# LED driving concepts and Linear LED drivers

## About this document

### Scope and purpose

This application note is intended to provide detailed application hints regarding the usage and design of the LITIX™ Linear and BCR LED Drivers. The selection of external components is shown within this application note. Furthermore, different principles of LED driver concepts are explained.

### Intended audience

HW designers, LED system architects and engineers for LED lighting applications.

## Table of contents

# 1 Introduction

The LITIX™ Linear and BCR LED drivers are two families of single-channel current sources. The typical output current range is from 20 mA up to 2500 mA, which can be adjusted in all cases. Furthermore, some device also offer diagnosis features (See Table 1).

This document shows how to define the external circuitry for the required output current and gives hints for diagnosis function.

# 2 How to control LEDs

Light emitting diodes (LED) are semiconductor PN-junctions. When the LED is forward biased, electrons are able to recombine with holes within the device, releasing energy in the form of photons. The LED's forward current, which has to be limited, defines the brightness of the LED.

The current limiting and setting can be done with different methods:

- A resistor to limit the forward current
- A linear current source to set a defined and stable current
- A DC/DC converter in constant current mode

In automotive applications LED-modules for exterior lighting are usually controlled via a switch on the central body control module (BCM) as it is shown in Figure 1, Figure 2 and Figure 3. The reason is to protect the wire from the BCM to the LED-module against short circuits. The LED-control ICs are mounted very close to the LEDs to ensure:

- A protection of the LEDs, if the wire from the BCM to the LED-module is shorted to the supply voltage
- To react on high temperature conditions in the LED-module (active current reduction to protect LEDs)

The following three chapters explain the different methods of LED control. Benefits and disadvantages are identified.

## 2.1 Resistor for LED current limitation

A resistor can act only as a current limiter, but not as a current control circuit for the LED. Figure 1 shows the simplified circuit schematic with a resistor solution:

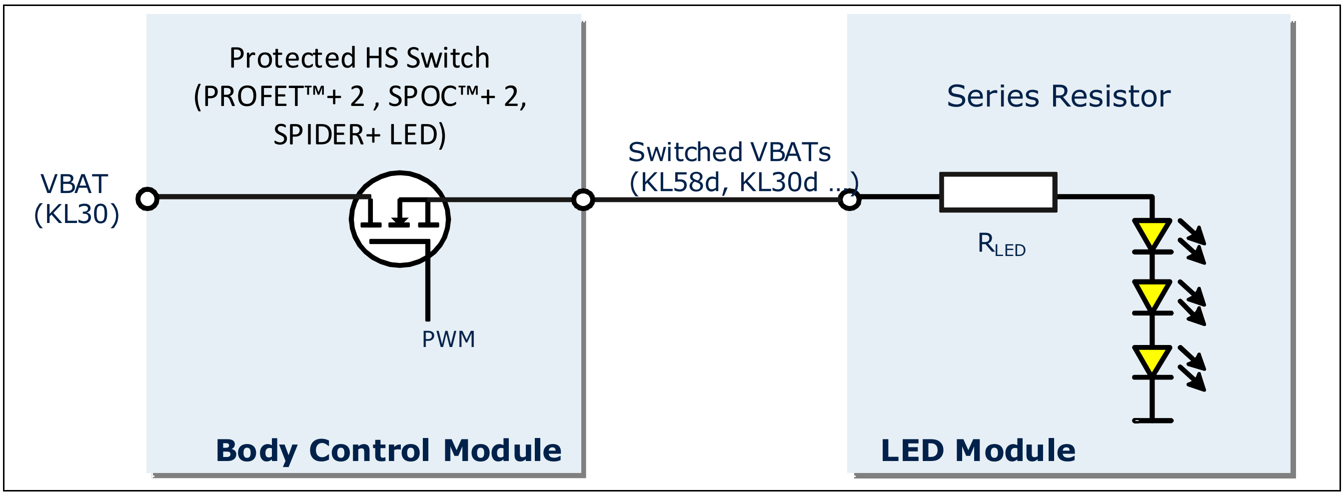


**Figure 1 LED driver schematic**

The resistor has to be defined for the worst case supply voltage e.g. $V_{BATs(max)}$ = 18 V.

Example: An LED for a typical rear light application is operated usually at a typical current of $I_{LED}$ = 50 mA with a typical forward voltage of $V_F$ = 2.2 V.

Therefore, the resistor $R_{LED}$ can be calculated for the example above (3 LEDs → n = 3):

(1) $$R_{LED} = \frac{V_{BATs(\max)} - n \cdot V_F}{I_{LED}} = \frac{18V - 3 \cdot 2.2V}{50mA} = 228\Omega$$

The resistor $R_{LED}$ has to withstand a power loss of:

$$(2)\quad P_{R_{LED}} = \left(V_{BATs(max)} - n\cdot V_F\right)\cdot I_{LED} = \left(18V - 3\cdot 2.2V\right)\cdot 50mA = 0.6W$$

So, a power resistor is required.

In case of lower supply voltages or voltage drops (e.g. start stop) the LED current is reduced, which leads to significantly reduced brightness! If the supply voltage drops down to e.g. $V_{BATs(min)}$ = 9 V:

$$(3)\quad I_{LED} = \frac{V_{BATs(min)} - n\cdot V_F}{R_{LED}} = \frac{9V - 3\cdot 2.2V}{228\Omega} = 11mA$$

**Pros**

- Simplest solution

**Cons**

- High power loss across the $R_{LED}$
- Resistor needs to be defined for maximum supply voltage conditions. For typical supply voltage conditions the LED current is much lower, which leads to a visible decrease of brightness e.g. during start stop operation
- LED nominal current range cannot be used for nominal operation conditions, because current has to be fixed for maximum supply voltage
- No intrinsic overvoltage protection (during supply voltage spikes the LEDs are stressed significantly, as a result of exceeding the LEDs maximum ratings) → degradation of LEDs
- No simple temperature protection of the LEDs possible → degradation of LEDs
- Reduced LED lifetime
- Any diagnosis functions needs to be realized by additional circuits
- Only limited LED chain length, dependent on the LED forward voltage $V_F$ and minimum supply voltage

## 2.2 Linear current source for constant current supply of LEDs

A linear current source provides a constant output current to the LED over the entire supply voltage range. In addition to the benefits of the constant LED current diagnosis functions are provided by most linear current sources. Figure 2 shows a simplified LED module using a constant current source.

