International Rectifier

APPLICATION NOTE

Application Note AN-1177

IRPLLED13
90-250VAC Offline LED Driver
using LEDrivIR™ IRS2980

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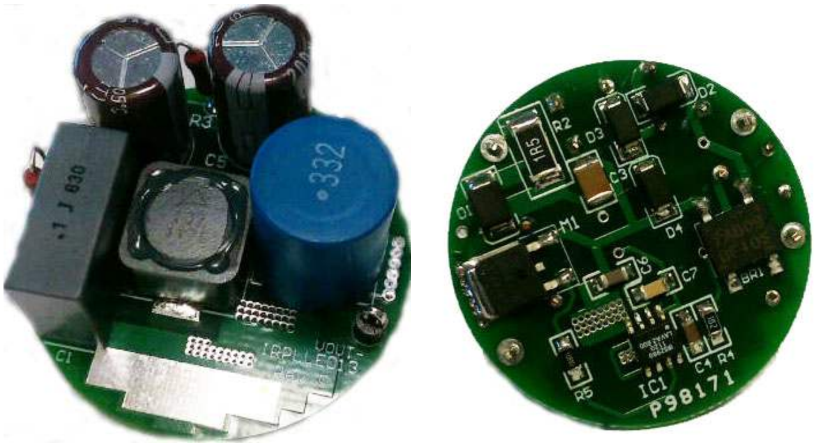
EVALUATION BOARD - IRPLLED13

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 IRPLLED13 evaluation board is an off line non-isolated constant current Buck regulator LED driver designed to supply a nominal 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. The IRPLLED13 demo board is not designed for use with dimmers.

Important Safety Information

The IRPLLED13 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.

It is recommended that for laboratory evaluation the IRPLLED13 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.

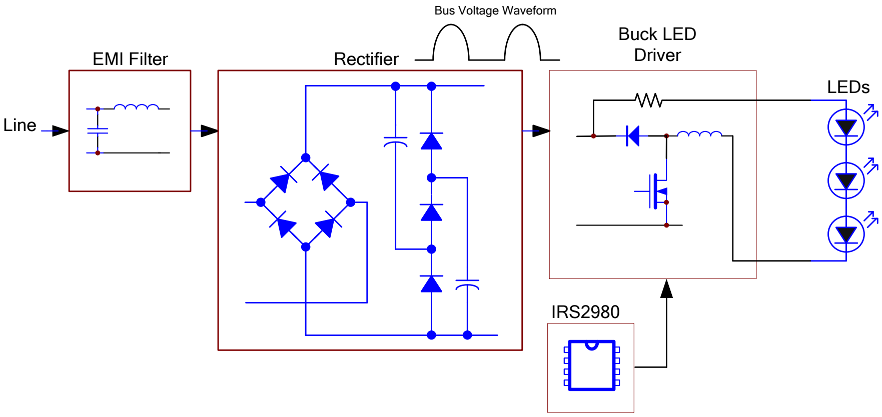


Figure 1: IRPLLED13 Block Diagram

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 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.

