

High Power LED Buck Driver PR4101

The PR4101 is a LED buck driver for driving one or several high power LEDs in series. The supply voltage can be up to 40V, with an output current of more than 1A 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.

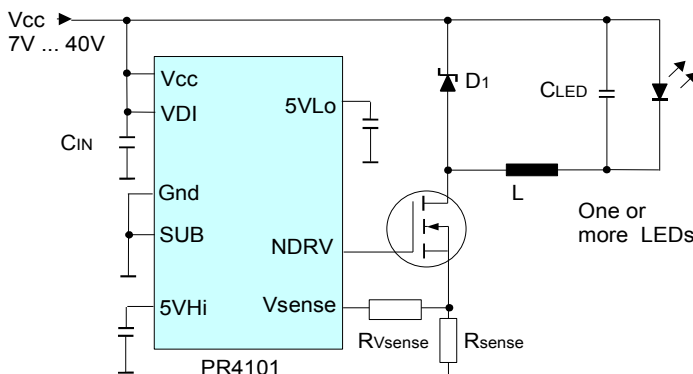
Features

- Adjustable output current of several amps
- Supply voltage up to 40V
- 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 <math>< 35 \mu\text{A}</math>
- Under voltage lockout

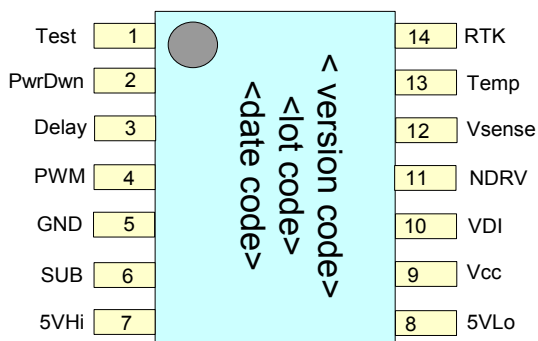
Applications

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

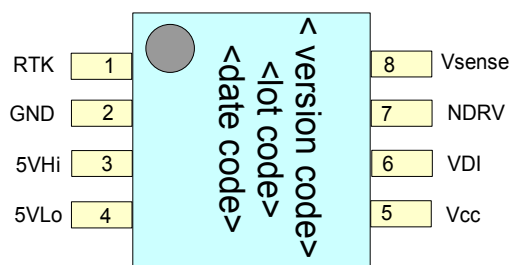
Typical Application



Pin Configurations



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



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

Pin Description

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 V_{sense} 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.

Absolute Maximum Ratings

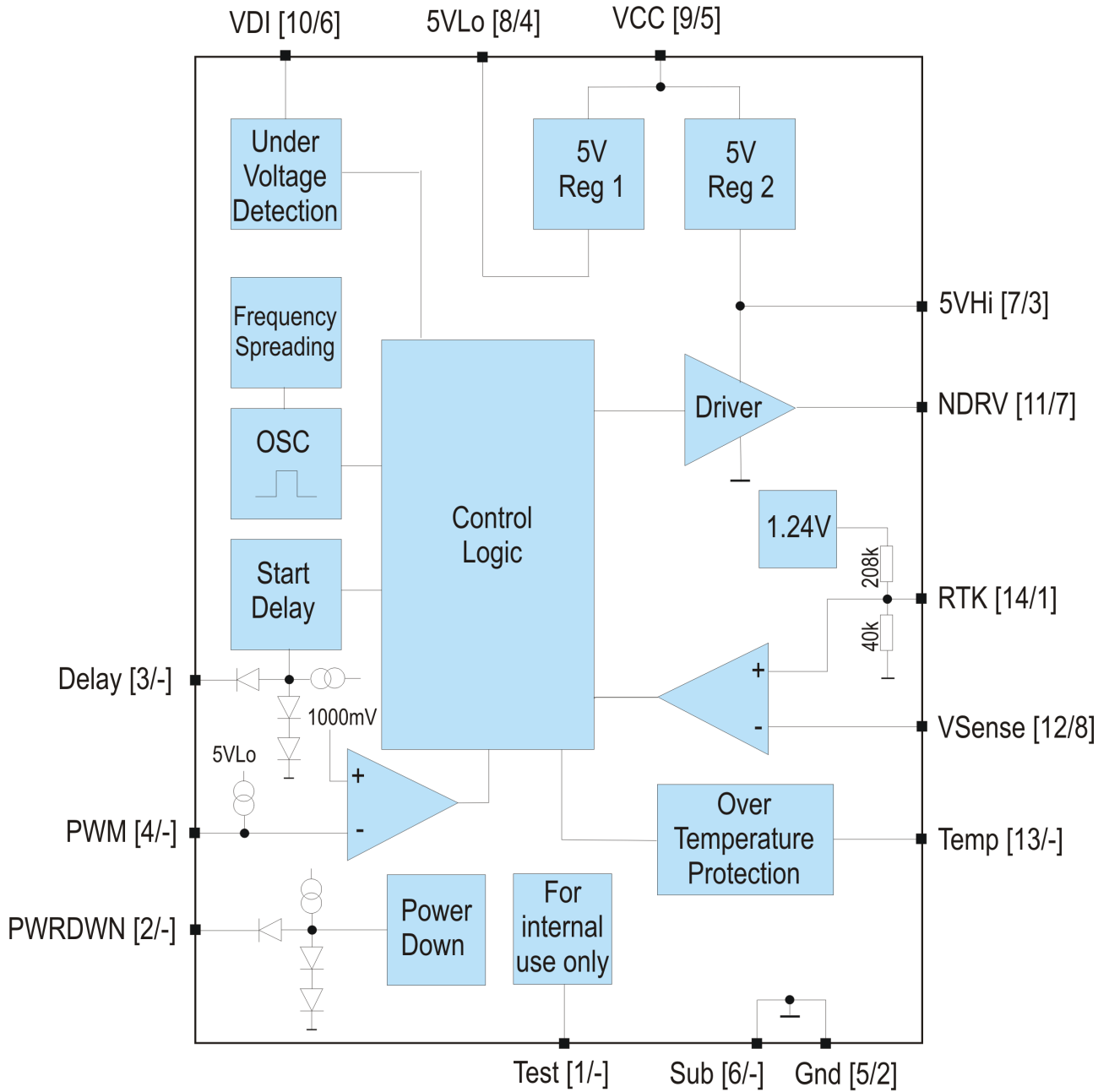
Parameter	Min	Typ	Max	Units
VCC, VDI (no damage)	-0.3		50	V
All other pins			14	V
Operating Chip Temperature Range (over temperature protection)	-20		125	°C
Storage Temperature Range	-55		150	°C
Electrostatic Discharge (ESD) Protection	2			kV

Electrical Characteristics

V_{CC}=12VDC, T_a = 25°C, L=470 µH (unless otherwise noted)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V _{CC}	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=0V			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