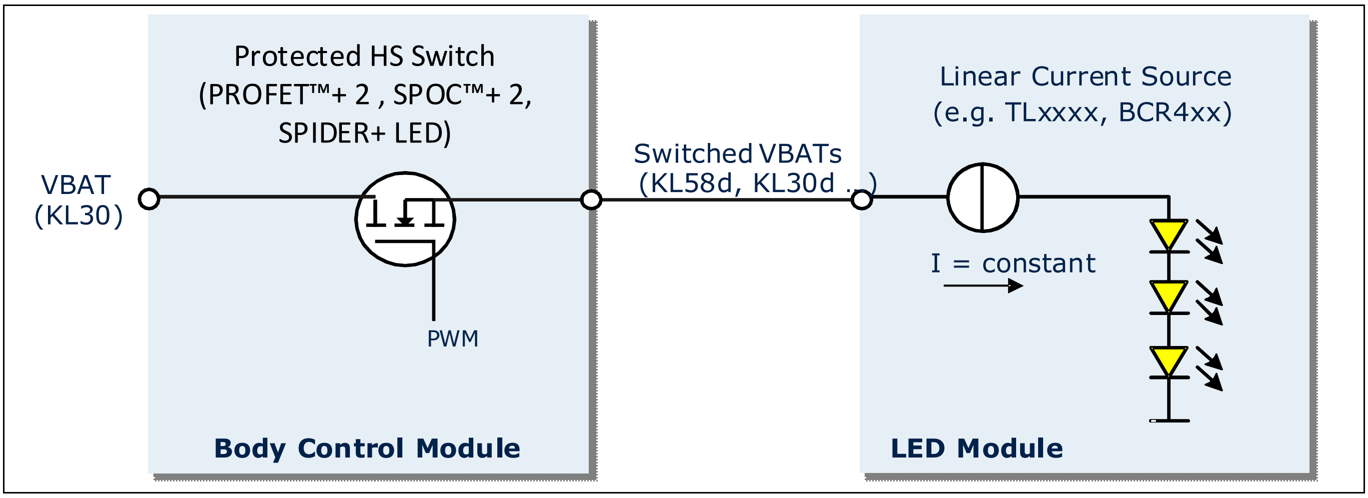


**Figure 2 LED driver schematic**

The LED current is controlled by the linear current source. The output current is constant and nearly fully independent of the $V_{BAT}$. The LED current can be adjusted very easily by using external resistors. Details about current control and diagnosis are explained later in this application note.

**Pros**

- LED can be used in the nominal operation condition → full brightness
- Stable brightness even during start stop
- Intrinsic overvoltage protection
- No LED degradation
- High temperature protection of LEDs possible
- Integrated diagnosis functions (optional)

**Cons**

- High power loss across the constant current source
- Increased components count
- Only limited LED chain length, dependent on the LED forward voltage $V_F$ and minimum supply voltage

To increase the efficiency of the total system a so-called matrix setup could be used as described in Chapter 2.4.

## 2.3 DC/DC converter in constant current mode

A DC/DC converter in constant current mode provides a constant output current to the LED over the entire supply voltage range. The power loss inside the LED control circuit is reduced to a minimum, because the configuration is optimized to the LED chain length. Furthermore, diagnosis functions are provided by most DC/DC converters. Figure 3 below shows a simplified LED module using a DC/DC converter.

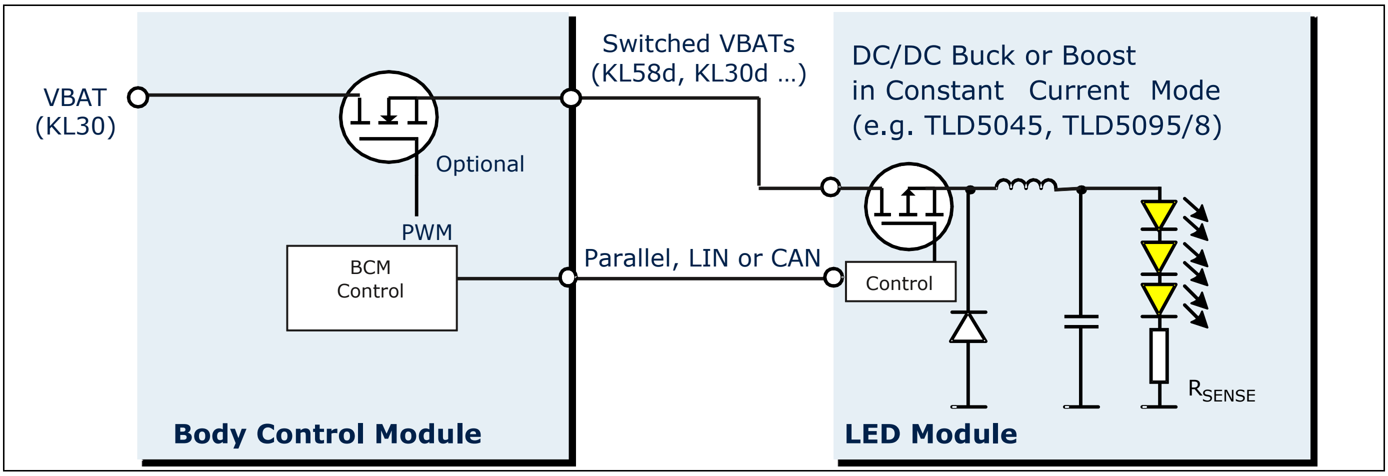


**Figure 3 LED driver schematic**

The LED current is controlled by the DC/DC converter. Different topologies (Buck, Boost, SEPIC …) can be used to fulfill requirements regarding LED chain length and supply voltage range. The output current is constant and nearly fully independent of the $V_{BATs}$. The LED current can be adjusted very easily by using external resistors.

