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Driving High Power LEDs Starting from 700mA with Low Cost LED Controller IC **ILD4001**

Application Note 213

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Application Note AN213
Revision History: 23 June 2011

Previous Revision: Previous_Revision_Number

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1 Introduction

1.1 Features

- Wide Input Voltage Range: 4.5 V ... 42 V
- Capable to drive N-channel MOSFETs that provide up to 3A output
- Temperature shut down mechanism
- Switching frequency up to 500 kHz
- Analog and PWM dimming possible
- Typical 3% output current accuracy
- Very low LED current drift over temperature
- Minimum external component required
- Small Package: SC-74

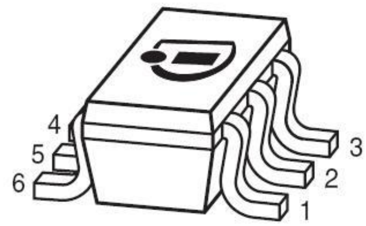

Figure 1 ILD4001

1.2 Applications

- LED controller for indoor and outdoor illumination
- LED replacement lamps, e.g. MR16 halogen replacement
- Retail, office and residential high power luminaires
- Architectural lighting
- Downlights and light engines
- Appliances, e.g. fridge / freezer

1.3 Description

This document contains informations about the LED-Less Demonstration Board for ILD4001. Please refer to the datasheet for the pins descriptions, functions descriptions and specifications.

The ILD4001 is a hysteretic buck LED controller IC for industrial applications.

The LED Controller is capable to drive external bipolar or MOSFET power transistors by using the internal push-pull output stage.

ILD4001 maintains a constant current through a string of LEDs as long as the input voltage exceeds the sum of the forward voltages of the LEDs in the string by at least 3V. The maximum input voltage for this demonstration board must not exceed 30V due to the board is optimizing for the 30V operation. If there is a need to test the board with a maximum supply voltage of 42V, please replace the schottky diode SD1 and the external MOSFET T1 with a suitable breakdown voltage.

The precise internal bandgap stabilizes the circuit and provides stable current conditions over temperature range.

Furthermore, temperature shut down mechanism enforce the IC to protect attached LEDs.

The board includes an **"**EN/PWM**" input terminal for** digital or analog dimming control signal.

The demonstration board is designed to operate at ambient temperatures up to 100°C.

The complete demonstration board schematic is shown in Figure 2. Typical waveforms and performance curves are shown in Figure 4 to Figure 8.

Although a wide variety of LED combinations and currents can be driven with the ILD4001, the sense-resistors have to be altered to achieve the desire LED current and inductance has to be changed to attain recommended switching frequencies below 500 kHz.

Table 1 Demo Board for ILD4001

Board Name	R1,R2,R3 /Ω	L1 /µH	External MOSFET	Vs /V	Suitable number of LEDs	Typical Switch. Freq. /kHz	Measured Vrsense = Vs - VLED+ /V	LED Average Current /A	Ambient temp. less than /°C
0.7A	0.47	68	BSR302N	12	3	224	0.115	0.74	90[1]
1.0A	0.33	47	BSP318S	12	3	222	0.116	1.06	90[1]

The above measured values are for typical case only.

1.3.1 Check List before powering up

Before powering on the ILD4001 demonstration board, please verify the following:

- Be sure that each LED can conduct 1000mA DC current within its safe region of operation.
- Make sure that the input voltage supply is less than 30V.
- Select the appropriate mode for EN/PWM:
    - to enable the ILD4001, please force the EN/PWM pin terminal to 3V or more, and
    - to select analog dimming, supply a dc source (1 to 3V) to EN/PWM pin terminal.
    - to select PWM dimming, supply a PWM signal source (0 to 5V) with frequency within range of (200Hz to 5 kHz) to PWM pin terminal.
- For the case when operating the EN/PWM pin less than 1V, please insert a 10kΩ resistor between the gate and source of the external MOSFET.

1.3.2 External MOSFET

The external MOSFET T1 is required to drive the LEDs in the ILD4001 application. There are a few factors to consider while choosing the suitable external MOSFET. First, choose the correct voltage and current rating of the MOSFET. Please ensure the VDS breakdown and current capability is sufficient, and ensure that the external MOSFET working within the SOA[2] region of DC mode. Second, the logic high level from ILD4001 is 5V and the external MOSFET must be able to be driven with a 5V gate voltage. Third, choose a low $R_{ds(on)}$ MOSFET. It can improve the efficiency of the system.

The BSR302N, BSS306N and BSP318S are recommended. Please refer to Table 2 for the external MOSFET comparison. BSR302N offer the lowest $R_{ds(on)}$, highest efficiency and the I_{LED} can operate up to 3.7A. BSP318S is suitable for the application up to Vs = 60V, also better in R_{th} and the I_{LED} can operate up to 2.6A. BSS306N offer the lowest cost, suitable for the application of I_{LED} up to 2.3A. The efficiency not as good as BSR302N but comparable to BSP318S.

Table 2 Comparison of BSP318S, BSR302N and BSS306N

	BSP318S	BSR302N	BSS306N
Package	SOT-223	SC-59	SOT23
$R_{ds(on)}$	90m	36m	93m
V_{DS}	60V	30V	30V
Max I_{LED}	2.6A	3.7A	2.3A
R_{thJA}	100K/W	250K/W	250K/W

[1] Demo board without heatsink
[2] Safe Operation Area

1.3.3 Capacitor C20 for Ripple Reduction

This component C20 is optional and not installed on the standard demo board. This capacitor can help to reduce LED ripple current. Recommended to use low ESR[1] capacitor and its rated voltage must be higher than the maximum input voltage.

1.3.4 Connection of LEDs

The ILD4001 demo board includes a 3-pin SIP [2] connector for the anode connection (LED +) and a 2-pin SIP connector for the cathode connection (LED -**) of the "LEDs in series". The anode connection is labeled as** *CON1-3* and cathode connection is labeled as *CON2-1* on the board.

