Application Note AN-1214

LED Buck Converter Design Using the IRS2505L

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1. Introduction

The IRS2505L SOT-23 control IC is a versatile solution for controlling power supplies in PFC Boost, Flyback, Buck, or Buck-Boost applications. This app note will cover the use of the IRS2505L in a peak current control Critical Conduction Mode (CrCM) Buck converter for LED driving. The IC includes all of the necessary circuitry to control the Buck converter on and off times, regulate the output current, and protect against over-current fault conditions. During the design of the Buck circuit, special care should be taken when generating the circuit schematic, selecting component values and ratings, and generating the PCB layout. This application note provides detailed design information to help speed up design time and avoid circuit problems that can occur due to wrong component values or ratings, incorrect programming of IC parameters, and noise susceptibility. Helpful information is included for designing the PFC circuit, designing the IC supply circuitry, and using the IC protection features. PCB layout guidelines are also included to help avoid noise problems that can cause circuit malfunction or poor power supply performance. Finally, an excel spreadsheet design tool ("IRS2505L Buck LED Design Calculator") [2] is also included that contains all of the necessary calculations described in this application note.

2. Buck Converter

The IRS2505L operates in Critical-Conduction (or transition) Mode for the Buck converter. The Buck circuit (Figure 1) includes an inductor (LBUCK), a switch (MBUCK), and a diode (DBUCK). In this Buck configuration, the switch is referenced to ground and the output is left floating. This enables simple driving of the switch. During the on-time of the switch, the inductor current ramps up linearly to a peak value (Figure 2). The peak value depends on the input voltage, output voltage, inductor value and the on-time. During the off-time of the switch, the inductor current flows through the diode to the load and discharges back down linearly to zero. When the current reaches zero, the Buck switch is turned on again and the cycle repeats.

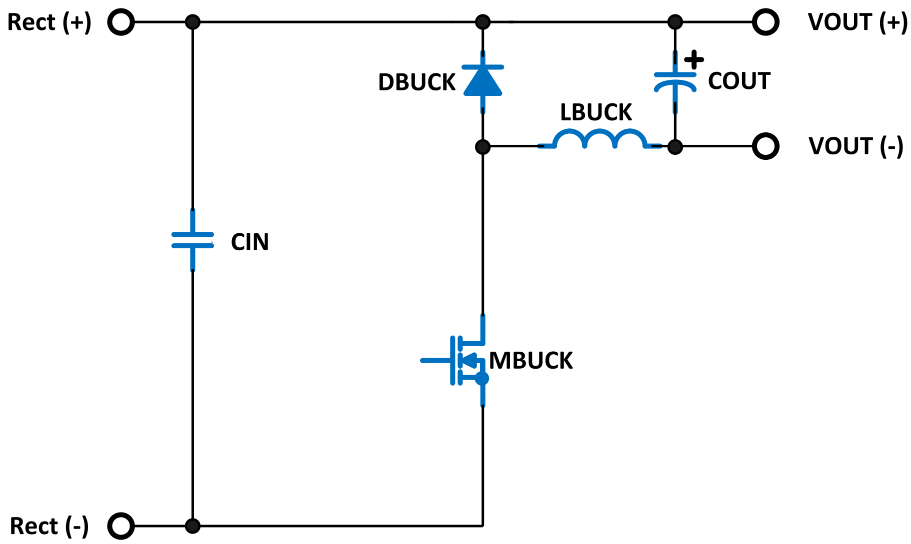


Figure 1: Buck converter with a floating output.