**Pros**

- Highest efficiency
- LED can be used in the nominal operation condition → full brightness
- Stable brightness even during start stop

- High brightness LEDs capable
- Various topologies possible
- Intrinsic overvoltage protection
- No LED degradation
- High temperature protection of LEDs possible
- Integrated diagnosis functions (optional)

**Cons**

- Increased components count
- PCB layout needs to be optimized regarding EMC performance

## 2.4 DC/DC converter combined with constant current source – matrix setup

A DC/DC converter in constant voltage mode is combined with one or more linear current sources. The DC/DC converter provides an output voltage, which is optimized for the required LED chain length. The DC/DC output voltage is converted into a constant output current by the linear current sources. This solution allows a more efficient LED control compared to a pure linear current source solution as described in Chapter 2.2. Figure 4 below shows a simplified LED module using the Matrix setup.

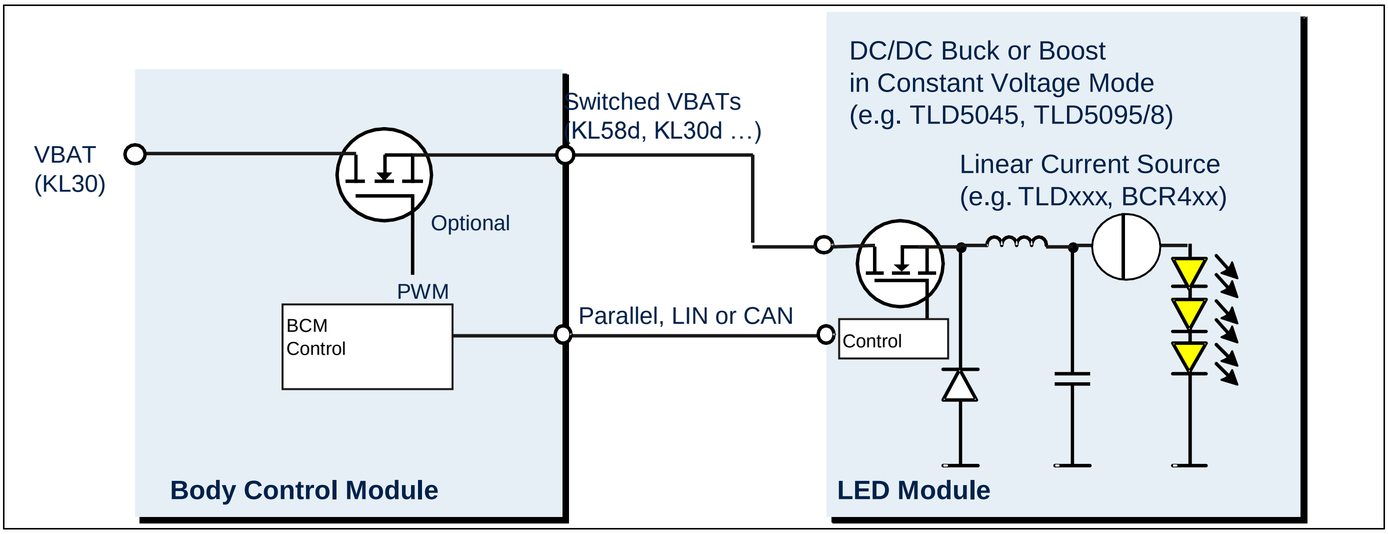


**Figure 4 LED driver schematic**

The LED current is controlled by the linear current source. The DC/DC converter output voltage is adjusted to the LEDs forward voltage. Different topologies (Buck, Boost, SEPIC …) can be used to fulfill requirements regarding LED chain length and supply voltage range. The output current is constant and nearly fully independent of the $m_{BATs}$. The LED current can be adjusted very easily by using external resistors.

**Pros**

- One DC/DC converter for multiple linear current sources
- Current source supply, which is the DC/DC output, optimized to LED forward voltage
- LED can be used in the nominal operation condition → full brightness
- Stable brightness even during start stop
- Various topologies possible
- Higher efficiency than pure linear current source solution
- Intrinsic overvoltage protection

- No LED degradation
- High temperature protection of LEDs possible
- Integrated diagnosis functions (optional)

**Cons**

- Increased components count
- PCB layout needs to be optimized regarding EMC performance

# 3 LITIX™ Linear and BCR LED drivers

Infineon provides numerous automotive qualified constant current source products for optimized LED control within automotive interior and exterior lighting applications. In the following explanation an overview of all current available products is given.

**Table 1 LITIX™ Linear and BCR LED drivers overview**

| | Current [mA] | Open load detection | PWM / Enable | High / low current switch | Package |
|---|---|---|---|---|---|
| BCR40xU | 10 - 50$_{typ}$ | | | | SC-74 |
| BCR420U | 150 $_{typ}$ | | | | SC-74 |
| BCR421U | 150 $_{typ}$ | | x | | SC-74 |
| TLD1211SJ | 85 $_{typ}$ | | x | | DSO-8 |
| TLE4241GM | 70 $_{max}$ | x | x | x | DSO-8 |
| TLE4242G | 450 $_{typ}$ | x | x | | TO-263 |
| TLD1211SJ + ext NPN | < 2500 | | x | | DSO-8 |

## 3.1 BCR4xx family – low cost linear current sources

The BCR4xx family includes low cost constant current source LED drivers offering current adjustment features without diagnostic functions for easiest design-in.

