BCR602 linear LED controller IC for dimmable applications

Design guide for a secondary side current regulated 60 V LED light engine

BCR602

About this document

Scope and purpose

This document presents a step-by-step design guide for a 60V Linear Current Regulator. The BCR602 contains features such as AC voltage ripple suppression, over-temperature- and hot plug protection. The BCR602 is available in a SOT23-6 package.

Intended audience

This document is intended for design engineers, application engineers and students, for example, who need to design low-cost, highly reliable linear LED dimming solutions with AC line ripple suppression.

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1 Introduction

This section gives an overview about key elements of a BCR602 LED system.

1.1 Product highlights

This section lists most important features of BCR602

- BCR602 supply voltage operating range 8 V to 60 V
- Supports use of NPN bipolar transistors and NMOSFETs
- 100 Hz/120 Hz supply voltage ripple suppression by highly effective current control loop
- Over-temperature protection
- 3 percent analog dimming of LED current by a resistor R_{set} or DC voltage at the *MFIO* pin
- 1 percent PWM dimming LED current precision
- 6-pin PG-SOT23-6 package
- Supports external PWM dimming down to 1 percent duty cycle
- Hot-plug capability

1.2 Pin configuration

This section defines the purpose of every pin of the IC.

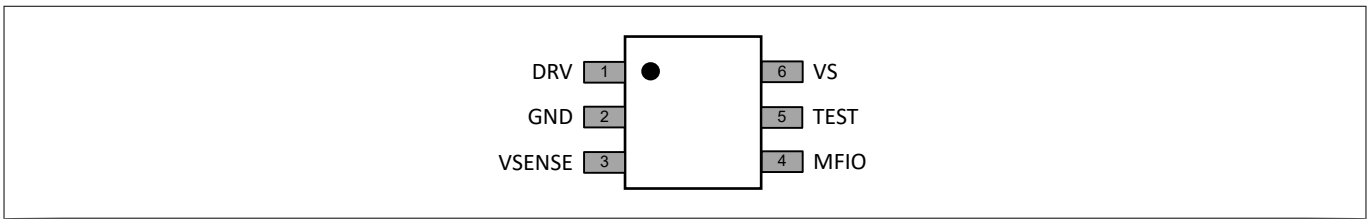


Figure 1 PG-SOT23-6 pin out

Table 1 Pin configuration

Pin no.	Pin name	Pin type	Function
1	*DRV*	Output	Driver output to control base or gate of the external transistor
2	*GND*	GND	IC ground
3	*VSENSE*	Input	Measurement of V_{sense} voltage
4	*MFIO*	Input	Multifunctional IO for resistive (via external R_{set}), DC voltage and PWM voltage dimming
5	*TEST*	Output	For test purpose, it must not be directly connected to ground. It is recommended to leave *TEST* pin open or attach a resistor to ground > 1 MΩ.
6	*VS*	Input	Supply voltage

1.3 BCR602 theory of operation

This section describes applications using the BCR602 linear current controller .

The BCR602 is a linear LED controller IC typically found on the secondary side of an AC-DC power supply with a voltage output. The BCR602 controls a linear pass element such as a MOSFET or BJT transistor that is placed in series with the LED array. BCR602 is intended for light engines.

Typical target applications:

1 Introduction

- LED light engines/modules
- LED replacement lamps

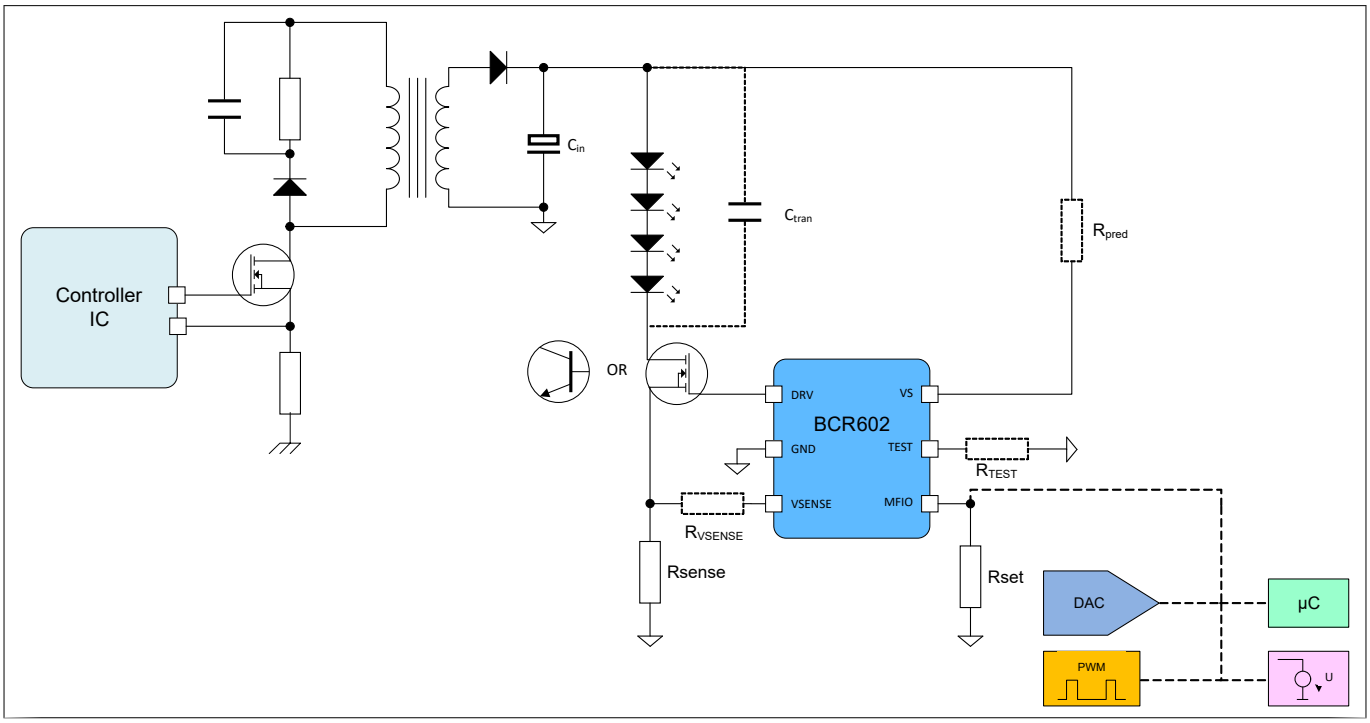


Figure 2 BCR602 typical application with AC-DC converter

1.4 Internal block diagram

This section shows the simplified internal block diagram of the BCR602.