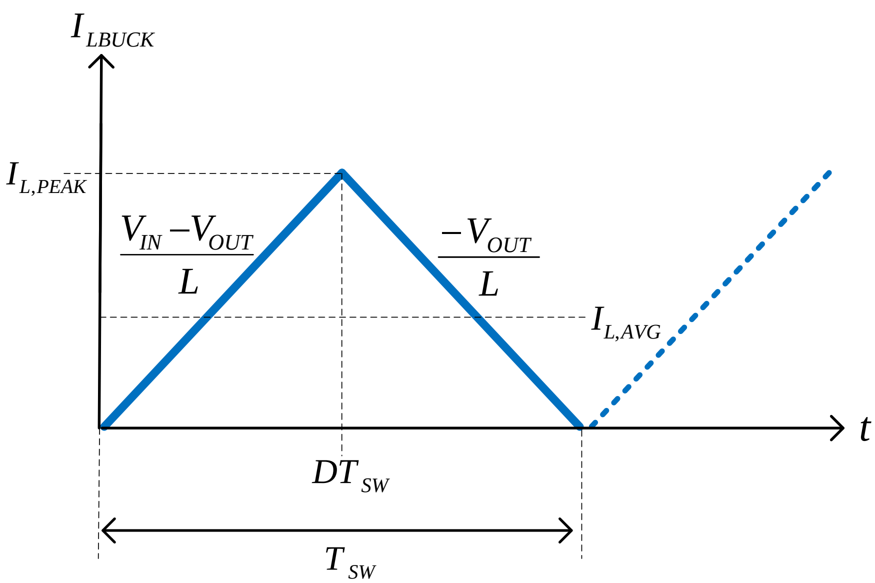


Figure 2: Inductor current during critical-conduction mode.

To calculate the inductor value as a function of the desired switching frequency, the following equations can be used. First, the following parameters need to be defined:

V_{IN}	= Input voltage. May be DC or rectified AC. For AC, use the peak voltage of the line ($VAC_{PK} = VAC_{RMS} \times \sqrt{2}$)
V_{OUT}	= Output voltage of the load, in this case the LED string.
η	= Buck converter efficiency (typically 0.85)

f_{SW}	= Buck switching frequency (occurs at the peak of nominal line voltage for AC)
T_{SW}	= The switching period ($\frac{1}{f_{SW}}$)
D	= Duty Cycle
$I_{L,AVG}$	= Average Buck inductor current
$I_{L,PEAK}$	= Peak Buck inductor current
L_{BUCK}	= Buck Inductor
I_{OUT}	= Output Current of the LED string
P_{OUT}	= Output Power

The peak current of the Buck inductor can be calculated from the slope of the inductor current from Figure 2, knowing the switching period T_{SW} and duty cycle D of our converter:

$$I_{L,PEAK} = \frac{(V_{IN} - V_{OUT})DT_{SW}}{L_{BUCK}} \quad \text{[A] [2.1]}$$

Where the duty cycle for the Buck converter is defined as:

$$D = \frac{V_{OUT}}{V_{IN}} \quad \text{[2.2]}$$

For a symmetric triangle as in Figure 2, the average value of the inductor current is its peak divided by 2:

$$I_{L,AVG} = \frac{I_{L,PEAK}}{2} \quad \text{[A] [2.3]}$$

We can approximate the average inductor current to equal the output current:

$$I_{L,AVG} = I_{OUT} \quad \text{[A] [2.4]}$$

Rearranging the equations leads to:

$$I_{OUT} = \frac{(V_{IN} - V_{OUT})DT_{SW}}{2L_{BUCK}} \quad \text{[A] [2.5]}$$

By selecting the nominal Buck switching frequency f_{SW} the only unknown remaining in equation 2.5 is the buck inductor, which we can solve for:

$$L_{BUCK} = \frac{(V_{IN} - V_{OUT})(\frac{V_{OUT}}{V_{IN}})}{2f_{SW}I_{OUT}} * 10^6 \quad \text{[uH] [2.6]}$$

3. Peak Current Control

To regulate the output LED current in a Buck converter, we will use the equations derived earlier along with the IRS2505L control circuit. Figure 3 shows the control circuit for the Buck converter.

