

BCR602 engineering report

Engineering report for a 60 V, 200 mA linear LED controller demonstration board

About this document

Scope and purpose

This document presents a demonstration board (DEMO_BCR602_60V_ICTRL) design for a linear LED driver based on an Infineon BCR602 controller IC. It is an engineering report on features and performance for a 60 V/200 mA solution, with explanations covering circuit and layout design. BCR602 is a linear LED controller IC in a small PG-SOT23-6 package regulating the LED current in operation with an external power transistor.

Intended audience

This document is intended for design engineers, application engineers and students, for example, who need to design cost-efficient, dimmable and highly reliable linear LED drivers for:

- LED engines
- LED modules
- LED strips

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1 Introduction

1 Introduction

This is an engineering report for a 60 V, 200 mA linear LED driver demonstration board. This document contains the technical specification for the LED driver, a description of the main features, circuit and layout descriptions, as well as the measurement results.

In this application a MOSFET controlled by a BCR602 is used as an LED driver for constant current control. The board can also be equipped with a BJT. BCR602 regulates the LED current using a power transistor. The LED current is fully scalable by dimensioning an external Current Sense (CS) resistor. BCR602 suppresses the voltage ripple of the power supply, driving a constant LED current for better light quality. The LED current can be dimmed by a resistor R_{set} as well as by analog PWM voltages connected to the Multi Function Input Output (MFIO) pin. The embedded hot plug protection allows plug in and plug out of any LED load during operation. The LED current level is configured to 200 mA and is tested using alternative configurations up to 1.0 A by connecting up to three current sense resistors at the *VSENSE* pin. The shunt resistors define the maximum LED current tested down to an effective resistor combination of R11, R12 and R13 of 267 mΩ. The voltage drop at the *VSENSE* pin caused by the shunt resistors is 400 mV, or in case of dimming less, improving the overall system efficiency and providing extra voltage headroom to compensate for tolerances of LED forward voltage or supply voltage. A smart Over-Temperature Protection (OTP) function reduces the LED current when the junction temperature of BCR602 gets too high.

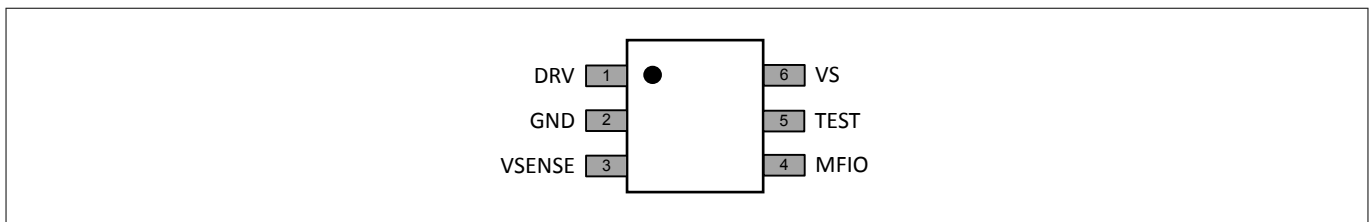


Figure 1 Pin configuration



Figure 2 Top side of the demonstrator design board (56.00 mm x 27.00 mm)

1 Introduction

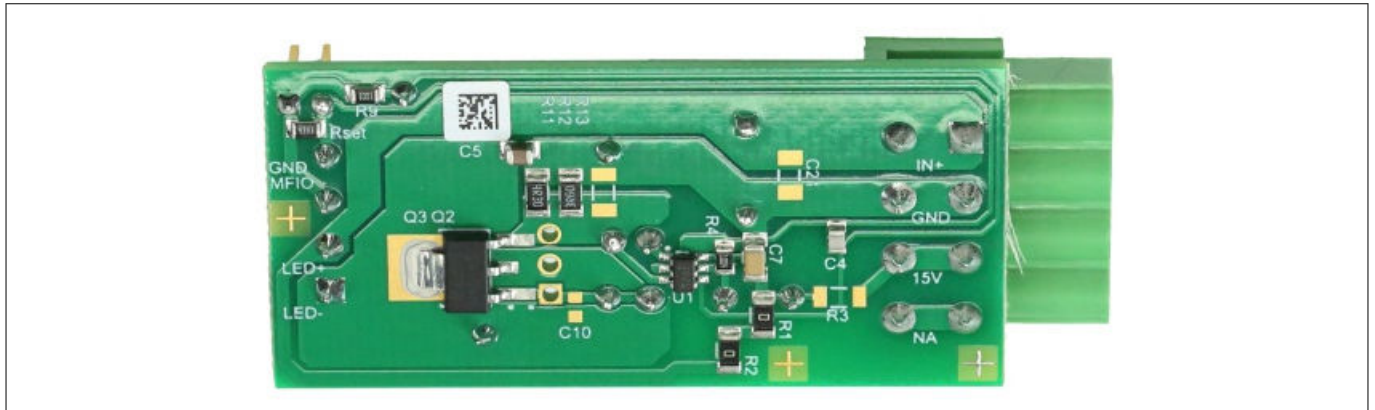


Figure 3 Bottom side of the demonstrator design board (56.00 mm x 27.00 mm)

2 List of features of the demonstrator system

2 List of features of the demonstrator system

Table 1 List of features

Supply voltage from 8 V to 60 V
Board configurable up to 1.5 A LED current control, precise current set-up via three shunt resistors in parallel
Supports use of NPN bipolar transistors and nMOS MOSFETS
100 Hz/120 Hz supply ripple suppression
LED current precision ± 3 percent
3 percent analog dimming or 1 percent PWM dimming of LED current at the <i>MFIO</i> pin
Board suitable for assembly with transistor packages of types SOT-223, DPAK, TO-220
R_{set} functionality at the <i>MFIO</i> pin
Flexible input capacity selectable as ceramic SMD device or as electrolyte device
Hot-plug protection to minimize LED inrush current
OTP function vs junction temperature

3 Circuit description

3 Circuit description

This chapter describes the BCR602 demonstrator design.

3.1 Circuit diagram

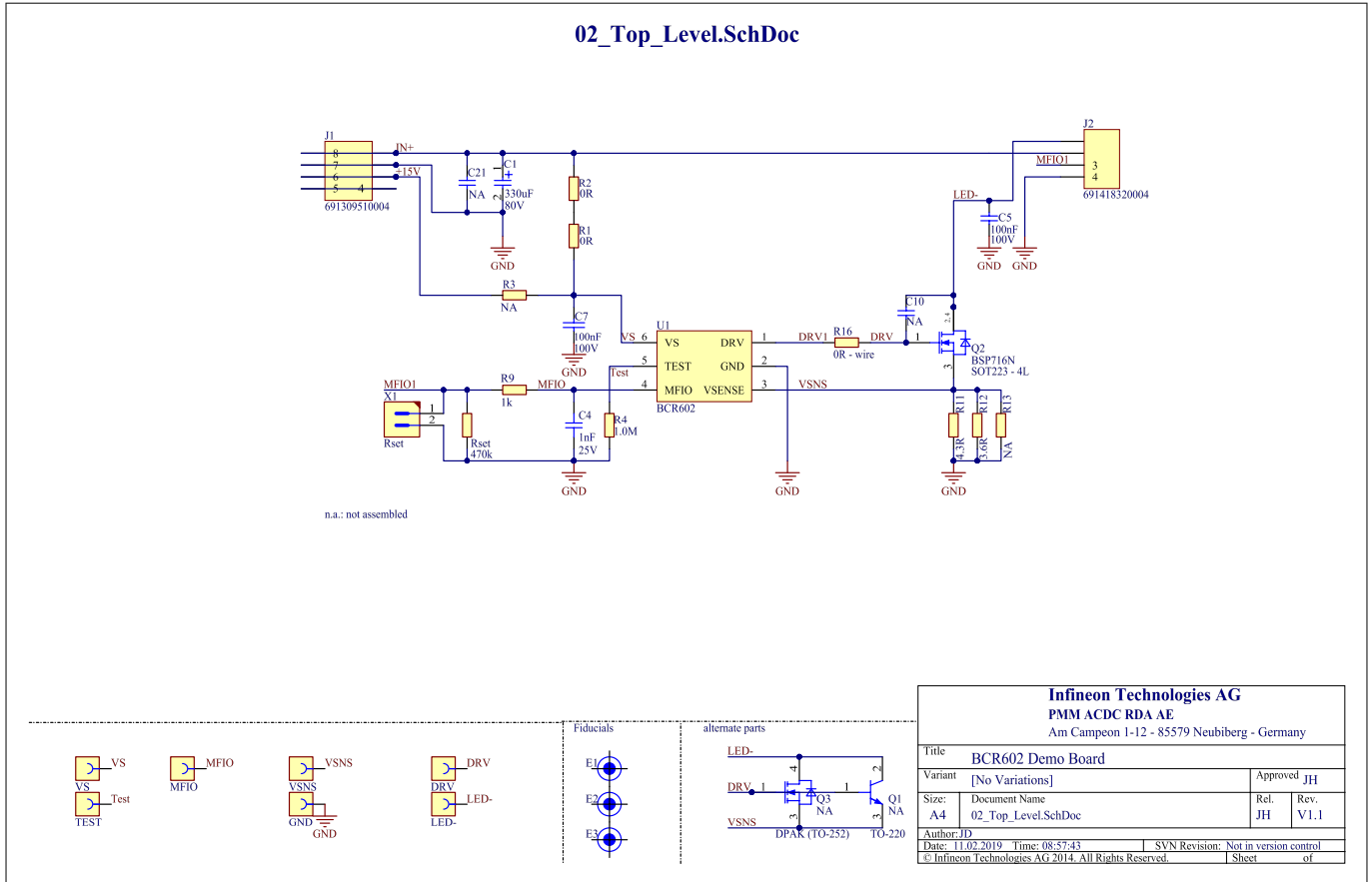


Figure 4 BCR602 PCB schematics

IN+: C1, C21 are input capacitors for spike and ripple suppression. C21 is an SMD component while C1 is a wired electrolytic capacitor. In the demonstrator design C1 is populated with a electrolytic capacitor.

The MFIO input signals are low-pass filtered by a first-degree filter consisting of R9 and C4.

In the demonstrator design IC power protection resistor R2 is assembled with 0 Ω.