Block Diagram



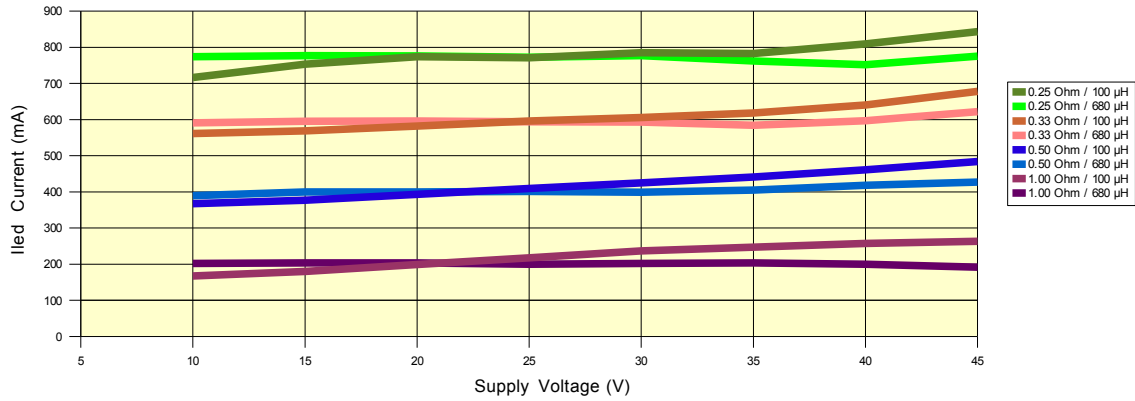
[... / ...]: Pin numbers for PR4101A / PR4101B

PR4101 data

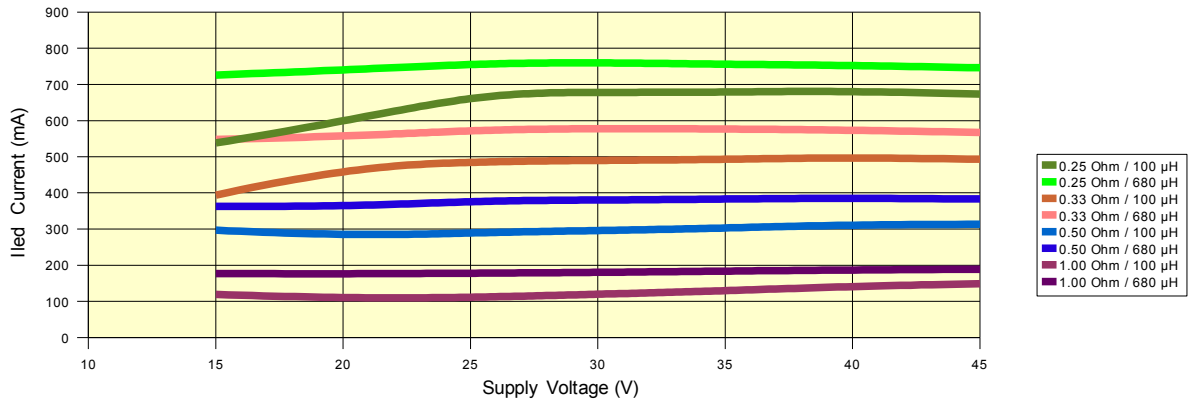
LED current vs. Supply Voltage for different values of R_{SENSE} and inductances with one and three LEDs in series, respectively.

$C_{IN}=470\mu F$, $R_{VSENSE} = 1k\Omega$, $C_{LED} = 100\mu F$, $C_{5VHi/L0} = 220nF$, $T_a = 25^\circ C$ (unless otherwise noted)

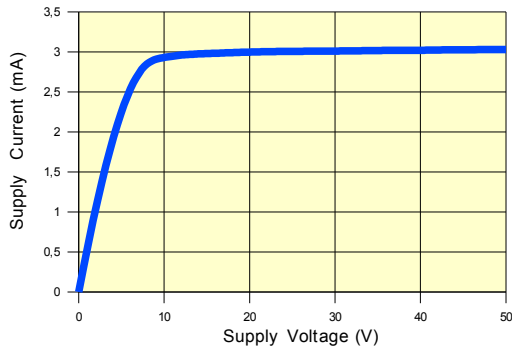
1x3W LED Current vs. Vcc @ L=100μH / 680μH



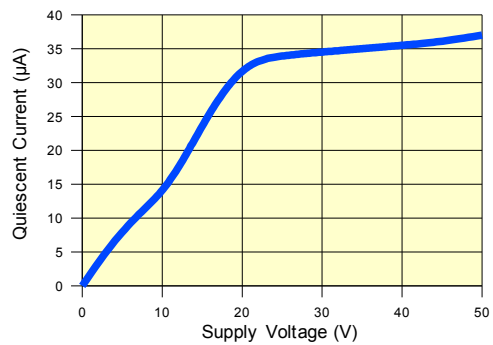
3x3.5W series LED Current vs. Vcc @ L=100μH / 680μH



