Texas Instruments

Application Report

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Calculating and Optimizing Efficiency in LCD Backlight Drivers

Cecilia Reyes, Sheng Jin

ABSTRACT

Backlight displays have become the largest power consumer in mobile devices and personal electronics. When selecting components for an LED driver, efficiency is the most important consideration. The five main backlight driver components that generate the most power loss include: the boost inductor, switching FET, Schottky diode, quiescent current, and headroom voltage. This application note will provide the equations to calculate power loss from these five main components along with comparing the trade-offs of optimizing each depending on preference. Calculations for power loss, as well comparison of trade-offs for optimizing each component, are also provided.

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1 Basic Configuration of an LED Driver

Figure 1 shows the basic configuration of an LCD driver while highlighting the five main power consuming components.

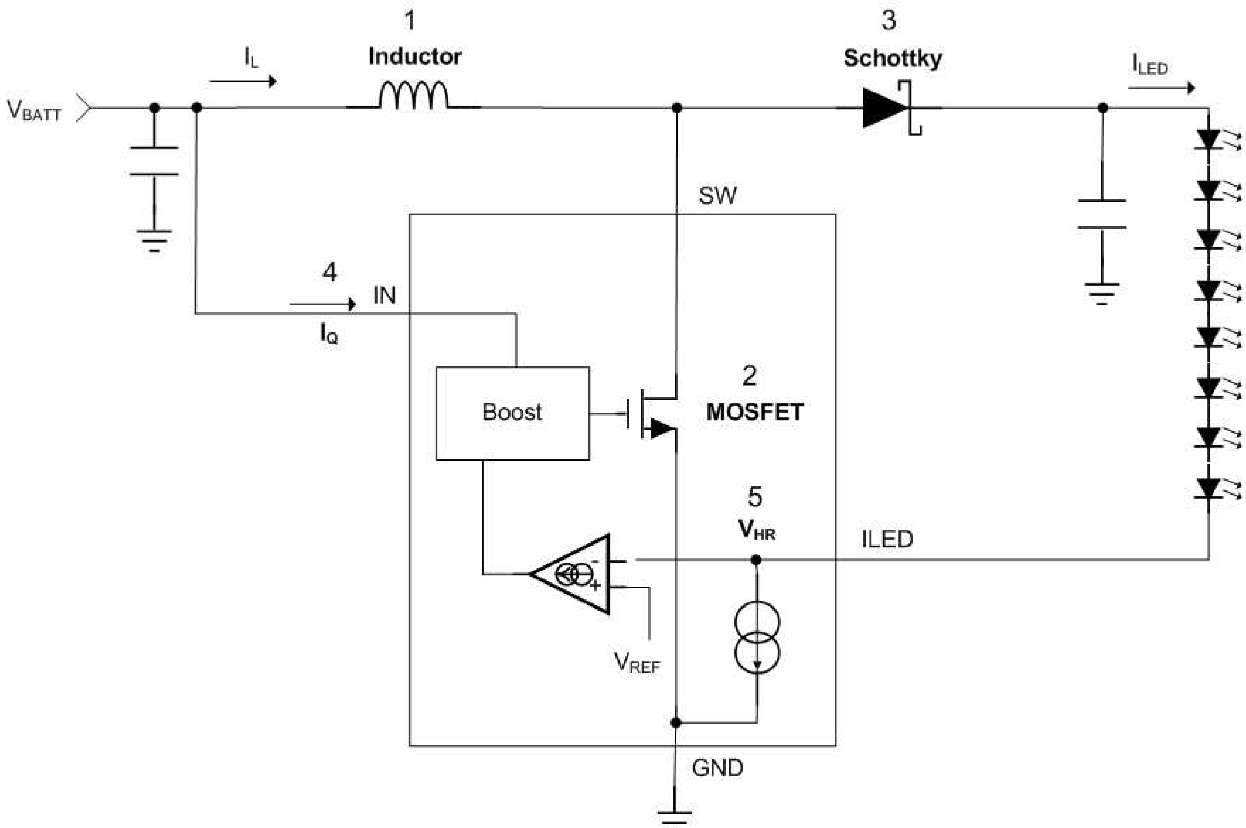

Figure 1. LCD Backlight Driver Configuration

1.1 Necessary Parameters for Efficiency Calculations

The following parameters are needed to calculate the power loss on each component:

- Inductor RMS Parameters
  - L = inductance
  - R_{LDCR} = inductor DC resistance
  - I_L = inductor current
- MOSFET Parameters
  - R_{SW} = resistance of MOSFET switch
  - C_g = gate capacitance
  - C_{DS} = drain-to-source capacitance
  - t_{rise}, t_{fall} = rise and fall time of switch voltage
  - D = duty cycle; ratio of MOSFET on-time to period
  - f_{SW} = switching frequency
  - I_L = inductor current

- Schottky Parameters
  - V_D = forward voltage
  - I_{LED} = LED current
  - R_D = Schottky series resistance
  - C_D = diode capacitance
  - I_{REV} = reverse leakage current
  - D = duty cycle
- Quiescent Current Parameters
  - V_{IN} = input voltage to LED driver
  - I_Q =quiescent current
- Headroom Voltage Parameters
  - V_{HR} = headroom voltage
  - I_{LED} = LED current

2 Efficiency Calculations

NOTE: PLEASE NOTE these calculations should be used as approximations and should only be used as reference to understand how efficiency is calculated. To receive more accurate measurements, run a simulated efficiency test in the lab or test bench.

$$\text{Efficiency }\% = \frac{P_{OUT}}{P_{OUT} + P_{TOTAL\_LOSS}} \times 100 \quad (1)$$

$$P_{TOTAL\_LOSS} = P_{INDUCTOR} + P_{SCHOTTKY} + P_{FET} + P_{IQ} + P_{HDRM} \quad (2)$$

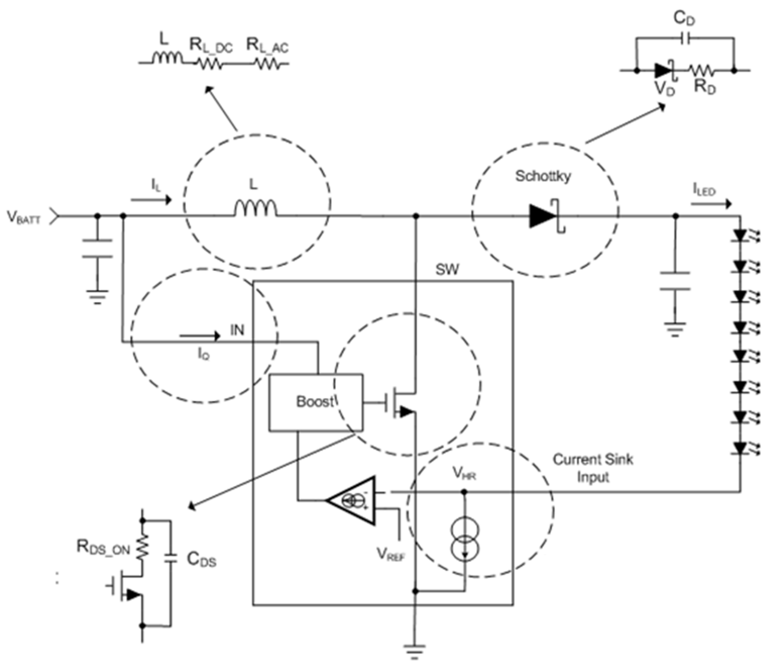

Figure 2. Highlighted Power-Consuming Components

Table 1. Calculating Power Loss from the Inductor

POWER LOSS	EQUATION	LOSS TYPE
Inductor DC resistance	$P_{L(DC)} = I_L^2 \times R_{L(DCR)}$ (3)	Conduction loss
Coreloss Power	Look at inductor manufacturer's website	Switching loss

Table 2. Calculating Power Loss from the Switching FET

POWER LOSS	EQUATION	LOSS TYPE
$R_{DS(ON)}$	$P_{VD} = I_L^2 \times R_{DS(ON)} \times D$ (4)	Conduction loss
Overlap power loss	$P_{RD} = \frac{1}{2} \times (t_{rise} + t_{fall}) \times V_{OUT} \times I_{IN} \times f_{SW}$ (5)	Switching loss
DC-capacitance loss	$P_{CDS} = C_{DS} \times V_{OUT}^2 \times f_{SW}$ (6)	Switching loss

Table 3. Calculating Power Loss from the Schottky Diode

POWER LOSS	EQUATION	LOSS TYPE
Forward voltage power loss	$P_{VD} = I_{LED} \times V_D \times (1 - D)$ (7)	Conduction loss
Diode resistance power loss	$P_{RD} = I_L^2 \times R_D \times (1 - D)$ (8)	Conduction loss
Diode capacitance power loss	$P_{CD} = C_D \times V_{OUT}^2 \times f_{SW}$ (9)	Switching loss