1.3.5 PWM Dimming

The PWM terminal on the PCB is an input for the pulse width modulated (PWM) signal to control the dimming of **the LED string. The PWM signal's logic high level should be at least** 2.5V or higher. The period of this PWM signal should be higher than 200µs. For the default demo board circuit, a dimming frequency less than 300Hz is recommended to maintain a maximum contrast ratio of at least 100:1. The maximum contrast ratio is shown on Figure 7, and the minimum is based on the measured average LED current at 3dB above/below the linear reference. The maximum contrast ratio depends largely on the rise time of the inductor current, and hence is dependent on input voltage, inductor size and LED string forward voltage. In addition, if C20 is installed, the maximum contrast ratio or DIM frequency will be further reduced. Please insert a 10kΩ resistor between the **MOSFET's gate and ground. This is due to the output stage of ILD4001 become high** impedance state when the PWM signal is lower than 0.7V. With the 10kΩ resistor, a dimming PWM frequency up to 5 kHz is possible.

1.3.6 Open Circuit of terminals LED+ and LED-

If the LED array is disconnected or fails with open state, the ILD4001 will operate at 100% duty cycle. The output voltage (at LED+) will rise to the level of the input voltage. The other output terminal (LED -) will fall to ground. Note that under the above said condition; please avoid reconnecting the LED array between LED+ and LED- terminals without powering down first. This precaution is to avoid excessive surge current that may damage the LEDs.

[1] Equivalent Series Resistance
[2] Single In-line Package

2 Application Information

2.1 Schematic

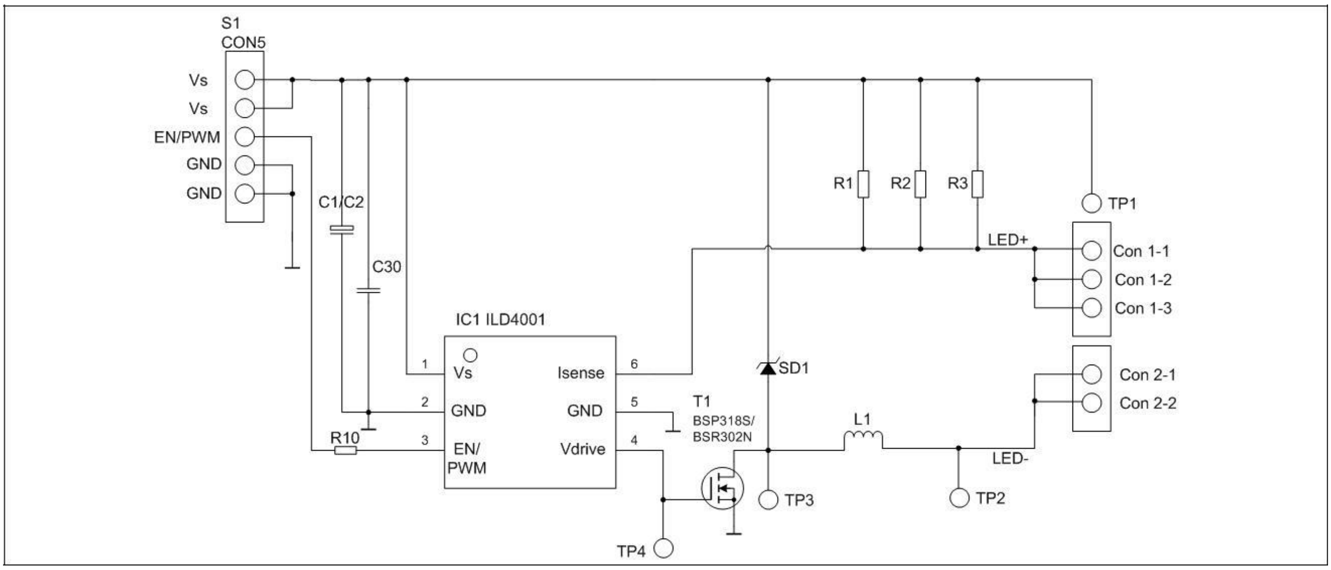

Figure 2Schematic of the demonstration board

Table 3 Bill-of-Materials

Symbol	Value	Unit	Size	Manufacturer	Comment
L1	*see Table 1	µH	10.4x10.4mm / 8x8mm	EPCOS / TAIYO YUDEN	Shielded Power Inductor
R1	*see Table 1	Ω	1206		Part of the current sense resistor
R2	*see Table 1	Ω	1206		Part of the current sense resistor
R3	*see Table 1	Ω	1206		Part of the current sense resistor
R10	0	Ω	0805		Jumper
SD1	BAS3020B		SOT363	INFINEON	Medium Power AF Schottky Diode 2A 30V
IC1	ILD4001		SC-74	INFINEON	Hysteretic Buck controller and LED driver
T1	*see Table 1		PG-SC-59 / PG-SOT-223	INFINEON	OPTIMOS®2 / SIPMOS® Small Signal Transistor
C30	4.7	µF	1812		Ceramic, 50V

