Engineering report: 36 W dimmable and flicker-free linear LED driver with BCR601

Active headroom control is cost effective and highly efficient

About this document

Scope and purpose

This document presents a high light quality and high efficiency LED driver reference design with BCR601, a 60 V linear LED controller IC with active headroom control (AHC).

Intended audience

LED driver design engineers and other technical experts who need to design energy-efficient drivers with highest light quality and want to evaluate the performance of linear regulators with AHC.

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1 Introduction

This is an engineering report for a reference design with **BCR601**, a linear LED driver with AHC. It contains the technical specification for the LED driver, a description of the main features and the key measurement results of its performance.

BCR601 regulates the LED current with high accuracy and removes any ripple that comes from the first stage, resulting in unsurpassed light quality. For light dimming the LED current can be reduced to 3 percent of its nominal value by means of an analog dimming input.

In order to maximize the efficiency of this linear regulator, a system with AHC contains a second control loop that delivers a feedback signal to the first stage and reduces the voltage overhead to the minimum possible. This results in efficiency numbers that go up to 96 percent, which is similar to switching regulators, without having their drawbacks.

The embedded hot-plug protection allows plug-in and plug-out of any LED load during operation.

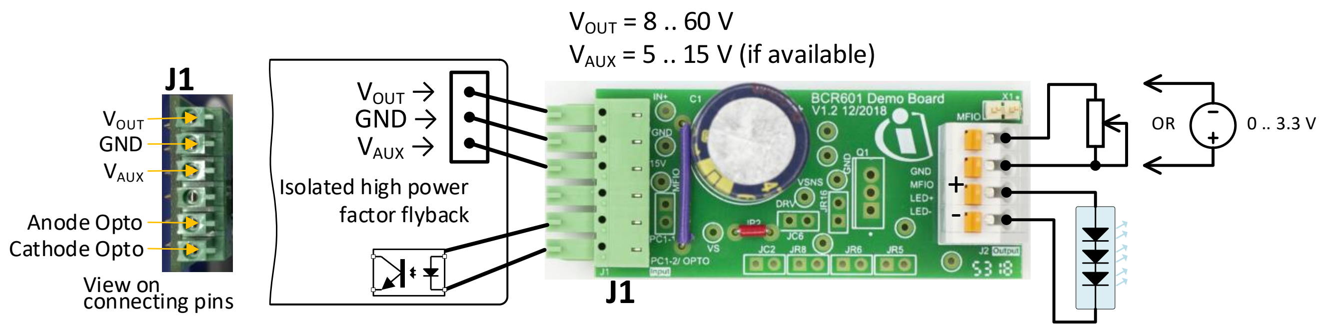
A smart overtemperature protection (OTP) function reduces the LED current when the junction temperature of **BCR601** is higher than 130°C.

An overvoltage protection (OVP) function provides a fast reaction to the feedback signal in case of overvoltage at the input.

2 Board specification

2.1 Board setup

a) Operation with a primary side **(REF-XDPL8219-U40W)** from Infineon's modular lighting reference designs.



b) Connection to other primary sides.

Figure 1 Board setup

2.2 Electrical specifications

Table 1 Electrical specifications – **board**

Parameters	Symbol	Min.	Typ.	Max.	Unit	Remarks
Input voltage range	V_{DD}	8		60	V	
Targeted LED voltage	V_{LED}	7		54	V	
Overvoltage protection	V_{OVP}	54.1		57.9	V	
Regulated headroom	V_{HR}		1.4		V	Average of drain voltage
LED current dimming range	I_{LED}	21		700	mA	
Light flicker	P_{st}^{LM}			0.15	–	Full load and input range
Stroboscopic effect	SVM			0.1	–	Full load and input range
Efficiency	η	94		95.6	%	V_{DD} ripple = 3 V_{PP}, V_{LED} = 52 V, I_{LED} = 700 mA

Table 2 Electrical specifications – **system**

Parameters	Symbol	Min.	Typ.	Max.	Unit	Remarks
Input voltage range	V_{IN}	90		277	V_{RMS}	
Power factor	λ		0.99		–	
Input current THD	iTHD		6.5		%	110 V AC, full load
Efficiency	η		88.0		%	
Power factor	λ		0.99		–	
Input current THD	iTHD		8.2		%	230 V AC, full load
Efficiency	η		90		%	

