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# Application Note AN-1171

## IRPLLED7 90-250VAC Offline LED Driver using **LEDdrivIR™** IRS2980

*By Peter B. Green*

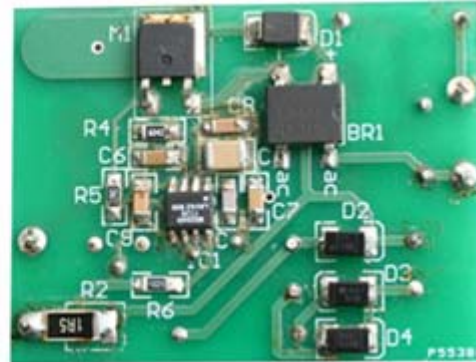
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#### **Safety Warning!**

The IRPLLED7 LED driver does not provide safety isolation. When operating the output drive to the LEDs can produce potentially dangerous voltages. This board is intended for evaluation purposes only and should be handled by qualified electrical engineers only!

## EVALUATION BOARD - IRPLLED7



### 1. Introduction

Solid state light sources are now available that offer viable alternatives to Fluorescent and HID lamps and far surpass incandescent lamps. Luminous efficacy expressed in Lumens per Watt has now reached levels enabling LEDs to be used for general illumination. High brightness LEDs also possess the added advantages of longer operating life span up to 50000 hours and greater robustness than other less efficient light sources making them suitable for outside applications such as street lighting.

High power LEDs are ideally driven with constant regulated DC current, requiring a "driver" or "converter" to provide the required current from an AC or DC power source. A simple single stage power converter based around the IRS2980 LED driver IC provides a controlled current output over a wide AC line or DC voltage input range.

The IRPLLED7 evaluation board is an off line non-isolated constant current Buck regulator LED driver designed to supply a 350mA DC output current. The LED output voltage can be up to 90% of the input voltage, operating from an AC line input voltage between 90 and 250VAC 50/60Hz or 50 to 300VDC. It also includes PWM dimming capability from 10% to 100% of light output controlled by an on board potentiometer.

#### **Important Safety Information**

The IRPLLED7 does not provide galvanic isolation of the LED drive output from the line input. Therefore if the system is supplied directly from a non-isolated input, an electrical shock hazard exists at the LED outputs and these should not be touched during operation. Although the output voltage is low this electrical shock hazard still exists.

It is recommended that for laboratory evaluation that the IRPLLED7 board be used with an isolated AC or DC input supply. The IRS2980 series Buck topology

is suitable only for final applications where isolation is either not necessary or provided elsewhere in the system.

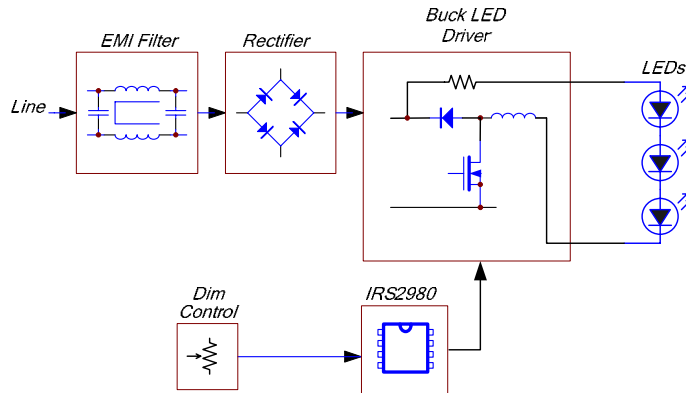


Figure 1: IRPLED7 Block Diagram

## 2. Constant current control

The IRS2980 is a hysteretic Buck controller operating in continuous conduction mode (CCM) and using a low side switching MOSFET as the controlled switch and a fast recovery diode as the uncontrolled switch connected to the positive DC bus. This mode of operation is opposite to the IRS25401 and includes a differential floating high side current sense circuit, which is used to hysteretically control the output current by sensing the voltage drop across a sense resistor and regulating the average to 0.5V. The IRS2980 is designed for use in current regulated circuits and not voltage regulated circuits.