Capacitor C5 supports the stability of the current loop in case of long connecting cables. In the demonstrator design it is assembled with 100 nF.

Current loop behavior can be influenced by capacitor C10 . C10 represents a Miller capacitor.

The MOSFET or the BJT is assembled using:

- Q1 for package TO-220
- Q2 for package DPAK/TO-252
- Q3 for package SOT223

The maximum current is set by resistors R11, R12 and R13.

The TEST pin is connected to ground via resistor R4.

3 Circuit description

3.2 Component description

This chapter gives an overview of components and technical parameters of BCR602 and the demonstrator design.

For placement of all components listed in [Table 2](#) in the schematic please refer to [Figure 4](#).

Table 2 Component description

Parameter	PCB ID	Value
Input voltage	IN+	8 V to 60 V
Default R_{set}	R_{set}	470 k Ω
Default LED current	IN+, LED-, R11, R12, R13	200 mA
Current configuration resistors, effective resistance	R11, R12, R13	2.0 Ω
Number of LEDs supplied	–	Up to 20 LEDs in series
Device dimensions	–	56.00 mm x 27.00 mm (L x W)
Default input capacitance	C1	330 μ F
Supported transistor packages	Q1, Q2, Q3	<ul style="list-style-type: none"> • TO-220AB • PG-SOT223 • D-PAK, TO-252AA
Samples transistor	Q2	OptiMOS BSP716N
Default VS protection resistor	R1, R2	0 Ω
External Miller capacity	C10	N/A
MFIO low pass filter	R9	1 k Ω
	C4	1 nF
Current loop low pass filter	R10	0 Ω
	C16	N/A
15V input filter	R3	N/A
	C7	100 nF
Test pin grounding	R4	1.0 M Ω
Switch-on protection capacitor	C5	100 nF

$R_{set} = 470 \text{ k}\Omega$ allows 100 percent LED current according to the $VSENSE$ resistor configuration. Technically there is no upper limit for this resistor. A suitable range is between

- 10 k Ω for minimum dimming and
- 600 k Ω

2 Ω represents a target current of 200 mA. The value is assembled by $R11 = 4.3 \text{ }\Omega$ and $R12 = 3.6 \text{ }\Omega$. By changing these resistors the target current can be adjusted. Technically the target current is limited by the power dissipation within the power transistor (, in case of a MOSFET: $U_{DS, mean} * I_{target}$).

The VS protection resistor is used to limit the power consumption of the BCR602 device. BCR602 can be operated within its whole operating range without this resistor. A non-zero value can be applied at high V_{IN+} . The voltage VS applied directly to the chip must not be below 8 V.

C7 is used as capacitor for the VS input filter in case BCR602 is supplied via IN+.

3 Circuit description

- For the OSOLON LEDs the forward voltage is 2.77V
- $\Delta V_{f,20^{\circ}\text{C}}$ is the change in the forward voltage per LED caused by the negative temperature coefficient of the LEDs and the temperature change between ambient temperature at system start and operating temperature of the LEDs
 - For the OSOLON LEDs the relative regarded as 0.13 V
- V_{SENSE} is the voltage drop at the CS resistors
- $R_{\text{DS(on)}}$ is the ohmic resistance of the power transistor
 - In case of a MOSFET the ohmic resistance of the power transistor, the datasheet value at 100°C shall be used
 - 180 mΩ is the value of BSP716N
 - In case of a BJT V_{CE} replaces $R_{\text{DS(on)}} \cdot I_{\text{target}}$ for the ohmic loss

Any DC input voltage greater than LED forward voltage determined by the junction temperature and target current plus any mean value of AC ripple applied to the input signal is transferred into heat. Besides the 400 mV at V_{SENSE} this is done within the power transistor. Per volt offset 200 mW of heat are generated. With a maximum thermal resistance of $R_{\text{thJA,max}} = 110 \text{ K/W}$ this causes a temperature increase of the power MOSFET of up to 38°C per volt offset. **Table 3** gives an overview of DC input voltage in case of OSOLON Square LEDs and BSP716N as power MOSFET.

Table 3 DC Input voltage

Number of LEDs BCR602 demonstrator board, OSOLON Square LEDs	Input voltage	Note
1	3.3	Input voltage below minimum operating voltage of the BCR602 (8 V) BCR602 must be supplied separately
2	6.2	Input voltage below minimum operating voltage of the BCR602 (8 V) BCR602 must be supplied separately
3	9.1	Unlimited operation
4	12.0	Unlimited operation
5	14.9	Unlimited operation
6	17.8	Unlimited operation
7	20.7	Unlimited operation
8	23.6	Unlimited operation
9	26.5	Unlimited operation
10	29.4	Unlimited operation
11	32.3	Unlimited operation
12	35.2	Unlimited operation
13	38.1	Unlimited operation
14	41.0	Unlimited operation
15	43.9	Unlimited operation

3 Circuit description

Table 3 **DC Input voltage (continued)**

Number of LEDs BCR602 demonstrator board, OSLO Square LEDs	Input voltage	Note
16	46.8	Unlimited operation
17	49.7	Unlimited operation
18	52.6	Unlimited operation
19	55.5	In case of AC ripple maximum voltage of BCR602 of 60 V must not be violated. In this case a protection resistor must be used.
20	58.4	In case of AC ripple maximum voltage of BCR602 of 60 V must not be violated. In this case a protection resistor must be used.

Note: Input voltages exceeding this equation can destroy the BCR602 demonstrator board. In this case usually the power transistor is damaged first by a excessively high power dissipation and a violation of the DC SOA area.

4 Test results

4 Test results

This section lists tests results and descriptions of application features.

4.1 Test setup

The setup for test engineering consists of:

- PCB for BCR602 and its configuration elements
- LED load of up to 20 LED for testing
- XDPL8218 PFC/Flyback plus an interface board for input voltage control as reference AC supply

Note: In some test cases XDPL8218 PFC/Flyback was used as DC supply; other test cases used a direct feed of a DC lab supply. As default lab DC supply a TTI QL355TP power supply was used.



Figure 6 Reference system of a BCR602 plus interface board and XDPL8218 PFC/Flyback

4.2 Current ripple suppression

Figure 7 shows the target current in case of an AC offset on the DC input signal. The input ripple has a frequency of 120 Hz.

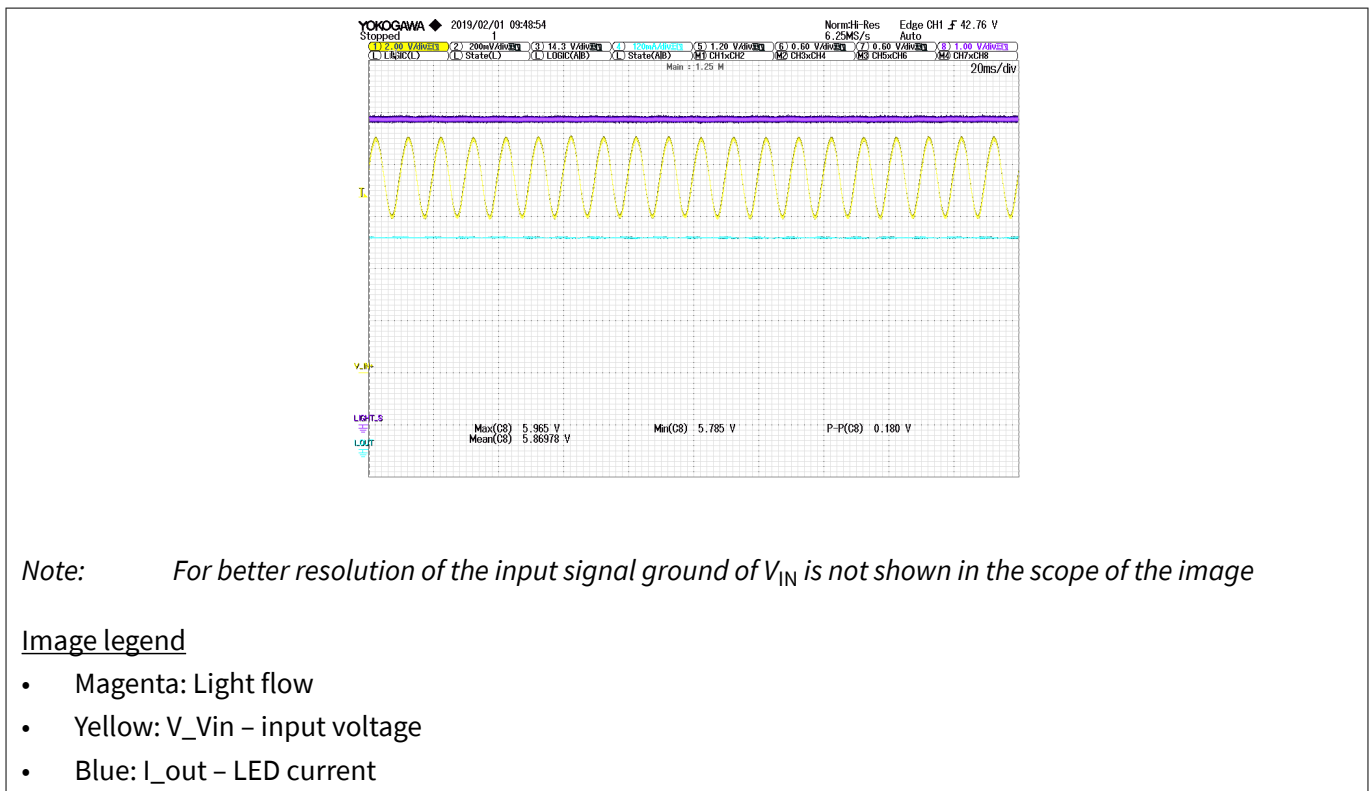


Figure 7 V_{SENSE} ripple suppression at $V_{MFIO} = 4.0$ V, 14 LEDs OSLO Square

4 Test results

The peak-to-peak value is maximum at no dimming and decreases the more the system is dimmed. Voltage ripple suppression was tested up to 8 V_{pp} and over an AC input frequency range from 40 Hz up to 70 Hz. Flickering is measured using an optical sensor showing the intensity of the light flow.