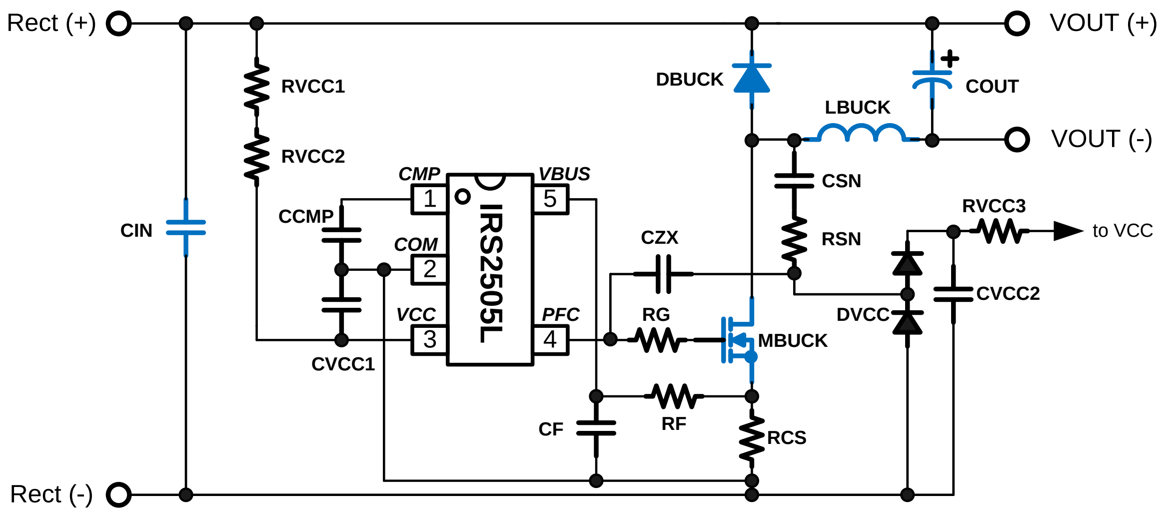


Figure 3: IRS2505L Control Circuit for Buck Converter

The VBUS pin over-current threshold for the IRS2505L, VBUSOC+, is used to regulate the peak current of the converter. At a test condition of VBUS=0V, the VBUSOC+ typical value is 0.8V.

From the typical control circuit in Figure 3, the RCS resistor programs the peak inductor current for peak current control during the on-time of the switch, which is fed back to the VBUS pin through a low pass filter, RF and CF, filtering out unwanted switching noise.

The value of RCS that gives the desired output LED current can be calculated by rearranging equations 2.3-2.4 with Ohm's law:

$$RCS = \frac{0.8V}{2I_{OUT}} \qquad \text{[Ohms] [3.1]}$$

4. Zero-Crossing Detection

The zero-crossing detection of the PFC inductor current utilizes the gate drive pin (PFC) together with the drain-to-gate capacitance of the external Buck MOSFET. An additional capacitor, CZX, in Figure 3 is used to couple the zero crossing information of the Buck inductor to the PFC pin to ensure proper detection in the Buck topology. During the on-time, the gate drive pulls the gate of the external Buck MOSFET up to VCC and turns the MOSFET on. The inductor ramps up to a peak level (Figure 4). When the on-time ends, the gate is pulled to COM for a short delay and then increased and held at a given offset voltage, VPFCOFF (0.6V, typical). When the Buck inductor current discharges to zero, the drain-gate capacitance with the additional help of CZX "pulls" the gate signal below the zero-crossing reset threshold, VPFCZX- (0.4V, typical), at the PFC pin and the gate turns on again. This new and innovative method from IR is simple and does not require a secondary winding from the inductor to detect zero-crossings.

A typical value for the CZX capacitor is 22pF.