**Table 2 BCR4xx Product and Feature Overview**

| Product type | Package | Topology | Input voltage min. [V] | Input voltage max. [V] | Output current [mA] | Inhibit | PWM |
|---|---|---|---|---|---|---|---|
| BCR420U | PG-SC74-6 | Linear | 4.5 | 40 | 150 | | |
| BCR421U | | | | | 150 | x | x |
| BCR401U | | | | | 10 | | |
| BCR402U | | | | | 20 | | |
| BCR405U | | | | | 50 | | |

**Key Features:**

- Low cost technology & package
- Output current adjustable by usage of external resistor, without external resistor output current is fixed to specified value
- Suitable for Pulse Width Modulation (PWM)
- Negative temperature coefficient (LED protection at high temperatures)
- Available in several package options: SOT143R, SOT343, SC74
- Possibility to operate as control circuit with an external NPN-power transistor as output stage
- Automotive qualified

### 3.1.1 Integrated output stage usage

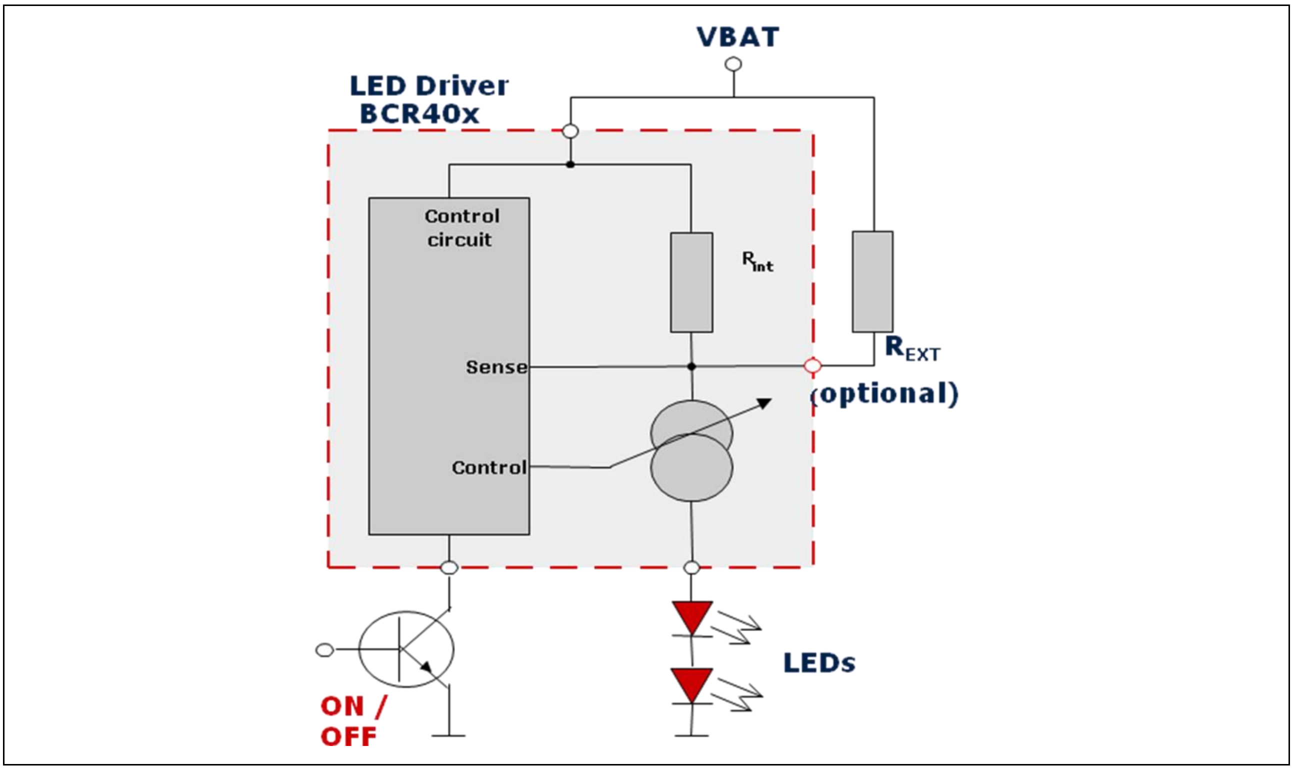


**Figure 5 Schematic**

The LED current can be adjusted by using the external resistor $R_{EXT}$. If no external resistor is mounted, the LED current is fixed to the specified value according to the data sheet. With equipped $R_{EXT}$ the output current is defined by equation (4). The values used for the example are based on the BCR401.

$$(4) \quad I_{OUT} = \frac{V_{drop}{}^{*}}{\dfrac{R_{int}{}^{**} \cdot R_{EXT}}{R_{int}{}^{**} + R_{EXT}}} \approx \frac{0.91V}{\dfrac{91\Omega \cdot R_{EXT}}{91\Omega + R_{EXT}}}$$

With:

* $V_{drop}$ according to data sheet graph "reference voltage ($V_{drop}$) versus $I_{OUT}$", typ. 0.91 V

** $R_{int}$ according to data sheet parameter $R_{int}$, typ. 91 Ω

### 3.1.2 External output stage usage

The devices of the BCR4xx family can be used also as control IC for an external NPN-transistor as output stage for high LED currents according to the following schematic. The LITIX™ Linear LED driver drives only a very small current, which is the base current for the external NPN transistor. Therefore, in a lot of cases the BCR401 devices are sufficient.