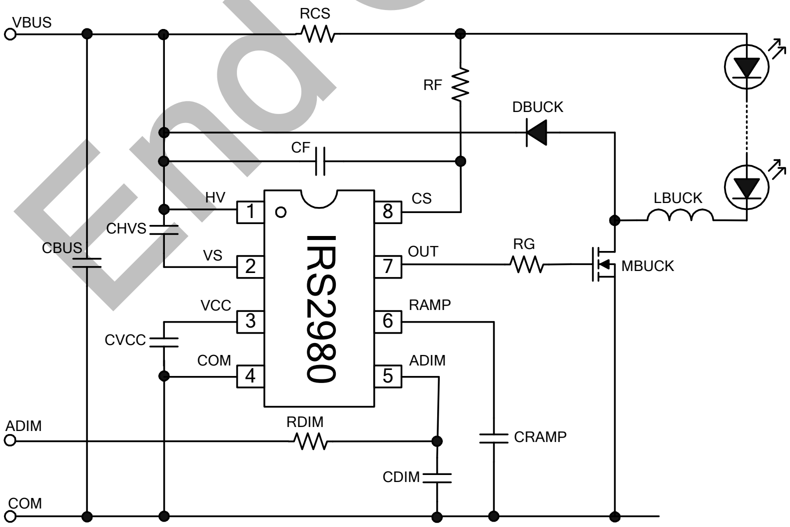


Figure 2: IRS2980 Basic Schematic

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 (MBUCK) is switched on the current in the inductor LBUCK rises linearly according to the relationship:

$$Vin - Vout = Lbuck.\frac{di}{dt} \qquad [1]$$

Where Vin is the bus voltage rectified from the AC line voltage and Vout 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 MBUCK switches off. When the MBUCK is off the inductor current flows instead through DBUCK. During this period the current decreases linearly according to the relationship:

$$Vout = -Lbuck.\frac{di}{dt} \qquad [2]$$

When the voltage at HV falls to 0.45V with respect to CS the gate drive to MBUCK switches on. The cycle repeats continuously to provide an average current in LBUCK which supplies the LED load. The frequency and duty cycle are dependent on the input and output voltages and the value of the LBUCK as can be inferred from the equations.
The output current can be set by selecting the appropriate value of RCS according to the relationship:

$$Iout(avg) = \frac{VCS}{RCS} \qquad [3]$$

where VCS is nominally 0.5V, therefore for an RCS of 1.5Ohms, the output current will be nominally 333mA. In practice there are some additional propagation delays in the circuit which give rise to some error in the current regulation and some variation over input voltage, however the performance is acceptable for most LED applications as shown in the test results section. Accuracy of regulation and amplitude of the current ripple are tradeoffs against inductor size and frequency.
The IRS2980 based LED driver is designed to operate up to 150kHz. This is necessary in order to limit the VCC current consumption since the internal high voltage regulator can supply only a limited current (ICC) dominated by gate drive current. Gate current charges and discharges the MOSFET input capacitance during each switching cycle and therefore increases with frequency.
Using hysteretic regulation to control the LED current some overshoot occurs due to propagation delays and well as a small undershoot. These vary depending on di/dt of the ripple current, which is a function of input and output voltage, inductor value and frequency as well as RC filter values (R_F and C_F). The average current is maintained over a wide input and output voltage range. Since the IRS2980S uses hysteretic current control to switch the Buck MOSFET on and off, the LED current (which is equal to the inductor current) is maintained half way between minimum and maximum currents. Because of this the switching

frequency and duty cycle vary to meet the operating conditions imposed by the input and output voltages, output current and inductor value.
The following diagram shows the rise and fall of the LED current as the MOSFET switches on and off:

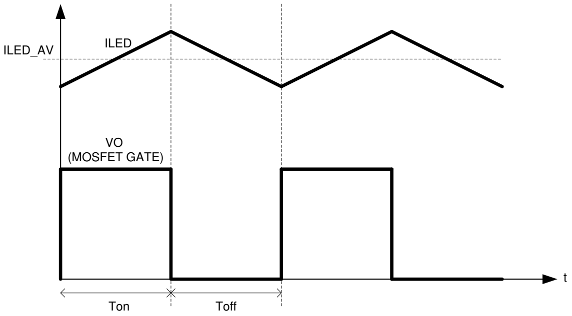


Figure 3: MOSFET gate drive and inductor/LED current.