Table 4. Calculating Power Loss from Quiescent Current

POWER LOSS	EQUATION	LOSS TYPE
Quiescent current power loss	$P_{IO} = V_{IN} \times I_O$ (10)	Conduction loss

Table 5. Calculating Power Loss from the Headroom Voltage

POWER LOSS	EQUATION	LOSS TYPE
Current sink headroom loss	$P_{HDRM} = V_{HR} \times I_{LED}$ (11)	Conduction loss

3 Component Optimization Trade-offs

Every consumer wants components with certain characteristics to fit the need of their solution. This portion of the applications note will highlight some common modifications in components and their tradeoffs. PLEASE NOTE that these are approximations and should be used as reference. The best way to see these tradeoffs is testing LED drivers in lab with different components and comparing results.

3.1 Switching Frequency

Increasing switching frequency allows customers to use smaller components for smaller solution sizes at the expense of higher switching losses. Below is a block diagram showing the tradeoffs of increasing and decreasing switching frequencies for the switching FET in the boost of an LCD driver.

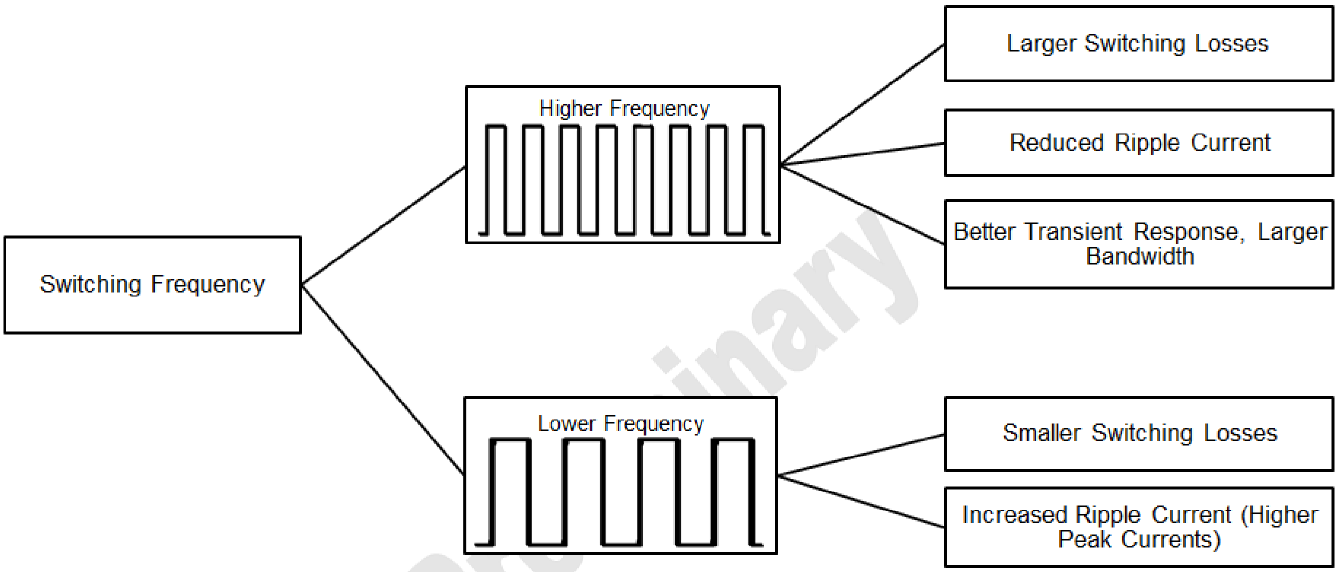

Figure 3. Block Diagram for Switching Frequency Trade-offs

3.2 Inductor Package Size at Fixed Inductance

Figure 4 shows the tradeoffs of different package sizes of inductors at a fixed inductance. As the package size increases, the cross-sectional area of the inductor also increases. This allows more current to flow through the inductor which then reduces the DCR.