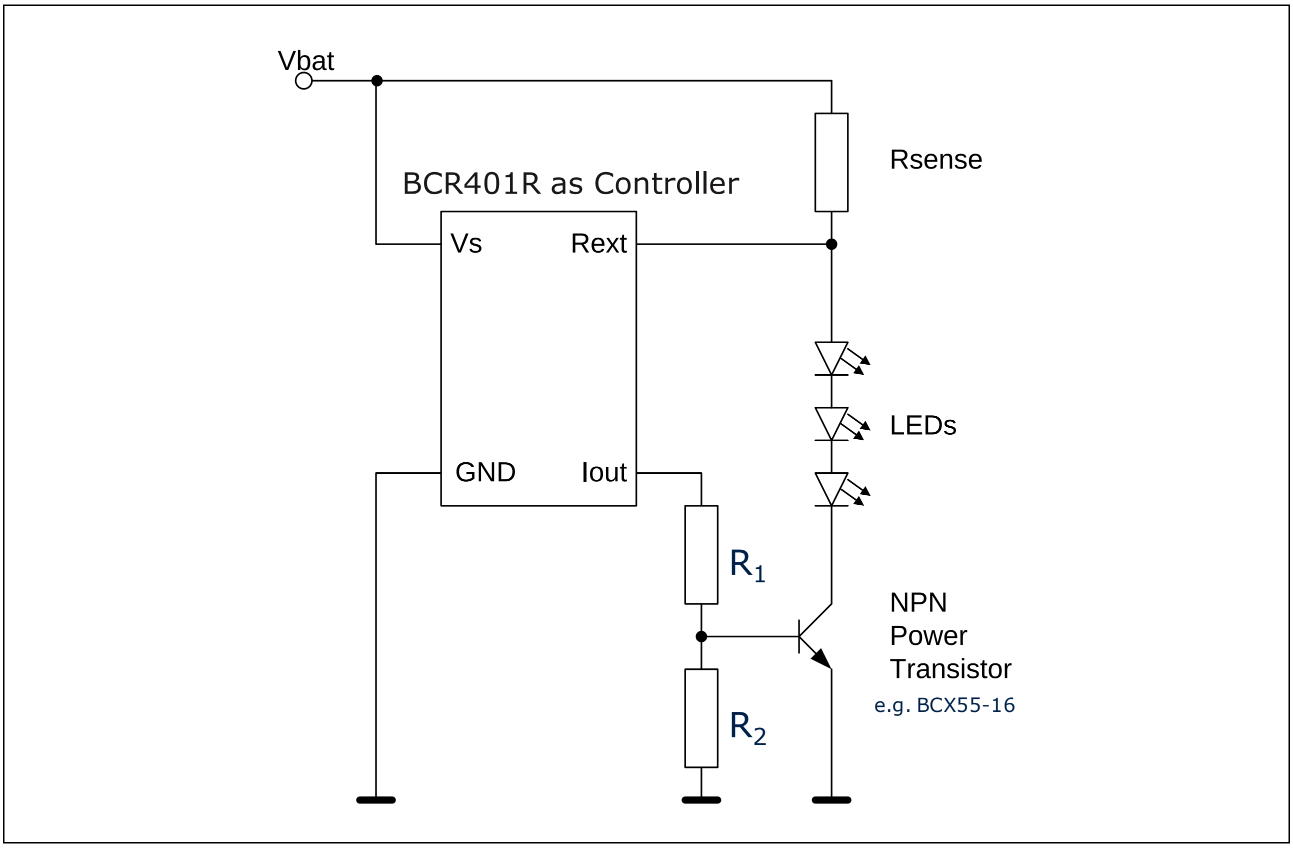


**Figure 6 Schematic**

The resistors $R_{sense}$, $R_1$ and $R_2$ can be calculated according to the following equations. All parameters marked with an asterisk * are related to the transistor and can be found in the data sheet of the selected transistor (e.g BCX55-16).

(5) $$I_{LED} = \frac{V_{drop}}{\frac{R_{\text{int}} \cdot R_{sense}}{R_{\text{int}} + R_{sense}}}$$

The transistor base current is defined by:

(6) $$I_B = \frac{I_{LED}}{B^*} \quad B\text{...}DC\ current\ gain\ \ of\ \ transistor$$

The resistor $R_2$ is calculated according to:

(7) $$R_2 = \frac{V_{BE(on)}{}^*}{I_{R2}} \qquad I_{R2} = 2\ldots10 \cdot I_B$$

The resistor $R_1$ is calculated according to:

(8) $$R_1 = \frac{V_{BAT(\min)} - V_{S(\min)} - V_{BE(on)}{}^*}{I_B + I_{R2}}$$

## 3.2 TLD1211SJ – LITIX™ Linear LED driver

The TDL1211SJ is a linear current source providing currents up to 85 mA and has an integrated high temperature current reduction feature to protect the connected LEDs against high temperatures. Furthermore, it supports the current control function of an external NPN transistor.

**Key Features:**

- Maximum output current 85 mA
- Temperature-dependent current reduction
- External transistor option LED currents up to 2.5 A
- Improved precision of output current: ± 10% in whole operating range ($V_{supply}$; $T_j$)
- Overvoltage protection
- Enable input for PWM operation
- DSO-8 package
- Automotive qualified