The operation of the IRS2980S based Buck LED driver can be modeled at an operating point as follows:
First determine the rising and falling slopes of the inductor current.

$$\frac{di}{dt}+=\frac{V_{BUS\_DC}-V_{LED}}{L} \qquad [4]$$

$$\frac{di}{dt}-=\frac{V_{LED}-V_{F}}{L} \qquad [5]$$

These slopes are then used to determine the amount of overshoot and undershoot based on the delay caused by the RC filter, gate charge and propagation delays.

$$i_{OS}\approx(R_F\cdot C_F+\frac{Q_G}{0.18}+t_{DR})\cdot\frac{di}{dt}+ \qquad [6]$$

$$i_{US}\approx(R_F\cdot C_F+\frac{Q_G}{0.26}+t_{DF})\cdot\frac{di}{dt}- \qquad [7]$$

Where,
R_F and C_F are the current sense filter components,
L is the inductor value,
Q_G is the MOSFET gate charge,
t_{DR} and t_{DF} are propagation delays and can be omitted for first order approximation.
V_F is the forward voltage drop of the Buck diode which may assumed as 0.7V.

Now that the overshoot and undershoot have been determined the on and off time, frequency and duty cycle can then be calculated.

$$t_{on} = \frac{0.2 \cdot L \cdot I_{LED} + i_{OS} + i_{US}}{V_{BUS\_DC} - V_{LED}} \qquad [8]$$

$$t_{off} = \frac{0.2 \cdot L \cdot I_{LED} + i_{OS} + i_{US}}{V_{LED} + V_F} \qquad [9]$$

$$f_{SW} = \frac{1}{t_{on} + t_{off}} \text{ (switching frequency)} \qquad [10]$$

$$d = \frac{t_{on}}{t_{on} + t_{off}} \text{ (duty cycle)} \qquad [11]$$

Operating frequency and duty cycle vary since there is a high ripple content in the DC bus voltage. This is a result of the passive valley fill circuit used for power factor correction (PFC). The LED current is regulated dynamically by the IRS2980 continually changing frequency and duty cycle to maintain a constant average. The passive valley fill circuit provides power factor between 0.85 and 0.9 depending on the AC input voltage and load, with two capacitors and three diodes as shown in figure 4. It should be noted that the line current THD will be about 50% using this technique but this is acceptable for many applications.

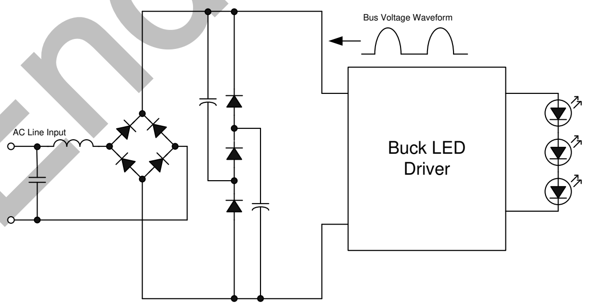


Figure 4: Passive valley fill PFC circuit

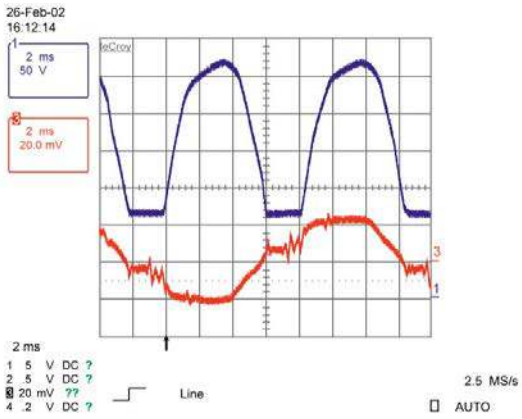


Figure 5: Passive valley fill PFC bus voltage (blue) and line input current (red) waveforms.

The efficiency of the IRPLLED13 like all Buck converters, varies depending on input and output voltage.

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 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 lower 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 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.

