ILD8150/E 80 V high side buck LED driver IC with hybrid dimming

Operation, design guide and performance

About this document

Scope and purpose

This application note introduces Infineon’s hysteretic high-side MOSFET buck DC-DC LED driver IC ILD8150 for general lighting applications. It describes the device operation, features and component value calculations and selection. An example of the reference design performance is shown. ILD8150 provides a highly efficient solution up to 97 percent with superior hybrid dimming performance, and various protections such as cycle-by-cycle current limitation and over-temperature protection.

Intended audience

This document is intended for engineers and students who design highly efficient LED drivers with a wide dimming range.

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Introduction

1 Introduction

This application note explains the operation of Infineon’s high-side MOSFET buck LED driver IC ILD8150. ILD8150 provides a highly efficient solution, with multiple protection features, superior hybrid PWM dimming performance and high accuracy across all conditions – input/output voltage, dimming and temperature.

ILD8150 is a next-generation buck DC-DC LED driver recommended for general LED lighting. The target application is a secondary stage together with AC-DC such as Power Factor Correction (PFC) flyback or PFC + LLC. ILD8150 is flexible enough to use up to 1.5 A with a short duty cycle. The hysteretic current control is extremely fast and always stable without the need for any loop compensation. A maximum duty cycle of up to 99 percent enables use in applications where the input and output voltage are close to each other. It is suitable for applications with a wide range of supply voltages from 8 V to 80 V, which gives flexibility and a clear advantage over existing 60 V solutions.

ILD8150 operates in hybrid dimming mode, which helps to minimize LED color shift and audible noise. In the range 12.5 to 100 percent it operates in analog dimming mode, and from 0.5 to 12.5 percent in PWM mode with fixed output frequency \( f_{out} \).

ILD8150 provides high accuracy across all conditions, as well AC 100 or 120 Hz input flicker rejection across the whole dimming range.

1.1 Features

- Wide input voltage range from 8 V to 80 V
- Capable of providing output current up to 1.5 A
- Up to 2 MHz switching frequency
- Digital soft-start
- PWM dimming input up to 20 kHz
- Hybrid output dimming
- Typical ±3 percent output current accuracy
- Very low LED current drift over-temperature
- Under-Voltage Lockout (UVLO)
- Cycle-by-cycle current limitation
- Shut-down mode with low self-consumption
- PG-DSO-8 package with and without exposed pad
- Over-Temperature Protection (OTP)

1.2 Applications

- LED driver for general lighting
  - with single output channel
  - with two output channels for tuneable white light
- LED driver for horticultural lighting
  - with multiple output channels

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Introduction

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2 Circuit description

2.1 Operation

![Typical application circuit diagram](image)

**Figure 1** Typical application circuit

### 2.1.1 Current regulation

*Figure 1* shows the typical application circuit. Current is controlled by the CS pin, which compares the voltage drop on $R_{CS}$ to internal references. Output current is proportional to the voltage drop on $R_{CS}$. When the CS voltage drops below $V_{CSL}$ the MOSFET switches on. Current and voltage on $R_{CS}$ rise accordingly. When the CS voltage achieves $V_{CSH}$ the MOSFET switches off, and stored energy in inductor L discharges through the diode D. In this way, the system maintains a constant average output current as shown in *Figure 2*.

$$I_{LED, AVG} = \frac{V_{CSH} + V_{CSL}}{2R_{CS}}$$

The output ripple of the instantaneous current is:

$$\Delta I_{OUT} = \frac{V_{CSH} - V_{CSL}}{R_{CS}}$$

![Current regulation graph](image)

**Figure 2** Current regulation

Current never goes down to zero, so the system operates in Continuous Conduction Mode (CCM), where
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Circuit description

\[ t_{ON} = \frac{\Delta I_{OUT}}{V_{IN} - V_{OUT}} \] and \[ t_{OFF} = \frac{\Delta I_{OUT}}{V_{OUT}}. \]

Output frequency is determined by the following equation:

\[ f_{SW} = \frac{R_{CS}}{2(V_{CSH} - V_{CSL}) + R_{CS}V_{IN}t_{delay}} \cdot \frac{V_{OUT}(V_{IN} - V_{OUT})}{V_{IN}}, \]

where \( R_{CS}V_{IN}t_{delay} \) is the delay contribution, with \( t_{delay} \approx t_{CSSW} + R_{flt}C_{flt} \). This part is negligible for low frequencies but it has a strong effect at high frequencies. Figure 3 shows the frequency curves not including the delay in blue and including the delay in red.

Figure 3  Typical frequency change character curve over output voltage, \( V_{IN} = 80 \) V, \( L = 680 \) µH, \( R_{CS} = 0.36 \) Ω, \( R_{flt} = 1.5 \) kΩ, \( C_{flt} = 180 \) pF

\( R_{flt} \) and \( C_{flt} \) are the RC filter, which reduces the noise from \( R_{CS} \), which can lead to unwanted operation.

