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.

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.

Efficiency % = \[ \frac{P_{OUT}}{P_{OUT} + P_{TOTAL\_LOSS}} \times 100 \] (1)

\[ P_{TOTAL\_LOSS} = P_{INDUCTOR} + P_{SCHOTTKY} + P_{FET} + P_{Q} + P_{HDRM} \] (2)

Figure 2. Highlighted Power-Consuming Components
Component Optimization Trade-offs

Table 1. Calculating Power Loss from the Inductor

<table>
<thead>
<tr>
<th>POWER LOSS</th>
<th>EQUATION</th>
<th>LOSS TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductor DC resistance</td>
<td>$P_{L(DC)} = I_L^2 \times R_{L(DCR)}$</td>
<td>Conduction loss</td>
</tr>
<tr>
<td>Coreloss Power</td>
<td>Look at inductor manufacturer’s website</td>
<td>Switching loss</td>
</tr>
</tbody>
</table>

Table 2. Calculating Power Loss from the Switching FET

<table>
<thead>
<tr>
<th>POWER LOSS</th>
<th>EQUATION</th>
<th>LOSS TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{DS(ON)}$</td>
<td>$P_{VD} = I_L^2 \times R_{DS(ON)} \times D$</td>
<td>Conduction loss</td>
</tr>
<tr>
<td>Overlap power loss</td>
<td>$P_{RD} = \frac{1}{2} \times (t_{on} + t_{off}) \times V_{OUT} \times I_{IN} \times f_{SW}$</td>
<td>Switching loss</td>
</tr>
<tr>
<td>DC-capacitance loss</td>
<td>$P_{CDS} = C_{DS} \times V_{OUT}^2 \times f_{SW}$</td>
<td>Switching loss</td>
</tr>
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</table>

Table 3. Calculating Power Loss from the Schottky Diode

<table>
<thead>
<tr>
<th>POWER LOSS</th>
<th>EQUATION</th>
<th>LOSS TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward voltage power loss</td>
<td>$P_{VD} = I_{LED} \times V_D \times (1 - D)$</td>
<td>Conduction loss</td>
</tr>
<tr>
<td>Diode resistance power loss</td>
<td>$P_{RD} = I_L^2 \times R_D \times (1 - D)$</td>
<td>Conduction loss</td>
</tr>
<tr>
<td>Diode capacitance power loss</td>
<td>$P_{CD} = C_D \times V_{OUT}^2 \times f_{SW}$</td>
<td>Switching loss</td>
</tr>
</tbody>
</table>

Table 4. Calculating Power Loss from Quiescent Current

<table>
<thead>
<tr>
<th>POWER LOSS</th>
<th>EQUATION</th>
<th>LOSS TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiescent current power loss</td>
<td>$P_{IQ} = V_{IN} \times I_Q$</td>
<td>Conduction loss</td>
</tr>
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</table>

Table 5. Calculating Power Loss from the Headroom Voltage

<table>
<thead>
<tr>
<th>POWER LOSS</th>
<th>EQUATION</th>
<th>LOSS TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current sink headroom loss</td>
<td>$P_{HDRM} = V_{HR} \times I_{LED}$</td>
<td>Conduction loss</td>
</tr>
</tbody>
</table>

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](image)

### 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](image)

### 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 \( V = L \frac{di}{dt} \), 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](image)
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.

![Block Diagram for Schottky Diode Size Trade-offs](image)

**Figure 6. Block Diagram for Schottky 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](image)

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.
Table 6. Recommended External Components

<table>
<thead>
<tr>
<th>DESIGNATOR</th>
<th>DESCRIPTION</th>
<th>VALUE</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C4, C5, C6, C&lt;sub&gt;Fly&lt;/sub&gt;</td>
<td>Ceramic capacitor</td>
<td>10 µF, 10 V</td>
<td>C1608X5R0J106M</td>
</tr>
<tr>
<td>C2</td>
<td>Ceramic capacitor</td>
<td>1 µF, 35 V</td>
<td>C2012X7R1H105K125AB</td>
</tr>
<tr>
<td>L1</td>
<td>Inductor</td>
<td>4.7 µH, 1.94 A</td>
<td>VLF504012MT-4R7M</td>
</tr>
<tr>
<td>L1</td>
<td>Inductor</td>
<td>10 µH, 1.44 A</td>
<td>VLF504015MT-100M</td>
</tr>
<tr>
<td>L1</td>
<td>Inductor</td>
<td>15 µH, 1.25 A</td>
<td>VLF504015MT-150M</td>
</tr>
<tr>
<td>L2</td>
<td>Inductor</td>
<td>2.2 µH, 1.5 A</td>
<td>DFE201612P-2R2M</td>
</tr>
<tr>
<td>D1</td>
<td>Schottky diode</td>
<td>30 V, 500 mA</td>
<td>NSR0530P2T5G</td>
</tr>
</tbody>
</table>

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.
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
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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