Application Note, Rev. 1.2, November 2007

Application Note No. 101

Using Infineon‘s BCR400 Family of Constant-Current, Linear-Mode LED Drivers for Lighting Applications from 10 mA - 700 mA

Small Signal Discretes

Never stop thinking

Edition 2007-11-07

Published by
Infineon Technologies AG
81726 München, Germany

Application Note No. 101

Revision History: 2007-11-07, Rev. 1.2

Previous Version: 2005-05-04, Rev. 1.1	
Page	**Subjects (major changes since last revision)**
All	Small changes in figure descriptions

Table of Contents

1 Using Infineon‘s BCR400 Family of Constant-Current, Linear-Mode LED Drivers for Lighting Applications from 10 mA - 700 mA

1.1 What’s New?

Infineon Technologies' linear-mode BCR400 series LED driver family has been described previously in applications note AN066 to address applications up to 65 mA. This applications note primarily emphasizes 'high current' applications from 65 mA up to ~ 700 mA. For the higher currents, a standard LED driver IC is used in conjunction with an external "boost" transistor to increase current range beyond 65 mA., e.g. for driving ½ W and 1 W LEDs. The reader who is familiar with the basic features and requirements of designing with these drivers can skip directly to section **“Boost” Concept, for LED Currents > 65 mA, or “How do I drive ½ W and 1 W LEDs?** of this applications note.

1.2 Features

- Flexible, easy-to-use devices with adjustable constant-current output from 10 - 65 mA; current may be extended from 65 to 700 mA with addition of suitable external boost transistor (BC817SU, BCX55-16 or BCX68-25) for use with ½ W, 1 W & 2 W LEDs.
- Closed-loop operation and high device output impedance maintains tight control over LED current regardless of temperature or power supply voltage variation.
- Low voltage drop across driver (1.2 - 1.5 V) maximizes system energy efficiency. Better current control and less wasted power as compared to using resistors for LED biasing.
- ON / OFF feature, with Pulse Width Modulation (PWM) capability for dimming control.
- Negative Temperature Coefficient (NTC) protects LED arrays from Thermal Runaway.
- Choice of 18 V, 27 V, and 40 V rated parts.
- Makes possible modular, low-cost, 'building-block' approach to LED drive circuit designs from 10 to 700 mA; sharing and re-use of common components simplifies logistics and reduces overall costs.
- Three package choices enable optimization of cost, size and thermal resistance / power dissipation. SOT143R (330 mW, $R_{TH\ J\text{-}S}$ < 200 °C/W), SOT343 (500 mW, $R_{TH\ J\text{-}S}$ < 110 °C/W) and SC74 (500 mW, $R_{TH\ J\text{-}S}$ < 50 °C/W).

SOT143R (BCR401R, BCR402R)	SOT343 (BCR401W, BCR402W)	SC74 (BCR401U, BCR402U, BCR405U)
SOT143-R (SC-61A) 	SOT343 (SC-82) 	SC74 (SC-74) 
2.9 x 1.3 x 1.1 mm P_{TOT} = 330 mW max. 18 Volt breakdown Thermal Resistance* < 200 °C/W	2.0 x 1.25 x 0.9 mm P_{TOT} = 500mW max. 18 Volt breakdown Thermal Resistance*< 110 °C/W	2.9 x 1.6 x 1.1 mm 40 volt breakdown (27V for BCR450U) P_{TOT} = 500mW max. Thermal Resistance* < 50 °C/W

AN101_tab_SOTs(1).vsd

Figure 1 Table of SOT143R, SOT343 and SC74

* Thermal resistance is device **J**unction to package **S**oldering point ($R_{TH\ J\text{-}S}$).

1.3 Overview and Background

The Solid State Lighting (SSL) market has experienced significant growth in the past decade, due to rapid advancements in **L**ight **E**mitting **D**iode (**LED**) technology. Higher light output levels, improved packaging, improvements in efficiency / efficacy and decreasing cost per lumen of light output, as well as long lifetimes and physical robustness, have helped drive LED-based light fixtures into niches formerly occupied by more traditional light sources. As of 2007, LEDs are the most energy-efficient sources of colored light available for nearly the entire visible light spectrum. The long lifetime, physical robustness and rapidly improving efficiency / efficacy of LED-based light sources makes a compelling argument for their use in a wider range of applications. On a world-wide basis, over 20% of total electrical energy use is in lighting [1], and thus the LED's potential for energy savings is tremendous.

Three key drivers for wider adoption of LEDs as light sources have been 1) the widespread emergence of so-called "high brightness LEDs", 2) the commercialization of the blue LED in 1993, and 3) the declining prices of LEDs. Commercially-viable blue LEDs made it possible to create cost-effective "White" LEDs, which are largely based on LED chips that emit light in the blue wavelength region (450 to 470 nanometers) [2]. The growing availability of cost-effective energy-efficient White LEDs has enabled lighting systems designers for the first time to utilize LED-based light sources for so-called "general lighting" applications. White LEDs continue to rapidly improve in terms of light output, energy efficiency, and color-rendering index (CRI). As of this writing (early 2007), vendors of White LEDs are announcing new products with efficacy numbers in excess of 100 lumen / W, which rival traditional fluorescent light sources in terms of energy-efficiency.

Fluorescent light bulbs in widespread use today are energy-efficient, and are often the standard by which other light sources are judged. However, fluorescent lights contain mercury (Hg), which is a toxic material, often require expensive starter or "ballast" circuits, and have lifetimes in the range of 2000 to 10,000 h. The premature failure of the starter circuit in Compact Fluorescent lights (CFL) often reduces the actual lifetime of CFLs to well below the manufacturer's claim. By contrast, LED's contain no mercury and thus do not have the same environmental and disposal problems of fluorescent lighting; furthermore, LEDs do not need complex starter circuits and offer lifetimes on the order of 80,000 to 100,000 h [3]. Due to the robustness, long lifetimes, improving energy efficiency and absence of mercury in LEDs, white LEDs are poised to begin displacing fluorescent lighting in the near future [4], [5]. While the initial cost of LEDs is still generally higher than for comparable incandescent or fluorescent light sources, if one takes into account cost factors including energy savings, robustness, and product lifetimes, there are already numerous applications where LEDs offer a significant advantage in Total Cost of Ownership (TCO). As LEDs improve and as up-front costs for LEDs continue to decrease, the number of applications where LEDs offer economic advantages will increase further.

In summary, LEDs have numerous advantages over other light sources. However, LEDs have unique characteristics that set them apart. In order for the lighting system designer to successfully bring an economically-viable LED-based system to market, the designer must be aware of the LED's traits, taking them into account during the design process.

1.4 What makes LEDs different?

LEDs differ from other light sources in several ways:

- Exponential V - I characteristic:
  LED's - like any semiconductor diode - have an exponential voltage - current characteristic. This is generally true, regardless of the particular materials used in the fabrication of different LED types that emit different wavelengths or colors of light. Please refer to **Figure 2**. Small changes in voltage across the LED can result in large changes in current through it. This exponential characteristic can make it difficult to maintain a constant LED current over variations in power supply voltage. As light output is proportional to LED current, this can present a problem.
- Wide statistical distribution of Forward Voltage (V_F):
  LED's of a given type, and even parts from the same semiconductor wafer lot, typically show a wide statistical distribution in their forward voltage (V_F) characteristic, which is the voltage across the diode when the LED is

forward-biased at a specified operating current. For example, one manufacturer's 1 W, white LED specifies the forward voltage at 350 mA as follows:
Minimum 2.7 V, typical 3.2 V, maximum 3.8 V. This represents a total variation of about 34 %, referenced to the typical 3.2 V value.

- Positive Temperature Coefficient and Thermal Runaway:
  LEDs generally have a positive temperature coefficient (PTC) with respect to current, e.g. the LED forward voltage V_F decreases as the LED gets warmer, causing the LED to draw more current as temperature goes up. If the current is not controlled, the LED can gets hotter, drawing more current, which heats it up more, causing increased current, and so on….potentially leading to a thermal runaway condition and destruction of the LED. To prevent thermal runaway, the current through the LED must be tightly controlled over variations in power supply voltage, temperature, and over device-to-device variations caused by manufacturing variation.

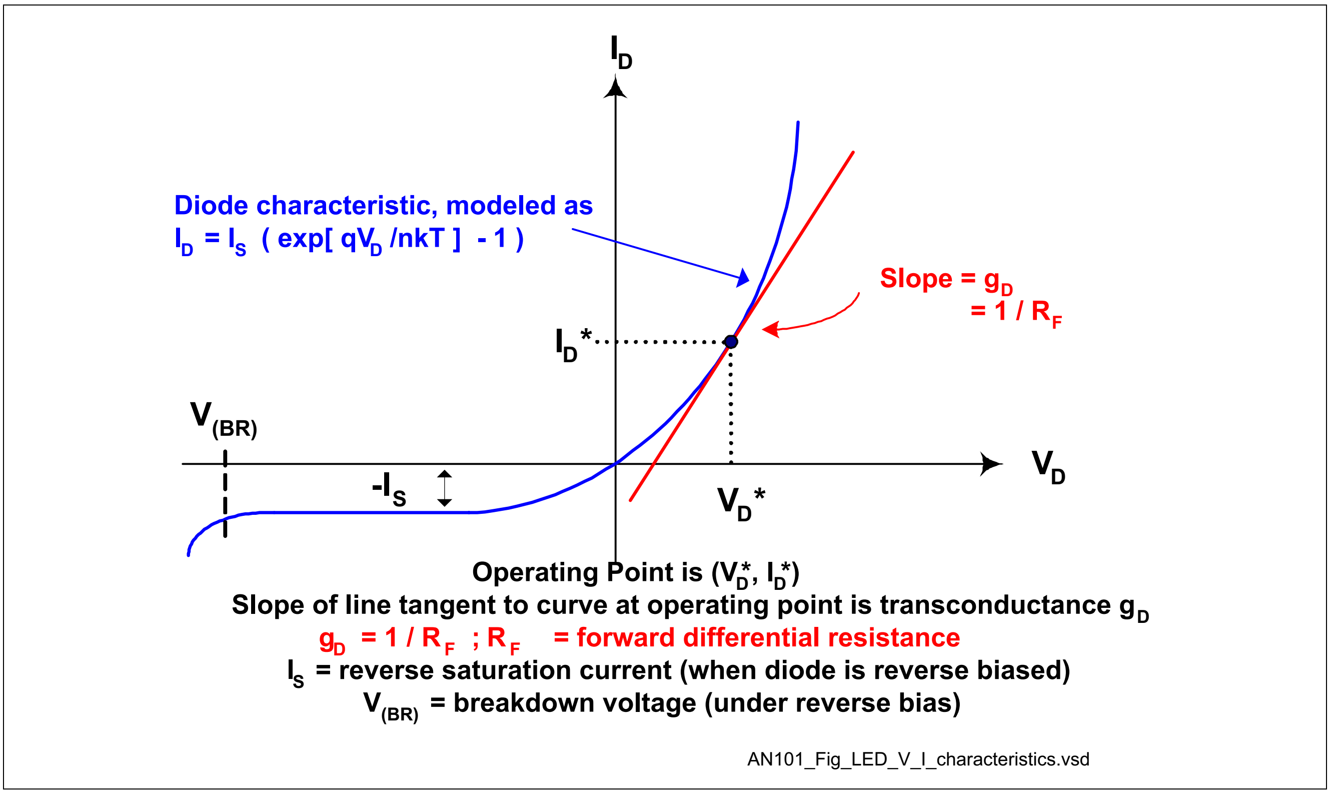


Figure 2 LEDs, like other diodes, have an exponential voltage - current characteristic. Small changes in voltage across the LED can result in large changes in LED current

1.5 Negative consequences of uncontrolled LED current variation

In a LED-based lighting design, if the designer does not take the LED's unique characteristics into account, negative consequences may result, including:

- Inhomogeneous light emission in parallel LED branches of a circuit, e.g. different light outputs between parallel "stacks" of LEDs, due to differing currents in each branch caused by varying LED forward voltage (V_F). Refer to **Figure 3** for a generic example of a circuit consisting of several parallel branches of LEDs.
- Thermal runaway and possible destruction of LED's. LED lifetime is strongly dependent on LED junction temperature. Overheating an LED - even for a short period - can markedly decrease the useful lifetime of the LED. This is a more serious problem than it seems at first inspection. A principal advantage of LED's versus other light sources is the relatively long life LED's, typically given in the tens of thousands, or even hundreds of thousands of hours. The long lifetimes of LEDs is often what justifies, in economic terms, the replacement of fluorescent or incandescent light sources with LEDs in commercial applications. If the LEDs are subjected

to excessive heat due to poor circuit design or from thermal runaway, the lifetime of the LEDs are drastically reduced and a fundamental reason for using LEDs in the first place is undermined.

