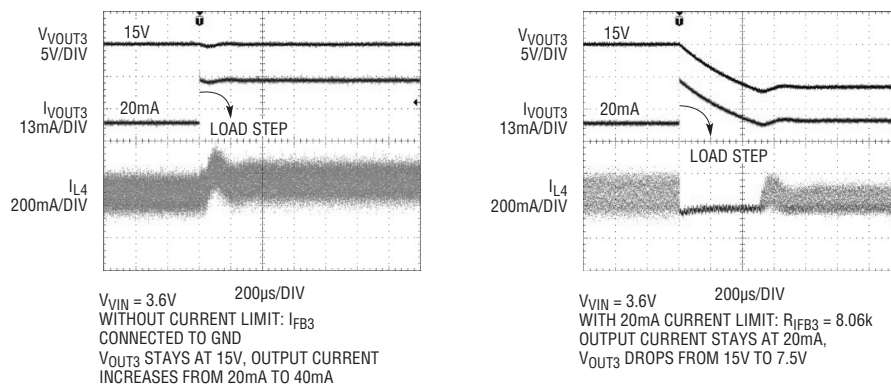
Channel 3 can be configured either as a voltage-regulated boost converter or as a current-regulated boost converter. The regulation loop of channel 3 uses the greater of the two voltages at V_{FB3} and I_{FB3} as feedback to set the peak current of its power switch. This architecture allows for a programmable current limit on voltage regulation or a voltage limit on current regulation.

the V_{OUT3} pin. In this case, when the load current is less than I_{LIMIT} , channel 3 regulates the voltage at the V_{FB3} pin to 0.8V. If there is an increase in load current beyond I_{LIMIT} , the voltage at V_{FB3} starts to drop and the voltage at I_{FB3} rises above 0.8V. The channel 3 loop then regulates the voltage at the I_{FB3} pin to 0.8V, limiting the output

current at V_{OUT3} to I_{LIMIT} . Figure 11 compares the transient responses with and without current limit when a current overload occurs.

The channel 3 CAP3 pin has over voltage protection. When the voltage at CAP3 is driven above 29V, the channel 3 loop is disabled and SW3 pin stops switching. When configured as a boost current regulator, a feedback resistor from the I_{FB3} pin to ground sets the output current at V_{OUT3} at a fixed level. In this case, if the V_{FB3} pin is grounded then the over voltage protection defaults to 29V.

On the other hand a resistor can be connected from the V_{OUT3} pin to the V_{FB3} pin to set an output voltage clamp (V_{CLAMP}) level lower than 29V. In this case, when the voltage level is less than V_{CLAMP} , the channel 3 loop regulates the voltage at the I_{FB3} pin to 0.8V. On the other hand, when the output load fails open circuit or disconnected, the voltage at I_{FB3} drops to reflect the lower output current and the voltage at V_{FB3} starts to rise. When the voltage at V_{OUT3} rises beyond V_{CLAMP} , the voltage at the V_{FB3} pin goes



above 0.8V. The channel 3 loop then regulates the voltage at the V_{FB3} pin to 0.8V, limiting the voltage level at V_{OUT3} to V_{CLAMP} . Figure 12 contrasts the transient responses with and without programmed V_{CLAMP} when the output load is disconnected.

Low Input Voltage

While the LT3587's V_{IN} supply voltage range is 2.5V to 6.0V, the inductors can run off a lower voltage. Most portable devices and systems have a separate 3.3V logic supply voltage, which can be used to power the LT3587. This allows the outputs to be powered straight from the lower voltage power source such as two alkaline cells. This configuration results in higher efficiency. Figure 13 shows a typical digital still camera application powered this way. It has positive and negative CCD supplies and an LED backlight supply.

Replace Inductor with Schottky for Smaller Footprint


If higher current ripple is tolerable at the output of the inverter (channel 2), replace inductor L3 with a Schottky diode D3 as shown in Figure 14. Since the Schottky diode footprint is usually smaller than the inductor footprint, this alternate topology is recommended for space constrained applications. This topology is only viable if the absolute value of the inverter output is greater than V_{IN} . This Schottky diode is configured with the anode connected to the output of the inverter and the cathode to the output end of the flying capacitor C2 as shown in Figure 14.