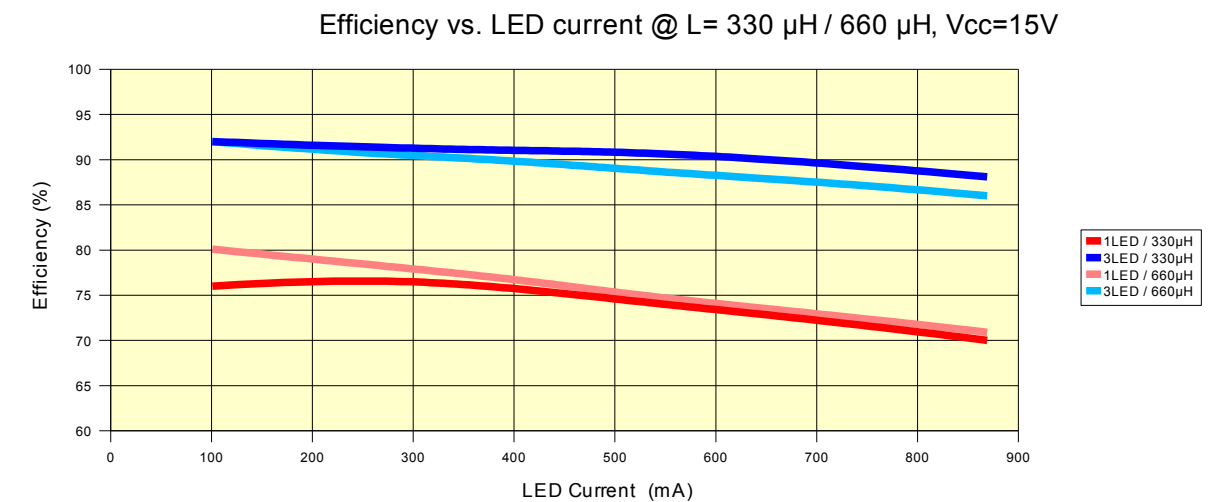
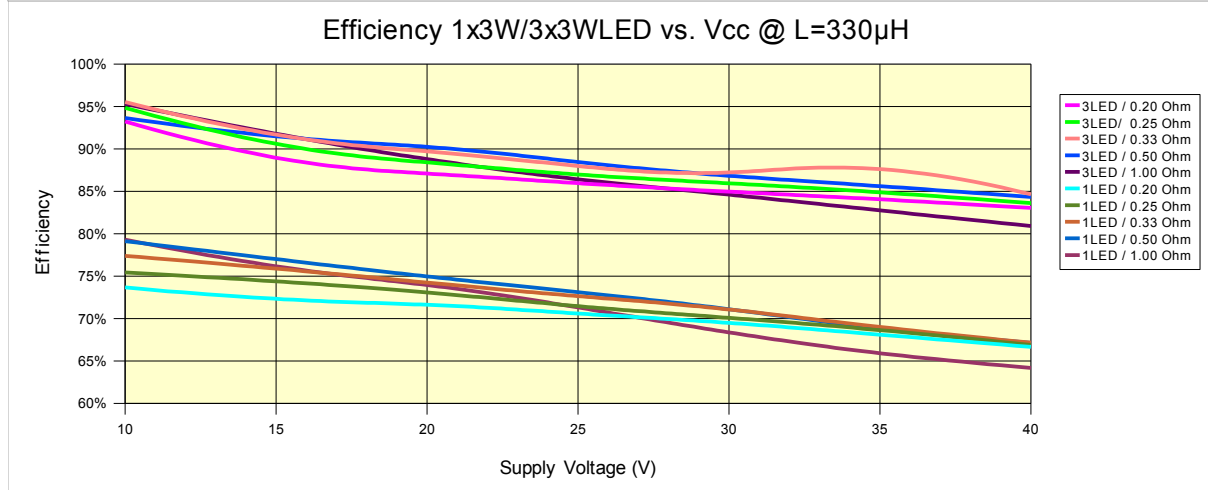
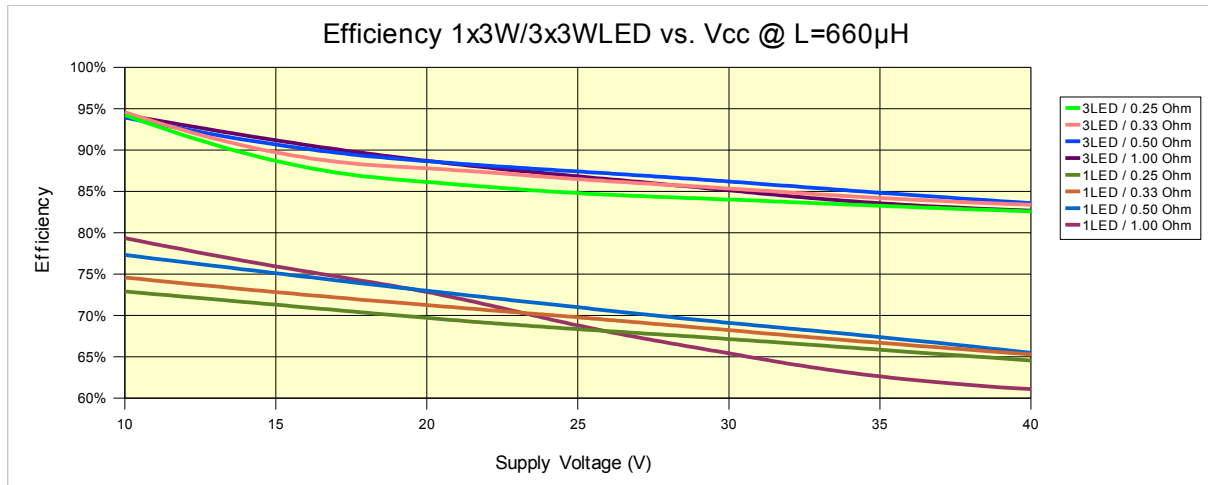
Supply Current vs. Supply Voltage



Quiescent Current vs. Supply Voltage



Conversion Efficiency vs. Supply Voltage and LED current



Application Notes

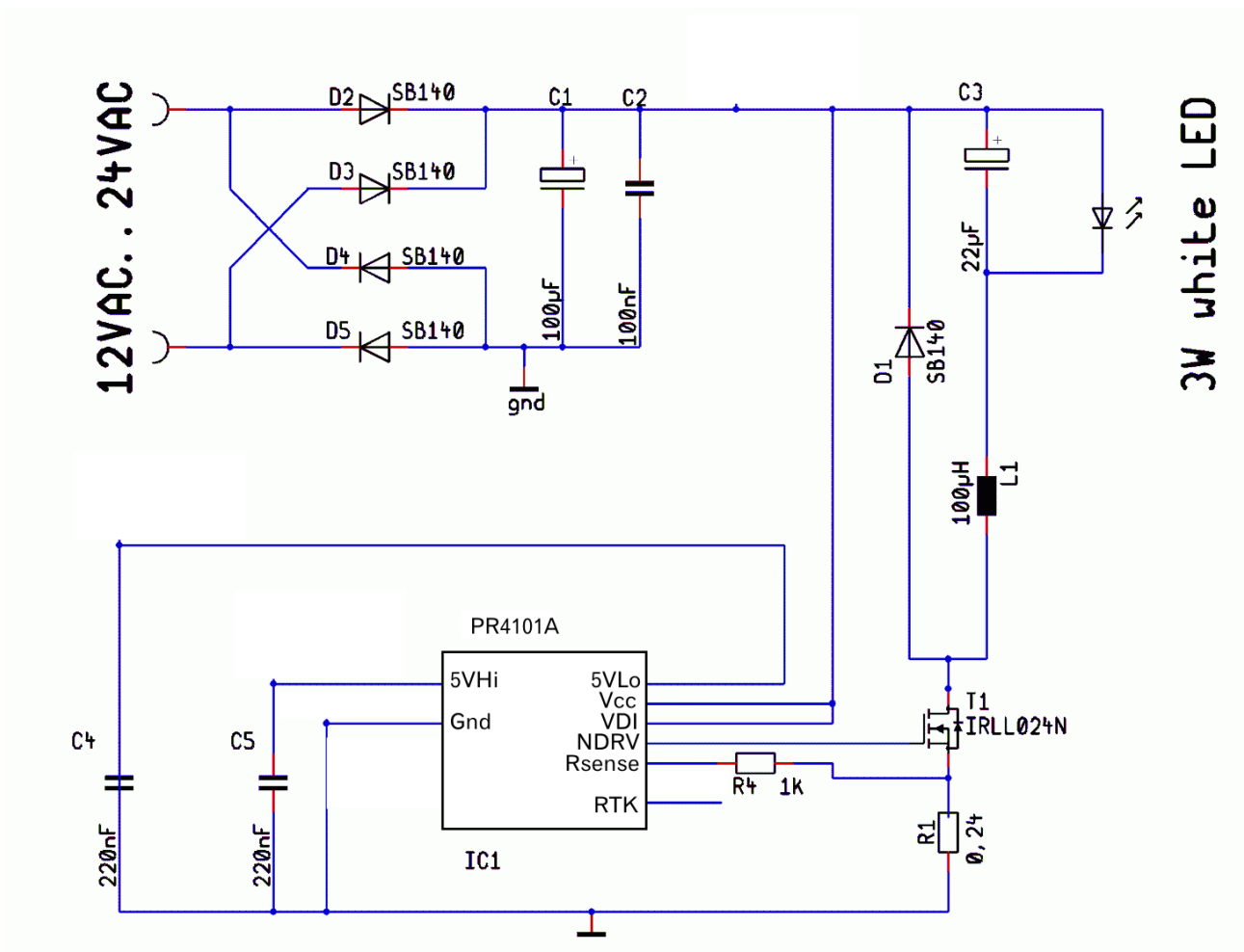
Typical application with 12/24VAC supply for a minimum board size

The following circuit drives one LED from a 12...24VAC 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 $R_{SENSE} = 0.24\Omega$ as in the diagram, the LED current is approx. 850mA. For other currents see below **Selection of R_{SENSE}** .