1.6 Sorting of LEDs by Forward Voltage (VF) to reduce variations in operating current

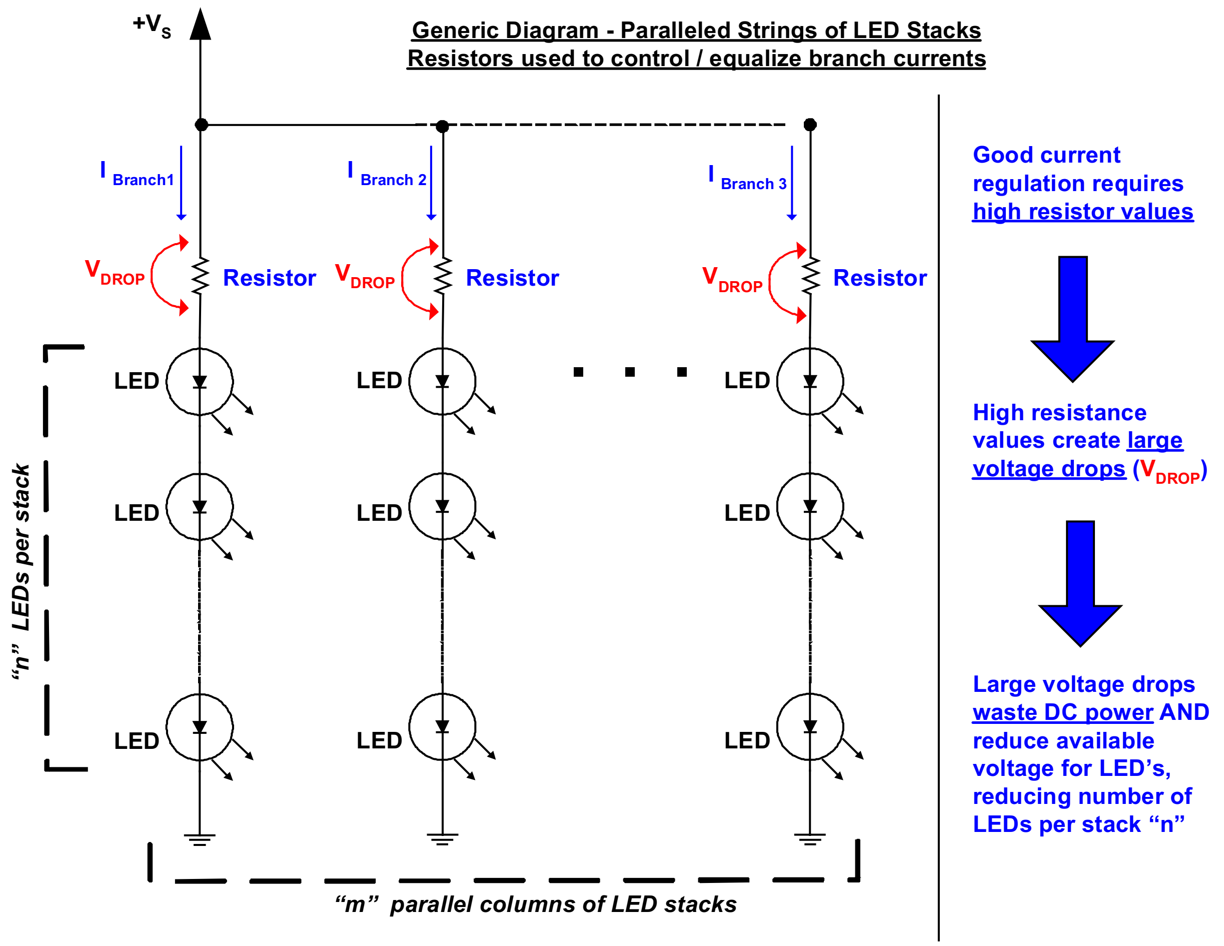
Due to the typically wide statistical spread in LED parameters caused by manufacturing variations, the LED manufacturer's customer base has requested that LED manufacturers sort LEDs of a given type or part number into different sub-groups or "bins". Sorting the LEDs into different groups reduces the variations within a given group to ranges suitable for manufacturing consistency and quality of the end product using the LEDs. Some of the criteria LED manufacturers sort for include:

- LED forward voltage (V_F)
- LED dominant wavelength (color)
- LED light output (e.g. brightness level for a given diode current)

For the purposes of maintaining consistent current in different branches of LED arrays, the sorting by forward voltage V_F is the one that matters. Using LED's all from one forward voltage 'bin' or sub-group can in fact help reduce current variations in LED arrays. However, even in an array with LEDs perfectly matched for forward voltage, thermal runaway can still be a problem. Furthermore, while often necessary, sorting or 'binning' LEDs into different groups requires additional testing, increased logistics overhead and drives up overall costs. In the interests of cost-reduction, reducing or eliminating testing, sorting and binning of LEDs wherever possible is desired.

1.7 The “Old” Way - Why using resistors to control / stabilize LED Current may be a bad idea

Resistors can be used to achieve some level of current stabilization and are frequently employed for this purpose. **Figure 3** depicts parallel columns or "stacks" of LEDs, where a series resistor is used in each stack to provide some degree of current control, stabilization, and consistency in current from stack-to-stack, given the potential variations in diode forward voltages V_F from one stack to the next. One way to view the situation is as follows: a voltage source (e.g. a standard power supply with low output impedance) in series with a sufficiently high resistance approximates an ideal current source, e.g. the resistor helps to give the voltage source a higher output impedance than it otherwise would have. It is precisely this high output impedance of the voltage source & series resistor combination that makes LED current less sensitive to variations in LED forward voltage caused by LED manufacturing tolerances or temperature effects. The higher the value of series resistor, the "stiffer" or stronger the control will be over LED current. Simply put, a power supply with high output impedance (e.g. a current source) is very desirable for driving light emitting diodes. For the case of a common voltage source (power supply with low output impedance) used with a series resistor, higher resistor values give higher net output impedance and thus better current stabilization.



Net result of resistor biasing:

1) reduction / degradation of system energy efficiency, due to

   a) power wasted in resistor
   b) fewer LEDs can be used in one "stack" due to large voltage drop in resistor

2) LED current is still sensitive to changes in power supply voltage $+V_S$

AN101_Fig_stabilizing_LEDs.vsd

Figure 3 Resistors used to stabilize / equalize LED operating current for multi-branch LED array, with "n" LEDs per stack and "m" parallel stacks or columns of LEDs

Unfortunately, there are serious disadvantages in using resistors for current regulation. As stated previously, the higher the value of the resistor, the better the current regulation will be. However, for a given current level, higher resistor values translate into larger voltage drops. The price to be paid for good LED current regulation when using resistors is a high voltage drop. The high voltage drop across the resistor not only burns or wastes power, reducing overall system efficiency, but it also leaves less voltage available for the LEDs, meaning one will be able to use fewer and fewer LED's in one 'stack' as the resistance value increases. This further degrades system energy efficiency. Resistor biasing of LED's, when practical resistor values are used (low enough values so as to permit acceptable voltage drops) is also still fairly susceptible to power supply voltage variations; LED current and thus LED brightness will fluctuate with power supply voltage. We want to have a current source with high output impedance to drive LED circuits, but we do not want the high voltage drop and consequent reduction in overall system energy efficiency associated with using resistors. The disadvantages and negative consequences of using resistors for LED current stabilization are summarized in **Figure 3**, and **Table 1** gives a comparison of resistor biasing versus using a BCR40xx LED driver IC in terms of output impedance and voltage drop for the case of 20 mA output current. As one can see, getting a sufficiently high output impedance while minimizing voltage drop and wasted power is rather difficult, if not impossible, when using standard low output impedance power supplies and resistors for LED biasing.

Table 1 Comparison of Output Impedance (Z_{OUT}) and Voltage Drop (V_{DROP}) for Resistor Bias and BCR40xx LED Driver biasing, 20 mA LED current.

	Standard power supply (voltage source) + 100 Ω series resistor	**Infineon BCR401/402R, BCR401/402/405U, BCR401/402W LED Driver biasing**	**Comments**
Voltage Drop V_{DROP}	2.0 V	~ 1.3 V	Output impedance of LED driver is ~ 25x higher than resistor biasing =>
Output Impedance Z_{OUT}	~ 100 Ω	~ 2.5 kΩ	=> better current stability over temperature, voltage, and over LED forward voltage variation.

2 Infineon's Cost-Effective Constant-Current LED Driver IC Family

Infineon Technologies low-cost linear-mode LED driver family offers several advantages over using resistors to bias and stabilize LED arrays. These driver ICs come in three different high-volume, RoHS compliant ("Green") industry-standard surface-mount (SMT) packages: SOT143R (SC-61A), SOT343 (SC-82) and SC74 (SC-74). **Table 2** gives an overview of these constant-current LED drivers, **Figure 4** shows output current ranges for the standard types and **Figure 5** gives a generic circuit diagram for 10 to 65 mA applications. **Figure 6** provides a flow-chart to help the user in deciding which driver type to select. The advantages of using these LED driver ICs as compared to resistors for LED current stabilization are as follows:

- Very high output impedance => being true 'current sources', these ICs provide much stronger stabilization / regulation of LED currents as compared to resistor biasing, regardless of variations in LED forward voltages (V_F) or power supply voltage (V_S).
- Low voltage drop => with voltage drops in the range of 1.2 to 1.5 V, less power is wasted, and more voltage is available to the LED stack(s), possibly permitting the designer to use more LEDs in a stack. Overall energy efficiency is improved.
- Negative Temperature Coefficient (NTC) => these LED drivers have a negative temperature coefficient (NTC) designed-in, in order to counteract the positive temperature coefficient of light-emitting diodes. As the LED driver IC gets warmer, it gradually reduces output current, helping to prevent thermal runaway and destruction of expensive LED arrays. Furthermore, the NTC can help prevent LED lighting fixtures from overheating and thus extend the usable lifetimes of the LEDs, potentially improving the Total Cost of Ownership (TCO) of the lighting design.
- Adjustable current: these flexible, easy-to-use products have a nominal current set point, however the current may easily be adjusted upwards from the nominal value to the maximum rated current specified in the datasheet by using an single external resistor. For example, the BCR401R has a nominal current output of 10 mA when used as a stand-alone device with no external resistor; but the current can be increased to any value between 10 and 60 mA simply by using an external resistor. This flexibility allows the end-user to simplify logistics, using one common part for different needs.
- Output current range may be extended for use with High Power LEDs: as will be described in **Design procedure for LED Driver circuit, for LED currents up to 65 mA** of this applications note, any of the standard LED driver IC's may be used for LED currents up to 60 or 65 mA, depending on the driver type. For increasing currents beyond this level, an external "booster" transistor may be employed. This boost concept enables the lighting designer to use a modular approach with standardized, off-the-shelf components to address a wide range of lighting requirements, from low-power LEDs drawing 10 mA, up to systems using ½ W and 1 W LED's, which typically consume 150 and 350 mA, respectively.
- ON / Off control pin, with Pulse Width Modulation (PWM) capability for dimming: these LED driver ICs can easily be switched on and off with a single external transistor, for ON / OFF or PWM applications. Please refer to **Figure 8**, where Q2 (BCR148W) is used as a simple switch for ON / OFF or PWM control.

Table 2 Overview of Stand-Alone LED drivers, for LED currents up to 65 mA.

LED Driver Part #	Description	I_{out} (adjustable) [mA] (note 1)	V_S [V]	P_{TOT} [mW]	$R_{TH\ J\text{-}S}$ [C/W] (note 2)	Relative Cost (note 3)
BCR401R (SOT143R[1)])	Adjustable low-current driver	10 to 60	18	330, T_S<84°C	200	Lowest
BCR402R (SOT143R[1)])	Adjustable universal driver	20 to 60	18	330, T_S<84°C	200	Lowest
BCR401W (SOT343[2)])	Adjustable low-current driver	10 to 60	18	500, T_S<95°C	110	Lower
BCR402W (SOT343[2)])	Adjustable universal driver	20 to 60	18	500, T_S<95°C	110	Lower
BCR401U (SC74[2)])	Adjustable low-current driver	10 to 65	40	500, T_S < 125°C	50	Low
BCR402U (SC74[2)])	Adjustable med.-current driver	20 to 65	40	500, T_S < 125°C	50	Low
BCR405U (SC74[2)])	Adjustable high-current driver	50 to 65	40	500, T_S < 125°C	50	Low
BCR450 (SC74[2)])	High Precision Driver / Controller with Thermal Shutdown	50 max	27	TBD	TBD	Moderate

1) Leadframe material: NiFe
2) Leadframe material: Cu

Notes

1. *All LED drivers except BCR450U may have output current adjusted upwards from minimum value by addition of a single external resistor. If used at minimum current, no external resistor is required. Example: BCR401R output current is 10 mA nominal with no external resistor; current may be adjusted upwards to any desired value up to 60 mA maximum limit with addition of 1 external resistor, e.g. BCR401U can cover the entire 10 to 60 mA range.*
2. *Thermal resistance of device from semiconductor chip Junction to device package Soldering point. Soldering point is package lead or pin which carries output current. For example, output pin of BCR402W is pin #2. Devices in packages with Copper (Cu) lead-frames ("W" and "U" types) offer superior thermal performance, but are slightly higher in cost.*
3. *Cost is given in relative terms, e.g. comparing cost of different categories of LED driver types.*
4. *MP = released to Mass Production; ES = Engineering Samples.*

A generic block diagram and application circuit of the BCR401 / 402 / 405 series LED drivers is given in **Figure 5**. When the LED driver is used at its nominal output current (e.g. 20 mA for BCR402U, 10 mA for BCR401R, 50 mA for BCR405U) no external current adjust resistor is needed; if the current needs to be increased upwards from the nominal value to any value up to the device's maximum rating, an external current adjust resistor is placed externally, in parallel to the BCR40xx's internal resistor. The net resistance value formed by the paralleling of the internal and external resistors determines the output current, with a lower net resistance giving higher current. The user must ensure that the device's maximum power dissipation rating (P_{TOT}) is not exceeded in each case. Lastly, an external switching transistor (e.g. BCR148W) may be added as shown in the diagram to enable ON / OFF or Pulse Width Modulation (PWM) control. The current consumed by the LED driver IC itself is very low - on the order of 400 µA - so the switching transistor need not dissipate much power. For specific details on pin configurations of the individual LED drivers, please refer to the LED Driver datasheets.