Note: ***Dimensions****: 100 mm x 26 mm x 26mm*

2.3 Schematic, circuit description and PCB layout

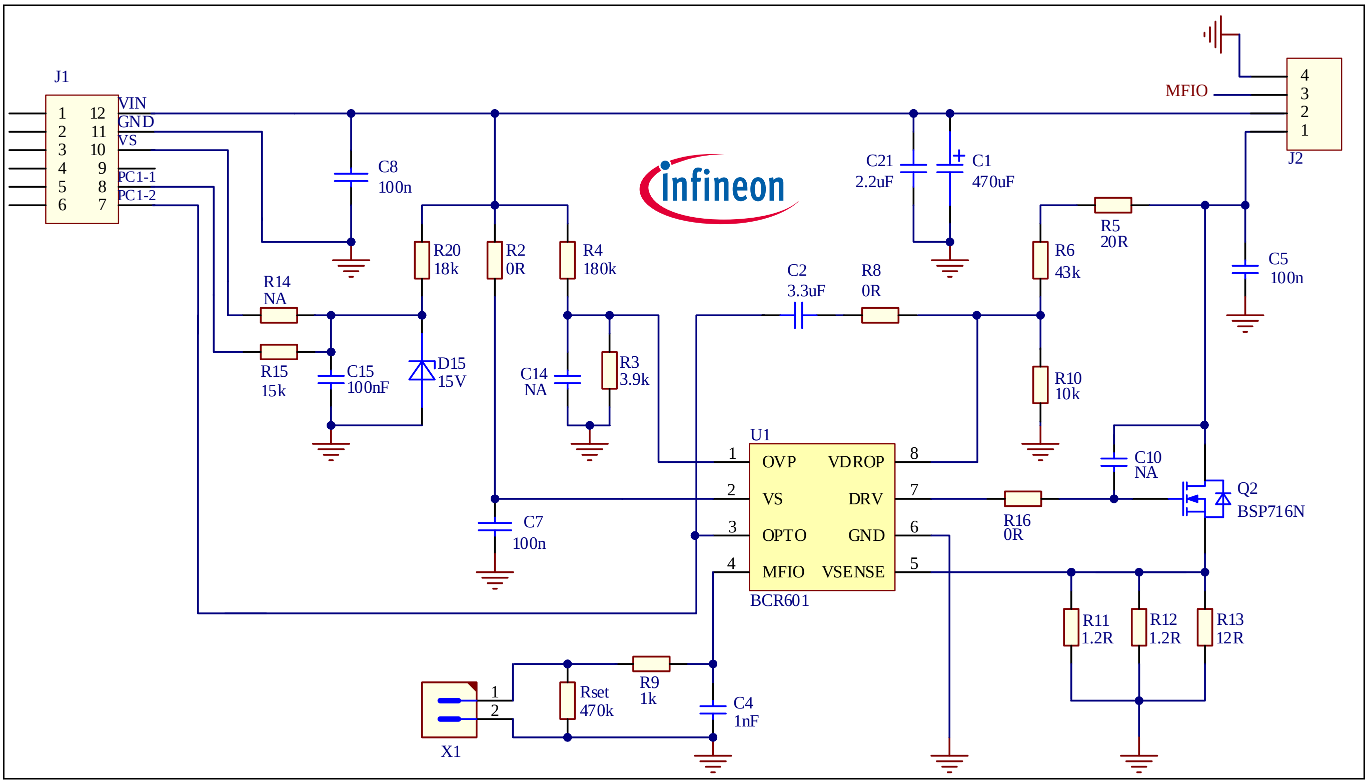


Figure 2 **Schematic**

Figure 2 and **Figure 3** illustrate the schematic and layout of the board, respectively.

Capacitors C1 and C21 respectively reduce the low- and high-frequency ripple on the input voltage V_{IN}.

C7 is a decoupling capacitor that lowers the impedance of the supply rail and reduces high-frequency noise further.

R11, R12 and R13 determine the maximum current of the LED. With the given values of 1.2 Ω, 1.2 Ω and 12 Ω the undimmed LED current is 700 mA typical.

R5 plus R6 together with R10 determine the headroom voltage of the MOSFET Q2. With the given values the average V_{HR} is 1.4 V typical.

Resistor R2 is assembled with 0 Ω on the board as delivered. Use non-zero values if a reduction of power dissipation of the two ICs is desired. If a BJT instead of a MOSFET is used and the maximum driver output current of 10 mA is needed, this may be the case. For details, refer to the **datasheet for BCR601**.

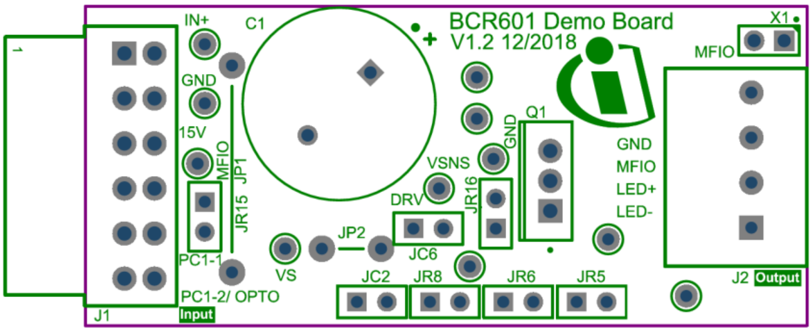
If a BJT is used as an active element R16 should be replaced with a 330 Ω resistor and C10 should have 47 nF to 100 nF to improve stability.

In case the primary side you intend to use delivers an auxiliary voltage in the range of 8 V to 15 V, you may use that to supply the control IC as well as the optocoupler circuit. To do this, you need to remove R20 and solder a suitable value for R14. If the auxiliary voltage is well below 15 V, a few tens of Ω are acceptable for R14. If the voltage is higher, a higher value for R14 is needed to protect D15 from overload. If you want to supply the control IC as well, you need to remove R2 and solder a wire from the cathode of D15 to pin VS of U1. Supplying the IC and optocoupler from an auxiliary voltage further improves efficiency.

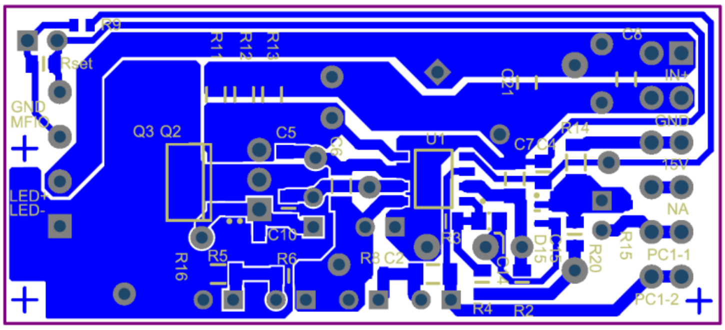
The voltage divider consisting of R3 and R4 determines the OVP level, which is 54 V typically.

R20 together with D15 and C15 generate a stable and noise-free supply for the optocoupler circuit. The optocoupler itself is located on the board of the first stage. The value of R15 defines the maximum optocoupler current. The selected value is optimized for operation with **REF-XDPL8219-U40W**. In case you use a different primary side this value needs to be adjusted, as well as potentially C2 and R8, which determine the frequency response of the feedback loop.

C5 reduces the susceptibility to oscillations in case of long LED connection cables and their inductance. The stability of current regulators in general is reduced with inductive load, and capacitance at the regulator output helps.



1. Top layer and components



2. Bottom layer and components

Figure 3 PCB layout

3 Reference design performance

This section describes the performance of the BCR601-based regulator that is essentially independent of the primary stage used. In some cases this is not totally true, since the performance of the first stage (e.g. output voltage ripple) will also influence BCR601 performance.