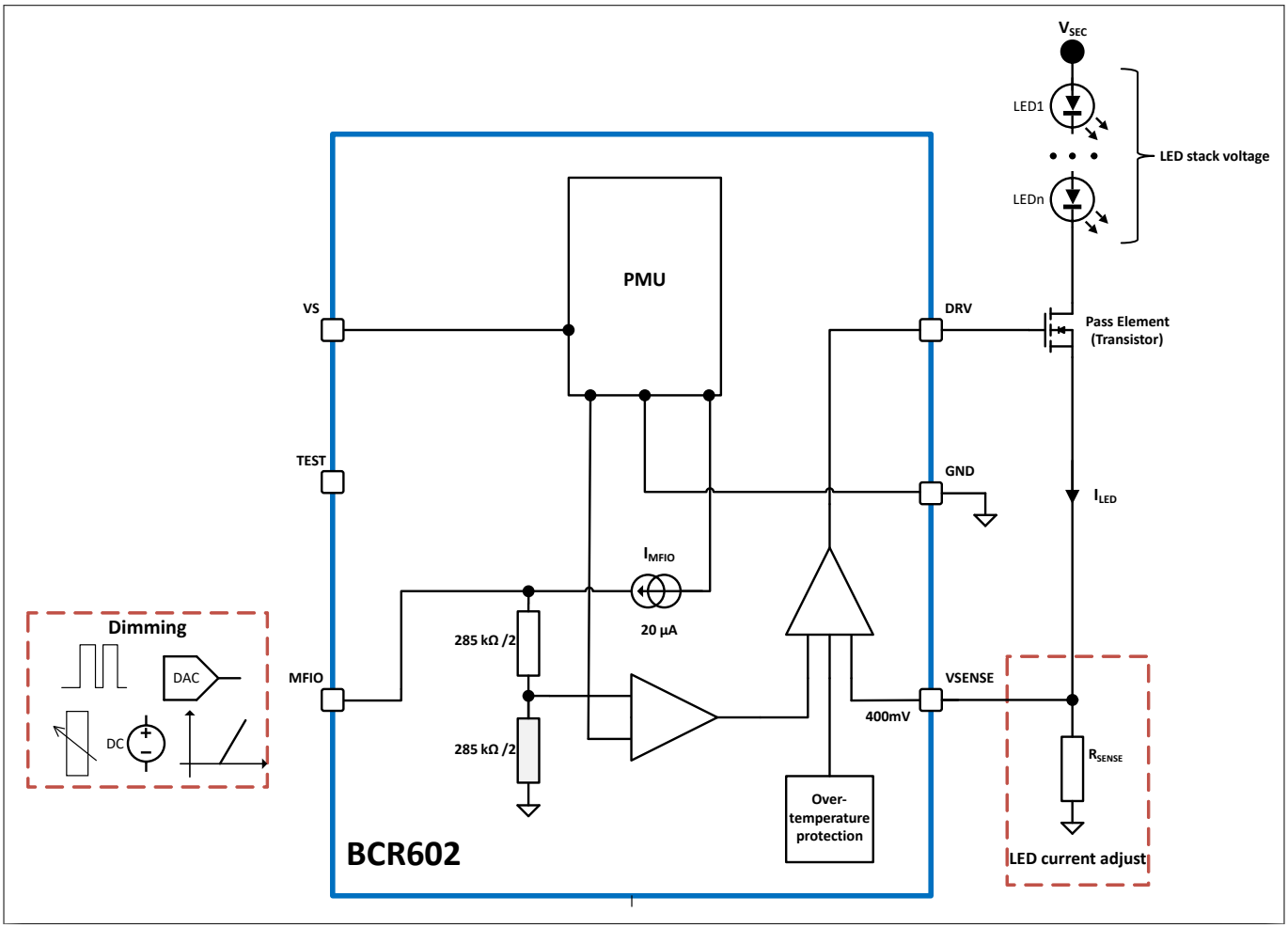


Figure 3 BCR602 block diagram

2 BCR602 detailed description

This section describes features and requirements for a fully functional and power optimized system configuration for BCR602.

BCR602 is used in LED lighting systems and light engines where a wide input voltage (up to 60 V) is required and efficiency optimization is desired. LEDs can vary their forward voltage considerably due to current density (forward current), and LED temperature. These two characteristics coupled with LED forward voltage drop variations due to the types of LEDs used forces the designer to ensure the voltage across the LED array and pass elements is large enough to satisfy all design requirements. The greater the difference between the LED array voltage and the input voltage to the linear pass element, the greater the power loss and temperature of the system.

Figure 3 illustrates a simplified internal block diagram of the BCR602 IC.

The BCR602 detailed description section of the BCR602 design document guides the designer how to use and optimize the BCR602 IC; topics include:

Optimization of the current loop

- LED array current control and regulation via a calculated current sense resistor value for the system target current
- Optional tuning of the current loop in case of usage of highly amplifying Darlington-BJTs

Power loss optimization and protections of BCR602 and of the system.

- Minimizing the IC power consumption

Notable electrical specifications for the power transistor (pass element):

- Input capacitor value
- Threshold voltage
- In case of BJT current amplification

2.1 LED current regulation

This section describes the configuration and optimization of the current feedback loop.

Current regulation considerations:

- Removal of AC ripples in the V_{IN+} input signal; usual AC ripples are non-ideal DC signals with an AC offset at double line frequency,
- Protection of the LEDs from:
  - Thermal overstress, thus improving LED lifetime significantly
  - Over-voltage applied to the LED array
  - Short-cut protection of the LED array

2.1.1 Setting LED target current

This section describes how to configure the target current of the application.

LED maximum current is configured via the current sense shunt resistor connected between pin *VSENSE* and ground.

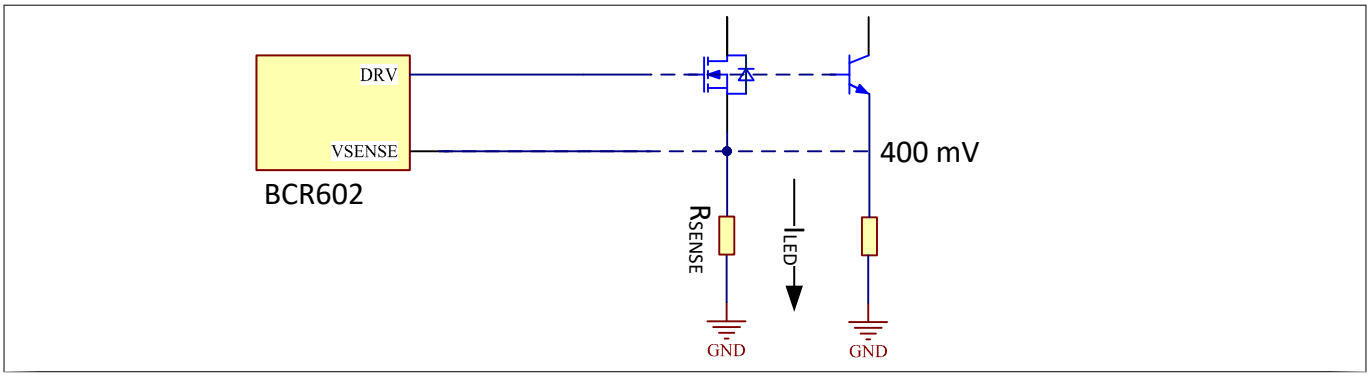


Figure 4 100 percent LED current set-point

Figure 4 illustrates current sense measurement using the BCR602. At 100 percent LED current output (non-dimming) the BCR602 regulates the current through the LED array so that the voltage drop over the shunt resistor is 400 mV. During dimming a fraction of the 400 mV regulation point is used and the final value depends on percentage of dimming.

The value of the series current sense resistor (R_{SENSE}) is determined by the formula:

$$R_{\mathrm{SENSE}} = \frac{400\ \mathrm{mV}}{I_{\mathrm{LED}}}$$

Equation 1 R_{SENSE} configuration

2.1.2 BCR602 system supply voltage requirements

This section describes requirements for input power supply requirements, and LED array limitations of a BCR602 controller.

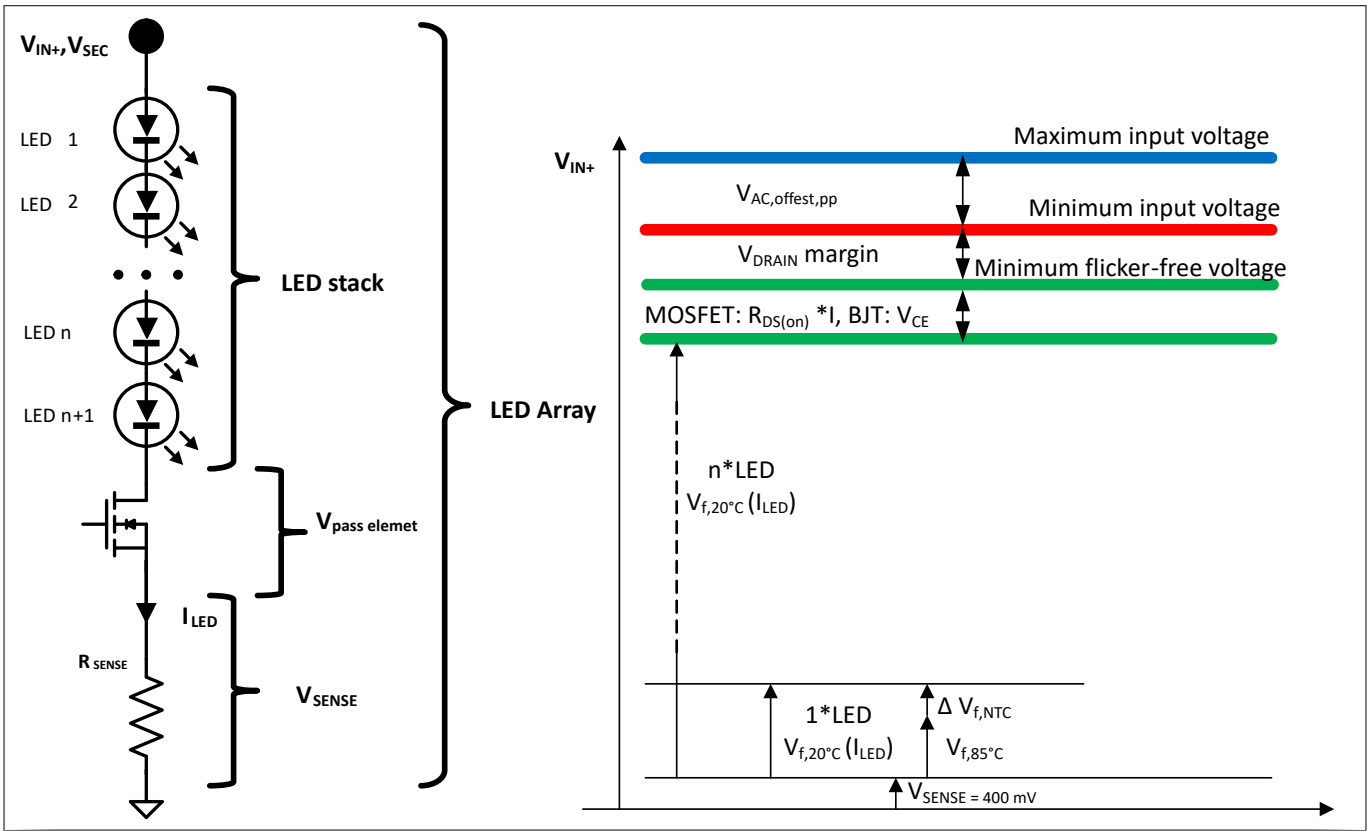


Figure 5 System input voltage components

Figure 5 shows the components contributing to the system input voltage.