2.2 Recommended method to measure Vsense w.r.t. Vs pin

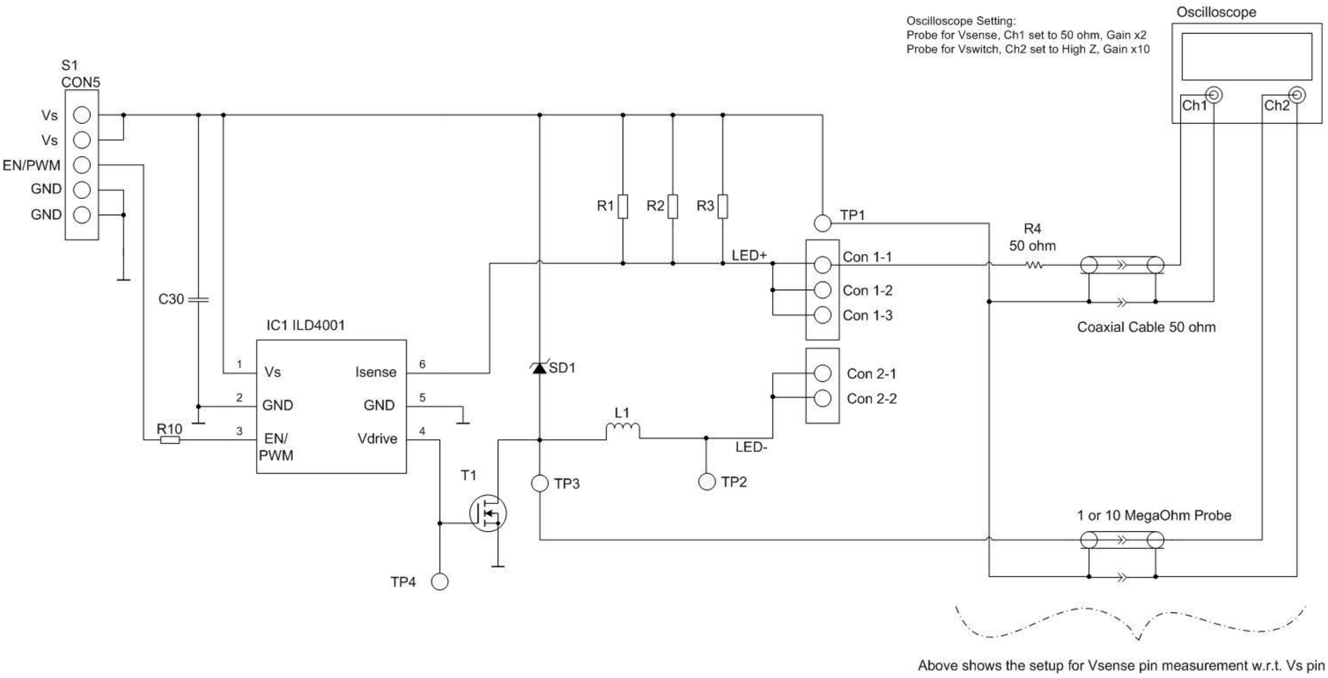

Figure 3 Measurement setup for measuring Vsense voltage w.r.t. Vs pin

By probing Vsense pin voltage with reference to Vs pin, it facilitates the observation and measurement of the ripple and average of Vsense vo**ltage at the same time with "Oscilloscope set to DC coupling"**, and without offsetting the DC voltage. This is shown in Figure 4.

2.3 Measured Graphs of the demonstration boards

Unless otherwise specified, the following condition labels apply:
Condition: Vs=12V, Ta=25°C, 700mA demo board with BSR302N