3.1 LED current stability and regulator efficiency

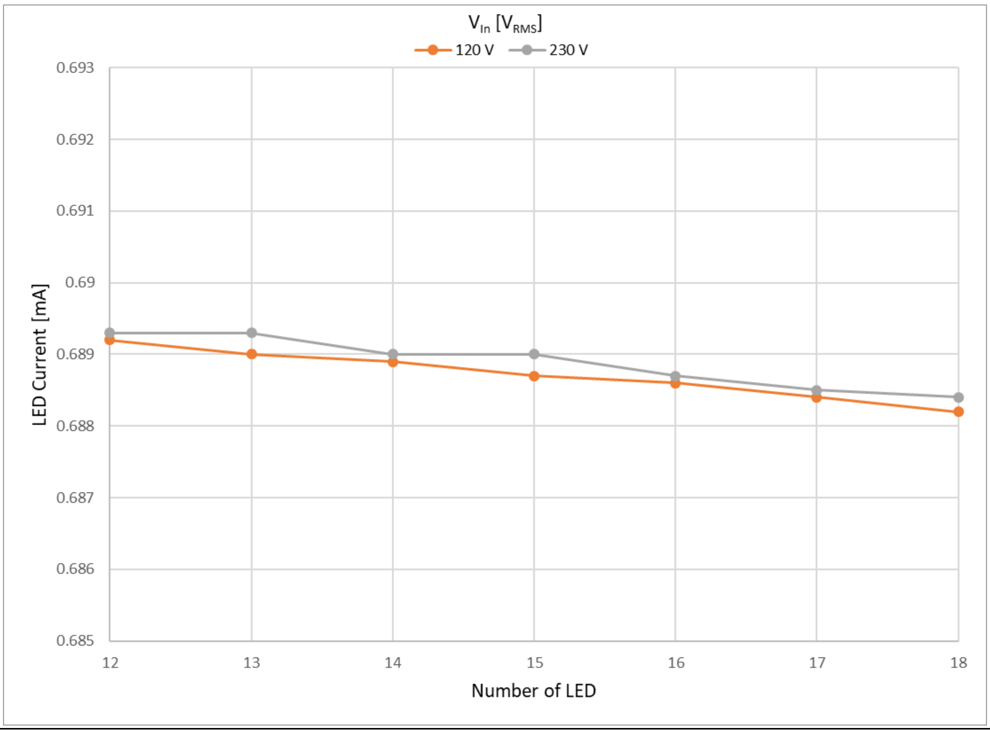


Figure 4 Undimmed LED current vs. number of connected LEDs

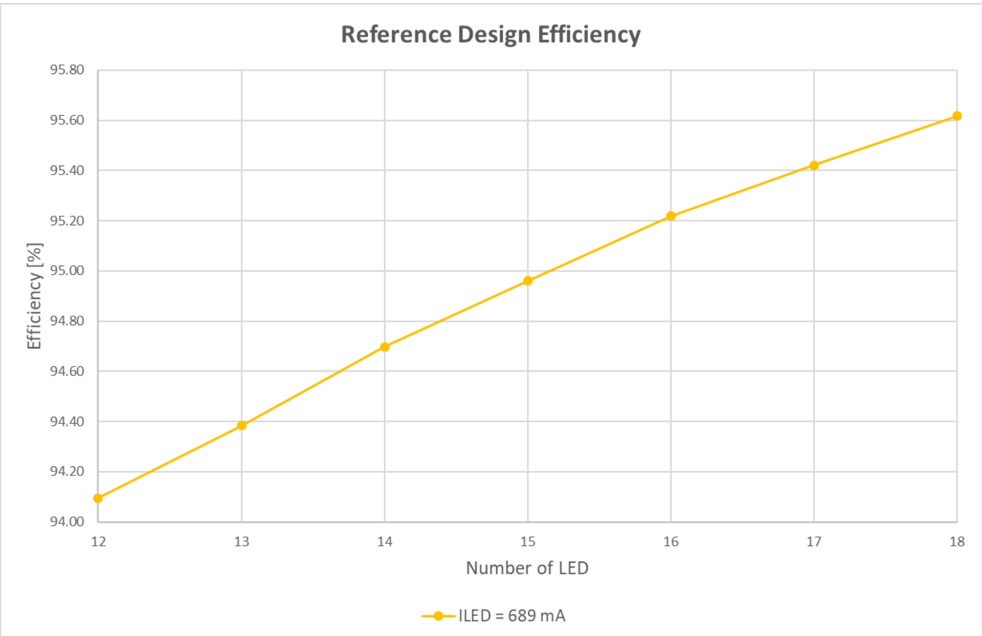


Figure 5 Board efficiency vs. number of connected LEDs (V_{Ripple} = 2.5 V_{pp})

3.2 Light quality

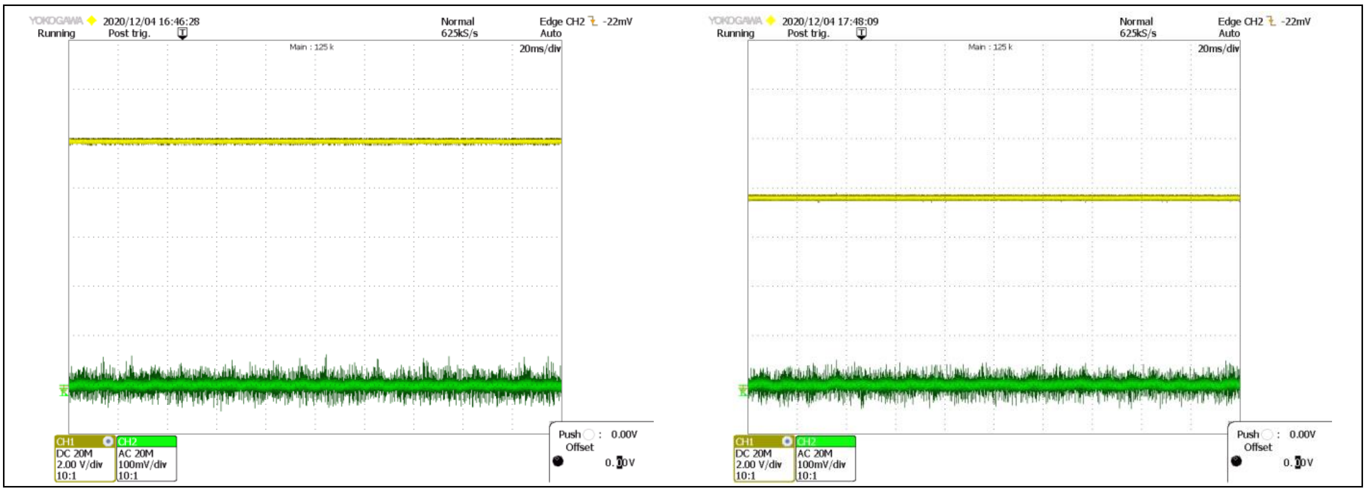


Figure 6 **Output of light sensor. CH1 (yellow) is the DC signal, which is proportional to the light intensity. CH2 is AC content of the same signal at 20 times higher sensitivity. Left: I_{LED} = 689 mA, right: I_{LED} = 515 mA (dimmed to 75 percent).**

