ILD8150E high-efficiency reference design engineering report

Headroom control in high-efficiency two-stage LED drivers

Author: Alexey Evstifeev

About this document

Scope and purpose

The document shows how to use an LED buck converter based on ILD8150 and an AC-DC primary power stage based on XDPL8219 together. Combining two products with innovative headroom control, which BCR601 also uses, can significantly increase system efficiency, lower ILD8150 temperature and reduce the cost of components such as the buck inductor.

Intended audience

This document is intended for engineers and students designing highly efficient LED drivers.

Table of contents

1 Introduction

Two-stage topology dimmable LED drivers are becoming more popular than single-stage because this topology can guarantee high light quality over the dimming range and comply with class C of **IEC 61000-3-2**. The primary stage provides constant bus voltage and is responsible for power factor correction (PFC). The secondary stage supplies the LEDs with a constant current in a wide dimming range and damps 100 Hz/120 Hz bus voltage ripple.

The hysteretic algorithm implemented in **ILD8150** is attractive because it's very fast, reasonably precise and doesn't require feedback loop compensation. Switching frequency changes according to the formula:

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

It changes over output voltage, as shown in **Figure 1**. The figure is actually for an inductor of 860 µH; for 100 µH the effect is much stronger. The typical output voltage for the majority of LED drivers varies by a factor of two. For example, 30 to 59 V for the SELV LED driver. As you can see in **Figure 1**, the switching frequency changes 1.5 times over the output voltage range. It means that switching losses rise significantly at a lower LED voltage. So the IC dissipates much more power.

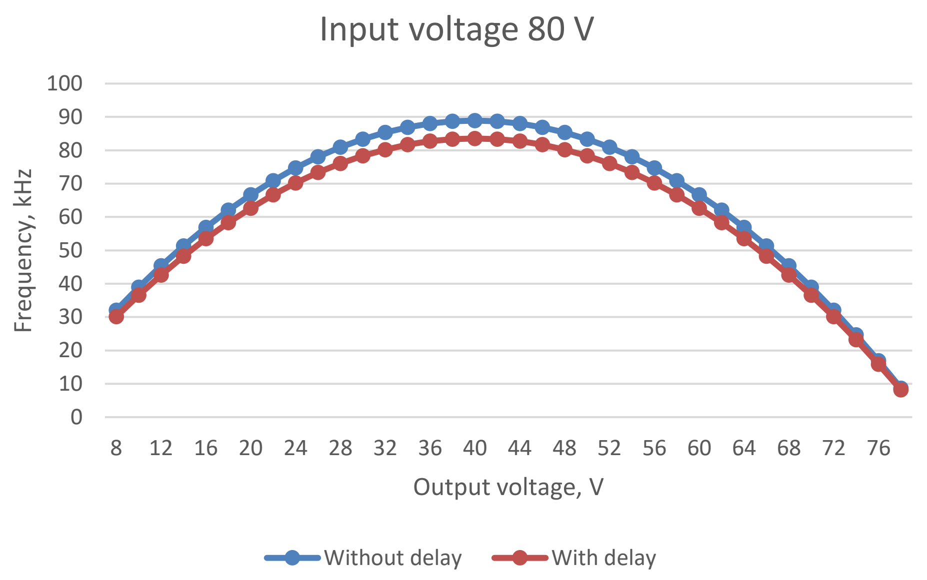

Figure 1 ILD8150(E) switching frequency over output voltage

In **Figure 2**, you can see two designs, REF_ILD8150_DC_1.5A (SP002798058) and REF_ILD8150_DC_1.5A_SMD (SP005351260), comparing conditions V_{IN} = 70 V, V_{LED} = 51 V, I_{LED} = 1 A with L = 860 µH (80 kHz) and L = 100 µH (460 kHz). The first design can provide up to 1.5 A LED current, but it requires the use of quite a large inductor. The second design is capable of providing up to 800 mA with a much smaller inductor. If you compare the distribution of both losses, the first has conduction losses dominant, and the second has switching losses dominant. Because the IC has a maximum limit of power dissipation (the power dissipation budget), designers must choose between optimizing switching frequency and power dissipation.

High-frequency operation involves two key points that designers should note:

- Radiated EMI is becoming more noticeable. An additional output EMI filter might be needed.
- IC internal delays have a greater effect on regulation accuracy.