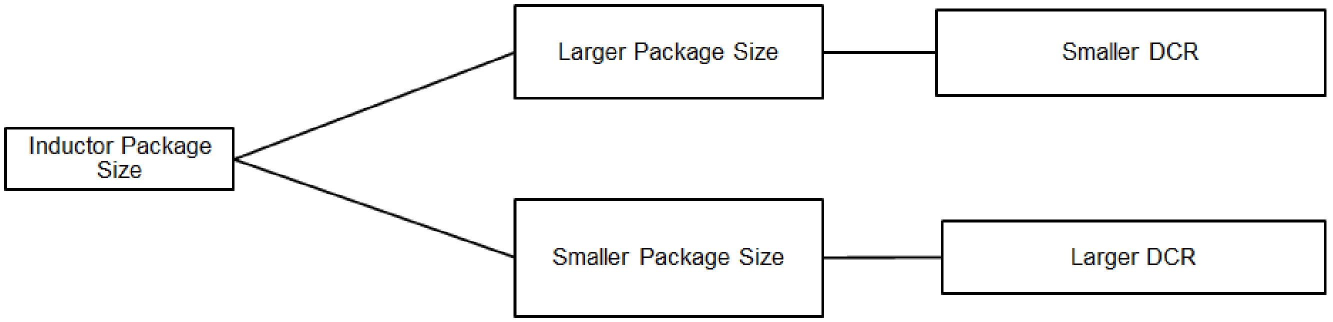

Figure 4. Block Diagram for Inductor Package Size Trade-offs

3.3 Inductance at Fixed Package Size

Figure 5 shows the trade-offs when increasing the inductance at a fixed package size. Using the formula V = L (di/dt), it is clear that as inductance increases, the rate of change in current decreases. As inductance also increases, the number of coils increases, therefore, increasing the resistance.

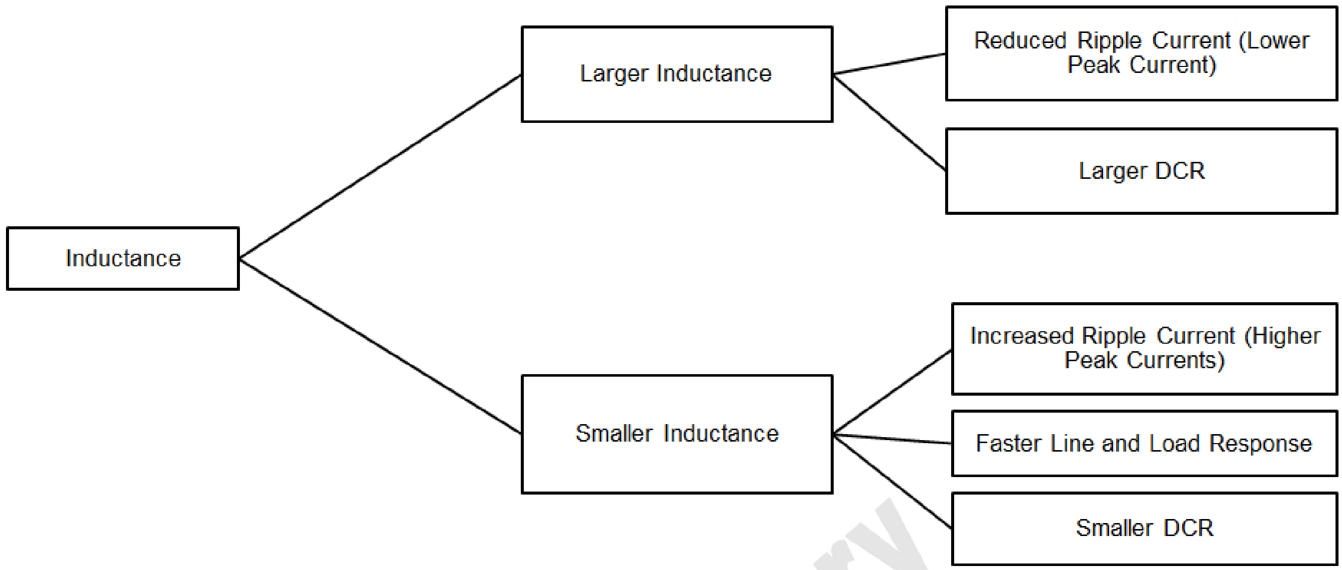

Figure 5. Block Diagram for Inductance Trade-offs

3.4 Schottky Diode Size

At larger package sizes, Schottky diodes reduce the forward drop and DC resistance but significantly increases the parasitic capacitance. This results to large switching losses and less efficient LED drivers.