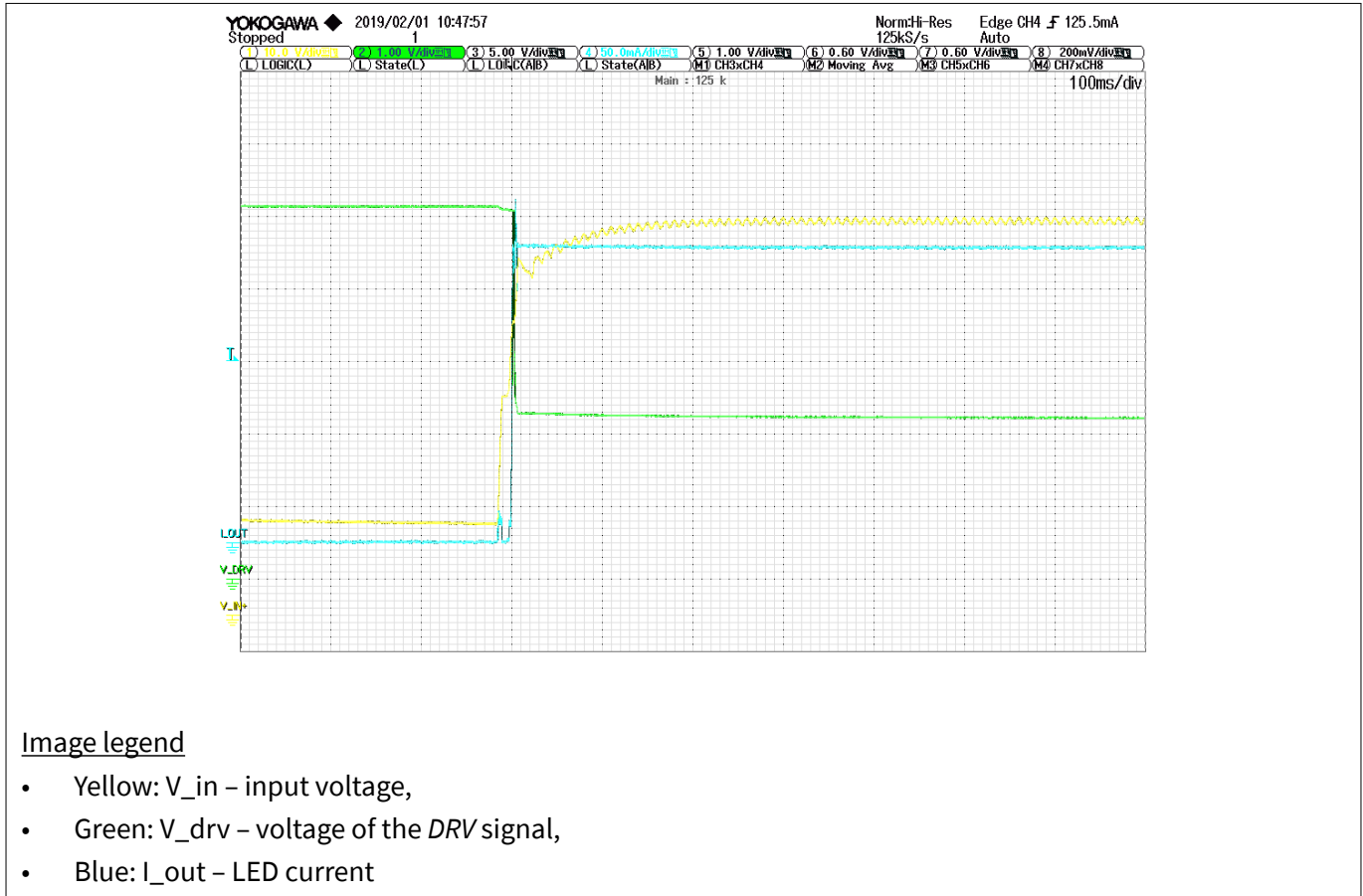


Figure 8 Current ripple suppression at start-up

Figure 8 shows the current ripple suppression at start-up and no-dimming conditions. Input voltage control is done by the XDPL8218 plug-in board placed between the BCR602 and the XDPL8218 PFC/Flyback. 14 OSLO Square LEDs were driven in this case. The current is regulated to its target value as soon as the input voltage is sufficiently high to compensate for the forward voltage of the LED diodes. Already before the start BCR602 supply voltage is sufficient for IC operation and for fast start-up the DRV pin is driven to its maximum output value. The narrow current spike before the actual start-up is caused by the hot-plug protection. Ripple suppression has been tested up to 16 V_{pp}.

4.3 Dimming

This section describes the dimming options of BCR602.

BCR601 provides these dimming options:

- DC dimming by applying a variable external voltage to the MFIO pin
- R_{set} dimming to a fixed dimming value by connecting a resistor between the MFIO pin and ground
- Dimming via a PWM signal of a PWM frequency from 500 Hz up to 3.5 kHz

4 Test results

4.3.1 DC voltage dimming

A BCR602 system enables DC voltage dimming over the whole range without causing flickering at any voltage level.

Figure 9 shows the DC dimming curve depending on the input voltage at the *MFIO* pin. At the lower end of the dimming curve hysteresis provides a shut-off at a lower *MFIO* voltage compared to the *MFIO* switch-on voltage.

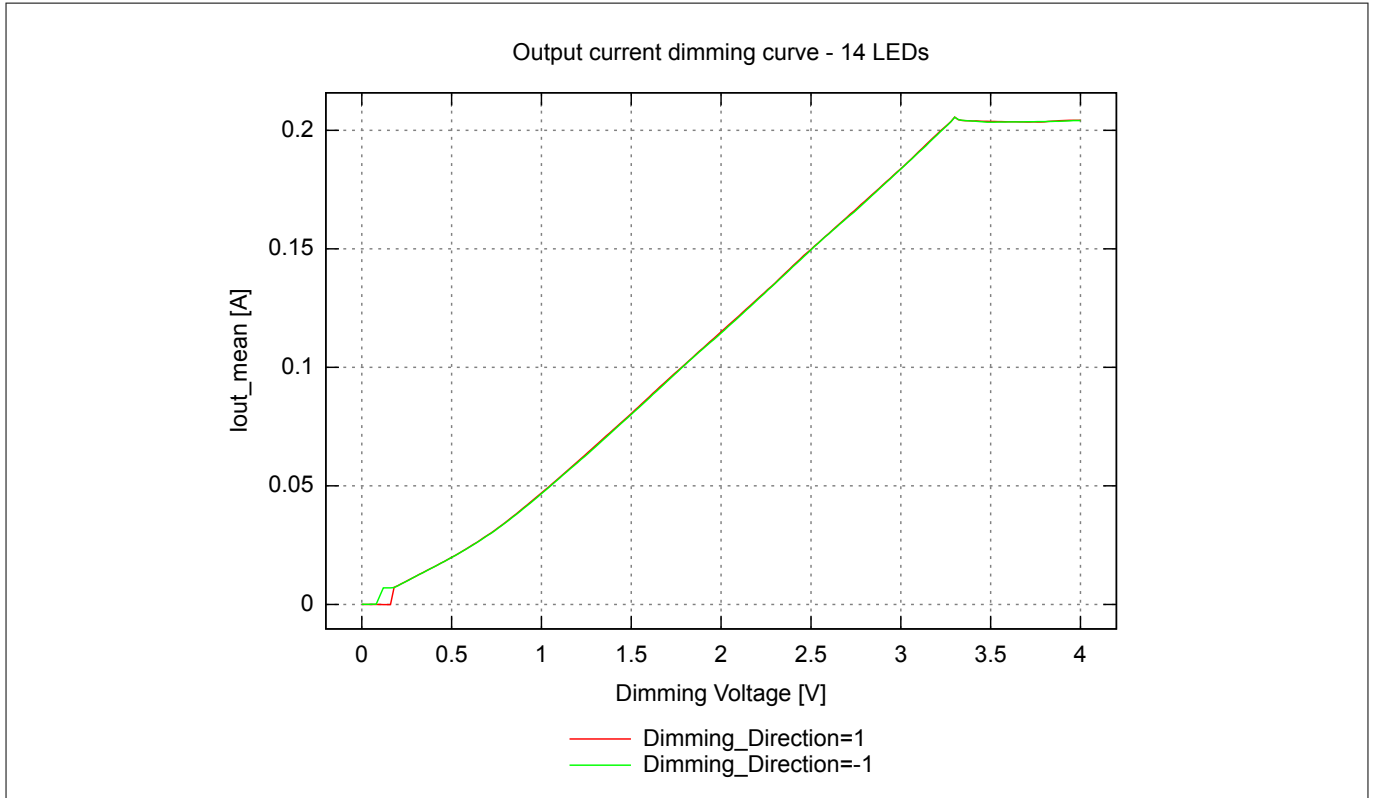


Figure 9 DC voltage dimming curve

Figure 10 shows dimming in the hysteresis range. In the phases with a negative slope of V_{MFIO} the current is shut off at $V_{MFIO} = 120$ mV. This is at the minimum level of V_{MFIO} and just at the shut-off level. V_{SENSE} at this level is 14 mV compared to the default of 400 mV in the no dimming case. At the rising slope of V_{MFIO} V_{SENSE} jumps from 0 V to 14 mV at the shut-on level of $V_{MFIO} = 180$ mV.