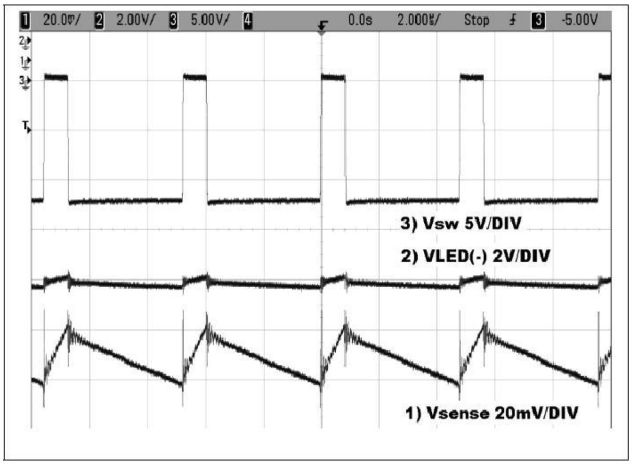

Figure 4 Vsw, Vsense and VLED(-), Vs=12

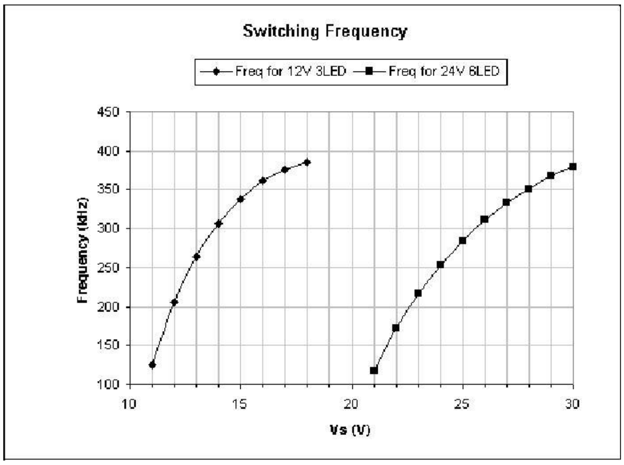

Figure 5 Switching Freq. vs Input Voltage,Vs

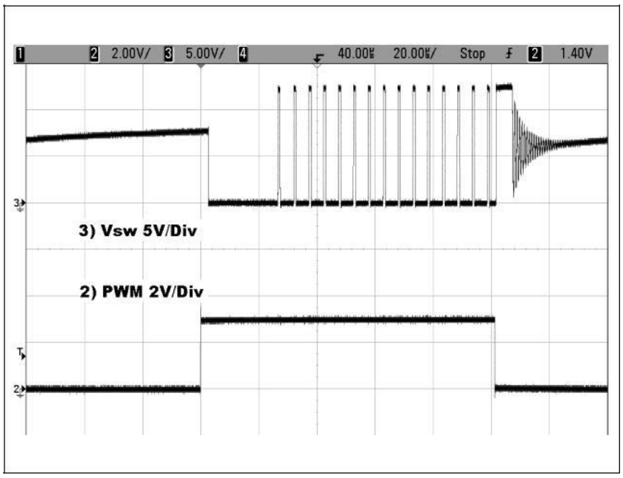

Figure 6 **Dimming waveforms**

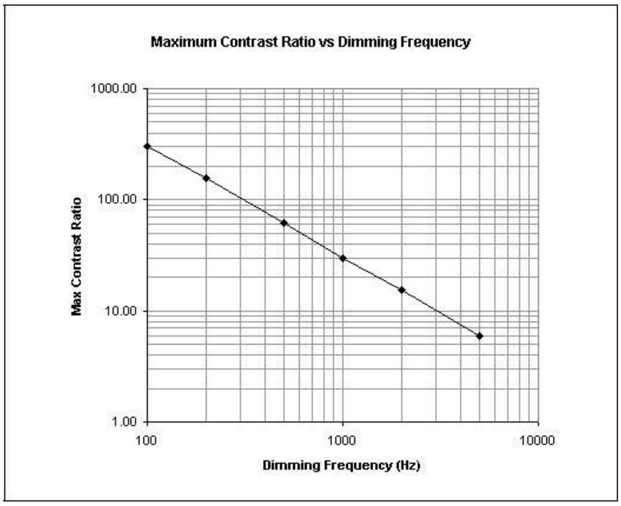

Figure 7 **Maximum Contrast Ratio vs Dimming frequency (100:1=1% Duty)**

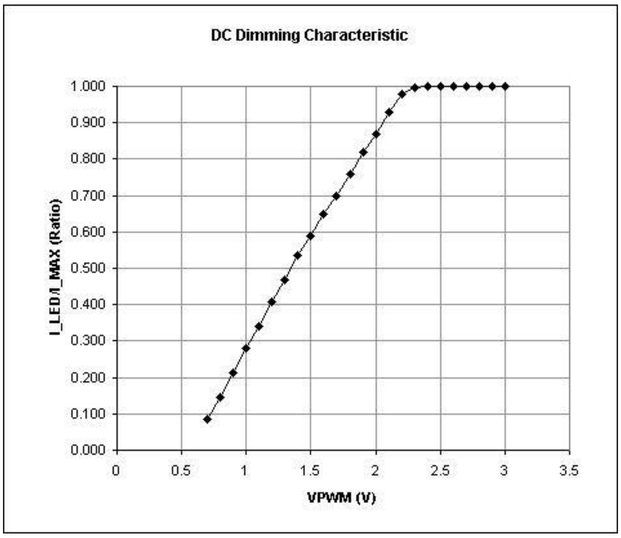

Figure 8 **Analog Dimming Characteristic**

2.4 Analog Dimming Characteristic

The analog dimming characteristic graph is shown Figure 8. To achieve a linear change in LED current versus control voltage, the recommended range of voltage at EN/PWM pin is from 1.0V to 2.0V.

Table 4 Percentage of max LED current vs DC voltage at PWM pin

Ven_pwm /V	Percentage of max. LED Current / %
< 0.4	0
1.0	25
1.4	50
1.8	75
2.1	90
>2.4	100

2.5 Setting the nominal LED current

The internal reference for the voltage across the external sense resistor was design to be 0.121V as stated in the datasheet. A first order approximation for the LED current can be calculated with this formula:

$$I_{LED} = \frac{V_{sense}}{R_{sense}} = \frac{0.121V}{R_{sense}}$$

If a certain level of LED current is desired; the estimation for the Rsense is given by:

$$R_{sense} = \frac{V_{sense}}{I_{LED}} = \frac{0.121V}{I_{LED}}$$

The Vsense can vary depending on the number of LEDs and voltage supply. Please take reference from Figure 10 and Figure 11 to help select the Rsense for your application.

2.6 External pull-up resistor for EN pin

The input stage of the EN pin is an NPN transistor with high ohmic base resistor. With a higher voltage apply at the EN pin; the current flowing into the EN pin will become higher. This result a lower efficiency of the system due to the current flowing into EN pin is increased. Figure 9 shows the relationship of the EN pin input current with respect to the EN pin voltage.

To improve this, by adding an external resistor between the EN pin and the Vs pin can reduce the current hence improve the system efficiency.

The value of the external resistor depends on the operating supply voltage; Vs. An approximation of the external resistance is given by:

$$R_{EN} = \frac{V_S - V_{EN}}{I_{EN}}$$

Where I_{EN} is 250µA as maximum, provided in the datasheet.

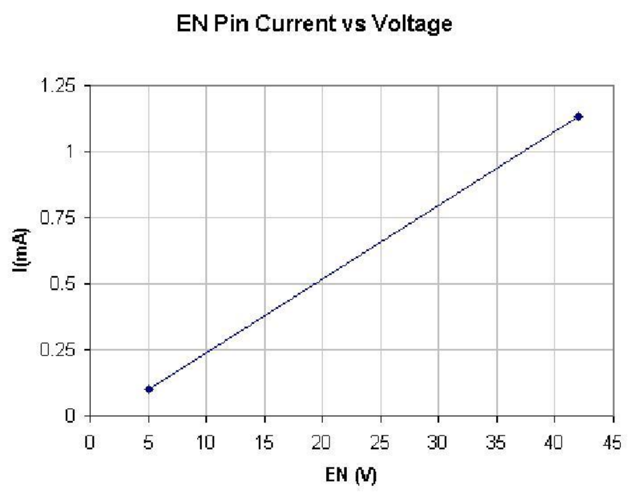

Figure 9 EN pin current versus voltage

3 Characteristic Graphs for different Inductors, no. of LEDs, Rs

3.1 Vsense, ILED versus Supply Voltage Characteristics

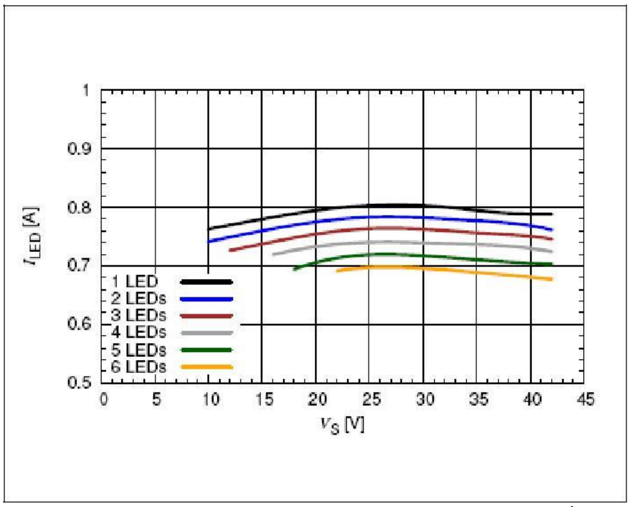

Figure 10 ILED vs Vs (Rs = 0.158, L = 68µH)[1]

