LED Driver PR4101

High Power LED Buck Driver

The PR4101 is a LED buck driver for driving one or several high power LEDs in series. The supply voltage can be up to 40 V, with an output current of more than 1 A using an external n-channel MOSFET switching transistor. The PR4101A with additional PWM and power down input is delivered SOP14 packaged, while the PR4101B is offered SO8 packaged.

APPLICATIONS

- Halogen lamp or filament bulb replacement by LEDs
- General illumination
- Warning lights
- Automotive lighting
- Indicator signs
- LCD backlighting

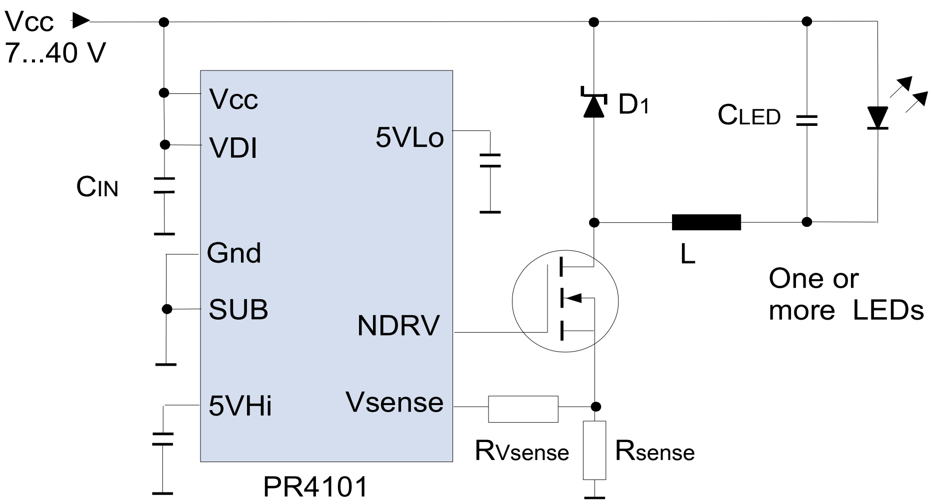
FEATURES

- Adjustable output current of several amps
- Supply voltage up to 40 V
- Dimming with phase-cut dimmer
- Brightness control with PWM (PR4101A only)
- Output current temperature compensation
- Delayed start possible (PR4101A only)
- Over temperature protection
- Frequency spreading for improved EMI
- Low standby current of < 35 µA
- Under voltage lockout

ABSOLUTE MAXIMUM RATINGS

Parameter	Min	Max	Units
V_{CC}, VDI (no damage)	-0.3	50	[V]
All other pins		14	[V]
Operating Chip Temperature Range (over temperature protection)	-20	125	[°C]
Storage Temperature Range	-55	150	[°C]
Electrostatic Discharge (ESD) Protection	2		[kV]

TYPICAL APPLICATION CIRCUIT



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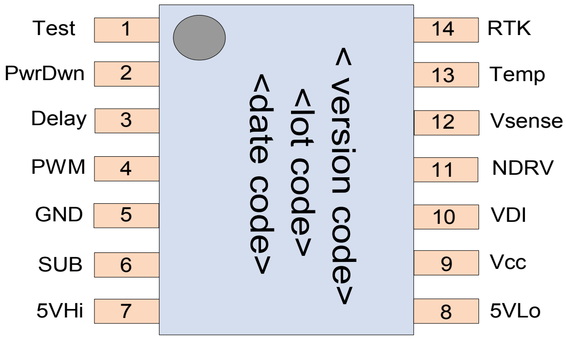
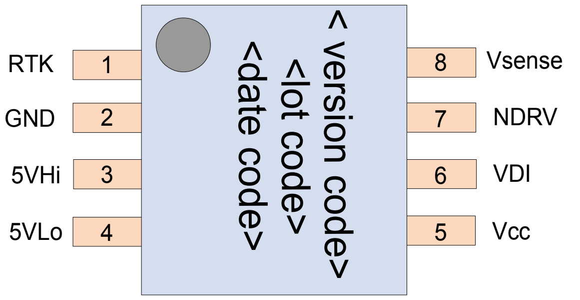
PIN Configurations / PIN Descriptions



PR4101A: Package SOP14
Topside marking: version code "PR4101"



PR4101B: Package SOP8
Topside marking: version code "PR4101B"

Pin No. PR4101A	Pin No. PR4101B	Pin Name	Pin Function Description
1	n.c.	Test	For test and internal use only
2	n.c.	PwrDwn	Power Down, sleep mode for min. power consumption. When connected to GND, NDRV is clamped to GND.
3	n.c.	Delay	Not connected: Delay Start is disabled connected to GND: Delay Start is enabled
4	n.c.	PWM	If $V_{PWM} < V_{refPWM}$ the buck converter is switched off. If $V_{PWM} > V_{refPWM}$ the buck converter is switched on.
5	2	GND	Ground
6	2	SUB	Substrate has to be connected to GND for PR4101A (internally connected to GND for PR4101B)
7	3	5VHi	Internal 5V linear regulator output for high currents. Connect a capacitor of 100 nF to GND. Voltage is not for external use.
8	4	5VLo	Internal 5V linear regulator output for low currents. Connect a capacitor of 100 nF to GND. Voltage is not for external use.
9	5	Vcc	Supply voltage
10	6	VDI	Undervoltage detection pin. If unused, connect to Vcc. For use with phase fired controllers (see application notes).
11	7	NDRV	Gate connection for an external n-channel MOSFET.
12	8	VSense	Feedback for controlling the output current. Connect this pin to the series resistor R_{VSENSE} and the sense resistor R_{SENSE}. The external MOSFET is switched off when the voltage at this pin is higher than V_{SENSE}.
13	n.c.	Temp	Voltage output of the internal chip temperature sensor (over temperature protection). Please see „Electrical Characteristics" for relationship between V_{TEMP} and the chip temperature T_{CHIP}.
14	1	RTK	Softstart feature and temperature compensation of the output current. By connecting for example a NTC resistor from RTK to GND the sensing threshold voltage Vsense will be decreased depending on the NTC´s temperature. A capacitor C_{SOFT} connected to GND offers a soft ramp up of the LED current.

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Electrical Characteristics

Vcc=12 VDC, Ta = 25°C, L=470 µH (unless otherwise noted)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
Vcc	Supply voltage		7		40	[V]
VDI	Undervoltage detection Start-up Shut-off		 6.0	 7.0	 9.0	 [V] [V]
$I_{suppOFF}$	Supply current, PwrDwn=0 V			30		[µA]
I_{suppON}	Supply current, PwrDwn=open			3.0		[mA]
V_{NDRV}	Gate output voltage HIGH		3.0	3.8		[V]
$I_{OUTsource}$	Output source current at NDRV				50	[mA]
$I_{OUTsink}$	Output sink current at NDRV				20	[mA]
f_{OP}	Operating center frequency			125		[kHz]
f_{SP}	Frequency spreading			5		[%]
V_{SENSE}	Threshold voltage at R_{SENSE}	Pin RTK not connected		200		[mV]
t_{DELAY}	Delay start period (PR4101A only)			250		[µs]
V_{RefPWM}	Threshold voltage PWM input (PR4101A only)			1000		[mV]
f_{PWM}	Frequency of external PWM signal (PR4101A only)				500	[Hz]
t_{PWM}	Min. pulse duration of PWM (PR4101A only)		2			[µs]
V_{TEMP}	Output voltage of internal temperature sensor at pin TEMP (PR4101A only)	T_{chip} = 100°C T_{chip} = 0°C		1.60 2.15		[V] [V]
T_{OT}	Overtemperature protection junction temperature Shut-off Resume			 125 90		 [°C] [°C]

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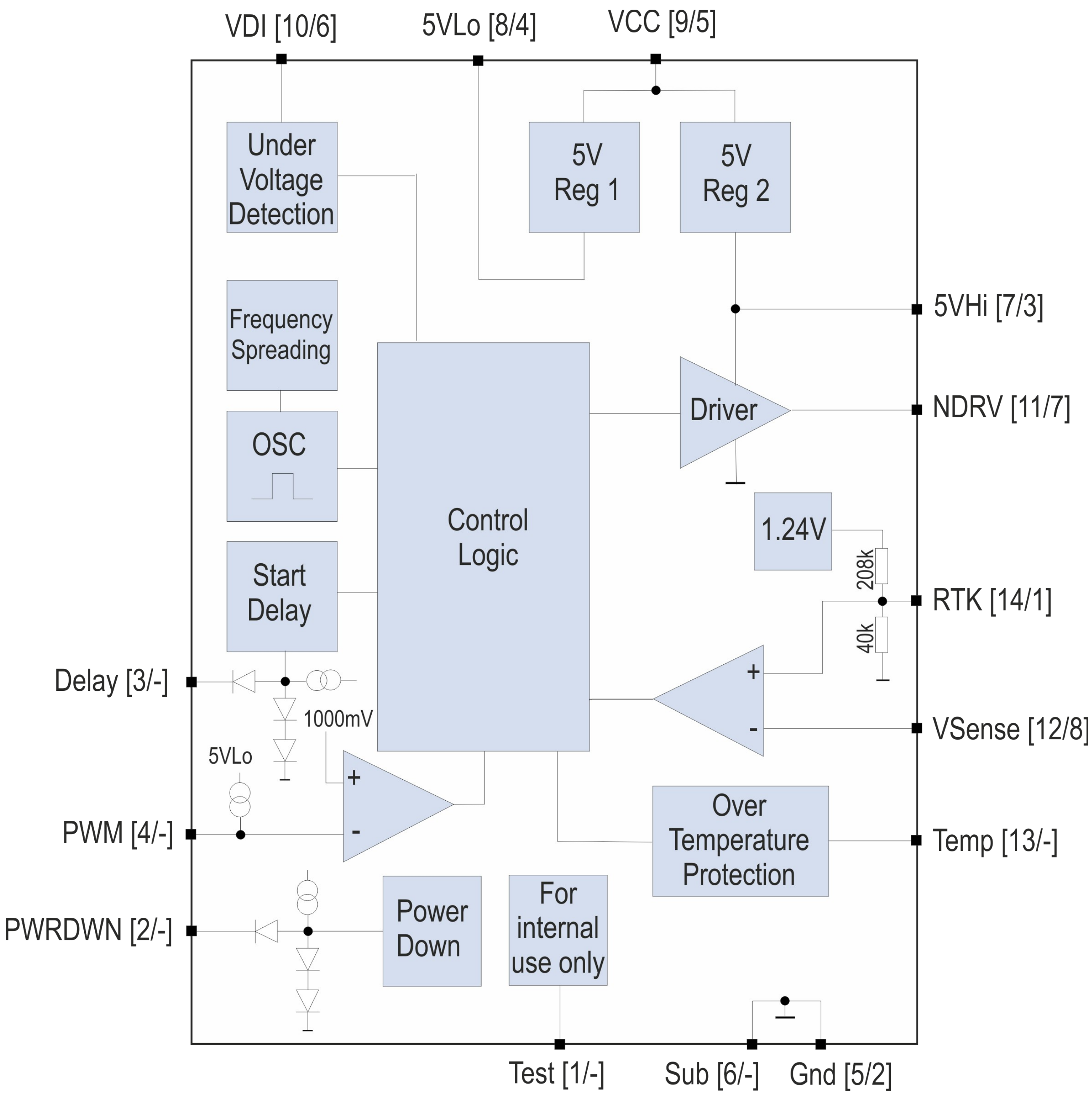
Block Diagram