4 Test results

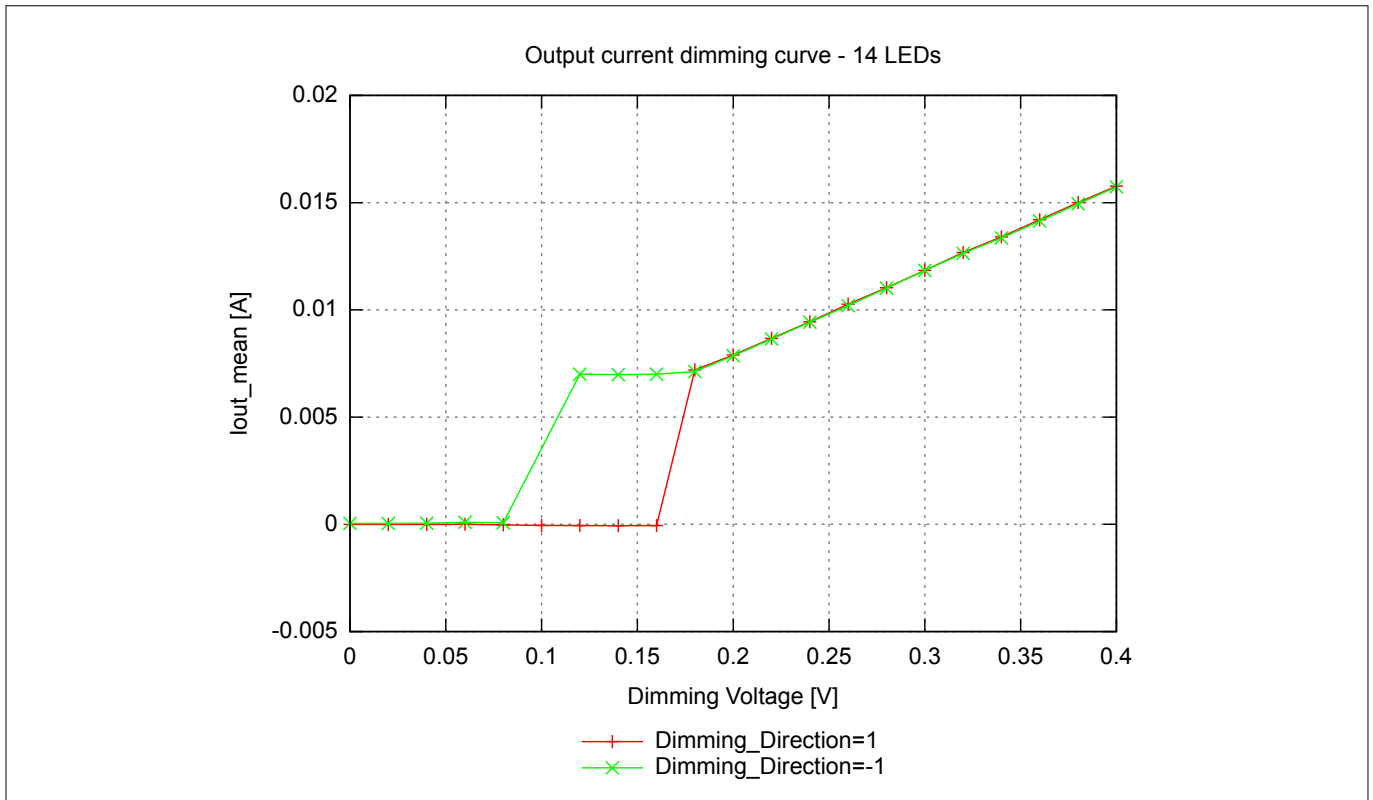


Figure 10 Hysteresis

4.3.2 R_{set} dimming

This section describes the dimming to a fixed value using a resistor.

Figure 11 shows the measurement results of M_{FIO} dimming values compared to the calculated results. The equation of the calculated results can be found in the datasheet. The deviation between the measured and the calculated curve is based on component variation. The LED current level can be adjusted by placing varying R_{set} resistors.

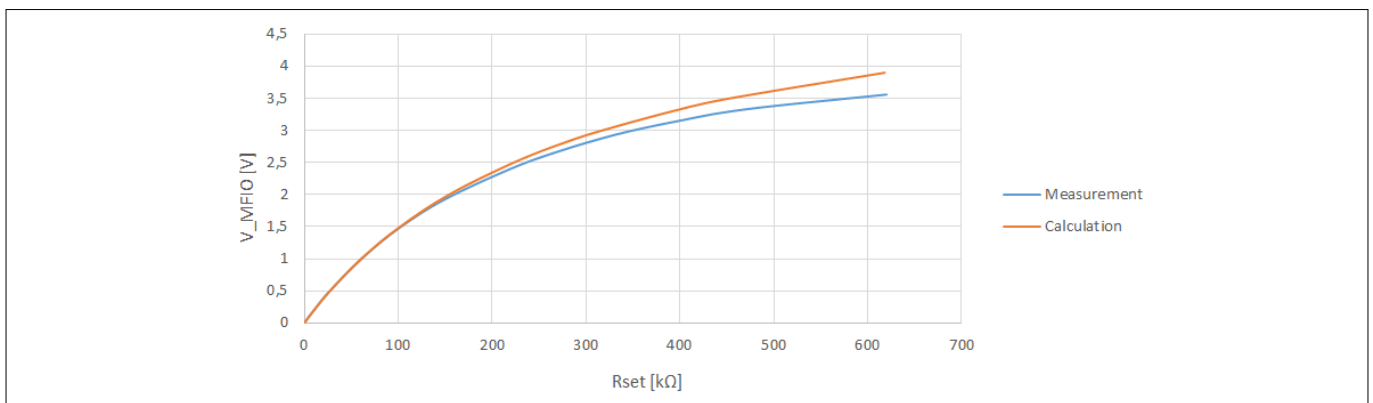


Figure 11 R_{set} measurement results

4.3.3 PWM dimming

MOSFET

Figure 12 shows PWM dimming in case of a MOSFET.

The start of the PWM active phase acts as a step signal on the current control loop.