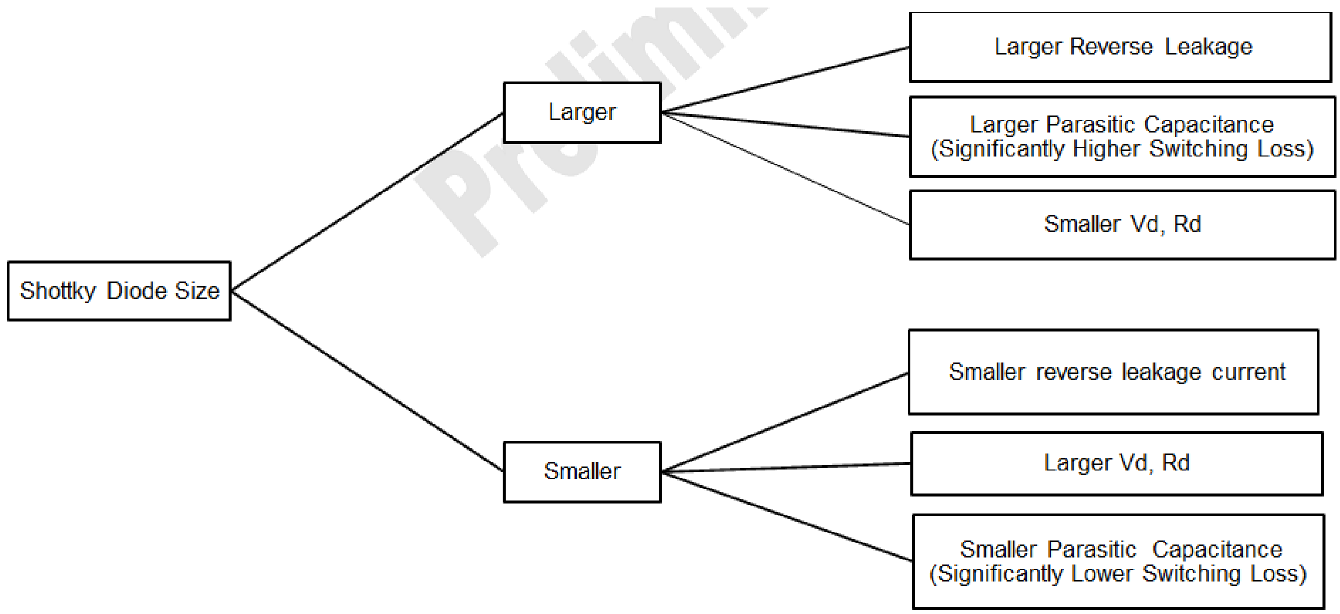

Figure 6. Block Diagram for Shottky Diode Size Trade-offs

3.5 MOSFET Package Size

In the case of an external switching FET, Figure 7 describes the tradeoffs between power loss and FET size.