[... / ...]: Pin numbers for PR4101A / PR4101B

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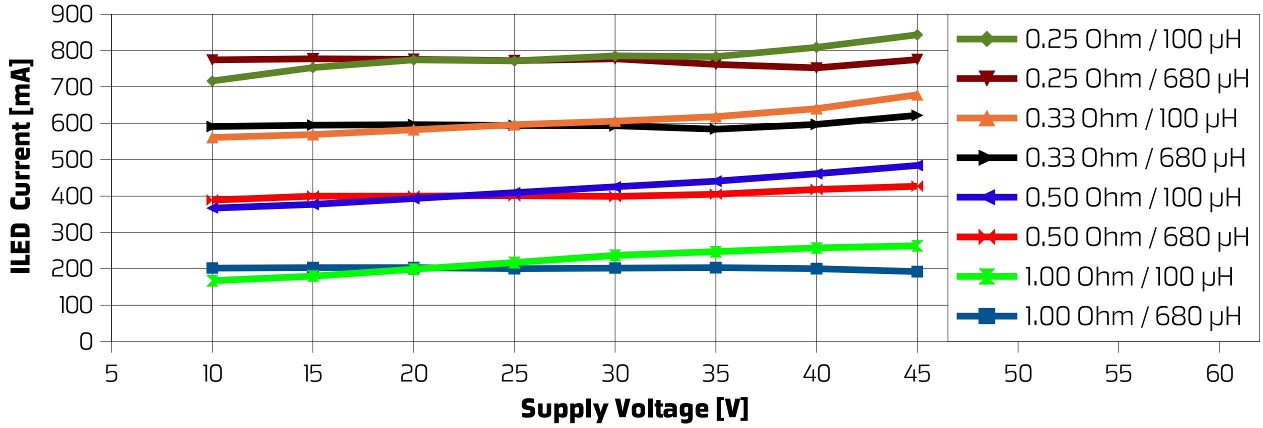
Characteristic Performance Curves

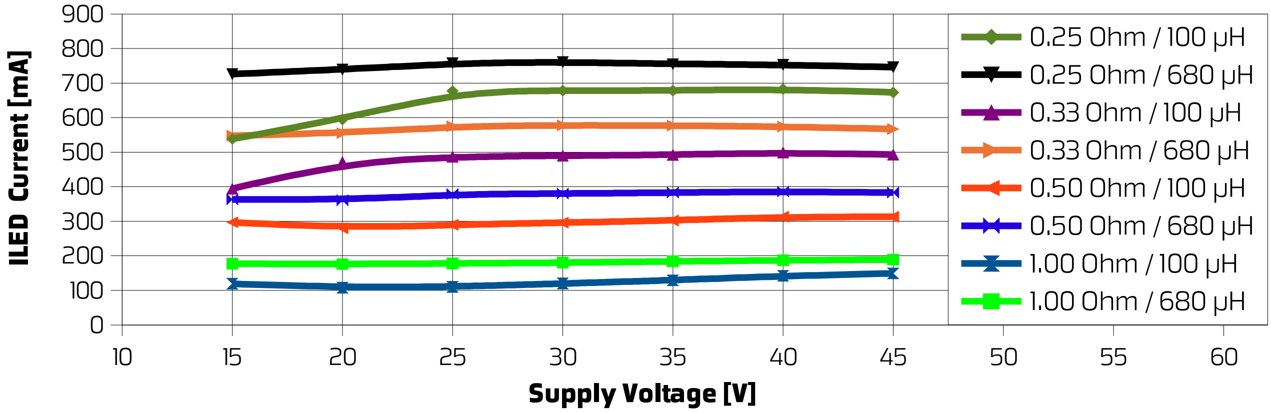
1 x 3 W LED operated by varied R_{sense} and Inductances (given in the caption)

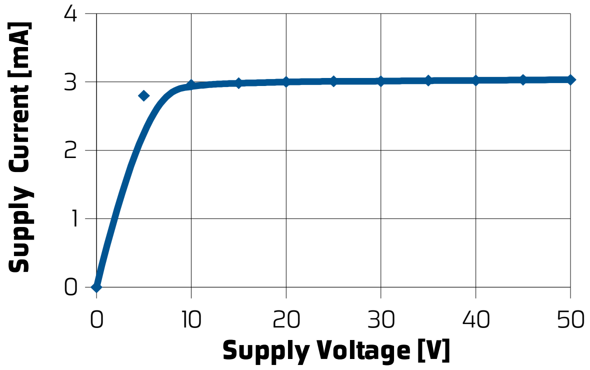
C_{IN}=470 µF, R_{VSENSE} = 1 kΩ , C_{LED} = 100 µF, $C_{5VHi/Lo}$ = 220 nF, Ta = 25°C (unless otherwise noted)

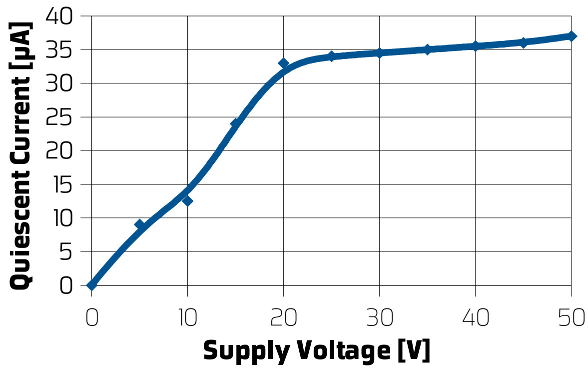


3 x 3.5 W LED operated in series by varied R_{sense} and Inductances (given in the caption)

C_{IN}=470 µF, R_{VSENSE} = 1 kΩ , C_{LED} = 100 µF, $C_{5VHi/Lo}$ = 220 nF, Ta = 25°C (unless otherwise noted)







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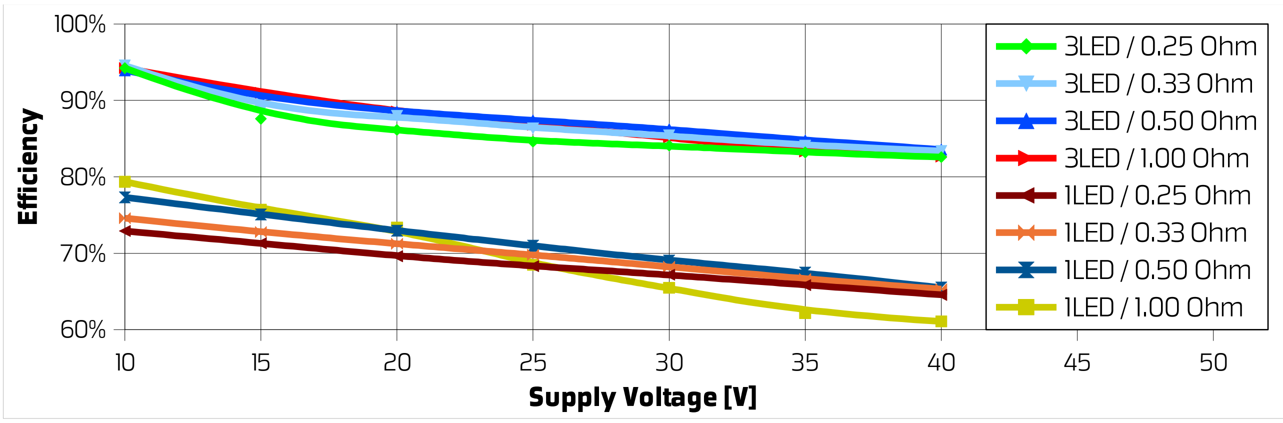
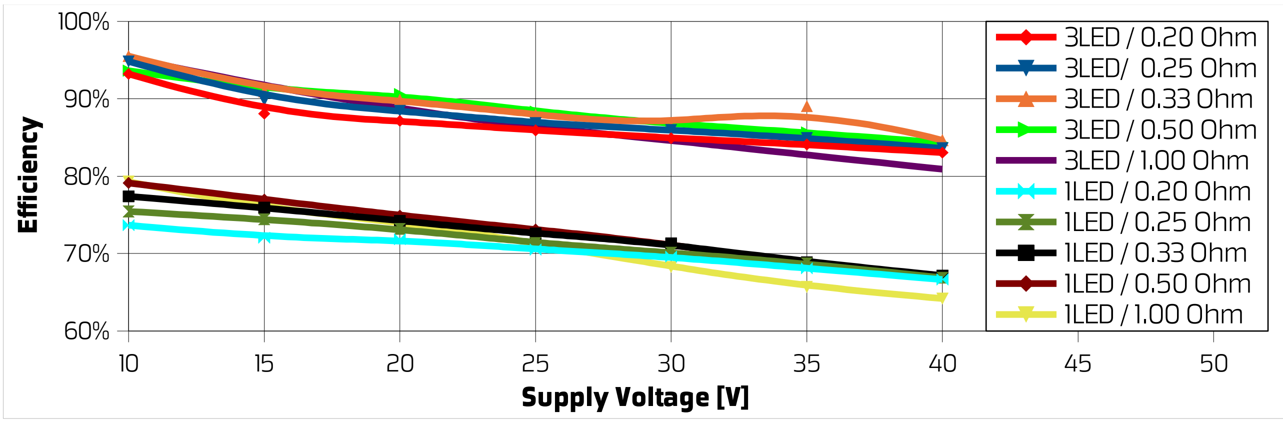
Characteristic Performance Curves