4 Test results

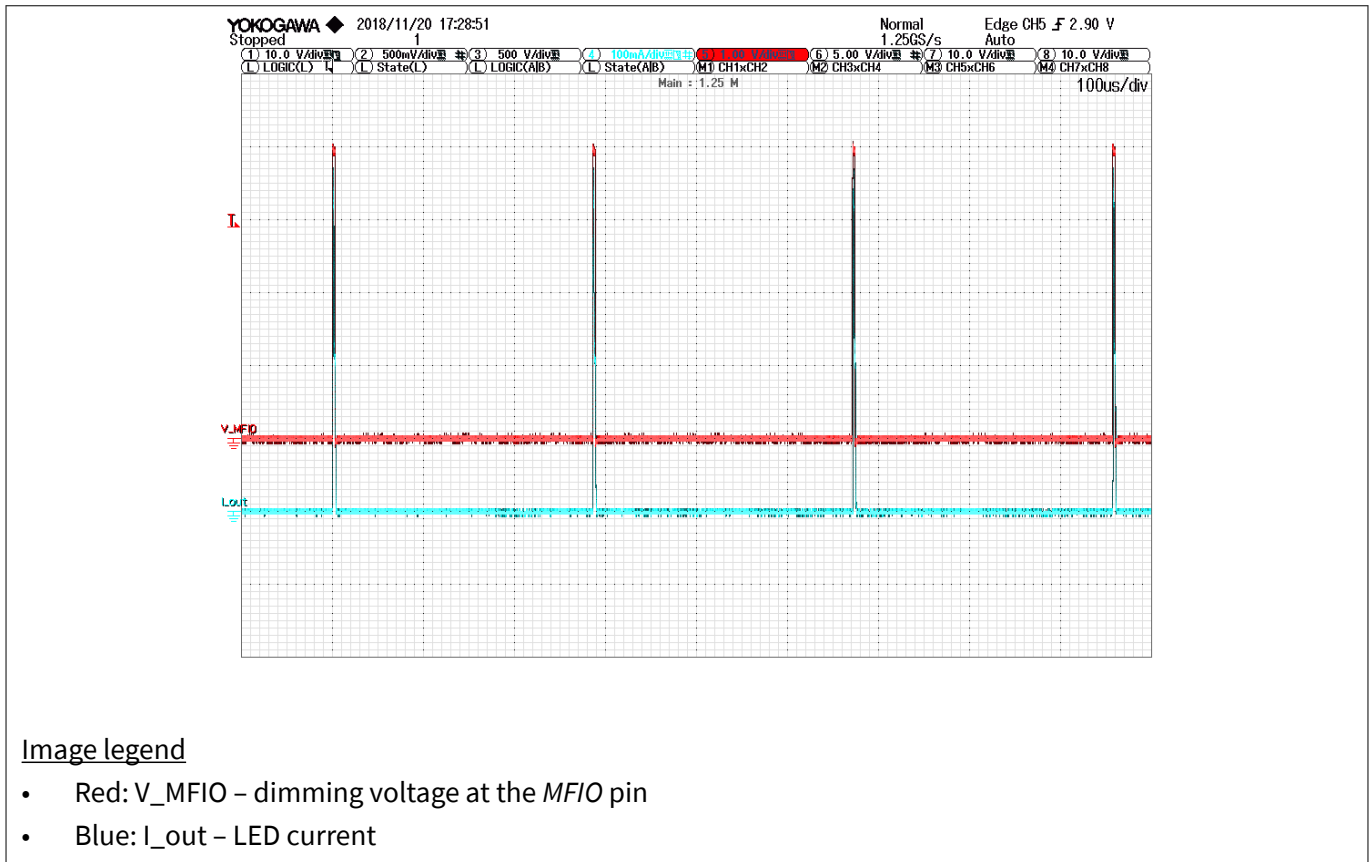


Figure 12 PWM dimmed MOSFET system at $f_{PWM} = 3.5 \text{ kHz}$

4 Test results

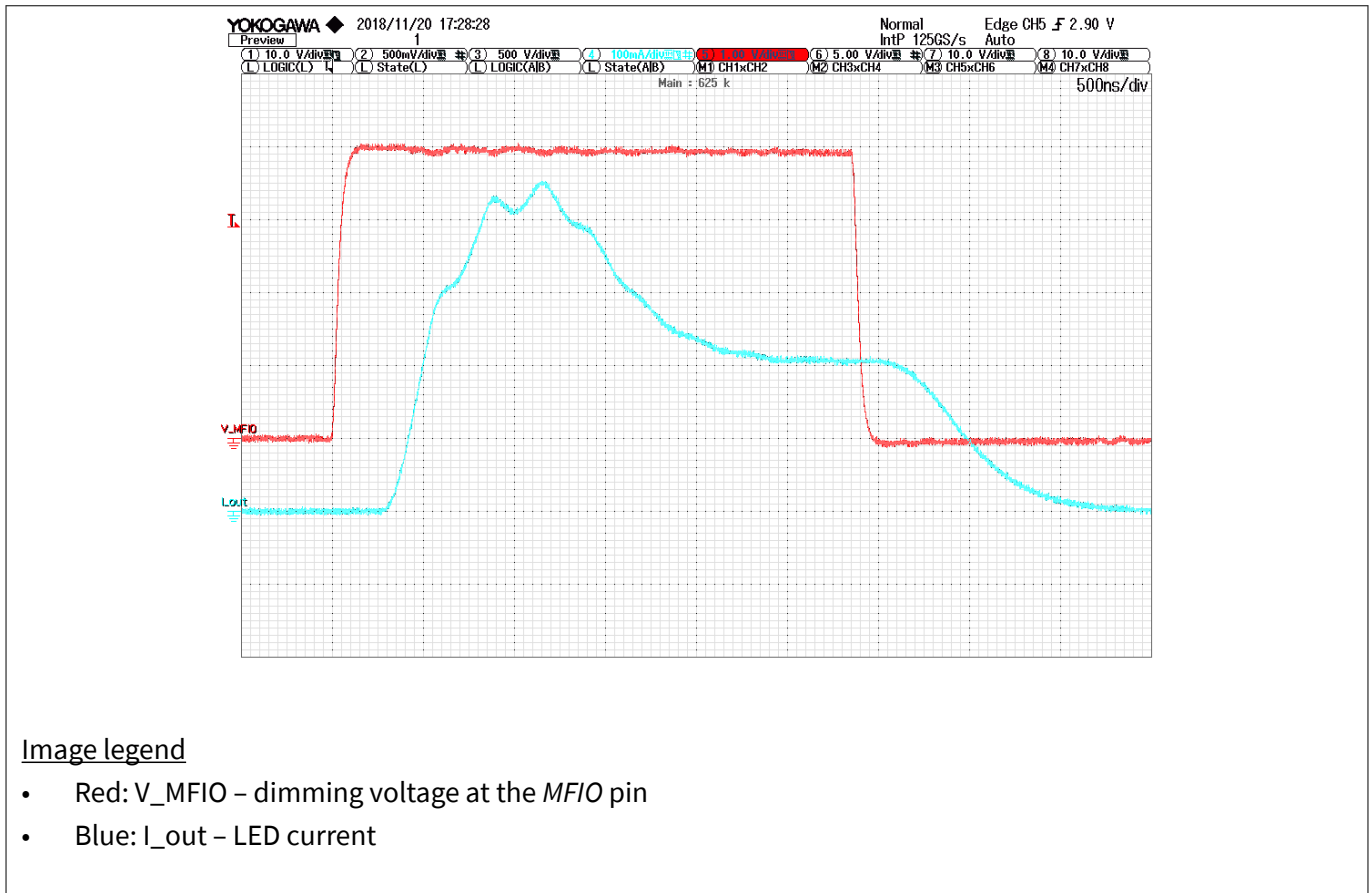


Image legend

- Red: V_MFIO – dimming voltage at the MFIO pin
- Blue: I_out – LED current

Figure 13 PWM-on reference design MOSFET, $f_{PWM} = 3.5 \text{ kHz}$

4.4 Protections

BCR602 offers protection features for hot-plug, stable current in case of shorts of LEDs, OTP. Hot-plug, short and over-temperature protections are independent of the system configuration.

4.4.1 Hot-plug

Hot-plug protection allows plug-in and plug-out of any LED load during operation without damaging the LEDs caused by surge currents.

Hot-plug condition is detected a V_{SENSE} threshold of 8 mV. Its purpose is the controlled power-up of the system to stable operation.

Reference design using BSP716N as power MOSFET

Figure 14 shows a hotplug condition in case of 12 LEDs. At hot-plug a current overshoot of 30 mA, 15 percent over the undimmed target current, is seen as a current spike.

The numbers in the figure show:

1. Hot-plug-out is occurring before and not shown in the figure
2. The crossing of the hot-plug-in level of 8 mV
3. The spike limitation at plug-in with respect to current and time

4 Test results

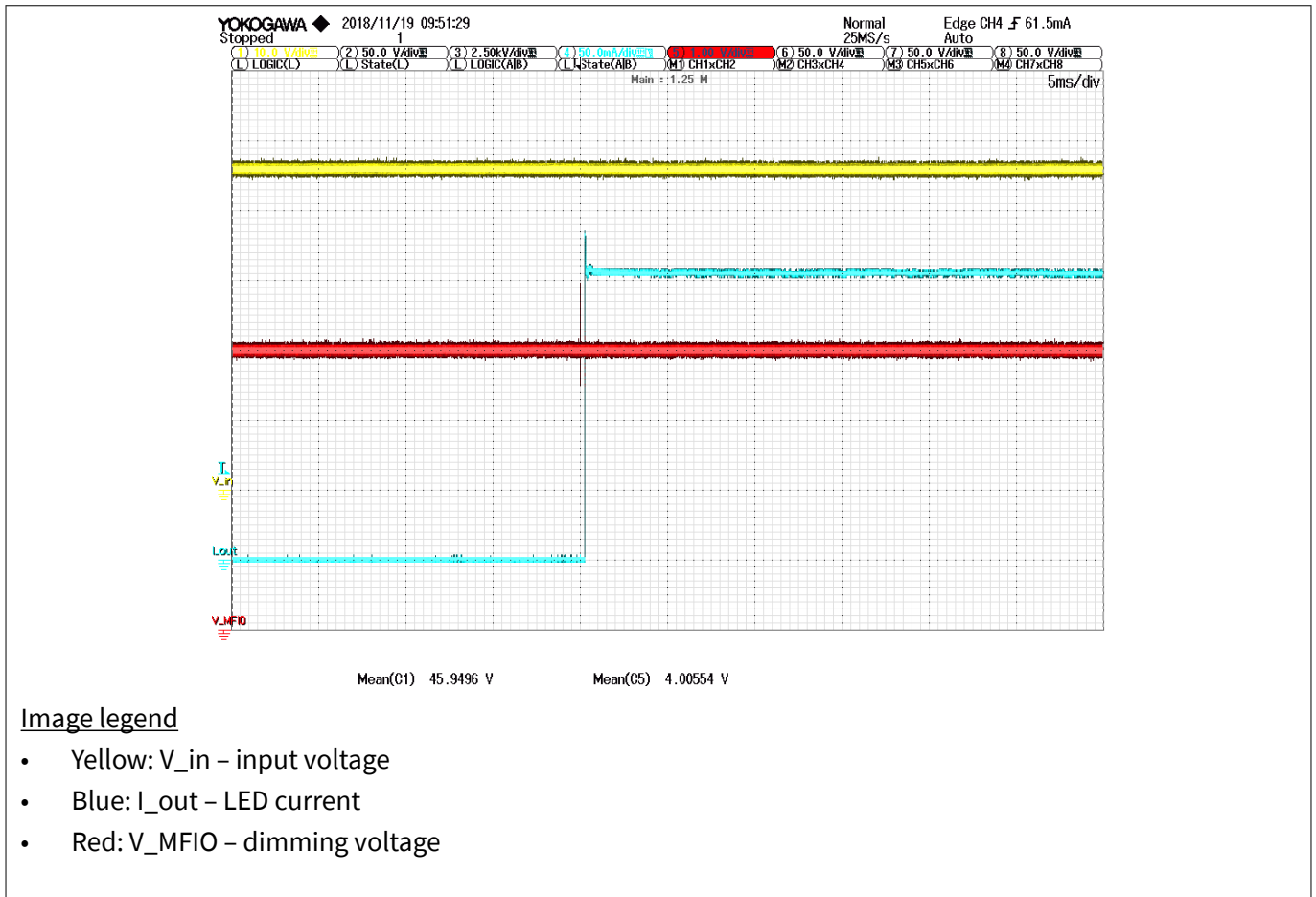


Image legend

- Yellow: V_in – input voltage
- Blue: I_out – LED current
- Red: V_MFIO – dimming voltage

Figure 14 Hot-plug at three LEDs, 200 mA target current, power MOSFET

4.4.2 Overtemperature protection OTP

The OTP circuit protects the IC by reducing the target LED current to one-third.

Tip: With respect to dimming OTP is independent from the type of MFIO dimming used, i.e. the target current is also reduced the same way in case of PWM dimming.

OTP protects the device from damage in case of high ambient temperature. Activation temperature is higher than deactivation temperature, hence there is a hysteresis of greater than 20°C. OTP is independent of the grade and type of MFIO dimming.

Figure 15 shows the leave of the OTP at 116°C. The LED current returns to its normal level.