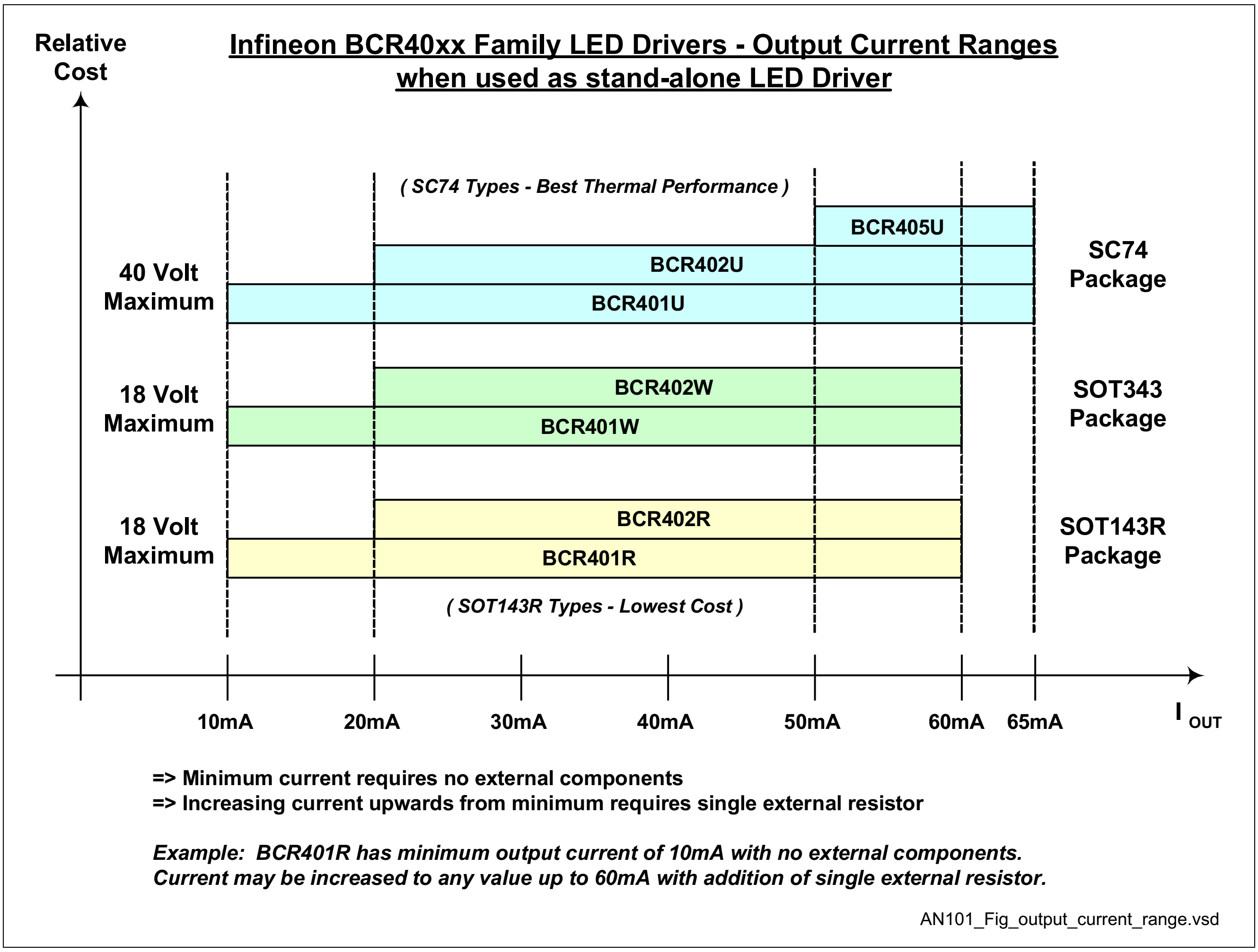
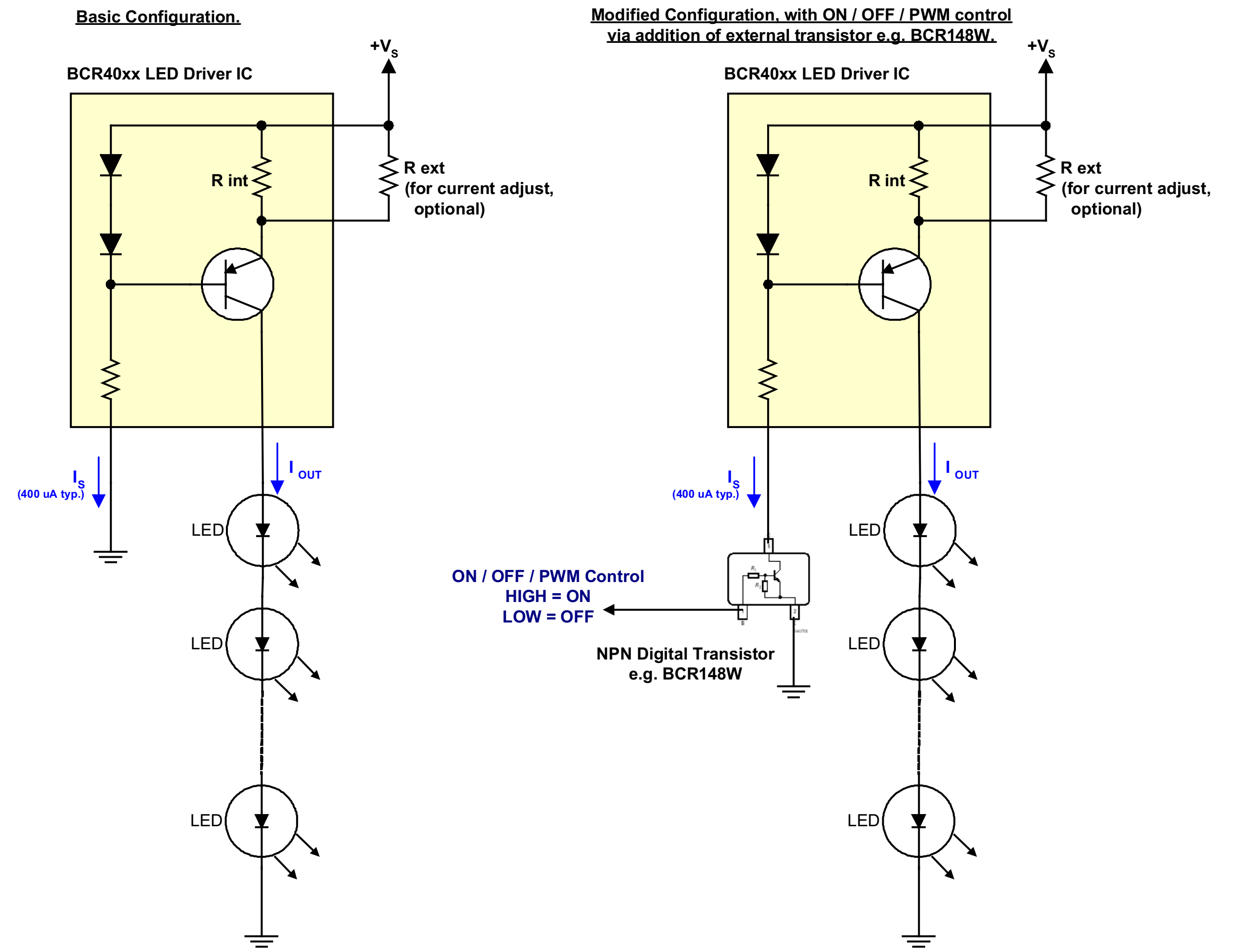


Figure 4 **Output current ranges for the standard LED Driver types. Bare device outputs nominal, minimum current with no external elements; current may be increased upwards from minimum value by addition of one external resistor. SOT143R packaged-devices are generally lowest in cost; SC74 packaged devices have best thermal performance**



Generic Block Diagram of BCR401R, 402R, 401U, 402U, 405U, 401W and 402W application circuit. Output current is determined by net resistance between +Vs pin and emitter of internal PNP transistor. If Rext is not used, device outputs its nominal, minimum current. If Rext is placed in parallel to internal resistor, net resistance between +Vs and emitter decreases, and output current increases. Output current may be increased to any value up to device maximum rating as specified in datasheet. User needs to ensure power dissipation (Ptot) also stays below device maximum rating. Switch transistor (e.g. BCR148W or others) may be added for ON / OFF / Pulse Width Modulation (PWM) control.

AN101_Fig_generic_block_diagramm.vsd

Figure 5 Generic Block Diagram & Application Circuit, Stand-Alone LED Driver (10 - 65 mA current range). Circuit on right has added an external switching transistor to enable ON / OFF and Pulse Width Modulation (PWM) for dimming function. Optional Reverse Polarity Protection (RPP) may be added by placing a Schottky diode between +V_S and the LED Driver IC

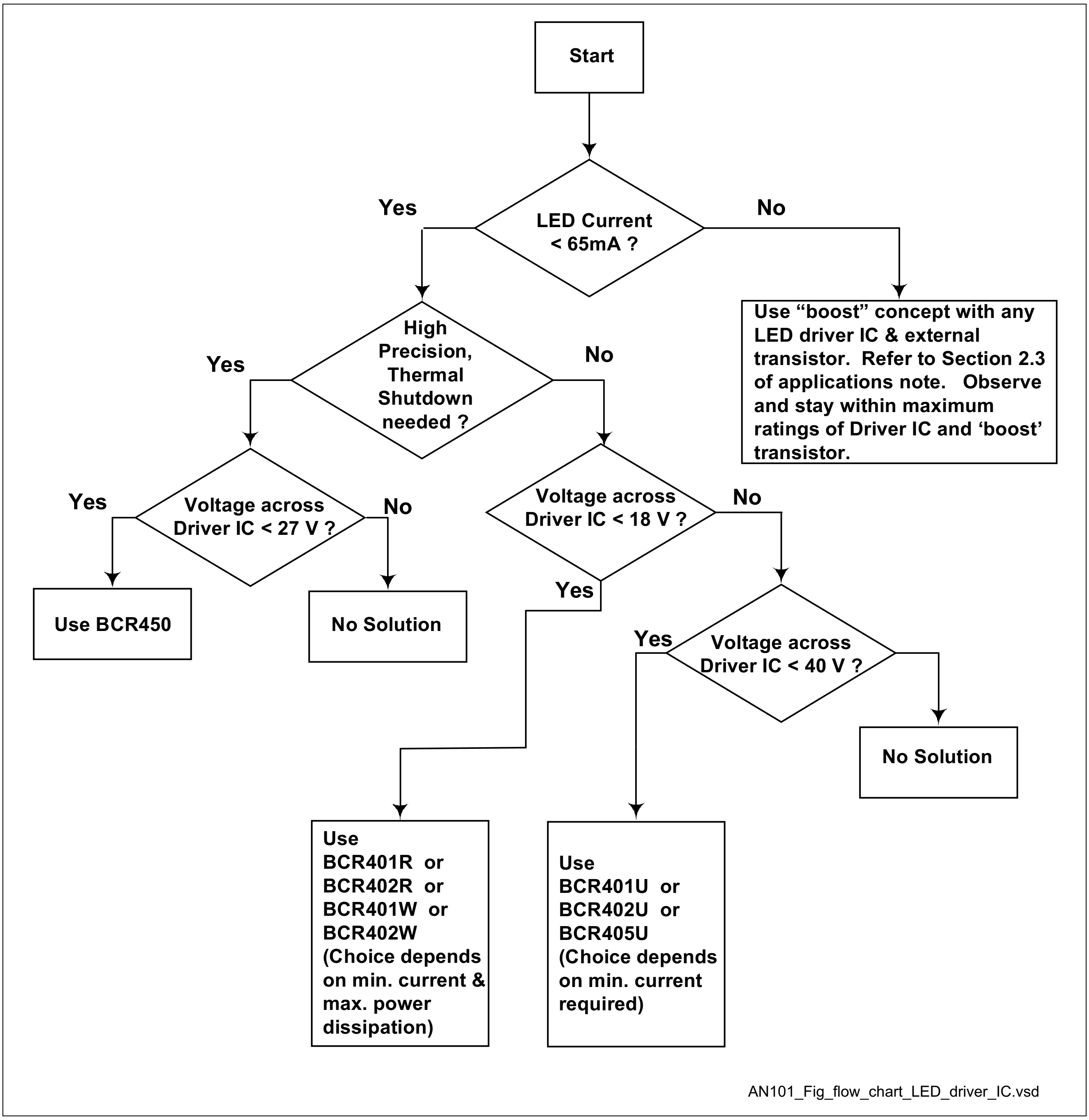


Figure 6 Flow Chart to aid in selection of the appropriate LED Driver IC

2.1 Design procedure for LED Driver circuit, for LED currents up to 65 mA

The design procedure for setting up an LED Driver circuit using one of the BCR40xx series ICs in a stand-alone configuration for currents up to 65 mA may be roughly outlined as follows:

- Select a device which has a minimum output current at or below your desired LED current. For example, if you need 10 mA to drive your LED(s), you are limited to the BCR401R, BCR401W or BCR401U. If you need 50 mA, any of the devices can provide 50 mA output current, but you will need an external resistor to increase current up to 50 mA for the BCR401x or BCR402x types. The BCR405U, however, has a nominal output current of 50 mA and thus needs no external resistor for 50 mA operation.

- From the devices above, then further down-select based on the maximum anticipated power dissipation in the LED driver IC. For example, if you anticipate driving 50 mA LEDs, the LED driver IC will be required to dissipate more heat than, say, for driving 10 mA LEDs. For driving 50 mA LEDs, a good starting point would be the BCR405U in SC74 package, as this device needs no external components for 50 mA operation (no external current adjust resistor needed) and the SC74 package with copper lead-frame material has the best thermal performance with the lowest thermal resistance. For lower currents (e.g. 10 - 20 mA range) or for PCB designs with very good heat-sinks where the thermal resistance of the driver IC is not critical, the user could reduce costs by selecting one of the SOT143R types. This step is an iterative process and involves trading off power dissipation, cost, and thermal resistances. A user who needs to drive numerous 20 mA LEDs placed into a very narrow, thin, densely populated low-cost FR4 material PC board (e.g. "strip light") with high thermal resistance (e.g. poor thermal performance) would be best to start out with the BCR402U in SC74 package, as the SC74 package has the best (lowest) thermal resistance and is more able to get rid of heat in a poor PC board environment. By contrast, a user with a metal-clad printed circuit board with excellent thermal performance should start with one of the SOT143R packaged devices in order to reduce costs.
- Do additional selection on the basis of breakdown voltage. The standard driver IC types, as shown in **Figure 4**, can be grouped into 18 V breakdown and 40 V breakdown types. A designer working on a Rear Combination Lamp (RCL) design for an automotive application where voltage-transient tests (e.g. 'load dump test') are performed would be best to select from the 40 V parts, BCR401U, BCR402U, BCR405U. But designers of systems with no such transient requirements have two choices:
  a) select a device with a breakdown voltage above the system power supply voltage or
  b) employ a "trick" described below to drop the supply voltage below the maximum rating of the driver IC.
  The key benefit of this "trick" is to enable the designer to reduce costs by using the lowest-cost, lowest-breakdown voltage driver ICs (SOT143R or SOT343 types) in a system with a power supply voltage over the18 V breakdown voltage of these types. An example of how to employ this trick is given in **Safe Operation of BCR40xx series LED Drivers in systems with supply voltages in excess of LED Driver IC maximum ratings**.
- Set up your LED string or "stack": using the basic circuit diagrams in **Figure 5**, set up each string of LEDs in your lighting array. The idea is to maximize the number of LEDs in each stack, to maximize overall system energy efficiency, and minimize power dissipation in the LED driver IC. Subtract the LED driver IC's voltage drop from the power supply voltage, using the chart on the next page as a reference for this driver IC voltage drop. (If you use a Schottky diode for Reverse Polarity Protection you also need to subtract the Schottky diode voltage from the power supply voltage). Take this result and divide by the maximum specified forward voltage V_F for the LED, as specified in the LED manufacturer's data sheet. Round this number down to the next integer value. This result is the number of identical LEDs that may be placed in the string or stack. Note the LED forward voltage V_F is usually specified at specific LED currents as the forward voltage is a function of LED current.
- "Run the numbers": do a calculation of power dissipation for the LED driver IC, e.g. LED current multiplied by voltage across the driver IC. Verify power dissipation is within the IC's maximum ratings. For the purposes of this discussion, the voltage across the LED driver is the voltage between the $+V_S$ pin and the current output pin (e.g. collector output of internal PNP transistor). Note, the voltage across the LED driver IC itself will depend on the number and type of LEDs in your stack. As an example, suppose you are using a BCR402R driver, running a stack of 4 Red color LEDs which have a forward voltage of 2.0 V each at 20 mA, from a +12.0 V power supply. The voltage across the LED driver IC would then be: 12.0 V - (4 x 2.0) = 4.0 V, and the total power dissipation in the LED driver is (4 V)(20 mA) = 80 mW, well below the 330 mW maximum rating for BCR402R. The designer must also take into consideration the power dissipation of all the LEDs and other heat sources in his or her circuit, the thermal performance of the circuit board, the required ambient operating temperature range, etc. in order to ensure neither the LEDs nor the LED driver IC has its maximum junction temperature ($T_{J\,MAX}$) exceeded.