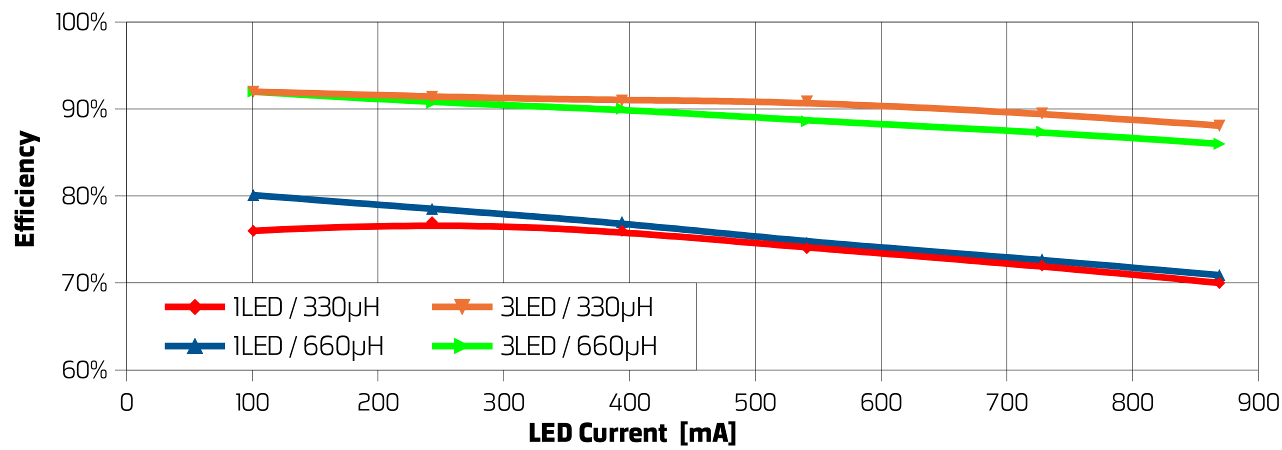
EFFICIENCIES ARE GIVEN FOR VARIED CONDITIONS USING A FIXED INDUCTANCE OF 660 µH



EFFICIENCIES ARE GIVEN FOR VARIED CONDITIONS USING A FIXED INDUCTANCE OF 330 µH



EFFICIENCIES ARE GIVEN FOR VARIED CONDITIONS USING A FIXED SUPPLY VOLTAGE OF 15 V



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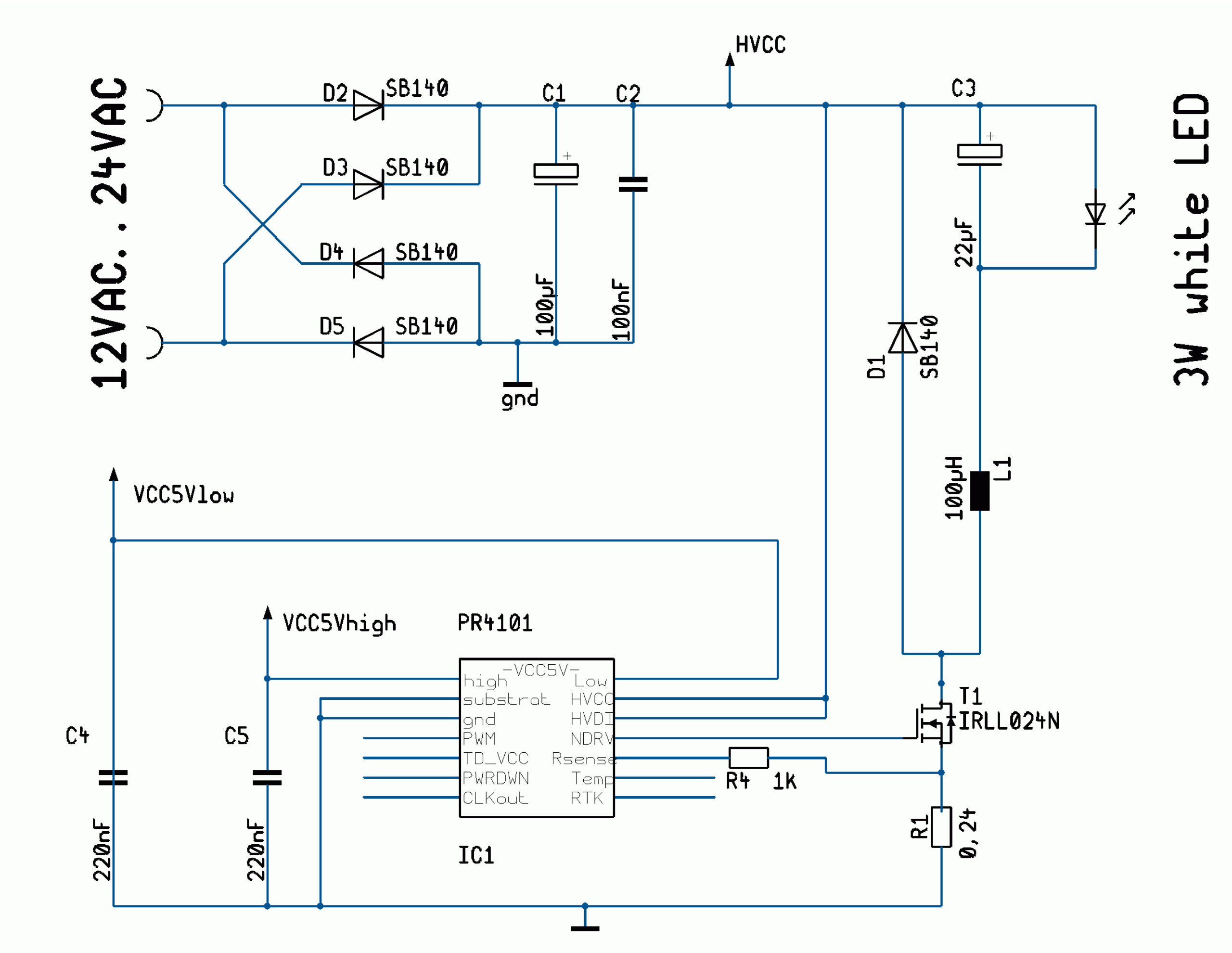
Examples for varying LED applications

TYPICAL APPLICATION WITH 12/24 VAC SUPPLY FOR A MINIMUM BOARD SIZE

The following circuit drives one LED from a 12...24 VAC supply. This circuit uses the PR4101B in SOP8 package and is optimized for a low number of small-sized external components to have a small PCB.
LED and driver are supplied from the full-wave rectified and smoothed voltage. Ripples on the supply should be small enough to avoid a period in which the voltage becomes lower than the LED forward voltage, or below the undervoltage shut-off (see specification of VDI).
The undervoltage detection pin VDI is connected to Vcc.



With R_{SENSE} = 0.24 Ω as in the diagram, the LED current is approx. 850 mA. For other currents see below Selection of R_{SENSE}.