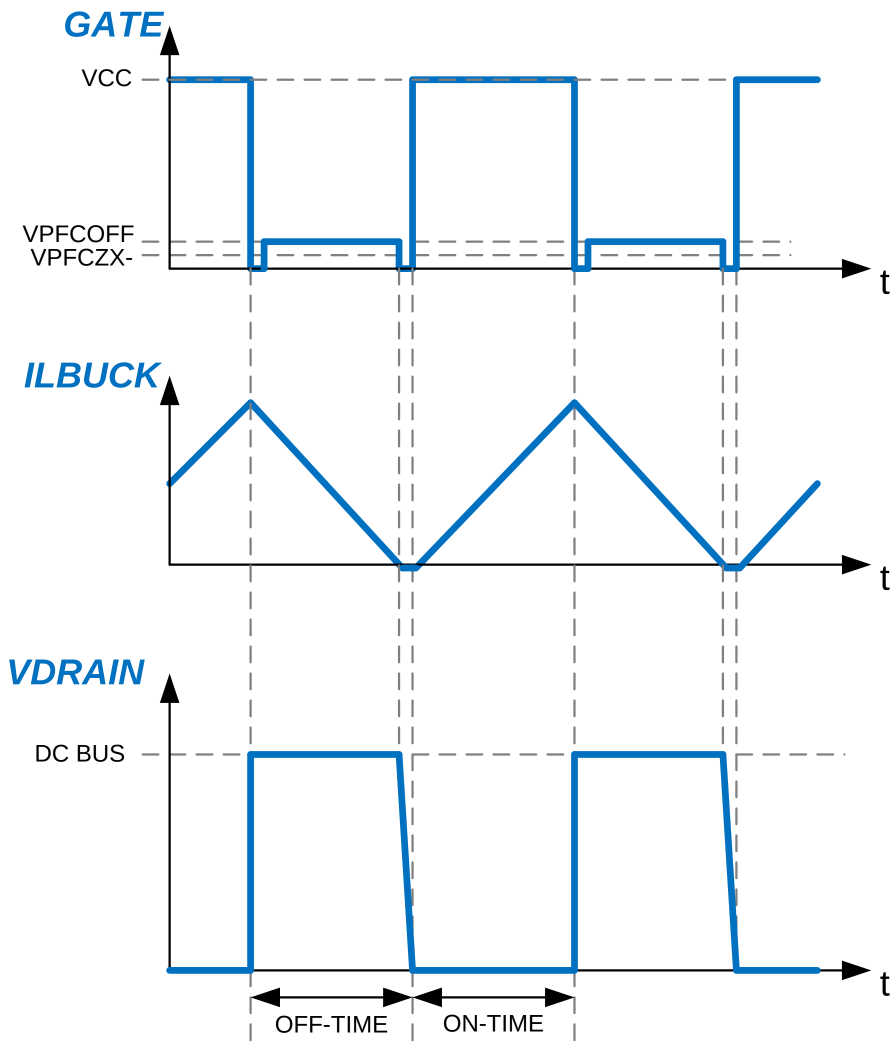


Figure 4: Gate voltage (upper trace), Buck inductor current (middle trace), and MOSFET drain voltage (lower trace) during normal on- and off-time switching period.

5. IC Start-Up and Supply Circuitry

The external IC supply circuit is designed to perform two main functions:

1) Supply the start-up and stand-by current to VCC.
2) Supply the necessary ICC current to VCC during all operating modes.

The start-up current to VCC is supplied by the start-up resistors, RVCC1 and RVCC2, connected between the rectified input voltage and VCC (Figure 3). Two resistors are used in order to properly withstand the high voltage between the rectified BUS and VCC.

The values for resistors RVCC1 and RVCC2 are calculated using the desired VCC start-up time (t_{START}), the VCC capacitor value (C_{VCC1}), the IC rising VCCUV+ turn-on threshold (11.1V, typical) and the minimum rectified input voltage (VIN_{MIN}). The resistor values are calculated as:

$$R_{VCC1} = R_{VCC2} \cong \frac{-t_{START}}{2C_{VCC1}\ln(1-\frac{VCCUV+}{VIN_{MIN}})} \quad \text{[sec] [5.1]}$$

The maximum power loss for resistors RVCC1 and RVCC2 occurs when the rectified input voltage is at the maximum value of the specified input voltage range. The power loss in each transistor is calculated as:

$$P_{RVCC1} = P_{RVCC2} \cong \frac{(VIN_{MAX}-VCC)^2}{2(R_{VCC1}+R_{VCC2})} \quad \text{[Watts] [5.2]}$$

The power loss and resulting temperature of RVCC1 and RVCC2 should be measured on the bench under high input voltage conditions to make sure the power rating of the resistors is adequate.

When the input voltage is first applied to the circuit, VCC ramps up with a time constant given by RVCC1, RVCC2 and CVCC1 (see Figure 5). After VCC exceeds VCCUV+, the IC turns on and the gate driver output (PFC pin) begins oscillating. The PFC pin turns the external Buck MOSFET on and off causing the drain node to switch between the rectified input and COM. The auxiliary VCC supply circuit (CSN, RSN, DVCC, CVCC2, RVCC3) then takes over as the main supply circuit for the IC and VCC increases up to the clamp voltage of the external Zener diode on VCC (not shown, typically 14-16V).