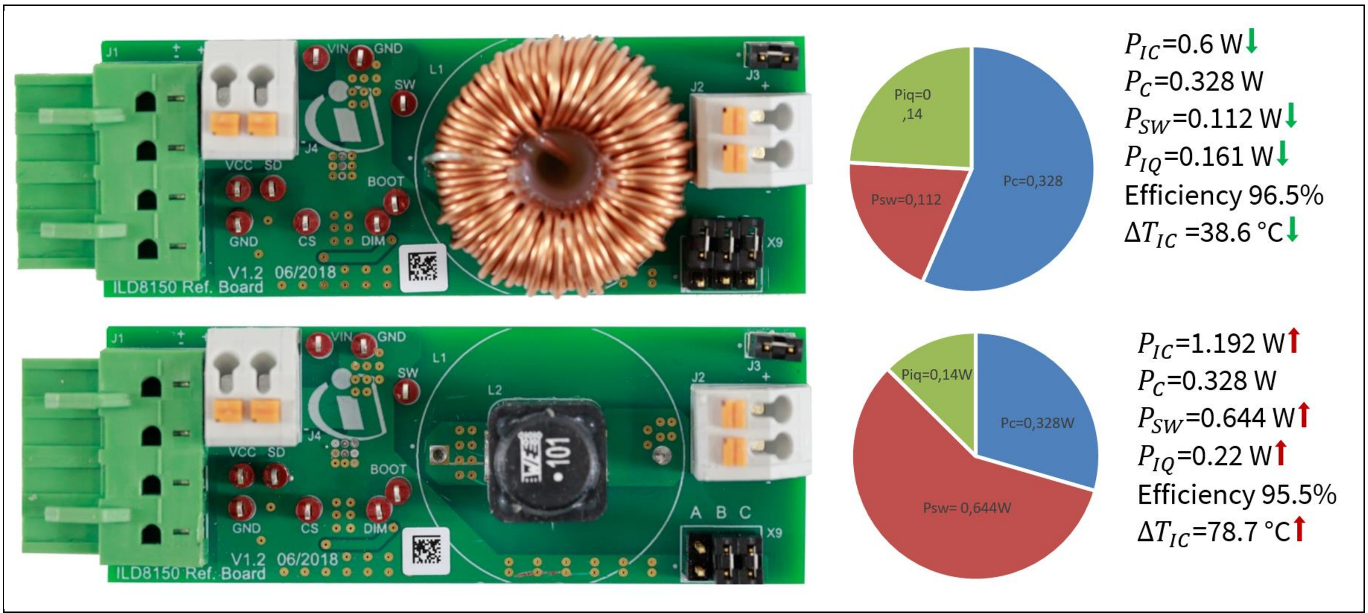

Figure 2 REF_ILD8150_DC_1.5A (SP002798058) and REF_ILD8150_DC_1.5A_SMD (SP005351260) comparison

The proposed method addresses the issues and helps to minimize power dissipation, inductor size and frequency variation. The method is explained in **Figure 3** and in the simplified circuit in **Figure 4**. The schematic on the left shows the standard feedback loop with constant bus voltage V_{out}. The schematic on the right shows the alternative block diagram with headroom control. Based on the operational amplifier, the headroom control changes bus voltage V_{out} according to LED voltage drop V_{LED}. It regulates the voltage difference between V_{out} and V_{LED} to the predefined level of a few volts. The difference V_{out} - V_{LED}, or the headroom, can guarantee the buck converter's proper operation and bus voltage ripple suppression. Since the voltage difference V_{out} - V_{LED} is a constant and has only a low-frequency ripple, switching frequency doesn't change so much, as shown in **Figure 5**, compared with the standard feedback loop. Normally, the crossover frequency of the feedback is chosen in the range of a few Hertz, the same as for PFC, such that 100 Hz or 120 Hz ripple would never affect regulation.

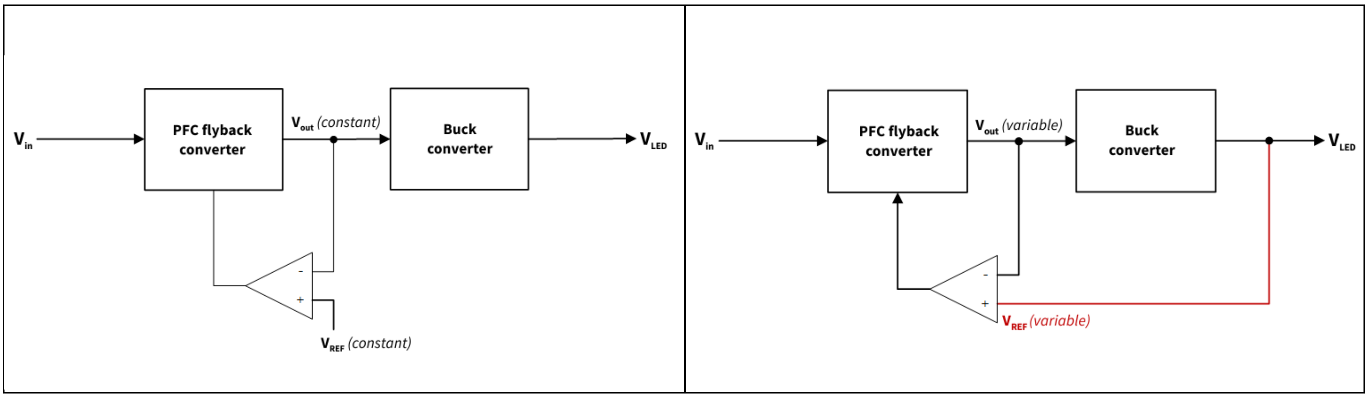

Figure 3 Block diagrams of two-stage topologies; standard on the left, headroom control on the right