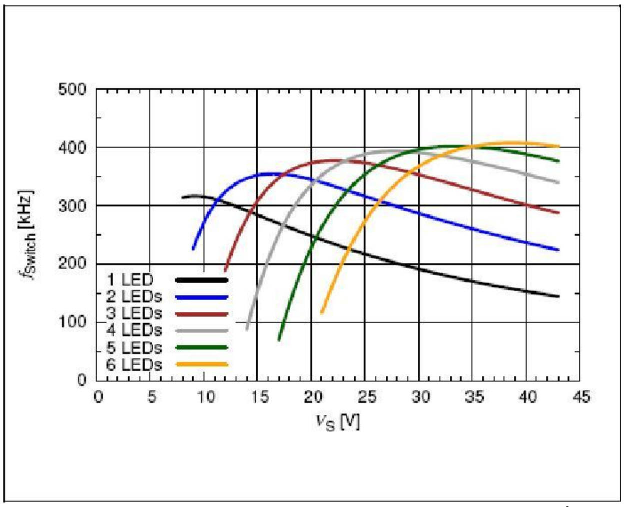

Figure 12 Freq vs Vs (Rs = 0.158, L = 68µH)[1]

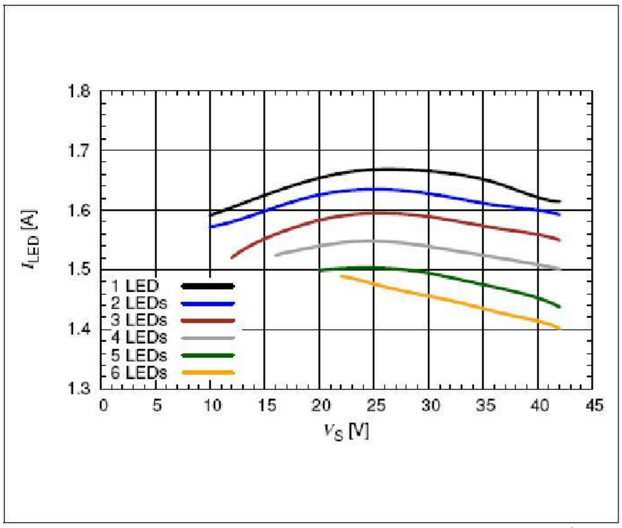

Figure 11 ILED vs Vs (Rs = 0.075, L = 33µH)[1]

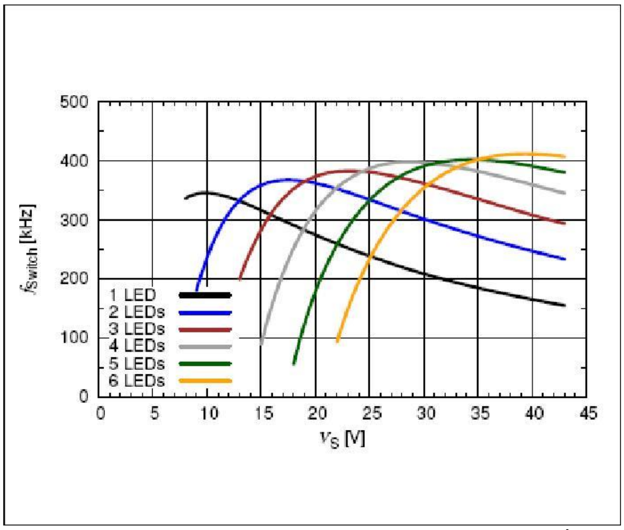

Figure 13 Freq vs Vs (Rs = 0.075, L = 33µH)[1]

[1] Using BSP318S as external MOSFET

3.2 Efficiency versus Supply Voltage Characteristic

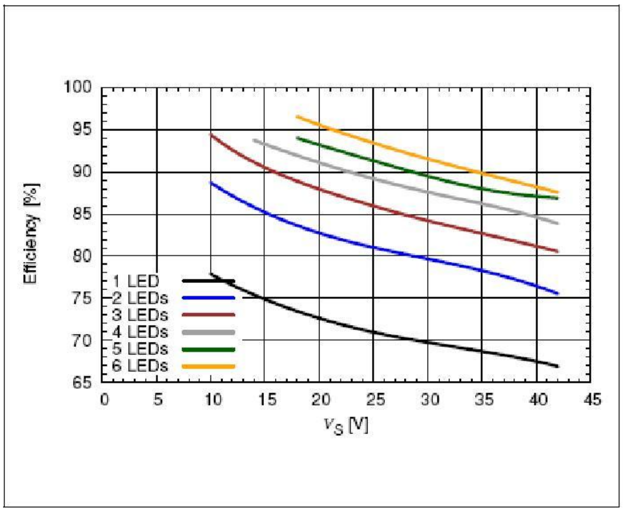

Figure 14 Efficiency vs Vs (Rs = 0.158, L = 68µH)[1]