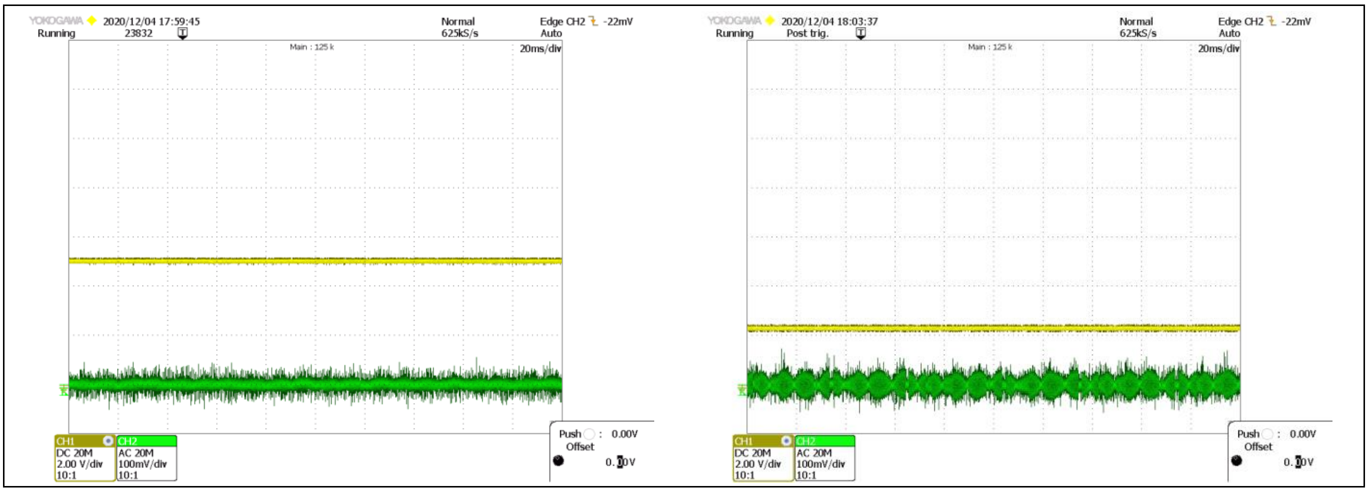


Figure 7 **Same as Figure 6. Left: I_{LED} = 320 mA, right: I_{LED} = 130 mA**

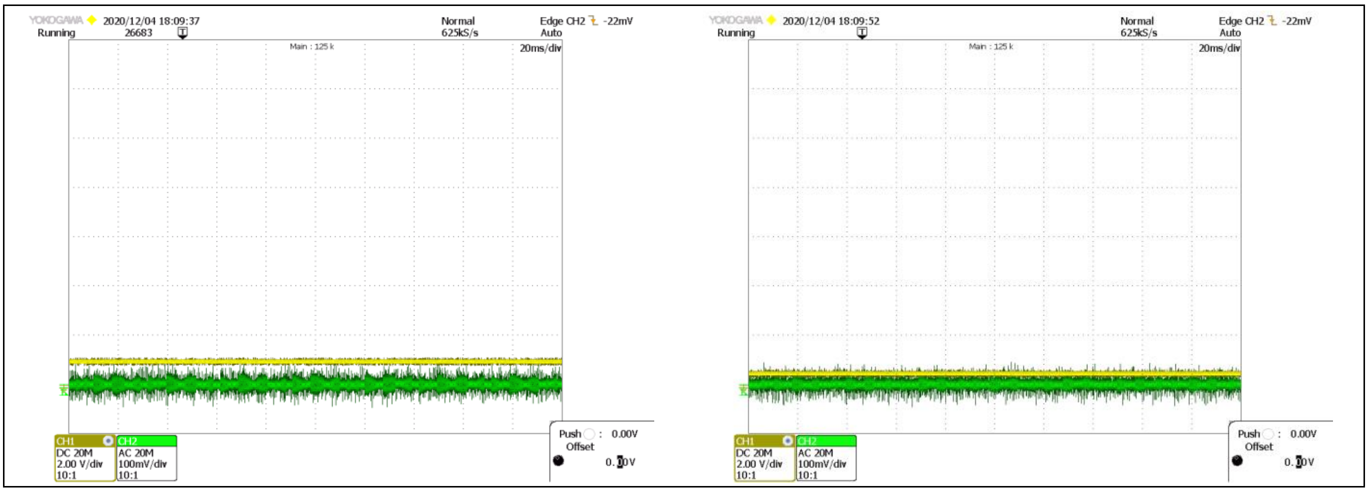


Figure 8 **Same as Figure 6. Left: I_{LED} = 56 mA, right: I_{LED} = 23 mA**

The output level of the light sensor at maximum I_{LED} is about 10 V, while the noise level is less than 100 mV_{pp} (**Figure 6**, left). From that a modulation index of less than 0.1 percent can be determined. The AC component of the sensor signal doesn't vary with light output (**Figure 6**, right), which indicates that the AC signal is mainly determined by sensor noise. When the output current is reduced to 20 percent and below, the effect of primary-side burst mode becomes visible (**Figure 7**, right).

The temporary lighting artifacts (TLA) have been determined with a BTS256-EF spectral light meter with flicker measurement function from Gigahertz-Optik. The results for different LED currents are summarized in Table 3.

Table 3 Light quality vs. output current

		LED current					
		689 mA	515 mA	320 mA	130 mA	56 mA	23 mA
TLA measure	P_{st}^{LM}	0.0	0.0	0.0	0.042	0.066	0.122
	SVM	0.042	0.042	0.042	0.042	0.042	0.042
	Assist Mp	0.009	0.012	0.02	0.03	0.046	0.087