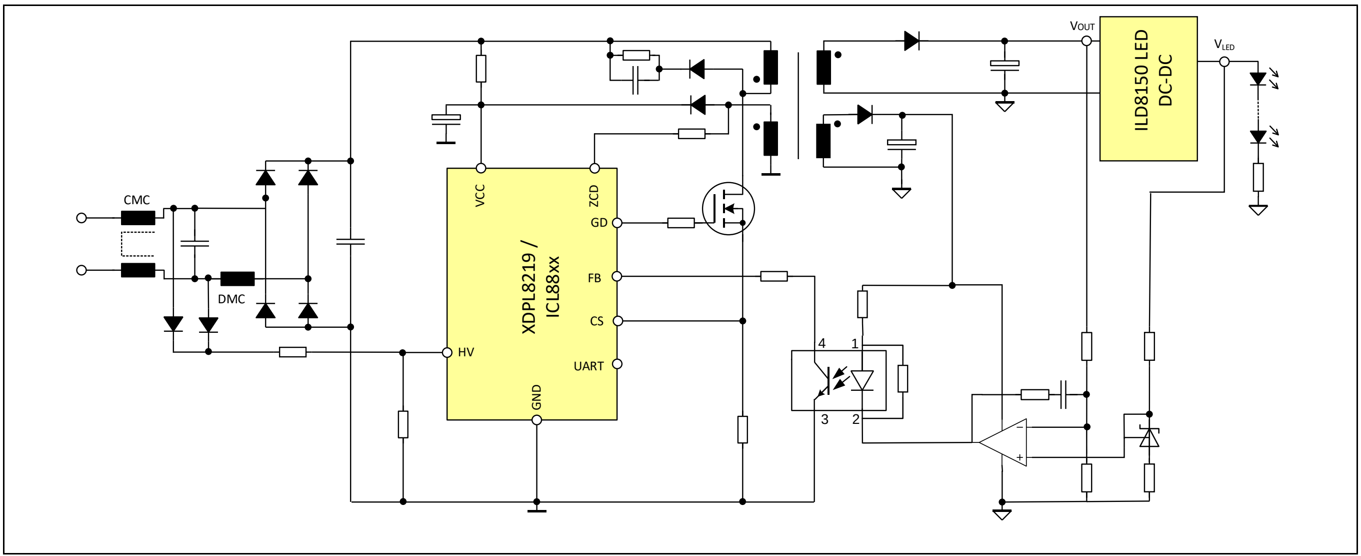

Figure 4 **XDPL8219/ICL88xx + ILD8150 high-efficiency solution with headroom control – simplified schematic**

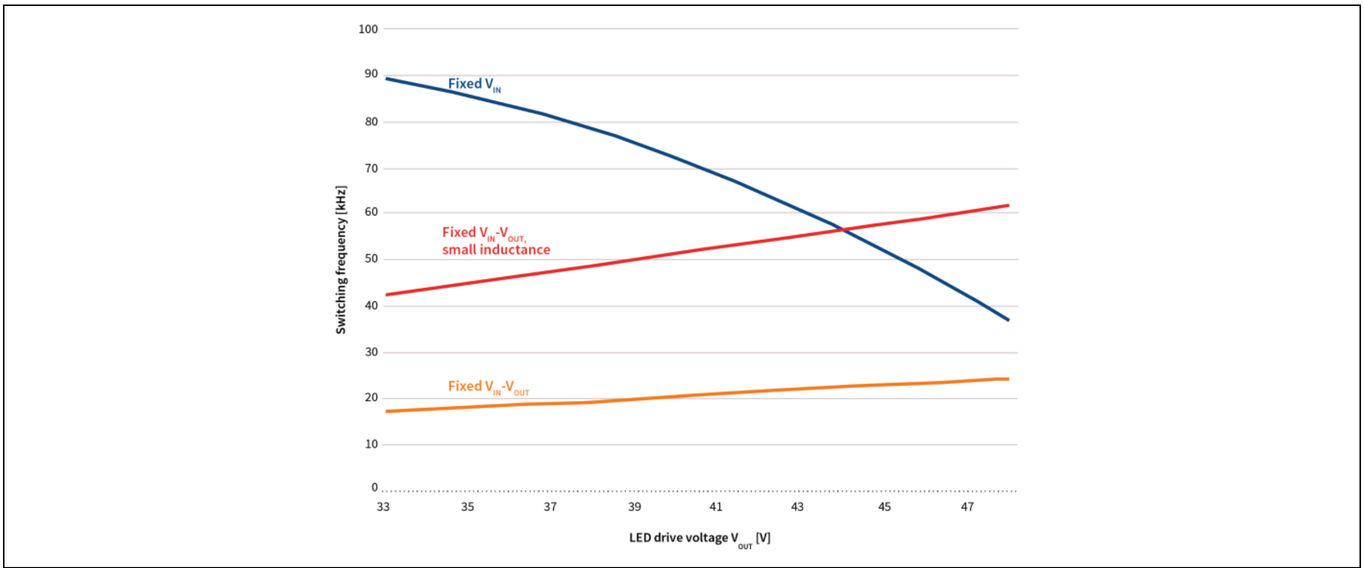

Figure 5 **Frequency variation over LED voltage drop. The blue line shows the standard feedback loop. Orange shows the headroom control loop with the large inductor of 860 µH; red shows the headroom control loop with the small inductor of 100 µH**

A comparison of system efficiency between the standard feedback loop vs. the headroom control loop is shown in **Figure 10**.