The system input voltage depends on

- The voltage drop over the *VSENSE* resistor, V_{SENSE}
- With respect to the configured maximum LED current
  - The forward voltage per LED, $V_{f,LED}(I, T)$, depending on
    - The given current, I,
    - Due to the negative temperature coefficient (NTC) of the LEDs on the operating temperature, T, highest at the lowest temperature,
  - The voltage drop over the pass element, that is in case of:
    - A MOSFET V_{DS}, depending on $R_{DS(on)}$,
    - A BJT V_{CE},
- In BCR602 V_{OV} is the voltage offset between the minimum input voltage for the given samples of all system components and worst case conditions.
- The AC ripple of the input voltage.

1. MOSFET

$$V_{\mathrm{IN+,\ target}}\left(n, I_{\mathrm{target}},\ T,\ V_{\mathrm{ACoffset,\ pp}},\ V_{\mathrm{sense}}\right)$$
$$= n * V_{\mathrm{LED}}\left(I_{\mathrm{target}},\ T\right) + \frac{V_{\mathrm{ACoffset,\ pp}}}{2} + V_{\mathrm{sense}} + R_{\mathrm{DS(on)}}\left(T\right) * I_{\mathrm{target}} + V_{\mathrm{var}}$$
$$= n * V_{\mathrm{LED}}\left(I_{\mathrm{target}},\ T\right) + \frac{V_{\mathrm{ACoffset,\ pp}}}{2} + 400\ \mathrm{mV} + R_{\mathrm{DS(on)}}\left(T\right) * I_{\mathrm{target}} + V_{\mathrm{var}}$$

2. BJT

$$V_{\mathrm{IN+,\ target}}\left(n, I_{\mathrm{target}},\ T,\ V_{\mathrm{ACoffset,\ pp}},\ V_{\mathrm{sense}}\right)$$
$$= n * V_{\mathrm{LED}}\left(I_{\mathrm{target}},\ T\right) + \frac{V_{\mathrm{ACoffset,\ pp}}}{2} + V_{\mathrm{sense}} + V_{\mathrm{CE}}\left(T\right) + V_{\mathrm{var}}$$
$$= n * V_{\mathrm{LED}}\left(I_{\mathrm{target}},\ T\right) + \frac{V_{\mathrm{ACoffset,\ pp}}}{2} + 400\ \mathrm{mV} + V_{\mathrm{CE}}\left(T\right) + V_{\mathrm{var}}$$

Equation 2 System input voltage V_{IN+}

For all parameters, worst case operating points need to be considered..

- The LED array voltage (secondary side voltage) will be at its greatest value under the following circumstances:
  - Current thru the LED string is at 100 percent (I_{LED} = 100 percent)
  - And, LED component junction temperature is at its lowest.
- A possible common scenario where the maximum output voltage will be at its largest is when the system is initially powered up at 100 percent load at its lowest operating temperature,
- MOSFET V_{DS} ($R_{DS(on)}$ * I_{LED}) is at its highest value during full load and maximum operating temperature.

2.1.3 BCR602 system design aspects

This section describes the features and requirements of a BCR602 system. One system aspect is the maximum current limited by thermal heating. It is a step-by-step approach to design a BCR602 system.

Design steps of a BCR602 system:

Luminosity of the system, depending on

- Number of LEDs in the system, *n*
- Maximum LED current I_{LED} of the system

To achieve this luminosity a system input voltage for proper current regulation over the entire operating range is required, consisting of

- LED array voltage determinations
  - Number of LEDs in the system, *n*
  - Maximum LED current I_{LED} of the system
  - The total forward voltage of the LEDs used at the operating point
  - The voltage drop over the *VSENSE* resistor

This input voltage is increased by variation dependent voltage margin:

- The voltage drop over the pass element,
  - In case of a MOSFET: $R_{DS(on)}$*I_{LED}
  - In case of a BJT: V_{CE}
- An AC ripple superposed to the input signal received from the DC supply (primary side)
- Margin considering variations of the components used
- Delta between maximum forward voltage of the LED stack at operating temperature and the maximum forward voltage

Regarding the margin, the system is designed for the minimum DC voltage out of the series of DC supplies. DC supplies exceeding this minimum voltage contribute to the over-voltage.

$$V_{\mathrm{IN+,target,max}} = V_{\mathrm{IN+,target}}\left(1 + \frac{\mathrm{variation}}{100}\right)$$
$$V_{\mathrm{IN+,target,min}} = V_{\mathrm{IN+,target}}\left(1 - \frac{\mathrm{variation}}{100}\right)$$
$$\Delta V_{\mathrm{IN+,target}} = V_{\mathrm{IN+,target,max}} - V_{\mathrm{IN+,target,min}} = 2 * V_{\mathrm{IN+,target,min}} * \frac{\mathrm{variation}}{100}$$

Equation 3 Maximum and minimum input voltages

Due to the negative temperature coefficient of LEDs the maximum forward voltage is given by the ambient temperature. The LEDs are at the ambient temperature at the time of the system start.

$$\Delta_f = V_{f,T_{\max}} - V_{f,T_{\mathrm{ambient}}}$$

Equation 4 LED forward voltage delta

$$V_{\mathrm{var}} = n * \left(V_{f,\mathrm{LED,max}} - V_{f,\mathrm{LED,min}}\right) + V_{\mathrm{component\ variation}} + 2 * V_{\mathrm{IN+,target,min}} * \frac{\mathrm{variation}}{100} = n * \Delta_f$$
$$+ V_{\mathrm{component\ variation}} + 2 * V_{\mathrm{IN+,target,min}} * \frac{\mathrm{variation}}{100}$$

Equation 5 Sum of voltage variation

$$V_{\mathrm{DS|CE,\ power\ dissipipation}} = \frac{V_{\mathrm{ACoffset,pp}}}{2} + \left[R_{\mathrm{DS(on)}} * I_{\mathrm{LED}} \middle| V_{\mathrm{CE,min,Iled}}\right] + n * \left(V_{f,\mathrm{LED,max}} - V_{f,\mathrm{LED,min}}\right)$$
$$+ V_{\mathrm{component\ variation}} + 2 * V_{\mathrm{IN+,target,min}} * \frac{\mathrm{variation}}{100} = \frac{V_{\mathrm{ACoffset,pp}}}{2} + \left[R_{\mathrm{DS(on)}} * I_{\mathrm{LED}} \middle| V_{\mathrm{CE,min,Iled}}\right] + n * \Delta_f$$
$$+ V_{\mathrm{component\ variation}} + 2 * V_{\mathrm{IN+,target,min}} * \frac{\mathrm{variation}}{100}$$

Equation 6 Total voltage across pass element

$V_{\mathrm{component\ variation}}$ subsumes some additional margin caused by variations in *VSENSE* and component variation of LED forward voltage. Usually in total this is in the range of a few hundred mV.

$V_{\mathrm{DS|CE,\ power\ dissipation}}$ is transferred to heat in the pass element. All heat will be dissipated over the case of the LED engine, causing a temperature rise of the pass element and the case. This temperature rise is limited by the maximum allowed case temperature. It can be reduced by reducing the LED current. By this the LED maximum LED current I_{max} is limited by:

- The maximum case temperature
- The thermal resistance of $R_{th(JA)}$ of the pass element

Maximum case temperature is the measurement point of the mechanical enclosure of the system.

Thermal resistance

Via the thermal resistance R_{thJA} of the power transistor the maximum power dissipation at the transistor is given.

Example

OptiMOS™ BSP716N: R_{thJA} = 70 K/W,

Maximum case temperature: 90°C,

Ambient temperature: 20°C,

Maximum power dissipation: $P_{\text{dissipation, max}} = \frac{T_{J,\max} - T_{\text{ambient}}}{R_{\text{thJA}}} = \frac{90\,°\text{C} - 20\,°\text{C}}{70K/W} = 1\,W$.

(1)

$$I_{\text{LED}} < I_{\max}$$

(2)

$$P_{\text{diss, pass, max}} = \frac{T_{\max,\text{case}}}{R_{\text{th(JA)}}} = [V_{\text{DS}} | V_{\text{CE}}] * I_{\max}$$

(3)

$$I_{\max} = \frac{T_{\max,\text{case}}}{R_{\text{th(JA)}} * V_{\text{DS}|\text{CE, power dissipation}}}$$

Equation 7 Maximum system current

Because the input voltage variation is proportional to the input voltage, the maximum target current declines with increasing numbers of LEDs.