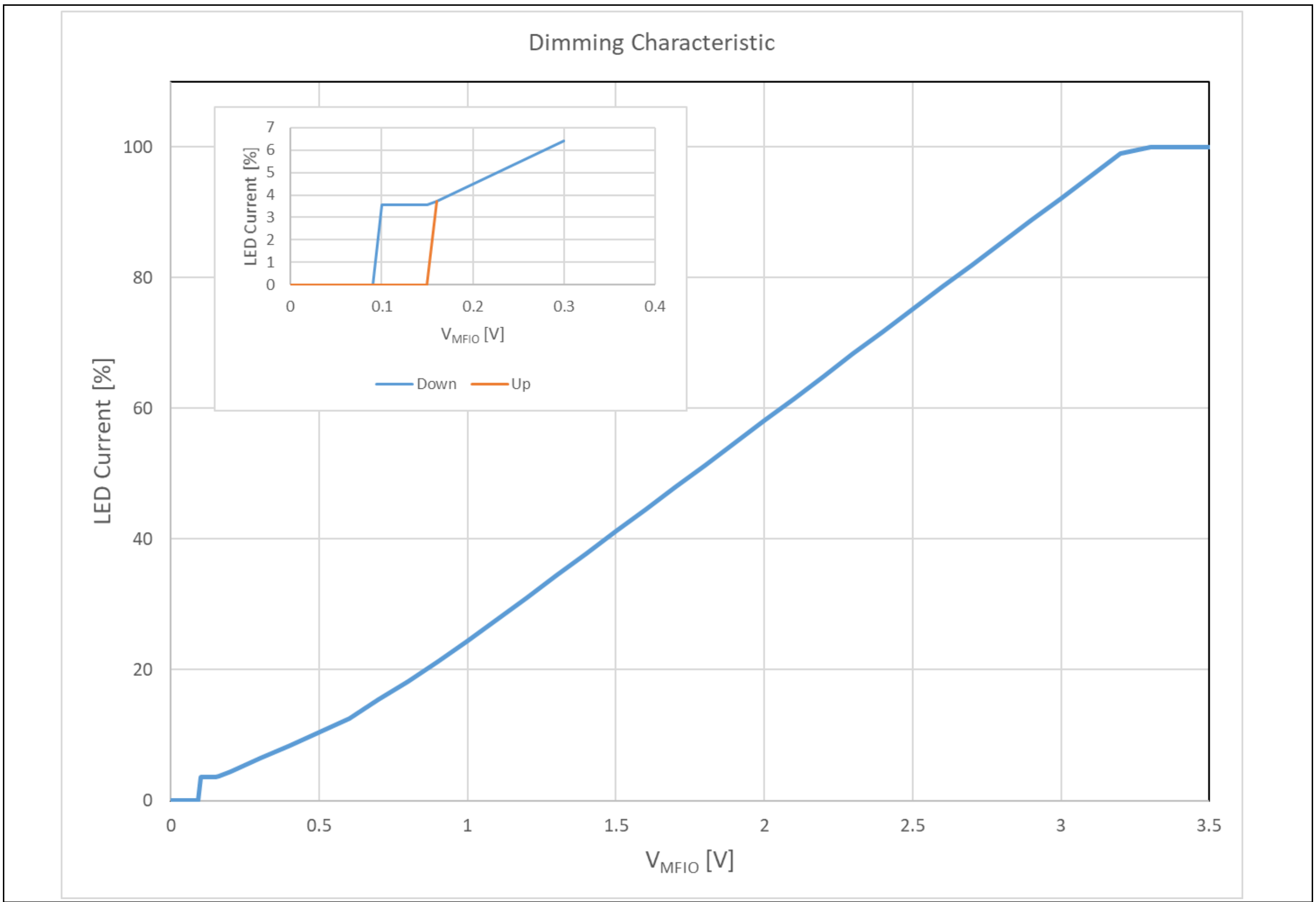


Figure 9 Dimming characteristic: relative LED current vs. V_{MFIO}

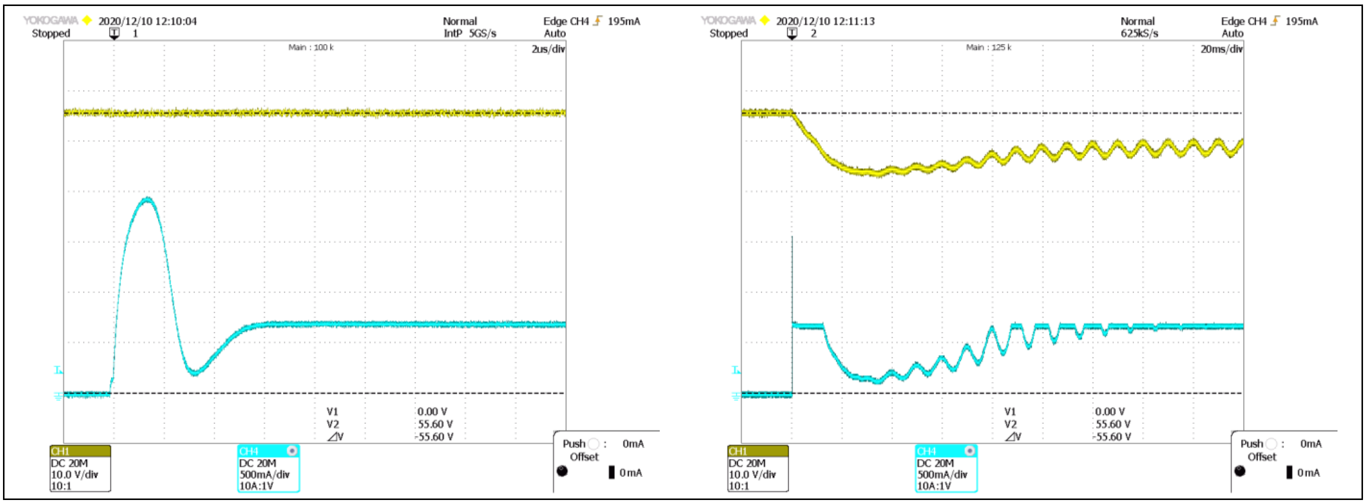


Figure 10 LED hot plug. CH1 (yellow): V_{OUT} of first stage, CH2 (blue): I_{LED}