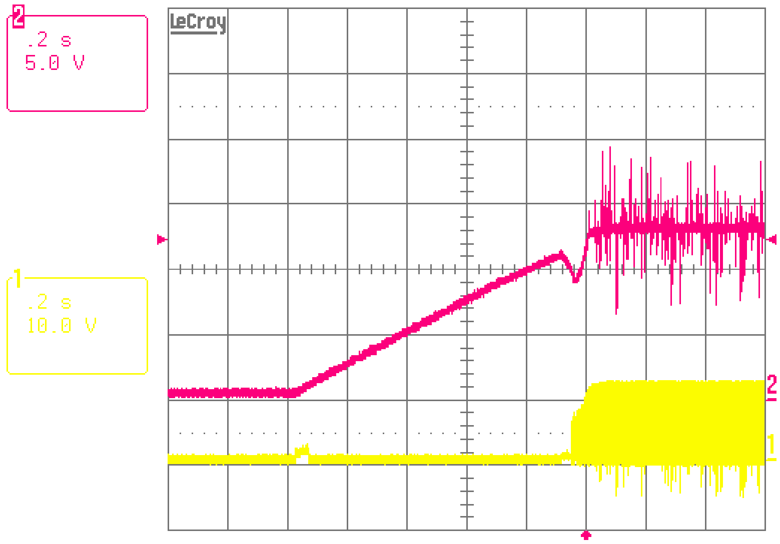


Figure 5: VCC (red) and PFC pin gate voltage (yellow) during normal start-up conditions.

6. Buck LED Design Example 1: Offline Converter

All of the necessary design calculations have been included inside the excel spreadsheet calculation tool ("IRS2505L Buck LED Design Calculator") [2] that accompanies this application note. The following design example calculations are for a 9W LED driver with an offline 120VAC nominal input (+/-10%). Please use the "AC" tab in the excel tool for this type of design. The input parameters for the circuit are determined as the following:

$V_{AC,NOM}$ = 120VAC
V_{OUT} = 25V
I_{OUT} = 350mA
$f_{SW,NOM}$ = 100kHz

These values are input into the yellow fields of the "User Input Parameters" section of the spreadsheet as follows:

User Input Parameters

Parameter	User Input Value	Units	Description
VAC_nom	**120**	Vrms	Nominal r.m.s. input voltage
VOUT_max	**25**	VDC	Max Output LED String Voltage
IOUT_nom	**0.35**	A	Nominal Output LED Current
POUT	**8.75**	W	Output power
FSW_nom	**100**	kHz	Nominal Switching Frequency

The buck circuit calculations are then given in the green sections of the "Buck Circuit Calculations" section of the spreadsheet as follows:

Buck Circuit Calculations

Parameter	Calculated Value	Units	Description
I_LBUCK_peak	0.7	Apk	Maximum peak inductor current
LBUCK	304	uH	Buck inductor value

The IRS2505L programming components are then calculated in the green sections of the "IRS2505L Programming Components" section using the yellow fields as the user inputs. The red sections are fixed and typically should remain fixed for different designs.

IRS2505L Programming Components

Parameter	Calculated Value	Units	Description
CVCC1	10	uF	VCC capacitor value (user input value)
CVCC2	0.1	uF	VCC filter capacitor value (fixed)
RVCC1	120	k Ohms	VCC start-up resistor no. 1 (user input)
RVCC2	120	k Ohms	VCC start-up resistor no. 2 (user input)
RVCC3	10	Ohms	VCC limit resistor (user input)
t_startup	231	msec	VCC start-up time at VAC_min

RCS	1.14	Ohms	Peak-current programming resistor value

RG	22	Ohms	Gate resistor value (user input)
CSN	220	pF	VCC charging capacitor (user input)
RSN	10	Ohms	VCC charging resistor (user input)
CZX	22	pF	ZX coupling capacitor (fixed)
RF	1.0	k Ohms	Current-sense filter resistor value (fixed)
CF	100	pF	Current-sense filter capacitor value (fixed)
CCMP	10.0	nF	CMP pin compensation capacitor value (fixed)

The corresponding circuit (Figure 3) for all of these calculations is also given inside the spreadsheet.