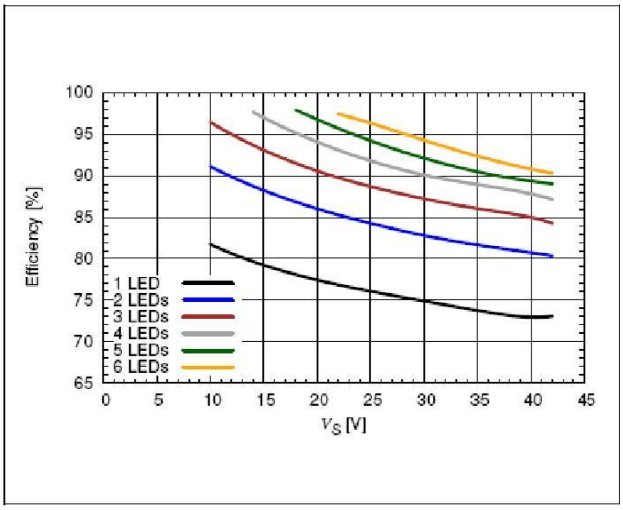

Figure 15 Efficiency vs Vs (Rs = 0.075, L = 33µH)[1]

[1] Using BSP318S as external MOSFET

3.3 Temperature Characteristics (Rs=0.11Ω L=68µH)

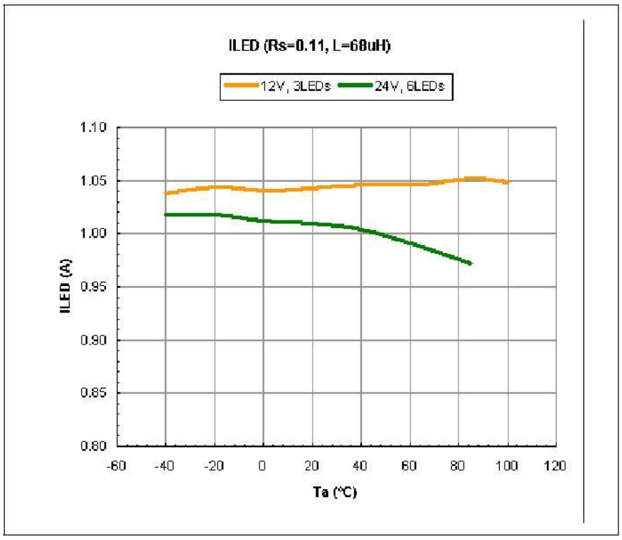

Figure 16 ILED vs Ambient Temperature

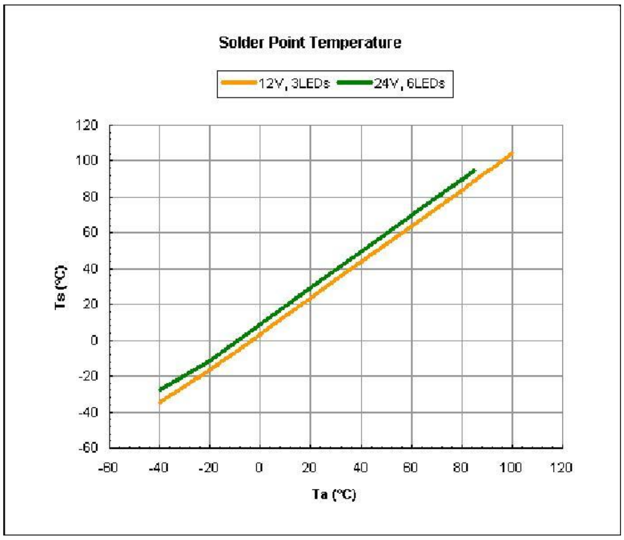

Figure 18 Solder Point Temperature vs Ambient Temperature.

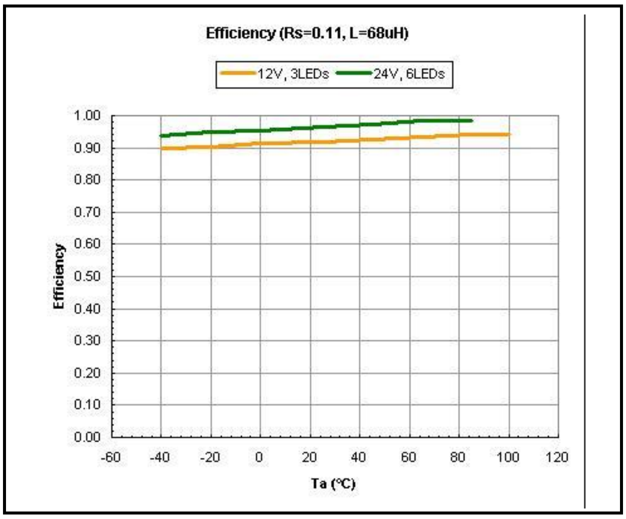

Figure 17 Efficiency vs Ambient Temperature

4 Evaluation Board and layout Information

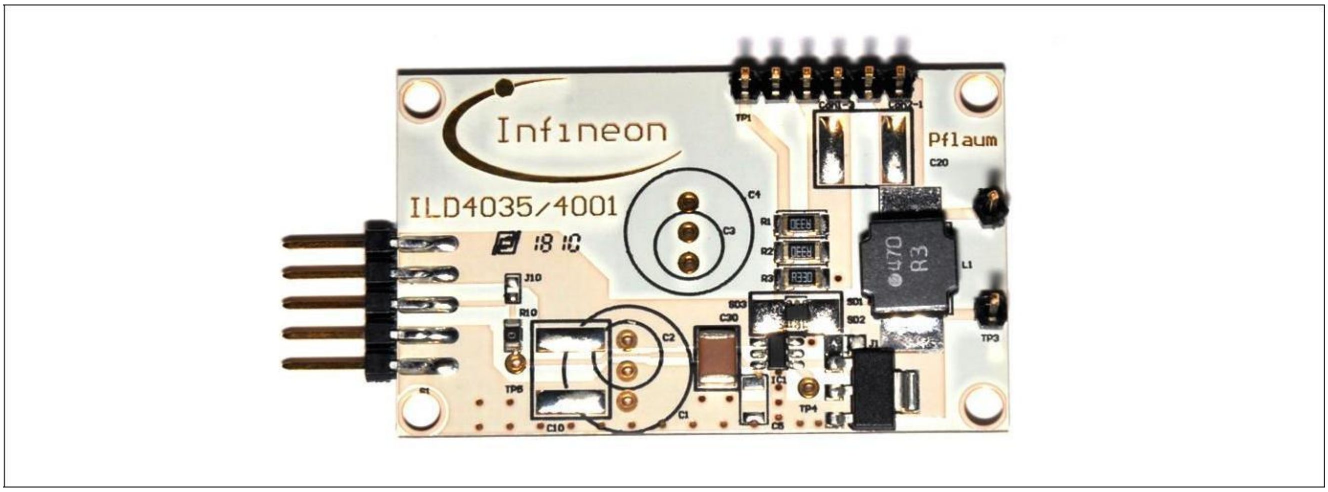

Figure 19 Photograph of Demo Board using BSP318S external MOSFET (size of PCB: 50mm x 30mm)