2.2  Cycle-by-cycle current limitation

Because ILD8150 operates in current mode, it does not allow operation with higher current than it sets. Output current is limited cycle-by-cycle. Thus, it safely operates even when the LED output gets shorted. \( R_{CS} \) short-circuit may cause damage.

2.2.1  OTP

ILD8150 has integrated OTP based on the junction temperature measurement on the chip. OTP is required to prevent the IC from operating at a critical temperature. The high threshold when the IC turns off is \( T_{OT,OFF} \); the low threshold when the IC turns on is \( T_{OT,ON} \).

2.2.2  UVLO

ILD8150 has hysteretic UVLO protection against operation at insufficient supply voltage. ILD8150 also has UVLO that shuts down the IC when the minimum supply voltage drops below the internal threshold, typically \( V_{IN,UVLO,OFF} \), and releases the IC from lockout at \( V_{IN,UVLO,ON} \).
2.2.3 Dimming

Input dimming signal is PWM with minimal amplitude $V_{\text{DIM}}$ with frequency $f_{\text{DIM,input}}$. Current accuracy over dimming is high enough, and so is the feedback speed, that any input voltage change does not affect output current (no flicker). The IC operates in hybrid dimming mode. The dimming curve is shown in Figure 6, which eliminates color shift and audible noise. In the range from 12.5 to 100 percent it operates in analogue dimming mode as shown in Figure 5, and from 0.5 to 12.5 percent in PWM mode as shown in Figure 4, with fixed output frequency $f_{\text{OUT}}$.

![Figure 4 PWM dimming](image1)

![Figure 5 Analog dimming](image2)

![Figure 6 Hybrid dimming curve](image3)
ILD8150 80 V high side buck LED driver IC with hybrid dimming

Circuit description

2.2.4 Dim-to-off

ILD8150 turns the output stage off when the PWM dimming input signal duty cycle is less than $D_{PWM, IN, OFF}$, and on when the PWM dimming input signal duty cycle is higher than $D_{PWM, IN, ON}$, as shown in Figure 7. The dim-to-off hysteretic algorithm helps to avoid unstable states at the on/off boundary.

![Figure 7 Dim-to-off](image)

2.2.5 Soft-start

Soft-start helps to reduce component stress when the application starts. It further reduces under-shoot of the input voltage. The soft-start is digitally preset at $t_{SS, 100 \text{percent}}$, defined as the maximum time to reach full light, in the undimmed condition and up to $10 \times T_{\text{dim}}$ in the dimmed condition where $T_{\text{dim}} = 1/f_{DIM_{\text{input}}}$. Start-up time may also be set by a microcontroller independently of the preset soft-start. The soft-start process is shown in Figure 8. The number of current steps may vary depending on the actual and previous dimming level.

![Figure 8 Soft-start](image)
Circuit description

2.2.6 Shutter-down

ILD8150 has a shutoff control pin SD. If the shutoff signal (SD neg.) is driven low for more than $t_{SD,LO}$, the low power mode is active. If the shutoff signal is held high for more than $t_{SD,HI}$, the IC resumes from low power mode. $-I_{SD,HPU}$ dynamic current is needed to turn the IC into low power mode, then the current changes into static $-I_{SD,LPU}$. DIM pin needs to be driven externally with at least $V_{DIM,SD}$ voltage during low power mode.

![Diagram of Shut-down signal interfacing](image)

**Figure 9** Shut-down signal interfacing

2.2.7 Floating driver and bootstrap supply

The high-side MOSFET gate driver is supplied by the bootstrap circuit. Capacitor $C_{BOOT}$ is charged when the high-side MOSFET is switched off and the diode D conducts current from $V_{CC}$. $C_{BOOT}$ can be calculated as:

$$C_{BOOT} > \frac{Q_G}{\Delta V_{C_{boot}}}$$

Where $Q_G$ is the internal MOSFET gate charge, 2.5 nC and $\Delta V_{C_{boot}}$ is voltage deviation on the bootstrap capacitor. The internal supply circuit provides voltage to the bootstrap capacitor $V_{C_{boot}} \approx 8.6$ V, which is a little higher than $V_{CC}$. This circuit helps to maintain the voltage in dim-to-off and standby conditions. Higher voltage improves the $R_{ON}$ of the internal MOSFET.
Circuit description

The IC contains an internal bootstrap diode. An external high-speed signal or Shottky diode, with voltage robustness higher than \( V_{\text{IN}} \), can be used between the \( V_{\text{CC}} \) and \( \text{BOOT} \) pins as shown in Figure 10. This decreases IC power dissipation at high switching frequency.