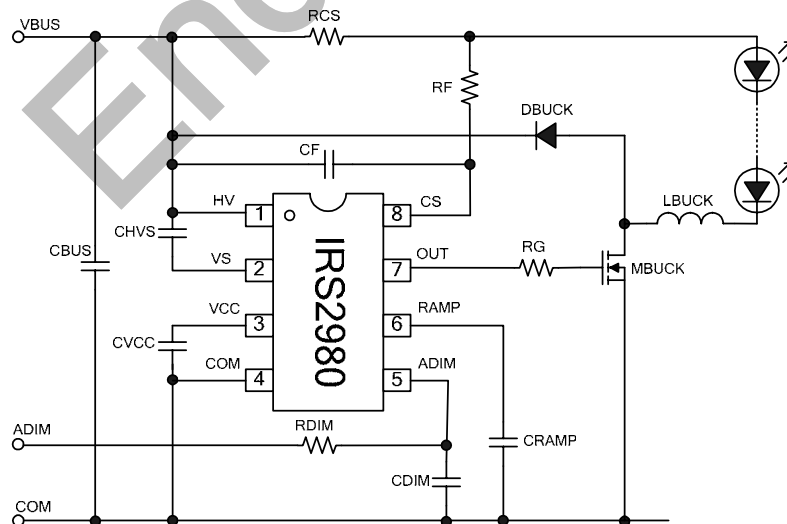


Figure 2: IRS2980 Basic Schematic

Figure 2 illustrates how the current is sensed by differentially measuring the voltage between the HV and CS inputs, RF and CF have been added to provide noise filtering. When the MOSFET (M<sub>BUCK</sub>) is switched on the current in the inductor L<sub>BUCK</sub> rises linearly according to the relationship:

$$V_{in} - V_{out} = L_{buck} \cdot \frac{di}{dt}$$

Where  $V_{in}$  is the bus voltage rectified from the AC line voltage and  $V_{out}$  is the combined series voltage of the string of LEDs making up the load.

When the voltage at HV rises to 0.55V with respect to CS the gate drive to M<sub>BUCK</sub> switches off. When the M<sub>BUCK</sub> is off the inductor current flows instead through D<sub>BUCK</sub>. During this period the current decreases linearly according to the relationship:

$$V_{out} = -L_{buck} \cdot \frac{di}{dt}$$

When the voltage at HV falls to 0.45V with respect to CS the gate drive to M<sub>BUCK</sub> switches on. The cycle repeats continuously to provide an average current in L<sub>BUCK</sub> which supplies the LED load. The frequency and duty cycle are dependent on the input and output voltages and the value of the L<sub>BUCK</sub> as can be inferred from the equations.

The output current can be set by selecting the appropriate value of R<sub>CS</sub> according to the relationship:

$$I_{out(avg)} = \frac{V_{CS}}{R_{CS}}$$

where  $V_{CS}$  is 0.5V, therefore for an R<sub>CS</sub> of 1.5V, the output current will be nominally 333mA. In practice there are some additional propagation delays in the circuit which give rise to a small variation in the current regulation over input voltage, however the accuracy adequate for LED applications. Accuracy of regulation and amplitude of the current ripple are tradeoffs against inductor size. The IRS2980 incorporates a frequency limiting function that prevents the frequency from exceeding approximately 150kHz. This is necessary in order to limit the V<sub>CC</sub> current consumption since the internal high voltage regulator can supply only a limited current (I<sub>CC</sub>) which is dominated by gate drive current. Gate current charges and discharges the MOSFET gate capacitance during each switching cycle and therefore increases with frequency.

### 3. High Voltage Regulator

The IRS2980 contains an internal high voltage regulator to supply VCC from the high voltage DC bus. Figure 2 shows that pin 1 (HV) is connected directly to the DC bus. Current is supplied to the VCC supply at pin 2 through an internal current source capable of operating up to 450V. The internal regulator can supply up to 3mA, which is sufficient to supply VCC for most MOSFET gate capacitances and frequencies normally required in an LED driver. ICC can be reduced by selecting a MOSFET with a low gate capacitance (25nC or less) and selecting an inductance (LBUCK) that will allow the regulator to operate at a reduced frequency. A regulator operating at 60kHz for example will require much less ICC than one operating at 120kHz. As explained earlier this is a tradeoff against inductor size. It is also important to consider the temperature rise of the IRS2980. Since the internal regulator operates linearly the associated power loss is dependent on bus voltage and ICC.