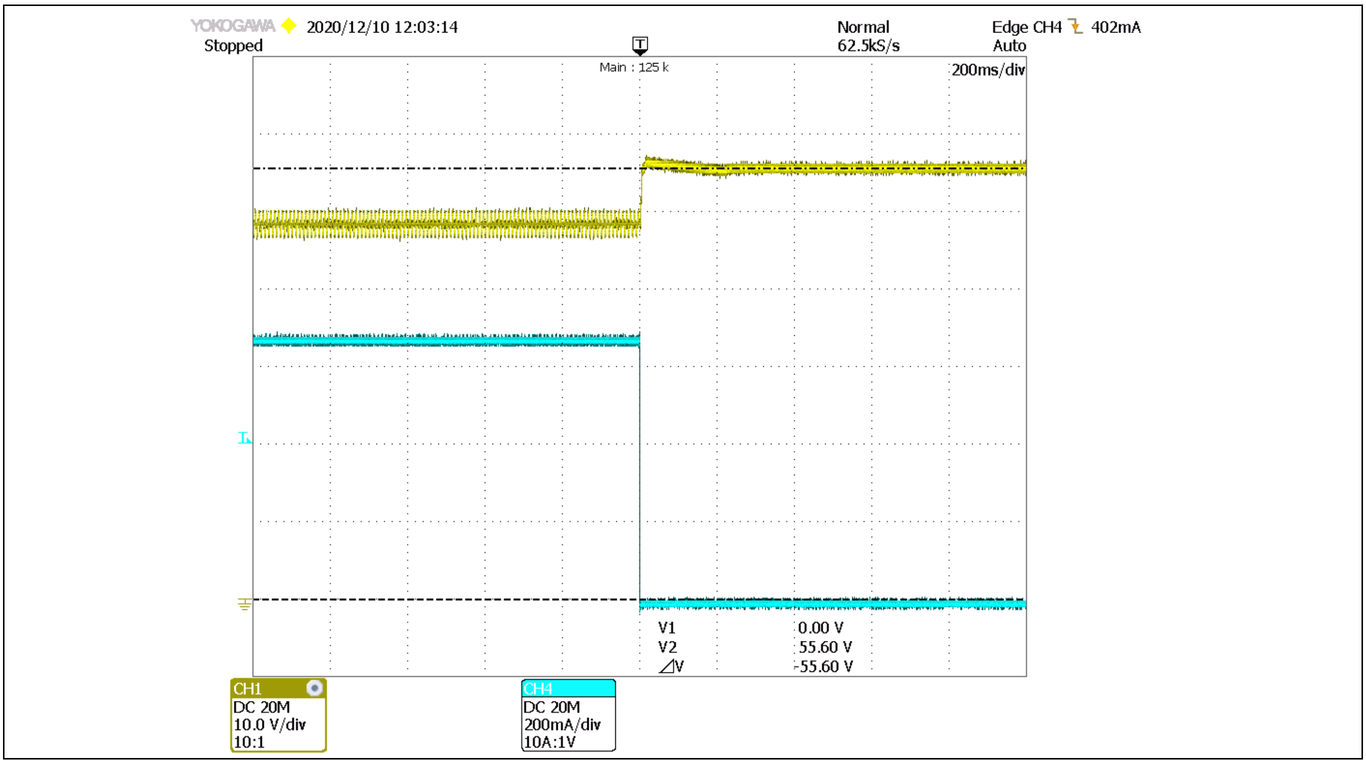


Figure 11 OVP. CH1 (yellow): V_{OUT} of first stage, CH2 (blue): I_{LED}

4 System performance

The board as delivered is ready to work with **REF-XDPL8219-U40W** as primary side, and the below-mentioned performance data are determined in combination with that board.

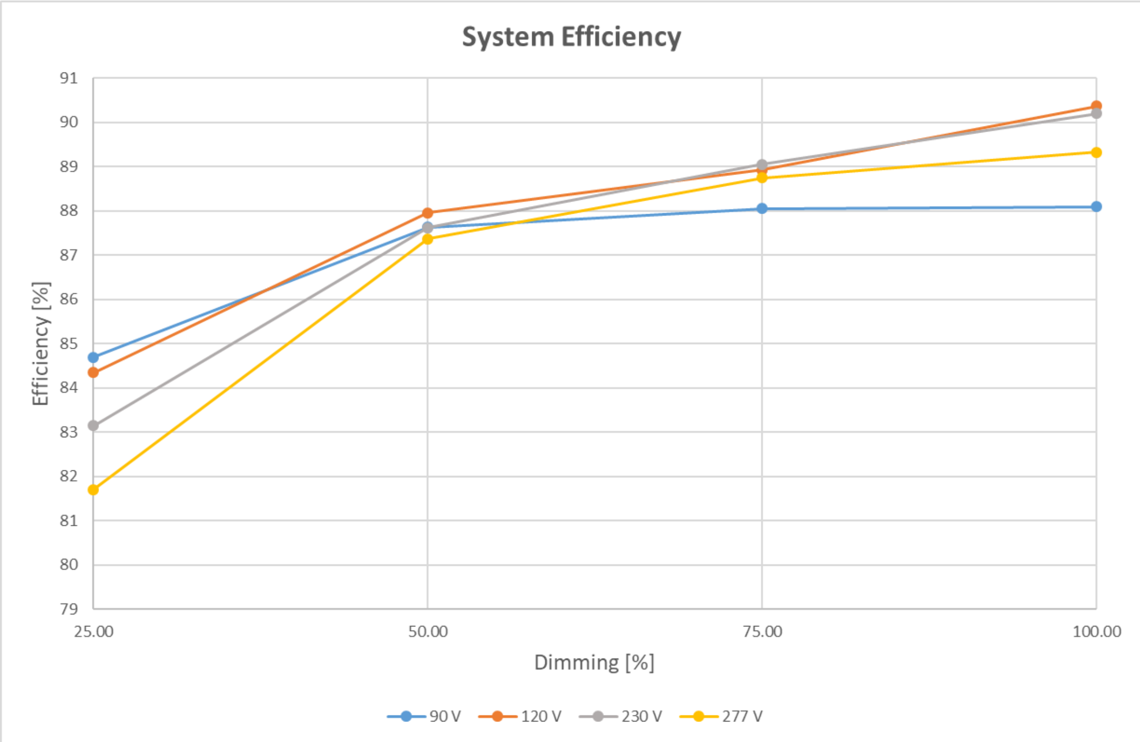


Figure 12 Total system efficiency of BCR601 reference design in combination with XDPL8219-U40W

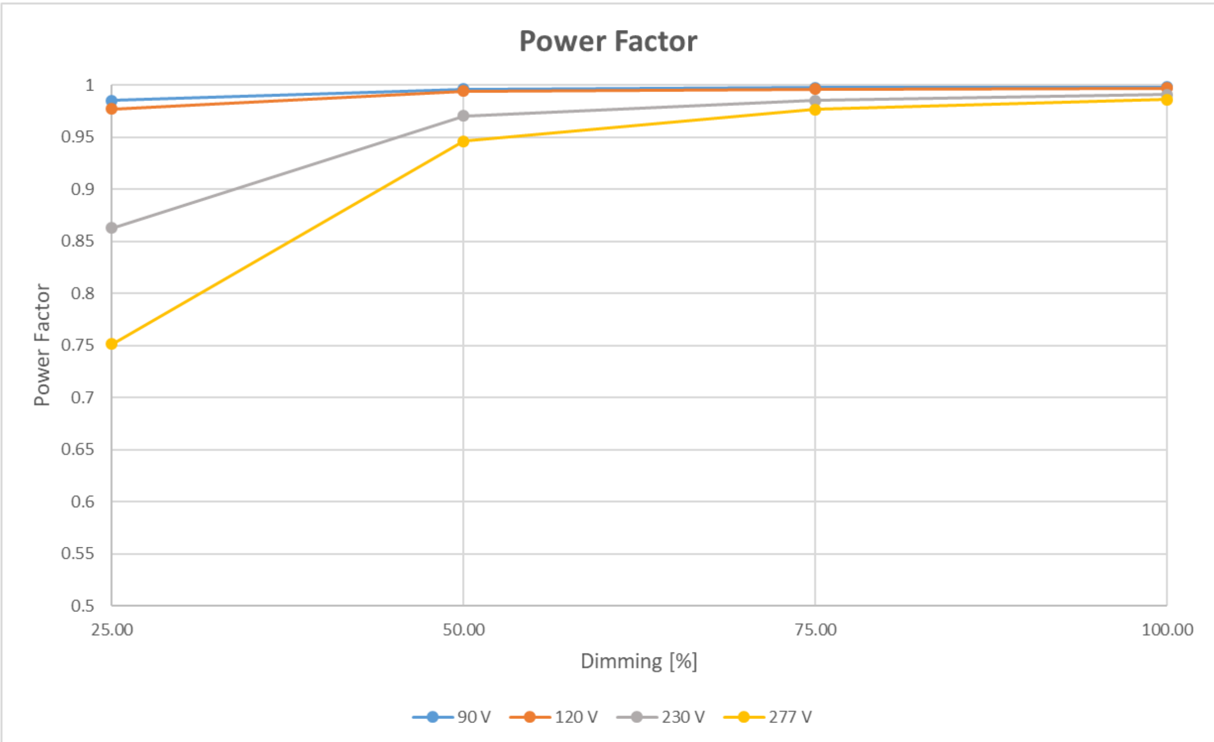


Figure 13 Power factor of BCR601 reference design in combination with XDPL8219-U40W