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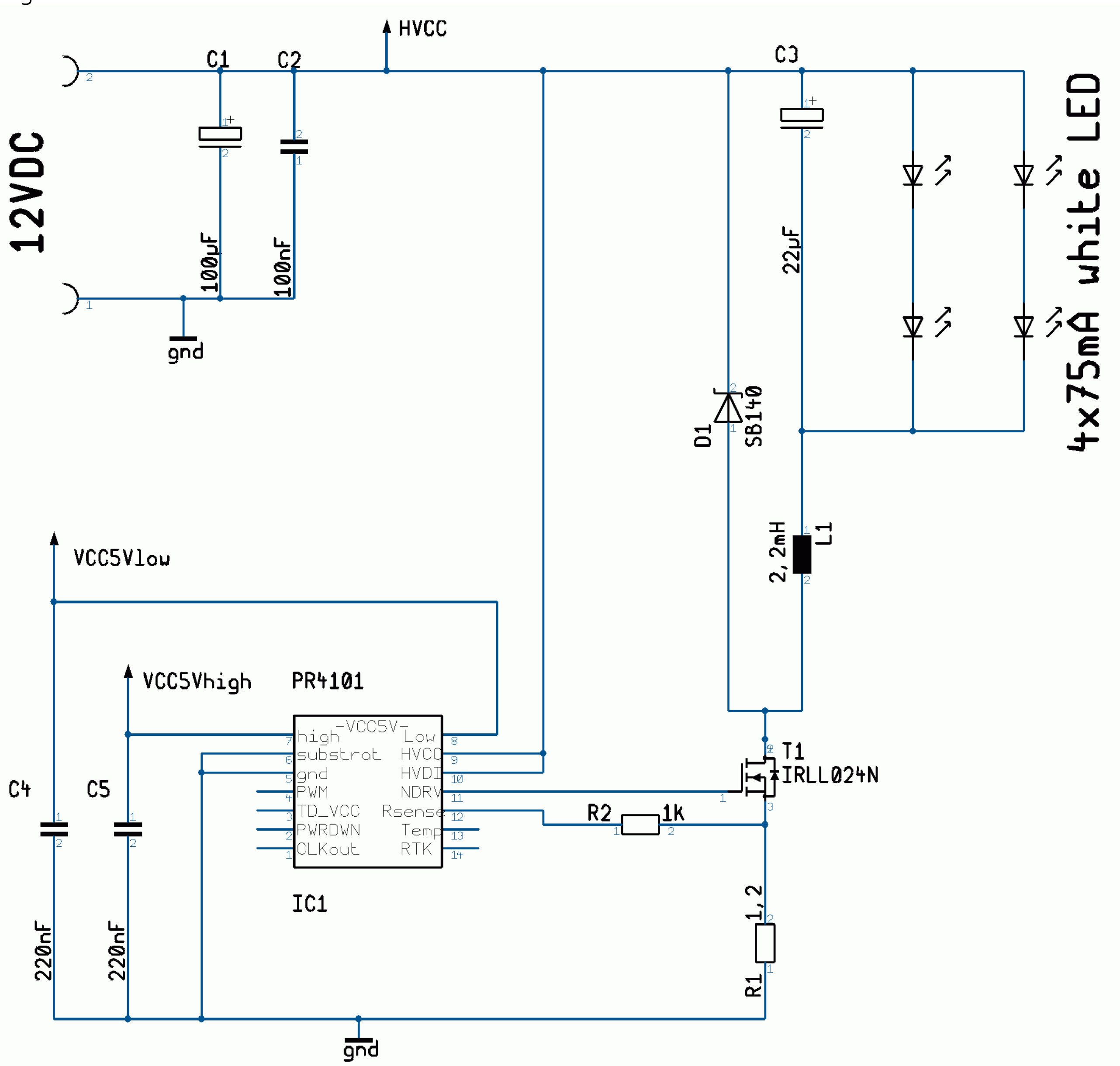
Examples for varying LED applications

TYPICAL APPLICATION WITH 12 VDC SUPPLY

The shown circuit drives 2 strings of 2 LEDs in series from a 12 VDC supply. The minimum supply voltage is given by the forward voltage of the LEDs, the DC resistance of the inductor, and the R_{DSon} of the FET. As a rule of thumb, in most cases the supply voltage should be at least 2 V higher than the forward voltage of the LEDs. Assuming a V_F of 3.5 V per LED, this means that the circuit will work with a supply of 9V and higher.



As there are two strings of LEDs in parallel, the forward voltage of the LEDs must be matching to avoid an unequal current distribution.

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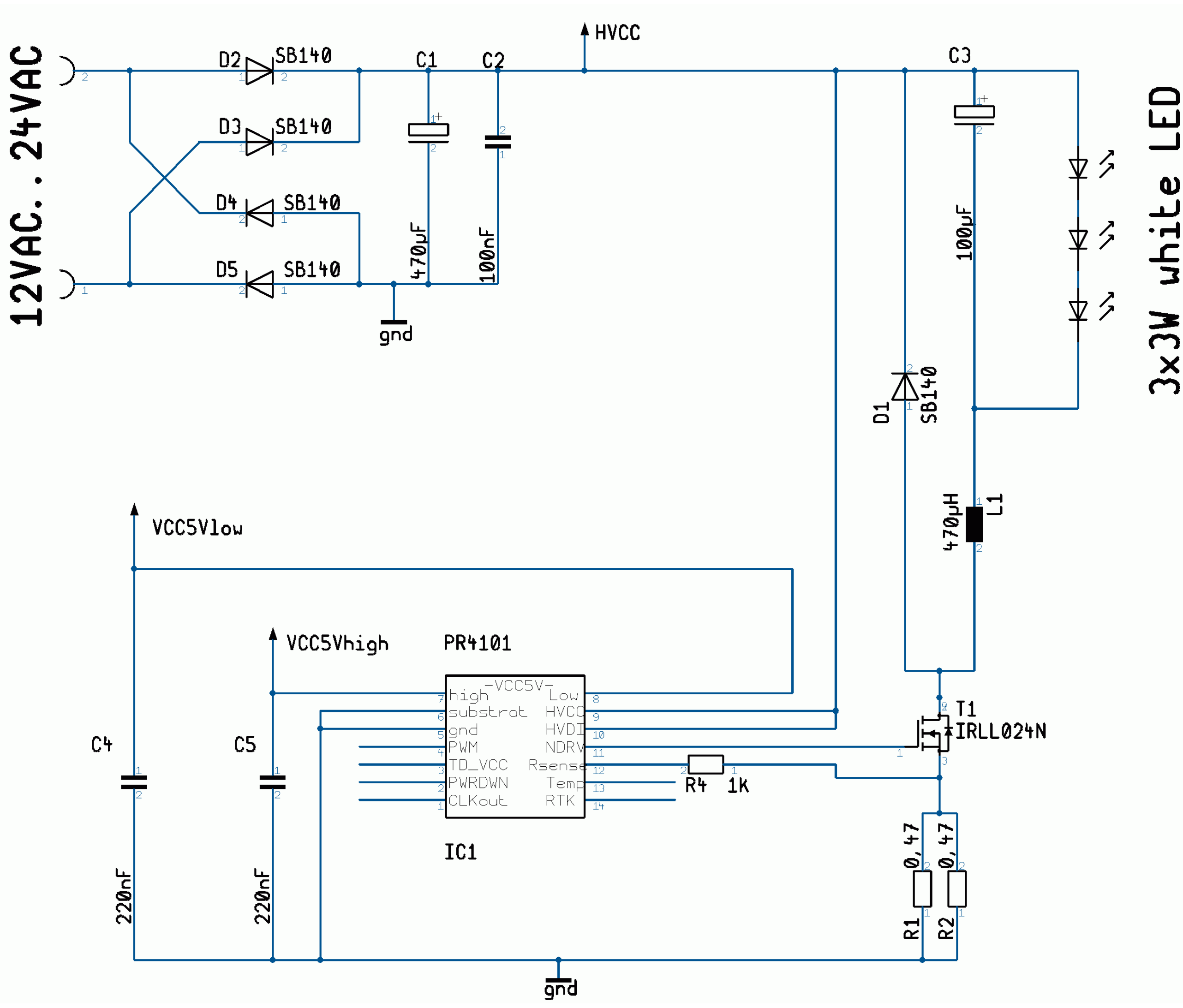
Examples for varying LED applications

TYPICAL APPLICATION WITH 12 VAC SUPPLY

The following circuit drives three LEDs in series from a 12...24 VAC supply. LED and driver are supplied from the full-wave rectified and smoothed voltage. Ideally, after the full-wave rectifier, Vcc is VAC x 1.41, which is sufficient to drive three LEDs in series from VAC = 12 V. Ripples on the supply should be small enough to avoid a period in which the voltage becomes lower than the LED forward voltage, or below the undervoltage shut-off (see specification of VDI).
The undervoltage detection pin VDI is connected to Vcc.



With R_{SENSE} = (0.47/2) Ω as in the diagram, the LED current is approx. 850 mA. For other currents see below Selection of R_{SENSE}.

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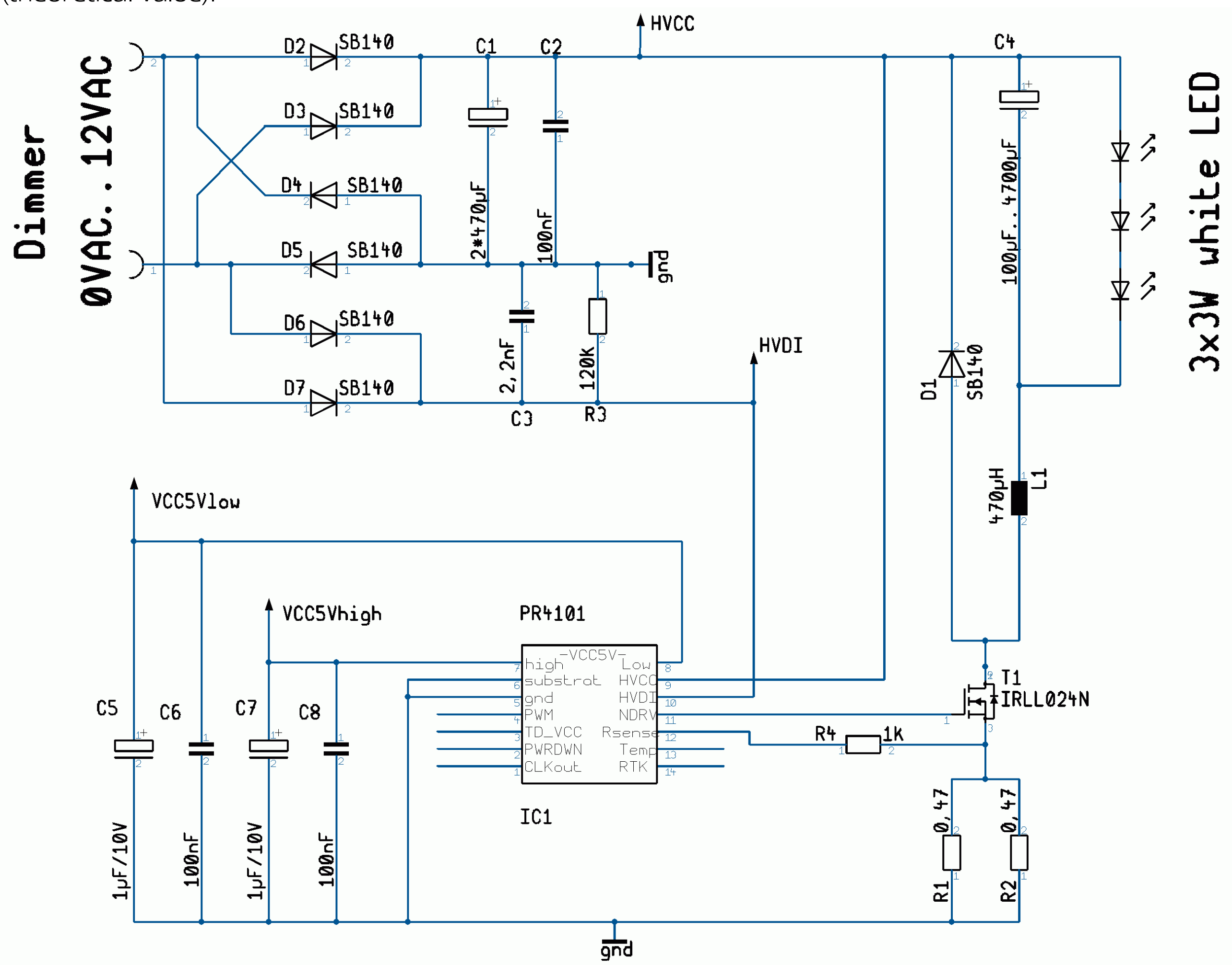
Examples for varying LED applications