For the total input voltage please refer to section BCR602 system supply voltage requirements.

2.1.4 BCR602 dimming

This section describes means and aspects of dimming in a BCR602 system.

BCR602 LED systems can be dimmed by:

- Dimming by means of pin *MFIO*
  - Applying a DC signal between 0 V and 4 V (analog dimming)
  - A PWM signal of 500 Hz up to 3.5 kHz
  - A combined signal consisting of a DC signal and a PWM signal
  - Connecting a series resistor R_{SET} between pin *MFIO* and ground

2.1.4.1 BCR602 analog dimming

This section describes the means of dimming by applying a DC voltage to pin *MFIO*.

DC dimming is continuously increasing from the minimum dimming level at V_{MFIO} = 0.18 V up to the no dimming level starting at V_{MFIO} = 3.3 V.

For further information please refer to the datasheet.

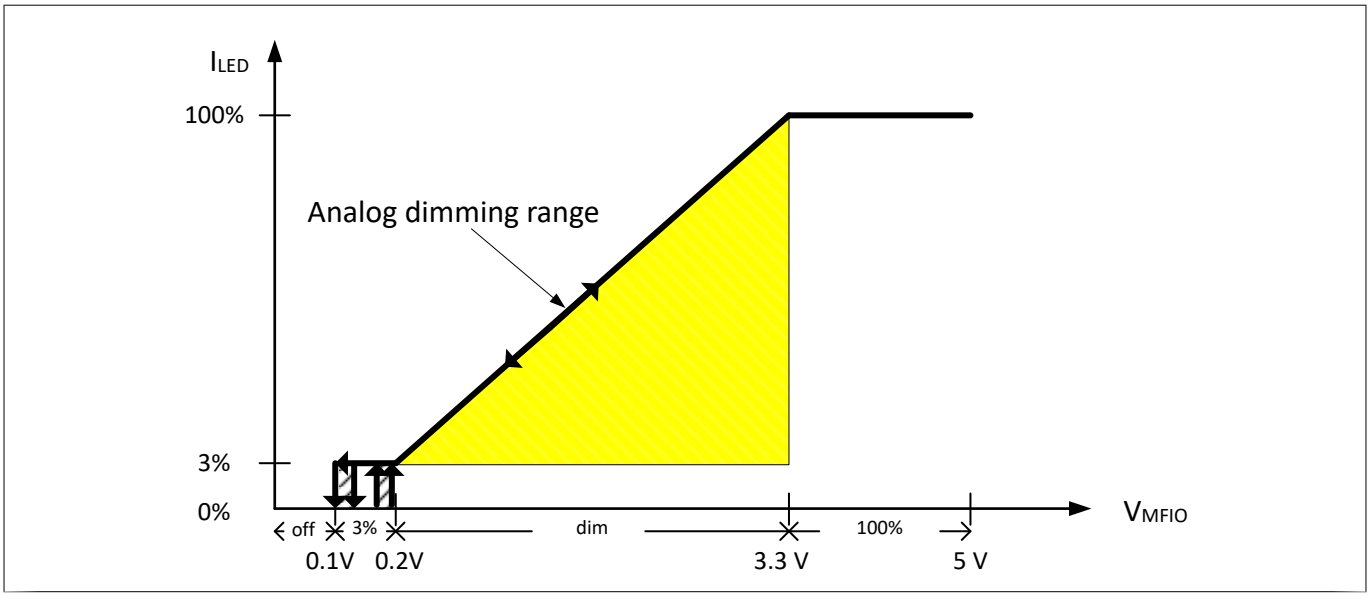
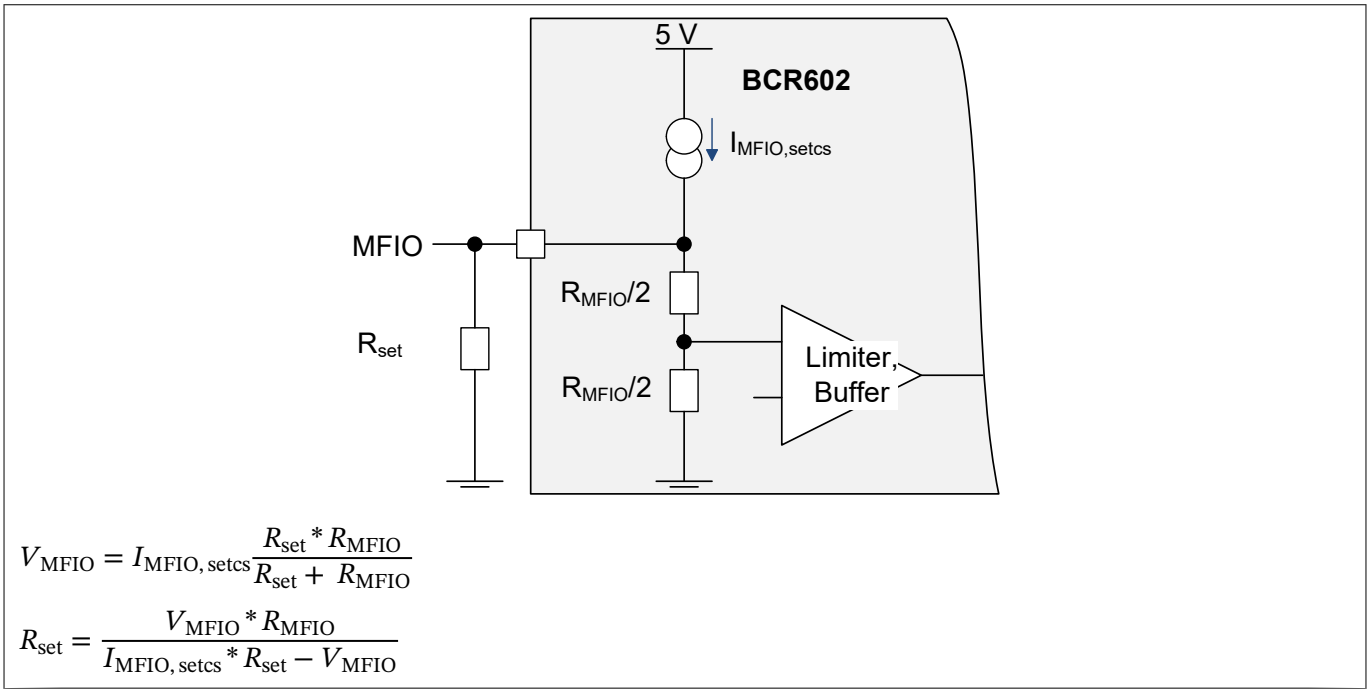


Figure 6 DC dimming curve

2.1.4.2 Resistor dimming

This section describes dimming to a fixed dimming value using an external resistor R_{set}.



$$V_{MFIO} = I_{MFIO,setcs} \frac{R_{set} * R_{MFIO}}{R_{set} + R_{MFIO}}$$

$$R_{set} = \frac{V_{MFIO} * R_{MFIO}}{I_{MFIO,setcs} * R_{set} - V_{MFIO}}$$

Figure 7 R_{set} dimensioning for resistor dimming

Figure 8 describes the correlation between R_{set} and the effective value for V_{MFIO}. Typical values to be used in the formula are:

- $R_{MFIO,typical}$ = 285 kΩ
- $I_{MFIO,setcs,typical}$ = 20 µA

Figure 8 illustrates the correlation between R_{set} and the voltage level seen at V_{MFIO}.