### 2.2.8 \( V_{\text{IN}} \) pin ESD Protection

The \( V_{\text{IN}} \) pin is protected by an internal ESD structure. If \( V_{\text{IN}} \) exceeds the absolute maximum ratings with a slew rate higher than 5 V/ns, which may happen not even by an ESD event, but might also occur if the LED driver gets hotplugged into a power supply and the \( V_{\text{IN}} \) blocking capacitor has a too small capacitance. ESD protection will remain triggered as long as the slew rate condition is met. If the ESD protection gets triggered while \( V_{\text{IN}} \) is supplied, the IC might be damaged. At HV spikes or hotplug, the ESD structure conducts and absorbs the ESD stress. If the application is a DC-DC LED driver with very low input capacitance and permanent ESD stress, it is recommended to use an external TVS diode, which protects the IC.

### 2.2.9 OVP by CS pin

If the load is disconnected, output voltage moves to the \( V_{\text{IN}} \) level. External output Over-Voltage Protection (OVP) may be used as shown in Figure 11. The TVS diode conducts current when the output voltage achieves its level, voltage on the CS pin rises to \( V_{\text{CSH}} \) level, the high-side MOSFET switches off, and output voltage drops. TVS diodes have a high voltage deviation connected with technology and temperature. TVS voltage should be chosen, as this does not affect operation and also limits output voltage to the right level. \( R_{\text{TVS}} \) and \( R_{\text{PR}} \) limit the current through the TVS, reduce dissipated power and reduce switching frequency in OVP mode.
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Circuit description

![Circuit Diagram]

**Figure 11** OVP by CS pin

### 2.2.10 Microcontroller use

A microcontroller may be used together with ILD8150. This enables control of dimming to read out the output voltage and drive the IC into shut-down mode. The microcontroller use case is shown in **Figure 12**.

![Microcontroller Use Diagram]

**Figure 12** Microcontroller use

During the design, possible to bump up with an after-flash effect. In a two-stage configuration, when a LED driver input is disconnected from the AC line, short series of after-flashes may occur. ILD8150(E) has an internal current source that charges the bootstrap capacitor. It helps during start-up and also helps to achieve an extremely high duty cycle up to 99.9 percent. When the voltage on the bootstrap reaches $V_{GD\_UVLO,ON}$, the gate driver activates, and the IC is active again until it discharges the bus capacitor to the voltage less than the LED voltage.
Circuit description

The issue can be fixed in two different ways: A 120 kOhm resistor bleeder between Boot and SW pins prevents the boot capacitor charge from the current source. Either a 20 kOhm resistor on the SD pin to GND. It switches the IC into the shut-down mode when voltage drops on the microcontroller, and it cannot control the circuit anymore.

2.3 Component selection

2.3.1 Current Sense (CS) resistor

The average LED current is determined by the value of the CS resistor $R_{cs}$. The mean CS threshold voltage is $V_{CS} = \frac{V_{CSH} + V_{CSL}}{2}$, $V_{CS} = 360$ mV. Hence, the proper value of $R_{CS}$ is given by:

$$R_{CS} = \frac{360 \text{ mV}}{I_{LED,AVG}}$$

Power dissipated on the resistor also has to be considered:

$$P_{dis} = R_{CS}I_{LED,AVG}^2$$

2.3.2 Inductor and switching frequency selection

The inductor $L$ has to maintain a constant current in the LEDs, so that the circuit operates in CCM. The inductor value $L$ is related to the switching frequency $f_{SW}$, as shown below:

$$L = \frac{R_{CS}(V_{OUT} - V_{IN}t_{delay}f_{SW})}{f_{SW}(V_{CSH} - V_{CSL})} = \frac{R_{CS}V_{OUT}^2}{V_{IN}f_{SW}(V_{CSH} - V_{CSL})}$$

Where $V_{IN}$ is the input voltage, $V_{OUT}$ is the output voltage, $V_{CSH}$ and $V_{CSL}$ are high and low CS thresholds accordingly, and where $t_{delay} \approx t_{CSSW} + R_{fltr}C_{fltr}$, $t_{CSSW}$ is the internal delay (less than 120 ns).

$f_{SW}$ should be chosen so that it never runs in an audible range less than 20 kHz across all conditions. Lower inductance leads to smaller inductor size, but on the other hand it leads to higher switching losses, which has to dissipate the IC and efficiency decrease. An optimal frequency in which switching losses are not so critical should be found.

The saturation current ($I_{sat}$) of the chosen inductor has to be higher than the peak LED current $I_{pk} = I_{LED,AVG} + \Delta I_{OUT}/2$.

Because output ripple is very low it is recommended to use iron powder magnetics. The core should be a closed magnetic shape or shielded so as not to affect the IC’s sensitive inputs, such as CS.