7. Buck LED Design Example 2: DCDC Converter

All of the necessary design calculations have been included inside the excel spreadsheet calculation tool ("IRS2505L Buck LED Design Calculator") [2] that accompanies this application note. The following design example calculations are for a 9W LED driver with a DC input voltage varying from 40-60V. Please use the

"DC" tab in the excel tool for this type of design. The input parameters for the circuit are determined as the following:

$V_{IN,MIN}$ = 40V
$V_{IN,MAX}$ = 60V
V_{OUT} = 25V
I_{OUT} = 350mA
$f_{SW,MIN}$ = 100kHz

These values are input into the yellow fields of the "User Input Parameters" section of the spreadsheet as follows:

User Input Parameters

Parameter	User Input Value	Units	Description
VIN_min	**40**	VDC	Min DC input voltage
VIN_max	**60**	VDC	Max DC input voltage
VOUT_max	**25**	VDC	Max Output LED String Voltage
IOUT_nom	**0.35**	A	Nominal Output LED Current
POUT	**8.75**	W	Output power
FSW_min	**100**	kHz	Minimum Switching Frequency

The buck circuit calculations are then given in the green sections of the "Buck Circuit Calculations" section of the spreadsheet as follows:

Buck Circuit Calculations

Parameter	Calculated Value	Units	Description
I_LBUCK_peak	**0.7**	Apk	Maximum peak inductor current
LBUCK	**134**	uH	Buck inductor value
FSW_max	**156**	kHz	Maximum Switching Frequency

The IRS2505L programming components are then calculated in the green sections of the "IRS2505L Programming Components" section using the yellow fields as the user inputs. The red sections are fixed and typically should remain fixed for different designs.

IRS2505L Programming Components

Parameter	Calculated Value	Units	Description
CVCC1	**10**	uF	VCC capacitor value (user input value)
CVCC2	**0.1**	uF	VCC filter capacitor value (fixed)
RVCC1	**47**	k Ohms	VCC start-up resistor no. 1 (user input)
RVCC2	**47**	k Ohms	VCC start-up resistor no. 2 (user input)
RVCC3	**10**	Ohms	VCC limit resistor (user input)
t_startup	**302**	msec	VCC start-up time at VIN_min

RCS	**1.14**	Ohms	Peak-current programming resistor value

RG	**22**	Ohms	Gate resistor value (user input)
CSN	**220**	pF	VCC charging capacitor (user input)
RSN	**10**	Ohms	VCC charging resistor (user input)
CZX	**22**	pF	ZX coupling capacitor (fixed)
RF	**1.0**	k Ohms	Current-sense filter resistor value (fixed)
CF	**100**	pF	Current-sense filter capacitor value (fixed)
CCMP	**10.0**	nF	CMP pin compensation capacitor value (fixed)

The corresponding circuit (Figure 3) for all of these calculations is also given inside the spreadsheet.

8. PCB Layout Considerations

For correct circuit functionality and to avoid high-frequency noise problems, proper care should be taken when designing the PCB layout. Typical design problems due to poor layout can include high-frequency voltage and/or current spikes, EMC issues, latch up, abnormal circuit behavior, component failures, low manufacturing yields, and poor reliability. The following layout tips should be followed as early in the design phase as possible in order to reduce circuit problems, shorten design cycles, and to increase reliability and manufacturability:

1) Keep high-frequency, high-current traces as short as possible (drain switching node, output diode node). This will help reduce noise due to parasitic inductance of PCB traces.
2) Keep high-frequency switching nodes away from quiet or critical circuit nodes (CMP pin, VBUS pin). This will help reduce noise coupling from switching nodes to other circuit nodes.
3) Place high-frequency filter capacitors directly at their IC pins (VCC pin). This will help insure the best possible filtering against high-frequency noise.
4) Do not connect power ground through IC ground or small-signal filter or programming component ground. Keep separate traces for power and IC

or small-signal grounds and connect small-signal ground to power ground at a single point only. This will prevent high-frequency noise from occurring on critical small-signal nodes or IC pins which can cause circuit malfunction or failures.

5) Reduce the distance of the power switches to their gate drive pins as much as possible (PFC). This will help reduce the parasitic inductance in the traces. This will reduce possible voltage spikes due to gate drive switching and help prevent latch up due to voltage over- or under-shoot.
6) Use a limiting resistor in between the auxiliary supply and VCC. This will help prevent damage due to high-voltage or high-current spikes from the charge pump supply that can cause electrical overstress of the IC.
7) Place critical sensing nodes (current-sensing resistor, ZX detection) as close to the IC as possible. This will help eliminate false triggering or circuit malfunction due to noise being coupled onto to sensitive control signals.
8) Check inductor for saturation. Saturation of the inductor results in currents with very high di/dt levels. These high di/dt signals can induce noise everywhere in the circuit and cause many different noise related issues. Make sure the inductor is properly designed to handle the maximum peak currents under all operating conditions.
9) See Figure 6 for PCB layout guidelines around the IRS2505L.