As you can see from **Figure 5** and **Figure 10**, a 100 µH inductor is enough to operate at a reasonable switching frequency of 40 to 60 kHz with a significant efficiency increase.

Figure 13 shows a 22.2°C ILD8150E temperature drop with the headroom control V_{LED} = 33 V, I_{LED} = 1.5 A with L = 100 µH.

So, the headroom control feedback can significantly improve system efficiency, drastically decrease IC temperature, increase maximum LED current capability, shrink inductor size and reduce cost. The feedback components are similar compared with a standard feedback loop. No additional components are needed.

2 Schematics and performance

Table 1 Reference design specification

Specification	Symbol	Value	Unit
Maximum DC input voltage	V_{DC}	80	V_{DC}
Maximum LED current	I_{LED_max}	1.5	A
LED voltage range	V_{LED}	30 ~ 59	V
Dimming range	Dim	0.5 to 100	%
Maximum efficiency	Eff_{max}	97	%
Standard compliance			
Flicker	–	IEEE 1789	–
Board dimensions			
Size	L x W x H	Main board: 81 x 27 x 24	mm

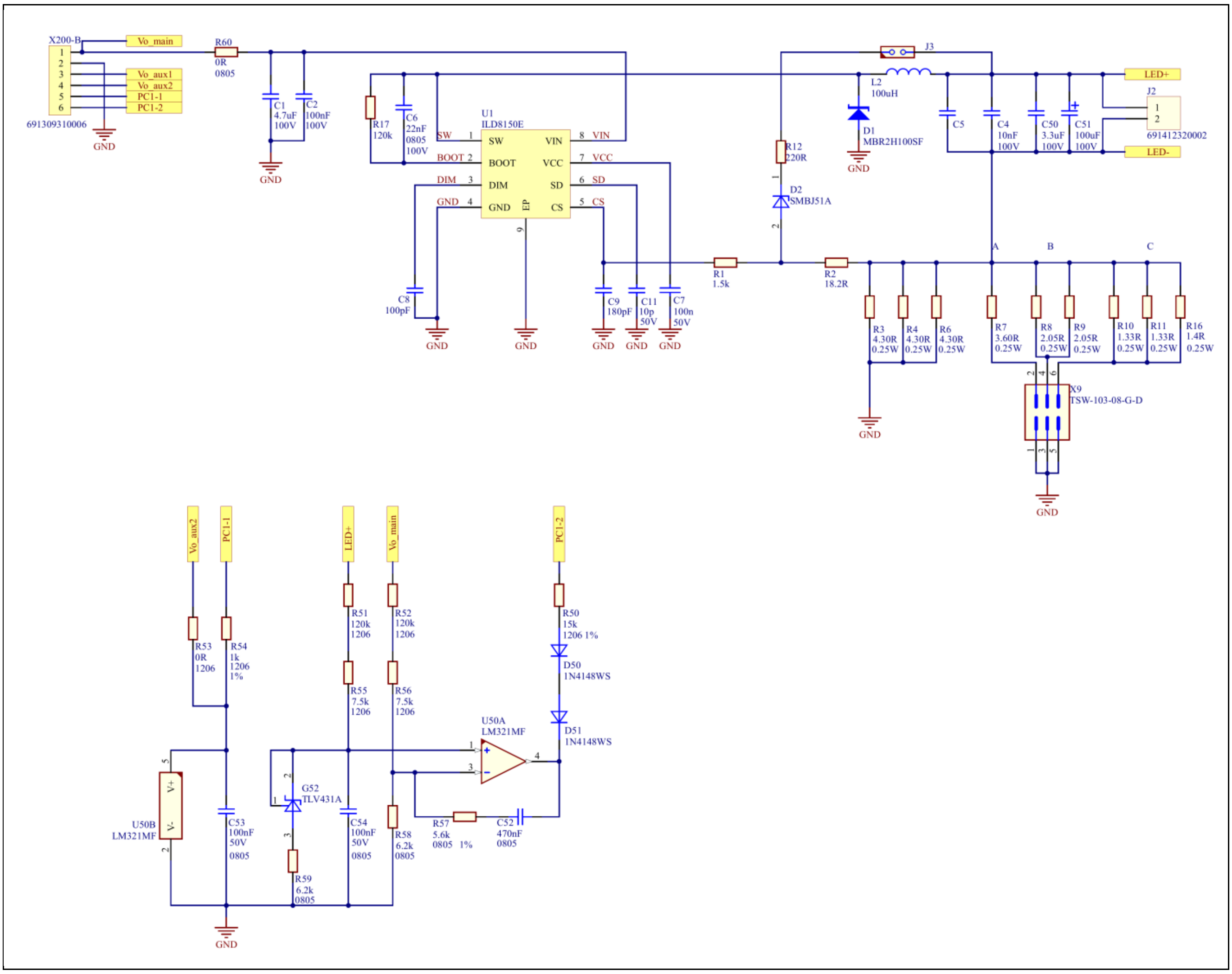

Figure 6 ILD8150_HE reference design circuit – ILD8150E LED buck controller plus the headroom control feedback loop