2.3.3 Diode D selection

Once the internal MOSFET turns off, the residual inductor energy is discharged through the diode D into the output capacitor and the LED load. Typically, a Schottky diode is used to reduce losses caused by the diode forward voltage and reverse recovery times.

The first parameter to consider when selecting a diode is its maximum reverse voltage $V_{BR}$. This voltage rating must be higher than the maximum input voltage $V_{IN}$ of the circuit, $V_{BR}$ more than $V_{IN}$.
The other two parameters defining the diode are average and RMS forward currents $I_{D, AVG}$ and $I_{D, RMS}$:

\[ I_{D, AVG} = I_{LED, AVG} \cdot (1 - D) \]
\[ I_{D, RMS} = I_{LED, AVG} \cdot \sqrt{1 - D} \cdot \sqrt{1 + \frac{1}{12} \cdot \left( \frac{\Delta I_{OUT}}{I_{LED, AVG}} \right)^2} \]

Where $D$ is the duty cycle of the switching waveform and is given by:

\[ D = \frac{V_{OUT}}{V_{IN}} \]

The diode must be chosen so that its respective current ratings are higher than these values.

### 2.3.4 Input capacitor $C_{IN}$ selection

The input current of the buck regulator is identical to the current through the MOSFET, i.e. it is pulsating and thus causes a ripple voltage at the input. A capacitor on the $V_{IN}$ pin reduces this ripple voltage by providing current when the switch is conducting. The RMS current through the input capacitor $I_{CIN, RMS}$ is purely AC and can be calculated from average and RMS input currents $I_{IN, AVG}$ and $I_{IN, RMS}$ as:

\[ I_{CIN, RMS} = (D \cdot \frac{1}{12} \cdot \left( \frac{\Delta I_{OUT}}{I_{LED, AVG}} \right)^2)\]

\[ I_{CIN, RMS} = I_{LED, AVG} \cdot \sqrt{D \cdot (1 - D) + \frac{1}{12} \cdot \left( \frac{\Delta I_{OUT}}{I_{LED, AVG}} \right)^2} \]

Use low-ESR capacitors, especially under high switching frequency applications. With low-ESR capacitors, the input voltage ripple can be estimated by:

\[ \Delta V_{IN} = \frac{I_{LED, AVG} \cdot f_{SW} \cdot C_{IN}}{f_{SW} \cdot \Delta V_{IN}} \cdot D \cdot (1 - D) \]

\[ C_{IN} \geq \frac{f_{SW} \cdot \Delta V_{IN}}{I_{LED, AVG} \cdot f_{SW} \cdot \Delta V_{IN}} \cdot D \cdot (1 - D) \]

The input capacitor must be chosen so that it is capable of withstanding the calculated RMS current rate and reducing input voltage ripples to an acceptable level.

### 2.3.5 Output capacitor $C_{OUT}$ selection

Due to the relatively low output ripple current, a capacitor in parallel to the LEDs is not needed in many applications. Due to the non-linear I-V characteristics of LEDs, it is very difficult to estimate the ripple voltage with and without an output capacitor. A generally accepted model is the approximation of LED V-I characteristics by a voltage source $V_{FD}$ that models the forward voltage of the LED with a series resistor $R_D$ to model differential resistance. Both parameters need to be determined from the LED datasheet. As a rule a $V_{FD}$ of 3 V and a differential resistance $R_D$ of 0.4 $\Omega$ (this parameter is being improved with every new LED generation) are very reasonable values for a typical white high-power LED. Consequently, for 17 LEDs in series this would lead to a $V_{FD}$ of 51 V and a total $R_D$ of 6.8 $\Omega$. The ripple voltage without capacitor is then approximated as:

\[ \Delta V_{OUT} = \Delta I_{OUT} \cdot R_D \]

A meaningful output capacitor should therefore have an impedance at $f_{SW}$, which is at least five to ten times lower than $R_D$:

\[ C_{OUT} \geq \frac{5}{2\pi \cdot f_{SW} \cdot R_D} \]
### Circuit description

#### 2.3.6 Bootstrap capacitor $C_{BOOT}$ selection

Integrated high-side MOSFET is driven by the gate driver. The bootstrap capacitor is defined as:

$$C_{BOOT} > \frac{Q_G}{\Delta V_{C_{boot}}}$$

Where $Q_G$ is internal MOSFET gate charge 2.5 nC, $\Delta V_{C_{boot}}$ is the bootstrap capacitor voltage ripple.

### 2.4 Layout consideration

An optimized PCB layout leads to better performance, reliability and lower cost. Certain layout guidelines must be kept in mind while routing the PCB. The power components include the internal switch, Schottky diode, input capacitor, output capacitor and inductor. Place the input capacitor close to the IC, as parasitic inductance can be minimized by minimizing trace lengths and using short and wide traces. Extra parasitic inductance between the input capacitor’s terminals and the IC’s $V_{IN}$ and GND terminals creates high $dV/dt$ due to the switching process. This can lead to IC failure. Also, place the inductor as close as possible to the IC to reduce radiated EMI.