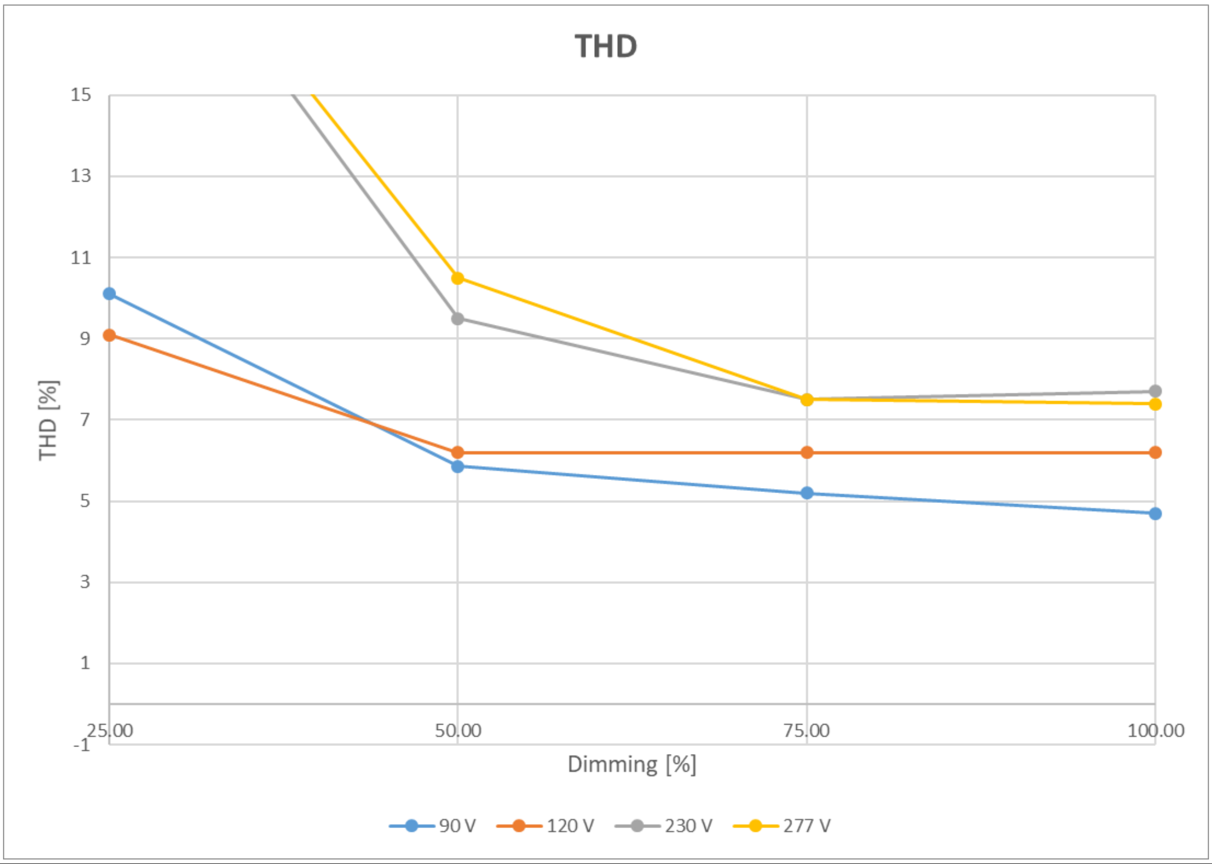


Figure 14 **iTHD of BCR601 reference design in combination with XDPL8219-U40W**

LED hot-plug performance is shown in **Figure 10**. The initial current spike of about 2.5 times the nominal current and 2 µs duration visible in the left part is mainly due to parasitic capacitances, and is not an issue. With the longer time base the setting of the feedback loop back to nominal LED current is visible.

When the LED is removed from the output, the headroom control loop would increase the output voltage of the first stage to unacceptable levels, because the headroom voltage seems too low. How the OVP prevents this and keeps the output at a desirable level is visible in **Figure 11**. Besides the hot-plug behavior, **Figure 10** also shows how the system recovers from such an event when the LED is reconnected.

The full-load system efficiency (**Figure 12**) is higher than 88 percent at low-line and achieves over 90 percent at high-line. This is an excellent result for a high power flyback in combination with a linear second stage, and is difficult to exceed even by more complex topologies. Power factor and iTHD (**Figure 13** and **Figure 14**) are excellent over a wide dimming range. When judging these data, remember that the full reference system output power of 36 W is only 90 percent of the rated power of the first stage. If the latter is optimized for 36 W, performance may be improved further.