More care must be taken at higher bus voltages to minimize frequency and ICC to minimize the IC operating temperature. The addition of heat sinking in the form of large areas of copper on the PCB or thermally conductive potting compounds can significantly reduce temperature. Inductor values are generally larger for 220V off line AC applications than for 120V in order to reduce switching frequency, which lowers power dissipation in the circuit.

### 4. Current sense level shifter

The IRS2980 uses a floating differential current sense circuit to measure the LED current in the high side of the supply circuit. The Buck regulator configuration uses a low side switch, which is opposite to the IRS25401. In order to realize average current control the current must be sensed both when the MOSFET (MBUCK) is switched on and when it is switched off and therefore must be sensed at the high side. In order to accomplish this the hysteretic current sensing circuitry within the IRS2980 is situated within a floating high side well constructed by means of International Rectifiers HVIC technology. A floating supply voltage (nominally 8V) for the circuitry contained within this well is developed between the HV and VS pins of the IC. The supply is provided by a current source located between VS and COM.

The high side contains a comparator with defined hysteresis connected to a -0.5V reference with respect to HV. The output from the comparator is transferred through high voltage level shift circuitry to the gate driver circuitry, which is referenced to COM. The incorporation of the floating high side well allows the LED current to be sensed at voltages up to 450V above COM.

## 5. Dimming

The IRS2980 includes a PWM dimming oscillator that provides a linear ramp waveform at the RAMP pin with the frequency determined by an external capacitor to COM (CRAMP). The IRPLED7 demo board uses a passive valley fill circuit comprising two electrolytic capacitors, three diodes and one resistor to provide a high power factor between 0.8 and 0.9 depending on line voltage and load, without the additional cost of an additional active stage. This circuit (C2,C5,D2,D3,D4 and R3) can be seen in the schematic shown in section 6. The passive valley fill circuit however, creates a high ripple on the DC bus at twice the line frequency (50-60Hz). The constant current Buck regulator is easily capable of compensating for this, however in PWM dimming designs it means that the PWM frequency needs to be significantly higher than 120Hz in order to avoid visible flicker of the LEDs. The PWM dimming frequency in the IRPLED7 demo board is approximately 800Hz determined by a CRAMP value of 10nF. The dimming ramp varies between 0 and 2V and is compared with a DC dimming control voltage from 0 to 2V applied to the ADIM input at pin 5. The IRPLED7 board includes a pot which adjusts the ADIM input over the 0 to 2V range to provide the full range of dimming.

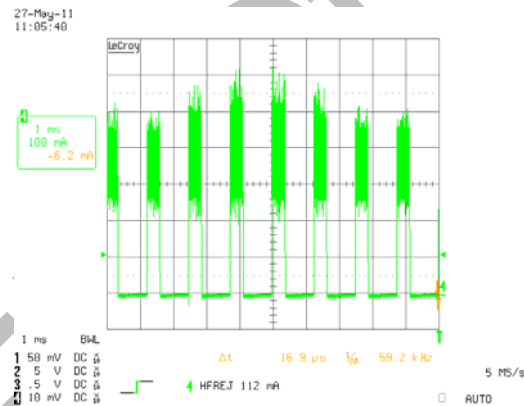


Figure 3: IRPLED7 PWM Dimming

Figure 3 shows the output current to the LED load at a dimming level of about 30%. It can be seen that the amount of current ripple varies slightly due to the DC bus voltage created by the passive valley fill circuit. At this PWM frequency there is no noticeable flicker during dimming.

The IRS2980 is designed for PWM dimming. It can also be used in a linear dimming mode with the addition of a few components.