The VCC current (ICC) drawn by the IRS2980S can be estimated from the following formula:

$$I_{CC} \approx 1mA + Q_G \cdot f_{SW} \qquad [12]$$

therefore power dissipation due to the high voltage regulator can be calculated as:

$$P_{REG} = V_{BUS\_DC\_AV} \cdot I_{CC} \qquad [13]$$

4. High side differential current sense

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 unlike the IRS25401 which uses a high side switch and low side current sense. 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 high voltage 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 floating high side current sense incorporated in the IRS2980S is able to operate up to 450V and withstand voltage surges up to 600V. A internal bias supply is derived between the HV and VS pins by a 1mA current source pulling down on VS so that a supply voltage is produced across the external capacitor CHVS to supply the high side circuitry. A value of 22nF is recommended for CHVS. The internal bias supply also dissipates some power, which can be calculated from the formula:

$$P_{BIAS} = (V_{BUS\_DC\_AV} - 10) \cdot 1mA \qquad [14]$$

In order for the high side current sense circuitry to function, a minimum bus voltage of 30V is required to provide adequate bias supply current and stand off voltage.

5. Thermal considerations

Since the IRS2980S dissipates some power during normal operation, temperature rise of the IC die must be considered as part of the design process. The SO8 IC package has a maximum power rating (PD) of 625mW, therefore the sum of P_{REG} and P_{BIAS} should not exceed this value. The junction temperature should remain below 125°C to ensure operation within specifications.

The junction temperature is normally 10°C above the case temperature for an SO8 package therefore the case temperature should not exceed 115°C at maximum ambient.

In order to reduce the junction temperature rise thermal relief has been added around the IRS2980S on the IRPLLED13 PCB layout. With adequate thermal relief the die temperature rise is greatly reduced. An area of copper has been placed on the opposite side of the PCB to the IC in the same position with several through hole vias added underneath the IC to conduct heat through to the other side. In addition an area of this thermal relief area has been left without solder resist to aid dissipation.