The output capacitor completes the routing of all the power components. It is the final component connected to the power ground terminal in the system. Improper output capacitor placement typically causes poor output current regulation. To ensure optimal operation, take care to minimize the area of the power-current loop.

The small-signal control components consist of all analog and digital components indirectly related to the power conversion, such as the CS pin, which is sensitive to noise. To reduce the noise coupling from the power stage to the control circuitry, it is necessary to keep the noisy switching traces far from the sensitive small-signal traces. The magnetic field from the inductor may cause noise on the CS path that could in turn lead to incorrect operation as double or triple pulses. To avoid this effect a shielded inductor should be used, but do not place this inductor close to the sensitive CS path. To minimize noise and ensure good output current regulation, it is critical to keep the $V_{CS}$ path as short as possible, and it is desirable to return the ground of the small-signal component to a “clean” point. Poor routing of small-signal components may lead to poor output current regulation. A power inductor placed close to the CS path can influence the regulation loop. An example layout is shown in Figure 13.

![Figure 13 Layout example](image)

Keep separate grounds for power components, which are noisy, and for the small-signal components, which are quiet. Then join these two grounds at one point, possibly the exposed pad under the IC, which is also the IC ground. A grid of thermal vias should be placed under the exposed pad to improve thermal conduction. The above guidelines ensure a well laid-out power supply design.

### 2.5 Design example

As an example, an LED driver with the following specification shall be designed:
ILD8150 80 V high side buck LED driver IC with hybrid dimming

**Circuit description**

- \( V_{\text{IN}} = 70 \, \text{V} \)
- \( I_{\text{LED,AVG}} = 1 \, \text{A} \)
- \( V_{\text{LED}} = 51 \, \text{V} \) (17 LEDs)

### 2.5.1 Determine \( R_{CS} \)

\[
R_{CS} = \frac{0.36 \, \text{V}}{1 \, \text{A}} = 0.36 \, \Omega
\]

### 2.5.2 Select switching frequency

80 kHz to 100 kHz may be a reasonable compromise between switching loss and inductor size. This needs to be verified by measurement of the finished design.

### 2.5.1 Inductor value and its current calculation

\[
L = \frac{0.36 \, \Omega \cdot (51 \, \text{V} - 70 \, \text{V} \cdot (120 + 270) \cdot 10^{-9} \, \text{s} \cdot 100000 \, \text{Hz})}{100000 \, \text{Hz} \cdot (0.39 \, \text{V} - 0.33 \, \text{V})} = \frac{0.36 \, \Omega \cdot 51 \, \text{V} \cdot 51 \, \text{V}}{70 \, \text{V} \cdot 100000 \, \text{Hz} \cdot (0.39 \, \text{V} - 0.33 \, \text{V})}
\]

\( R_{\text{filter}} C_{\text{filter}} \) assumed as 270 ns (1.5 kΩ and 180 pF accordingly \( F_{\text{filter}} \approx 600 \, \text{kHz} \))

\[
L \approx 860 \, \mu\text{H}
\]

The inductor average current is 1 A, while the peak current is \( I_{PM} = I_{\text{LED,AVG}} + \Delta I_{\text{OUT}} / 2 = I_{\text{LED,AVG}} \cdot 1.083 = 1.083 \, \text{A} \). Saturation current \( I_{\text{SAT}} \) of the inductor must be higher than this value.

### 2.5.2 Diode selection

To calculate diode currents the duty cycle \( D \) is needed:

\[
D = \frac{V_{\text{OUT}}}{V_{\text{IN}}} = 51 \, \text{V} / 70 \, \text{V} = 0.7285
\]

\[
1 - D = 0.2714
\]

RMS diode current: \( I_{D,RMS} = 1 \cdot \sqrt{0.2714 \cdot \left(1 + \frac{1}{12} \cdot \left(\frac{0.167}{1}\right)^2\right)} = 0.52 \, \text{A} \)

Average diode current: \( I_{D,AVG} = 1 \cdot 0.2714 = 0.27 \, \text{A} \)

For a design with variable number of LEDs, the highest diode currents will occur at the lowest output voltage. “1-\( D \)” is close to 1 under such conditions, and diode currents are close to the output current. In general a 1 A diode is recommended as long as the output current is below 1 A.

The reverse blocking voltage \( V_{\text{BR}} \) of the diode must be higher than the maximum input voltage \( V_{\text{IN}} \). A 100 V diode is sufficient in this example.