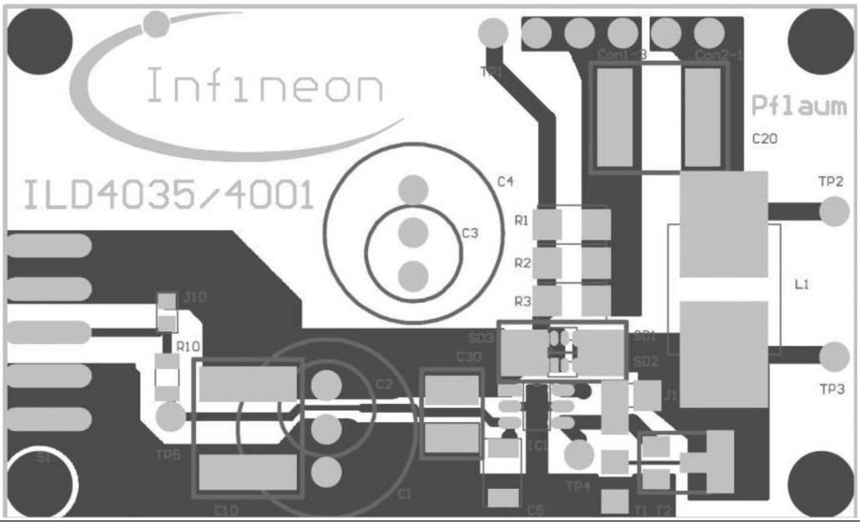

Figure 20 PCB Layer Information Top View

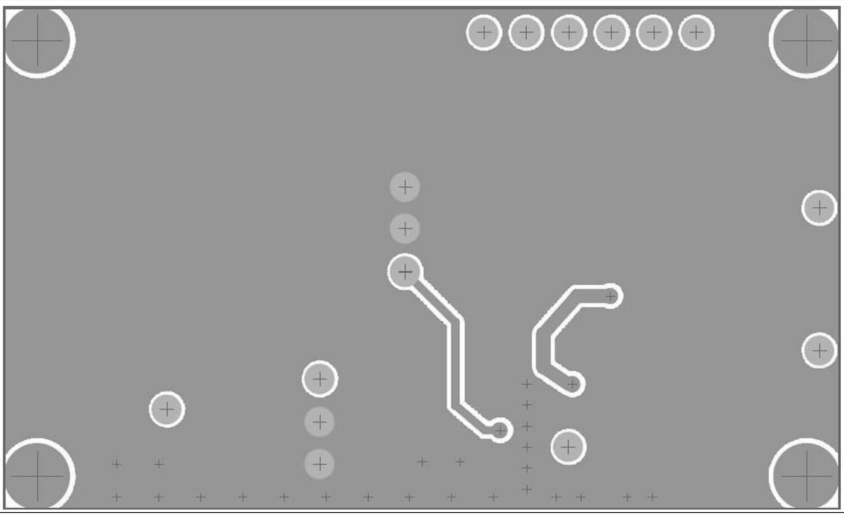

Figure 21 PCB Layer information Bottom View (unflip)

4.1 PCB Consideration

The free-**wheeling diode's path from inductor** to Vs pin of the integrated circuit is recommended to be as short a distance as possible. This is to minimize oscillation in the system.

The energy storage capacitor between Vs and Gnd is recommended to be placed as near to the IC as possible. This helps to stabilize the supply voltage when the IC draws large instantanoeus current during switching.

Ground plane should be as large as possible to improve heat dissipation.

As a reference for designing the surface area for the grounding for the PCB using FR4 to achieve a certain thermal resistance between desired solder point temperature and expected ambient temperature, the following chart can be used.