6. IRPLLED13 Circuit Schematic

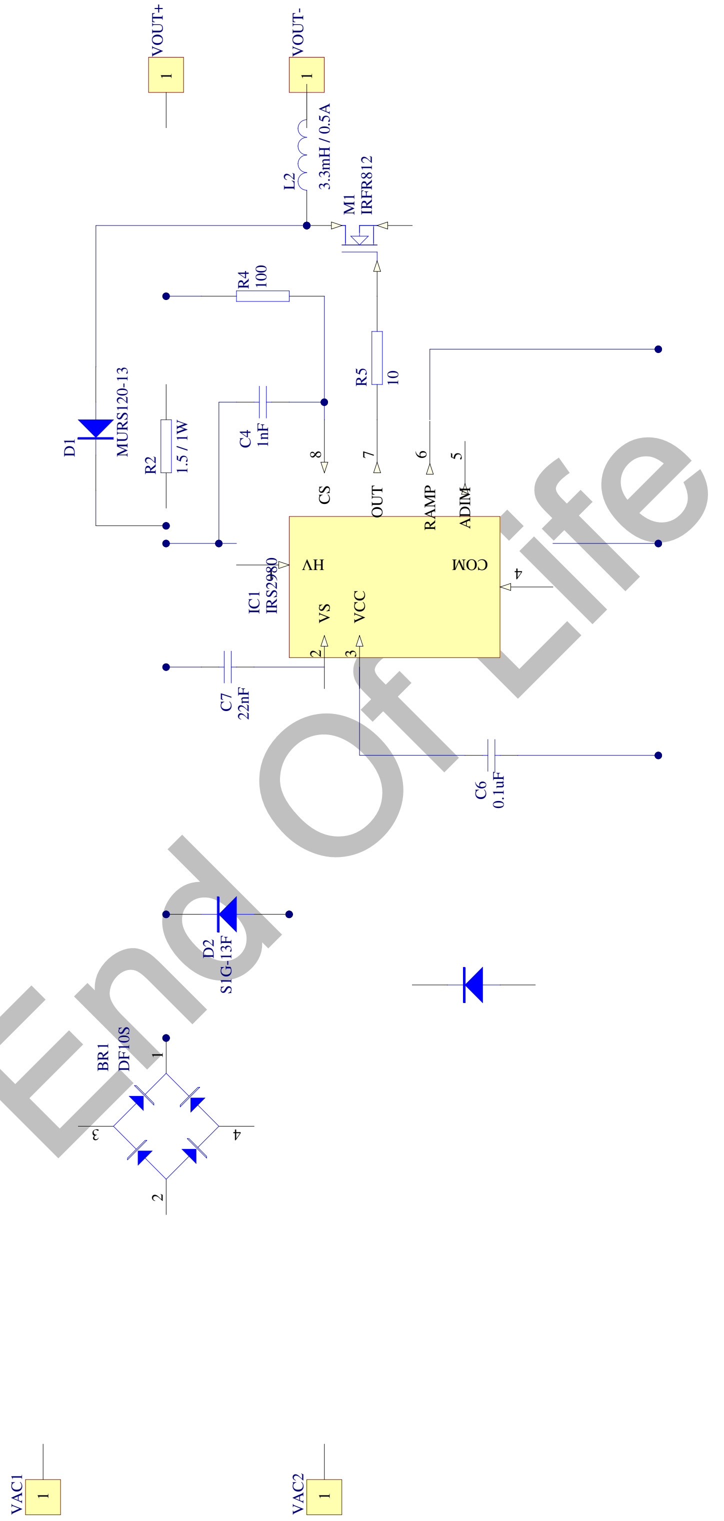
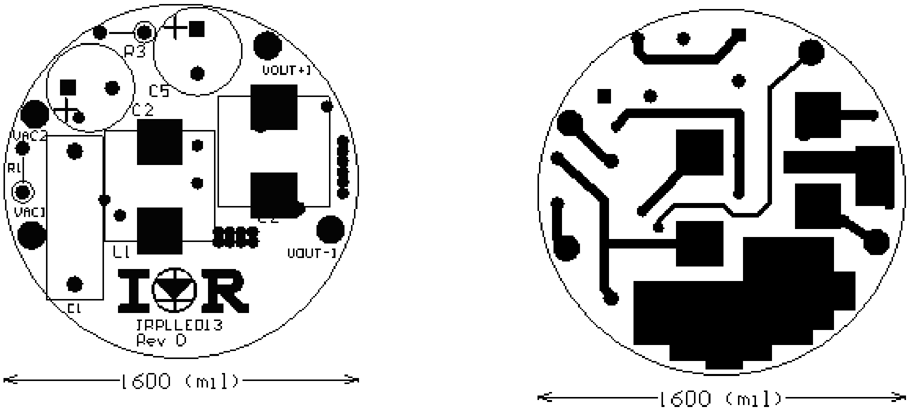