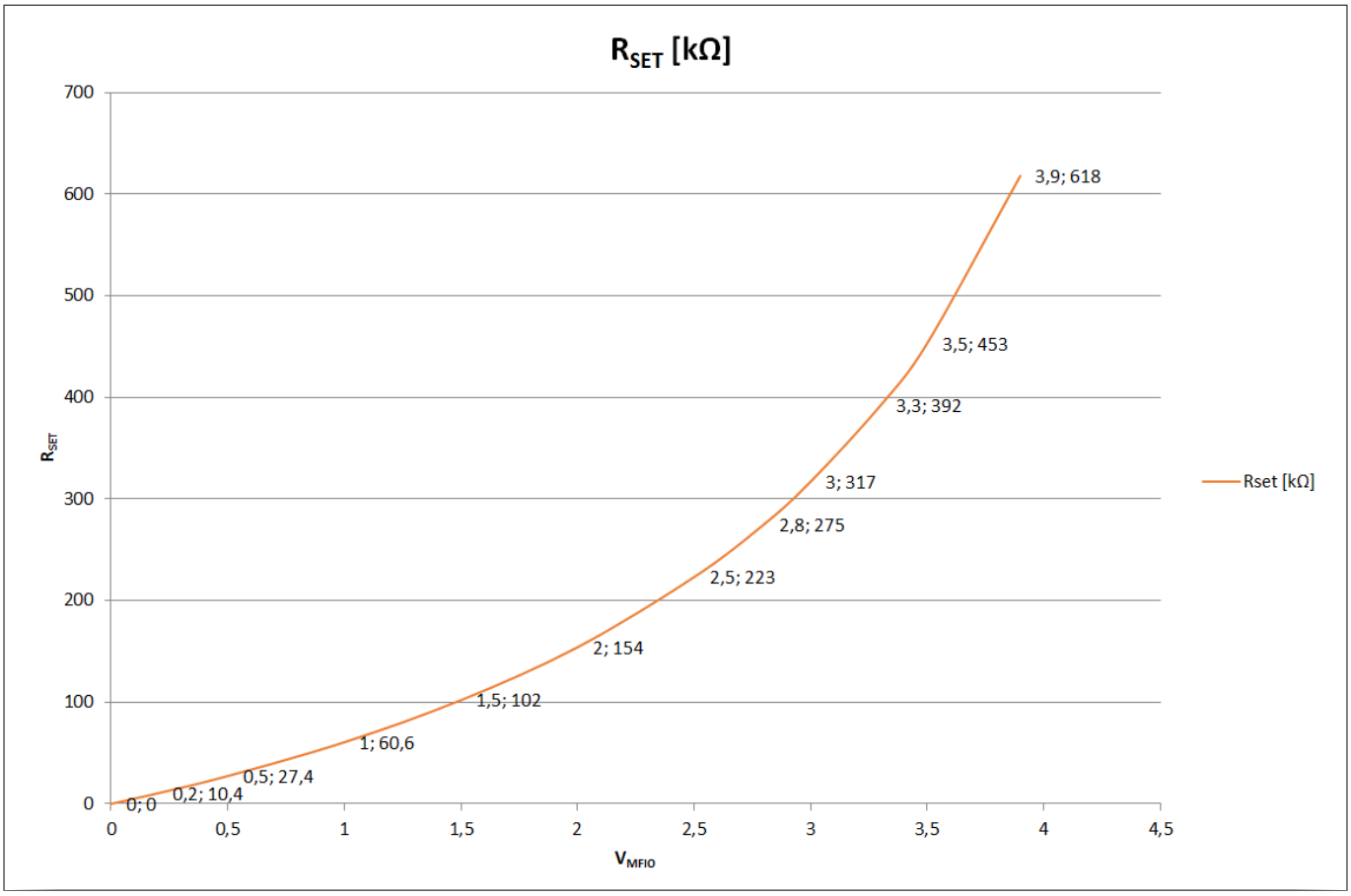


Figure 8 **R_{set} versus V_{MFIO}**

Note: *Figure 8 shows the correlation between R_{set} value and the effective V_{MFIO}. The curve is determined according to the formula in Figure 6 . (R_{set}→ V_{MFIO}→ I_{LED})*

2.1.4.3 BCR602 PWM dimming

This section describes aspects of the PWM dimming of BCR602.

For dimming any frequency between 500 Hz and 3.5 kHz can be applied to pin *MFIO*. Duty cycle can be modified continuously from 1 percent up to 100 percent. To achieve the full current configured by the resistor *VSENSE* the voltage of the active phase must be ≥ 3.3 V within operating conditions.

Combined PWM and analog (DC voltage) dimming is possible. Combined dimming is the application of a PWM signal at an active signal level < 3.3 V. In this case the DC dimming curve shown in Figure 6 is folded with the percentage of the active duty cycle. This enables extension of the dimming range at very low dimming values. For the requirements of DC dimming please refer to BCR602 analog dimming .

$$I_{\text{LED, combined dim}} = I_{\text{LED, dimDC}} * \text{Duty cycle}$$

Equation 8 **Combined PWM and DC dimming**

2 BCR602 detailed description

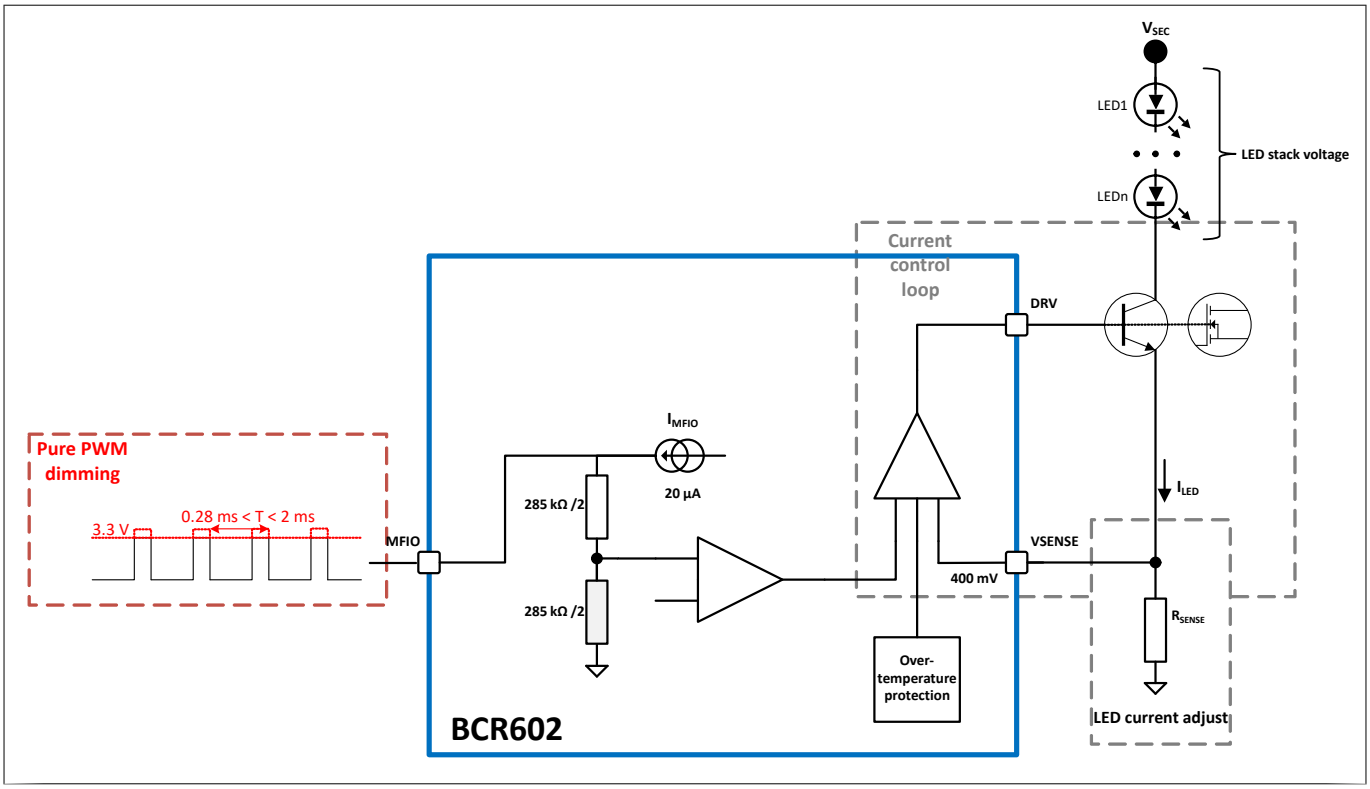


Figure 9 Pure PWM dimming

2.2 BCR602 pass element selection

This section describes requirements of Power MOSFETs and BJTs.

Note: This is a selection guide. It outlines necessary component parameters from the perspective of the BCR602.

Within a linear regulated system, transistor power loss (P_{loss}) is dominated by conduction losses:

- V_{DS}*I_{DS} in case of MOSFET
- V_{CE}*I_C in case of BJT

MOSFETs should be selected with this in mind, low $R_{DS(on)}$ being a critical specification.

BJTs are only recommended for use in low power, low LED current (< 200 mA) application where cost is critical.

2.2.1 MOSFET

This section describes the requirements in case of MOSFET usage.

Major MOSFET parameters to be considered for selection are (ordered according to degree of importance)

- Safe operating area (SOA)
- Threshold voltage ($V_{GS(th)}$)
- Maximum power dissipation (P_D)
- $R_{DS(on)}$,
- Continuous drain current (I_D)
- Operating junction temperature (T_J)
- Signal response characteristics
- Drain-to-source breakdown voltage ($V_{(BR)DSS}$)
- Total gate charge Q_g
- Logic level

Note: In Table 2 the typical values refer to the reference design. The reference design is equipped with an Infineon OptiMOS™ BSP716N.

Table 2 MOSFET selection parameters

Parameter	Selection criteria	Range	BCR602 demonstrator notes
SOA	The relation between V_{DS} and I_D must comply with the DC curve	See description below this table	2.8 V (at 500 mA), please refer to Figure 11

(table continues...)