1. Is the point in time when the OTP is left.

4 Test results

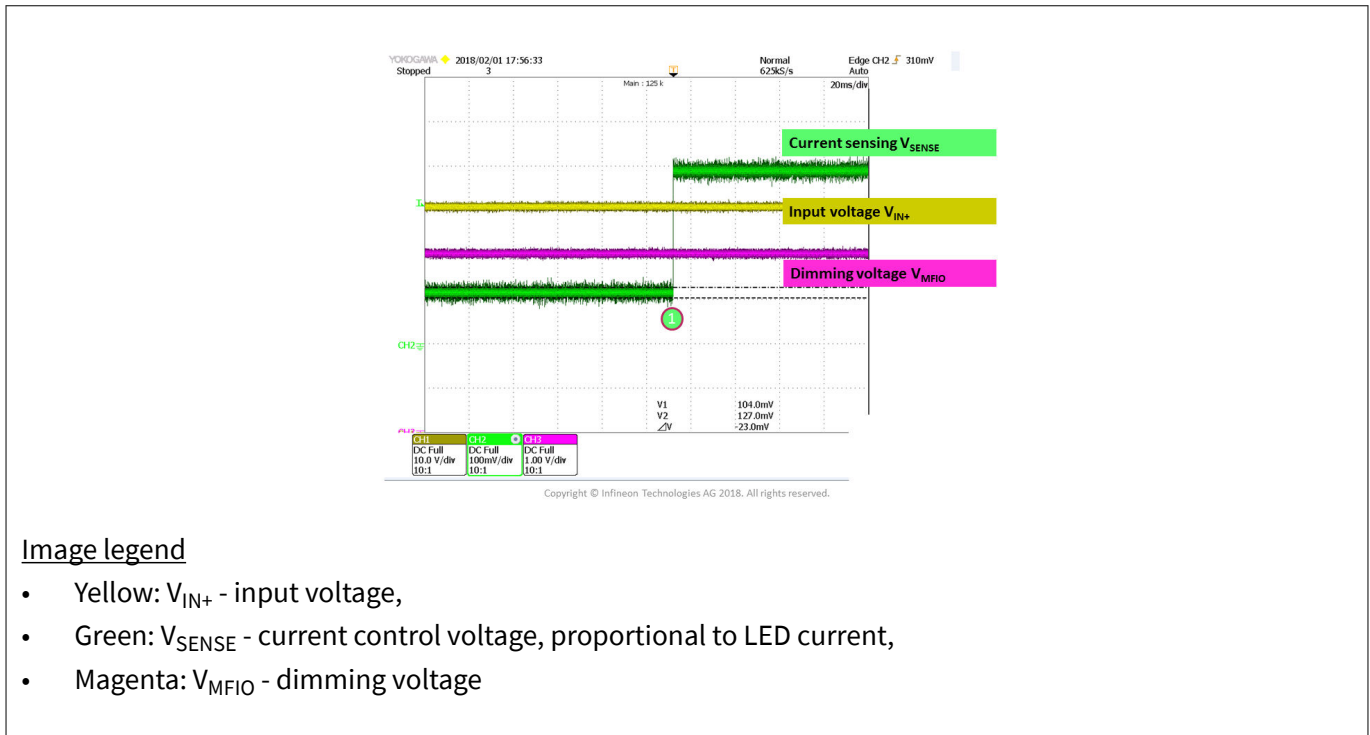


Figure 15 OTP deactivation at 116°C, 15 LEDs

4.4.3 Electrostatic discharge (ESD)

This chapter describes results of ESD gun tests with BCR602.

Figure 16 shows the access points of the ESD gun tests. Tests are executed according to IEC 61000-4-2. The input resistance of the spike source is $R_{IEC} = 330 \Omega$ and the capacitance is $C_{IEC} = 150 \text{ pF}$. The BCR602 system is operated using 16 LEDs at an input DC voltage of $V_{IN+} = 56 \text{ V}$.

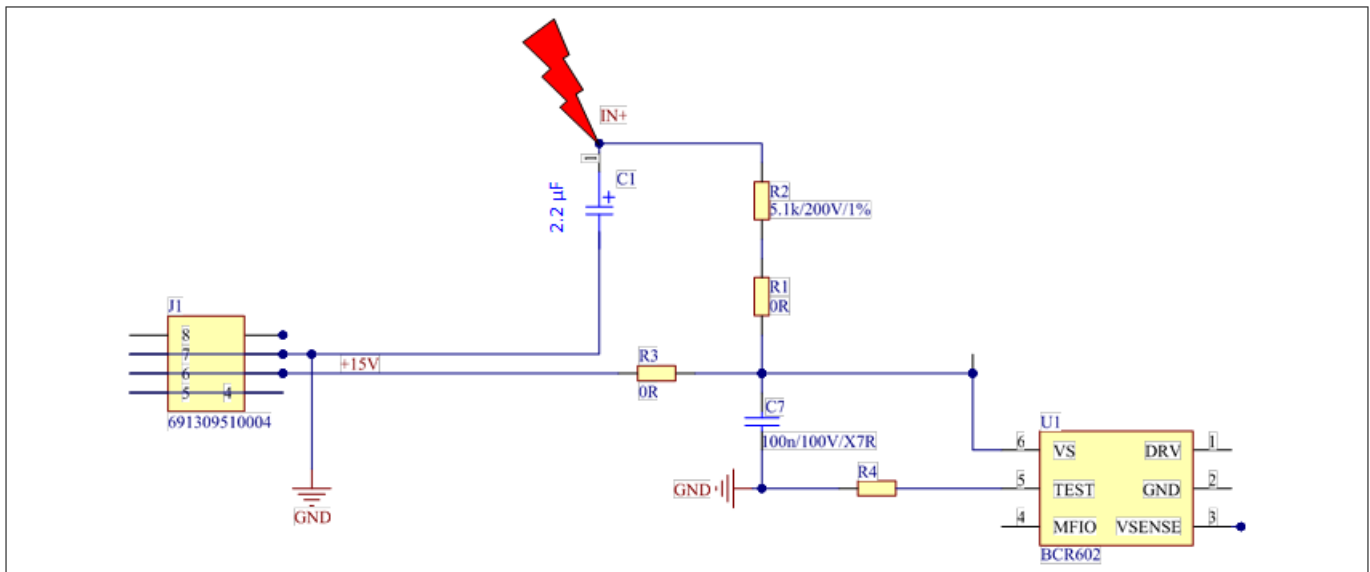


Figure 16 Access point of ESD gun test - schematic

Test results

Table 4 shows the results of the gun test sequence. Tests according to IEC 61000-4-2 cause a higher system stress than the Human Body Model (HBM) according to JS-001.

4 Test results

Table 4 Results of ESD gun tests according to IEC 61000-4-2

Test sequence no	PCB setup	Spike peak levels	Results
1	C1 = 2.2 μ F, C7 = 100 nF	1.5 kV	No disturbance of system
		2.0 kV	No disturbance of system
		3.0 kV	No disturbance of system
		5.0 kV	No disturbance of system
		8.0 kV	No disturbance of system
1	C1 removed, C7 = 100 nF	1.5 kV	No disturbance of system
		2.0 kV	No disturbance of system
		3.0 kV	No disturbance of system
		5.0 kV	No disturbance of system
2	C1 removed, C7 removed	1.5 kV	One pulse flickering at pulse exposition, operation continues
		2.0 kV	One pulse flickering at pulse exposition, operation continues, degradation on power supply, still dimmable
		3.0 kV	Device damaged

4.5 Thermal stress

This chapter describes the thermal behavior of the BCR602 demo board design under various operating conditions.

Operating the BCR602 demonstrator design the input voltage mainly depends on the number of LEDs used, the forward voltage per LED and the shift of the forward voltage depending on the temperature change of the LEDs at operation.

Input voltages at V_{IN+} distinguish between:

- The minimum voltage for flicker-free operation
- The minimum input voltage depending on datasheets of the LEDs used and the power transistor under worst case conditions
- The input voltage for production considering component tolerances

The minimum operating voltage is defined by [Equation 1](#).

4 Test results

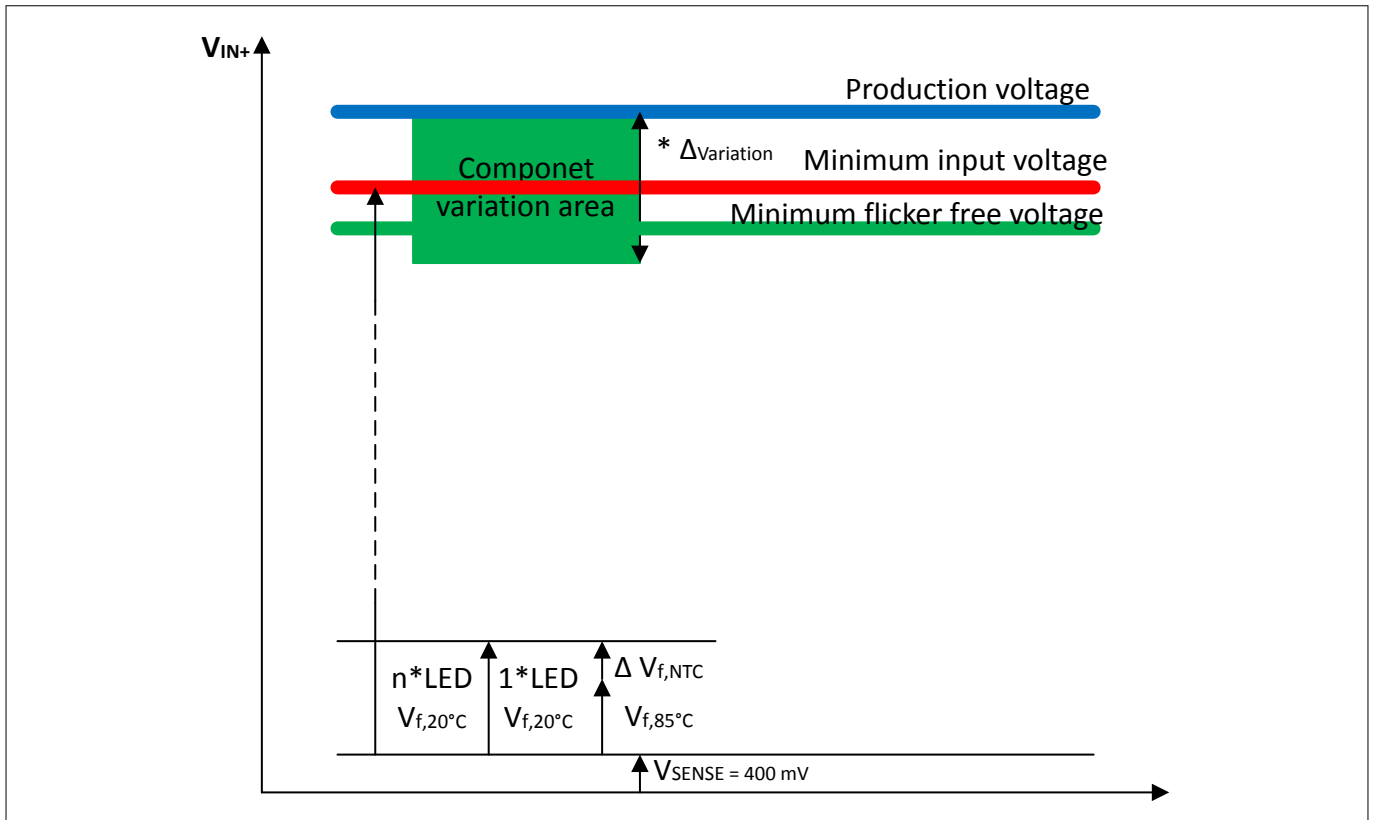


Figure 17 Relationship of input voltages

The minimum voltage for flicker-free operation is a measured value. It depends on the individual samples and is lower than the minimum operating voltage.