The circuit has two parts. Part one is based on ILD8150 LED buck. J3 is responsible for overvoltage protection. X9 is an LED current set. The second part has the feedback amplifier based on U50. PC1-1 and PC1-2 are connected to the optocoupler. V_{o_aux2} is the voltage supply of 12 V, which comes from the primary stage. LED+ senses LED voltage, V_{o_main} senses the bus voltage. G52 is a reference voltage V_{Ref}. The headroom voltage is defined as:

$$V_{OUT} - V_{LED} = V_{Ref} \cdot \frac{R_{51} + R_{55}}{R_{59}}$$

Figure 7 Reference design – dimensions 81 mm (L) x 27 mm (W) x 24 mm (H)

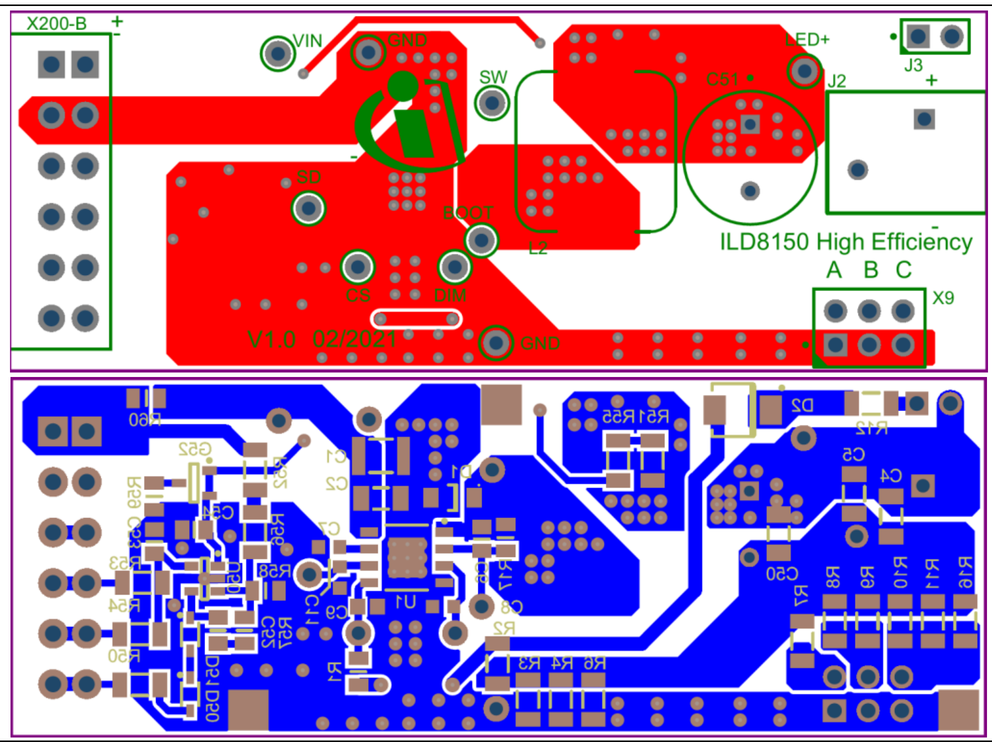

Figure 8 ILD8150E high-efficiency design PCB layout – top and bottom

Figure 9 shows the system primary stage based on XDPL8219 plus ILD8150_HE board. The ILD8150_HE board can also be used together with the ICL8810 SSR reference design. But the feedback loop must be adjusted by components R57 and C52.