### 2.5.3 \( C_{\text{IN}} \) capacitor selection

\[
C_{\text{IN}} \geq \frac{1}{80 \times 10^{-3} \times 0.01 \cdot 70} \cdot 0.7285 \cdot 0.2714 = 3.60 \, \mu\text{F}, \text{ decided to choose } 4.7 \, \mu\text{F}
\]
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Circuit description

\[ I_{\text{CIN,RMS}} = 1 \cdot \sqrt{0.7285 \cdot \left(1 - 0.2714 + \frac{1}{12} \cdot \left(\frac{0.167}{1}\right)^2\right)}, \quad I_{\text{CIN,RMS}} = 0.73 \, A \]

A 4.7 µF MLCC capacitor with a rated voltage of 100 V with RMS current rate of more than 0.73 A would be recommended in this case.

2.5.4 \( C_{\text{OUT}} \) capacitor selection

The value of \( C_{\text{OUT}} \) can be estimated as:

\[ C_{\text{OUT}} > \frac{5}{2\pi \cdot 80 \, kHz \cdot 6.8 \, \Omega} = 1.46 \, \mu F \]

For lower output voltage ripple a bigger output capacitor can be used. Because the value of this capacitor is relatively low even for low ripple demands, a MLCC capacitor is the best choice in terms of cost, lifetime and ESR. Switching frequency is very high and can be visible, so output capacitor may not be used just only 10 nF to improve EMI.

2.5.5 Bootstrap capacitor \( C_{\text{BOOT}} \) selection

\[ C_{\text{BOOT}} > \frac{2.5 \cdot 10^{-9}}{1 \, V} \approx 2.5 \, nF \] (deviation voltage assumed as 1 V, was chosen as 0.22 µF 25 V MLCC).

2.5.6 \( V_{\text{CC}} \) capacitor \( C_{\text{VCC}} \) selection

A 100 nF 25 V MLCC capacitor was selected, which has to be placed close to pin 7.
3 Application circuit

This section provides more information about the reference design available. The board is configurable to have an output current in the range 250 mA to 1500 mA, with current adjustment by jumpers X9 A, B and C, as shown in Figure 17. The operating voltage range for the demo board can be from 8 V to 80 V. Jumper J3 activates open-load protection and prevents output over-voltage to 60 V. The board is designed with two optional inductors – through-hole for high power and SMD for low power. The schematics and PCB layout are shown in Figure 14 and Figure 16, respectively. The Bill of Materials (BOM) is in Appendix A.

3.1 Schematic layout

Figure 14 Reference design circuit

Figure 15 Reference design, dimensions 82(L)x26(W)x16(H) mm
3.2 PCB layout

Figure 16 PCB layout of the reference design

<table>
<thead>
<tr>
<th>Jumper X9A</th>
<th>Jumper X9B</th>
<th>Jumper X9C</th>
<th>Output current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>250 (+/-3 percent)</td>
</tr>
<tr>
<td>V</td>
<td>-</td>
<td>-</td>
<td>350 (+/-3 percent)</td>
</tr>
<tr>
<td>-</td>
<td>V</td>
<td>-</td>
<td>600 (+/-3 percent)</td>
</tr>
<tr>
<td>V</td>
<td>V</td>
<td>-</td>
<td>700 (+/-3 percent)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>V</td>
<td>1050 (+/-3 percent)</td>
</tr>
<tr>
<td>V</td>
<td>-</td>
<td>V</td>
<td>1150 (+/-3 percent)</td>
</tr>
<tr>
<td>-</td>
<td>V</td>
<td>V</td>
<td>1400 (+/-3 percent)</td>
</tr>
<tr>
<td>V</td>
<td>V</td>
<td>V</td>
<td>1500 (+/-3 percent)</td>
</tr>
</tbody>
</table>

Figure 17 Jumper positions vs LED current
ILD8150 80 V high side buck LED driver IC with hybrid dimming

Measurement results with reference design

4 Measurement results with reference design

Table 1  Typical condition for measurement

<table>
<thead>
<tr>
<th>$V_{\text{IN}}$</th>
<th>$R_{\text{CS}}$</th>
<th>Inductance</th>
<th>LED load</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 V</td>
<td>0.36 $\Omega$</td>
<td>860 $\mu$H</td>
<td>17 pcs</td>
</tr>
</tbody>
</table>

Figure 18 shows the actual operating waveforms. The actual measured LED current is 1 A. The switching frequency is 85 kHz and the internal DMOS transistor on the duty cycle is 74 percent.

![Normal operation waveform](image)

4.1 LED current vs supply voltage

ILD8150 provides high output current accuracy despite the changes in supply voltage. Figure 19 shows the output current vs supply voltage in the range 52 V to 70 V. Over the supply range, the output LED current only deviates in the range of 1 percent.
ILD8150 80 V high side buck LED driver IC with hybrid dimming

Measurement results with reference design

Figure 19  Output LED current vs supply voltage

4.2 Dimming

Table 2  Condition

<table>
<thead>
<tr>
<th>$V_{IN}$</th>
<th>$I_{LED,AVG}$</th>
<th>Input PWM frequency</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 V</td>
<td>700 mA</td>
<td>1 kHz</td>
<td>17 pcs</td>
</tr>
</tbody>
</table>

Figure 20  Output current vs duty cycle
4.3 Soft-start

The soft-start process has two steps. Figure 21 shows the digital soft-start process with the steps described earlier.