The input voltage for production includes the component tolerance of all components used. To get to this value the minimum operating voltage is multiplied with a factor dominated by the tolerance of the power supply.

$$V_{\text{prod}} = V_{\text{min, input}} * \left(1 + \frac{\text{component tolerance}}{100} \right) \approx V_{\text{min, input}} * 1.05$$

Equation 2 Voltage for production

Using OSLO Square LEDs the system can be operated using the production voltage with up to 14 LEDs keeping case temperature of BSP716N below 93°C. Using more than 14 LEDs, care has to be taken that the power dissipation at the BSP716N MOSFET caused by voltage drop over the transistor multiplied with the target current of 202 mA does not violate the SOAs of BSP716N. It is possible to operate the BCR602 demonstrator design with up to 20 LEDs at the minimum voltage for flicker-free operation including an AC ripple of up to 6 V_{pp} and some margin lower than the margin of the production voltage. Including some margin for the input voltage the temperature peak usually is achieved at the BCP716N MOSFET. In all cases the operating temperature of BCR602 usually does not exceed 55°C when operated in an ambient temperature of 22°C.

Figure 19 shows the BCR602 demonstrator operated with 14 OSLO LEDs at a DC input voltage of 42.8 V, an AC input ripple of 6 V, a tolerance for the productive voltage of 6.2 percent and a tolerance of 9 percent over the minimum flicker-free voltage. The input voltage conditions can be see in **Figure 18**. **Figure 20** shows the BCR602 demonstrator operated with 14 LEDs at a DC input voltage with less margin.

Figure 21 shows the BCR602 demonstrator design operated with 20 LEDs with an input voltage of 59.9 V and an AC ripple of 8.2 V. In this case the BCR602 demonstrator design was reconfigured to 325 mA target current.