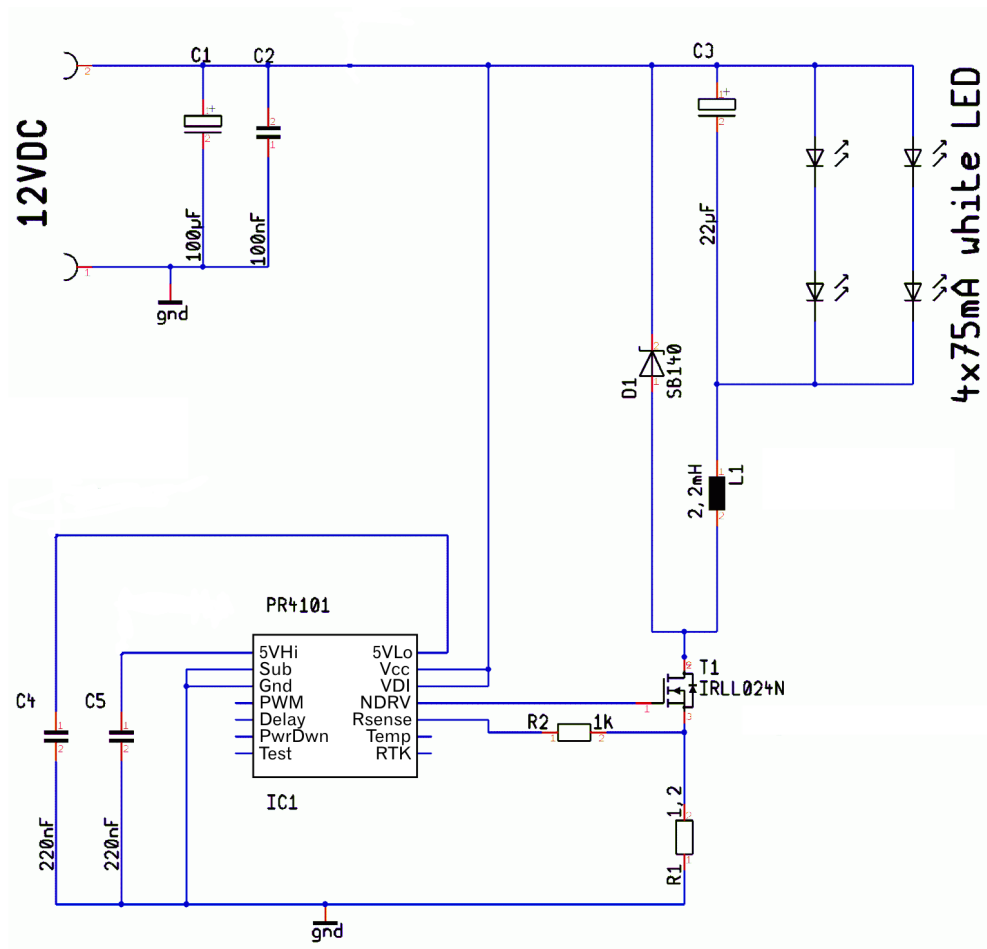
Typical application with 12VDC supply

The circuit shown 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 2V higher than the forward voltage of the LEDs.

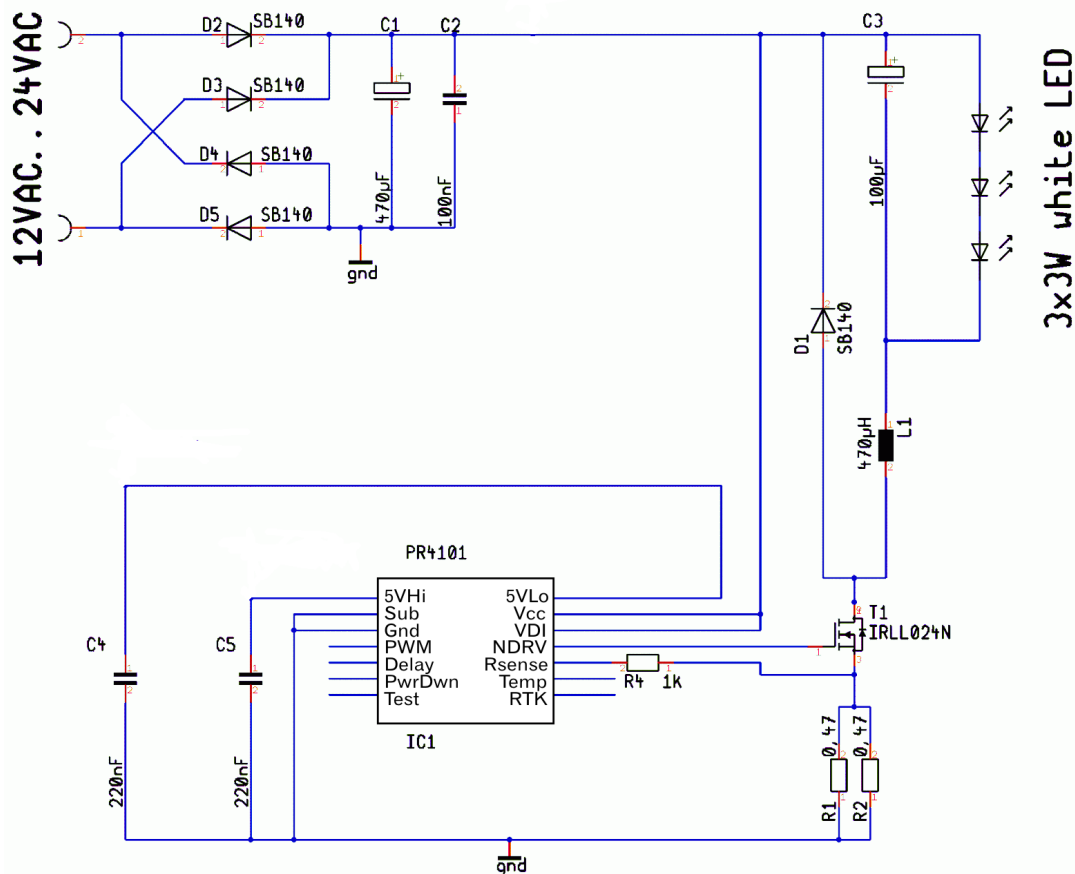
Assuming a V_F of 3.5V per LED, this means that the circuit will work with a supply of 9V and higher.



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

Typical application with 12VAC supply

The following circuit drives three LEDs in series from a 12...24VAC supply. LED and driver are supplied from the full-wave rectified and smoothed voltage. Ideally, after the full-wave rectifier, V_{CC} is $V_{AC} \times \sqrt{2}$, which is sufficient to drive three LEDs in series from $V_{AC}=12V$. 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 V_{CC} .