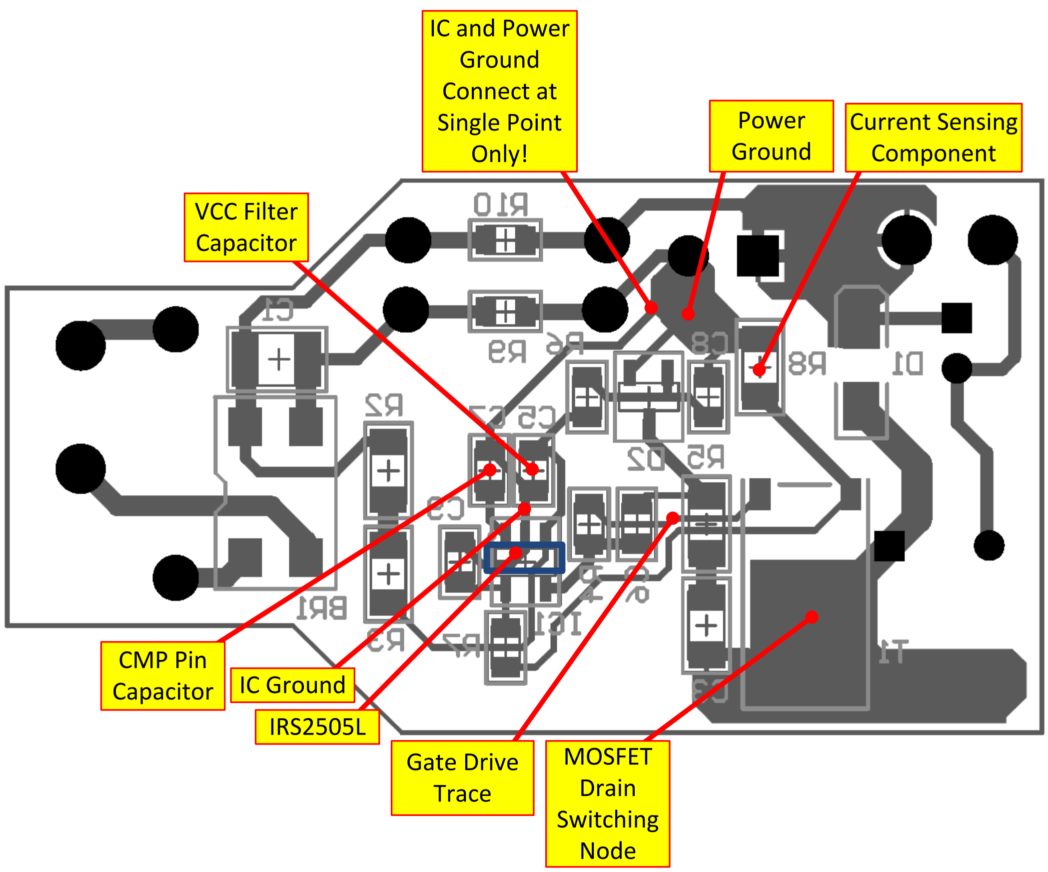


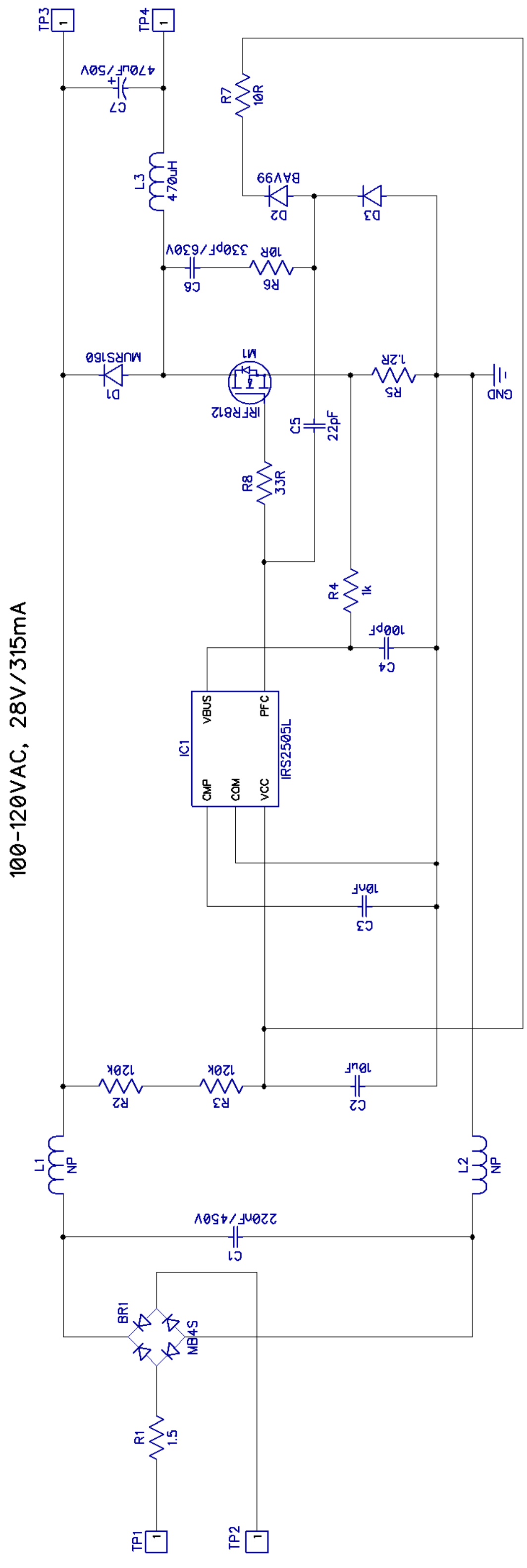
Figure 6: PCB Layout Guidelines

9. Conclusion

The information presented in this application note will help improve the design of the LED Buck converter and help reduce potential circuit problems. Ease of using and programming the IC, correct design of the Buck stage, design of the IC supply, and proper PCB layout guidelines help minimize design time, maximize performance, and maximize manufacturability and robustness of the final design. Finally, an excel spreadsheet design tool ("IRS2505L Buck LED Design Calculator") is also available that contains all of the necessary calculations described in this application note.

10. Appendix I: Reference Design (Schematic/BOM)

a. Schematic (VIN = 100-120VAC, VOUT = 28V, IOUT = 315mA)



b. BOM (VIN = 100-120VAC, VOUT = 28V, IOUT = 315mA)

Designator	Value	Description	Footprint	Quantity