Figure 9 System XDPL8219 reference design + ILD8150_HE board

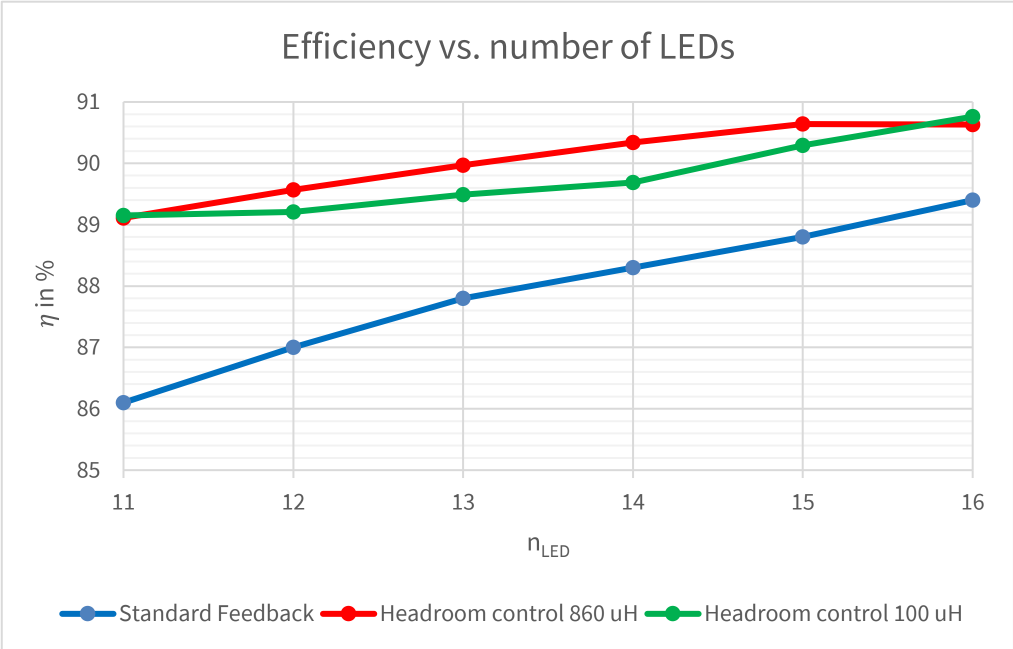

Figure 10 System efficiency. XDPL8219 reference design + ILD8150_HE. V_{in} = 230 V_{AC}, I_{LED} = 700 mA, number of LEDs = 10 to 18

Figure 10 shows the system efficiency improvement. The boards with the headroom control have different inductors of 100 and 860 µH compared with the standard solution. As you can see, the 100 µH inductor is already enough to achieve a good result – about 3 percent efficiency improvement with the output of 11 LEDs and about 1.4 percent improvement with 16 LEDs. Apart from system efficiency improvement, inductor size and cost reduction, there is another benefit. The IC temperature drops, as shown in **Figure 13**. The temperature drops by 22.2°C at an LED current of 1.5 A.

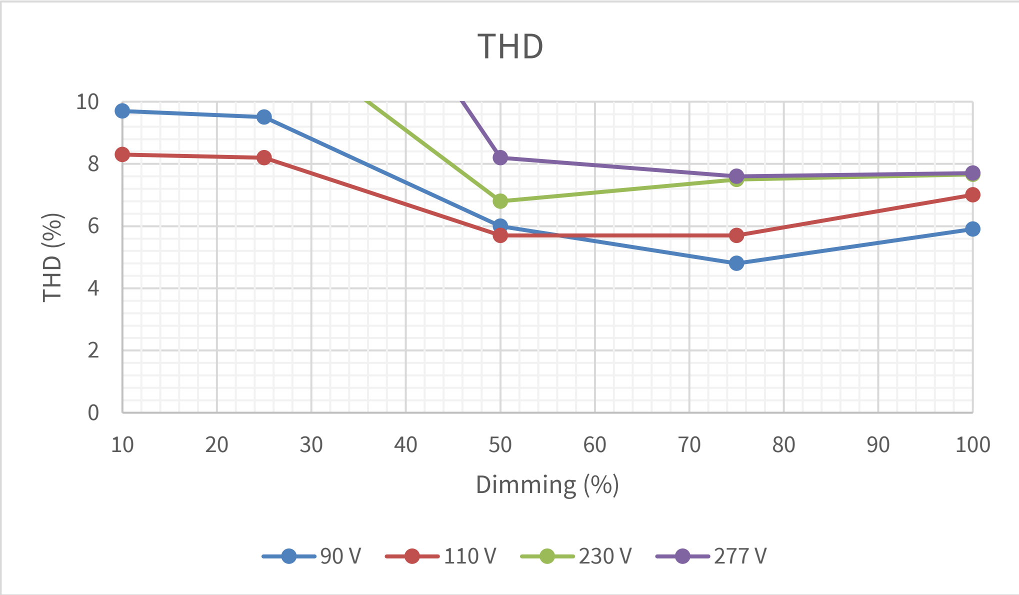

Figure 11 THD over dimming for different input voltages. Maximum output power 43 W

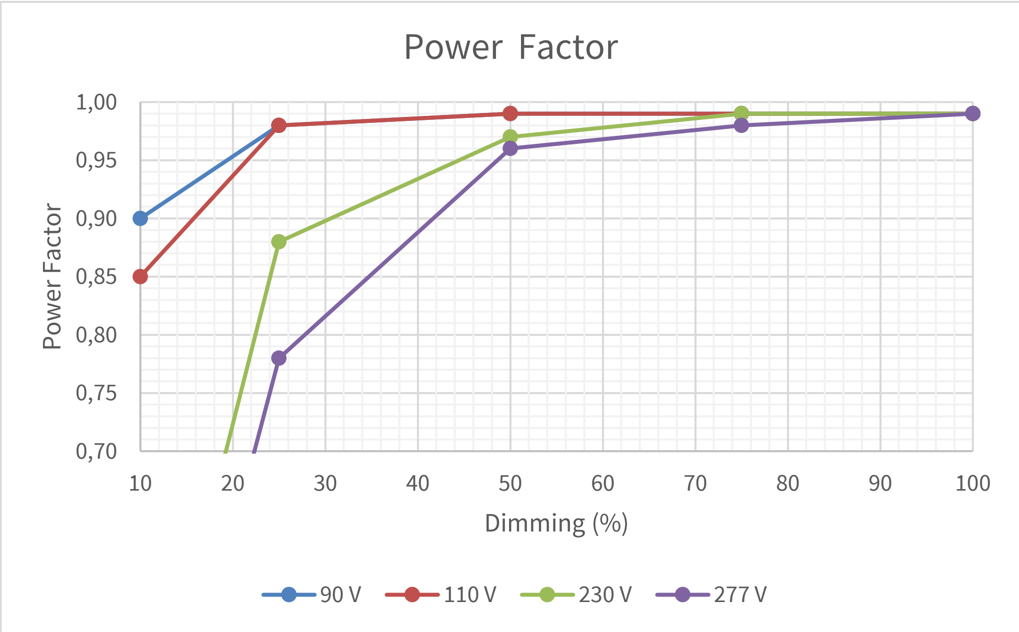

Figure 12 Power factor over dimming for different input voltages. Maximum output power 43 W