### 3.2.1 Integrated output stage usage

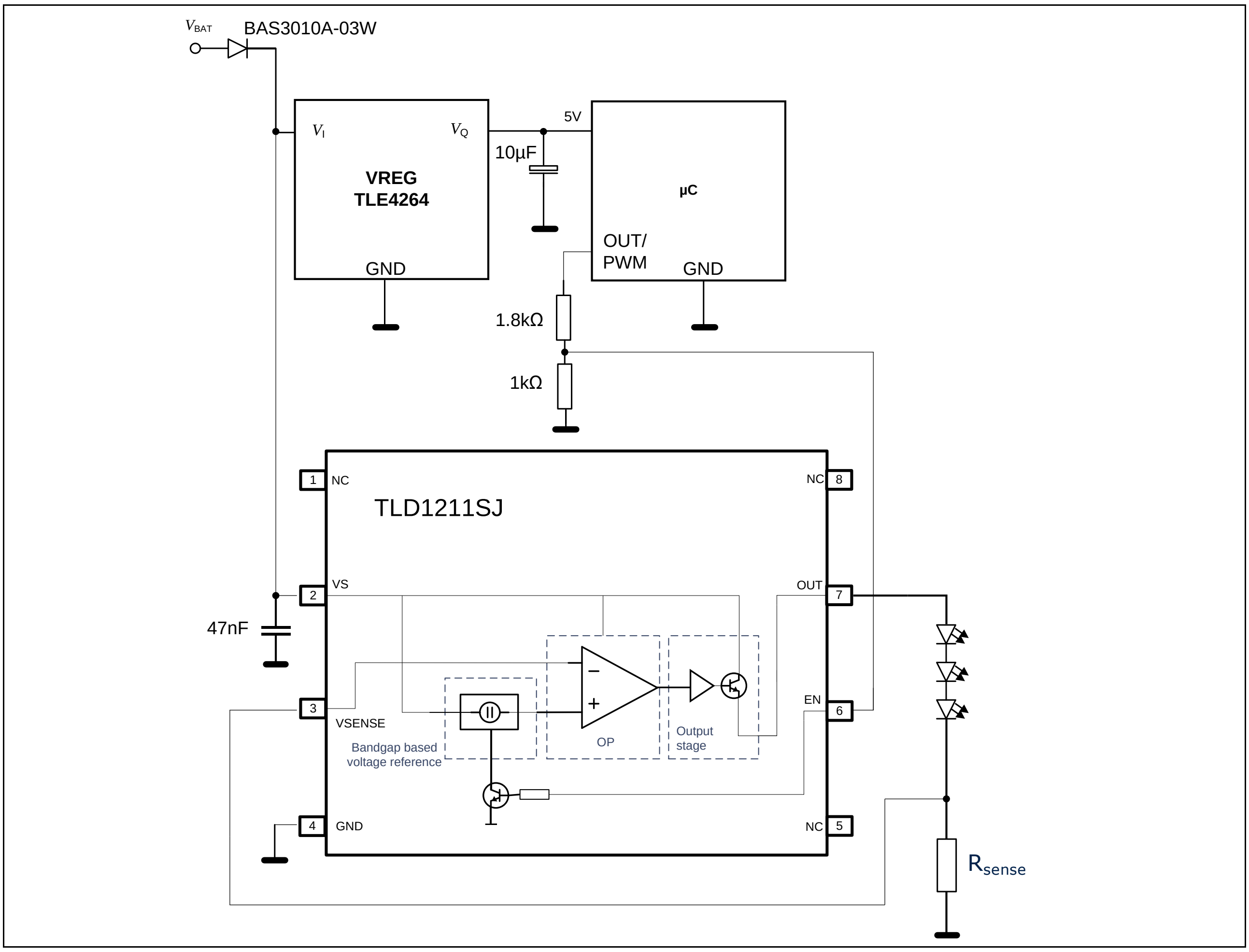


**Figure 7 Schematic**

The LED current can be adjusted by the sense resistor $R_{sense}$:

(9) $$I_{OUT} = \frac{V_{sense}^{*}}{R_{sense}}$$

with $V_{sense}$ according to datasheet parameter 4.3.9, typ. 150 mV.

### 3.2.2 External output stage usage

The TLD1211SJ can be used also as control IC for an external NPN-transistor as output stage for high LED currents according to the following schematic. The LITIX™ Linear LED driver drives only a very small current, which is the base current for the external NPN transistor.