Figure 4: IRPLLED13 Complete Schematic

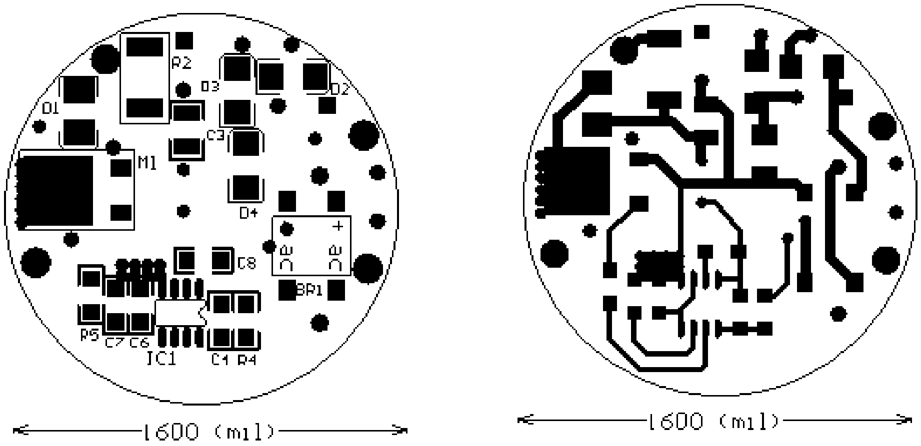
7. Bill of Materials

Item	Description	Part Number	Manufacurer	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 Semi	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, 250VAC, Radial	B32652A6104J	Epcos	1	C1
7	Capacitor, 1nF, 50V, 5%, 1206	1206A102JAT2A	AVX	1	C4
8	Capacitor, 0.1uF, 50V, 10%, 1206	GRM319R71H104KA01D	Murata	1	C6
9	Capacitor, 10uF, 200VDC, 20%	EKXG201ELL100MJ16S	United Chem	2	C2, C5
10	Capacitor, 0.10uF, 630V, 1812, X7R	GRM43DR72J104KW01L	Murata	1	C3
11	Capacitor, 22nF, 50V, 1206	12065C223KAT2A	AVX	1	C7
12	Resistor, 1.5Ohm, 1W, 5%, 2512	ERJ-1TYJ1R5U	Panasonic	1	R2
13	Resistor, 10Ohm, 1W, 5%, Axial	PR01000101009JR500	Vishay	2	R1, R3
14	Resistor, 1kOhm, 0.25W, 5%, 1206	ERJ-8GEYJ102V	Panasonic	1	R4
15	Resistor, 10, 0.25W, 5%, 1206	ERJ-8GEYJ100V	Panasonic	1	R5
16	Inductor, 1mH, 0.55A, 1.68Ohm	B82477G4105M	Epcos	1	L1
17	Inductor, 3.3mH, 0.44A, Radial	TSL1315RA-332JR44-PF	TDK	1	L2
18	Test point, 0.063"D Yellow	5009	Keystone	2	
19	Test point, 0.063"D Red	5005	Keystone	1	
20	Test point, 0.063"D Black	5006	Keystone	1	
21	PCB	IRPLLED13 Rev D		1	
22					
23					
24					

8. PCB Layout



Top Overlay Top Copper



Bottom Overlay Bottom Copper

Figure 5: PCB Layout

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 (R4) 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 AC supply and a load of 7 white LEDs being driven at a nominal 350mA.

	Calculated		Measured	
Line Voltage	Minimum	Maximum	Minimum	Maximum
120VAC	64.3	73.9	65.8	72.2
220VAC	73.1	78.3	65.0	72.8

Table 1: Predicted frequency and measured frequency (kHz):

The minimum frequency occurs when the bus voltage is at its lowest which is estimated to be half the peak voltage in the passive valley fill circuit. The maximum frequency occurs when the bus voltage reaches its peak. Table 1 shows that a first order calculation described in section 2 gives a frequency close to the actual frequency measured. The frequency is likely to vary from board to board due to component tolerances.

AC Input Voltage (V)	Input Power (W)	Output Voltage (V)	Output Current (mAav)	Ripple (mApp)	Output Power (W)
80	8.58	20.1	339	62	6.81
100	8.57	20.1	339	68	6.81
120	8.67	20.1	340	71	6.83
140	8.79	20.1	341	73	6.85
160	8.83	20.1	342	80	6.87
180	9.97	20.0	343	80	6.87
200	9.12	20.0	344	82	6.89
220	9.26	20.0	345	81	6.90
240	9.40	20.0	346	82	6.93
260	9.55	20.0	348	84	6.95