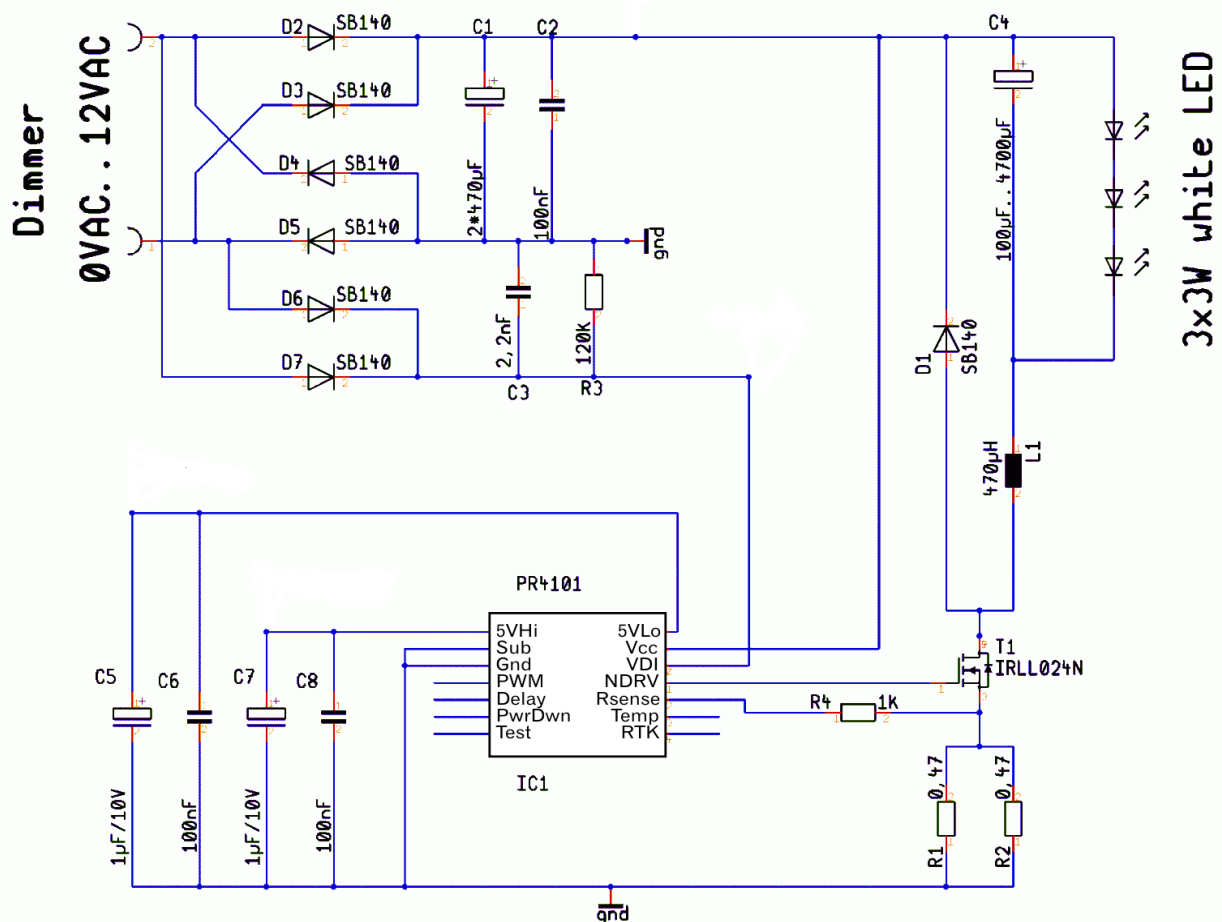


With $R_{SENSE} = (0.47/2) \Omega$ as in the diagram, the LED current is approx. 850mA. For other currents see below **Selection of R_{SENSE}** .

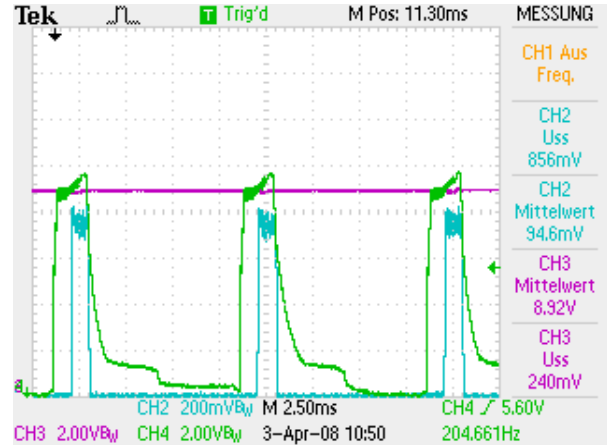
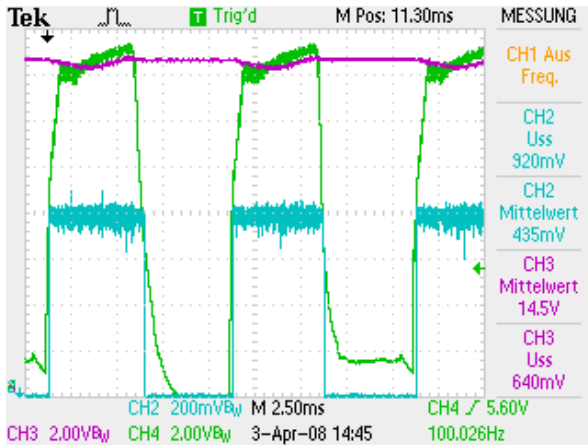
Typical application with 12VAC supply and phase cut dimmers

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 12VAC/50Hz 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.



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

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

Measured with $V_{CC}=12VAC$, $C_{LED}=C4=100\mu F$, $C_{5VH/L0}=220nF$, $C3=2,2nF$, $R3=100k\Omega$, $C_{IN}=C1=2000\mu F$, $L=470\mu H$, $R_{SENSE}=0.25\Omega$, LED:1x3W Luxeon

Cutting at large phase angles reduces both the average supply voltage V_{CC} 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.

PWM Control (PR4101A only)

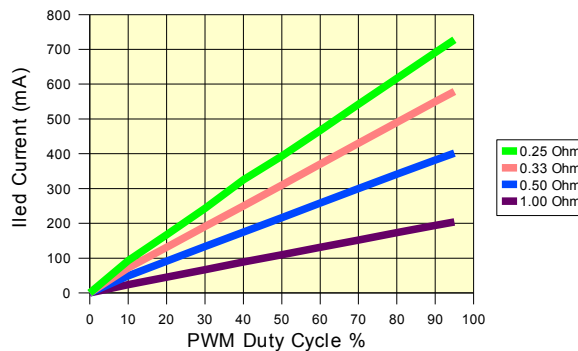
Brightness can also be controlled by an external PWM (pulse width modulation) signal via the PWM pin.