6. IRPILLED7 Circuit Schematic

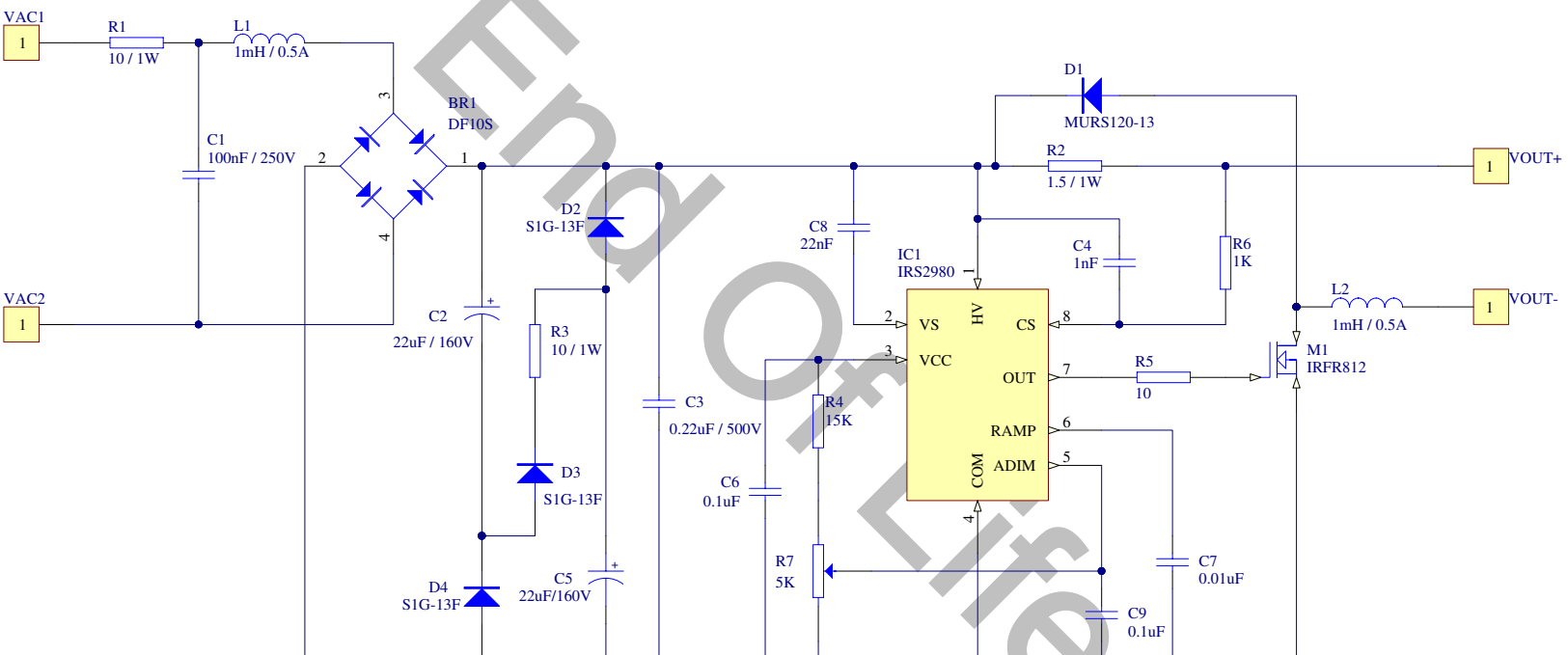


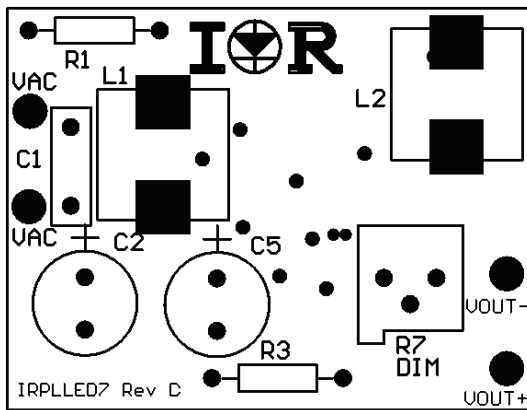
Figure 4: IRPILLED7 Complete Schematic



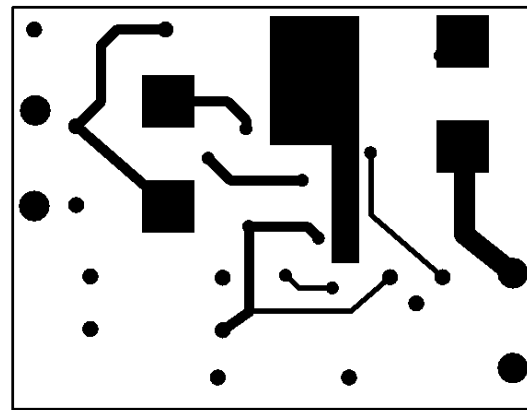
## 7. Bill of Materials

Item	Description	Part Number	Manufacturer	Quantity	Reference
1	IC, LED Controller	IRS2980S	International Rectifier	1	IC1
2	Rectifier ,1A , 400V, SMA	S1G-13-F	Diodes Inc	3	D2,D3,D4
3	Diode, 1A, 600V, 35nS, SMB	MURHS160T3G	On Semiconductor	1	D1
4	Bridge, 1000V, 1.5A, 4SDIP	DF10S	Fairchild	1	BR1
5	MOSFET, 500V, 2.2Ohm, DPAK	IRFR812	International Rectifier	1	M1
6	Capacitor, 100nF, 250V, Radial	B32520A3104K	Epcos	1	C1
7	Capacitor, 1nF, 630V, 10%, 1206	C32160G2J102J	TDK	1	C4
8	Capacitor, 0.1uF, 50V, 10%, 1206	C3216X7R1H104K	TDK	2	C6, C9
9	Capacitor, 22uF, 250VDC, 20%	EEU-EB2E220	Panasonic	2	C2, C5
10	Capacitor, 0.22uF, 450VDC, 1210	CKG32KX7T2W224M	TDK	1	C3
11	Capacitor, 22nF, 50V, 1206	CGA5C2C0G1H223J	TDK	1	C8