TYPICAL APPLICATION WITH 12 VAC SUPPLY AND PHASE CUT DIMMERS

The circuit shown next allows dimming with phase-fired control by a conventional thyristor dimmer, operation with electronic dimmers and electronic transformers is also possible. The PR4101 is dimmable with leading and trailing edge phase control. In this application the undervoltage detection pin VDI is connected to the rectified, but unsmoothed AC, allowing to sense the pulse width of the phase-cut supply. In this way the converter is shut off in the phase cut out by the phase fired controller, even if the smoothed supply at Vcc holds a sufficient voltage level, and the LED brightness is dimmed in a way similar to that of a conventional filament bulb.

Even without phase cutting, there is a period in which VDI falls below the undervoltage shut-off threshold, shutting the LED down in this period until the voltage reaches the startup threshold again. Therefore in the application shown the effective LED current is reduced against the circuit with VDI connected to the smoothed DC supply, e.g. at 12 VAC/50 Hz it is 68 % of the nominal brightness (theoretical value).



C3/R3 serves as a filter for high frequencies, e.g. from power supplies with switching regulators, that would interfere with the regulator loop of PR4101.

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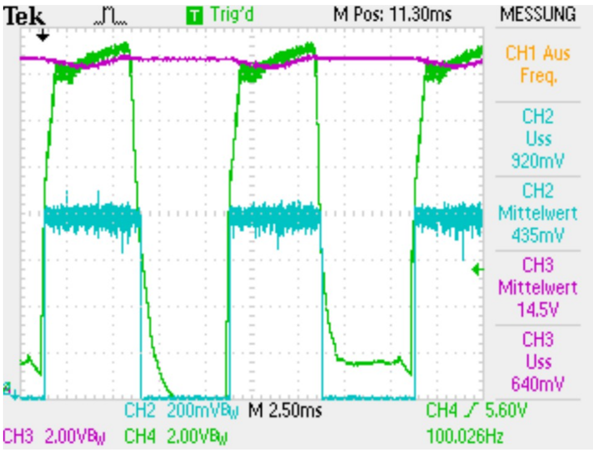
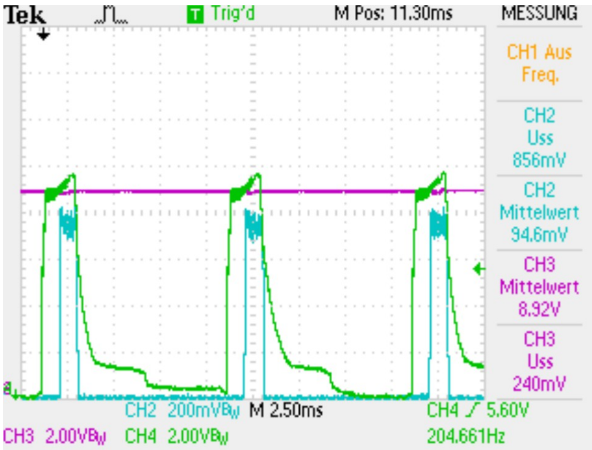
Further Information

TYPICAL APPLICATION WITH 12 VAC SUPPLY AND PHASE CUT DIMMERS





Supply from phase-fired SCR dimmer. Different duty cycles on VDI signal.

--- Vcc
--- VDI signal
--- LED current (voltage at a 1Ω resistor)

Measured with:

Vcc = 12 VAC	C_{LED} = C4 = 100 µF
$C_{5VHi/Lo}$ = 220 nF	C3 = 2,2 nF,
R3 = 100 kΩ	C_{IN} = C1 = 2000 µF
L = 470 µH	R_{SENSE} = 0.25 Ω
LED: 1 x 3W (Luxeon)	

Cutting at large phase angles reduces both the average supply voltage Vcc and also the VDI voltage. If it falls below the forward voltage of the LEDs, or below the undervoltage threshold, the circuit stops working. The right diagram shows the case at which the supply voltage and therefore also the VDI signal is close to the VDI threshold.

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A further Dimming Opportunity

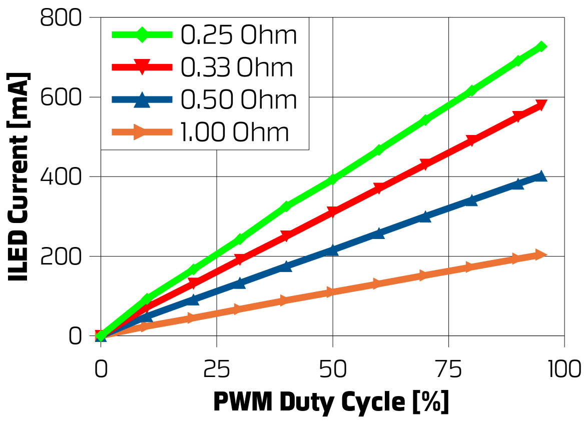
PWM CONTROL (ONLY PR4101A)

Brightness can also be controlled by an external PWM (pulse width modulation) signal via the PWM pin.
In this way a wide dimming range can be achieved. The device will be turned off and on depending on the duty cycle of the control signal resulting in a proportional average output current. The PWM pin can be driven directly from a micro controller output or with a NPN transistor. The average output current will be

$I_{LED\,AVG}=I_{LED\,nom}\cdot D$ with the duty cycle D:

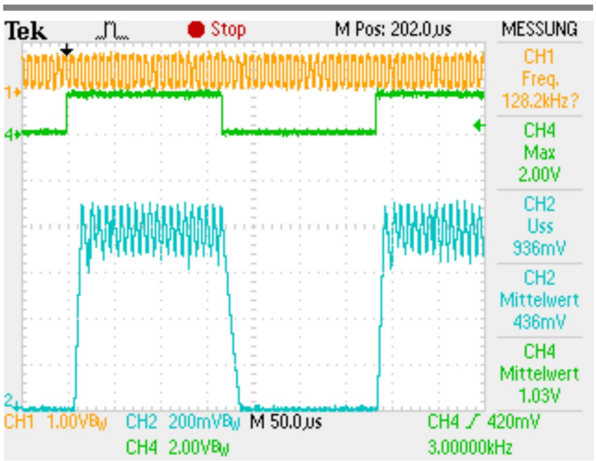
$$D=\frac{T_{OFF}}{(T_{ON}+T_{OFF})}$$

A PWM frequency of 500 Hz, or lower is recommended, to minimize linearity errors due to the rise and fall times of the converter output. In the following, the LED mean current vs. PWM duty cycle at a PWM frequency of 500 Hz is shown for different values of Rsense:

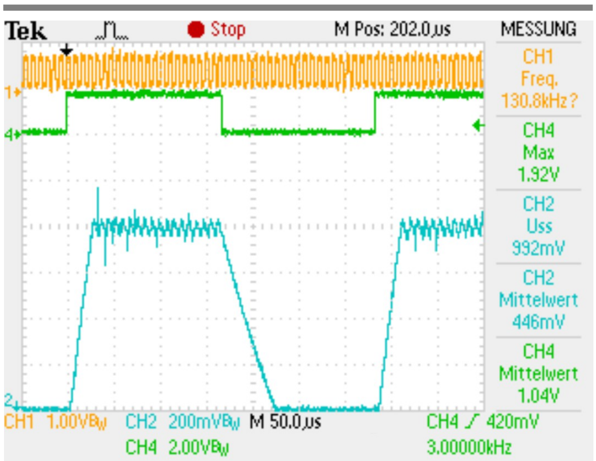


1 x 1 W LED; PWM @ Vcc = 40 V

PWM controlled with L = 100 µH



PWM controlled with L = 330 µH



--- PWM
--- LED current, voltage at a 1Ω resistor
--- clock signal (test pin)

Conditions:
duty cycle = 50 %
C_{IN} = 470 µF
C_{LED} = 100 µF
$C_{5VHi/Lo}$ = 220 nF
Vcc = 15 V
R_{SENSE} = 0.25 Ω
1 x 3 W Luxeon LED

Behaviour at a PWM frequency of 3000 Hz with two different inductors. The slow reaction, especially with the 330 µH inductance, causes a non-linearity in brightness vs. PWM duty cycle, limiting the recommended PWM frequencies to < 500 Hz, depending on the duty cycle range required. For operation with PWM control the inductance should be as small as possible, but on the other hand, also the LED current ripple will increase, as can be seen by comparison of the two graphs. Therefore it is important to find a compromise between current ripple, PWM frequency and duty cycle range.