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

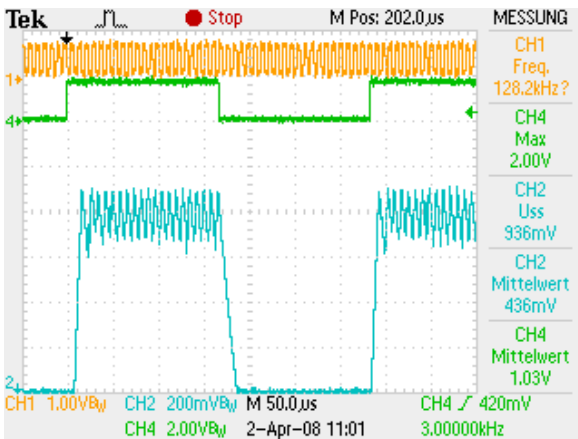
$$I_{LED\,AVG} = I_{LED\,nom} \cdot D \quad \text{with the duty cycle } D: \quad D = \frac{T_{OFF}}{(T_{ON} + T_{OFF})}$$

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.

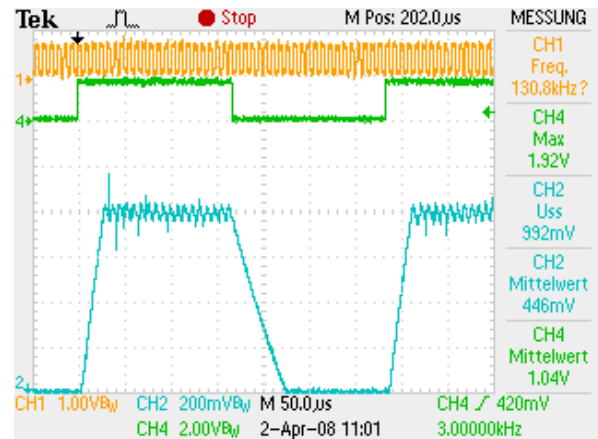
1x3W LED current vs. PWM @ Vcc=40V



Mean LED current vs. PWM duty cycle at a PWM frequency of 500 Hz at different values of Rsense.



PWM controlled with L=100µH, duty cycle=50%



PWM controlled with L=330µH duty cycle=50%

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

Measured with $C_{IN}=470\mu F$, $C_{LED}=100\mu F$, $C_{SVHI/LO}=220nF$, $V_{CC}=15V$, $R_{SENSE}=0.25\Omega$, LED: 1x3W Luxeon

Behaviour at a PWM frequency of 3000Hz with two different inductors.

The slow reaction, especially with the 330µH inductance, causes a nonlinearity in brightness vs. PWM duty cycle, limiting the recommended PWM frequencies to <500Hz, 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.

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 $100\mu\text{F}$ and $4,700\mu\text{F}$ for normal AC and of $470\mu\text{F}$ up to $10,000\mu\text{F}$ for phase-cut supply voltages is recommended.

In parallel a 100nF 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 $660\mu\text{H}$ should be used. In case that a minimized board size is desired inductor values around $100\mu\text{H}$ 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 C_{LED} between $22\mu\text{F}$ and $1000\mu\text{F}$ 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 3V and a low ON resistance. A recommended transistor is the International Rectifier IRL024N.

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.

Selection of R_{VSENSE} and R_{SENSE}

The input V_{SENSE} needs a series resistor $R_{VSENSE} = 1 \text{ k}\Omega$ 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 the „Electrical Characteristics“.

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

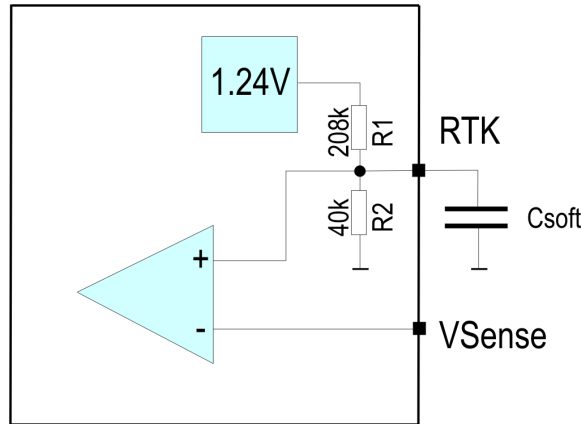
<i>LED Current</i>	<i>R_{SENSE}</i>
350 mA	0.571 Ω
700 mA	0.286 Ω
1A	0.200 Ω

Delay start feature (Delay, PR4101A only)

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.

Soft Start

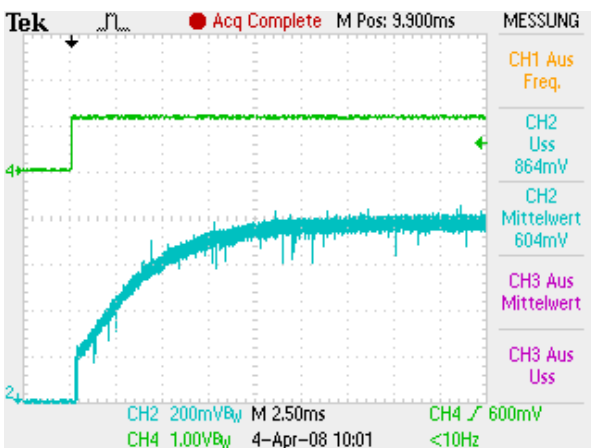
With an external capacitor at RTK the output current can ramp up continuously within a programmable period.



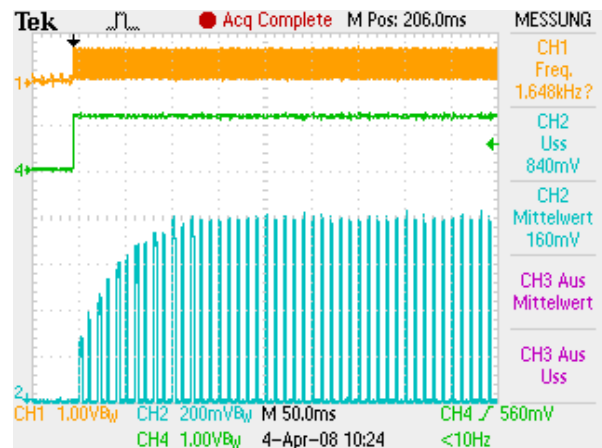
The following table gives some capacitor values

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

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.