12	Capacitor, 0.01uF, 50V, 1206	C3216C0G1H103J	TDK	1	C7
13	Resistor, 1.5Ohm, 1W, 5%, 2512	ERJ-1TYJ1R5U	Panasonic	1	R2
14	Resistor, 10Ohm, 1W, 5%, Axial	PR01000101009JR500	Vishay	2	R1, R3
15	Resistor, 15K, 0.25W, 5%, 1206	ERJ-8GEYJ153V	Panasonic	1	R4
16	Resistor, 10, 0.25W, 5%, 1206	ERJ-8GEYJ100V	Panasonic	1	R5
17	Resistor, 1K, 0.25W, 5%, 1206	ERJ-8GEYJ102V	Panasonic	1	R6
18	Pot, 5K, 0.5W, Single, Top adjust	3386P-1-502LF	Bourns Inc	1	R7
19	Inductor, 1mH, 0.55A, 1.68Ohm	B82477G4105M	Epcos	2	L1, L2
20	Test point, 0.063"D Yellow	5009	Keystone	2	
21	Test point, 0.063"D Red	5005	Keystone	1	
22	Test point, 0.063"D Black	5006	Keystone	1	
23	PCB	IRPLLED7 Rev C		1	
24					

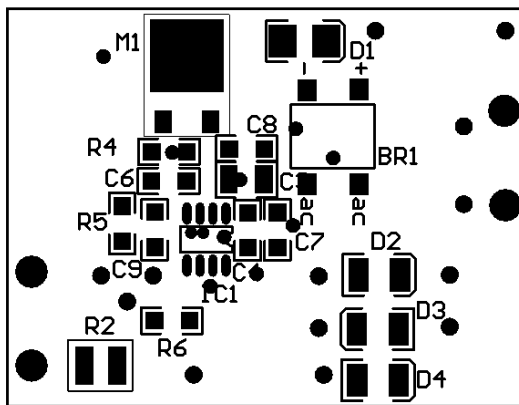
## 8. PCB Layout



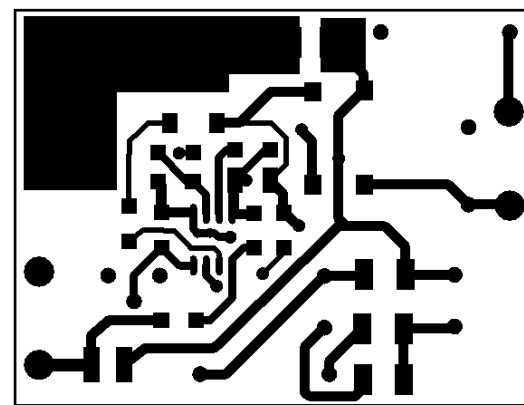
Top Overlay



Top Copper



Bottom Overlay



Bottom Copper

### Layout Considerations

It is very important when laying out the PCB for the IRS2980 based LED driver to consider the following points:

1. CVCC (C6) and CHVS (C8) must be as close to IC1 as possible.
2. The feedback path should be kept to a minimum length and separated as much as possible from high frequency switching traces to minimize noise at the CS input.
3. The current sense filter components RF (R6) and CF (C4) should be located close to the IRS2980 with short direct traces.
4. It is essential that all signal and power grounds should be kept separated from each other to prevent noise from entering the control environment. Signal and power grounds should be connected together at one point only,

which must be at the COM pin of the IRS2980. The IRS2980 may not operate in a stable manner if these guidelines are not followed!

All low side components associated with the IC should be connected to the IC signal ground (COM) with the shortest path possible.

5. All traces carrying the load current need to be sized accordingly.
6. Gate drive traces should also be kept to a minimum length.

## 9. Test Results

Measurements were carried out using a variable DC power supply and a load of 7 white LEDs being driven at a nominal 350mA.

DC Input Voltage (V)	DC Input Current (A)	Output Voltage (V)	Output Current (mA <sub>av</sub> )	Ripple (mApp)	Frequency (kHz)	Duty Cycle (%)
60	0.14	20.1	335	120	98	40
70	0.12	20.1	340	140	99	36
80	0.11	20.1	344	150	99	30
90	0.10	20.1	349	160	97	26
100	0.09	20.1	353	180	95	23
110	0.08	20.1	357	190	94	21
120	0.07	20.1	360	190	92	19
130	0.07	20.1	364	200	89	17.6
140	0.07	20.1	367	200	87	16.2
150	0.06	20.1	370	210	85	15.2
160	0.06	20.1	373	220	83	14.2
170	0.06	20.1	375	230	81	13.4
180	0.05	20.1	377	240	80	12.6

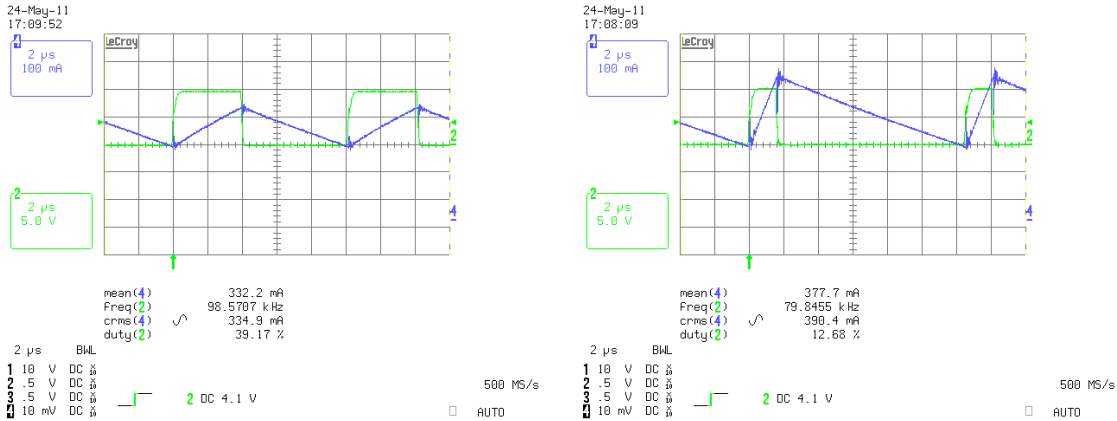
Table 1: IRPLLED7 Test Results

As expected table 1 indicates that the duty cycle is approximately equal to  $V_{out}/V_{in}$ , the LED total voltage drop divided by the supply voltage. It can be seen that the current ripple increases as the duty cycle reduces since the voltage difference is increasing. This is because:

$$V_{in} - V_{out} = L_{buck} \cdot \frac{di}{dt}$$

and therefore  $di/dt$  is increasing, which results in more overshoot in the hysteretic comparator due to inevitable propagation delays in the system. These delays actually provide an advantage because the operating frequency is decreasing with higher input voltage which limits ICC and switching losses in both MBUCK (M1) and DBUCK (D1).