Maximum number "N" of identical LED's that can be used in a series "stack":

1) Voltage available to LED's = V_{LED} ; $V_{LED} = V_S - V_{DROP\ IC}$, where $V_{DROP\ IC}$ is ~ 1.2 V for BCR401R, BCR401W, BCR401U, ~ 1.4V for BCR402R, BCR402W, BCR402U, and ~ 1.5V for BCR405U

2) Forward voltage of LED's = V_F (use the LED manufacturer's **maximum** value for V_F)

3) Maximum number of identical LED's that can be used "N" :

$N = V_{LED} / V_{F,}$ round down to nearest integer value.

AN101_Fig_number_identical_LEDs.vsd

Figure 7 Maximum number "N" of identical LEDs that can be used in a series "stack"

In the next section, we will show how it is possible to safely use an LED driver IC in a system where the power supply voltage is higher than the maximum rating of the LED driver.

2.2 Safe Operation of BCR40xx series LED Drivers in systems with supply voltages in excess of LED Driver IC maximum ratings

For some applications, including fixed or "architectural" lighting displays, voltages of greater than the 18 V maximum rating of the 18 V LED driver types may be encountered. We could opt for one of the 40 V driver types in the SC74 package as one option - e.g. BCR401U, BCR402U, BCR405U. But, since the 18 V driver types in SOT143R and SOT343 packages are the lowest-cost members of the product family, what can be done to permit us to use these lowest-cost parts where power supply voltages in excess of +18 V are used?

For operation in excess of the BCR401R / BCR402R / BCR401W / BCR402W maximum rating of 18 V, a "trick" can be employed to safely use the 18 V parts where supply voltage is higher than 18 V. The designer can simply stack a sufficient number of LEDs between the power supply voltage $+V_S$ and the power supply input pin on the LED driver (e.g. pin 3 on BCR401R or BCR402R) such that the voltage seen by this pin never exceeds the 18 V maximum rating of the driver. In other words, simply use additional LEDs to drop the voltage fed to the LED driver IC below the ICs maximum rating, and then finish up the string of LEDs with additional LEDs placed between the driver IC current output pin and ground, in the usual way. Refer to **Figure 8**. Note that the exact number of light emitting diodes required for the top or "voltage dropping" stack of LEDs will depend on

1) The supply voltage $+V_S$
2) The voltage drops across the particular LEDs being used

When used in this way, the LED driver acts as a "current sink" for the LEDs above it, and a "current source" for the diodes below. As there is only one current path, current stabilization is maintained for both upper and lower stacks of LEDs. There is a vanishingly small difference or "error" in terms of the difference in current between LEDs in the top stack and the bottom stack, this difference arising from the base current and bias current for the internal PNP transistor of the driver IC. This current is only on the order of 400 mA for an LED current of 20 mA. The additional 400 mA of current in the upper LED stack is so insignificant that the human eye will not be able to discern any difference in brightness between top and bottom LED stacks. In fact, there is far more variation in brightness between individual LEDs of the same type, if they are all driven with identical currents, than could be attributed to this small "error" current due to the LED BCR40xx PNP transistor base and bias currents.

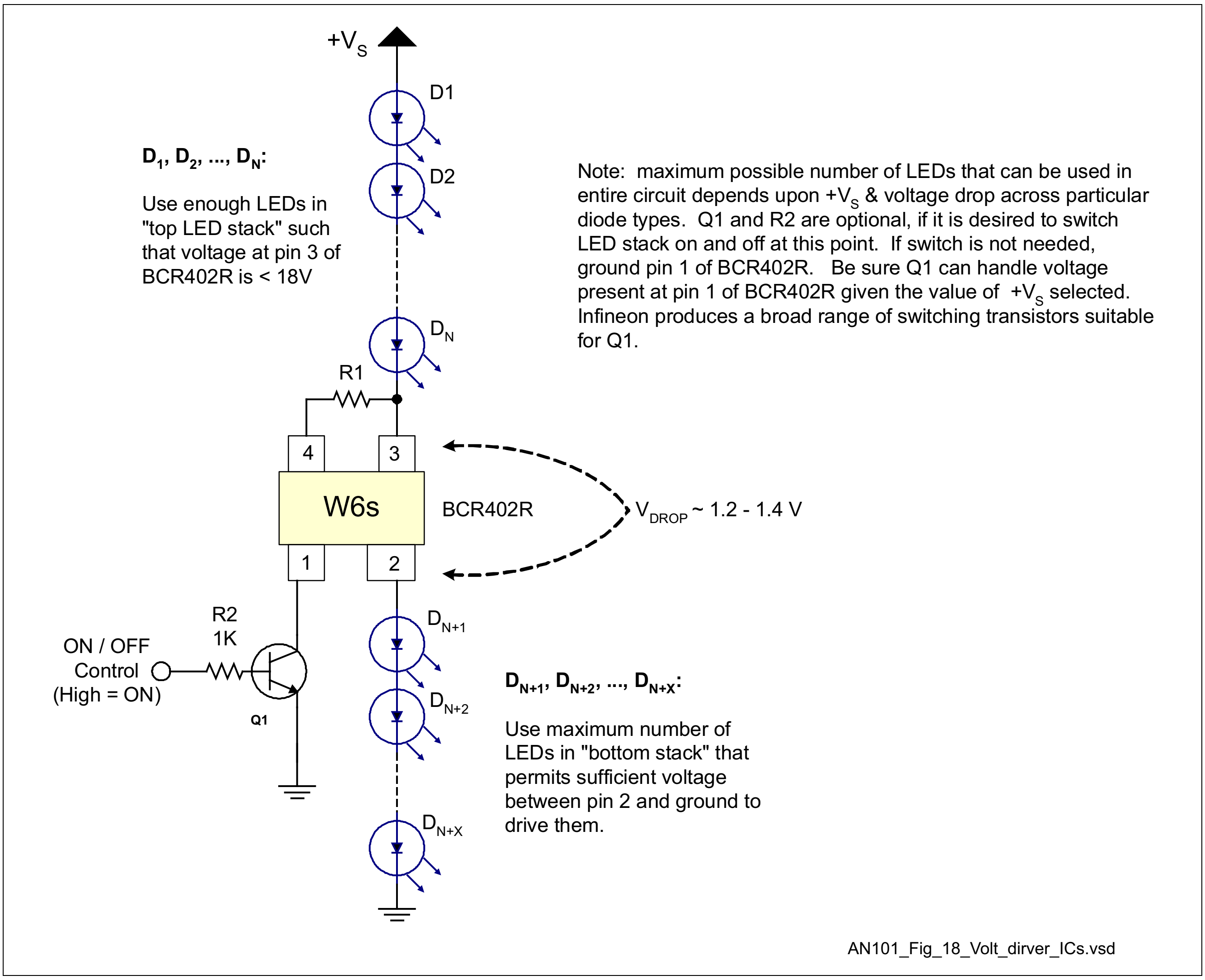


Figure 8 Operation of 18 Volt-rated LED Driver ICs (BCR401R / 402R / 401W / 402W) at "high" power supply voltages > 18 V. Additional LEDs are inserted between the power supply voltage and the LED driver, to reduce voltage seen by the LED driver IC to a safe level, < 18 V

2.3 "Boost" Concept, for LED Currents > 65 mA, or "How do I drive ½ W and 1 W LEDs?

To extend the current range of the previously described LED drivers to current levels beyond 60 / 65 mA, another approach is needed, as the LED driver ICs themselves cannot safely source in excess of 60 / 65 mA. So-called "half watt LEDs" require currents on the order of 150 mA, and 1 W LEDs need ~ 350 mA. For these higher current, higher power applications, the LED driver is used as a "controller" and an external "booster transistor" is employed to handle the higher current and heat dissipation. In this approach, the LED driver IC and external boost transistor still operate in a closed-loop system; the voltage seen across the external current-setting resistor is 'sensed' by the LED driver IC in the usual way, and the LED driver IC adjusts its output current up or down to maintain a constant voltage drop across the sense resistor. (Please refer to the schematic diagram in **Figure 11**). Since the system is still operating in closed-loop mode as before, LED current is still tightly controlled over temperature and power supply voltage variations. In this circuit, the LED driver IC can even reduce its output current below the IC's nominal minimum output current, if needed, to preserve the necessary voltage drop across the sense resistor. The basic concept is simple: the LED driver takes its output current and feeds it into the base terminal of the external bipolar boost transistor. (Remember, the bipolar transistor may be viewed as a current-controlled current source).

The boost transistor then multiplies this base current by the DC current gain (h_{FE}) of the boost transistor, with a much higher output current at the collector. The collector current is what is used to supply the LED stack. Since the current is set by an external resistor inside the loop (creating the sense voltage for the driver IC), the value of, or changes in value of the DC current gain of the boost transistor do not adversely impact circuit operation. In other words, the absolute value of the boost transistor's h_{FE} or shifts in h_{FE} over temperature are not critical parameters - the control loop takes care of any variations. Since the required output current from the standard LED driver is reduced or divided by the DC current gain of the boost transistor, most of the power dissipation burden is now placed upon the boost transistor, instead of on the LED Driver IC. The advantages of the low-current, stand-alone LED Driver IC circuit - including tight current regulation over temperature and supply voltage - are preserved. In addition, the negative temperature coefficient (NTC) of the stand-alone LED driver still functions in the usual manner, so protection of expensive, high power LEDs against thermal runaway is preserved.

The next section gives an application example of this boost concept in use in a metal-clad circuit board running three 1 W LEDs in an application board. Measurement data is presented, showing how LED current is maintained over temperature and across operating voltage variation. **Table 3** and **Figure 9** gives an overview of some Infineon transistors that are recommended for booster transistors for this application. The power dissipation and maximum ratings of the devices must be checked and verified for each individual circuit design, but as a rough general guideline, the BC817SU is recommended for ½ W LEDs with currents up to 200 mA, and the BCX68-25 or BCX55-16 are recommended for 1 W or higher power LEDs e.g. 300 mA and higher. In general, the upper limit on output current for this circuit is only limited by the maximum power dissipation & junction temperature of the boost transistor. It is even possible to parallel multiple boost transistors for extremely high current operation, provided one uses very low value "ballast resistors" in between the emitters of the boost devices and ground, to ensure equal sharing of current. Of course, practically speaking, the system designer will need to consider the cost versus power dissipation trade-off in terms of overall energy efficiency. At some point, as current is increased further, even if the individual components can tolerate the power dissipation, the efficiency advantages of more expensive switch-mode solutions will become more attractive.

It is important to note, that the booster transistor in the application circuit described in the following section does not have to have large voltage drops across it, as the LEDs are placed 'above' the boost transistor in the circuit, e.g. the voltage drops of the LEDs reduce the voltage (and thermal load) in the boost transistor. Therefore, breakdown voltage in the boost device should not be an issue. Again, the value of, or shift in, DC current gain (h_{FE}) of the booster transistor from device-to-device or over temperature is not critical - the transistor is operating in a closed-loop system, e.g. the self-correcting nature of the closed loop system compensates for such variations. For the application circuit described in the next section, the only critical parameters that need to be paid close attention to in terms of selecting an appropriate boost transistor are 1) current-handling capacity and 2) power dissipation rating / junction temperature.

Table 3 Overview of Infineon's Transistors suitable as "booster" devices.