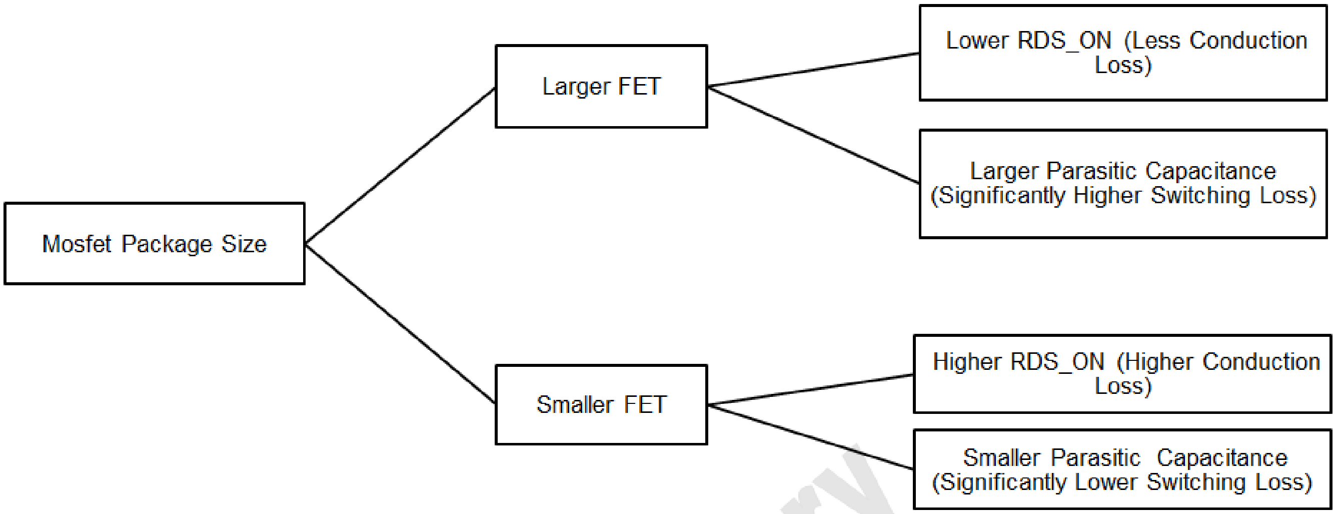

Figure 7. Block Diagram for Switching FET Size Trade-offs

4 Example

Referencing the LM36272 LCD backlight driver, Figure 8 illustrates some of the calculations provided along with a better understanding of the efficiency trade-offs that come with selecting components.

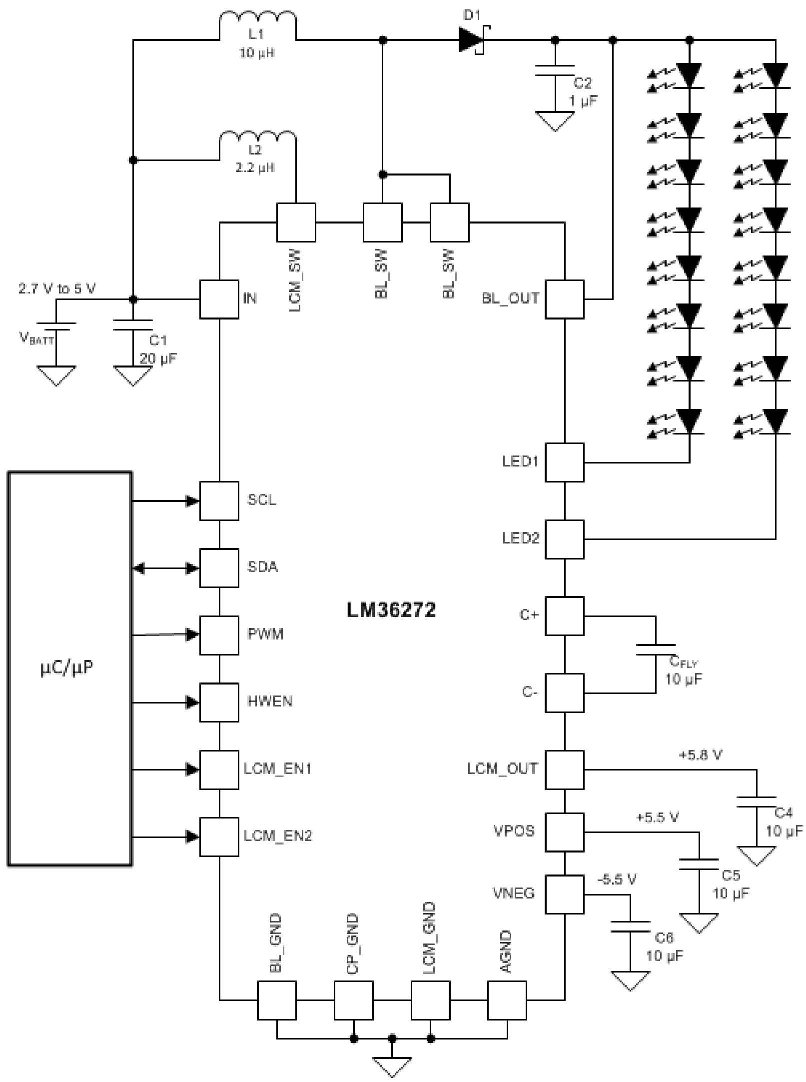

Figure 8. Typical Application Circuit of LM36272

Table 6. Recommended External Components

DESIGNATOR	DESCRIPTION	VALUE	EXAMPLE
C1, C4, C5, C6, C_{FLY}	Ceramic capacitor	10 µF, 10 V	C1608X5R0J106M
C2	Ceramic capacitor	1 µF, 35 V	C2012X7R1H105K125AB
L1	Inductor	4.7 µH, 1.94 A	VLF504012MT-4R7M
L1	Inductor	10 µH, 1.44 A	VLF504015MT-100M
L1	Inductor	15 µH, 1.25 A	VLF504015MT-150M
L2	Inductor	2.2 µH, 1.5 A	DFE201612P-2R2M
D1	Schottky diode	30 V, 500 mA	NSR0530P2T5G

Table 6 shows examples of external components for the LM36272. The LM36272 requires a typical inductance in the range of 4.7 µH to 15 µH. In this demonstration, the VLF504015MT-100M 10-µH inductor was used for the efficiency test. To highlight the effect of inductor selection on efficiency, the following inductors were used to replace the inductor L1.