Conclusion

The LT3587 is a versatile, highly integrated device that provides a simple solution to devices such as cameras, handheld computers and terminals requiring multiple high voltage supplies. A low part count and a compact 3mm × 3mm package keep the solution size small. High efficiency conversion makes it suitable for battery powered applications.

Adjustable output voltage and wide output range of up to 32V for the positive boosts, and -32V for the inverter, make it a flexible solution for systems that require high voltage supplies. Channel 3's ability to work as a voltage regulator or as a true 1-wire current

regulator give the LT3587 status as a true all-in-one power supply.

Additional features, such as soft-start, supply sequencing, output disconnect and fault handling also add to the versatility of this part and further simplify power supply design. 

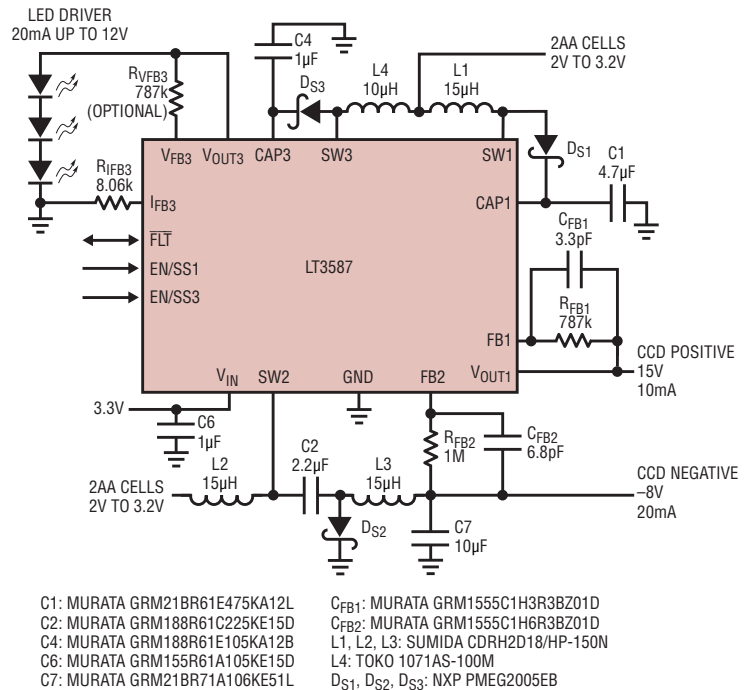


Figure 13. Two AA cells produce CCD positive and negative supplies and a driver for a 3-LED backlight.

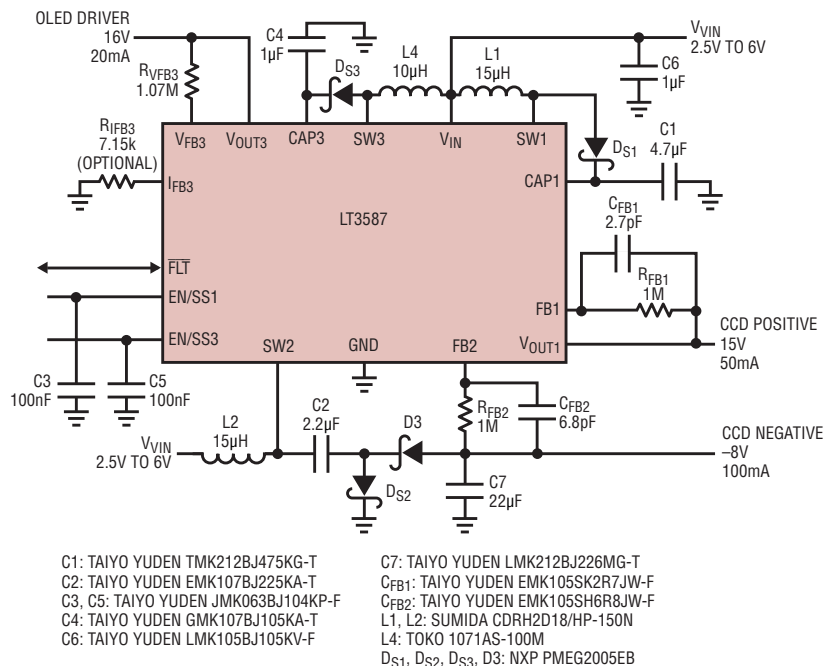


Figure 14. Li-ion driver for an OLED panel and a CCD imager with a Schottky diode replacing the inverter's output inductor