Booster Transistor Part #	Description	Package	Maximum Collector Current in mA	Maximum Collector-Emitter Voltage V_{CEO} in V	Maximum Power Dissipation in mW	Leadframe Material	Thermal Resistance (note 2) $R_{TH\ J\text{-}S}$ in °C/W	Relative Cost (note 3)	Production Status (note 4)
BC817SU	NPN Si AF Transistor	SC74	500	45	1000 for T_S > 100°C	Cu	50	Lowest	MP
BCX55-16	NPN Si AF Transistor	SOT89	1000	60	1000 for T_S > 130°C	Cu	20	Low	MP
BCX68-25	NPN Si AF Transistor	SOT89	1000	20	1500 for T_S > 120°C	Cu	20	Low	MP

Notes

1. *Thermal resistance of device from semiconductor chip Junction to device package Soldering point. Soldering point is package lead or pin tied to collector of transistor. Collector junction of transistor is where most heat is generated*
2. *Cost is given in relative terms, e.g. comparing cost of different categories of LED driver types.*
3. *MP = released to Mass Production; ES = Engineering Samples.*

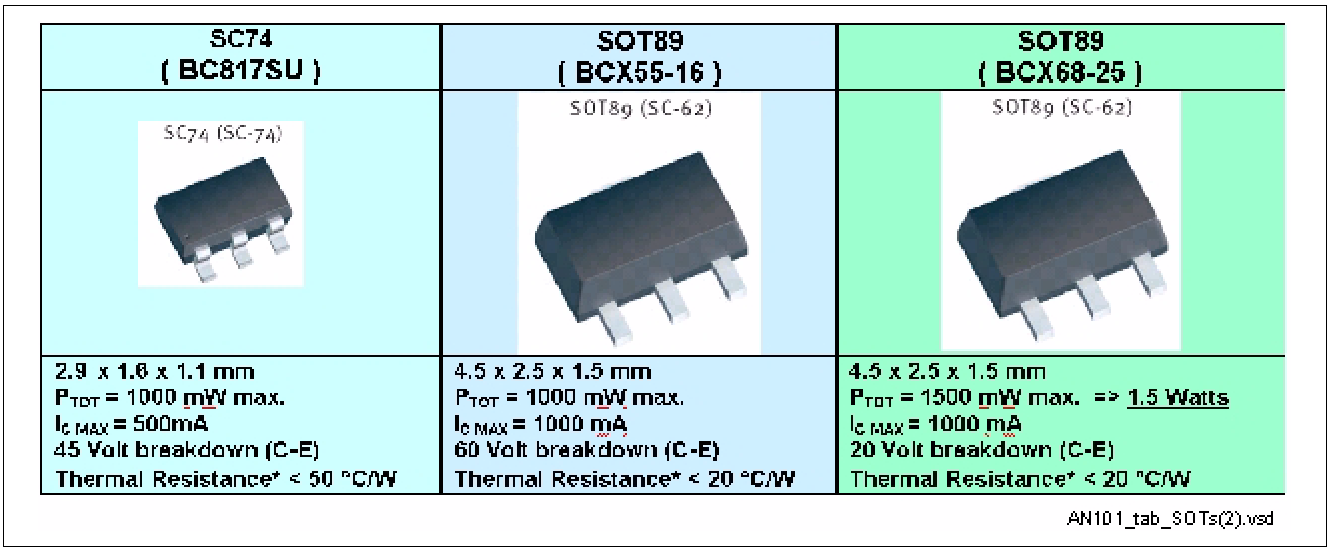


Figure 9 Recommended Infineon "Booster" Transistors for High Current LED Driver Applications

* Thermal resistance is device **J**unction to package **S**oldering point ($R_{TH\ J\text{-}S}$).

2.4 Application example with circuit used to drive 1 W white LEDs

Managing heat - thermal considerations - are paramount in all LED circuits, but in higher power LEDs this issue takes on especially high importance. LED junction temperatures must be kept below their maximum ratings in order to ensure long LED lifetimes. In order to remove heat from the LEDs and other circuit elements, a metal-clad-circuit board (MCPCB) design was employed. Flex-Circuit material (DuPont "Kapton" ®) is attached with adhesive (DuPont "LF" ®) to low-cost "3003" series aluminum sheet for the circuit board design. The "3003" series aluminum is lower in cost and is generally easier to work with than the well-known "6061" aluminum alloy. The aluminum back-plate of the PCB serves as a heat sink for the LEDs, LED driver IC (BCR401R in this case) and BCX55-16 booster transistor. Only one side of the dielectric has traces or metallization on it. A cross-section diagram of the circuit is given in **Figure 10**. Note the thin dielectric layer (flex-circuit) of 0.05 mm thickness minimizes thermal resistance, permitting heat to flow from the high power LEDs and circuit components into the aluminum baseplate relatively easily. A schematic diagram of the circuit, along with measured node voltages and currents from testing is given in **Figure 11**, and a photograph of the PC board is provided in **Figure 12**. The LEDs used are white-color OSRAM Opto Semiconductor LW W5SM series "Golden Dragons". These LEDs are thin-film devices with the unusually low forward voltage (V_F) of 3.2 V, typical. This low forward voltage for white LEDs permits 3 LEDs to be used in the stack, instead of 2, which increases overall system energy efficiency while reducing the voltage across (and thus power dissipation in) booster transistor Q1. The basic design procedure outlined in **Design procedure for LED Driver circuit, for LED currents up to 65 mA** was followed; however the booster transistor requires a minimum of ~ 0.5 V from collector-to-emitter to operate properly, slightly reducing the voltage available for the LED stack. Power dissipation in the LED driver IC itself is no longer an issue, as it only needs to output a very small 'control current' to the booster transistor. Therefore the lowest-cost members of the LED driver IC family were selected, with either the BCR401R or BCR402R working equally well in this application. A +12 V power supply voltage is used, and Infineon Schottky Diodes (BAS3010A-03W) are employed for (optional) Reverse Polarity Protection (RPP). The configuration of the Schottky Diodes D1 - D4 "steers" the applied voltage in the correct direction regardless of whether the DC power plug is put in the correct way, or flipped 180 ° in the "wrong" orientation, and Schottky diodes were selected due to their low forward voltage, which leaves more voltage available for the LED stack. The reader can see how the PCB lights up properly with either orientation of the DC power plug in **Figure 14**. Test results from testing a unit over temperature (-40 °C to +85 °C) and over power supply voltage (+11.4 to +12.6 V) are given in **Discussion of measurement results, current consumption versus voltage and temperature** of this applications note. A power dissipation budget is detailed in **Power Dissipation Budget for PCB Components**. The thermal resistance of the PCB assembly, from LED junction to ambient ($R_{th\ J\text{-}A}$, LED) and from booster transistor junction to ambient ($R_{th\ J\text{-}A}$, Q1) were determined in **Determination of thermal resistances (RTH S-A) of PCB assembly and junction temperatures (TJ) of LED Booster Transistor**. A photo of how thermocouples were attached is given in **Figure 18**.

Please note, the LED current is determined by the value of the sense resistor R1. For this circuit, 2.7 Ω yields an LED current of ~ 340 mA. This current is highly repeatable from one unit to the next. Please take care to select a resistor capable of handling the power dissipation - in this example, approximately 300 mW. For assistance in selecting the correct sense resistor value for the desired operating current, **Figure 13** and **Table 4** give a plot of resistor values versus LED current. Note, the results were determined experimentally.

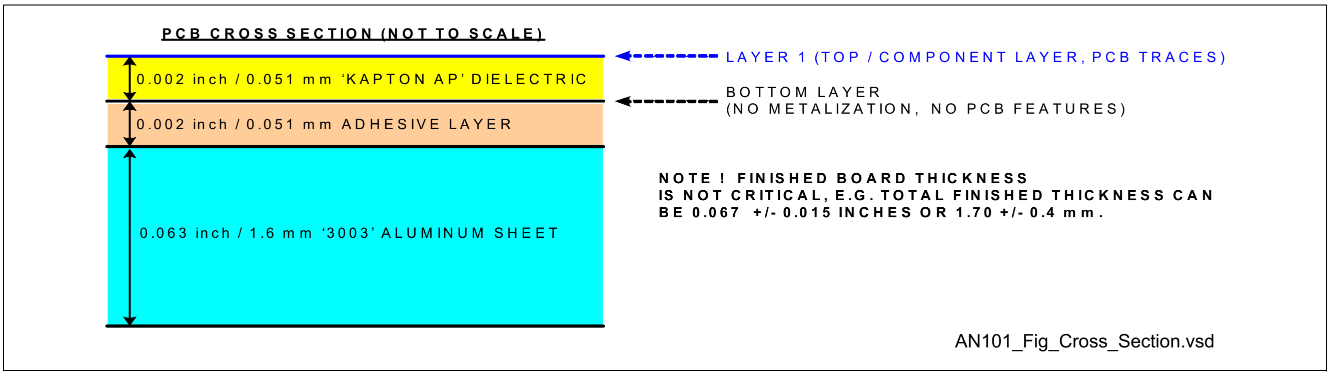


Figure 10 Cross Section Diagram of metal-clad PCB

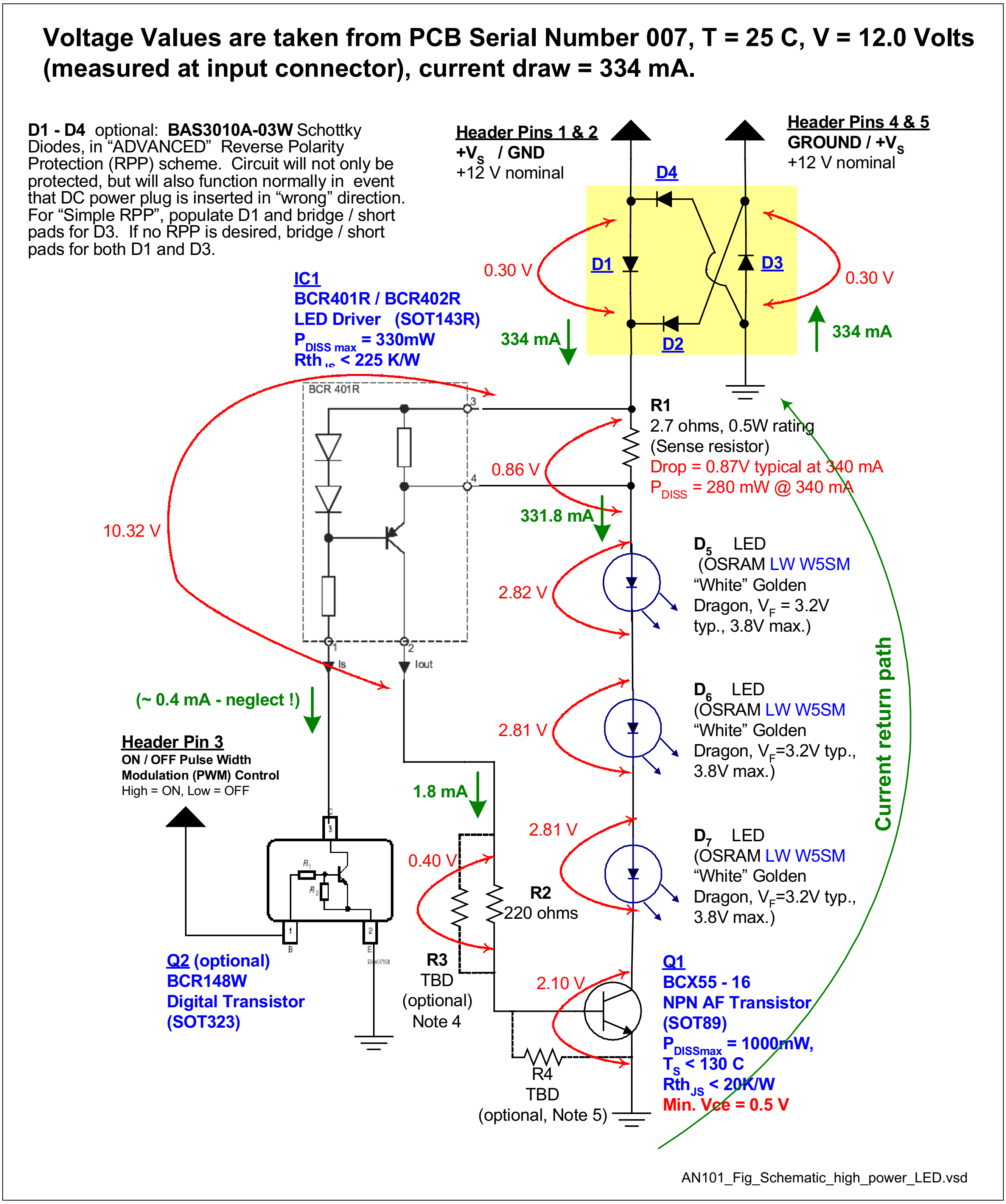


Figure 11 Schematic Diagram of High Power Application Example, with 1 W LEDs

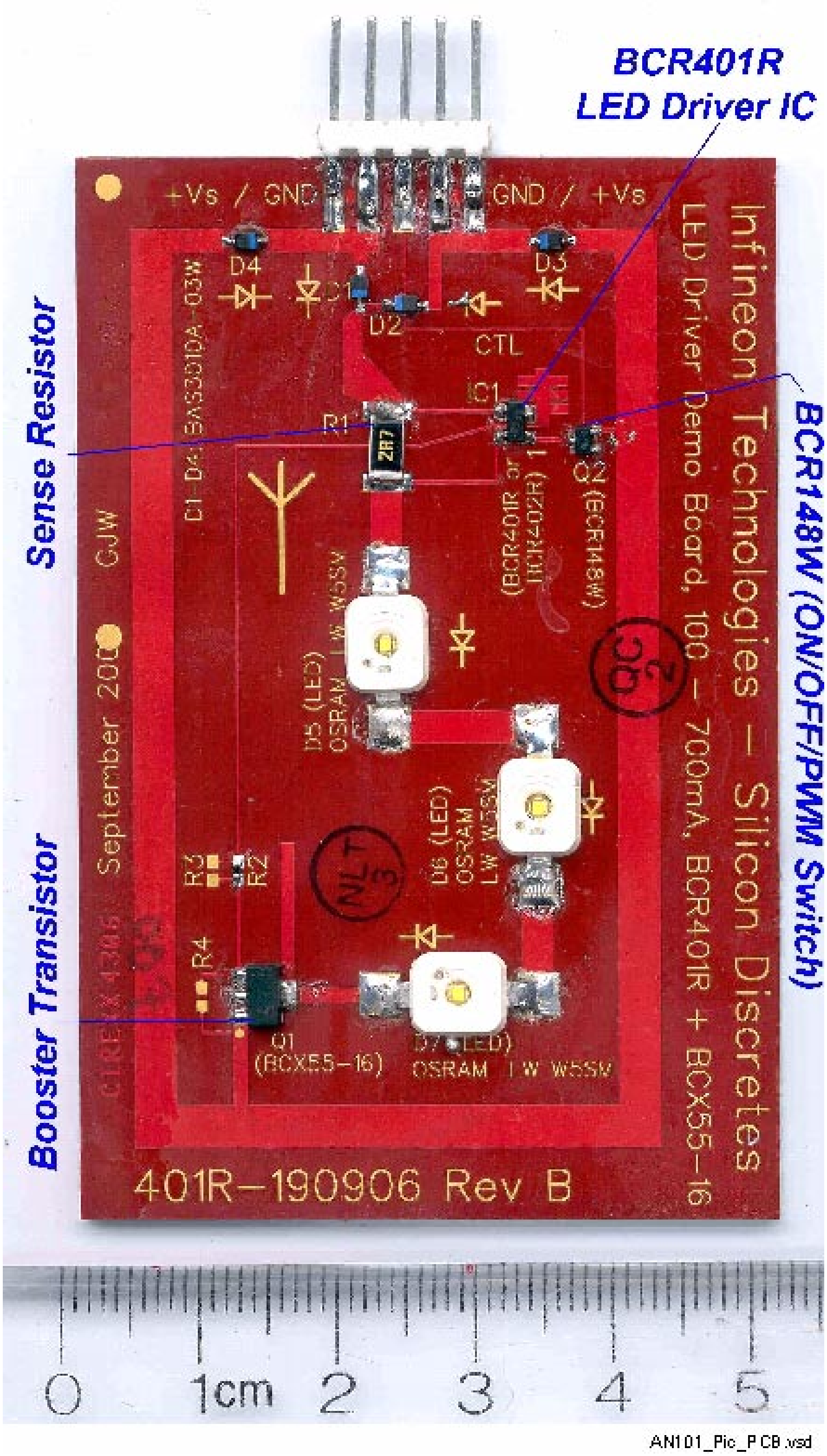


Figure 12 Photograph of Application Circuit

Table & plot of Sense Resistor value (R1) vs. LED current:
Maximum rating of LEDs used in this circuit is 500 mA. Booster Transistor (Q1, BCX55-16) can handle up to 1 A, provided power dissipation rating (P_{TOT}) of 1000 mW, and Junction Temperature (T_J) of 150 °C are not exceeded.