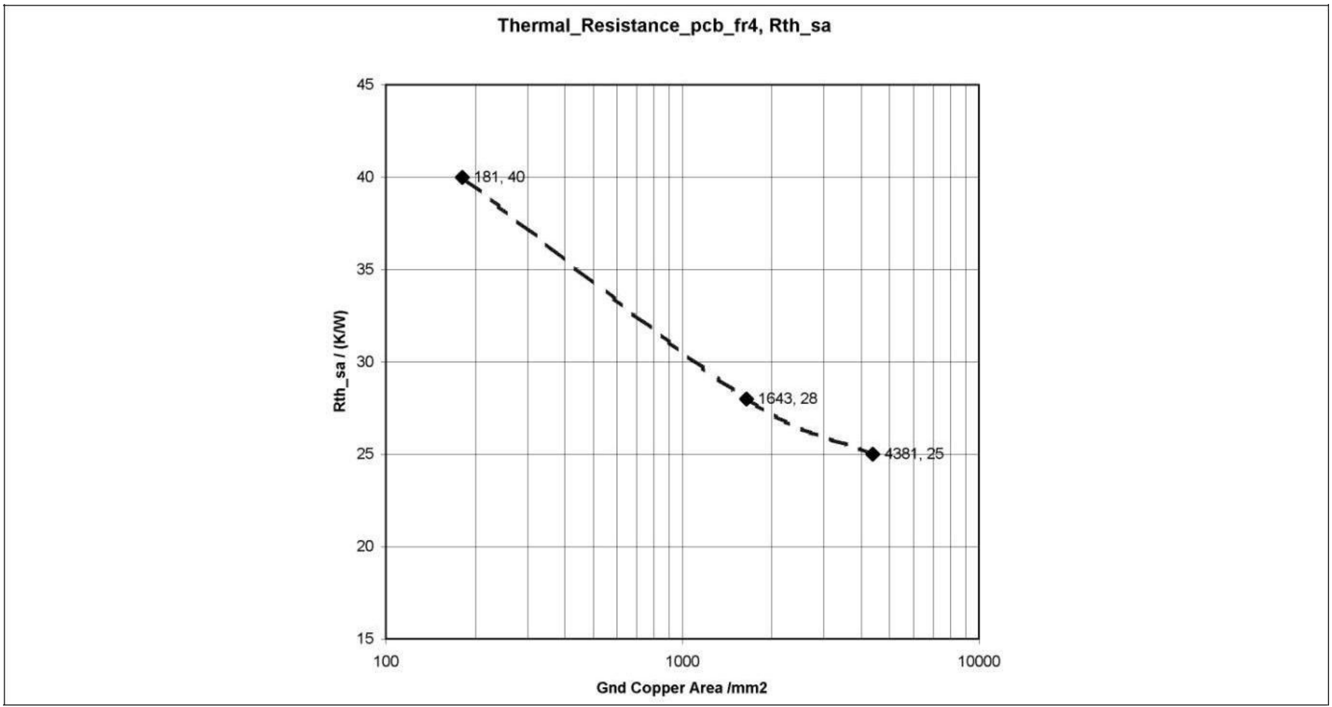

Figure 22 Thermal Resistance of PCB-FR4 versus Ground Copper Area

The data in the above Figure 22 were measured with following conditions:

- Two copper layers.
- 2 oz copper (70um thick) and board thickness of about 1.6mm.
- Ground pin connection of the IC is used to dissipate heat.
- FR4 material.
- No forced convection.
- No heat sink.
- No special mask opening for improved heat dissipation.
- In the chart, only three points are marked by diamond symbol. These are measured data. The broken line represents intermediate points which can de derived by linear interpolation.

An example where ILD4001**'s PCB is separated from LED PCB and there is not heat transmission between the** two PCBs.

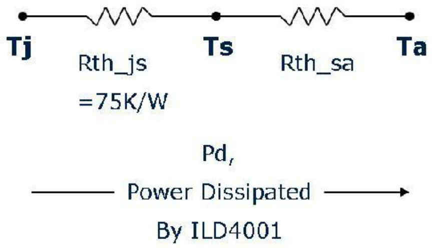

Figure 23 Thermal Resistance

T_j is the junction temperature of the ILD4001**'s output transistor connected to switch pin.**

T_s is the soldered temperature of the ILD4001**'s ground pin to FR4**-PCB.

T_a is the ambient temperature.

R_{th_js} is the thermal resistance from junction to soldered point with reference to ILD4001**'s** SC-74 package. This is stated as 70K/W in the datasheet.

R_{th_sa} is the thermal resistance from soldered point to ambient which is dependent on size of grounding area of PCB.

Pd is the power dissipated by ILD4001 which is approximately 10% of total power from supply (for rough calculation), or it can be derived by (Total power from supply **– LEDs' power –** Power Loss on other external components).

The above variables are related in the equations on the next line.

$$P_d = \frac{T_j - T_s}{R_{th\_js}} = \frac{T_s - T_a}{R_{th\_sa}}$$

With the above equations, and setting T_j (recommended to be below 100°C), the T_s can be calculated.

By choosing a desired T_a, the R_{th_sa} can be calculated.

With the calculated R_{th_sa}, reference Figure 22 to correlate the approximated ground copper area required in PCB layout.

4.2 High power LED application design consideration

The ILD4001 is also suitable for the high power LED application. With a proper MOSFET and configure the LED current up to 3A, the ILD4001 is able to drive the LEDs up to 60W for a 24V input supply voltage.

Below are the design considerations for the high power application:

- Use a low $R_{ds(on)}$ external MOSFET.
- The R_s is critical for high power application, use a wide terminal SMD resistor and place it as close to V_s and I_{sense} terminal as possible.
- For PCB, layout the copper track connected V_s and R_s as short as possible to reduce the copper resistance.

5 Equations for estimating switching frequency or Inductance

5.1 Estimation of switching frequency

Table 5 Steps to calculate the switching frequency for the demo board

		Board Versions	**0.7A**	**Units**
Force	Vs =	input voltage =	12	V
Assume	Vrsense =	voltage acoss sense resistor =	0.116	V
Assume	V_{LED} =	avg voltage of one LED =	3	V
Assume	N =	number of LEDs =	3	pcs
Assume	V_{LEDxN} =	voltage across LED+, LED- =	9	V
Assume	V_T =	voltage at Vswitch (low state) =	0.1	V
Assume	V_D =	on-voltage of schottky diode =	0.38	V
Use	Rsense =	effective sense resistance =	0.157	ohm
Use	L =	Inductance =	68	uH
1.) Set LED average current I_average				
	I_{LEDavg} =	Vrsense / Rsense =	0.739	A
	factor =	ratio of (Peak to Peak change of LED current) to(average LED current) =	0.220	Ratio
	ΔI_{LED} =	factor * I_{LEDavg} =	0.163	A
2.) Determine SW pin Duty cycle, Dsw				
	Dsw =	$1 - \dfrac{V_{LEDxN} + V_D + Vrsense}{V_S - V_T + V_D} =$	0.227	Ratio
3.) Estimated typical operating frequency				
	f =	$\dfrac{Dsw}{factor*L} * \dfrac{(V_{LEDxN} + V_D + Vrsense)}{I_{LEDavg}} =$	195	kHz

The inductance, L can be make the subject of equation in step 3; given the desired switching frequency, f.

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