![Figure 21](image1)

Figure 21  Soft-start, output current

4.4 Cycle-by-cycle current limitation

Figure 22 shows the waveforms under short-circuit condition where the IC limits output current cycle-by-cycle.

![Figure 22](image2)

Figure 22  OCP waveforms
4.5 Efficiency

Efficiency measurement results in the input range 52 V to 70 V for 17 LEDs is shown in Figure 23. The efficiency is measured with different inductors – 860, 150 and 100 µH. It reflects the maximum switching frequency – 86, 360 and 520 kHz accordingly. As seen from the character of the curves, when the difference between input and output voltage is quite low efficiency is quite high with a wide inductance range, because the switching frequency is relatively low. In applications with fixed output voltage, which is close to the output voltage, and low input voltage deviation/ripple, a small inductor may be used. In applications with wide output voltage range and input voltage ripple, such as 100 or 120 Hz, and 10 percent of ripple, which is normal on the primary stage, switching losses create additional power dissipation. In this case inductance should be increased or output current limited.

![Efficiency vs Input voltage](image)

Figure 23  Efficiency vs supply voltage

4.6 Thermal behavior

The maximum temperature attained by the demonstration board is 73.8°C, as shown in Figure 24. The test was performed with input 70 V and 17 LEDs.
4.7 Output current ripple

Figure 25 shows output current waveforms with capacitors of 10 nF and 4.7 µF accordingly. It can be seen that placing a 4.7 µF capacitor in parallel with the LED reduces output ripple current from 21.6 percent to 5.6 percent.

Some applications, such as machine vision, are not allowed to use PWM dimming. In this case an output electrolytic capacitor, which filters output PWM, is recommended. Figure 26 shows output current waveform with input voltage 70 V, 17 LEDs or 51 V, dimming level 6.25 percent, output capacitor 100 µF. An electrolytic capacitor reduces output ripple to 12.5 percent peak-to-peak.
ILD8150 80 V high side buck LED driver IC with hybrid dimming

Measurement results with reference design

Figure 26  Output current waveform at 6.25 percent dimming level with electrolytic output 100 µF
Application with flyback converter XDPL8219

The ILD8150 IC operates as the secondary stage along with a primary-stage flyback or LLC converter. For example, it may be used together with a PFC flyback based on XDPL8219. XDPL8219 is a digitally configurable Secondary-Side Regulated (SSR) controller suitable for PFC flyback operating in Constant Voltage (CV) mode. The XDPL8219 board operates with a universal AC input of 90 Vrms to 305 Vrms and provides a constant voltage of 54 V. So the ILD8150 hysteretic buck converter operates with a fixed input voltage of 54 V and has constant output current. ILD8150 can provide a wide dimming range from 0.5 to 100 percent, with high accuracy across all conditions. It dumps 100 or 120 Hz ripples from the primary side, so the output current is pure DC, which eliminates flicker. The efficiency of such a system is shown in Figure 27.

![Efficiency vs LED number](image)