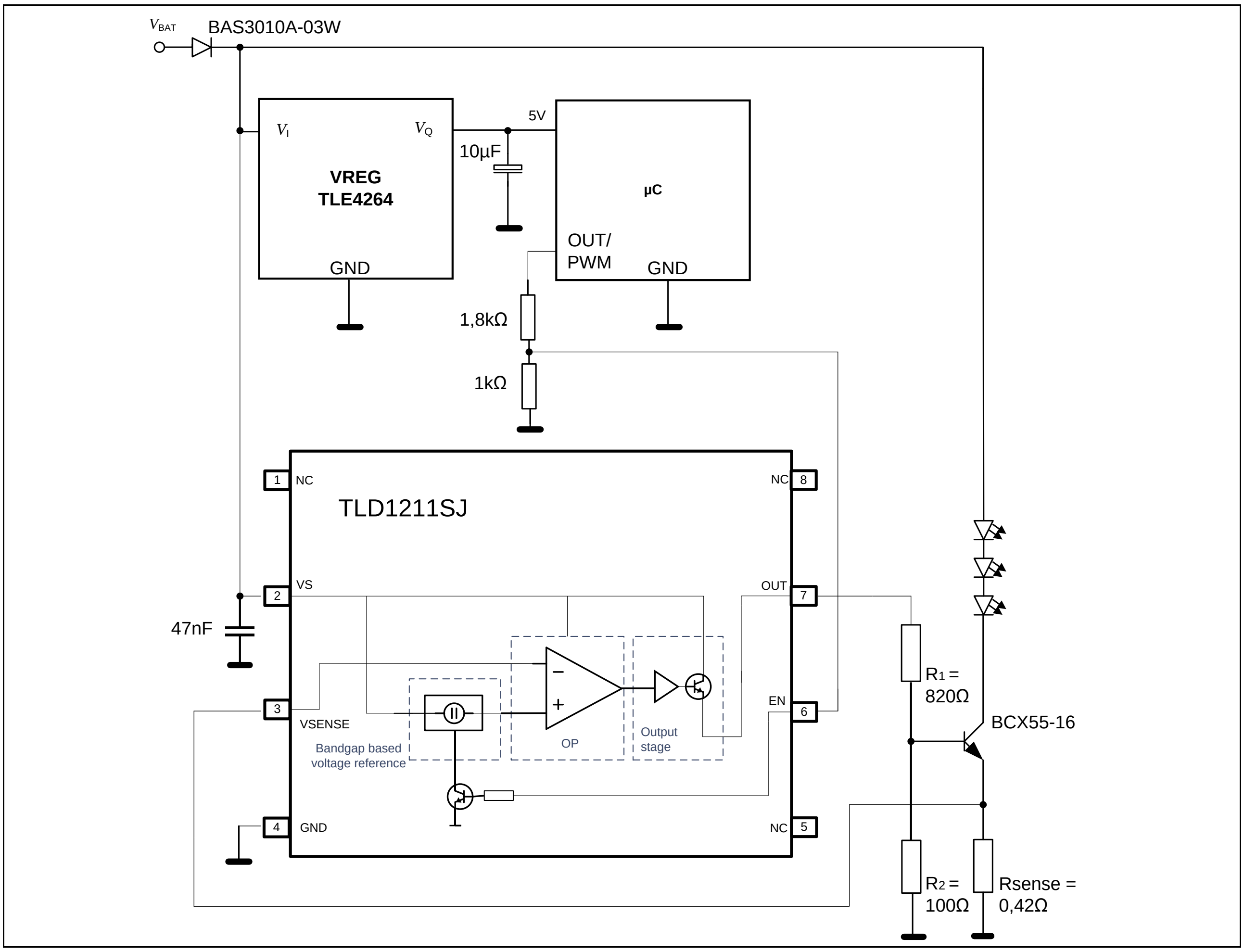


**Figure 8 Schematic**

The resistors $R_{sense}$, $R_1$ and $R_2$ can be calculated according to the following equations. All parameters marked with an asterisk * are related to the transistor and can be found in the data sheet of the selected transistor (e.g BCX55-16).

(10) $$I_B = \frac{I_{LED}}{B^{*}} \quad B\text{...DC current gain of transistor}$$

(11) $$R_{sense} = \frac{V_{sense}}{I_{sense}} \text{ with } I_{sense} = I_{Load} + I_B$$

The resistor $R_2$ is calculated according to:

(12) $I_{R2} = n \cdot I_B \ with \ n = 2...10$

(13) $R_2 = \frac{V_{BE}^{*} + V_{sense}}{I_{R2}} \ with \ I_{sense} = I_{Load} + I_B$

The resistor $R_1$ is calculated according to:

(14) $R_1 = \frac{V_{OUT} - V_{BE}^{*} - V_{sense}}{I_B + I_{R2}} \ with \ V_{OUT} = V_S - V_{drop}^{**}$

** $V_{drop}$ is the datasheet parameter 4.3.11 ($V_s$-$V_{out}$), max. 1.3 V.

## 3.3 TLE4241GM – LITIX™ Linear dual mode LED driver

The TLE4241GM is a dual mode linear current source with adjustable output current up to 70 mA. By applying a low or high signal at the SET-pin the output current can be changed by a ratio of typ. 7.

**Key features:**

- Adjustable constant output current up to 70 mA
- Low dropout V´voltage
- Dual mode for tail and stop light (low/high current SET)
- PWM input (e. g. for individual dimming) up to 1 kHz
- Open load diagnosis output
- Input voltage range up to 45 V
- Reverse polarity protected
- Short circuit protection to GND and VBAT
- Small SMD Package: P-DSO-8
- Operating range: -40…150 °C
- Overtemperature protection
- Automotive qualified

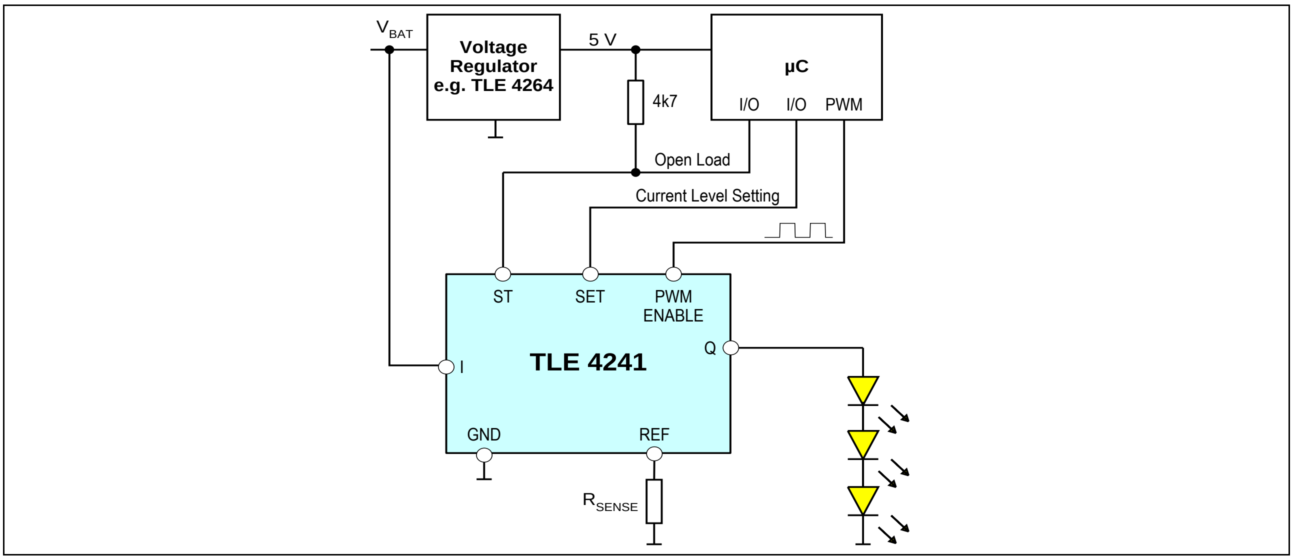


**Figure 9 Schematic**

When the SET-pin is at low potential the output current is the low level. As soon as the SET-pin is switched to high potential (up to $V_{BAT}$) the high output current is active. The output current can be adjusted additionally by the sense resistor $R_{SENSE}$.