Table 2: IRPLLED13 Test Results

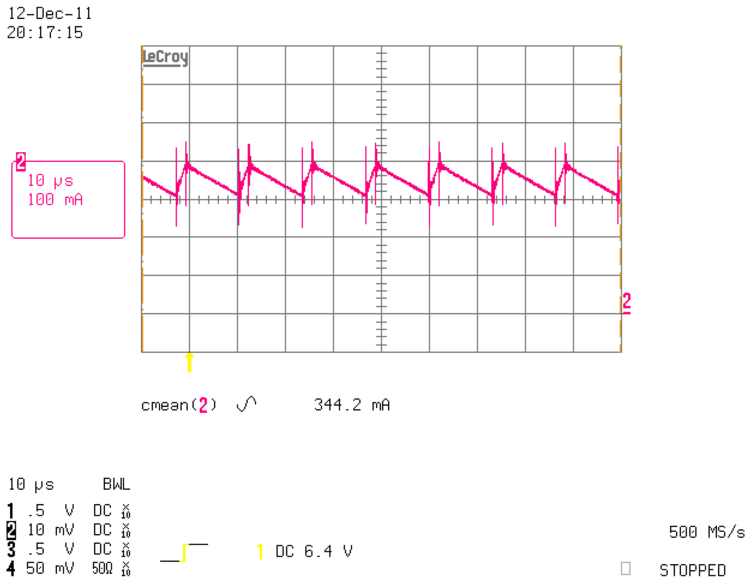


Figure 6: LED Current at 120VAC Input

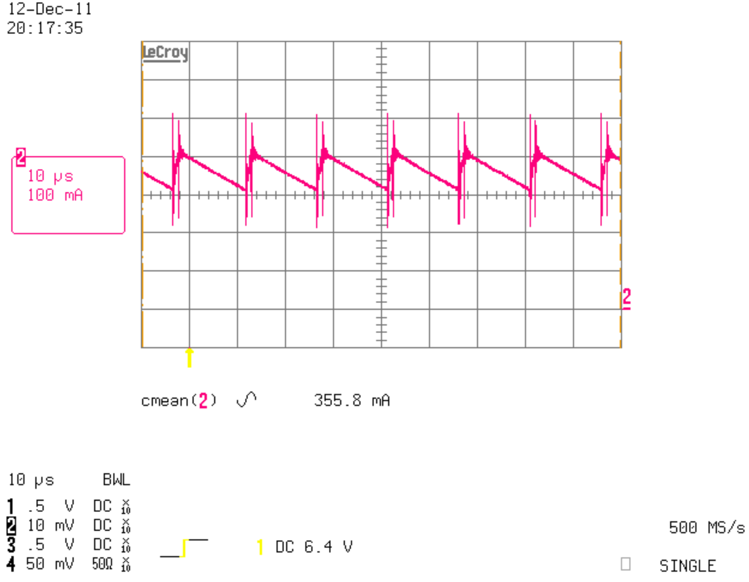


Figure 7: LED Current at 220VAC Input

The case temperature of the IRS2980 (IC1), the IRFR812 (M1) and the Buck diode (D1) were measured with a thermocouple attached to each device after 30 minutes of operation with the board positioned with the discrete component side facing up.

AC Line Voltage (Vrms)	120	220
AC Line Current (mArms)	114	65
Input Power (W)	12.21	12.98
Power Factor	0.892	0.896
Output Voltage (Vdc)	30.5	30.5
Output Current (mAdc)	340.9	352.6
Output Power (W)	10.40	10.65
Frequency (kHz)	60.1	50.2
IC1 Case Temperature (ºC)	56.5	75.0
M1 Case Temperature (ºC)	57.0	71.3
D1 Case Temperature (ºC)	66.5	74.6

Table 3: Component Temperatures

Component temperatures should be kept below their maximum rating and as low as possible at maximum ambient temperature. Reducing frequency by increasing the inductor size or increasing the value of filter resistor R4 reduces power dissipation due to switching losses. Thermally conductive potting material is often used in LED products, which conducts heat away from the components.
If the value of R4 is increased to lower frequency rather than increasing inductor size, the output current ripple increases. This leads to larger variation in current with input voltage because of the increased delay. It is important to consider that the current sense filter is necessary for the circuit to work correctly. Without this filter noise transients caused by high dv/dt resulting from switching cause false triggering of the hysteretic circuit, which causes the IRS2980 to detect a fault and shut down. The values of C4 and R4 required for correct operation depend on the MOSFET parasitic capacitances, the diode reverse recovery time and how well the PCB layout shields the IFB input from noise. C4 must be placed as close to the IRS2980 as possible with short traces.