Table 2 (continued) MOSFET selection parameters

Parameter	Selection criteria	Range	BCR602 demonstrator notes
$V_{GS(th)}$	MOSFETs are usable with threshold voltages up to 4 V. Ideal PWM signals have rectangular steps at the transition between PWM-on and PWM-off phase. The time until the threshold is reached causes a delay in the response. So for PWM applications it is recommended to use MOSFETs at low thresholds, default is 2 V.	See description below this table	2 V
P_D	The maximum value of this voltage together with the target current sets the required power dissipation of the MOSFET.	> V_{DRAIN}* I_{LED}	1.8 W
$R_{DS(on)}$	A higher $R_{DS(on)}$ increases the MOSFET power dissipation. Usually the power dissipation caused by $R_{DS(on)}$ can be neglected compared to the power dissipation caused by the AC ripple on the input signal.	< 0.3 Ω	0.18 Ω
I_D	Set by the target current of the application plus margin	> I_{LED}+ 10 percent	2.3 A
T_J	Application system conditions plus margin. For optimal usage of the over-temperature protection (OTP) feature it shall be higher than $T_{OTP,on}$	> 140 °C	150 °C
Signal response characteristics, C_{iss}	Set by $\tau = R_{Gate}$* C_{iss}. The input capacitance acts as integration element in the current control loop	< 3000 pF	237 pF

(table continues...)

Table 2 (continued) MOSFET selection parameters

Parameter	Selection criteria	Range	BCR602 demonstrator notes
$V_{(BR)DSS}$	The breakdown voltage is limited by the input voltage	> V_{IN+}+10 percent	75 V
Q_g	Gate charge is of importance in case of fast transitions of the current in the dimming case	< 60 nC	8.7 nC

$V_{GS(th)}$ selection

For safe selection of a MOSFET with an appropriate threshold value:

- $V_{GS(th),max}$ < 4.5 V,
- The margin between maximum and typical values of $V_{GS(th)}$ must be evaluted, e.g. with $V_{GS(th),max}$ = 1.8 V and a $V_{GS(th),typical}$ this yields a factor of $\gamma = \frac{V_{GS(th),\,max}}{V_{GS(th),\,typical}}$
- In the datasheet of the MOSFET check the typical transfer characteristics curve to evaluate the voltage V_{GS} for your target current $V_{GS,target,evaluated}$; see Figure 10, note that this diagram shows typical values,
- Multiply the determined voltage $V_{GS,I\text{-}target}$ with the factor y,
- The resulting voltage must fulfill the formula $V_{GS,\,target,\,max} = \gamma * V_{GS,\,target,\,evaluated} < 4.5\,V$.

Note: Generally the variance of $V_{GS(th)}$ between minimum and maximum value in the datasheets of used MOSFETs is very high. Also it is measured at very low drain current, at values of e.g. 100 µA or 250 µA.

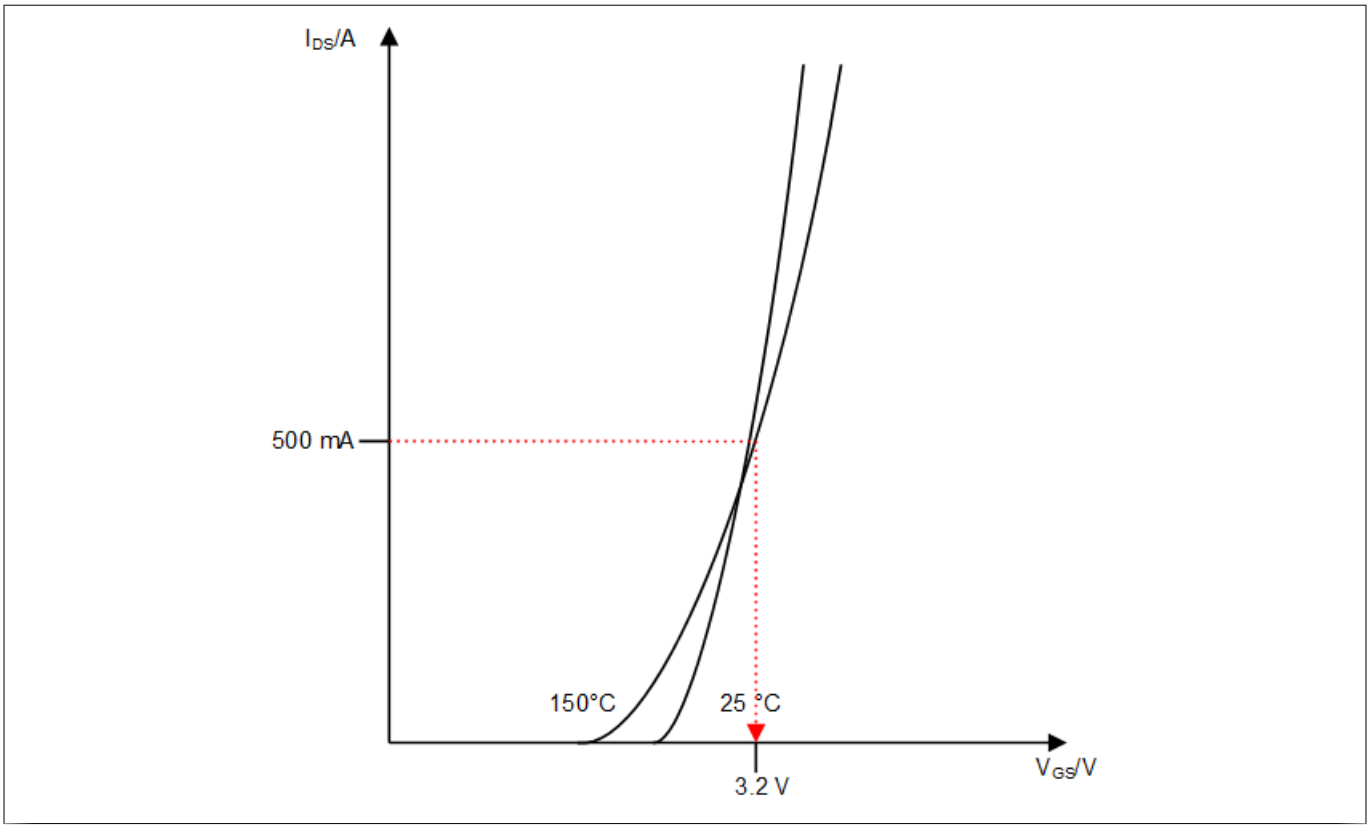


Figure 10 Example of a typical transfer characteristics curve

Safe operating area (SOA)

SOA curves for MOSFETs that are used in linear regulator systems are important diagrams to ensure the MOSFET meets system design requirements. When choosing operating conditions of the MOSFET in the system use worst case voltage (V_{DS}) and current (I_{LED}, I_{DS}) operating points. These are found on the DC graphs. For optimization please refer to LED current regulation and Power loss optimization.