Table 4 Sense Resistor Value (R1) vs. LED current

Sense Resistor Value (R1) Ω	**LED Current** **mA**
1.8	476
2.0	433
2.2	401
2.4	373
2.7	334
3.0	304
3.3	276
3.6	257
3.9	248
4.3	228
4.7	209
5.1	193
5.6	176
6.2	160
6.8	147
7.5	136

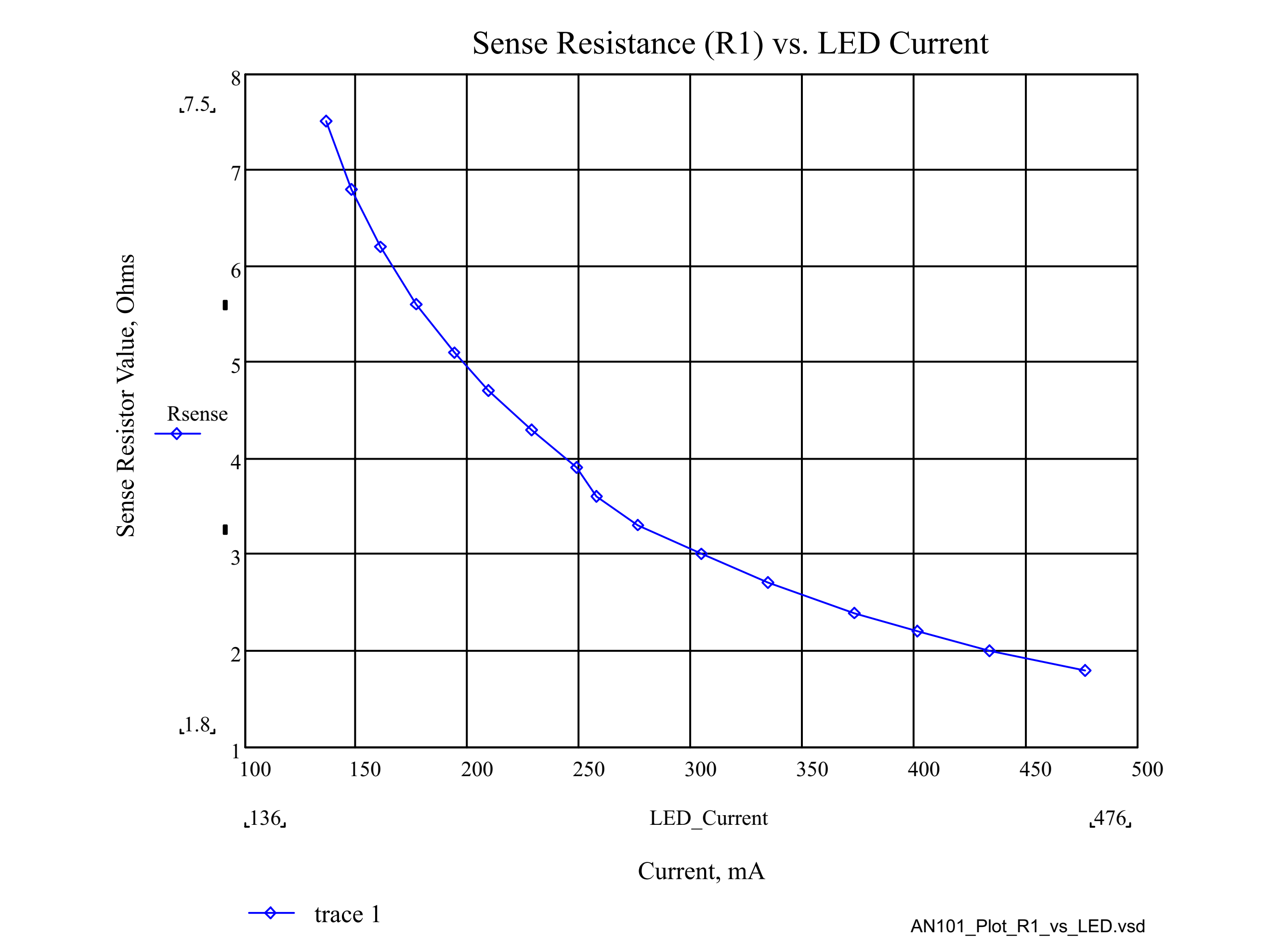


Figure 13 Sense Resistor Value (R1) vs. LED current

Photo of PCB showing Reverse Polarity Protection (RPP) scheme in operation. Four Infineon BAS3010A-03W Schottky diodes nor only protect the circuit from damage in the event of reverse polarity being applied, but the circuit also functions properly with DC power plug inserted in either orientation. Such protection can prevent lighting system installers from inadvertently damaging expensive LED lighting fixtures.

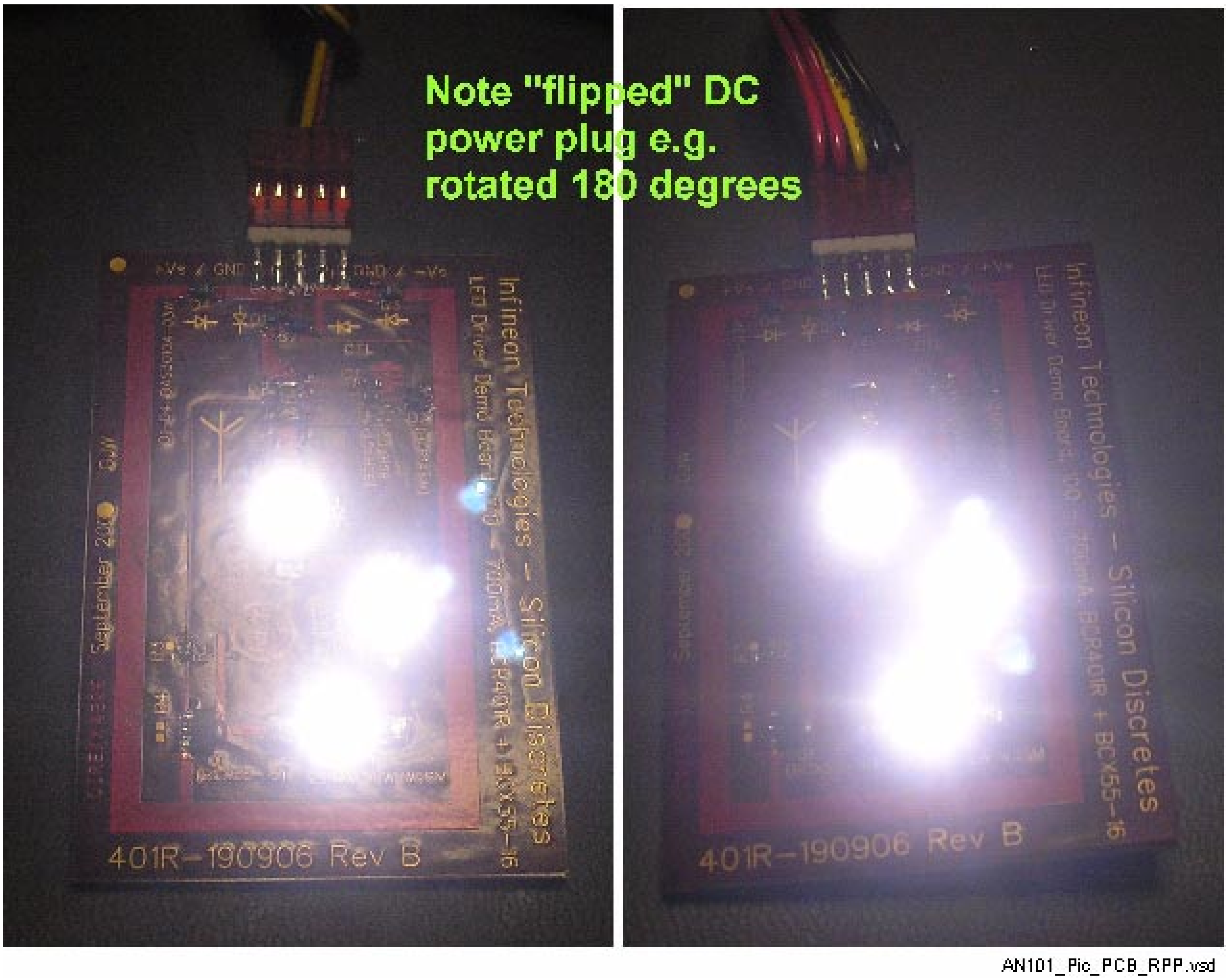


Figure 14 Photo of PCB showing RPP scheme in operation

2.5 Discussion of measurement results, current consumption versus voltage and temperature

The test procedure may be described as follows:

- The circuit board assembly is placed into a temperature chamber. The PCB is weighted down to ensure good thermal contact between the floor of the test chamber and the bottom of the metal-clad PC board (please see Figure 12). The circuit is turned on, with power supply voltage set to +12.0 V. The circuit is allowed to "settle" at room temperature for ~ 10 minutes. (LED current was initially set by the value of R1, with a value of 2.7 Ω yielding a current of ~ 340 mA). Record total current consumption.
- Reduced supply voltage $+V_S$ to +11.4 V. Record current consumption.
- Increase supply voltage to +12.6 V. Record current consumption. Then reduce voltage back to +12.0 V.
- Decrease temperature of test chamber to -40 °C. allow until to "settle" for 10 minutes. Record current draw at +11.4, +12.0 and +12.6 V.

- Increase temperature of test chamber to +85 °C. Allow unit to "settle" for 10 minutes. Record current draw at +11.4, +12.0 and +12.6 V.

Results are given in **Table 5** below. A Photograph of the unit as placed into the temperature test chamber is given in **Figure 15**.

Table 5 PCB Current Consumption vs. Voltage and Temperature

Chamber Temperature, °C	Power Supply Voltage, V	PCB Current Consumption, mA
-40	+11.4	358
-40	+12.0	362
-40	+12.6	365
+25	+11.4	339
+25	+12.0	340
+25	+12.6	343
+85	+11.4	318
+85	+12.0	323
+85	+12.6	326

- Percent shift in operating current, at +11.4 V, going from - 40 °C to +85 °C (with +25 °C as baseline value): ⇒(358 mA - 318 mA) / 339 mA x 100 % = - 11.8 %; slope is - 0.32 mA / °C
- Percent shift in operating current, at +12.0 V, going from - 40 °C to +85 °C (with +25 °C as baseline value): ⇒(362 mA - 323 mA) / 340 mA x 100 % = - 11.5 %; slope is - 0.31 mA / °C
- Percent shift in operating current, at +11.4 V, going from - 40 °C to +85 °C (with +25 °C as baseline value): ⇒(365 mA - 326 mA) / 343 mA x 100 % = - 11.4 %; slope is - 0.31 mA / °C

Conclusions:

- LED current is well-regulated over both temperature and voltage variation, with approximately 11 to 12 % total current shift (decrease) when going from cold (-40 °C) to hot (+85 °C) at all three supply voltages tested.
- The negative slope of current versus temperature is consistent with the intentionally designed-in negative temperature coefficient (NTC) of Infineon's LED driver family, which gradually reduces current as temperature increases. This NTC helps to prevent thermal runaway in LED-based lighting designs, helping to prevent destruction of expensive LED arrays. The value of the NTC is given in the respective LED driver data sheet, "output current change versus T_A", and is on the order of -0.2 % per degree C.