MANUFACTURER	VALUE	PART NUMBER
Taiyo Yuden	4.7 µH, 1.7 A, 263 mΩ	MDMK3030T4R7MM
Wurth Electronics	15 µH, 4 A, 21.8 mΩ	WE-PDF 7447798151

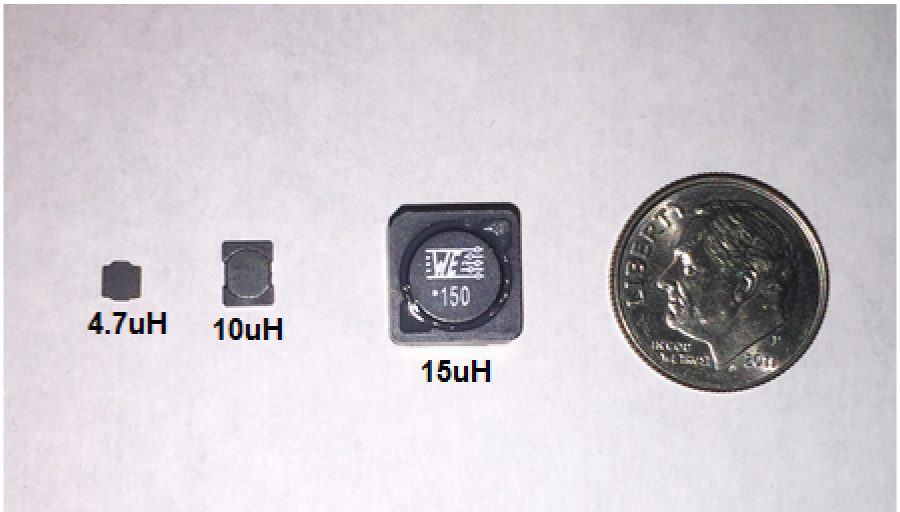

Figure 9. Size Reference for the Tested Inductors

Figure 10, Figure 11, and Figure 12 show the boost efficiency tested with the different inductors. It is clear to see that the smallest inductor and package size had the lowest efficiency while the largest inductance and package size had the highest efficiency of the three parts. It is up to the designer to decide which tradeoffs they would prefer when selecting components for their solution.