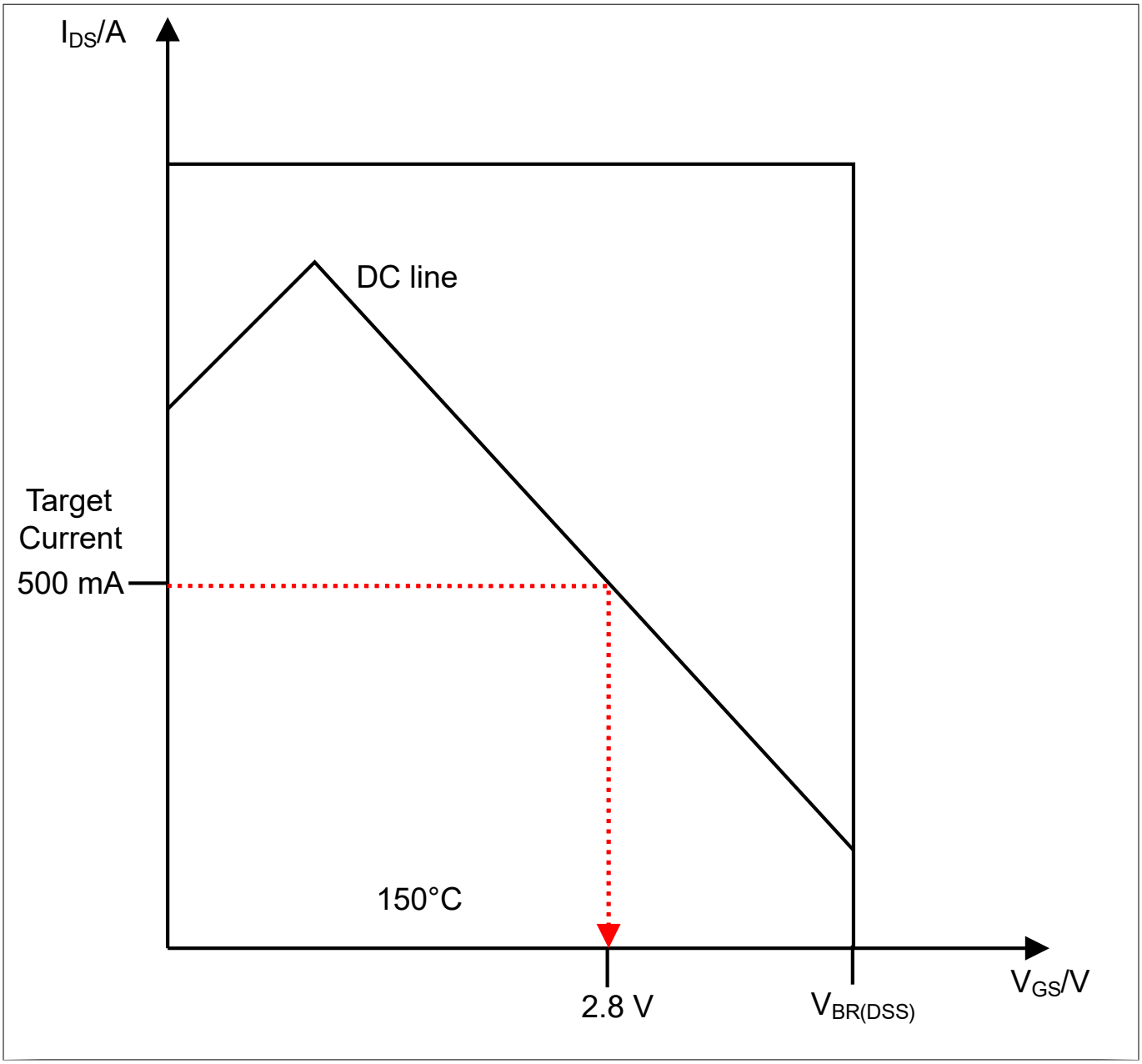


Figure 11 Example of a MOSFET SOA

Logic level

MOSFETs used shall be of type "logic level". Non-logic level MOSFETs require higher levels of V_{GS}. Using “logic level“ MOSFETs the current control is more robust because of a larger control range usable by the controller output.

Recommended MOSFETs

This list gives a selection of recommended MOSFETs.

Table 3 Recommended MOSFETs

Type	Package	$V_{gs,\ typ}$	$V_{gs,\ max}$	V_{gs} at specified $R_{DS(on),max}$	SOA maximum current at V_{DRAIN} = 2 V DC	SOA maximum current at V_{DRAIN}= 5 V DC
BSP761N	SOT-223	1.4 V	1.8 V	180mV at 4.5V	0.9 A	0.2 A
BSP372N	SOT-223	1.4 V	1.8 V	270 mV at 4.5V	0.9 A	0.1 A

2.2.2 BJT

This section describes requirements for the BJTs used.

The main BJT parameters to be considered for selection are (ordered according to degree of importance):

- DC current gain
- Collector-emitter breakdown voltage at I_B = 0 ($V_{(BR)CEO}$)
- Collector-base breakdown voltage ($V_{(BR)CBO}$)
- Continuous collector current (I_C)
- Total power dissipation (P_D)
- Operating junction temperature (T_J)

Table 4 BJT selection parameter

Parameter	Selection criteria	Range
DC current gain	Necessary to achieve target current of the system	$h_{FE} > \frac{I_{target}}{I_{DRV,\ source}}$
$V_{(BR)CEO}$	Set by the system configuration, more than the input voltage of the BCR602 system	> V_{IN+}+10 percent
$V_{(BR)CBO}$	Set by the system configuration, more than the input voltage of the BCR602 system	> V_{IN+}+10 percent
I_C	Set by the target current of the application plus margin	> I_{target}+ 10 percent
P_D	Proper current regulation requires a remaining $V_{Collector}$ offset voltage. The maximum value of this voltage together with the target current sets the required power dissipation of the BJT	> $V_{collector}$* I_{LED}
T_J	Application system conditions plus margin. For optimal usage of the OVP protection feature it shall be higher than $T_{OTP,on}$	140°C

2.3 BCR602 thermal optimization

This section describes how to optimize power consumption of the BCR602.

The total current consumption consists of IC self-supply consumption plus current for the DRV supply .

The BCR602 has a self-supply current consumption of up to 2.2 mA.

To this current the maximum possible source current at the pin *DRV* of -10 mA must be added. High source currents at pin *DRV* usually occur in case of a BJT used as a pass element at low h_{FE} of the BJT.

In a static operating condition of constant dimming and usage of a MOSFET the *DRV* current component can be neglected.

PWM mode

For MOSFETs as well as for BJTs PWM increases the peak current on pin DRV.

Calculation of IC power consumption

BCR602 power consumption is: $P_{\mathrm{BCR}} = V_S * I_{\mathrm{BCR,\ total}}$

Power consumption of the BCR602 can be lowered by a reduction of the voltage applied to the *VS* pin. Lowering the voltage at *VS* is achieved by adding a series resistor between the input voltage V_{IN+} and *VS*.

VS series resistor power consumption: $P_{\mathrm{Rpred}} = R_{\mathrm{pred}} * I^2_{\mathrm{BCR,\ total}}$

BCR602 power consumption reduction by adding a resistor is recommended when secondary-side output voltage is large (high voltage LED array). To ensure proper start-up of the IC, the supply voltage of the IC at *VS* must not drop below the minimum operating voltage of 8 V.

In case of PWM a drop below 8 V at pin *VS* at the time of the PWM-on edge might cause a delay in reaching the target *DRV* voltage, leading to a greater dimming than expected and a non-linearity in the dimming curve.

$$V_{\mathrm{VS}} > 8\ V$$

Equation 9 IC supply voltage requirement

$$I_{\mathrm{BCR,\ VS,\ max}} = 12.2\ \mathrm{mA}$$

Equation 10 Maximum IC current consumption according the datasheet

Protected by the resistor the maximum power consumption of the IC can be reduced to:

$$P_{\mathrm{BCR,\ 8\ V,\ wc}} = 8\ V * 12.2\mathrm{mA} = 97.6\ \mathrm{mW}$$

Equation 11 Maximum IC power consumption at V_{VS} = 8 V

To avoid a drop below the minimum IC supply voltage Equation 12 must be fulfilled.

$$R_{\mathrm{pred}} < \frac{V_{\mathrm{in+}} - 8\ V}{I_{\mathrm{BCR,\ 8V,\ wc}}} \Leftrightarrow R_{\mathrm{pred}} < \frac{V_{\mathrm{in+}}}{12.2\ \mathrm{mA}} - 656\ \Omega \Leftrightarrow R_{\mathrm{pred}} < \frac{V_{\mathrm{in+}}}{12.2\ \mathrm{mA}} - 656\ \Omega$$

Equation 12 Maximum R_{pred}

2.4 Over-temperature, hot-plug and shortcut protection

Besides the OVP protection BCR602 provides over-temperature and hot-plug protection, plus the protection of a short of LEDs.

For the over-temperature protection an internal IC sensor is used. No further configuration steps are required for this protection. Over-temperature is activated at 140°C junction temperature. With activation I_{LED} is reduced to one third. Please refer to the datasheet.

Hot-plug protection protects the LED array from spikes and surges during the turn-on and connection phase. No further configuration steps are required for this protection. Hot-plug is activated whenever V_{SENSE} is below 8 mV. During this time $I_{LED}$is limited to 4 percent of $I_{LED,max}$ by reduction of the reference voltage for *VSENSE* from 400 mV to 16 mV. On reconnection this protects the LED string from surge current.

In case of a short of one or more LEDs the given LED current does not deviate from its set-point. .

2.5 Troubleshooting

Unstable current regulation can be caused by

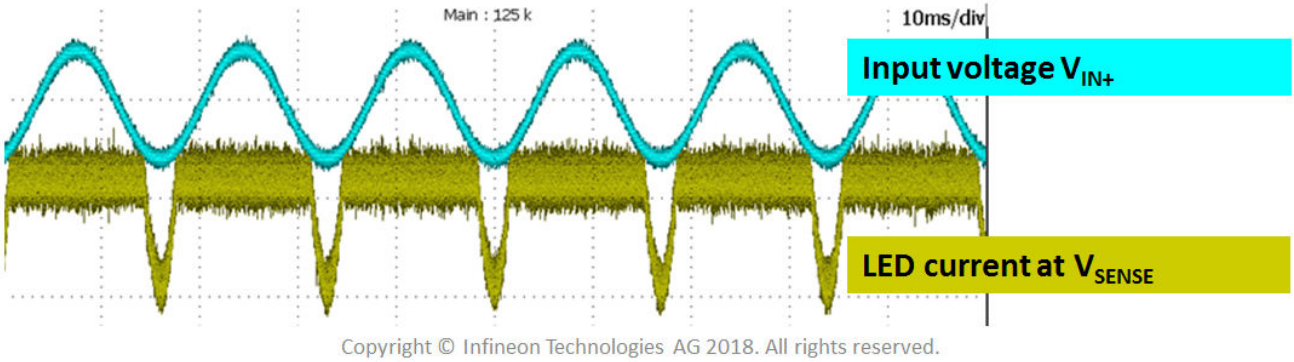
- Insufficient input voltage (V_{IN+}), that is the voltage drop over the power transistor is too low
- In case of BJTs by a too high current amplification h_{FE}. This effect typically affects Darlington transistors only

2.5.1 Unstable current regulation

This section covers the effects of an unstable current regulation loop caused by insufficient voltage headroom on the secondary side output voltage (V_{IN+}).