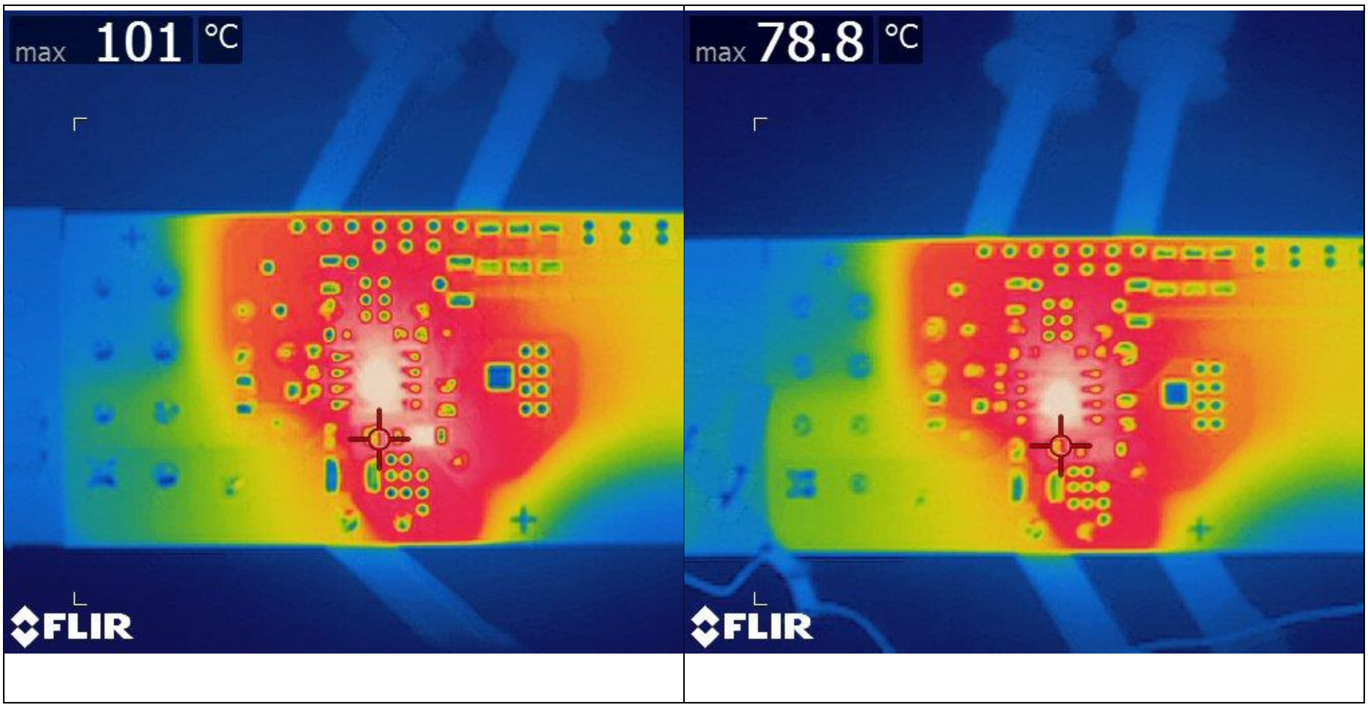

Figure 13 **IC temperature with standard feedback loop and headroom control, V_{LED} = 33 V, I_{LED} = 1.5 A with L = 100 µH**