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Application Notes

SELECTION OF THE INPUT CAPACITOR C_{in}

The input capacitor is necessary in case of AC supply voltages to smooth the supply voltage. A value between 100 µF and 4700 µF for normal AC and of 470 µF up to 10000 µF for phase-cut supply voltages is recommended.
In parallel a 100 nF capacitor should be placed close to the IC supply pins.
Step-down regulators draw current from the input supply in pulses with very fast rise and fall times. The input capacitor is also required to reduce the resulting voltage ripple at the PR4101 input and to force this switching current into a tight local loop, minimizing EMI. The input capacitor must have a low impedance at the switching frequency to do this effectively, and it should have an adequate ripple current rating.

SELECTION OF INDUCTOR AND C_{LED}

Selection of the inductor value depends a lot on the supply voltage, the number of connected LEDs, but also on the allowed current ripple and the desired efficiency. For a smaller LED current higher values above 660 µH should be used. In case that a minimized board size is desired inductor values around 100 µH may be selected but efficiency and LED current ripple are not optimized in this case. The saturation current of the inductors must be higher than the LED peak current. A low DC resistance of the coil avoids additional loss of efficiency.
A capacitor value of CLED between 22 µF and 1000 µF in parallel to the LED is recommended to reduce the LED current ripple and avoid exceeding the LED current rating.

SELECTION OF EXTERNAL MOSFET

The n-channel MOSFET must have a gate threshold voltage of less than 3 V and a low ON resistance. A recommended transistor is the International Rectifier IRLL024N. To improve the behaviour of the module, long lines between the IC and the transistor should be avoided.

SELECTION OF THE EXTERNAL DIODE

A Schottky diode with fast recovery is needed to reduce the voltage drop. The diode must be able to carry the LED current flowing during the OFF time of the driver. The reverse voltage of the diode should be higher than the input voltage.

DELAY START FEATURE (only PR4101A)

A delayed start is possible by connecting the pin Delay to Gnd. Within the delay start period the output current is switched off. After the delay start period the output current rises to 100 % of the nominal current. The delay start period is fixed and cannot be changed by external components.

SELECTION OF R_{VSENSE} AND R_{SENSE}

The input V_{SENSE} needs a series resistor R_{VSENSE} = 1 kΩ while the LED current is defined by the selection of R_{SENSE}. The nominal value of the current sense resistor can be calculated with the following formula:

$$R_{SENSE} = \frac{V_{SENSE}}{I_{LED}}$$

The value of V_{SENSE} can be found in „*Electrical Characteristics*".

For example: With an LED current of 1 A and V_{SENSE} =200 mV, R_{SENSE} has a value of 200 mΩ.
The following table gives some resistor values

LED Current	R_{SENSE}
350 mA	0.571 Ω
700 mA	0.286 Ω
1000 mA	0.200 Ω

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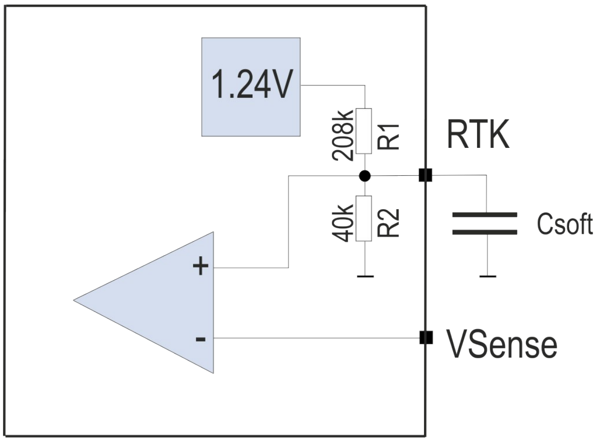
Application Notes

SOFT START

With an external capacitor at RTK the output current can ramp up continuously within a programmable period.

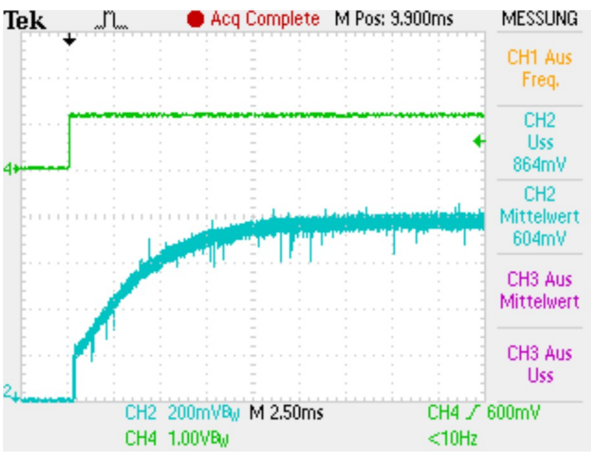


The following table gives some capacitor values:

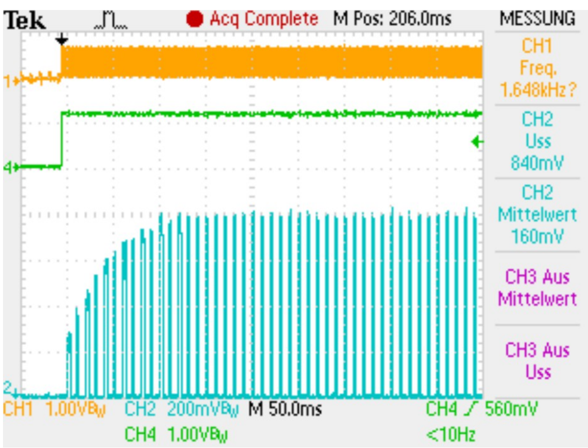
Soft Start Time	C_{SOFT}
10 ms	100 nF
100 ms	1 µF
3 s	22 µF

It is possible to combine temperature compensation and softstart functionality. A soft start is triggered by a reset that is initiated either by applying the supply voltage, or by starting the IC up with the PWRDWN signal.
Passing the threshold at VDI does not trigger the soft start however, therefore supply by a phase-cut voltage from a dimmer does not interfere with soft start - see oscilloscope diagram.

CORRESPONDING OSCILLOSCOPE IMAGES



Softstart on RTK, C_{SOFT} = 100 nF



Softstart on RTK, C_{SOFT} = 1 µF
(phase-cut input voltage)

--- Vcc
--- PwrDwn

--- LED current (voltage at a 1Ω resistor)
--- clock signal (test pin)

Measured with C_{IN} = 470 µF, L = 470 µH, 1 x 3 W Luxeon LED, C_{LED} = 100 µF, Vcc = 15 V, $C_{5VHi/Lo}$ = 220 nF, R_{SENSE} = 0.25 Ω

Supply by a phase-cut voltage from a dimmer does not interfere with soft start - see right diagram.

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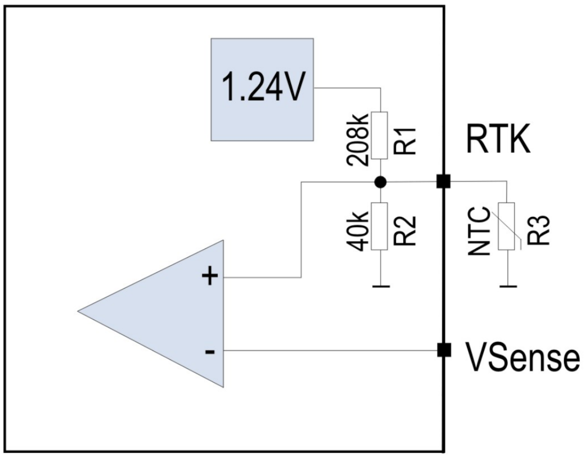
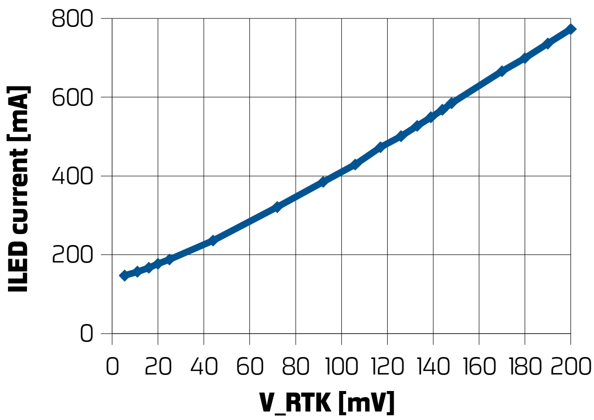
Application Notes

TEMPERATURE COMPENSATION OF THE OUTPUT CURRENT



The NTC changes the voltage at RTK, thus influencing the VSense threshold and the LED current.

High brightness LEDs often need to be supplied by a temperature compensated current in order to get a stable and reliable operation also at higher temperatures. This is normally achieved by reducing the LED current proportionally from its nominal set value when the LED temperature rises above a predefined threshold. For this thermal compensation an NTC resistor at the RTK pin can be used to sense the temperature. The NTC value has to be selected according to the application requirements. For many purposes a nominal value around 470 kΩ is suitable.