The gate drive and output current waveforms are displayed in Figure 5:



Input = 60VDC

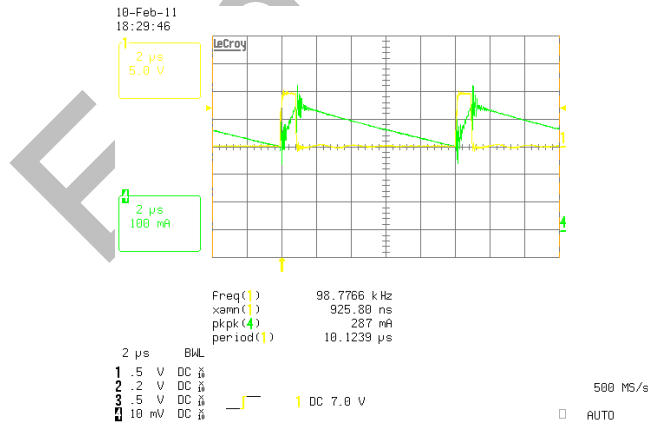
Input = 180VDC

Green Trace = Gate Drive, Blue Trace = Output Current

Figure 5: IRPLED7 Typical Waveforms

The IRPLED7 board uses an inductor of 1mA. Increasing this value would reduce frequency and ripple. Ripple can also be reduced by adding a capacitor to the output although this is not necessary in most applications and may reduce the PWM dimming range.

In the example shown in figure 6 below, where a load of fewer series LEDs was attached:



Yellow = Gate, Green = LED Current

Vin = 60V, Iin = 0.09A, Pin = 5.4W

Vout = 13.87V, Iout = 0.338A, Pout = 4.66W

Figure 6: IRPLED7 at lighter load

In the following example, a combination of LEDs was connected with a combined voltage drop of approximately 30V. The board is capable of operating down to 60VDC input, below which the high voltage regulator does not operate. In applications requiring a lower input voltage VCC can be supplied directly from an alternate source, the simplest option being a resistor from the DC bus to VCC.

DC Bus Voltage (V)	Output Voltage (V)	Output Current (mAav)	Ripple (mApp)	Frequency (kHz)	Duty Cycle (%)
60	30.76	334	100	150	54.4
70	30.60	330	110	154	46
80	30.55	329	120	155	41.8
90	30.52	329	130	155	37.3
100	30.43	331	140	157	33.0
110	30.43	332	150	157	30.3
120	30.43	335	150	158	27.4
130	30.43	337	160	159	25.2
140	30.44	340	170	159	25
150	30.45	343	170	160	23.1
160	30.47	346	170	160	21.6
170	30.49	349	170	161	20.5
180	30.51	353	170	161	19.6

**Table 2: IRPLED7 Additional Test Results**

Since the IRS2980 incorporates an internal high voltage regulator and level shifting circuitry it dissipates some heat during operation which increases with frequency and line voltage. It is necessary as with the MOSFET (MBOCK) and diode (DBUCK) to ensure that these components do not overheat in the application. This is done by providing additional copper around the components on the PCB to allow heat conduction from the devices. In 220VAC off line applications it is necessary to use a sufficiently large inductor (LBOCK) in order to maintain a low operating frequency in the 30 to 60kHz range. This will substantially reduce heat dissipation in all of the components mentioned. Replacing the the 1mH inductor used in the IRPLED7 demo board with a 3.3mH part lowers the frequency and reduces heat loss in at 200VAC. Efficiency varies depending on input voltage, output voltage, output current and switching frequency.

## 10. Design Procedure Summary

1. Determine the systems requirements: input/output voltage and current needed
2. Calculate current sense resistor
3. Determine the operating frequency required.
4. Select LBUCK so that they maintain supply into the load during  $t_{HO\_on}$ .
5. Select the switching MOSFET and diode) to minimize gate drive current and switching losses.

End Of Life