BR1	MB4S	Bridge rectifier	TO269AA	1
C1	220nF/450V	Capacitor	1210	1
C2	10uF/25V	Capacitor	1206	1
C3	10nF/25V	Capacitor	0805	1
C4	100pF/25V	Capacitor	0805	1
C5	22pF/25V	Capacitor	0805	1
C6	330pF/630V	Capacitor	1206	1
C7	470uF/50V	Electrolytic Capacitor	Through Hole	1
D1	MURS160	Diode	SMA	1
D2, D3	BAV99	Dual High Speed Diode	SOT23N	1
IC1	IRS2505L	Control IC	SOT23-5L	1
L1	NP	EMI Inductor	Axial	1
L2	NP	EMI Inductor	Axial	1
L3	470uH	Single Inductor	Axial	1
M1	IRFR812	N Channel MOSFET	DPAK	1
R1	1.5R 1/3W 5%	Fuse Resistor	Axial	1
R2, R3	120k 1/4W 5%	Chip Resistor	1206	2
R4	1k, 1/8W 5%	Chip Resistor	0805	1
R5	1.2R, 1/4W 1%	Chip Resistor	1206	1
R6	10R, 1/4W 5%	Chip Resistor	1206	1
R7	10R 1/8W 5%	Chip Resistor	0805	1
R8	33R 1/8W 5%	Chip Resistor	0805	1

11. References

[1] IRS2505L SOT-23 Boost PFC Control IC Datasheet
[2] IRS2505L Buck LED Design Calculator

12. Revision History

Date	Revision	Changes	Author
01/09/2015	1	Initial version	Ektoras Bakalakos