Loss of LED current regulation is normally the result of an insufficient voltage level on the input to the system (V_{IN+}). First indications of insufficient voltage to the system are observed when the AC voltage ripple at the input to the system is at its lowest point. At this point the headroom across the pass element is insufficient to maintain current regulation. (See Figure 12.)

The magnitude of the AC offset therefore also defines the minimum voltage drop over the transistor. The higher peak-to-peak value of the AC offset, the higher the required average voltage drop over the transistor.



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Image legend

- Blue: V_{IN+} - Input voltage,
- Yellow: V_{SENSE} - LED current sensing.

Figure 12 Partial loss of current control caused by too low V_{IN+}

In case the voltage drop at U_{DS} is that high, causing a drop of the sensing voltage of the resistor in the minimum phase of V_{IN+} to V_{SENSE} < 8 mV , a following increase shows also effect of the hot-plug mechanism. (See Over-temperature, hot-plug and shortcut protection.)

In case of a mean voltage V_{IN+}, already too low to reach the set point given by V_{MFIO} during the whole phase0 of the sinusoidal signal, this causes current only during the phases, when V_{IN+} is high enough for a significant V_{DS} drop (in case of a MOSFET), V_{CE} drop (in case of a BJT). Because of the linear mode in these phases a current in phase and proportional to the V_{IN+} is generated.

Note: Cases of an insufficient level of V_{IN+} can be detected by dimming, which means by reduction of V_{MFIO}. At an appropriate dimming level the required current level is lower and so the LED flickering at no dimming is changed into stable conditions. In these cases V_{IN+} must be increased.

2.5.2 BCR602 and Darlington BJTs

This section describes aspects to be considered when using a Darlington BJT.

Darlington transistors and BJTs with high current amplification (h_{FE}) can be used, but the current regulation feedback loop may need to be slowed down to compensate for their increased amplification.

Note: All contents of this section also applies to high h_{FE} standard BJTs.

Current feedback stability can be regained by reducing current feedback response, this is achieved by placing an additional capacitor into the loop that is connected between the base, the DRV pin of the BCR602 and the collector of the transistor.

Remedy

Table 5 lists some high current amplification BJTs and the minimum capacitor size to remove oscillations caused by the high gain.

Figure 13 shows how to place the Miller cap.

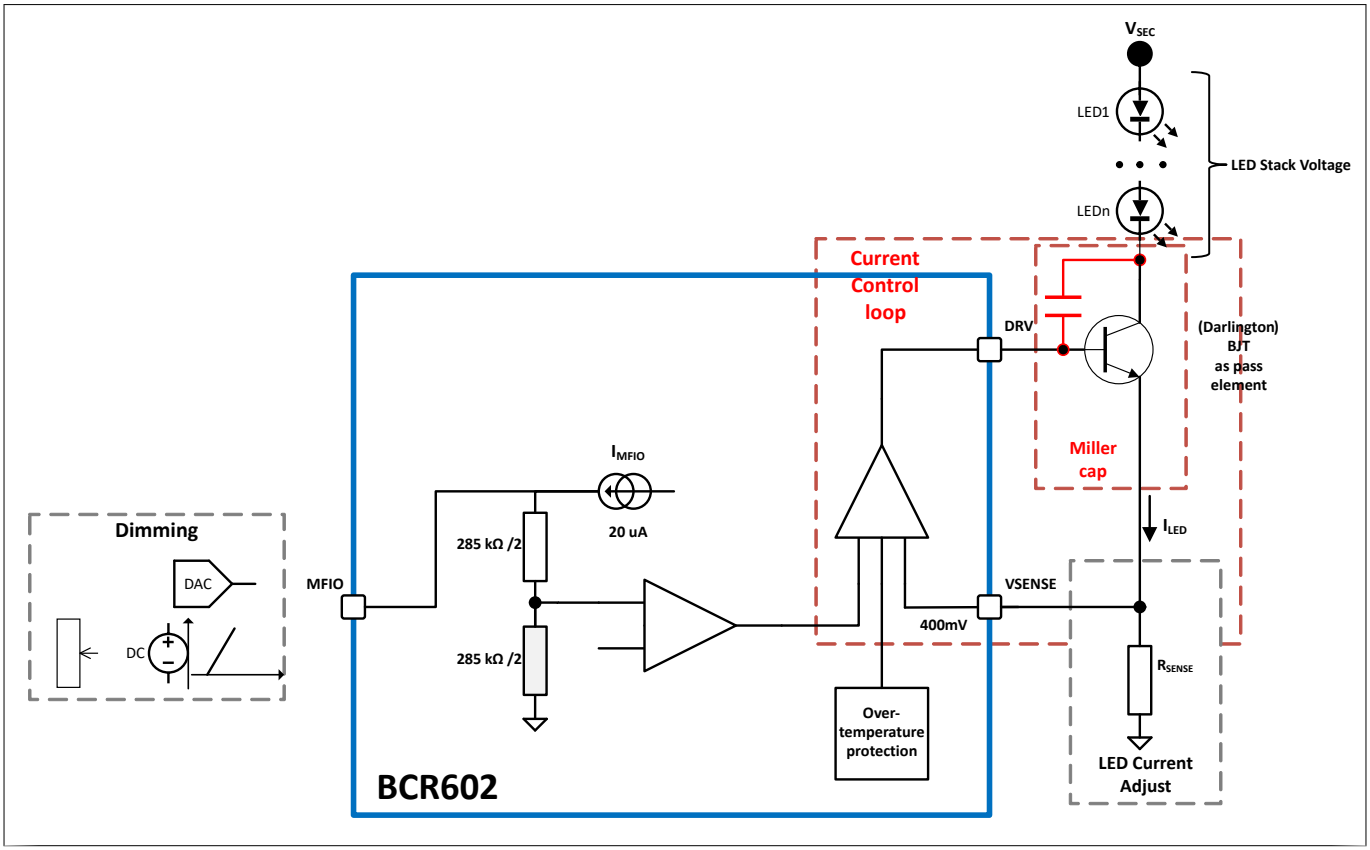


Figure 13 Miller cap to stabilize the current control loop

Table 5 Minimum Miller capacitors at different DC current gains in a 200 mA system

BJT	Type	h_{FE}	C [nF]
TIP-122	Darlington	1000	68
NZT7053	Darlington	1000	56

(table continues...)

Table 5 (continued) Minimum Miller capacitors at different DC current gains in a 200 mA system

BJT	Type	h_{FE}	C [nF]
MJF6039	Darlington	2500	100
NZT602	Standard	5000	100

Note: DC current gains h_{FE} according to the datasheets of the devices.

3 Implementation and design steps

This section describes the design steps and gives two application examples.

Design steps:

1. Selection of:
   - **a.** Type of LEDs and number of LEDs,
   - **b.** Target output current and number of LEDs in the system
   - **c.** Supply of input voltage and power
   - **d.** Power transistor for linear control
2. Selection of the *VSENSE* resistors for the current control loop. The resistors must fulfill the power class of the power drop required by the target current.
3. Check of IC supply level 8 V < V_S < 60 V
   - **a.** Calculate the highest DC input voltage. The highest input voltage assumes the elements, especially the LEDs at their highest achievable forward voltage per element during operation.
   - **b.** Calculate the maximum output power of the system consisting of the primary and the secondary side. The primary side must fulfill the power limits of the secondary side.
   - **c.** Check the thermal conditions of the power transistor; the heating of the power transistor must not violate peak thermal conditions of the system.

.

For compatibility of the target current to the maximum power dissipation over the power transistor please refer to section BCR602 system design aspects.

For the power selection of the power transistor please refer to BCR602 pass element selection.

The input stage is usually an ACDC stage. The ACDC stage is very often realized by a PCF/Flyback like the Infineon XDPL8218. Usually the input voltage is offset by an AC ripple. This AC ripple can be reduced by an increased input capacitor and must be considered with regard to thermal aspects. Please refer to Thermal limits.

4 References

This section contains references to documents useful for this design guide.

1. Engineering Report for BCR602, Infineon Technologies AG, Munich 2018
2. BCR602 Datasheet, Infineon Technologies AG, Munich 2018
3. BCR602, Application Board Schematics and PCB, Infineon Technologies AG, Munich 2018

Revision history

Document version	Date of release	Description of changes
1.1	2023-01-20	Editorial changes
1.0	2019-02-07	Initial release

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