The relationship between the voltage at RTK and the LED current (1 x 1 W) for Rsense = 0.25 Ω is shown. The nominal RTK voltage without NTC is 200 mV

OVER TEMPERATURE PROTECTION (only PR4101)

An internal temperature sensor detects the chip temperature. Over temperature is detected at T_{OFF}, then the NDRV and the 5VHi-regulators are switched off and switched on again at a chip temperature of T_{ON}. The voltage V_{TEMP} at the pin TEMP relates to the internal chip temperature, please see „Electrical Characteristics".

FREQUENCY SPREADING

To reduce the EMI of the converter the switching frequency is varied in a range around the center frequency. This decreases the EMI power density that is otherwise concentrated at a single clock frequency.

OPERATION WITH INSUFFICIENT VOLTAGE

In operation with several LEDs in series, it is possible that the supply voltage is higher than the undervoltage detection threshold, but insufficient to drive the programmed LED current because of the LED forward voltage. Then the desired LED current can obviously not be reached.
In this case the MOSFET is permanently switched through, allowing the maximum LED current possible, but always less than the current setpoint.
PWM control does not work in this mode.
When the supply rises, the converter will resume normal operation.
In any mode the converter can be safely switched off with the PwrDwn signal.

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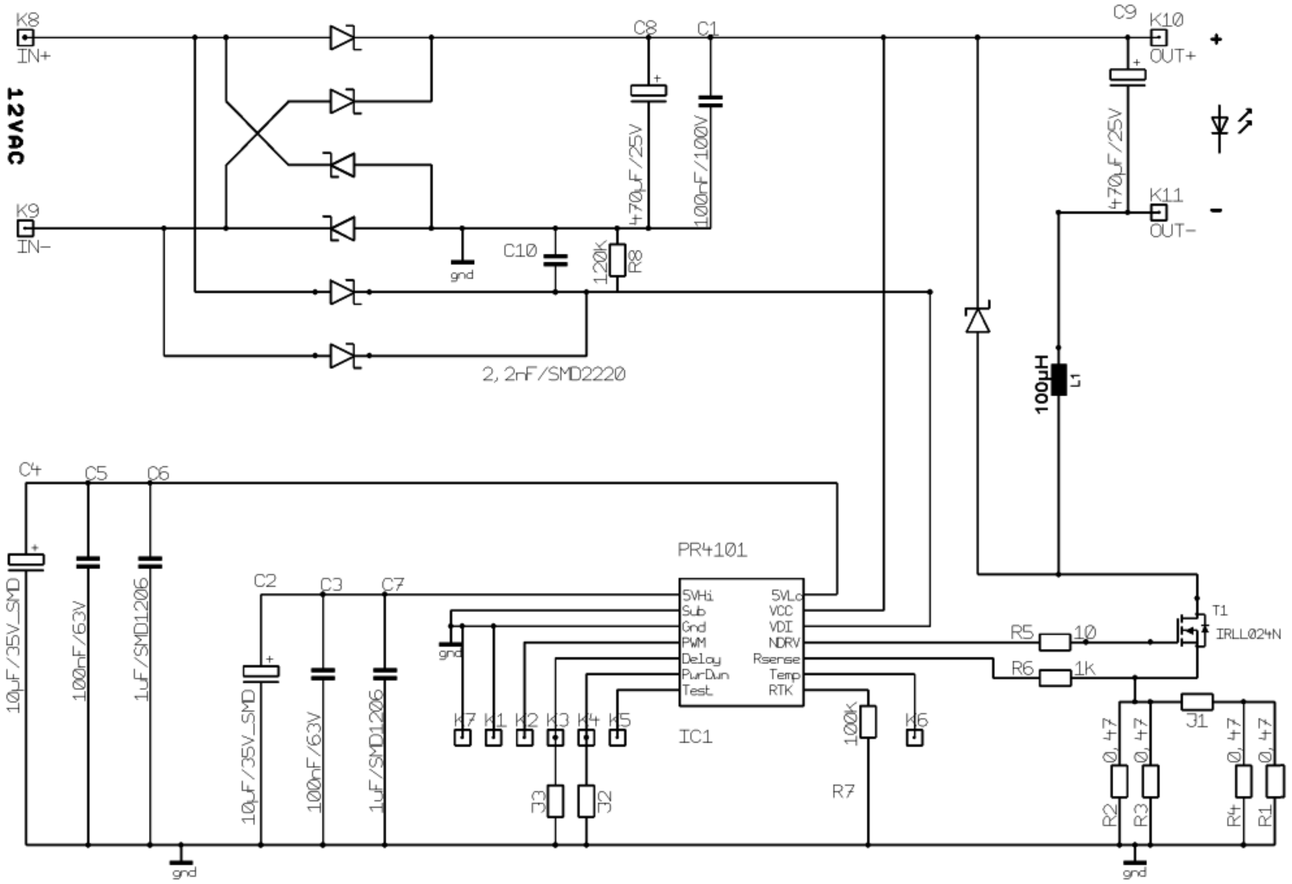
Demoboard

For PR4101 a demoboard is available that shows the operation of the components. Here, a LED driver and several power LEDs are replacing halogen lamps. At the pins IN+ and IN- an AC voltage up to 24 V or a DC voltage from 9 V up to 35 V can be supplied. Several LEDs can be connected, the potental number depends on the input voltage. The demoboard includes a bridge rectifier, necessary capacities, an external MOS transistor, a sense resistor and an inductor. The size of the board is 35 x 35 ± 2 mm.

SCHEMATIC DIAGRAM



LIST OF COMPONENTS

Name	Value	Descriptions
D1 – D7	40 V / 1 A Schottky diode MBRS140	
C1	100 nF /100 V	Cin
C3 / C5	100 nF/63 V	
C8 / C9	100 µF/35 V electrolytic capacitors	if higher current ripples are allowed, C9 (Cled) is not needed
C10	2.2 nF	

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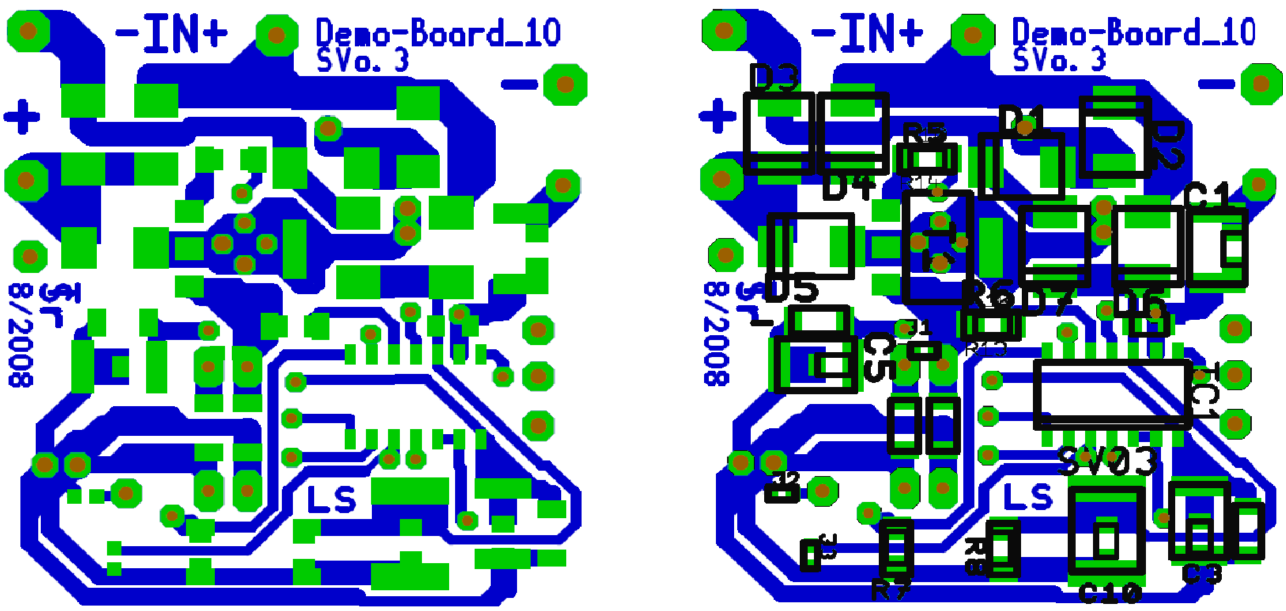
R2 / R4 R1 / R3	1.2 Ω / 1 % 1 Ω / 1 %	Rsense
R5	10 Ω	10 Ω resistor as a shunt for current measurements
R6	1 kΩ	Rvsense
R8	120 kΩ	Together with C10 a low pass filter for operation with electronic transformers
L1	220 µH, WE-PD Type L (Würth)	
IC1	PR4101A (PREMA)	SO14 package
T1	IRLL024N (International Rectifier)	External NDMOS switch
J1	Sets Rsense	Solder bridge (open) Open: Iled around 350 mA* (Rsense = 0.54 Ω) Closed: Iled around 700 mA* (Rsense =0.27 Ω)
J2	Activates PwrDwn	Solder bridge (open)
J3	Activates Delay	Solder bridge (open)
J4	Dimming operation	Solder bridge (open), close for deactivate dimming operation