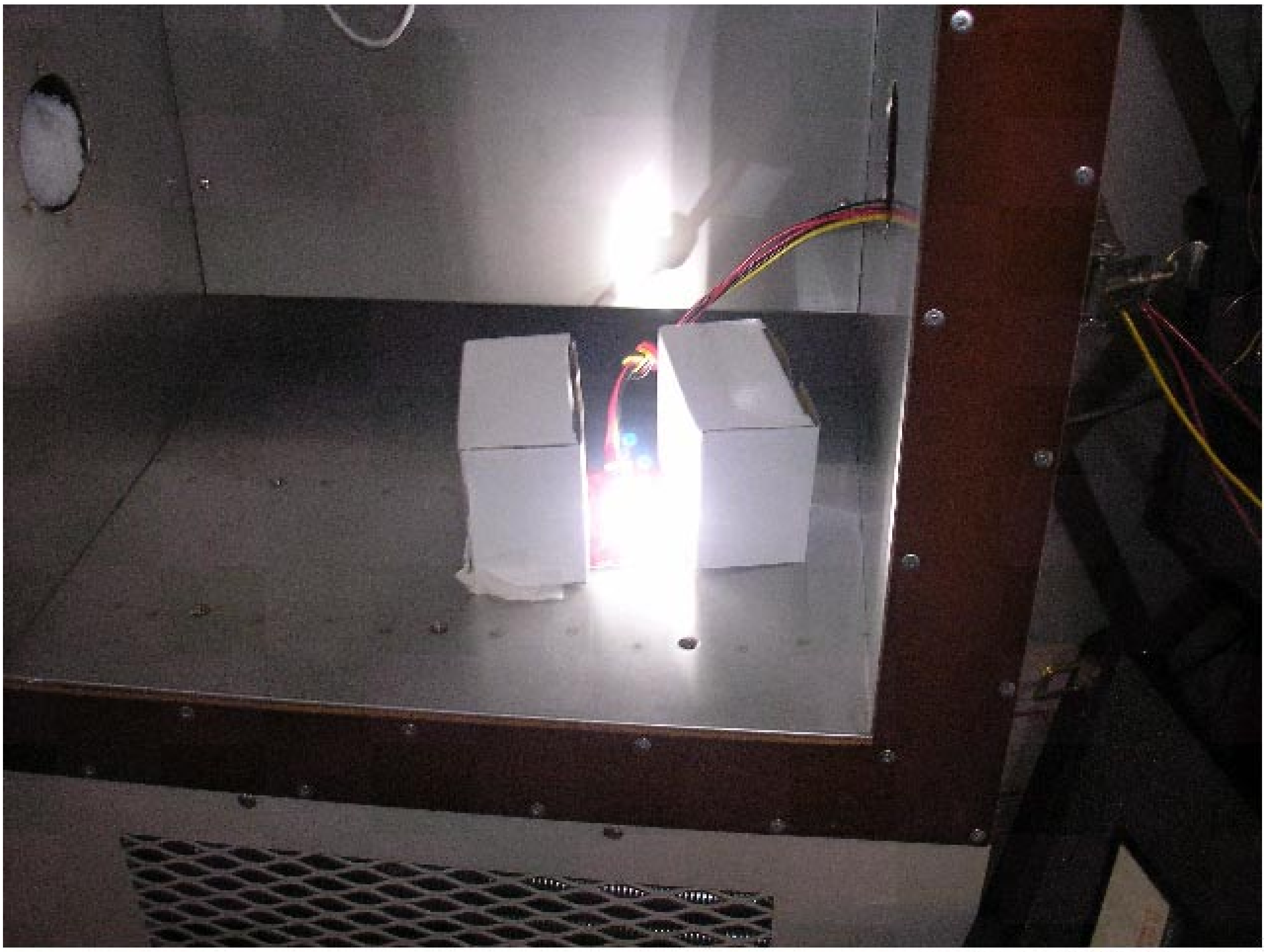


Figure 15 Photo of PCB Assembly in Temperature Test Chamber

2.6 Power Dissipation Budget for PCB Components

The power dissipation budget, e.g. total DC input power and power dissipated in each circuit element, is given below. Note that the maximum power dissipation rating (P_{TOT}) has not been exceeded for any of the circuit elements, particularly the LEDs, Booster Transistor (Q1) or the BCR401R LED driver IC (IC_1). A "pie chart" showing power dissipation in each circuit element is given in **Figure 17** to give the reader a graphical means to assess where the available DC power is used. Even though this simple, low-cost linear-mode circuit is not as efficient as a more complex driver circuit using switch-mode components, some 70 % of the available power is used by the LEDs themselves.

Power Dissipation Budget

Assumptions: Header Pins 1 and 2 =+12.0 V, Header Pins 4 and 5 = Ground

Total DC input power = (12.0 V) (334mA) = 4008 mW

P (D1) = (0.30 V) (334 mA) = 100.2 mW => **below MAX rating (1A diode)**

P (D3) = (0.30 V) (334 mA) = 100.2 mW => **below MAX rating (1A diode).**
This is ground-return path when RPP scheme is used.

P (R1) = (0.86 V) (331.8 mA) = 285.3 mW => **below MAX rating of "2010" resistor**

P (D5, D6, D7) = (2.82 V) (331.8 mA) = 935.7mW => **below LED MAX rating of 2W**

P (Q1) = (2.10 V)(331.8 mA) = 696.8 mW => **below MAX rating 1000 mW for Ts < 130 C**

P (R2) = (1.8 mA)^2 (220) = 0.71 mW => **below MAX rating for "0402" resistor chip**

P (IC1) = (10.32 V)(1.8 mA) = 18.6 mW => **below MAX rating of 330 mW for Ts < 84 C**

P (Q2) => negligible, e.g. (~ 0.4mA)($V_{CE\ SAT}$ Q2) ~ nil

Sanity Check: sum up all individual power dissipation numbers, see if they sum to 4008 mW total DC input power:

100.2 mW+100.2mW+285.3mW+3(935.7 mW)+696.8mW+0.71mW+18.6mW = **4009 mW**
(very close)

AN101_Fig_power_dissipation_budget.vsd

Figure 16 Power Dissipation Budget

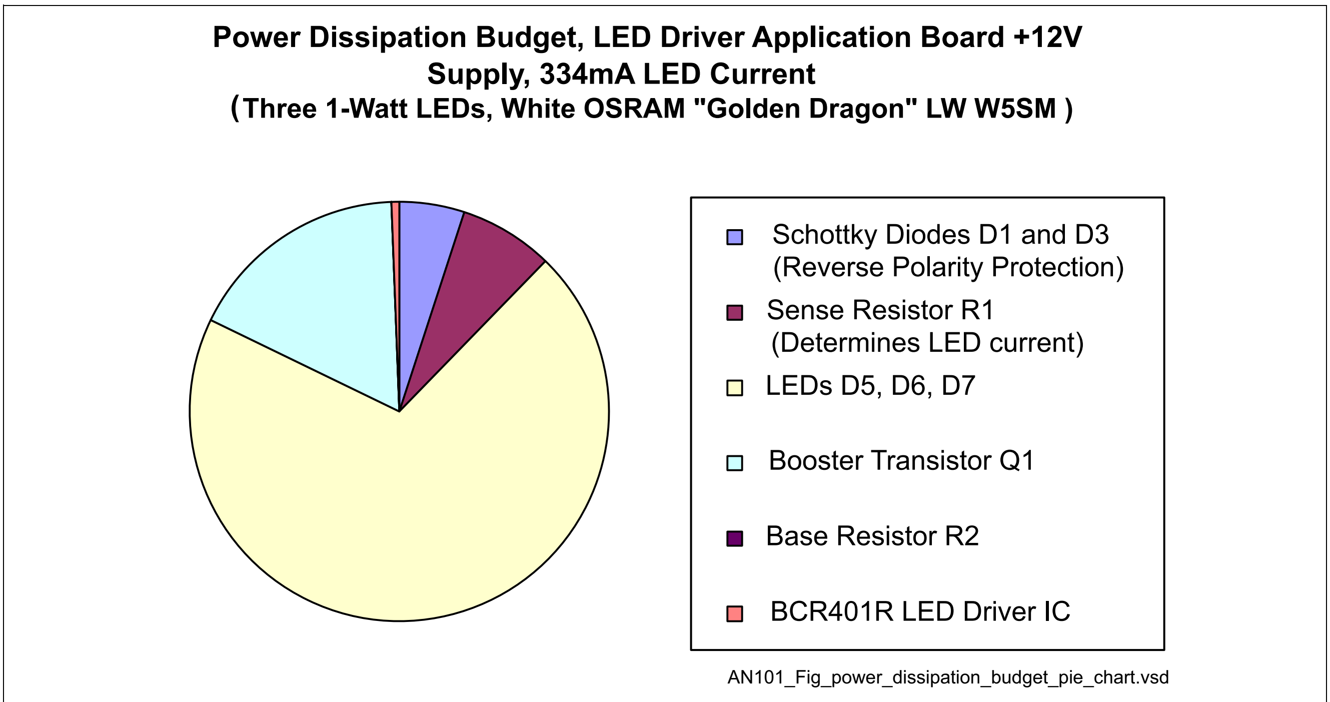


Figure 17 Pie Chart showing power dissipation in circuit elements. Note that ~ 70 % of the available power (4008 mW) is consumed in the Light Emittig Diodes

2.7 Determination of thermal resistances (RTH S-A) of PCB assembly and junction temperatures (TJ) of LED Booster Transistor

The main purpose of this exercise, is to determine whether or not this PCB design has sufficiently good thermal performance to ensure the semiconductor devices used do not have their maximum rated junction temperatures (T_J) exceeded. In this circuit, the LEDs (D5, D6 and D7) and the booster transistor (Q1) are the components that are subjected to the most thermal stress. Therefore, the junction temperature and thermal resistance from semiconductor junction to ambient ($R_{TH\ J\text{-}A}$) are determined for one of the three LEDs and for Q1 via measurement. The LEDs used here, OSRAM LW W5SM series "Golden Dragons", are thin-film devices and are flipped or turned over during production. Therefore, most of the heat is generated in the anode of the LED, which is connected directly to the LED's lead-frame. The power dissipation in the LED is determined by the product of the voltage across it (LED forward voltage V_F) by the current through it. For Q1, most of the heat is generated in the collector region of the transistor, and the power dissipated in Q1 is defined as the product of (collector current I_C) x (collector-emitter voltage V_{CE}). For these reasons, two separate thermocouple wires are connected as follows:

- One thermocouple to the collector of the booster transistor, Q1
- The second thermocouple to the anode of one of the OSRAM LW W5SM "Golden Dragon" LEDs.

Again, the goal is to determine the thermal resistance from device junction to ambient ($R_{TH\ J\text{-}A}$) such that the LED (D6 here) and boost transistor's (Q1) junction temperature can be determined. We wish to keep these devices operating below their maximum specified junction temperatures to ensure long-term reliability.

Please refer to **Figure 18** for a photograph of the test setup. Note that the PCB assembly is clamped to a bench vise in a very small area (corner) of the PCB, to minimize heat flow from the PCB to the vise, thus reducing measurement error. Furthermore, the jaws or contact surfaces of the bench vise have a rubber coating with a high thermal resistance, which should further minimize heat flow from the PCB to the bench vise. Results are presented in **Table 6**.

Table 6 Data Recorded for $R_{TH\ J\text{-}A}$ Test, to determine $R_{TH\ J\text{-}A}$ for PCB Assembly, along with selected datasheet parameters for the LED and Q1

Device	Soldering Point Temperature T_S (°C)	Device Voltage (V)	Device Current (mA)	Device Power Dissipation P_{TOT} (Watts)	Maximum Permitted Device Power Dissipation P_{TOT} (Watts)	Thermal Resistance, Device Junction to Soldering Point $R_{TH\ J\text{-}S}$ (C / W)
LED (D6)	63	V_F = 2.81	I_D = 332	0.933	2.0 for T_A = 25 °C	< 15
Q1	64	V_F = 2.1	I_C = 332	0.697	2.0 for T_S < 130 °C	< 20

Calculations:
Goals are to determine

- Junction temperatures for Q1 and LED D6
- Thermal resistance of PC Board, from device soldering point to ambient, to gauge or benchmark the PCB design and construction, in terms of thermal performance / heat sink qualities.

Definitions used:

T_J = device junction temperature inside chip (LED or boost transistor, in this case)

T_A = ambient temperature, °C

T_S = soldering point temperature (biggest collector lead on Q1; anode lead on LED D5)

$R_{TH\ J\text{-}A}$ = thermal resistance from device junction to ambient (dependent on PCB construction, etc.)

$R_{TH\ J\text{-}S}$ = thermal resistance from device junction to soldering point (given in device datasheets, not dependent upon PCB construction)

Determine device junction temperatures from this formula: $T_J = T_D + P_{TOT} \times R_{TH\ J\text{-}S}$

For junction temperature of LED:

$T_{J\ LED\ (D6)}$ = 63 °C + (0.933 W)(15 °C/W) = 77 °C, 48 degrees C below maximum specified T_J of 125 °C

For junction temperature of booster transistor Q1:

$T_{J\ Q1}$ = 64 °C + (0.697 W)(20 °C/W) = 78 °C, below maximum specified T_J of 150 °C

Determination of $R_{TH\ S\text{-}A}$, for an LED, e.g. determine thermal resistance from LED soldering point to ambient, which will give an indication of how good this PCB design is in terms of thermal performance:

$R_{TH\ S\text{-}A\ (LED)} = (T_S - T_A) / P_{TOT}$ = (63 °C - 25 °C) / (0.933 W) = 40.7 °C/W

Determination of $R_{TH\ S\text{-}A}$, for Q1, e.g. determine thermal resistance from boost transistor soldering point (collector) to ambient, which will give an indication of how good this PCB design is in terms of thermal performance:

$R_{TH\ S\text{-}A\ (Q1)} = (T_S - T_A) / P_{TOT}$ = (64 °C - 25 °C) / (0.697 W) = 56 °C/W

Conclusions:

Metal Clad PC Board (MCPCP) does reasonable job of keeping LED and Boost Transistors below maximum ratings for junction temperature. There is approximately 48 °C margin in ambient temperature T_A - e.g. ambient temperature could increase from 25 °C to 73 °C before 125 °C maximum junction temperature of LED would be reached.