Softstart on RTK, $C_{SOFT}=100\text{nF}$



Softstart on RTK, $C_{SOFT}=1\mu\text{F}$, phase-cut input voltage

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

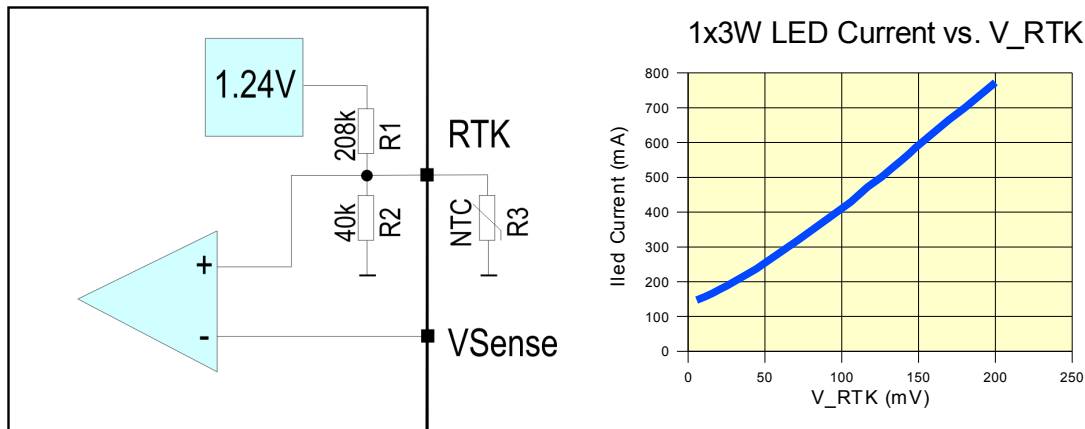
Measured with $C_{IN}=470\mu\text{F}$, $C_{LED}=100\mu\text{F}$, $C_{5VHI/LO}=220\text{nF}$, $L=470\mu\text{H}$, $V_{CC}=15\text{V}$, $R_{SENSE}=0.25\Omega$, LED: 1x3W Luxeon

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

Temperature compensation of the output current

High brightness LEDs often need to be supplied with 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 k Ω is suitable.



The NTC changes the voltage at RTK, thus influencing the VSense threshold and the LED current. The diagram on the right shows the relationship between the voltage at RTK and the LED current for $R_{Sense}=0.25 \Omega$. The nominal RTK voltage without NTC is 200mV

Over Temperature Protection (PR4101 only)

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“.

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.

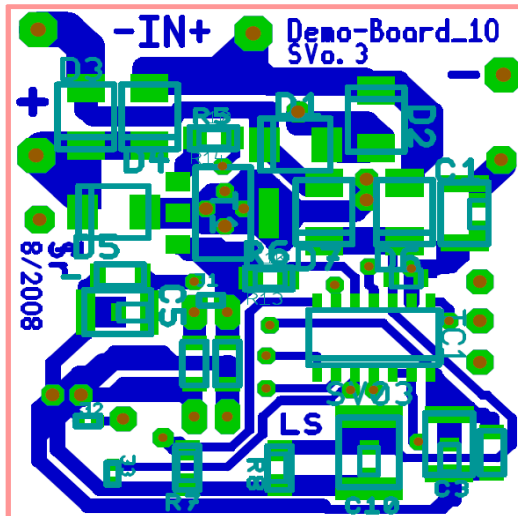
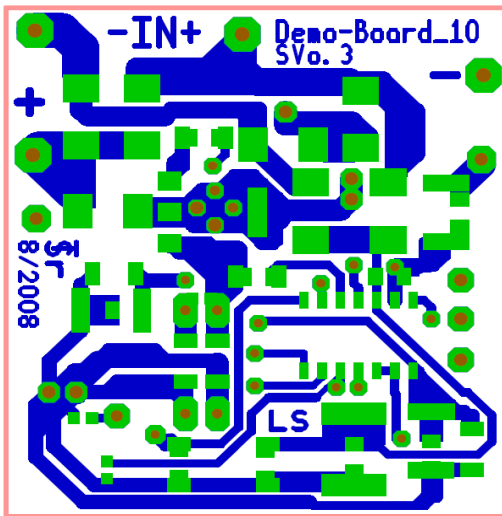
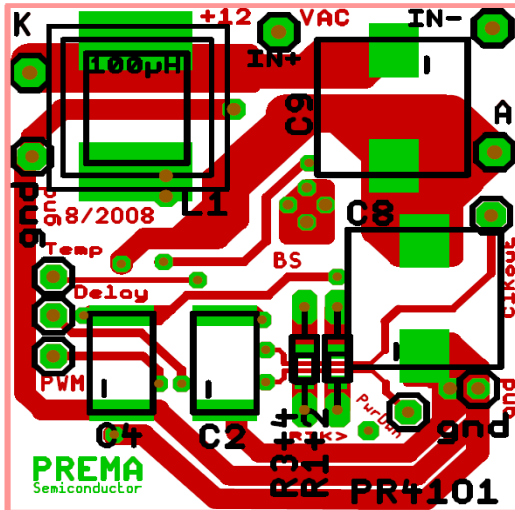
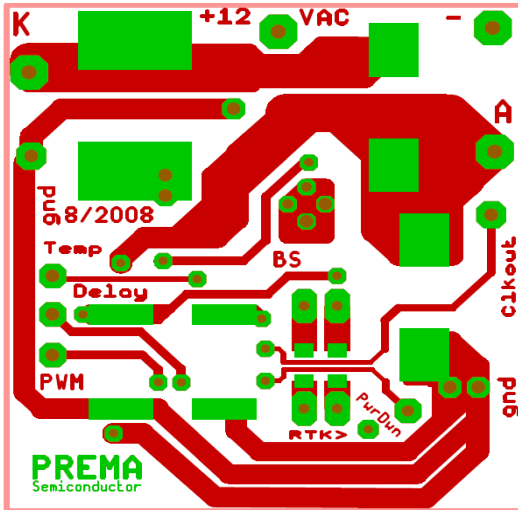
In any mode the converter can be safely switched off with the PwrDwn signal.

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.