If the SET-pin is connected to high potential (e.g. 5 V) the high output current can be calculated:

(15) $$I_{Q,typ,SET=H} = \frac{V_{ref}^{\ *}}{R_{ref}} \cdot 487 + 0.1$$

If the SET-pin is connected to low potential (0 V):

(16) $$I_{Q,typ,SET=L} = \frac{\frac{V_{ref}^{\ *}}{R_{ref}} \cdot 487 + 0.1}{I_{QH} / I_{QL}^{\ **}}$$

* According to data sheet diagram "Reference voltage versus junction temperature", typ. 1.2 V

** $I_{QH}/I_{QL}$ is the data sheet parameter "current ratio", typ. 7

## 3.4 TLE4242G – LITIX™ Linear 1 Watt LED Driver

The TLE4242G is a linear current source for driving high brightness LEDs up to 1 W. It provides a PWM input and a diagnosis output.

**Key Features:**

- Adjustable output current up to 500 mA
- Low dropout voltage
- PWM input (dimming, switching between brake and tail light, …)
- Diagnosis output
- Overtemperature protection
- Short circuit protection to GND and VBAT
- Reverse polarity protected
- Input voltage range up to 45 V
- Available package TO-263-7
- Automotive qualified

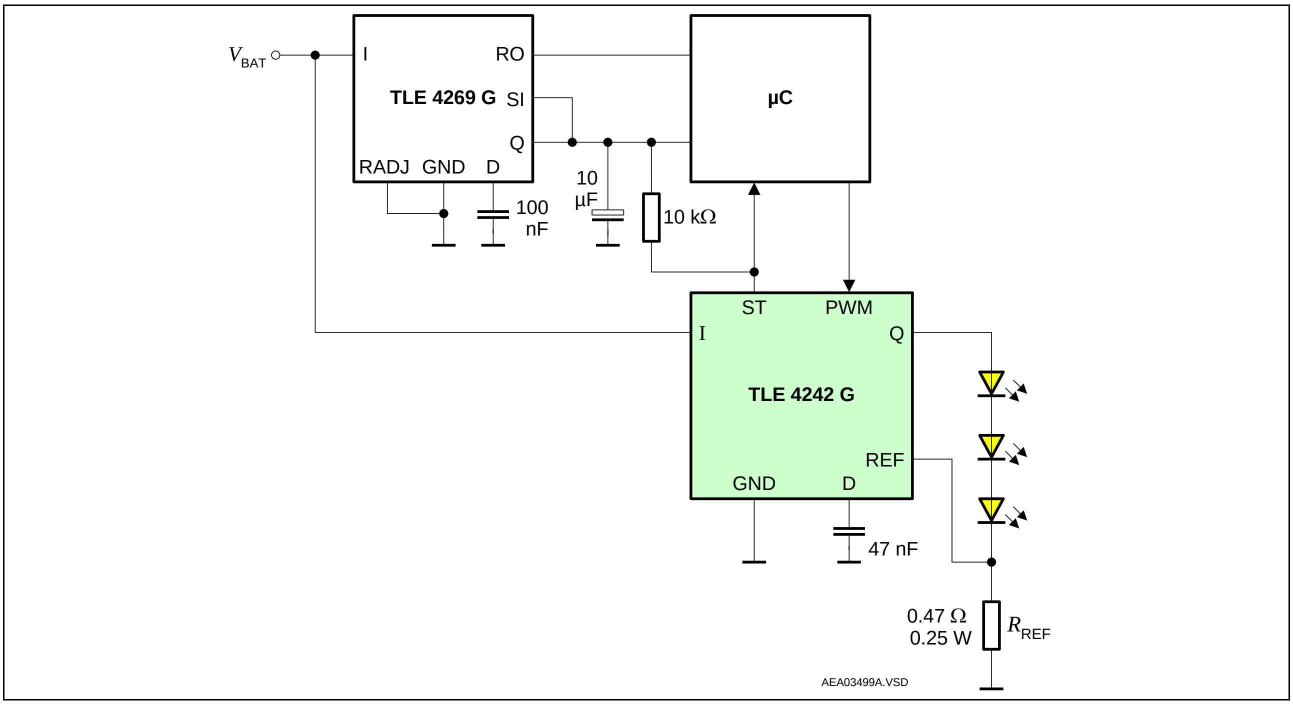


**Figure 10 Schematic**

The output current can be adjusted by the reference resistor $R_{REF}$.

If the SET-pin is connected to high potential (e.g. 5 V) the high output current can be calculated:

(17) $$I_{Q,typ} = \frac{V_{ref}^{*}}{R_{ref}}$$

* According to data sheet diagram "Reference voltage versus junction temperature", typ. 177 mV

The diagnosis response time can be adjusted by the capacitor connected to the diagnosis-pin D:

(18) $$t_{STHL,typ} = \frac{C_D}{47nF} \cdot 10ms \quad t_{STLH,typ} = \frac{C_D}{47nF} \cdot 10\mu s$$

# 4 Conclusion

LITIX™ Linear and BCR LED drivers are able to drive small signal LEDs up to high brightness LEDs. The dimensioning of the required external components is supported by this application note.

# 5 Additional information

- For further technical details, please contact www.infineon.com/litix-linear
- Existing App. Notes
    - AN101, Using Infineon's BCR400 Family of Constant-Current, Linear-Mode LED Drivers for Lighting Applications from 10 mA - 700 mA
    - AN97, Using BCR402R/BCR402U at High Supply Voltages
- For further information you may contact www.infineon.com/automotive-leddrivers

# Revision history

| Document version | Date of release | Description of changes |
|---|---|---|
| Rev. 1.20 | 2019-03-09 | - Update template<br>- Family name updated<br>- Remove TLE4240-2M and TLD4240-3M, page 9, 14 |
| Rev. 1.10 | 2011-06-29 | Page 9: BCR42xP removed |
| Rev. 1.00 | 2011 | Initial Application note |

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