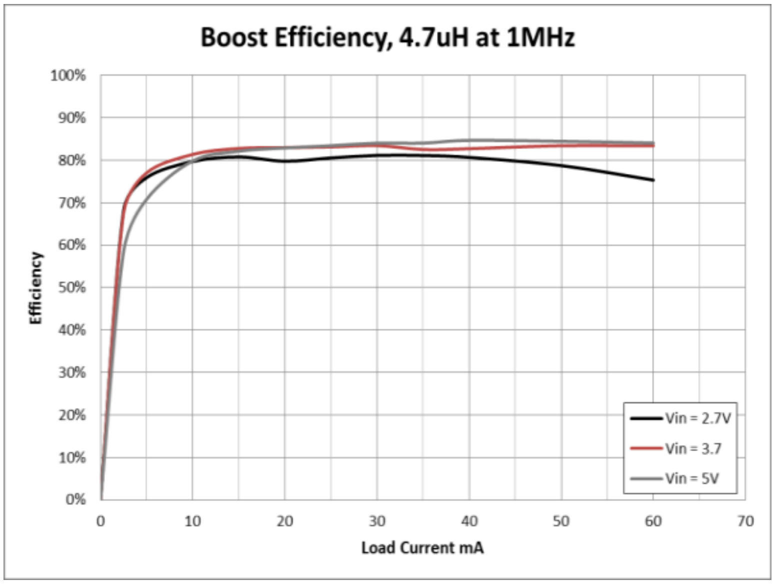

Figure 10. LM36272 Boost Efficiency With 4.7-µH Inductor

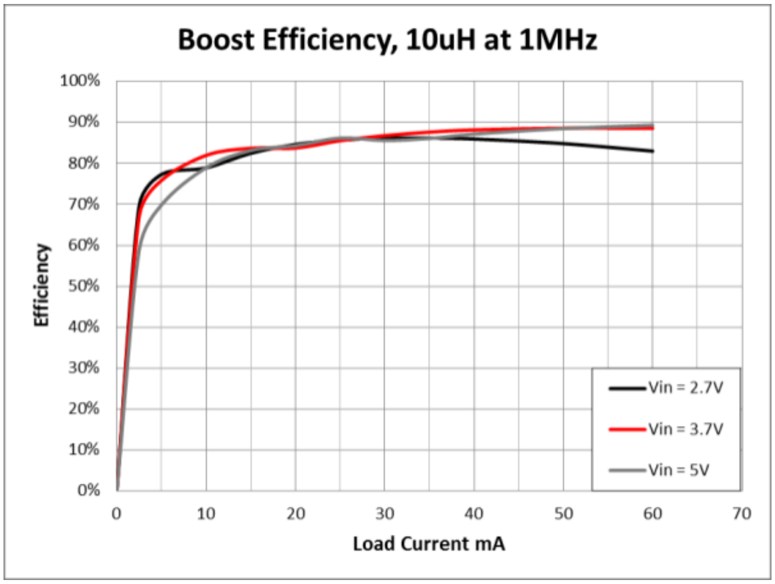

Figure 11. LM36272 Boost Efficiency With 10-μH Inductor

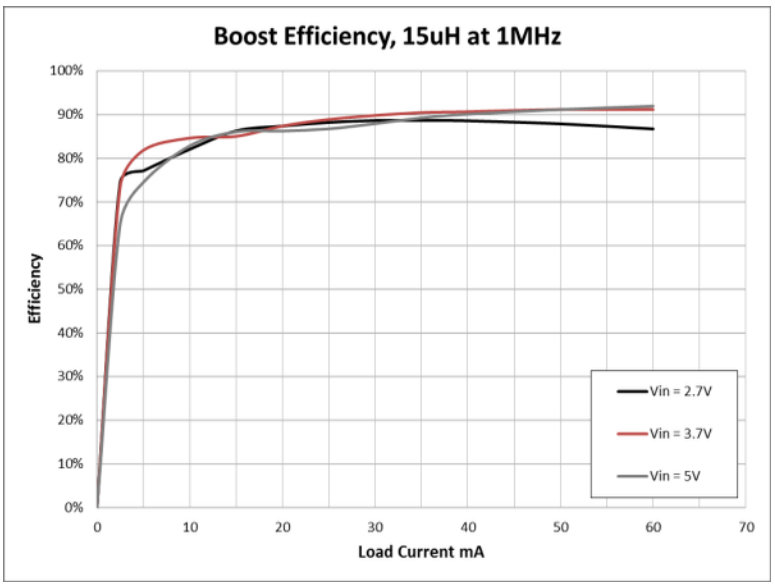

Figure 12. LM36272 Boost Efficiency With 15-μH Inductor

5 Optimizing Efficiency Outside of the Boost Converter

5.1 LED Selection

There are many other factors outside of the boost of an LCD driver that can still increase efficiency. Although costs of LEDs are extremely important in production, selecting LEDs with a lower voltage drop decreases power loss and heat dissipation.

5.2 LED String Configurations

Another factor to consider for power efficiency is having multiple strings at a smaller output voltage compared to a single string at a higher output voltage. Referring back to the equations in Section 2, a lower output voltage reduces the switching loss on the MOSFET yielding a more efficient LED driver. Keep in mind, having more strings in parallel reduces output voltage but may lead to more mismatch error between strings and higher routing overhead. The recommended configuration for personal electronics is typically two strings in parallel to ensure high efficiency with low routing overhead.

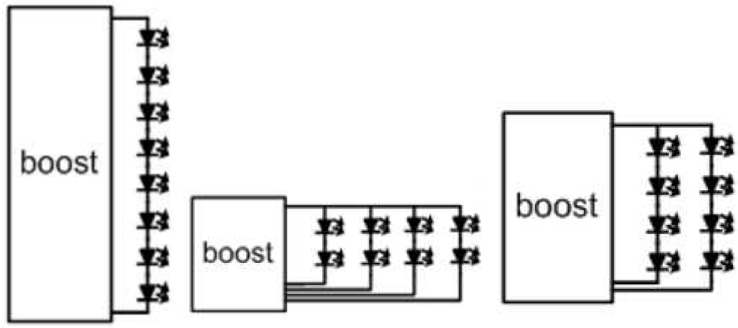

Figure 13. Various LED Configurations (1 × 8, 4 × 2, and 2 × 4)

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265