Demoboard with PR4101A

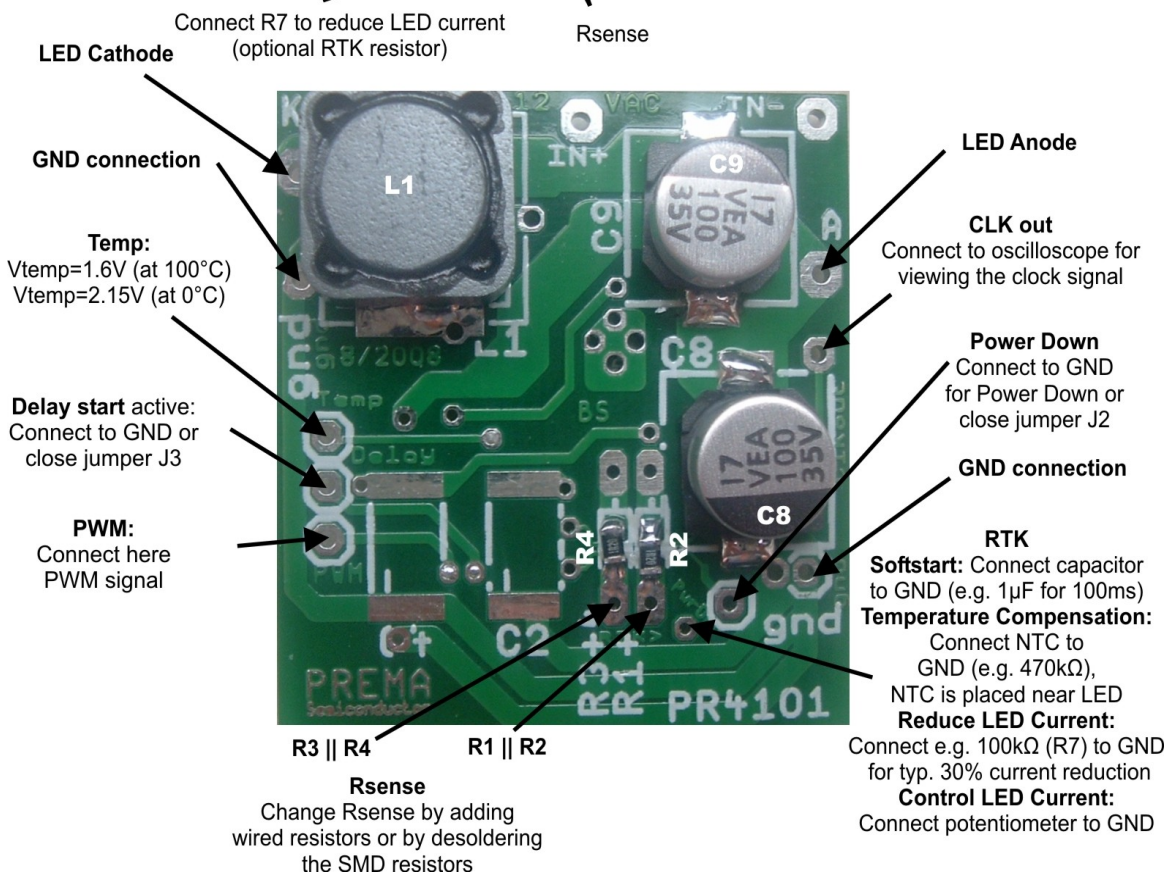
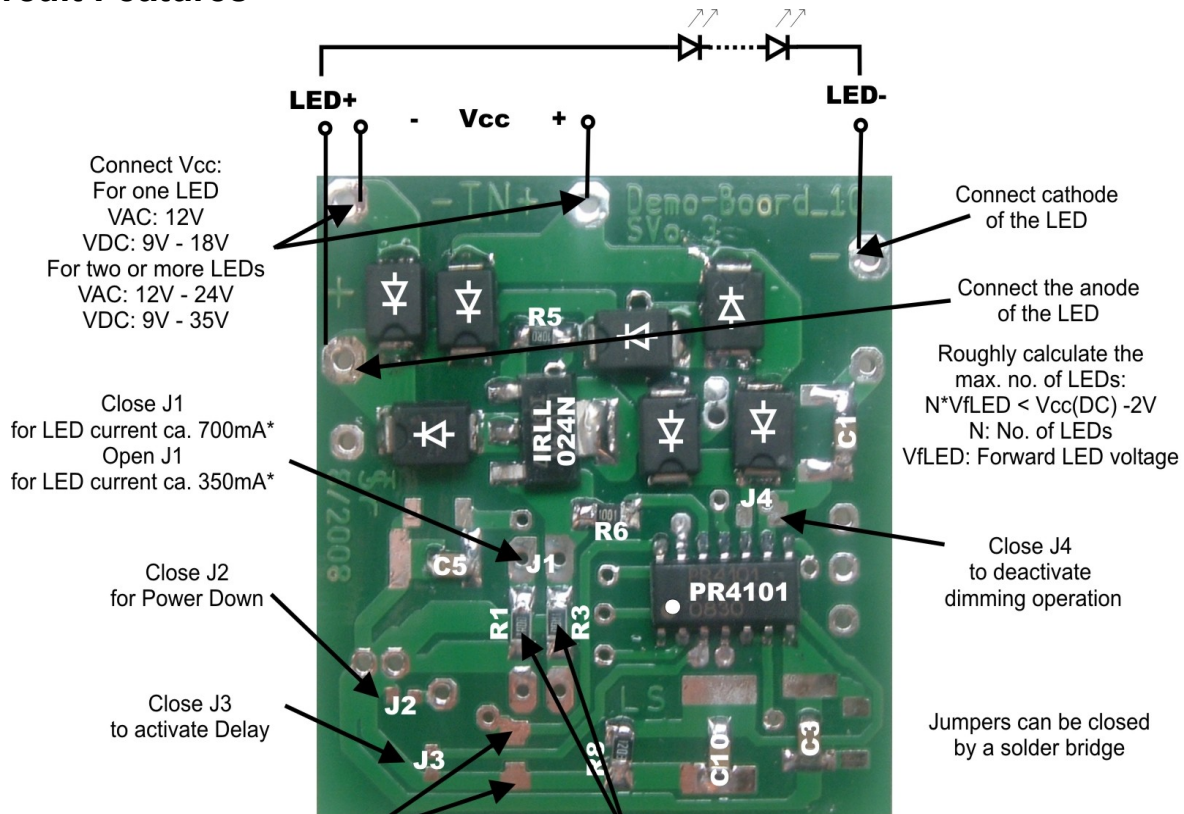
A demoboard is available for the PR4101 that shows the operation of the component, here for a LED driver replacing halogen lamps by several power LEDs. At the pins IN+ and IN- an AC voltage up to 24V or a DC voltage from 9V up to 35V can be supplied. Several LEDs can be connected, the possible number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



Connections

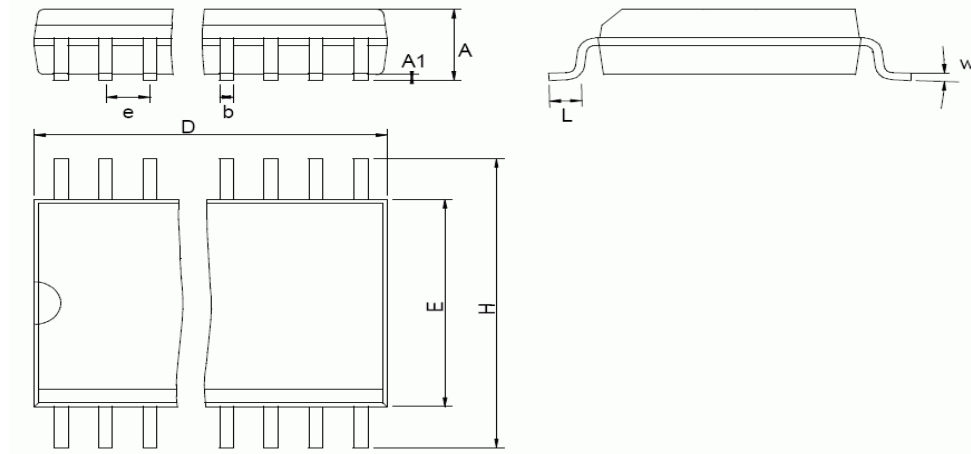
Name	Description
IN + / IN -	Connect Vac up to 24V or Vdc from 9V up to 35V
LED + / A	Connect the anode of the LED
LED - / K	Connect the cathode of the LED

Circuit Features



Available Packages

SOP 08L (PR4101B) or SOP 14L package (PR4101A)



Package		D	E	H	A	A1	e	b	L	Copl.	w
SOP 08L PR4101B	No m max	4.90	3.90	6.00	1.75	0.15	1.27	0.41	0.72	0.10	4°
SOP 14L PR4101A	No m max	8.65	3.90	6.00	1.75	0.15	1.27	0.41	0.72	0.10	4°

Delivery in die form upon request.
All parts delivered comply with RoHS. Finish is pure tin.



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