**Figure 27**  Efficiency of combined stages vs number of LEDs
### Appendix A

#### Table 3  BOM

<table>
<thead>
<tr>
<th>Designator</th>
<th>Value</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Manufacturer Part number</th>
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<tr>
<td>1</td>
<td>BOOT</td>
<td>5000 Test-point THT, red</td>
<td>Keystone</td>
<td>5000</td>
</tr>
<tr>
<td>2</td>
<td>C1</td>
<td>4.7 µF Commercial-grade multi-layer ceramic chip capacitor</td>
<td>TDK</td>
<td>C3225X7S2A475K200AB</td>
</tr>
<tr>
<td>3</td>
<td>C2</td>
<td>100 nF Surface-mount multi-layer ceramic chip capacitor</td>
<td>TDK</td>
<td>C3216X7R2A104K160AA</td>
</tr>
<tr>
<td>4</td>
<td>C4</td>
<td>10 nF Surface-mount ceramic capacitor automotive grade</td>
<td>AVX</td>
<td>12061C103K4Z2A</td>
</tr>
<tr>
<td>5</td>
<td>C5</td>
<td>-- Surface-mount ceramic capacitor automotive grade</td>
<td>AVX</td>
<td>12061C103K4Z2A</td>
</tr>
<tr>
<td>6</td>
<td>C6</td>
<td>22 n Cap-0805-22n/100 V/0.1/X7R</td>
<td>AVX</td>
<td>08051C223K4Z2A</td>
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<tr>
<td>7</td>
<td>C7</td>
<td>100 n Cap-0603-100 n/50 V/0.1/X7R</td>
<td>AVX</td>
<td>06035C104K4Z2A</td>
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<tr>
<td>8</td>
<td>C8</td>
<td>100 p Cap-0805-100 p/25 V/0.1/NP0</td>
<td>Kemet</td>
<td>C0805C101K3GACTU</td>
</tr>
<tr>
<td>9</td>
<td>C9</td>
<td>180 pF Surface-mount multi-layer ceramic chip capacitor</td>
<td>Kemet</td>
<td>C0603C181J5GACTU</td>
</tr>
<tr>
<td>10</td>
<td>C11</td>
<td>10 p GCM-series general-purpose monolithic ceramic capacitor for automotive</td>
<td>Murata</td>
<td>GCM1885C1H100JA16#</td>
</tr>
<tr>
<td>11</td>
<td>CS</td>
<td>5000 Test-point THT, red</td>
<td>Keystone</td>
<td>5000</td>
</tr>
<tr>
<td>12</td>
<td>D1</td>
<td>MBR2H100SF SMD Schottky power rectifier 2.0 A/100 V</td>
<td>ON Semiconductor</td>
<td>MBR2H100SFT3G</td>
</tr>
<tr>
<td>13</td>
<td>D2</td>
<td>SMBJ51A SMBJ 600 W Transil, uni-directional TVS diode/51 V</td>
<td>Bourns</td>
<td>SMBJ51A</td>
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<td>14</td>
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<td>Würth Elektronik</td>
<td>691309510004</td>
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<td>J2</td>
<td>WR-TBL Serie 4123 – 3.81 mm screwless 45-degree entry, 2 p</td>
<td>Würth Elektronik</td>
<td>691412320002</td>
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<tr>
<td>18</td>
<td>J3</td>
<td>HTSW-102-07-L-S Through-hole .025&quot; SQ post header, 2.54 mm pitch, 2-pin, vertical, single row</td>
<td>Samtec</td>
<td>HTSW-102-07-L-S</td>
</tr>
<tr>
<td>19</td>
<td>J4</td>
<td>WR-TBL Serie 4123 – 3.81 mm screwless 45-degree entry, 2 p</td>
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<tr>
<td>20</td>
<td>L1</td>
<td>860 µH Bobbin-type inductor</td>
<td>Würth Elektronik</td>
<td>7447075</td>
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<tr>
<td>21</td>
<td>L2</td>
<td>WE-PD SMD shielded power inductor, size 1210, 1.4 A, 0.56 Ω, 470 µH</td>
<td>Würth Elektronik</td>
<td>7447709471</td>
</tr>
<tr>
<td>22</td>
<td>R1</td>
<td>1.5 k 1.5 k/150 V/1 percent</td>
<td>Vishay</td>
<td>CRCW08051K50FKEA</td>
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<tr>
<td>23</td>
<td>R2</td>
<td>18.2 R 18.2R/200 V/1 percent</td>
<td>Vishay</td>
<td>CRCW120618R2FKEA</td>
</tr>
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### Appendix A

<p>| | | | | |</p>
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<td>24</td>
<td>R3</td>
<td>4.30 R</td>
<td>Standard thick-film chip resistor</td>
<td>Vishay CRCW12064R30FK</td>
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<td>25</td>
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<td>26</td>
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<td>30</td>
<td>R10</td>
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<td>Vishay CRCW12061R33FK</td>
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<td>31</td>
<td>R11</td>
<td>1.33 R</td>
<td>Standard thick-film chip resistor</td>
<td>Vishay CRCW12061R33FK</td>
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<tr>
<td>32</td>
<td>R12</td>
<td>0 R</td>
<td>0 R/200 V/20 mΩ</td>
<td>Vishay CRCW12060000Z0EA</td>
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<tr>
<td>33</td>
<td>R15</td>
<td>220 R</td>
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<td>R16</td>
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<td>DC-DC LED driver IC</td>
<td>Infineon ILD8150E</td>
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<td>X9</td>
<td>TSW-103-08-G-D</td>
<td>2.54 mm pitch header strip, 6 pins, vertical, double row</td>
<td>Samtec TSW-103-08-G-D</td>
</tr>
</tbody>
</table>
7 References

Please refer to the ILD8150 datasheet for more information:

Link to ILD8150 datasheet
**ILD8150 80 V high side buck LED driver IC with hybrid dimming**

## References

**Revision history**

<table>
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<tr>
<th>Document version</th>
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<th>Description of changes</th>
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<td>November 2018</td>
<td>First release</td>
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<td>V 1.1</td>
<td>10 March 2021</td>
<td>Shut-down explanation, ESD chapter update, after-flash effect explanation</td>
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