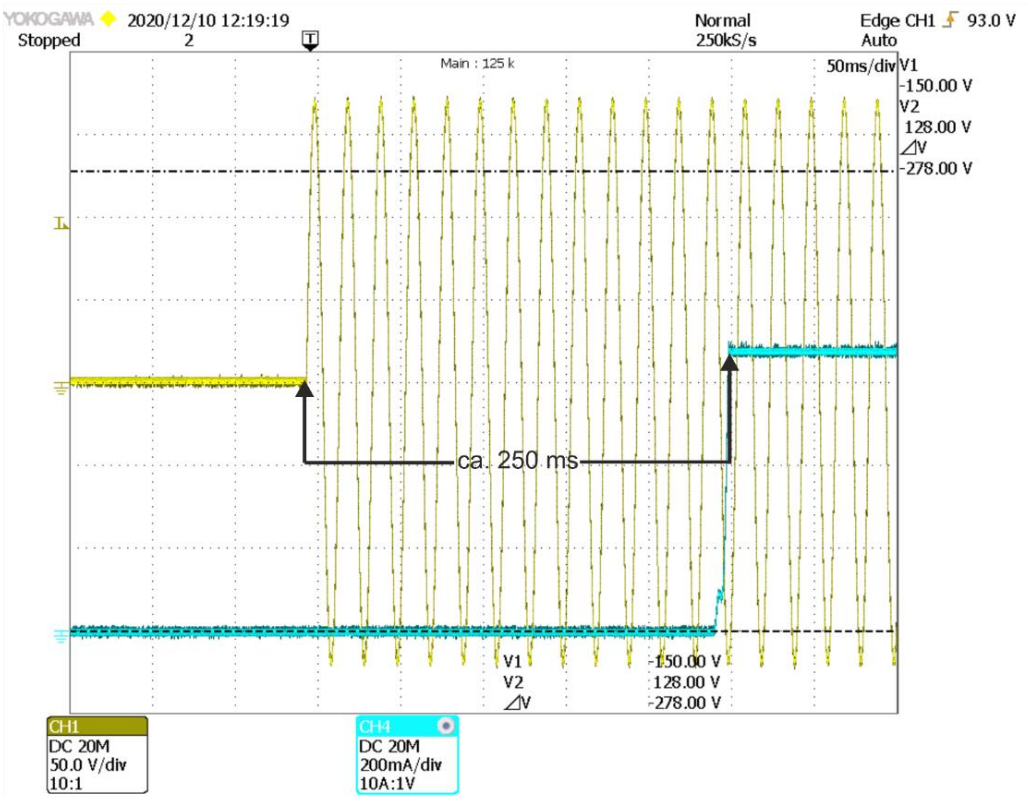


Figure 15 Time to light. CH1 (yellow): line input voltage, CH2 (blue): I_{LED}

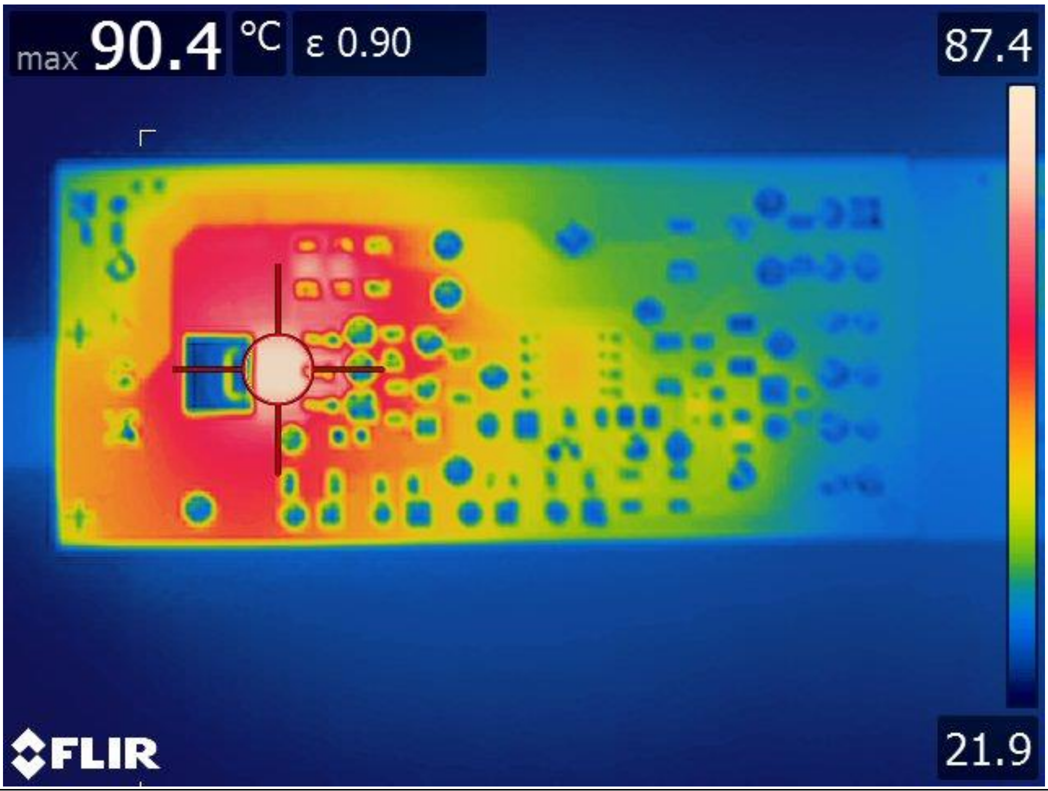


Figure 16 Thermal performance of BCR601 reference design. Bottom side, free air, T_{amb} = 22°C

5 Bill of materials

#	Qty	Designator	Description	Manufacturer	Manufacturer part number
1	1	C1	470 µF/63 V	Panasonic	EEU-FC1J471
2	1	C2	3.3 µF/25 V/1206/X7R/10%	Würth Elektronik	885012208067
3	1	C4	1 nF/25 V/0805/X7R/5%	Kemet	C0805C102K3RACTU
4	1	C5	100 nF/100 V/0805/X7R/10%	TDK	C2012X7R2A104K125AA
5	1	C7	100 nF/100 V/1206/X7R/10%	AVX	12061C104KAZ2A
6	1	C8	100 nF/100 V/1206/X7R/10%	AVX	12061C104K4Z2A
7	1	C15	100 nF/50 V/0603/X7R/10%	AVX	06035C104K4Z2A
8	1	C21	2.2 µF/100 V/1206/X7R/10%	Murata	GRM31CR72A225KA73
9	1	D15	Zener/15 V/SOD-523	N/A	SZMM5Z15VT1G
10	1	J1	Connector 6-pole	Würth Elektronik	691309310006
11	1	J2	Connector 4-pole	Würth Elektronik	691418320004
12	1	Q2	BSP716N/SOT-223-4L	Infineon	BSP716N H6327
13	2	R2, R16	0 R/0805	N/A	N/A
14	1	R3	3.9 k/150 V/0805/1%	N/A	N/A
15	1	R4	180 k/150 V/0805/1%	N/A	N/A
16	1	R5	20 R/200 V/1206/1%	N/A	N/A
17	1	R6	43 k/150 V/0805/1%	N/A	N/A
18	1	R8	0 R/0603	N/A	N/A
19	1	R9	1 k/75 V/0603/1%	N/A	N/A
20	1	R10	10 k/200 V/0805/1%	N/A	N/A
21	2	R11, R12	1.2 R/200 V/1206/1%	N/A	N/A
22	1	R13	12 R/200 V/1206/1%	N/A	N/A
23	1	R15	15 k/75 V/0603/1%	N/A	N/A
24	1	R20	18 k/150 V/0805/1%	N/A	N/A
25	1	Rset	470 k/150 V/0805/1%	N/A	N/A
26	1	U1	BCR601	Infineon	BCR601
27	1	X1	Connector 2-pole	Samtec	HTSW-102-07-L-S

Revision history

Document version	Date of release	Description of changes
V 1.0	29-01-2021	First release

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