* LED current can vary and depends on supply voltage and number of LEDs

DEMOBOARD

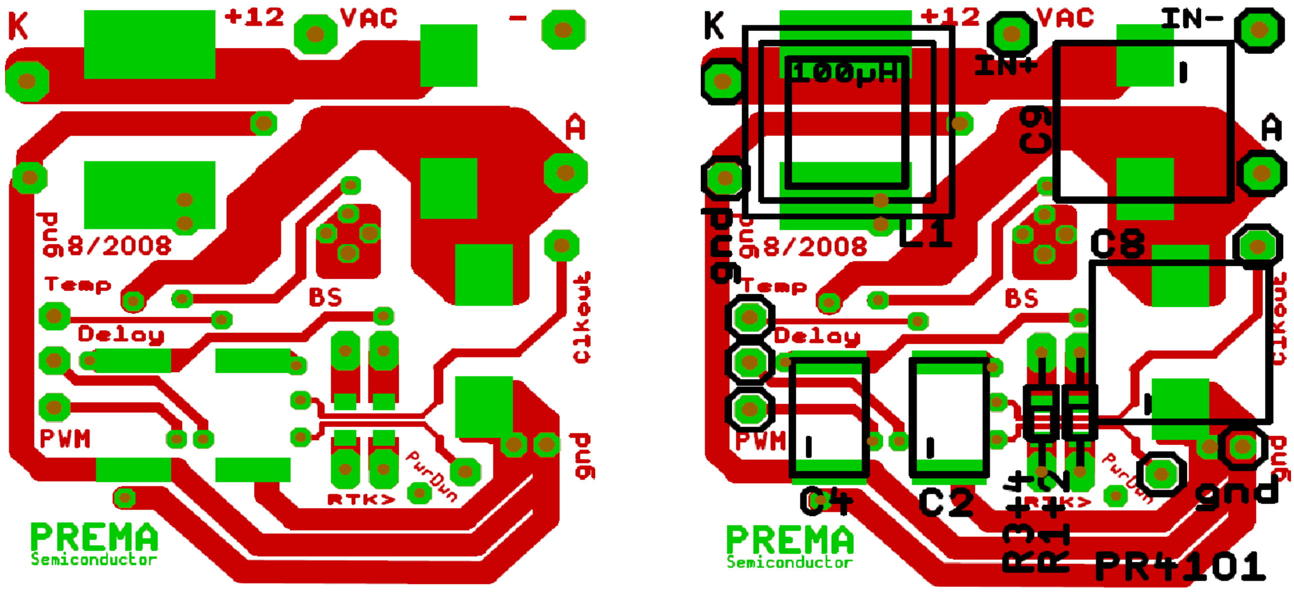
1st SIDE



LED Driver PR4101

Demoboard

2nd SIDE

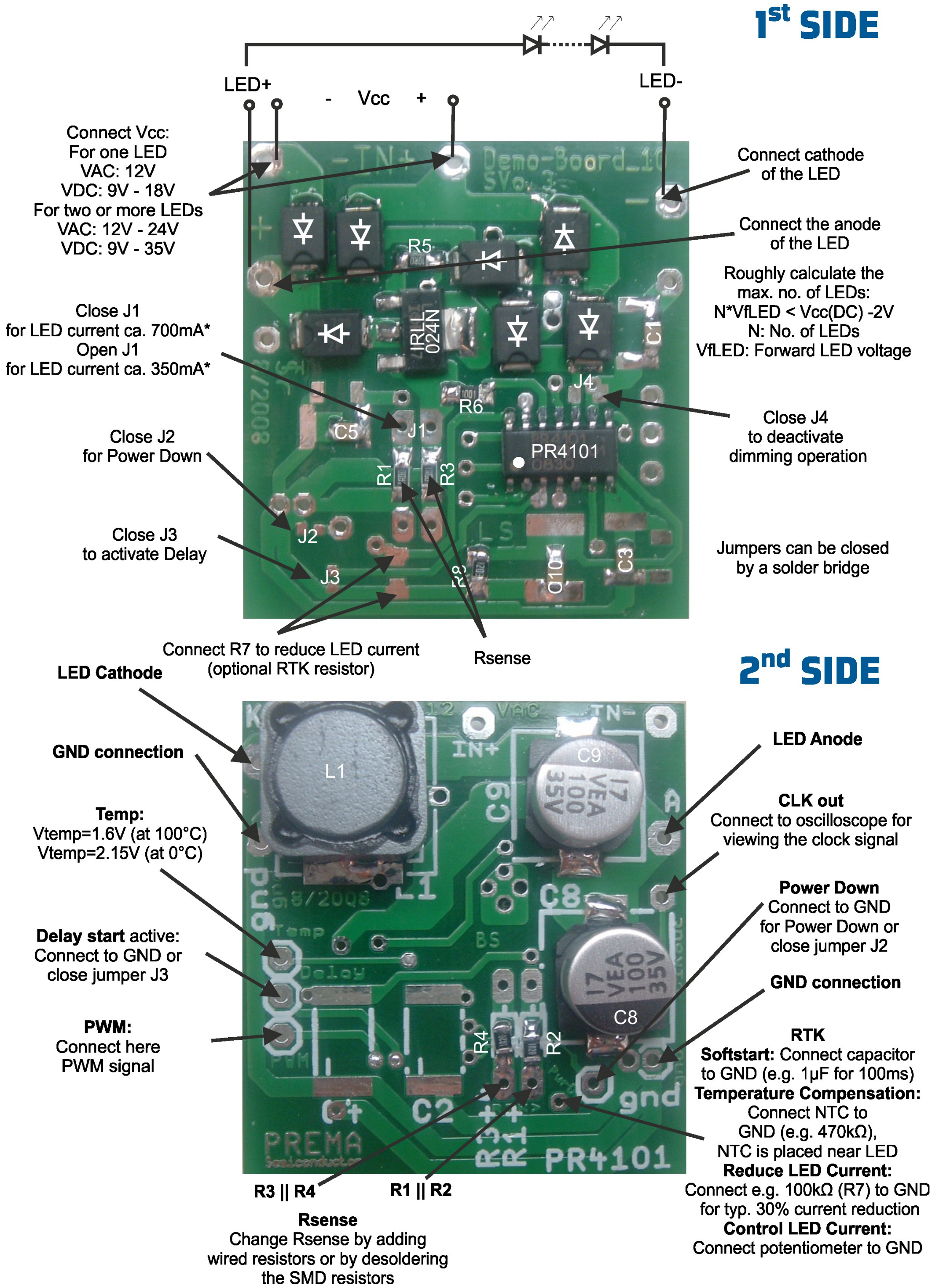


CONNECTIONS

Name	Description
IN + / IN -	Connect Vac up to 24 V or Vdc from 9 V up to 35 V
LED + / A	Connect the anode of the LED
LED - / K	Connect the cathode of the LED

LED Driver PR4101

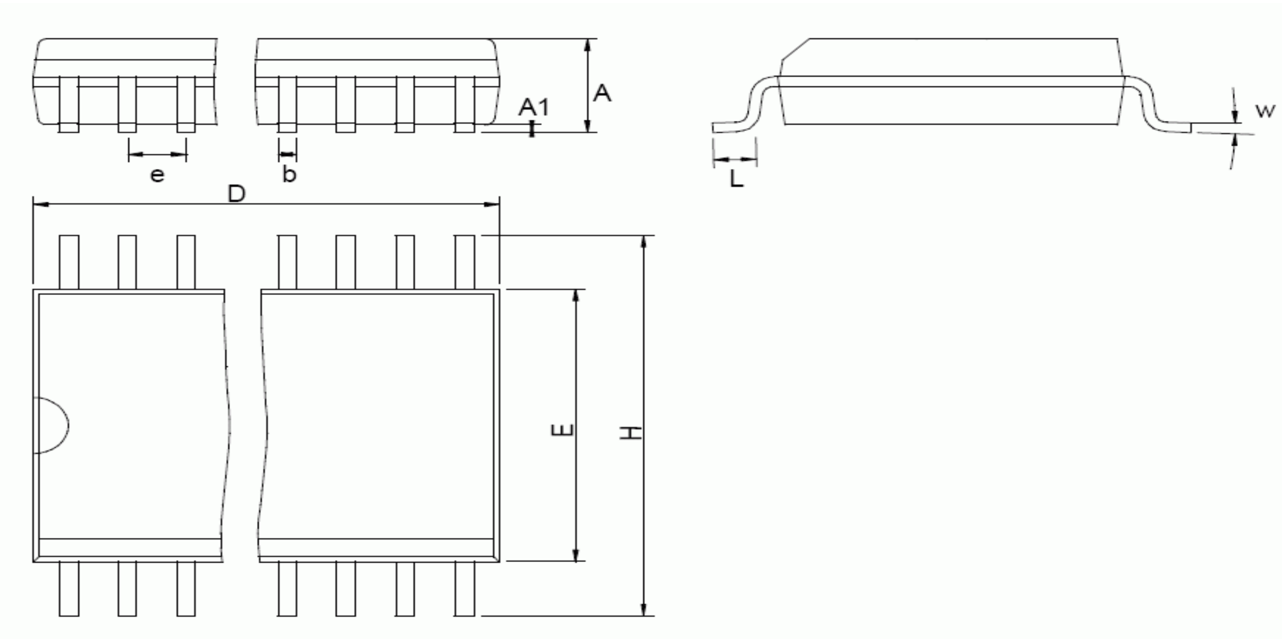
Demoboard



LED Driver PR4101

Available Package

TECHNICAL DRAWING



Package type: SOP 08L (PR4101B) or SOP 14L package (PR4101A)
Delivery in die form upon request.

Package		D	E	H	A	A1	e	b	L	Copl.	w
SOP 08L	Nom	4.90	3.90	6.00	1.75	0.15	1.27	0.41	0.72		4°
PR4101B	max									0.10	
SOP 14L	Nom	8.65	3.90	6.00	1.75	0.15	1.27	0.41	0.72		4°
PR4101A	max									0.10	

ALL PARTS DELIVERED, COMPLY WITH RoHS. FINISH IS PURE TIN.

Pb-free   pure tin

LED Driver PR4101

Disclaimer

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

PREMA Semiconductor GmbH
Robert-Bosch-Str. 6
55129 Mainz   Germany
Phone: +49-6131-5062-0
Fax: +49-6131-5062-220
Email: prema@prema.com   Web site: www.prema.com