3 Appendix

Table 2 Bill of materials

#	Designator	Description	Manufacturer	Manufacturer part number
1	BOOT	5000/CON-THT-TP-5000	Keystone	5000
2	C1	Capacitor 4.7 µF/100 V/1210/10%	TDK	C3225X7S2A475K200AB
3	C2	Capacitor 100 nF/100 V/1206/X7R/10%	TDK	C3216X7R2A104K160AA
4	C4	Capacitor 10 nF/100 V/1206/X7R/10%	AVX	12061C103K4Z2A
5	C6	Capacitor 22 nF/100 V/0805/X7R/5%	Murata	GRM21BR72A223JA01
6	C7	100 n/50 V/0603/X7R/10%	AVX	06035C104K4Z2A
7	C8	Capacitor 100 pF/CAPC1608X90N/C0G/5%	KEMET	C0603C0G1H101J030BA
8	C9	Capacitor 180 pF/0603/C0G/1%	KEMET	C0603C181J5GACTU
9	C11	10 p/50 V/CAPC1608X90N/C0G (EIA)/5%	Murata	GCM1885C1H100JA16#
10	C50	Capacitor 3.3 µF/100 V/1206/20%	TDK	C3216X7S2A335M160AB
11	C51	Capacitor 100 µF/100 V/radial type/20%	Panasonic	ECA-2AM101
12	C52	Capacitor 1.5 µF/16 V/0805/X7R/10%	Murata	GCM21BR71C155KA37
13	C53	Capacitor 100 nF/50 V/ 0805/X7R/10%	Yageo	CC0805KRX7R9BB104
14	C54	Capacitor 100 nF/50 V/ 0805/X7R/10%	Yageo	CC0805KRX7R9BB104
15	CS	5000/CON-THT-TP-5000	Keystone	5000
16	D1	MBR2H100SF/100 V/SOD-123F	onsemi	MBR2H100SFT3G
17	D2	Diode SMBJ51A/DO-214AA	onsemi	SMBJ51A
18	D50	Diode 1N4148WS/75 V/SOD-323	Diodes Incorporated	1N4148WS-7-F
19	D51	Diode 1N4148WS/75 V/SOD-323	Diodes Incorporated	1N4148WS-7-F
20	DIM	5000/CON-THT-TP-5000	Keystone	5000
21	G52	Power TLV431A/SOT23-3 (DBZ)	Texas Instruments	TLV431AIDBZR
22	GND	5000/CON-THT-TP-5000	Keystone	5000
23	J2	691412320002	Würth Elektronik	691412320002
24	J3	HTSW-102-07-L-S/ HDRV2W64P254_1X2_496X248X838B	Samtec	HTSW-102-07-L-S
25	J3-J	Jumper, black	Samtec	SNT-100-BK-T

26	L2	100 µH/WE-PD_1210_metal base	Würth Elektronik	7447709101 alt. 784770101
27	LED+	5000/CON-THT-TP-5000	Keystone	5000
28	R1	1.5k/150 V/0805/1%	Vishay	CRCW08051K50FKEA
29	R2	18.2 R/200 V/1206/1%	Vishay	CRCW120618R2FKEA
30	R3	Resistor 4.30 R/1206/1%	Vishay	CRCW12064R30FK
31	R4	Resistor 4.30 R/1206/1%	Vishay	CRCW12064R30FK
32	R6	Resistor 4.30 R/1206/1%	Vishay	CRCW12064R30FK
33	R7	Resistor 3.60 R/1206/1%	Vishay	CRCW12063R60FK
34	R8	Resistor 2.05 R/1206/1%	Vishay	CRCW12062R05FK
35	R9	Resistor 2.05 R/1206/1%	Vishay	CRCW12062R05FK
36	R10	Resistor 1.33 R/1206/1%	Vishay	CRCW12061R33FK
37	R11	Resistor 1.33 R/1206/1%	Vishay	CRCW12061R33FK
38	R12	Resistor 220 R/1206/1%	Vishay	CRCW1206220RFK
39	R16	1.4 R/200 V/1206/1%	Vishay	CRCW12061R40FKEA
40	R17	Resistor 120k/150 V/0805/1%	Vishay	CRCW0805120KFK
41	R50	Resistor 15k/200 V/1206/1%	Vishay	CRCW120615K0FK
42	R51	Resistor 36k/200 V/1206/1%	Vishay	CRCW120636K0FK
43	R52	Resistor 36k/200 V/1206/1%	Vishay	CRCW120636K0FK
44	R53	Resistor 0 R/200 V/1206/0R	Vishay	CRCW12060000Z0
45	R54	Resistor 1k/200 V/1206/1%	Vishay	CRCW12061K00FK
46	R55	Resistor 7.5k/200 V/1206/1%	Vishay	CRCW12067K50FK
47	R56	Resistor 7.5k/200 V/1206/1%	Vishay	CRCW12067K50FK
48	R57	Resistor 22k/150 V/0805/1%	Vishay	CRCW080522K0FK
49	R58	Resistor 6.2k/150 V/0805/1%	Vishay	CRCW08056K20FK
50	R59	Resistor 6.2k/150 V/0805/1%	Vishay	CRCW08056K20FK
51	R60	Resistor 0 R/150 V/0805/0R	Vishay	CRCW08050000Z0
52	SD	5000/CON-THT-TP-5000	Keystone	5000
53	SW	5000/CON-THT-TP-5000	Keystone	5000
54	U1	ILD8150E/SOP8	Infineon	ILD8150E
55	U50	Analog LM321MF/SOT-23-5	Texas Instruments	LM321MF
56	VIN	5000/CON-THT-TP-5000	Keystone	5000
57	X5	5000/CON-THT-TP-5000	Keystone	5000
58	X9	TSW-103-08-G-D/ HDRV6W64P254_3X2_508X762X838B	Samtec	TSW-103-08-G-D
59	X9-J	Jumper, black 3x	Samtec	SNT-100-BK-T
60	X200-B	Terminal block/6 pins/3.81 mm pitch/3.81*6 – duplicate – duplicate	Würth Elektronik	691309310006
61	C5	Capacitor NA/100 V/1206/X7R/10%	AVX	12061C103K4Z2A

4 References

Please refer to the ILD8150 datasheet for more information:

- **ILD8150 datasheet**
- **ILD8150 application note**
- **ILD8150 high-frequency operation**
- **ILD8150 tunable white**

Revision history

Document version	Date of release	Description of changes
V 1.0	2021-09-07	First release

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