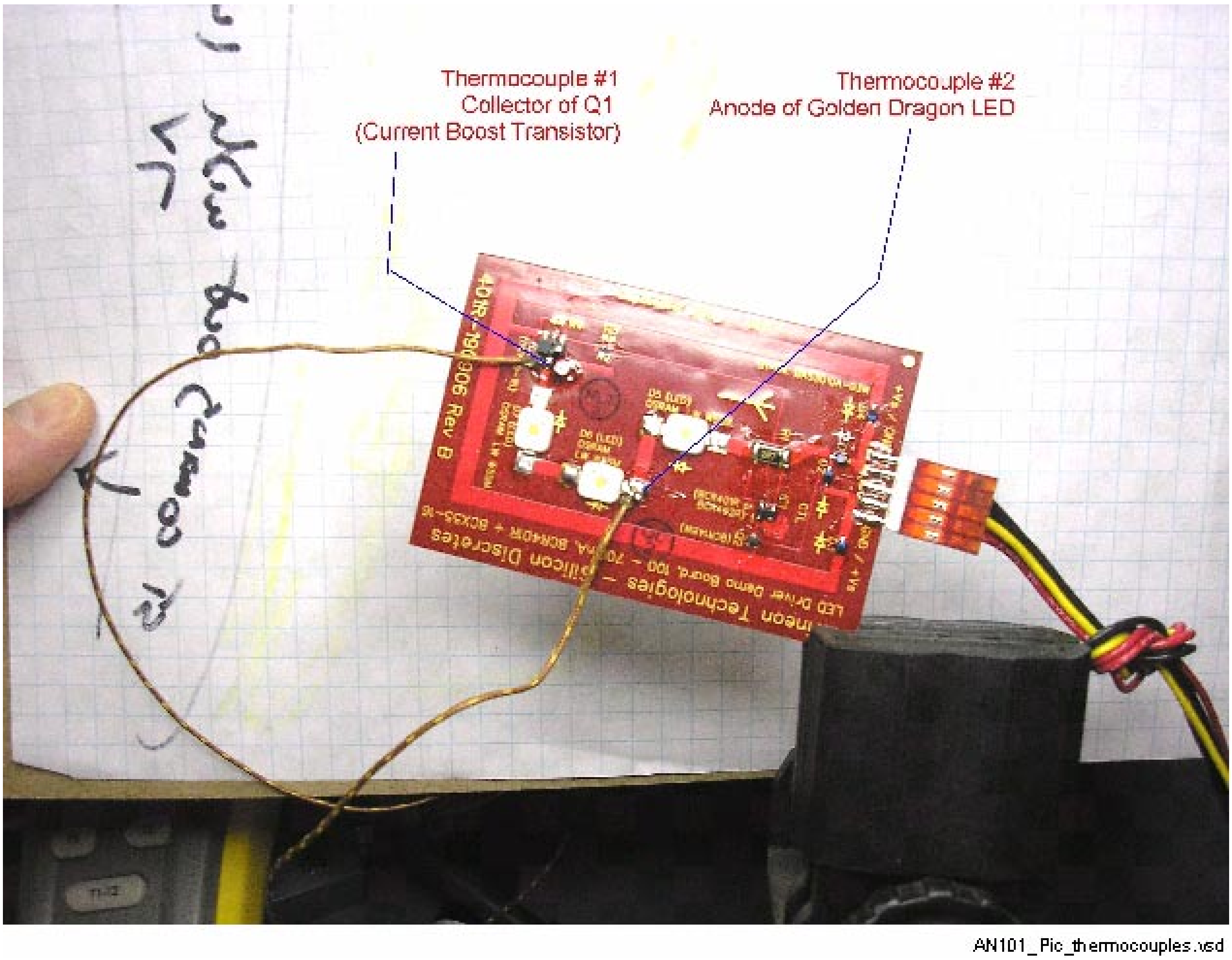


Figure 18 Photograph of locations of Thermocouples used in thermal resistance measurement

2.8 A brief overview of Reverse Polarity Protection (RPP) options

Many lighting applications involve involvement of multiple groups of people, including the LED vendor, light fixture manufacturer, lighting system designer, sheet-metal fabricator and system installer, as well as various sub-contractors. It is possible that a sub-contractor or system installer can inadvertently make errors either in making the necessary wire harnesses, or in hooking up the power supply wires. The result can be reverse-voltage applied to the light fixture or module, resulting in damage or destruction to the (expensive) LEDs being used. There are different ways to prevent this problem, including using special "keyed" wire connectors and the like. Another possibility for the light module or light fixture manufacturer is to implement some kind of Reverse Polarity Protection (RPP) scheme into the light module.

Diodes make a good candidate for RPP applications, and Schottky diodes are particularly well-suited. The reduced forward voltage of Schottky diodes (e.g. 0.3 V threshold voltage) as compared to standard silicon diodes (0.7 V threshold) offers several advantages:

- The lower forward voltage of Schottky diodes wastes less of the available voltage. Minimizing voltage drops might mean that the designer can insert one additional LED into the LED stack.
- The low forward voltage of the Schottky diode results in less power dissipation, permitting a smaller diode package to be used for a given current, as well as improving overall system energy efficiency.

Figure 19 gives a comparison of power dissipation or power loss for different diode types. Note that the Schottky diode offers a ~ 70 % improvement as compared to the standard silicon diode.

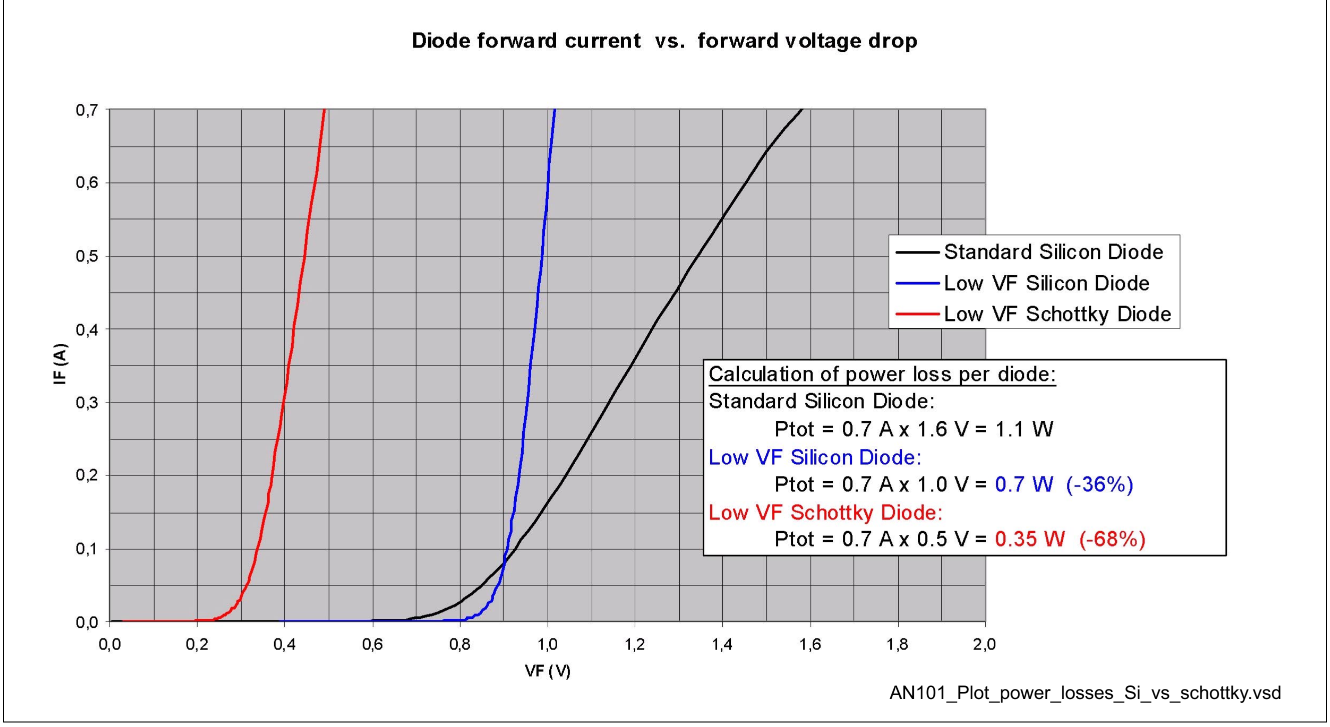


Figure 19 Power Losses in Silicon versus Schottky Diode Types

Figure 20 gives an overview of three possible RPP schemes using Schottky diodes. The simplest method, on the far left of the figure, uses a single diode on the $+V_S$ line, to prevent any current flow if the $+V_S$ and GROUND wires are cross-connected. This so-called 'Basic RPP' scheme will provide protection against damage to the circuit; however, the circuit will not function (e.g. will not "light up") if the wire harness is cross-connected. The second method, referred to as 'Advanced RPP', not only protects the circuit from damage, but actually enables the circuit to function normally if the DC power plug is connected in the proper way, or flipped over by 180 ° and inserted the 'wrong' way. This method is used in the circuit board described in this applications note, and the reader can see from the photo in **Figure 14** that the LEDs work with either orientation of the DC power plug. The 'Advanced RPP' is implemented with 4 pieces of the Infineon BAS3010A-03W Schottky Diode, which has an exceptionally low forward voltage, is rated at 1 A and has a breakdown voltage of 30 V - well above the +12 V DC used in this circuit. The last RPP type shown on the right side of **Figure 20** is referred to as 'Advanced + Integrated RPP'. This approach takes four Schottky diodes, and integrates them with the necessary internal connections into a single 4-pin package, allowing for a single-package solution. This device, the BAS3007A-RPP, is currently in development. This single-package RPP solution reduces the parts count from 4 to 1, reducing cost and minimizing PCB area.

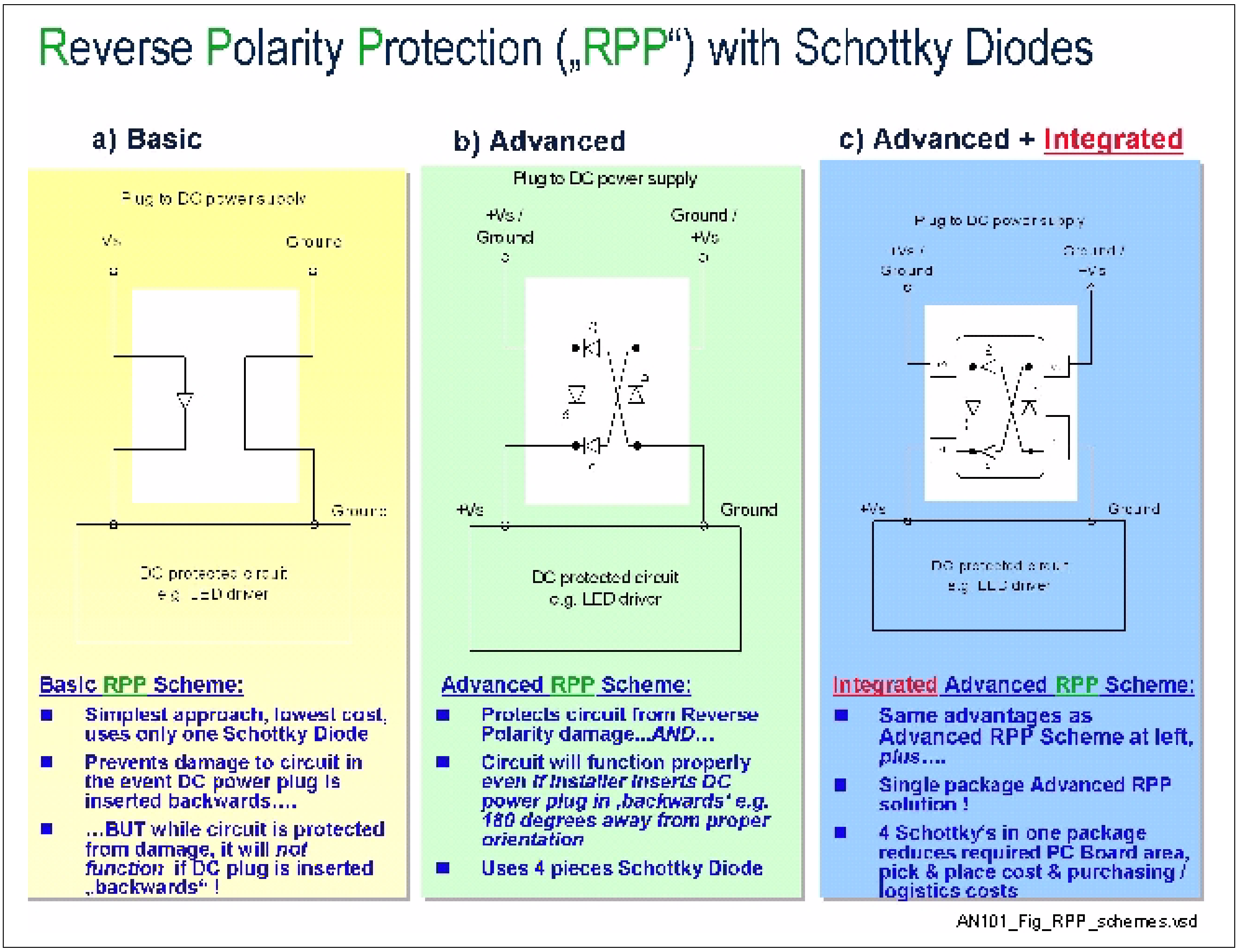


Figure 20 Three possible Reverse Polarity Protection (RPP) Schemes using Schottky Diodes

3 Summary

Infineon's BCR400 series of linear-mode constant-current LED drivers offer the LED lighting system designer a flexible, versatile and cost-efficient solution for his or her drive circuit designs. These drivers maintain constant current over temperature and supply voltage variation, while having low voltage drops (1.2 to 1.5 V), thereby maximizing system energy efficiency as compared to designs using resistors for current control. The high output impedance of these driver ICs make LED current less sensitive to statistical variations in LED parameters, and may enable the end user to reduce or relax 'binning' requirements on LED forward voltage V_{F}, reducing costs and simplifying logistics. The negative temperature coefficient (NTC) of these driver ICs helps to protect expensive LED arrays from thermal runaway. Drive current may be increased beyond the 60 / 65 mA level of the stand-alone driver IC by addition of a single external booster transistor, permitting light fixture designs with 1/2 W, 1 W and 2 W high power LEDs to be addressed. Pulse Width Modulation (PWM) capability may be incorporated with the addition of a single low-cost, low power switching transistor such as the Infineon BCR148W digital transistor. Optional reverse polarity protection (RPP) may be implemented with Infineon Schottky diodes (e.g. BAS3010A-03W) having low forward voltages, which consume less of the available supply voltage, maximizing overall power efficiency and leaving more voltage available for the LEDs.

w w w . i n f i n e o n . c o m

Published by Infineon Technologies AG