4 Test results

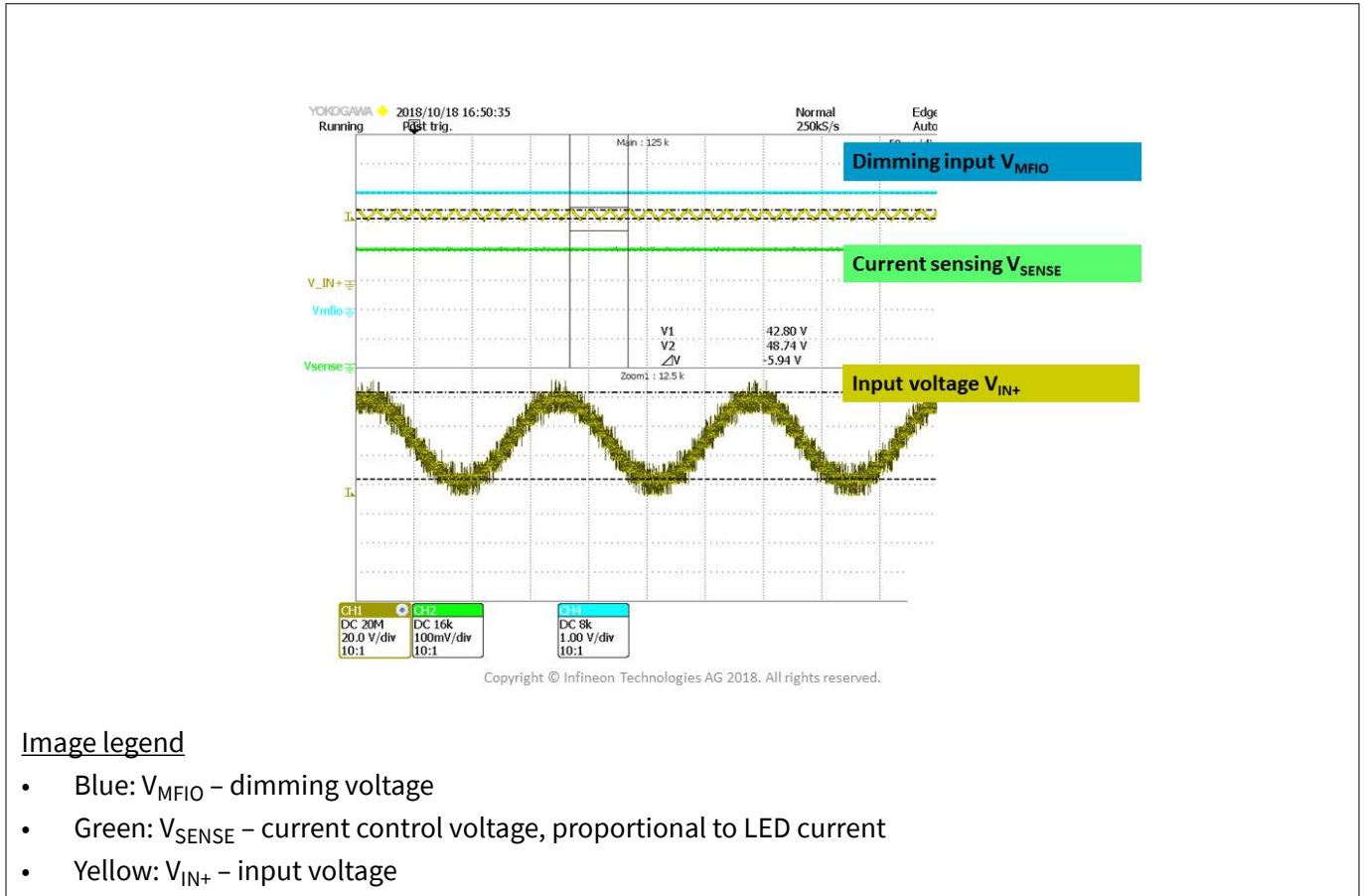


Figure 18 Input voltage including AC ripple at 14 LEDs, production voltage

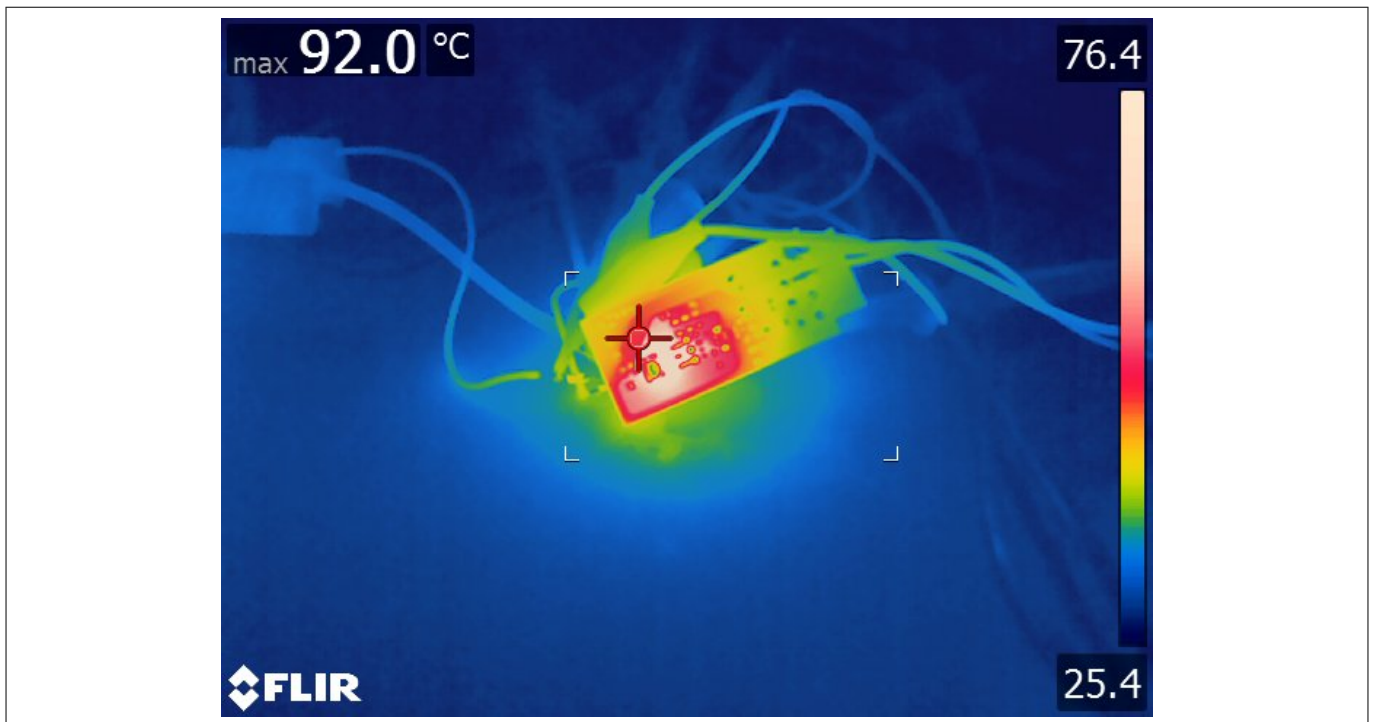


Figure 19 BCR602 demonstrator design at 14 LEDs, production voltage

4 Test results

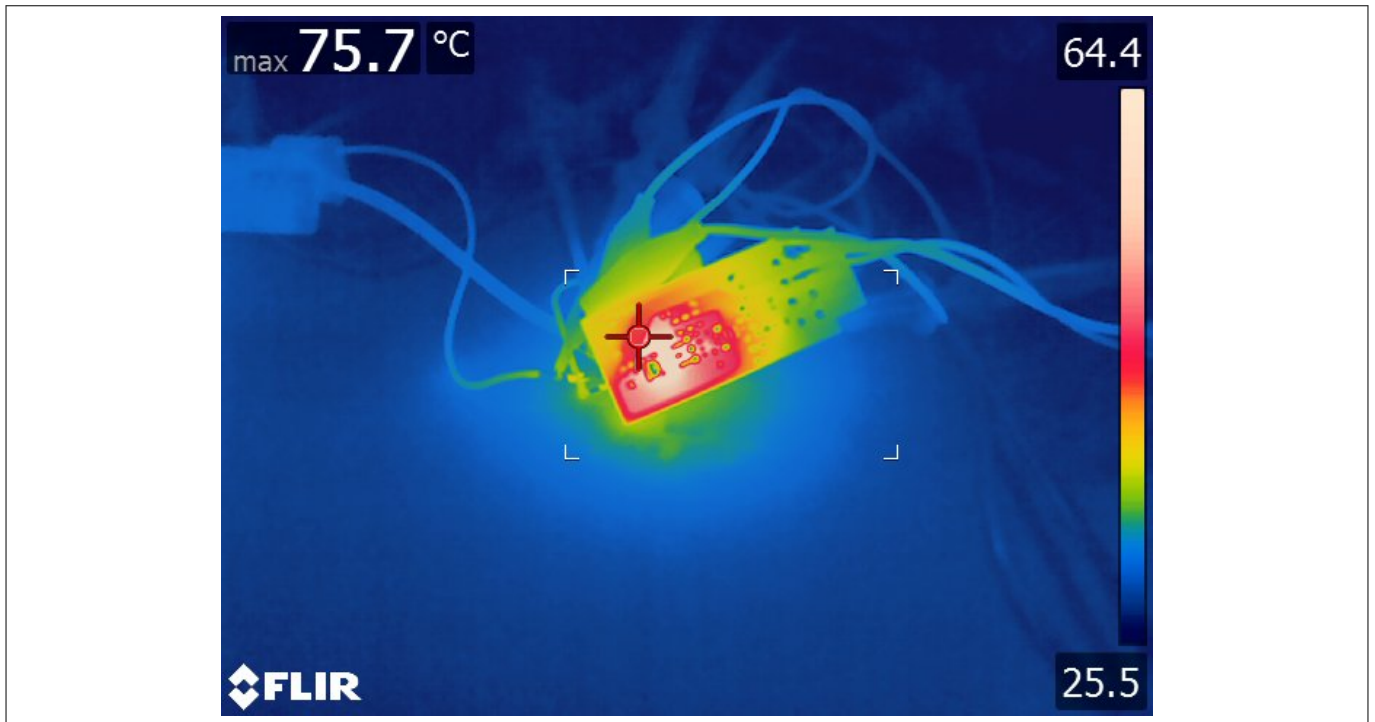


Figure 20 BCR602 demonstrator design at 14 LEDs, 6 V AC ripple, 41 V DC voltage

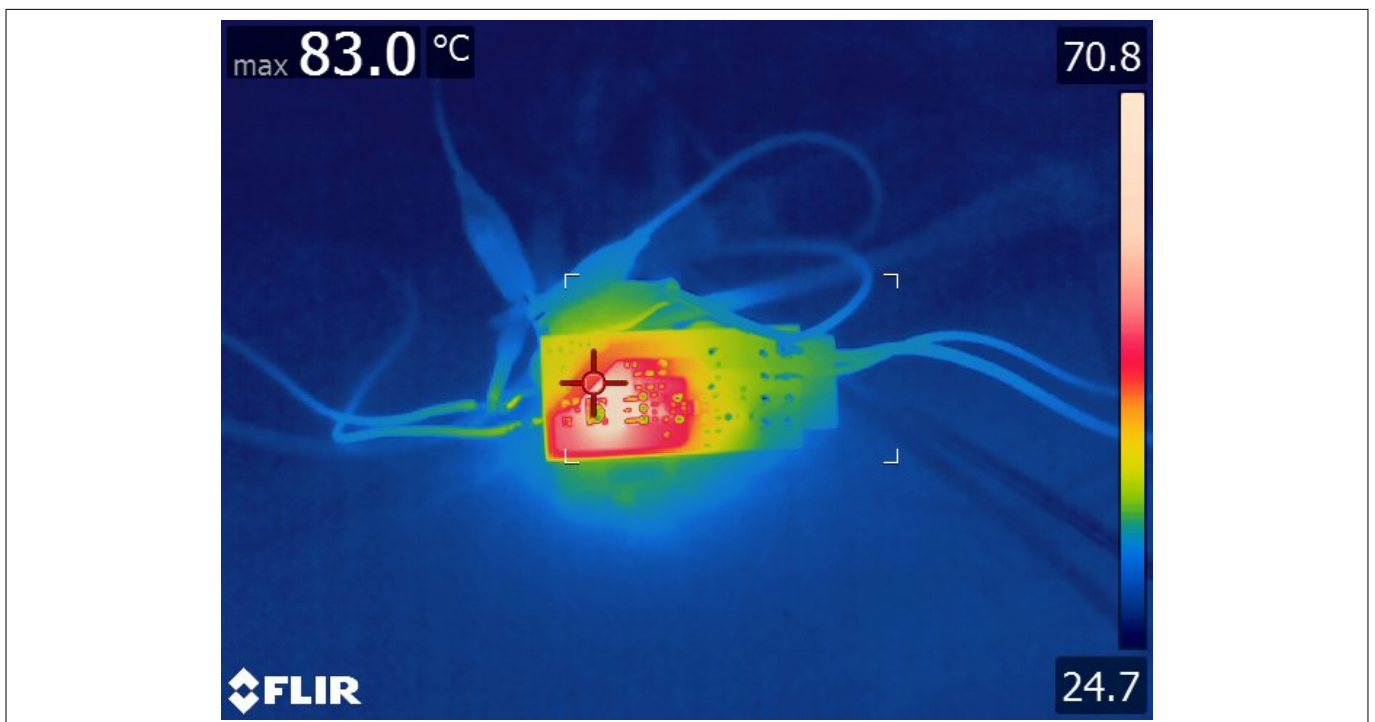


Figure 21 BCR602 demonstrator design at 20 LED, 8.2 V AC ripple

5 Bill of materials (BOM)

5 Bill of materials (BOM)

This chapter lists the material required for full equipment of a BCR602 demonstration board.

Table 5 BOM

Designator	Value	Footprint	Description	Manufacturer	Manufacturer part number
C1	330uF	CAPPRD750W80 D1625H2200B	Aluminium Electrolytic Capacitor,16x20	United Chemi Con	EKZE800ELL331 ML2
C4	1nF	CAPC2013X70N	Chip Monolithic Ceramic Capacitor	Kemet	C0805C102K3RA CTU
C5	100nF	CAPC2013X145N -2	Multilayer Ceramic Chip Capacitor	TDK	C2012X7R2A104 K125AA
C7	100nF	CAPC3216X70N	Cap-1206-100n/100V/0.1/X7R	AVX	12061C104KAZ2 A
C10	N/A				
C21	N/A				
DRV	20-2137	TPCW100D120H 460B	Black bead terminal assembly 1.02mm hole	Vero Technologies	
GND	20-2137	TPCW100D120H 460B	Black bead terminal assembly 1.02mm hole	Vero Technologies	
J1		691309510004	WR-TBL Serie 3095 - 5.08 mm Reversed Gender Horizontal PCB Header, 04p	Würth Elektronik	691309510004
J2		691418320004	WR-TBL Serie 4183 - 3.81 mm 45° Entry Screwless, 4p	Würth Elektronik	691418320004
LED-	20-2137	TPCW100D120H 460B	Black bead terminal assembly 1.02mm hole	Vero Technologies	
MFIO	20-2137	TPCW100D120H 460B	Black bead terminal assembly 1.02mm hole	Vero Technologies	
Q1	N/A				IPP093N06N3

5 Bill of materials (BOM)

Table 5 BOM (continued)

Designator	Value	Footprint	Description	Manufacturer	Manufacturer part number
Q2	BSP716N	SOT230P700X18 0-4N-4	N-Channel Logic Level Enhancement Mode Field Effect Transistor	Infineon	BSP716N H6327
Q3	N/A				
R1	0R	RESC3116X65N	0R/200V/1%	Yageo/Phycomp	RC1206FR-0710R
R2	0R	RESC3116X65N	0R/200V/1%	Yageo/Phycomp	RC1206FR-0710R
R3	N/A				
R4	1.0M	RESC2113X50N	1.00M/150V/1%	Vishay	CRCW08051M00 FKEA
R9	1k	RESC2113X50N	Standard Thick Film Chip Resistor	Vishay	CRCW08051K00F K
R11	4.3R	RESC3216X60N	Standard Thick Film Chip Resistor	Vishay	CRCW12064R30F K
R12	3.6R	RESC3216X60N	Standard Thick Film Chip Resistor	Vishay	CRCW12063R60F K
R13	N/A				
R16	0R - wire	JP-THT-1.00_2.20_5_0.80-2P	Standard Thick Film Chip Resistor	Manufacturer	L5(+2x2)mm, dia 0.8mm
Rset	470k	RESC2113X50N	Standard Thick Film Chip Resistor	Vishay	CRCW0805470KF K
TEST	20-2137	TPCW100D120H 460B	Black bead terminal assembly 1.02mm hole	Vero Technologies	
U1	BCR602	SOT95P280X145-6N-6		Infineon	
VS	20-2137	TPCW100D120H 460B	Black bead terminal assembly 1.02mm hole	Vero Technologies	
VSNS	20-2137	TPCW100D120H 460B	Black bead terminal assembly 1.02mm hole	Vero Technologies	

5 Bill of materials (BOM)

Table 5 **BOM (continued)**

Designator	Value	Footprint	Description	Manufacturer	Manufacturer part number
X1	HTSW-102-07-L-S	HDRV2W64P254 _1X2_496X248X8 38B	Through hole .025" SQ Post Header, 2.54mm pitch, 2 pin, vertical, single row	Samtec	HTSW-102-07-L-S

6 Related links and support material

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A selection of useful internet shortcuts.

- BCR602 documents
 - <http://www.infineon.com/bcr602>
- Power Management selection guide
 - <http://www.infineon.com/powermanagement-selectionguide>
- Search videos
 - <http://www.infineon.com/mediacenter>
- Where to buy
 - <http://www.infineon.com/wheretobuy>
- Cross reference search
 - <http://www.infineon.com/crossreference>
- Evaluation boards
 - <http://www.infineon.com/evaluationboards>
- Package information
 - <http://www.infineon.com/packages>
- Contact and support
 - <http://www.infineon.com/support>

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Офис по работе с юридическими лицами:

105318, г.Москва, ул.Щербаковская д.3, офис 1107, 1118, ДЦ «Щербаковский»

Телефон: +7 495 668-12-70 (многоканальный)

Факс: +7 495 668-12-70 (доб.304)

E-mail: info@moschip.ru

Skype отдела продаж:

moschip.ru

moschip.ru_4

moschip.ru_6

moschip.ru_9